Response of Marine Ecosystems to Climatic Variability:

time-series studies in the tropical open ocean and shelf seas.

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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Motivation

Why does climate change affect phytoplankton?

- Temperature (enzymes, solubility of gasses)
- Circulation and mixing (nutrients, light)
- Ocean acidification

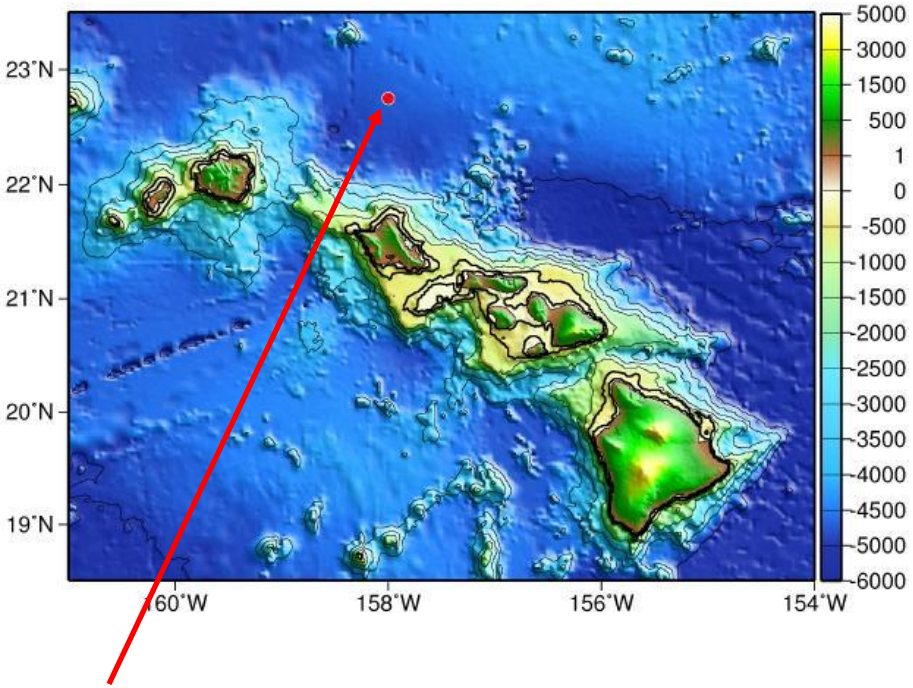
Why are phytoplankton important?

- Carbon fixation
- Export and support of higher trophic levels
- Biogeochemical cycles

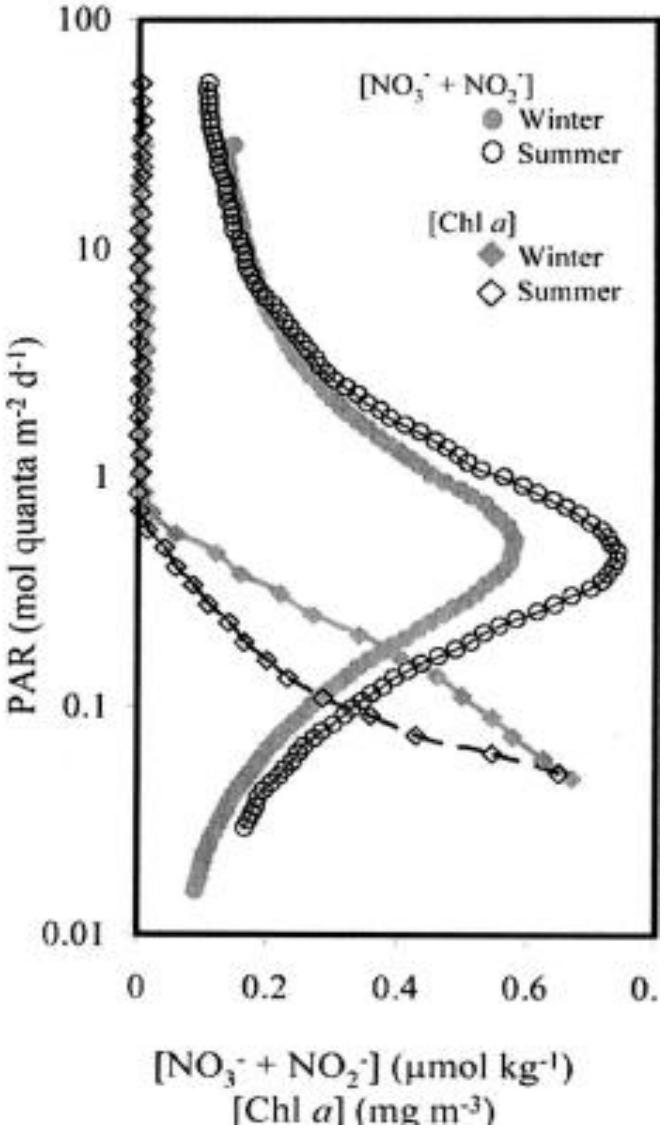
The Tropical North Pacific

Subtropical gyre:

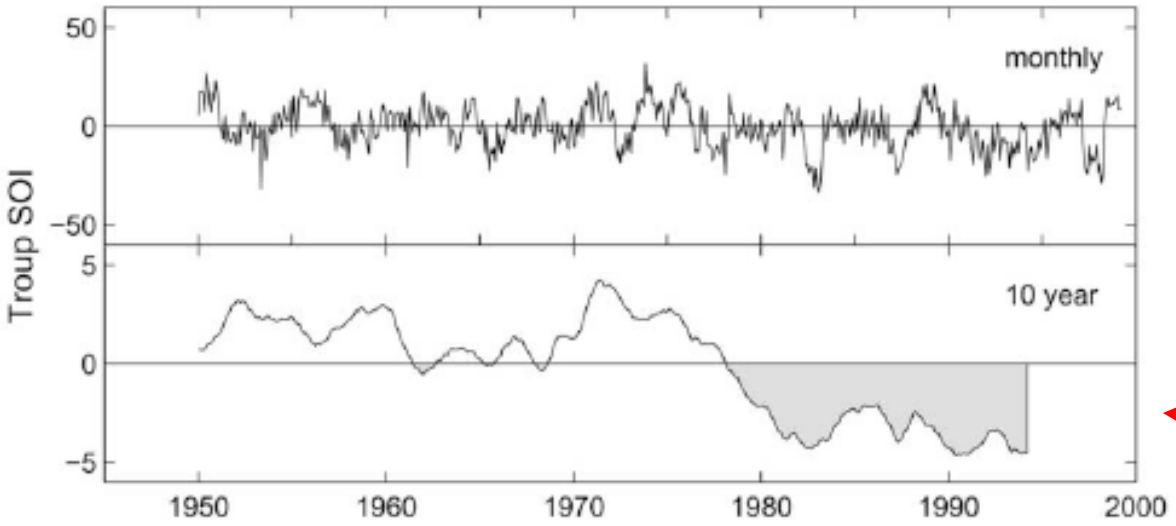
- CLIMAX station 1960's to 1970's
- Station ALOHA 1988 to present



Station ALOHA



Climatic changes in ocean properties



- 1960-1970's: CLIMAX
- 1988-present: ALOHA

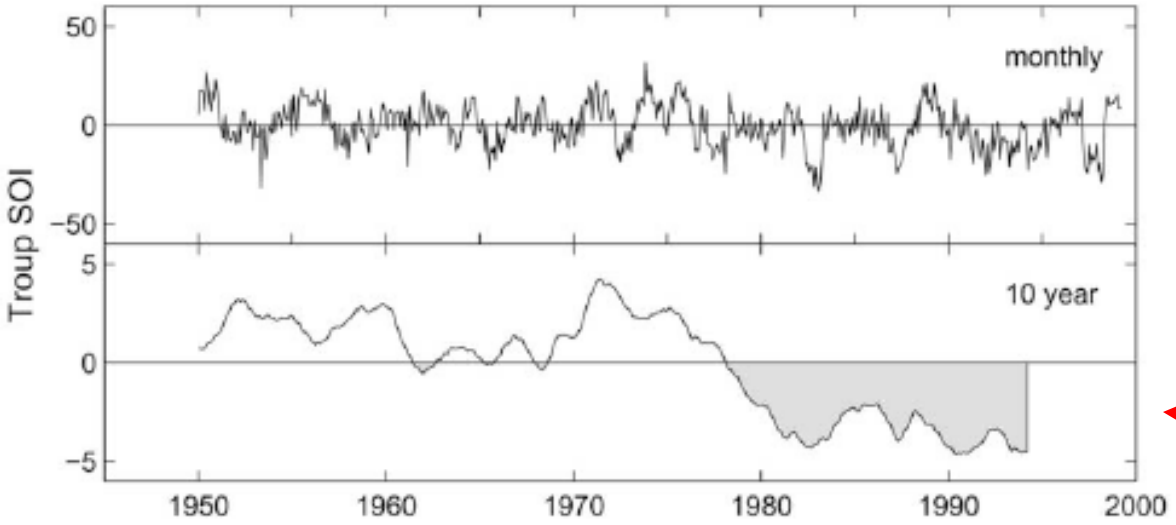
Low SOI:
El Niño-
favourable

Transition to low SOI:

- Increased temperature
- Decreased trade winds
- Altered gyre circulation

See: Karl *et al.,* Deep Sea Research PtII, **48**: 1449-1470, 2001

Climatic changes in ocean properties



- 1960-1970's: CLIMAX
- 1988-present: ALOHA

Low SOI:
El Niño-
favourable

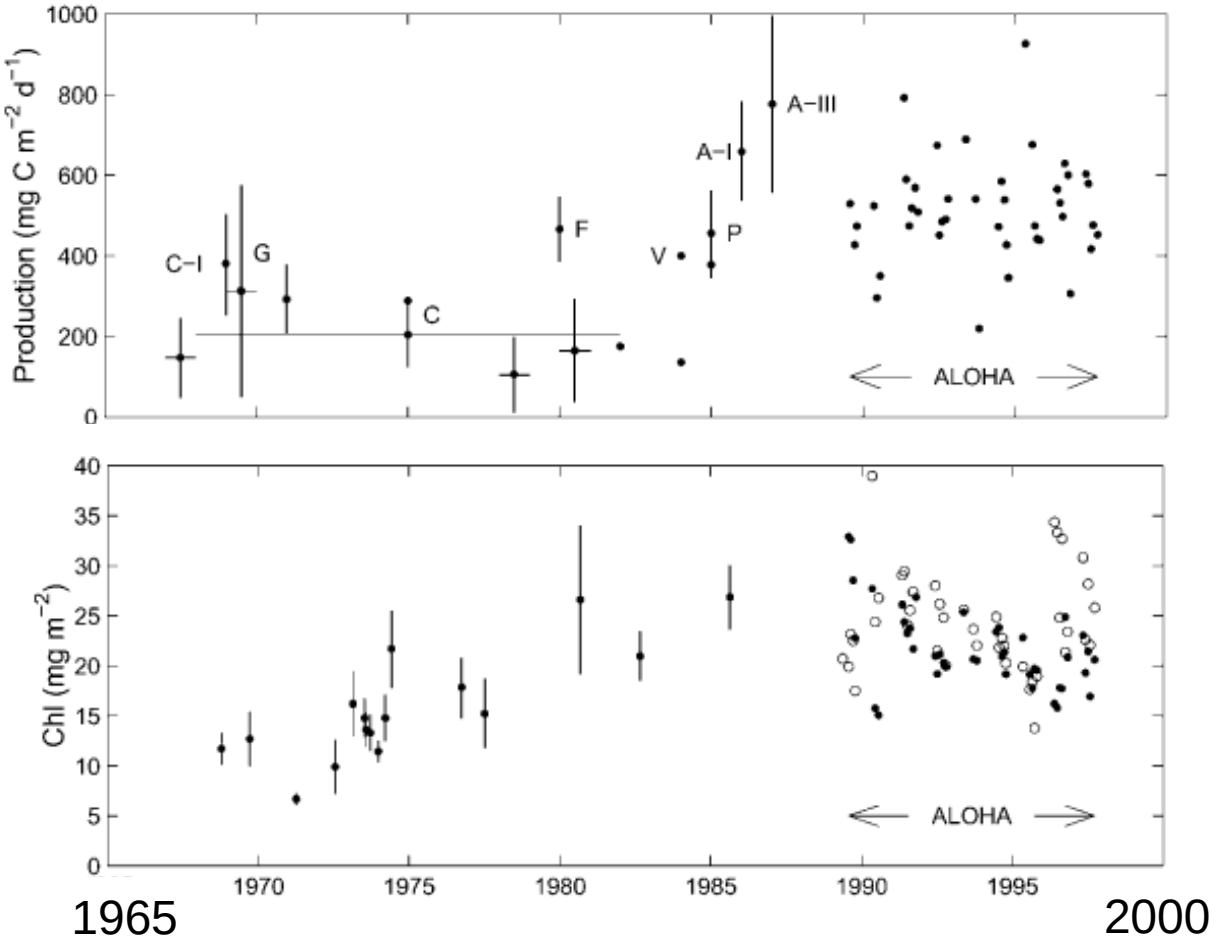
Transition to low SOI:

- Increased temperature
- Decreased trade winds
- Altered gyre circulation

- Decreased MLD
- Increased stratification
- Decreased nutrient supply from deep waters

See: Karl *et al.,* Deep Sea Research PtII, **48**: 1449-1470, 2001

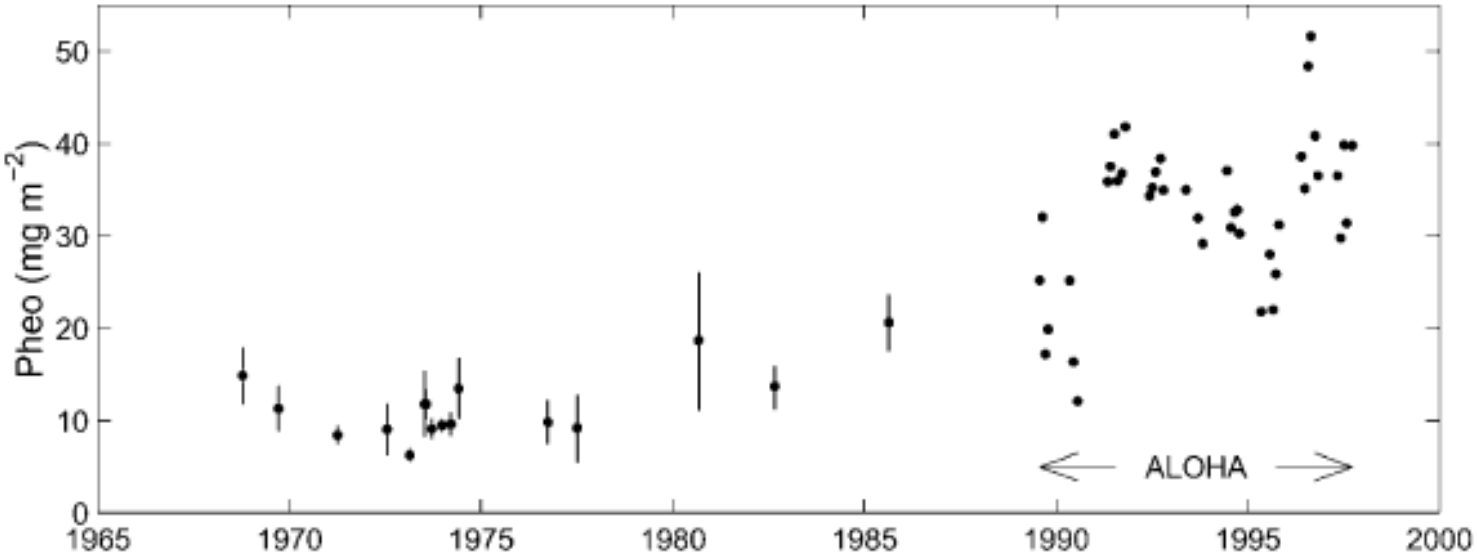
Phytoplankton response



- Increased PP
- Increased Chl

Karl *et al.,* 2001

Phytoplankton response



Transition to low SOI:

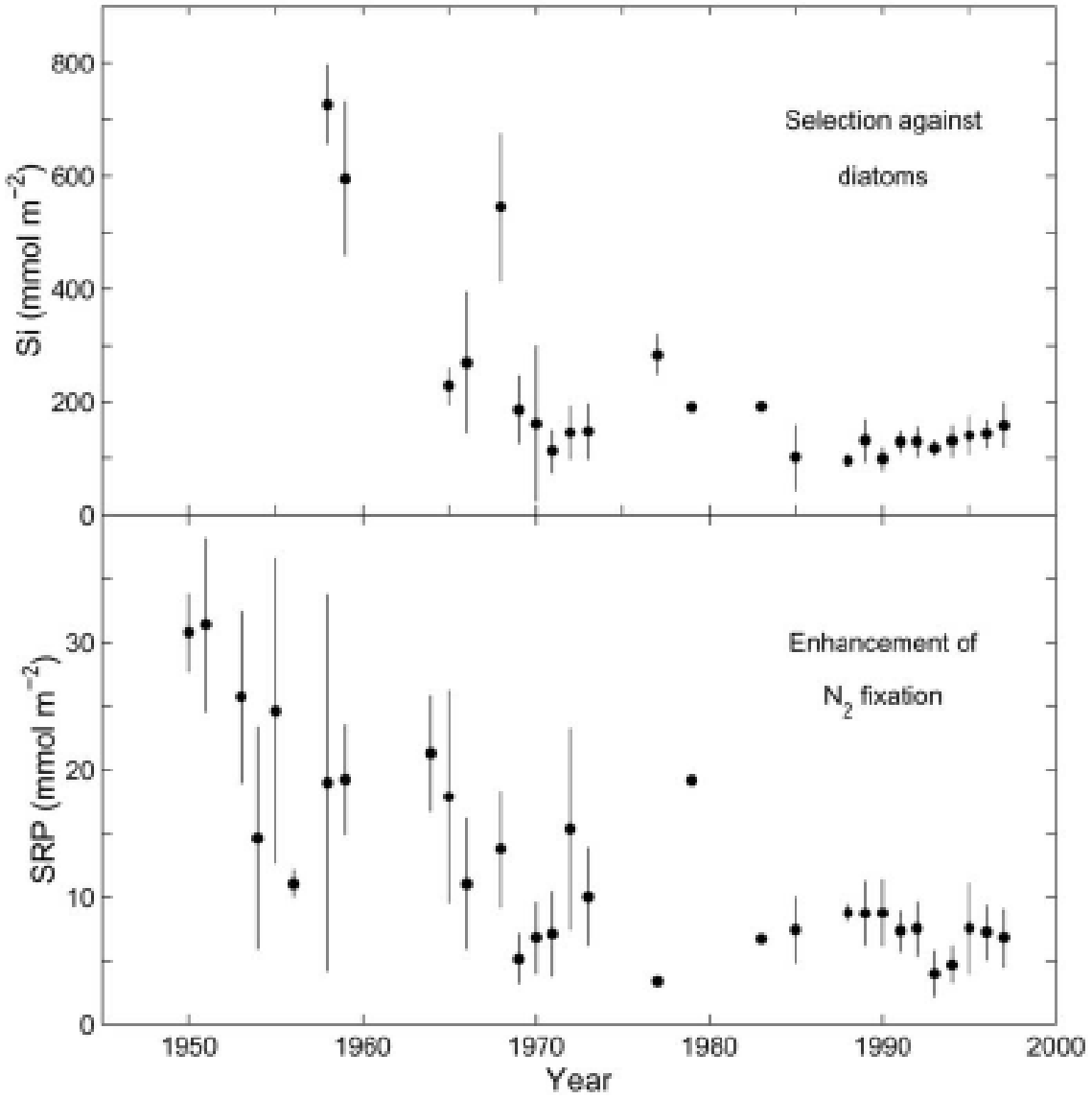
- Change in pigments
- Decrease in Si
- Increased N:P

- Increase in small cells
- Decrease in large diatoms
- Increase in N^2 fixers

Shift from nitrogen to phosphorous limitation

Karl *et al.*, 2001

Effect on biogeochemistry

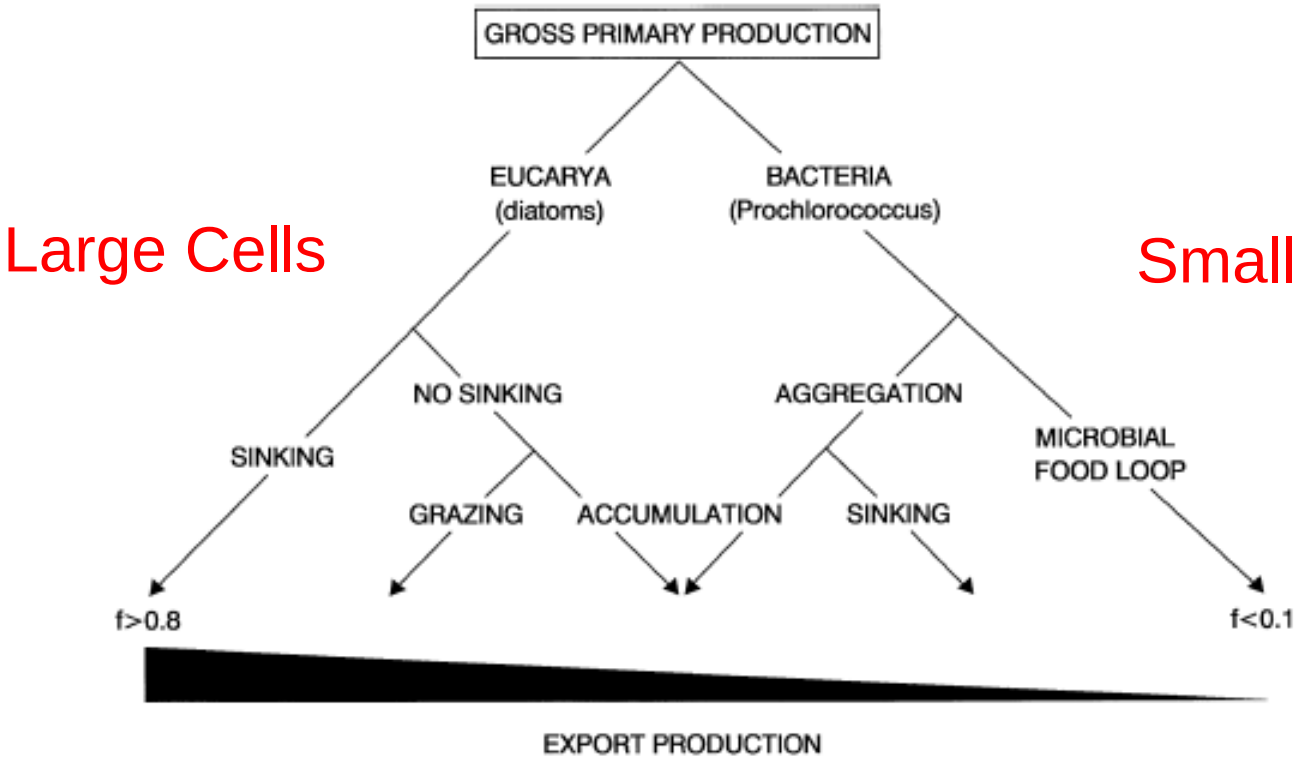


Decrease in silicate

Decrease in phosphate

Karl *et al.,* 2001

Effect on marine ecosystem



Shift to smaller cells:

- Adjusts N:P cycling
- Reduces export
- Reduces energy supply to higher trophic levels

Karl *et al.,* 2001

Summary: Hawaii Observations

Phytoplankton species changes:

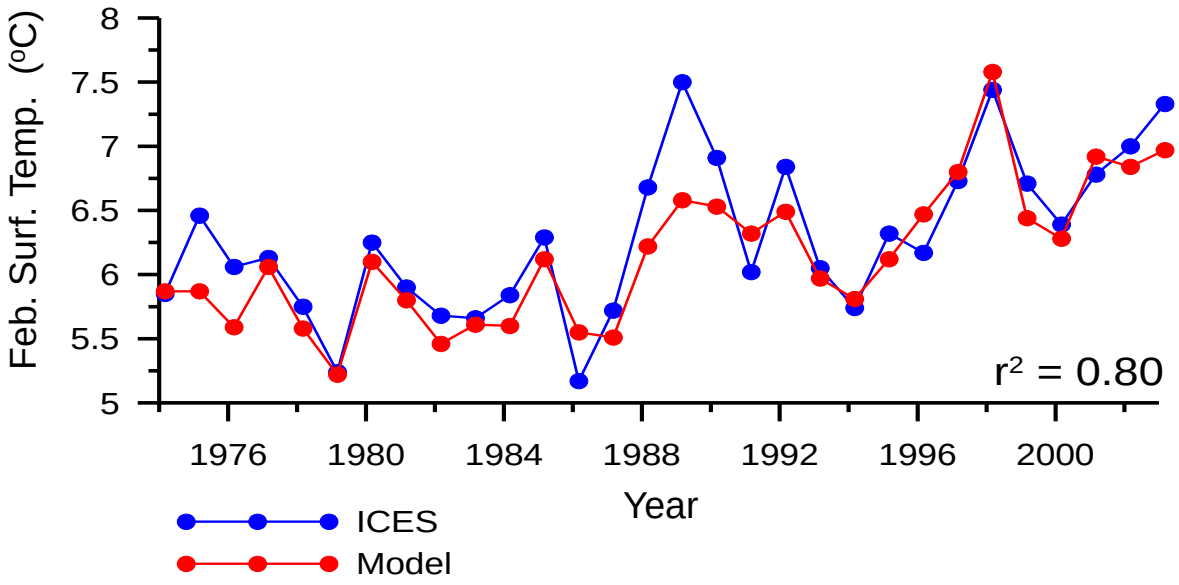
- Carbon sequestration
- Food web
- Biogeochemical cycles

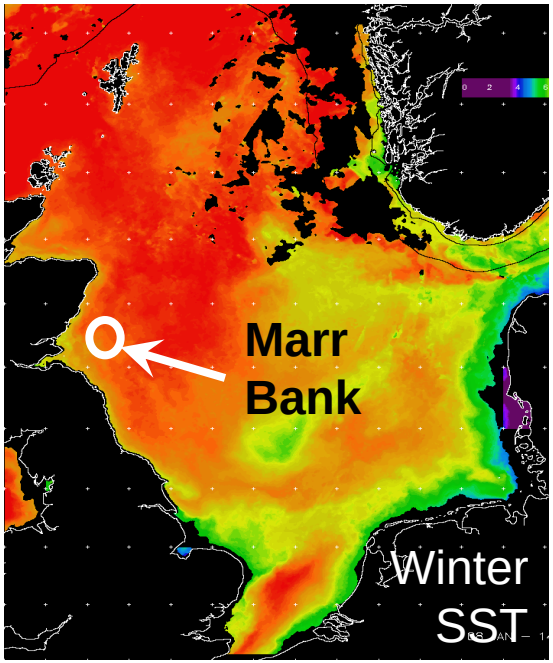
Important physical changes included:

- Stratification
- Upward nutrient flux

Med-timescale studies show how changes in physical conditions effect phytoplankton

NW North Sea Modelling Study

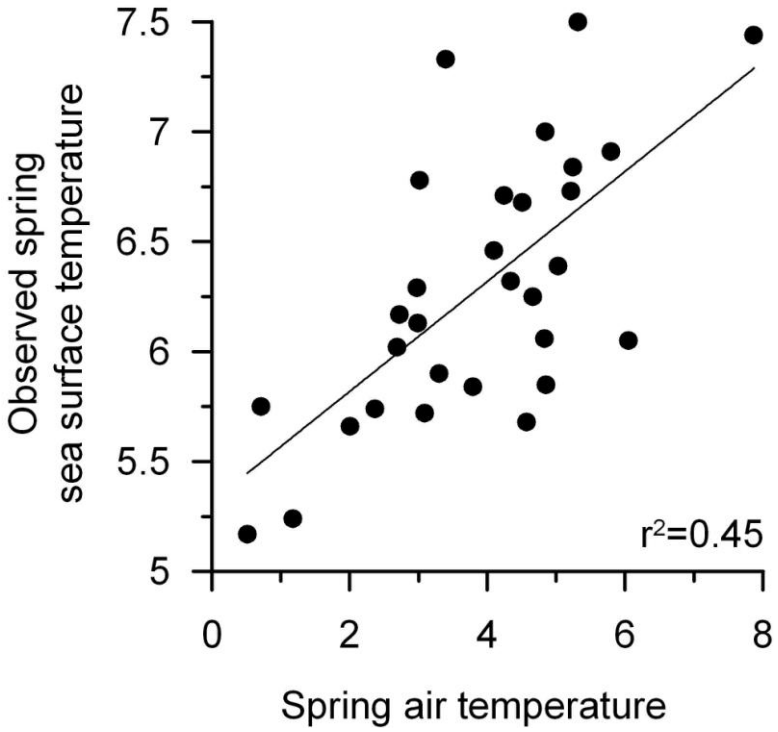




1-D physics model successfully tracks SST

See: Sharples *et al.,* Continental Shelf Research, **26**, 733-751, 2006.

NW North Sea Modelling Study



Sea conditions driven by local meteorology

NAO:

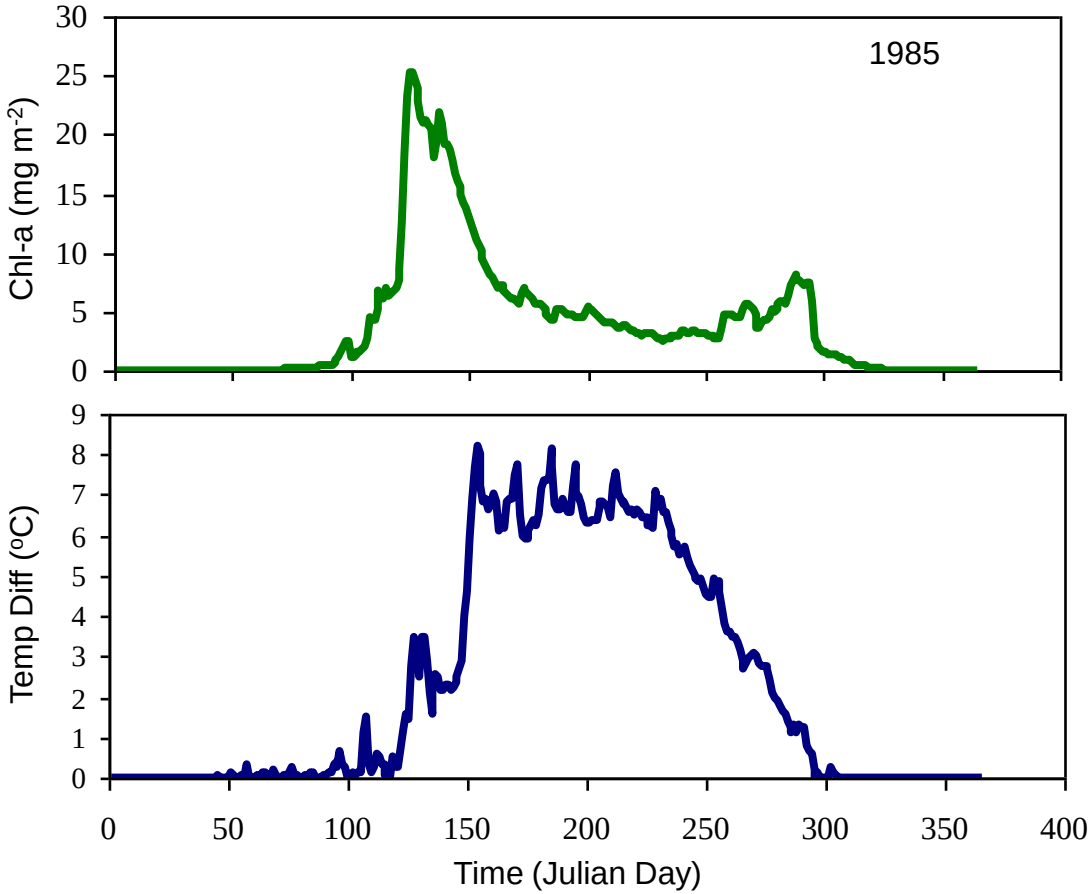
NE Atlantic winter SST may influence spring weather on shelf?

Timing of spring bloom

- WAS - spring wind stress
- NOW - spring air temperature

Sharples *et al.*, 2006.

NW North Sea Modelling Study



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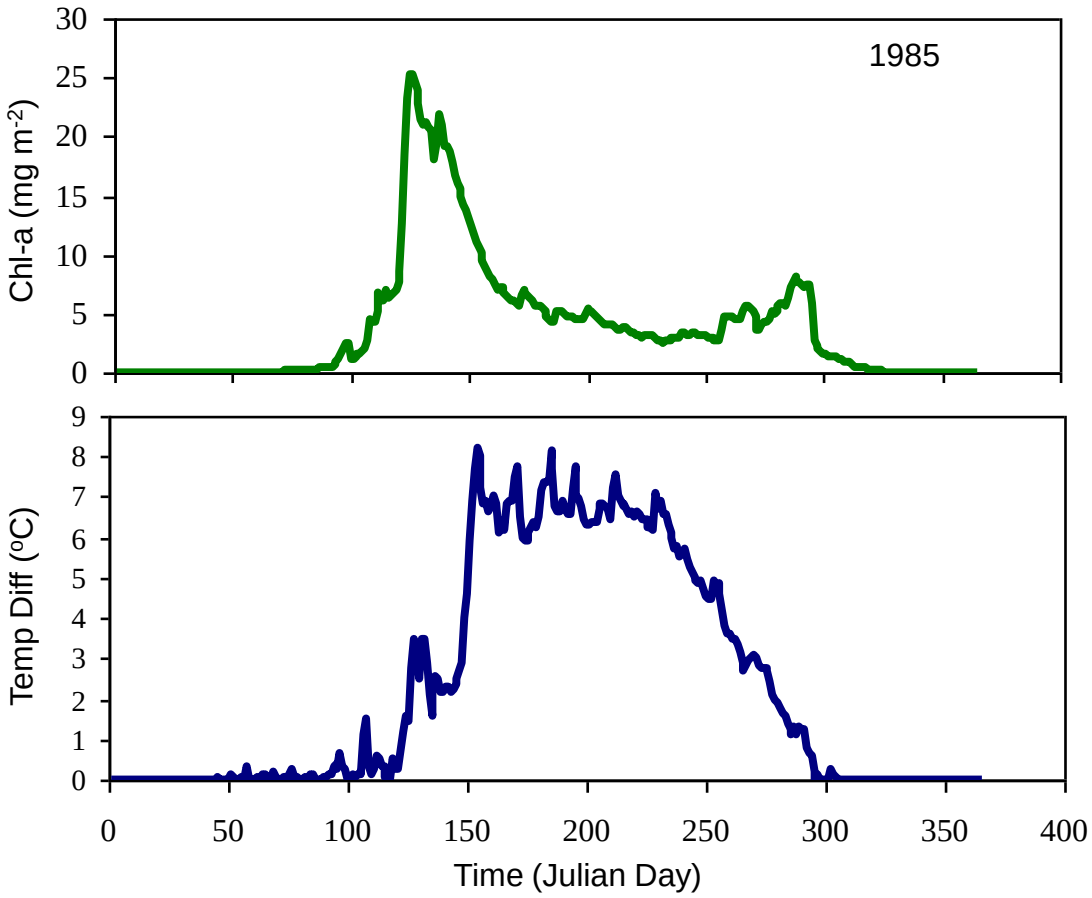

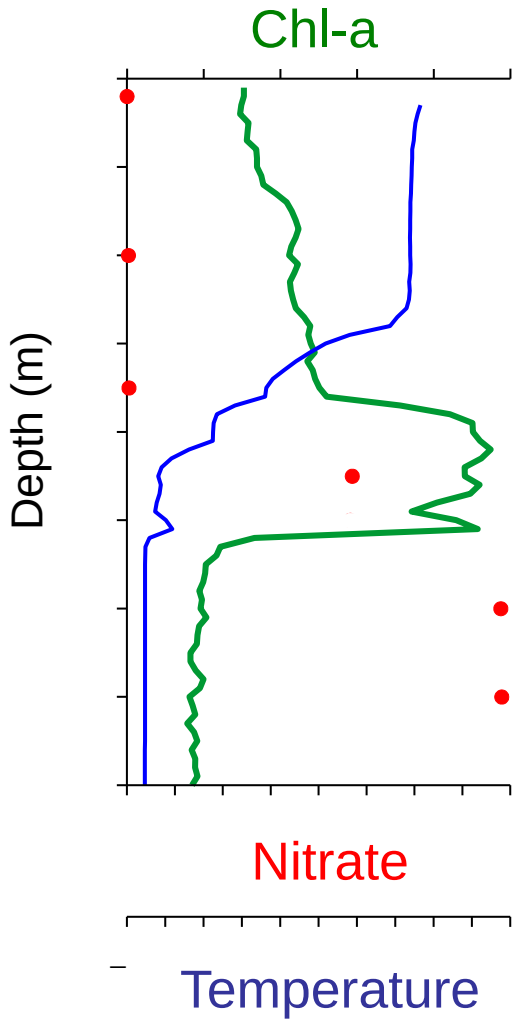

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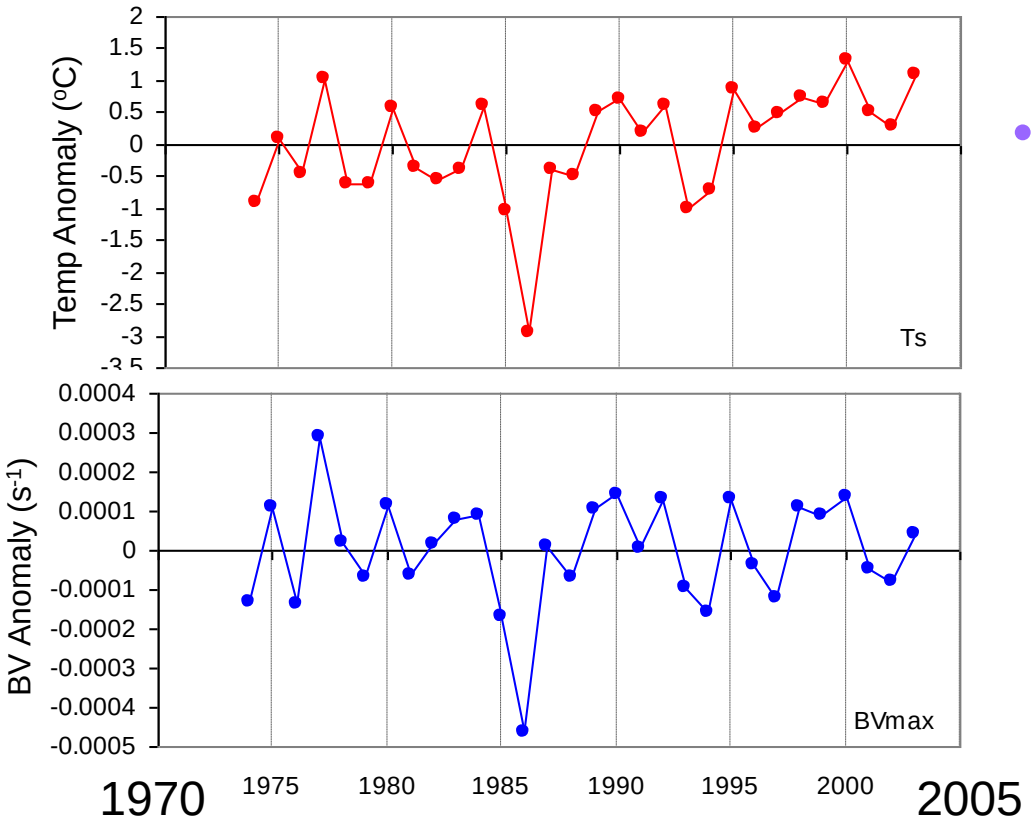
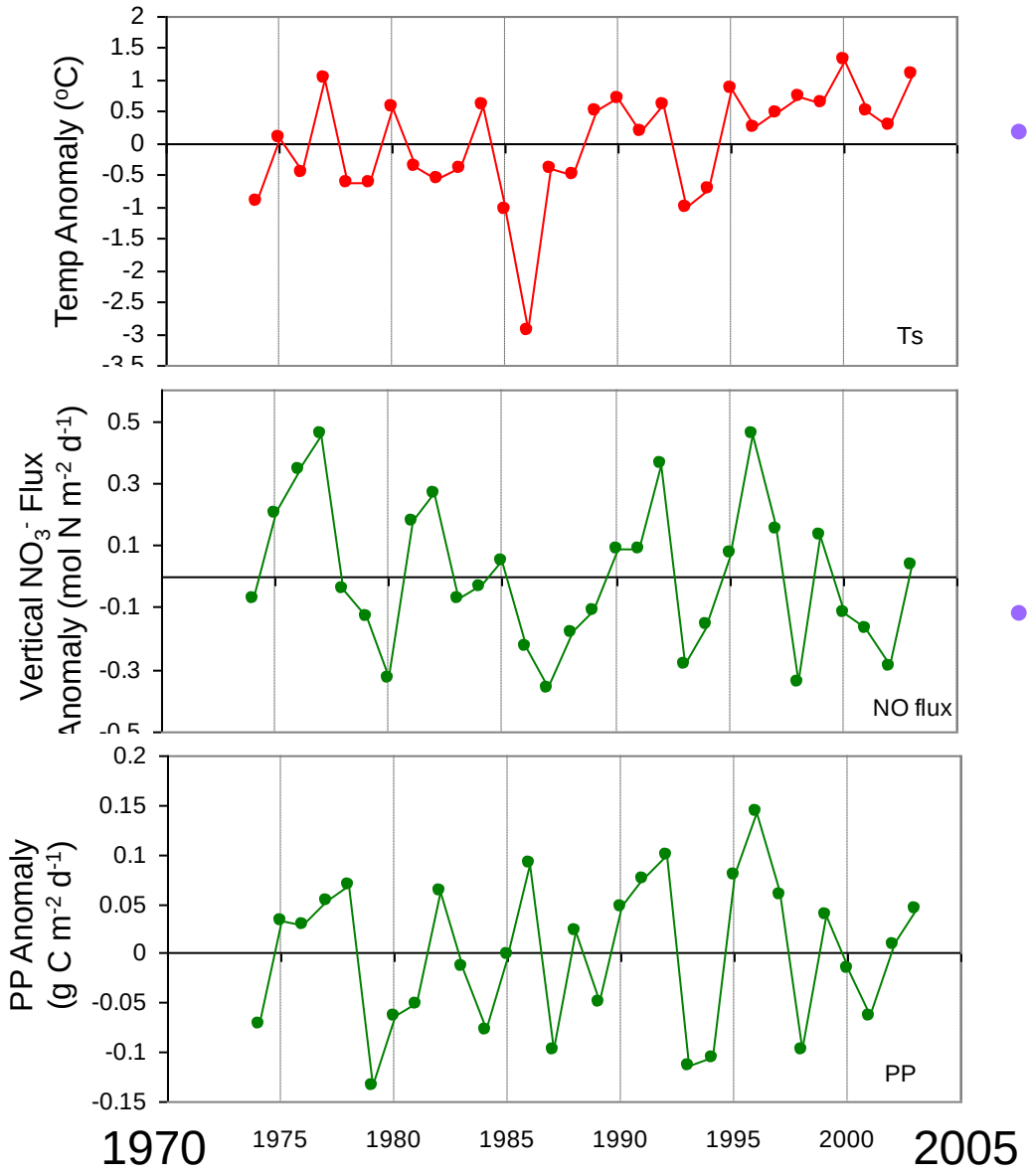


- Surface temperature
  - PAR
  - Stratification

NW North Sea Modelling Study



- Surface temperature
  - PAR
  - Stratification
- Nitrate flux correlated to
  - Primary production
  - Total chl-a

Summary: NW North Sea

Similar to Hawaii Tropical Ocean:
- Wind and temperature key environmental variables
- Changes in stratification

Increased wind forcing:
- Reduced length of stratified period
- Reduced seasonal PP
- Weakly correlated to stratification

Increased temperature:
- Likely increase length of stratified period
- Enhanced stratification

Summary: NW North Sea

In contrast to Hawaii Tropical Ocean:

- Stratification not correlated to nutrient flux
- Nutrient flux different effect on PP

Summary: NW North Sea

In contrast to Hawaii Tropical Ocean:

- Stratification not correlated to nutrient flux
- Nutrient flux different effect on PP

What controls vertical nutrient flux?

- Long-term changes lost (e.g. remineralisation)
- Feedback from PP (Hickman, et al. *In Prep.*)
- Wind induced mixing (Rippeth et al., *In Prep*)

Summary: NW North Sea

In contrast to Hawaii Tropical Ocean:

- Stratification not correlated to nutrient flux
- Nutrient flux different effect on PP

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- Long-term changes lost (e.g. remineralisation)
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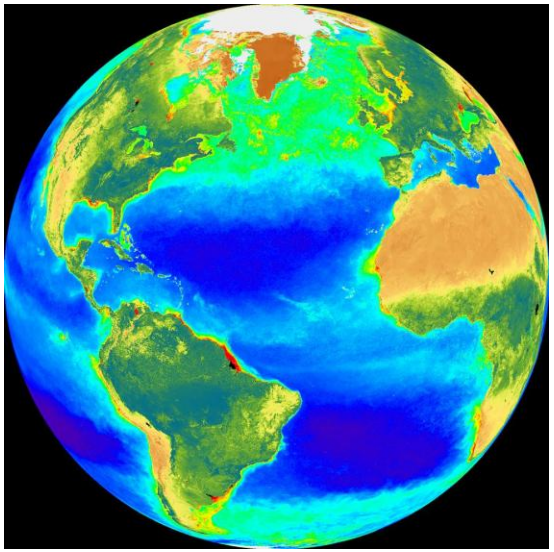
Likely impact on phytoplankton?

- Chl-a and PP correlated to nutrient flux
- Nutrient flux adjusts size structure?
  - Export (benthos)
  - Energy for higher trophic levels (fisheries)

Ecological modelling strategy

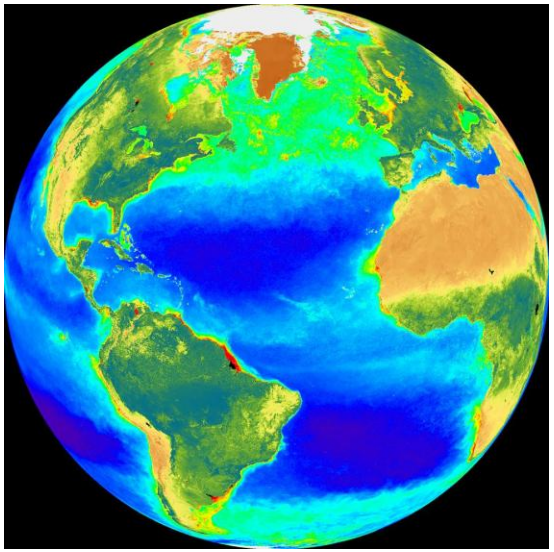
MIT Darwin Ecosystem Model:

- MIT: open ocean (Follows *et al.* 2007)
- 100's of 'ecotypes'
- Self-organised community



See: Follows et al., *Science,* 2007

Ecological modelling strategy



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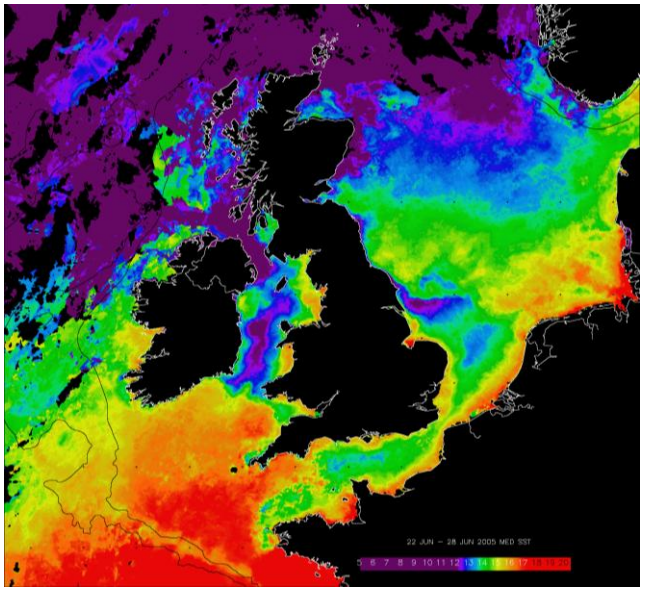


MIT – Liverpool collaboration:

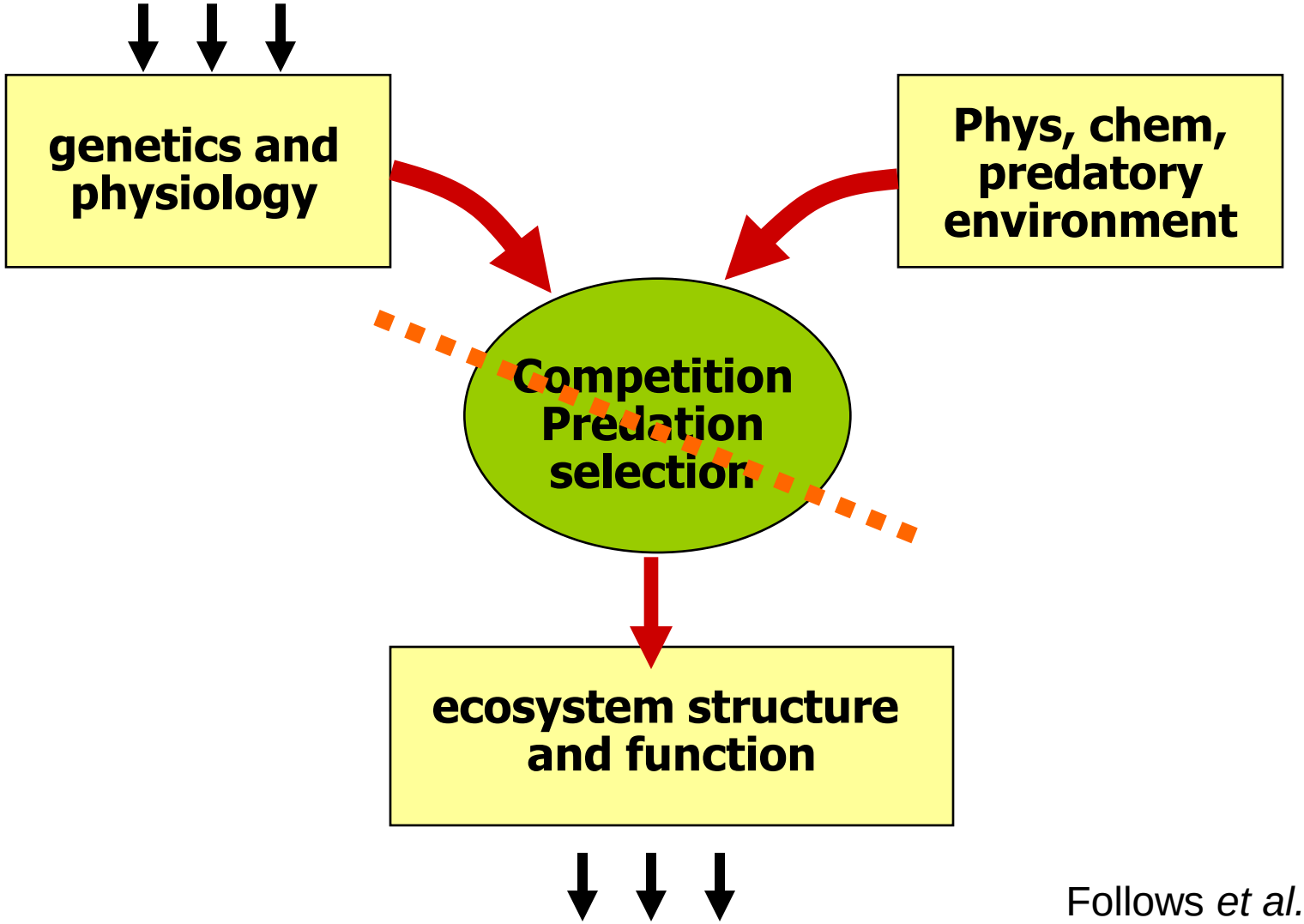
- Liverpool: coastal ocean

Ric Williams (DEOS)
Jonathan Sharples (POL)
Anna Hickman (POL)
Follows, Dutkiewicz (MIT)

See: Follows et al., *Science,* 2007

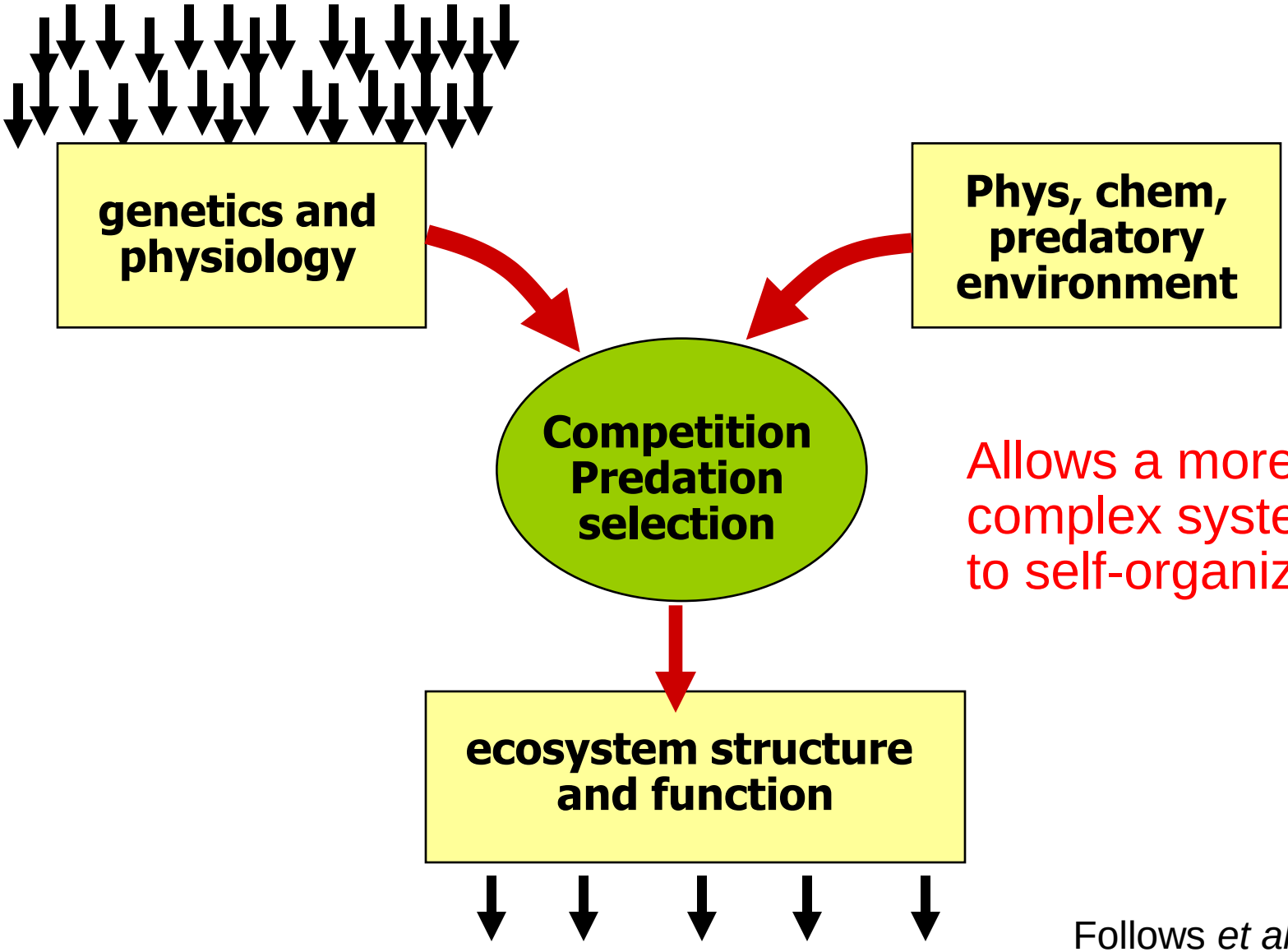
MIT Darwin Ecosystem Model

NPPPZ MODEL: Several phytoplankton



Follows *et al.*, 2007

MIT Darwin Ecosystem Model

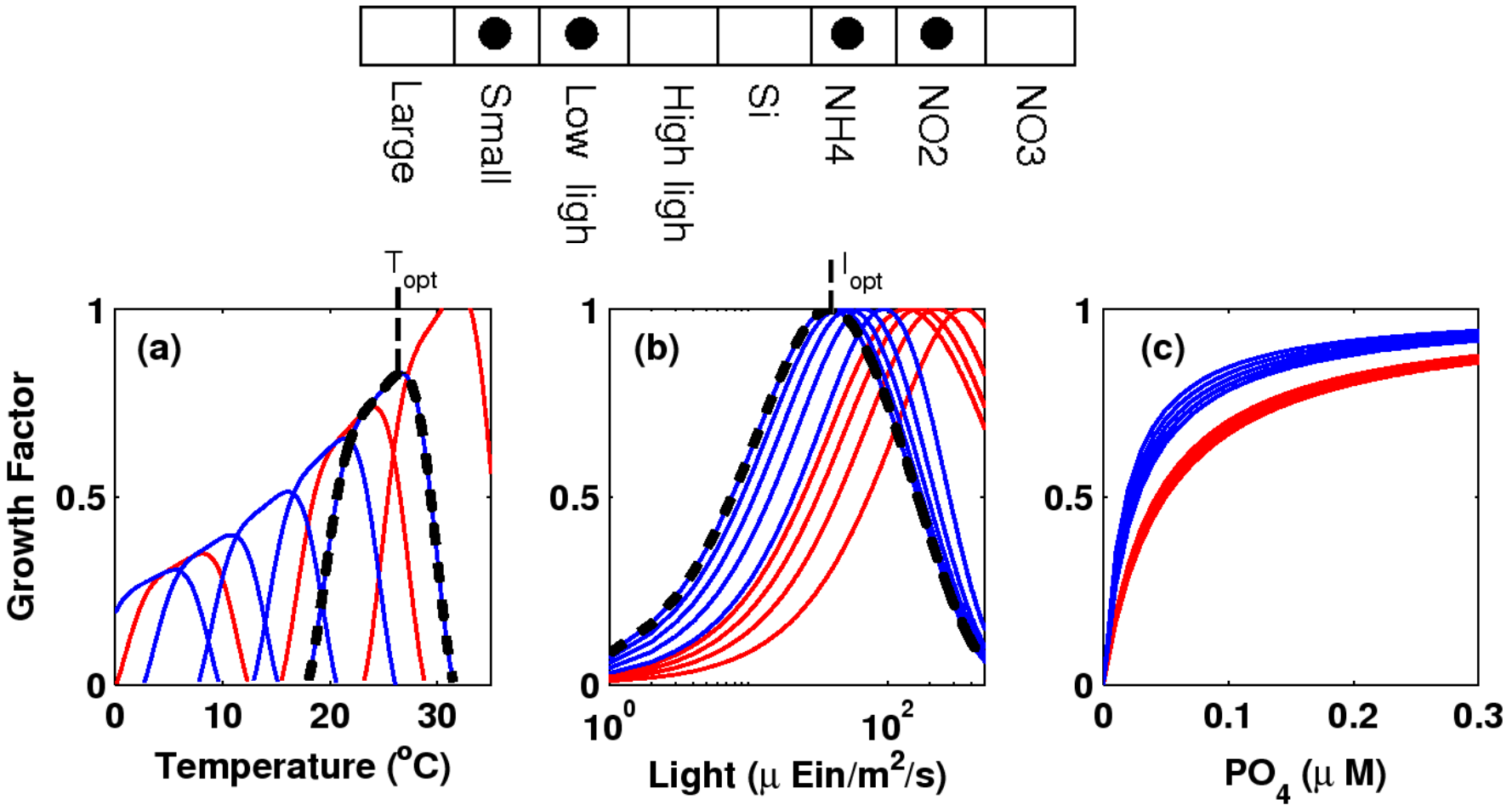


Allows a more complex system to self-organize

Follows *et al.*, 2007

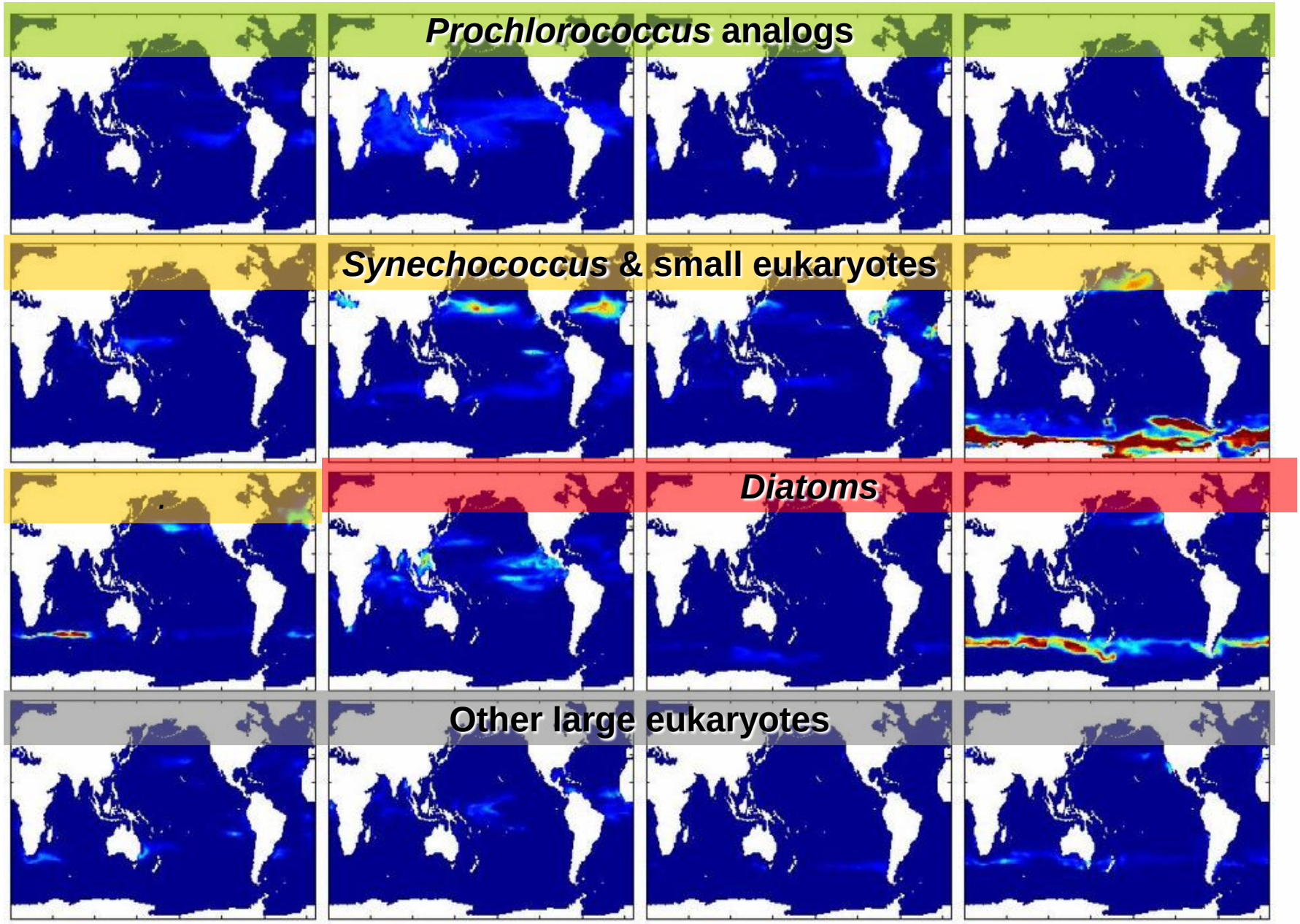
MIT Darwin Ecosystem Model

- "Random" assignment of functional properties, with some simple allometric trade-offs
- Virtual coin-flips assign functional properties

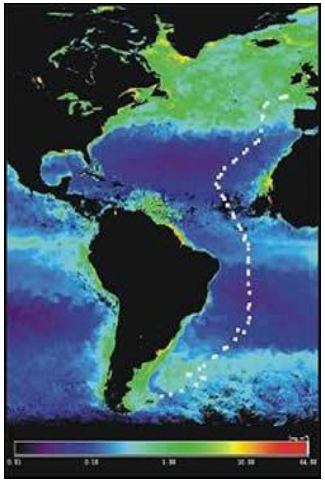


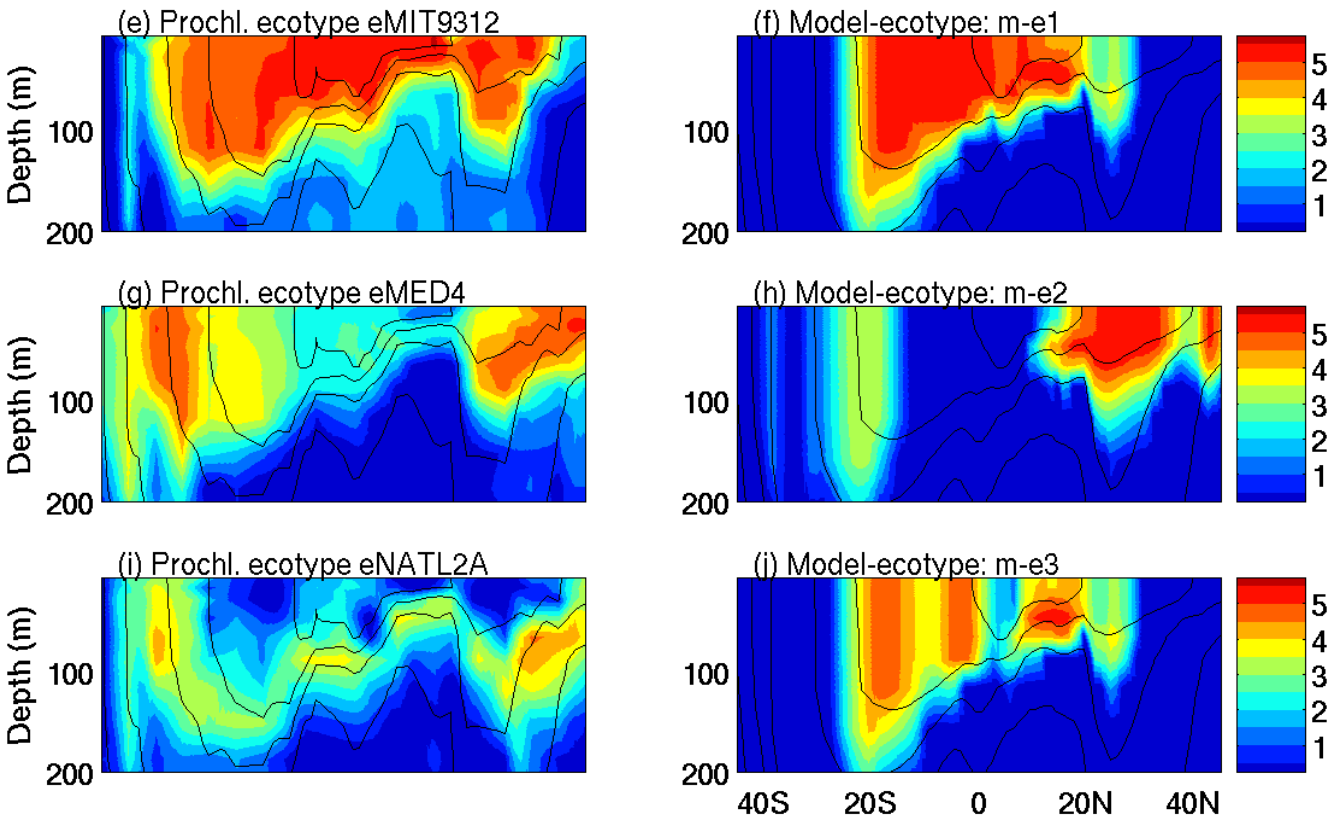
Single ensemble member, all functional types, 0-50m

16 most abundant phytoplankton functional types in emergent ecosystem



Plausible analogs of *Prochlorococcus* on AMT13 track





***Prochlorococcus* ecotypes AMT13 (Johnson et al., 2006)**

model-ecotypes

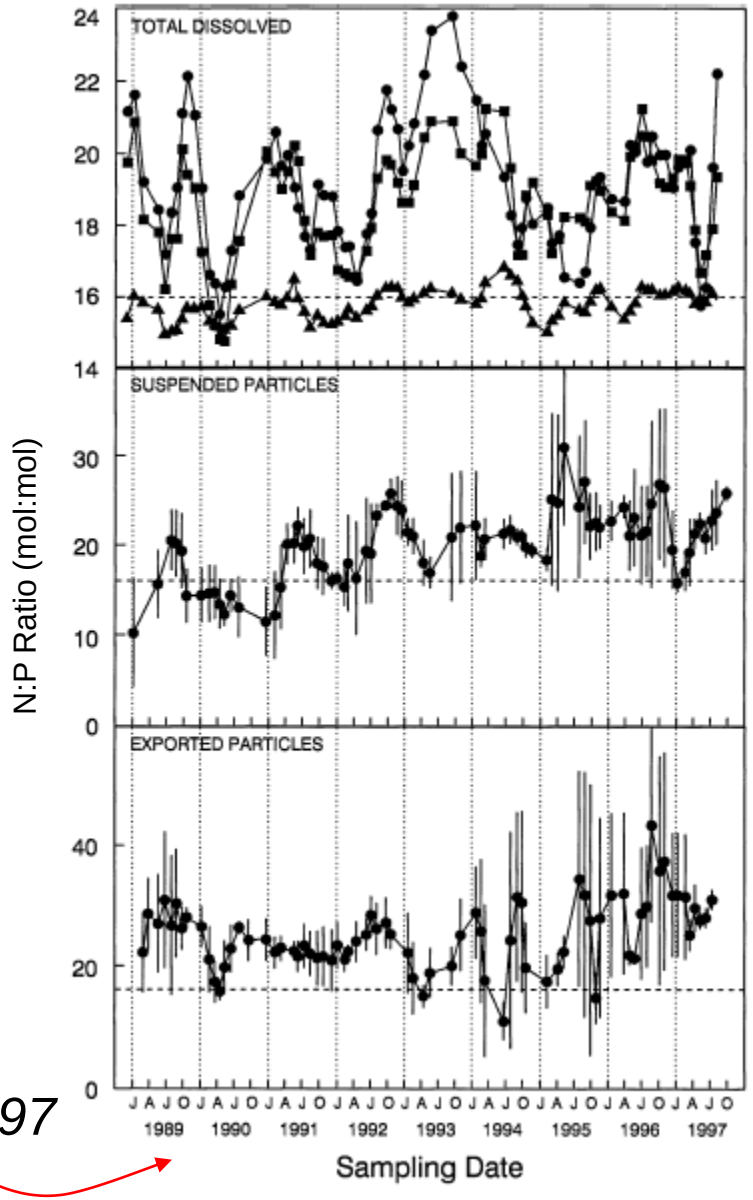
- Model ecotypes consistent with observed counterparts

Follows *et al.*, 2007

Effect on biogeochemisty

- Increase in particulate N:P
- Increase in exported N:P

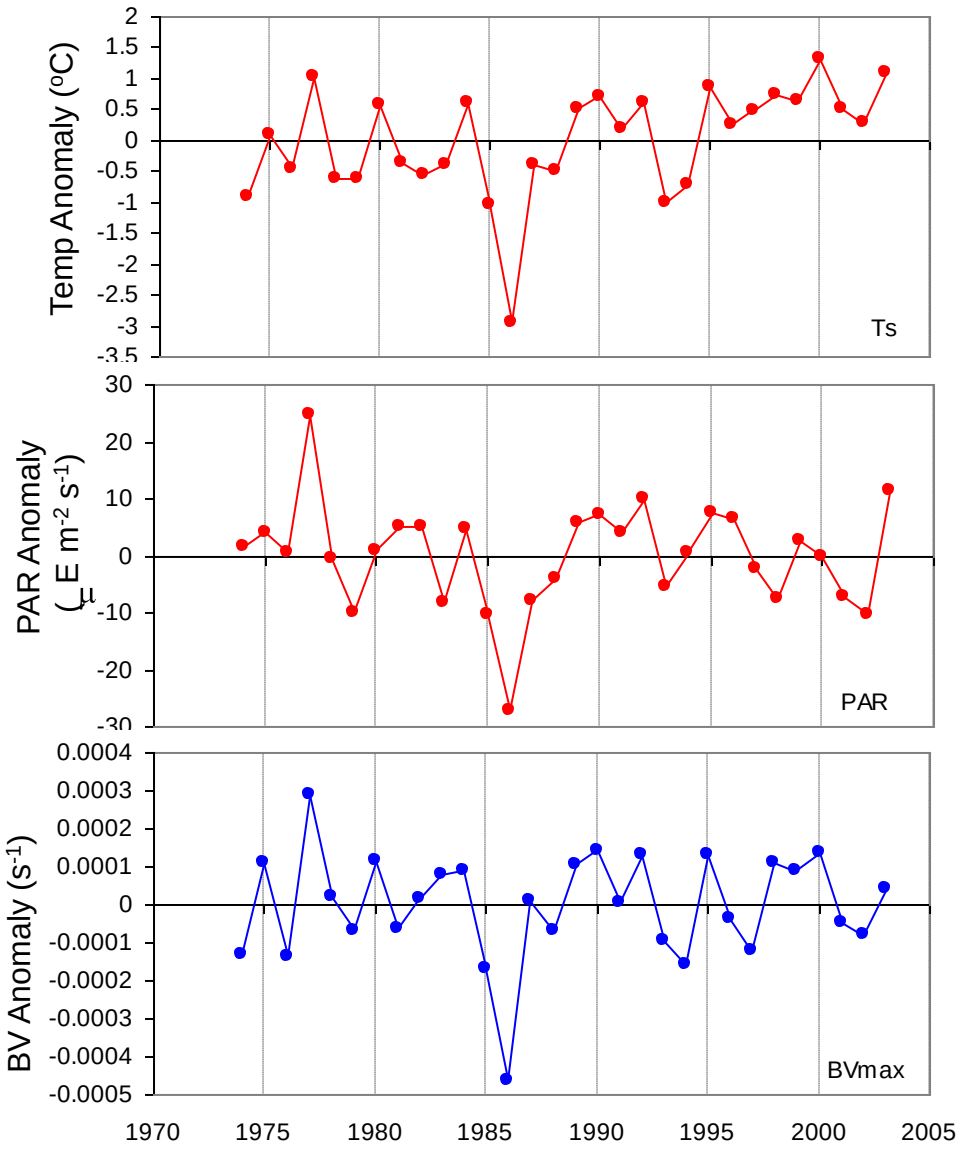
Shift from nitrogen to phosphorous limitation



Note timescale 1999-1997

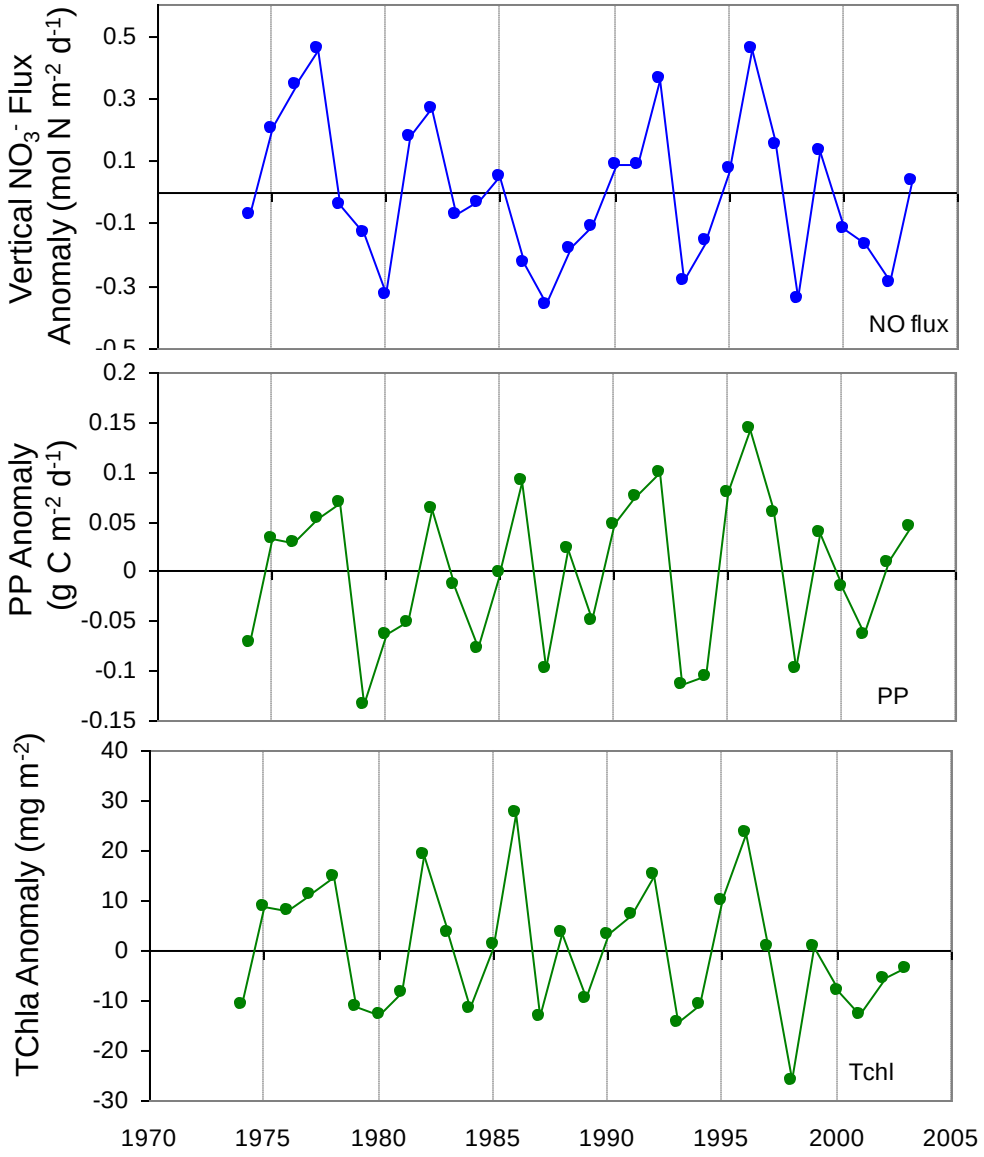
Karl *et al.,* 2001

NW North Sea Modelling Study



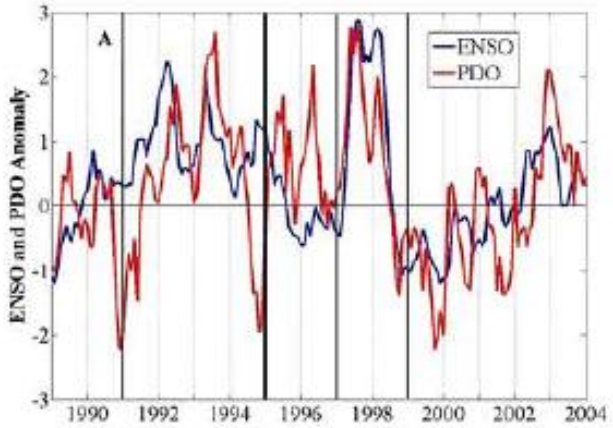
- Strength of stratification
  - Surface temperature
  - PAR

NW North Sea Modelling Study

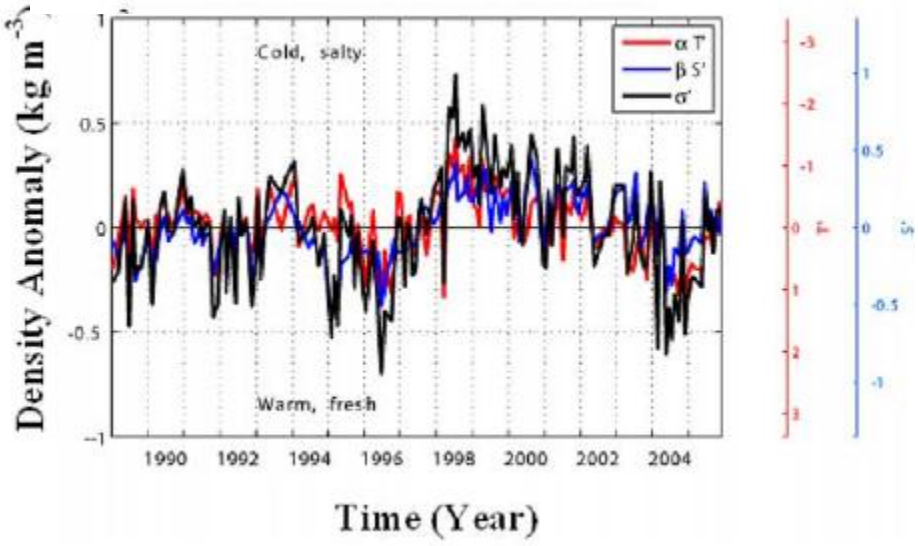


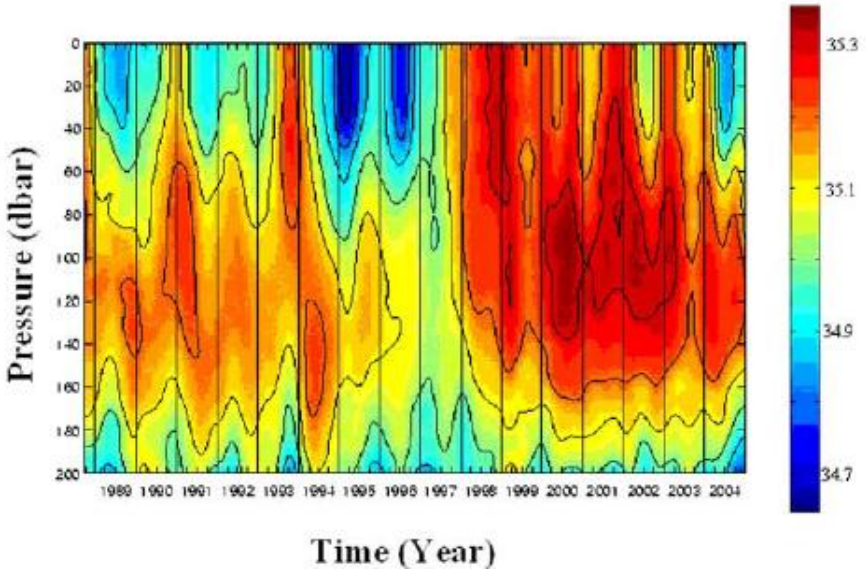
- Nitrate flux correlated to
  - Primary production
  - Total chl-a

Climate driven changes in water column properties



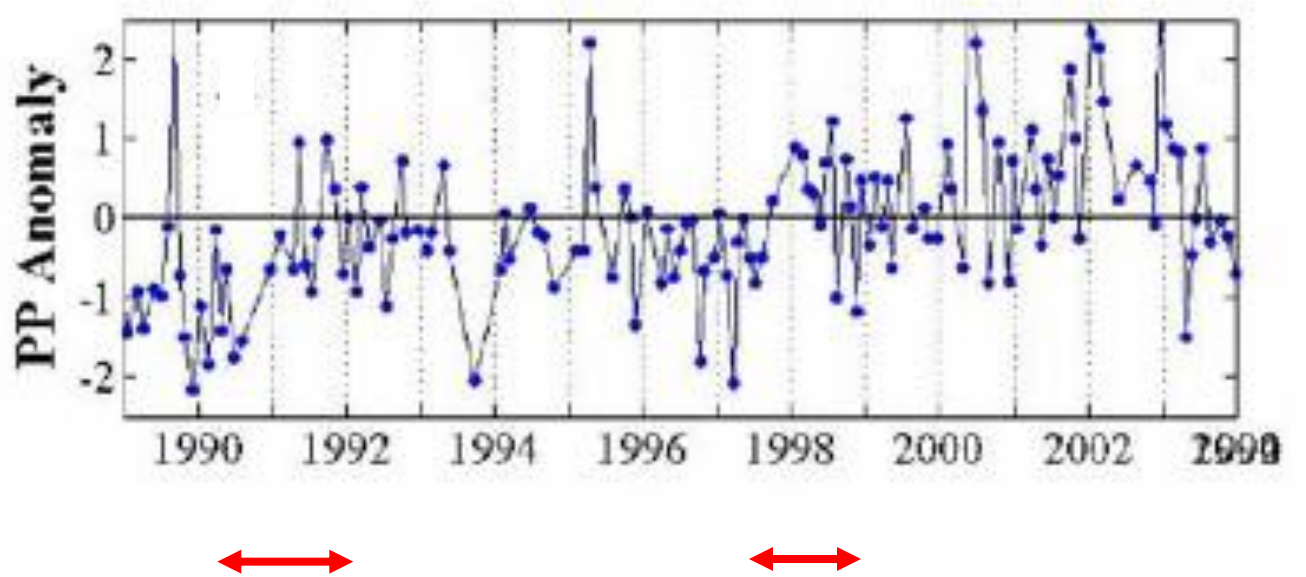
1996 to 1998: transition from warm/fresh to cold/salty conditions





Corno *et al.*, 2007

Biological response: primary production

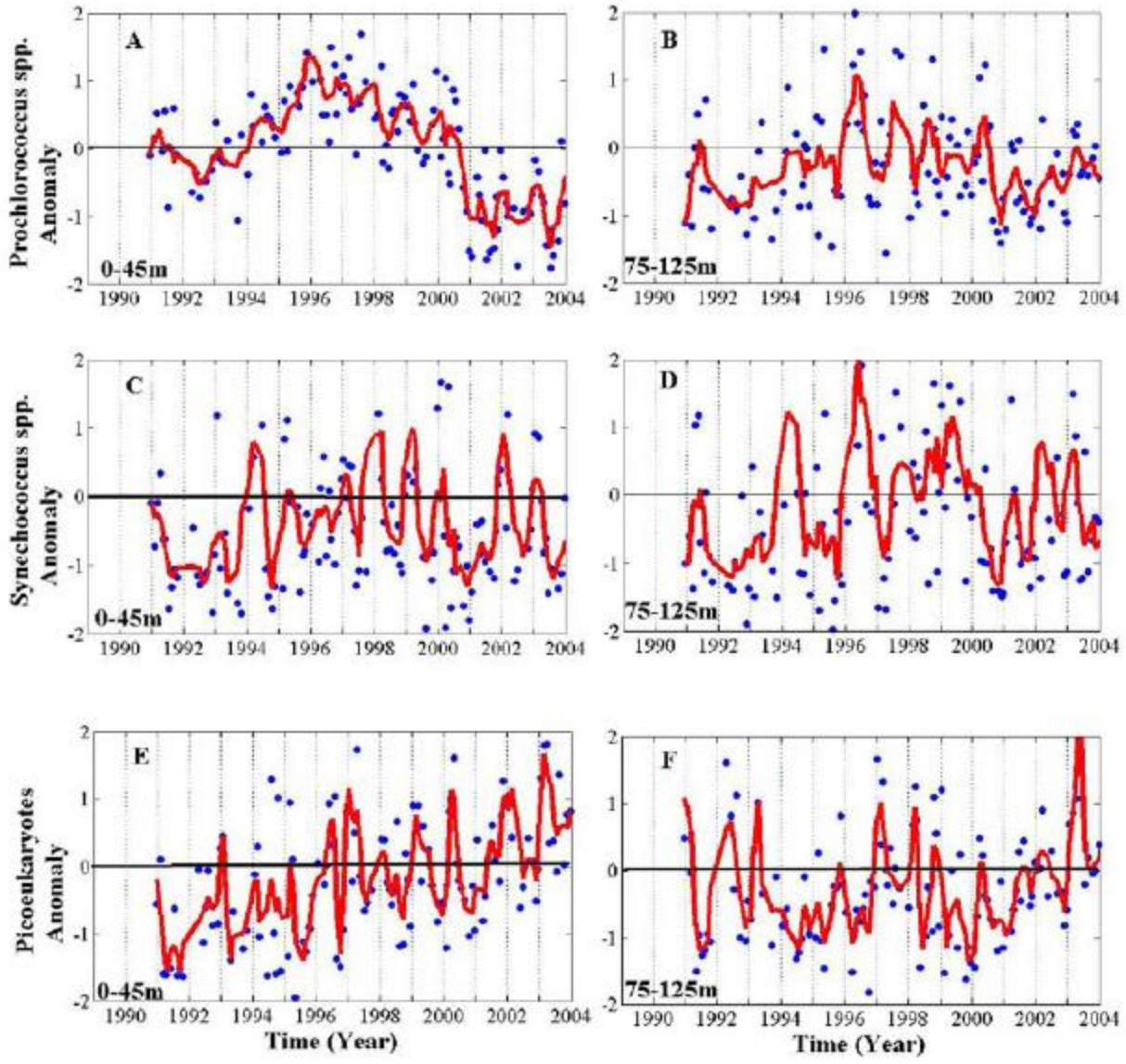


+ 25%

+ 30%

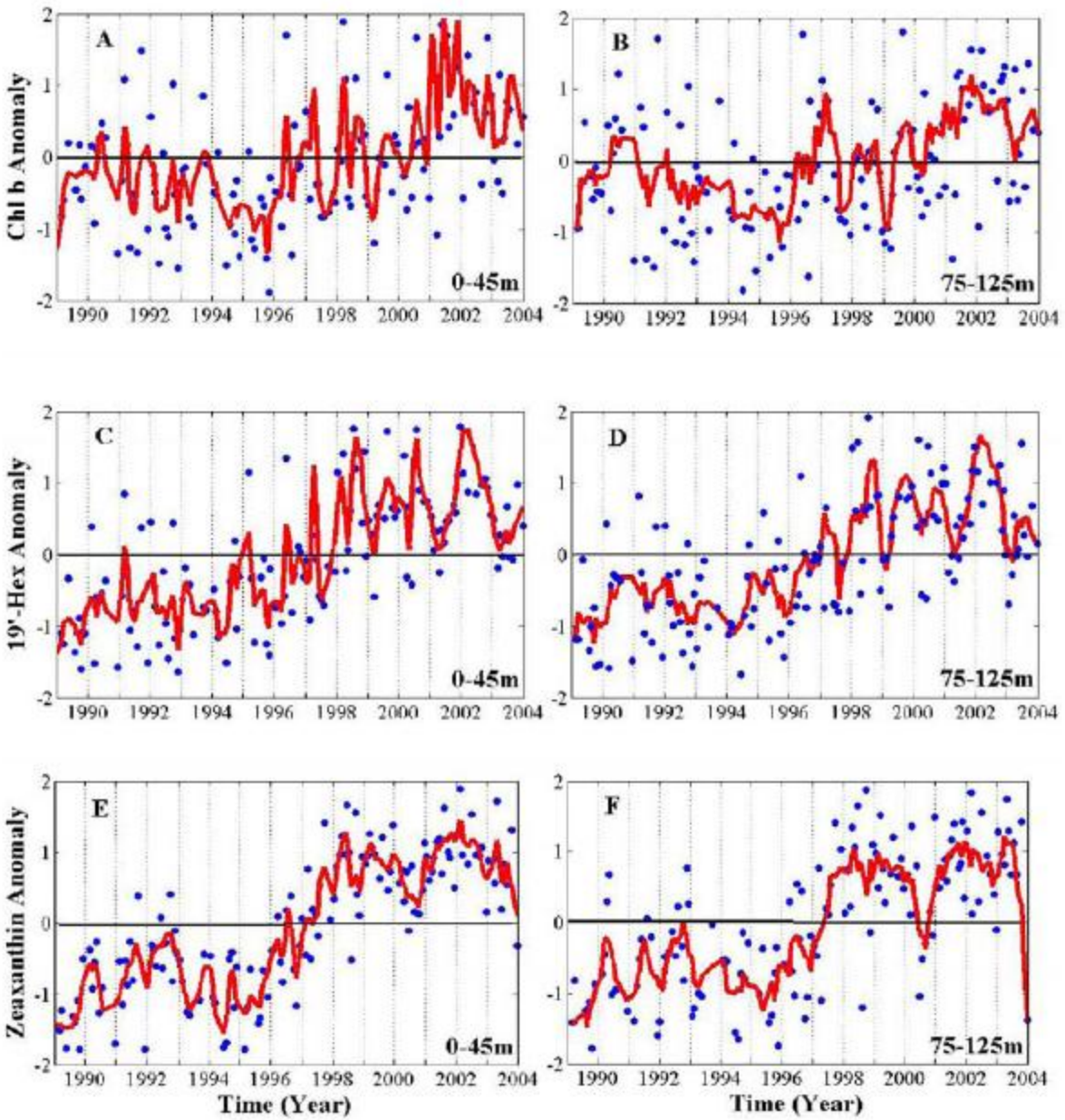
Corno *et al.*, 2007

Biogeochemical response: Biomass



Corno *et al.*, 2007

Biogeochemical response: Community structure



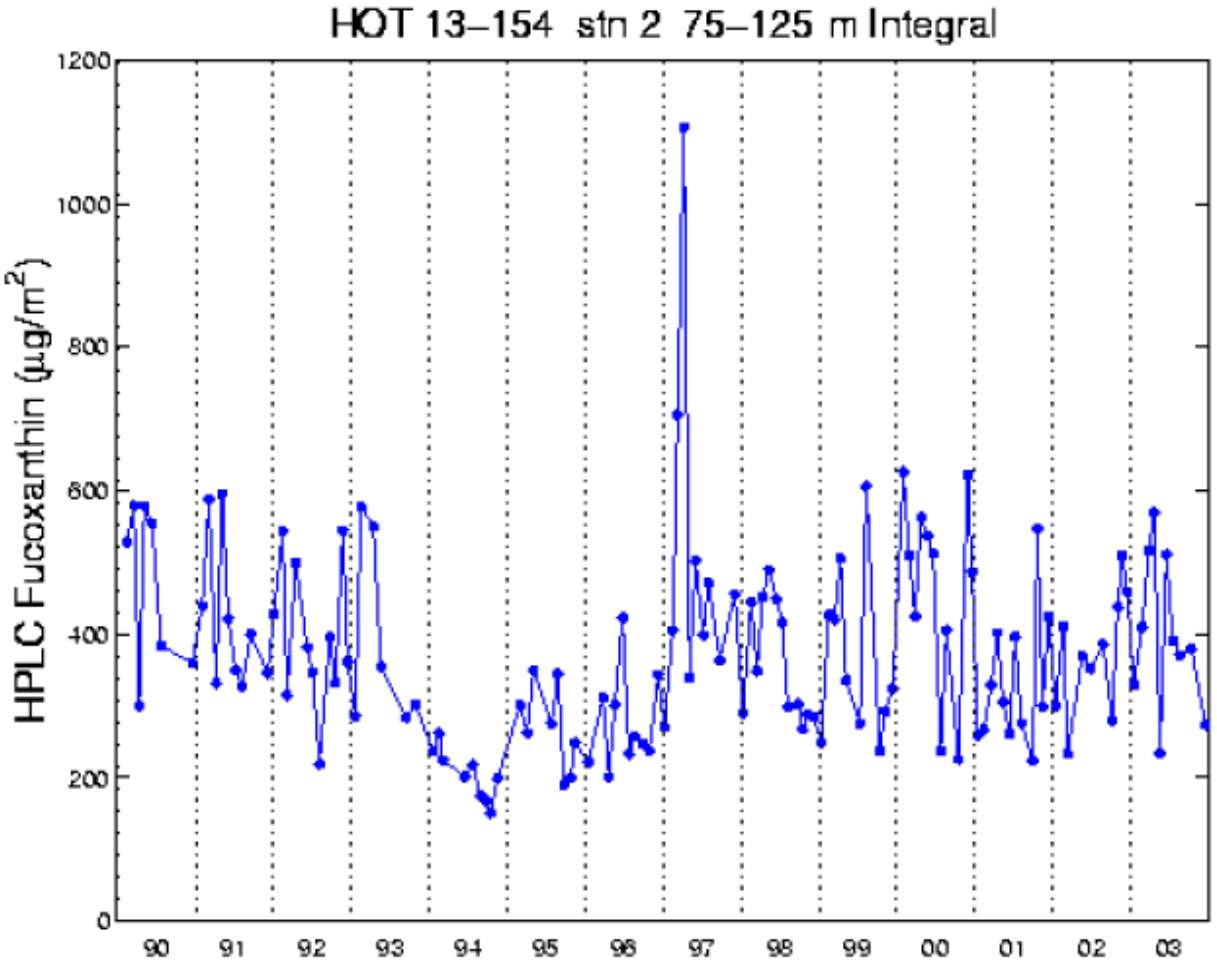
Chl b
~ prochlorophytes

19-Hex
~ prymnesiophytes

Zea ~
cyanobacteria

Corno *et al.*, 2007

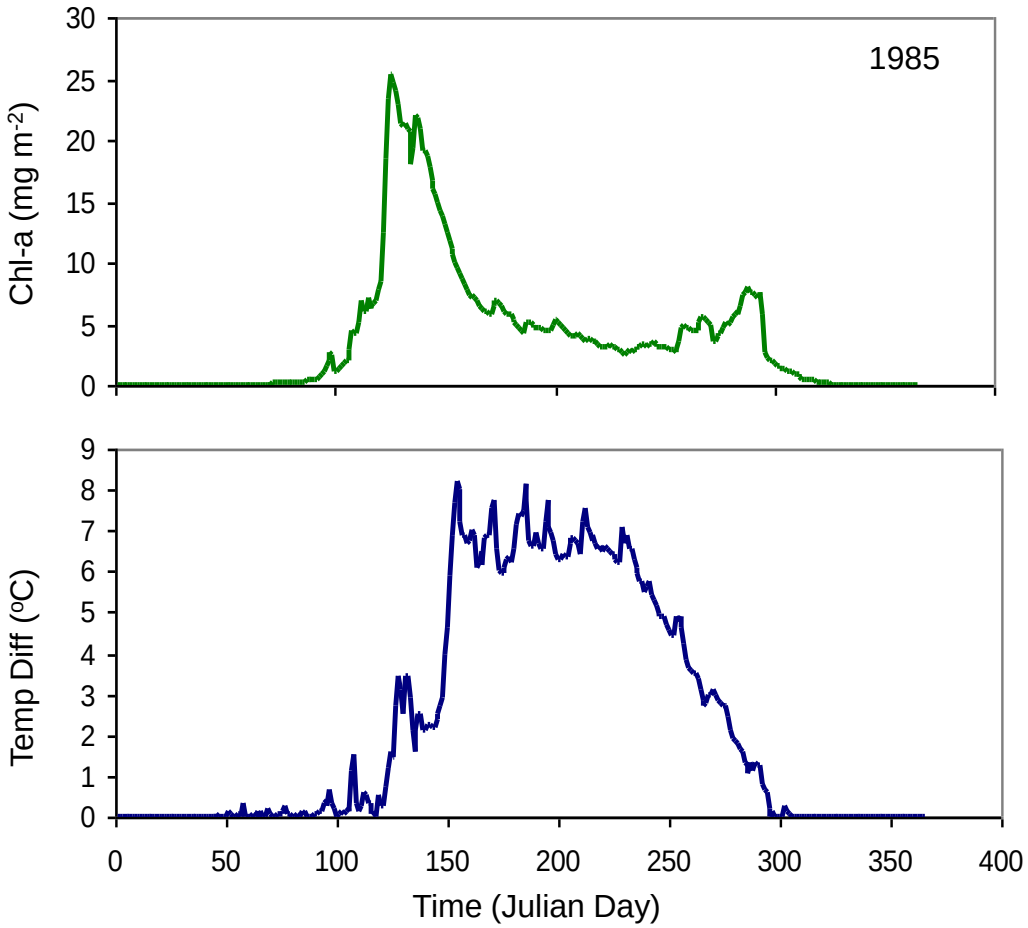
Biogeochemical response: Community structure

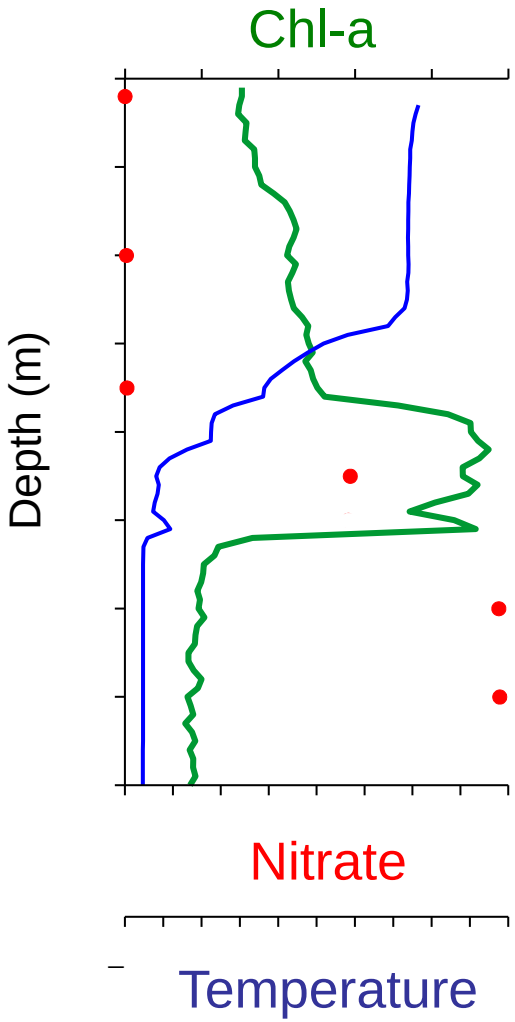


Fuco ~ diatoms

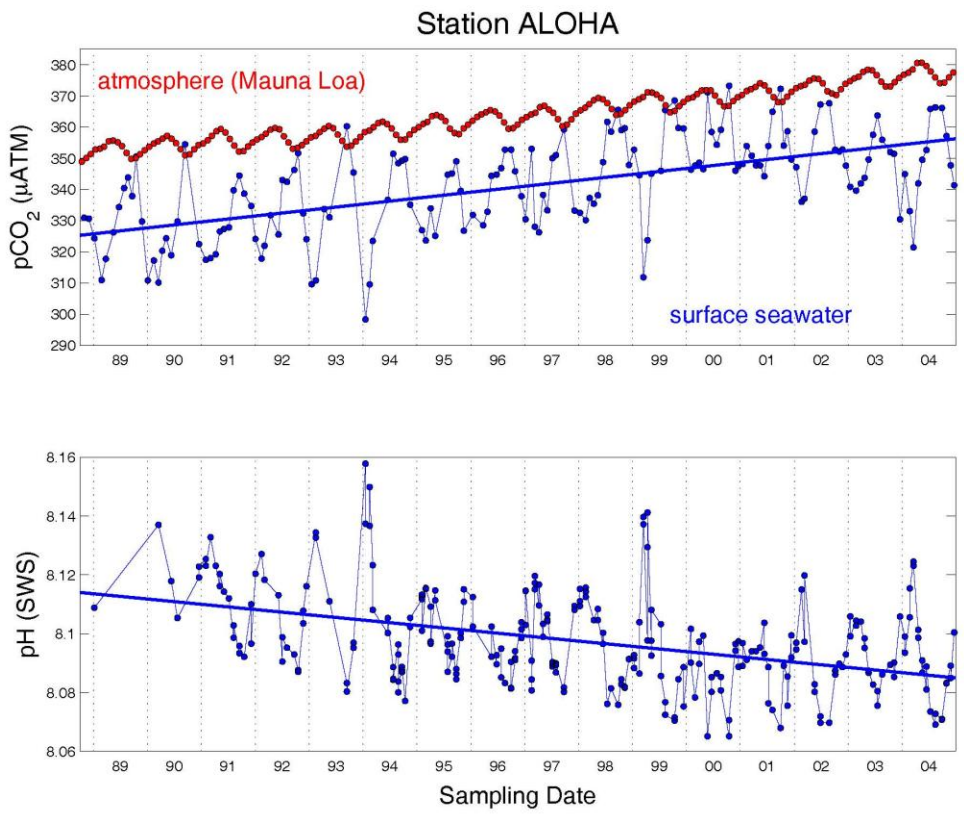
Scharek *et al.*, 1999

NW North Sea Modelling Study





What's HOT at station ALOHA?



Climate-driven changes to the atmospheric CO_2 sink in the subtropical North Pacific Ocean

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Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawaii, 1000 Pope Road, Honolulu, Hawaii 96822, USA