RESPONSE OF PHYTOPLANKTON AND OCEAN BIOGEOCHEMISTRY IN A WARMING WORLD

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INTRODUCTION:

Marine Ecosystem
- responsible for trapping large amount carbon in deep ocean
- responsible for large portion of food for many nations

Phytoplankton
- microscopic organisms at base of marine foodweb
- fix carbon in the surface sunlight layers
- different communities more/less responsible for removing carbon to deep ocean

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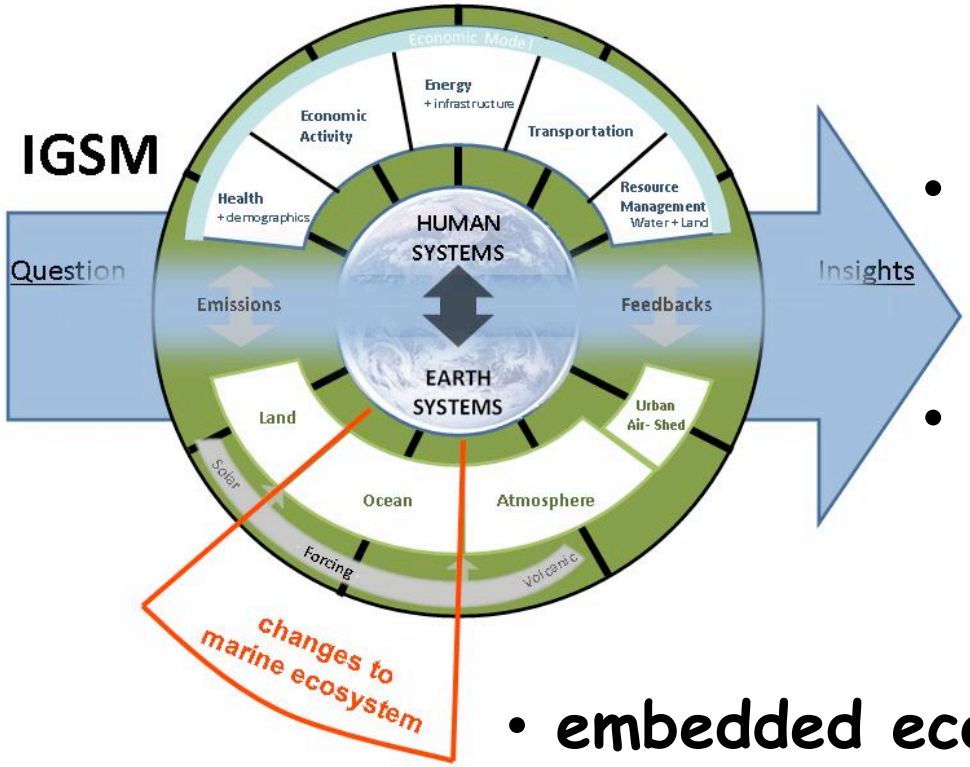
What processes will cause phytoplankton habitat and community structure to change in a future warmer ocean?

MODEL DESIGN:

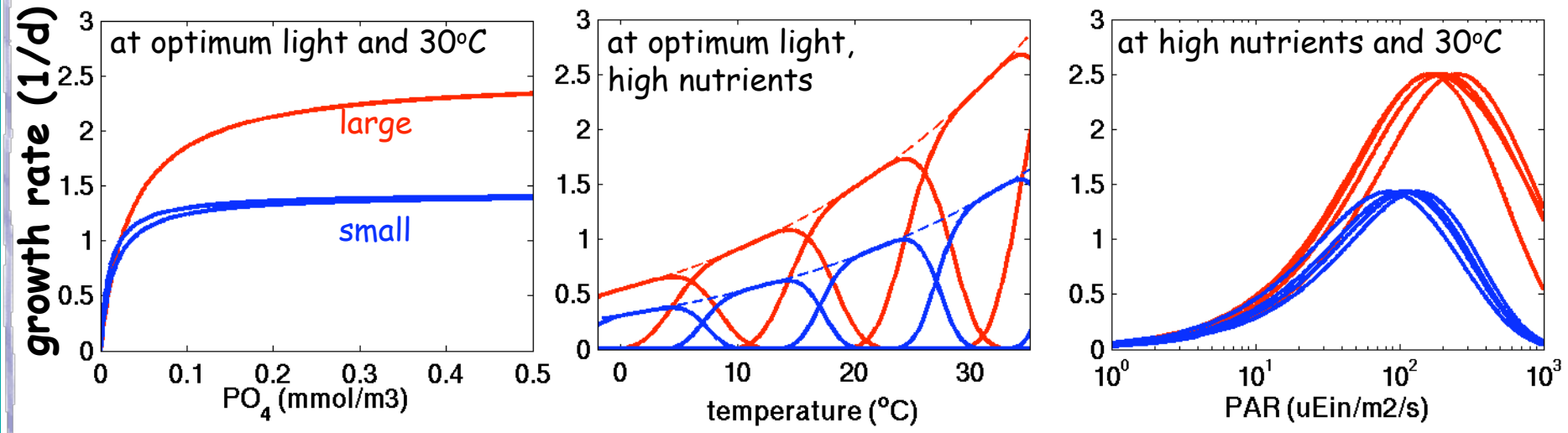
MIT Integrated Global Systems Model



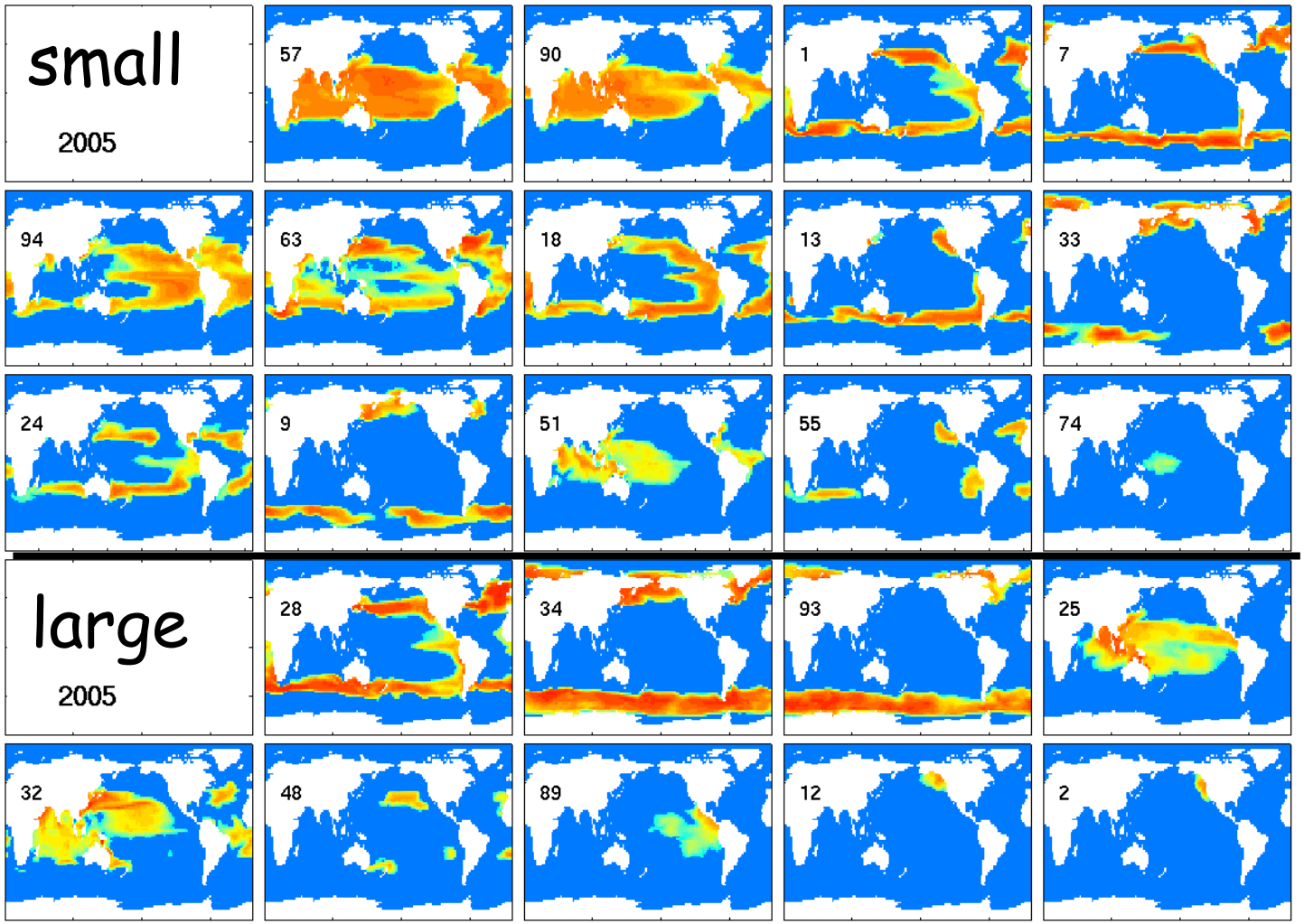
- atmosphere, ocean, land, economics components
- 3-D ocean (2°x2.5° resolution, 22 levels in vertical)
- embedded ecosystem and biogeochemical module (the MIT "Darwin Project" Model, Follows et al, Science, 2007)

ECOSYSTEM MODEL DESIGN:

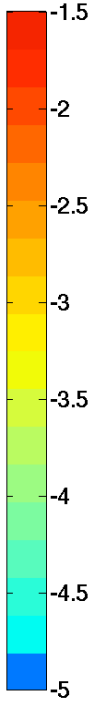
- 100 phytoplankton types with random combination of characteristics:
  - large: high carbon export
    small: lower carbon export
  - temperature optimum and range
  - light optimum and inhibition



ECOSYSTEM: CURRENT DAY HABITAT



2005



log10 (biomass) 5 year average

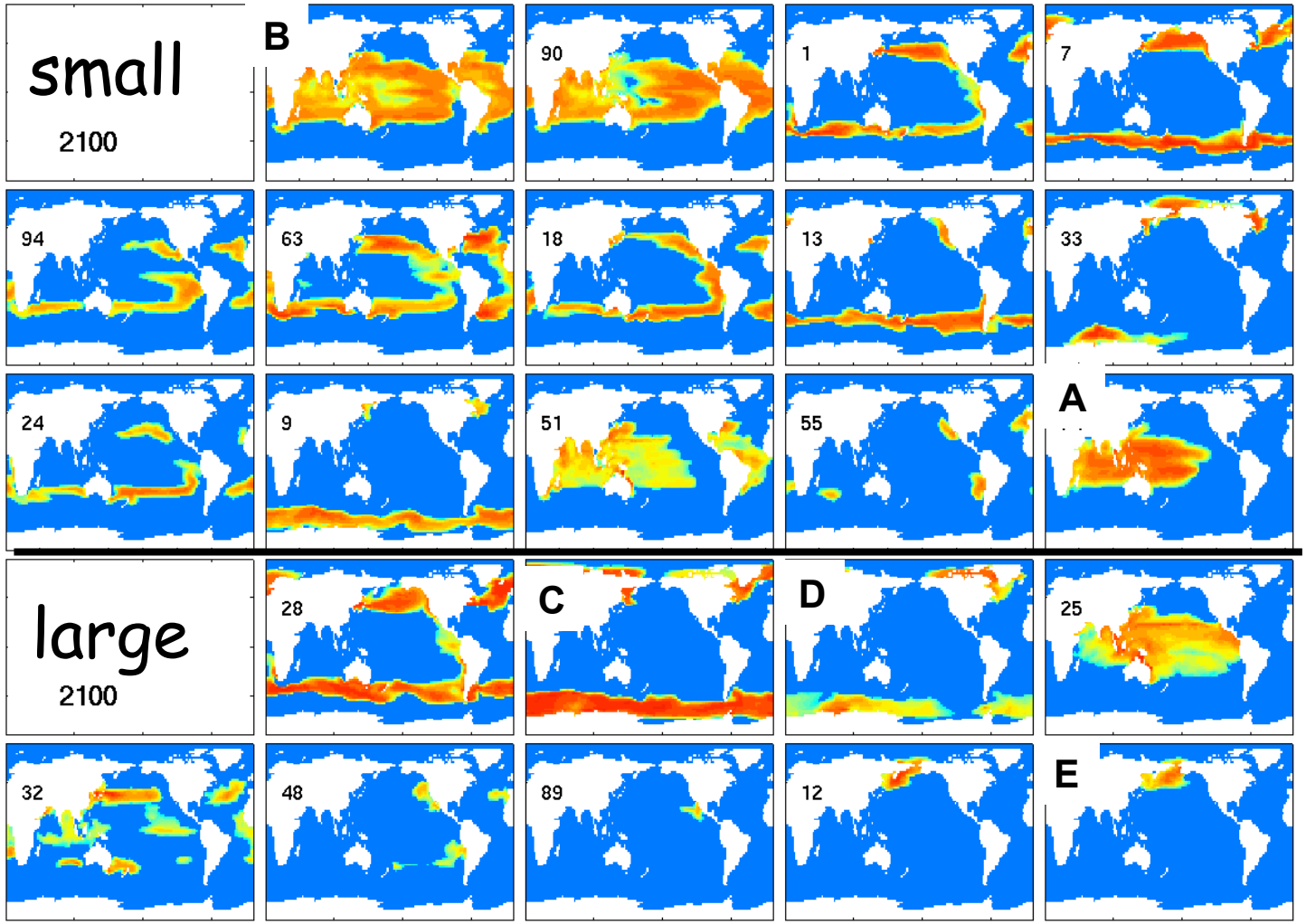
MODEL DESIGN:

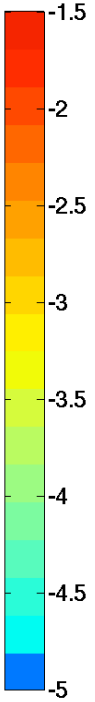
- "Business as usual" emissions scenario to 2100

- By 2100: atmospheric pCO2 is 1100ppmv
  global surface air temperatures up 5°C
  sea surface temperatures up 3°C

How does modeled phytoplankton habitat and community structure change in this future warmer ocean?

ECOSYSTEM RESPONSE: HABITAT SHIFTS





log10 (biomass) 5 year average

- **Some winners, some losers**

SEPARATING EFFECTS OF A WARMING OCEAN

What processes will cause phytoplankton habitat and community structure to change in a future warmer ocean?

SEPARATING EFFECTS OF A WARMING OCEAN

Direct Effect

Increased surface temperature → increased biological rates

SEPERATING EFFECTS OF A WARMING OCEAN

Direct Effect

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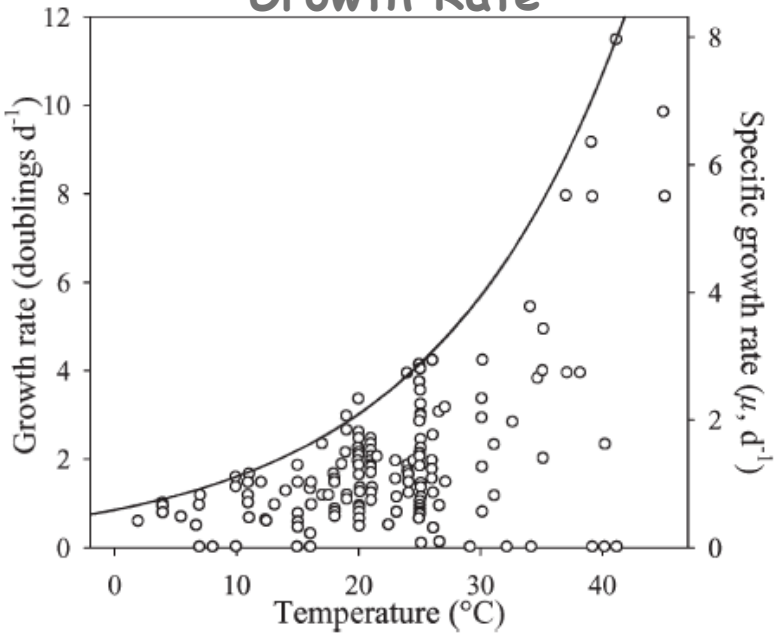
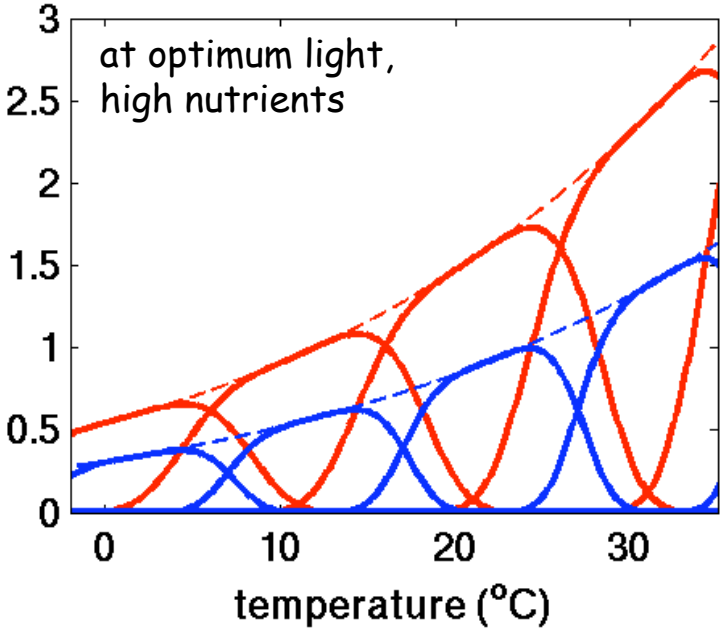
Observed Phytoplankton Growth Rate



Bissinger et al, L+O, 2008

Modeled Phytoplankton Growth Rate



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http://ocean.mit.edu/~stephd

SEPERATING EFFECTS OF A WARMING OCEAN

Direct Effect

Increased surface temperature → increased biological rates

Indirect Effect

Decreased mixing at surface → changes light environment

SEPARATING EFFECTS OF A WARMING OCEAN

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Increased surface temperature → increased biological rates

Indirect Effect

Decreased mixing at surface → changes light environment and reduction in nutrient supply

Changes to ocean circulation → changes light environment and reduction in nutrient supply

SEPARATING EFFECTS OF A WARMING OCEAN

Direct Effect

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Indirect Effect

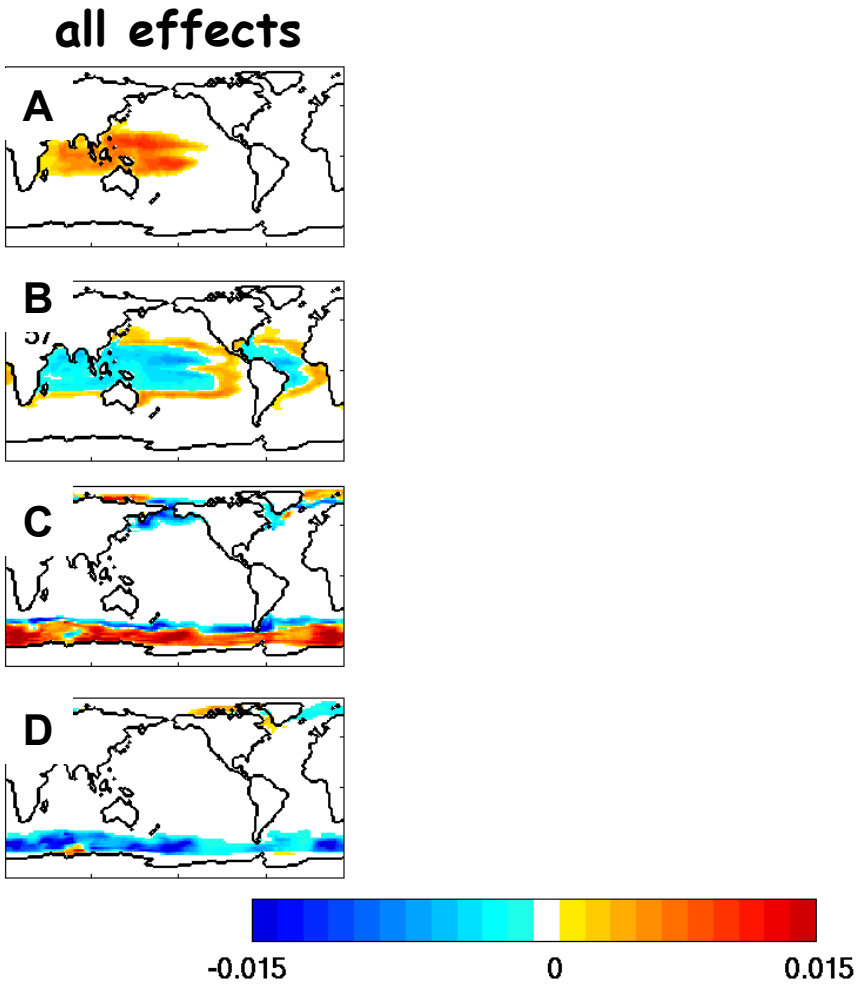
Decreased mixing at surface → changes light environment and reduction in nutrient supply

Changes to ocean circulation → changes light environment and reduction in nutrient supply

SENSITIVITY EXPERIMENTS:

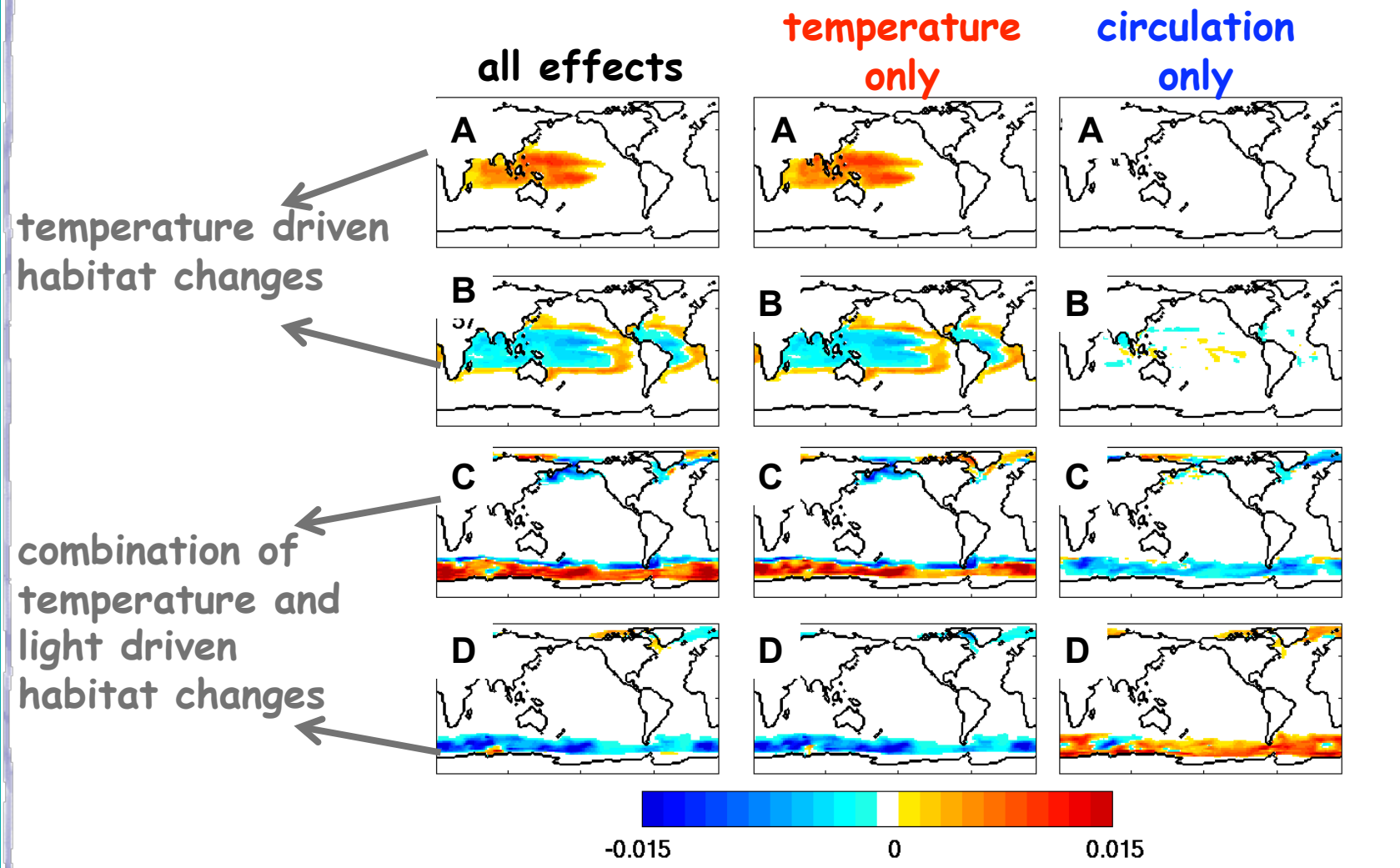
1) only consider direct effect on biological rates
   "TEMPERATURE"
2) only consider circulation and mixing changes: indirect effect of reduced nutrient supply and light changes
   "CIRCULATION"

ECOSYSTEM RESPONSE: HABITAT SHIFTS

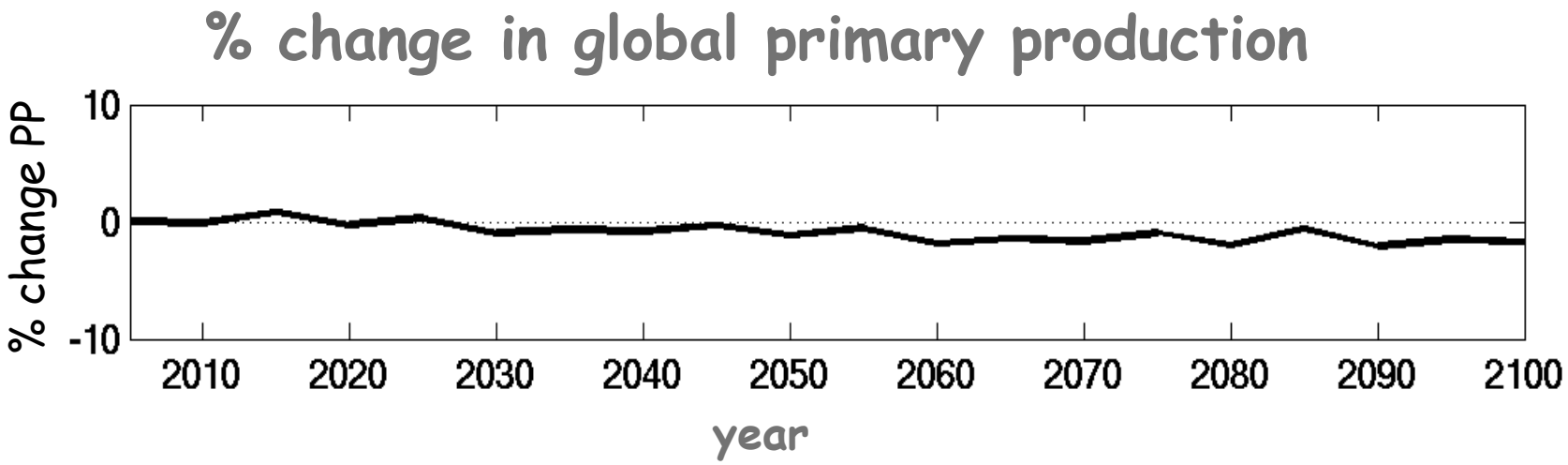


change in phytoplankton biomass (2100-2000)
(positive=increase in 2100)

ECOSYSTEM RESPONSE: HABITAT SHIFTS

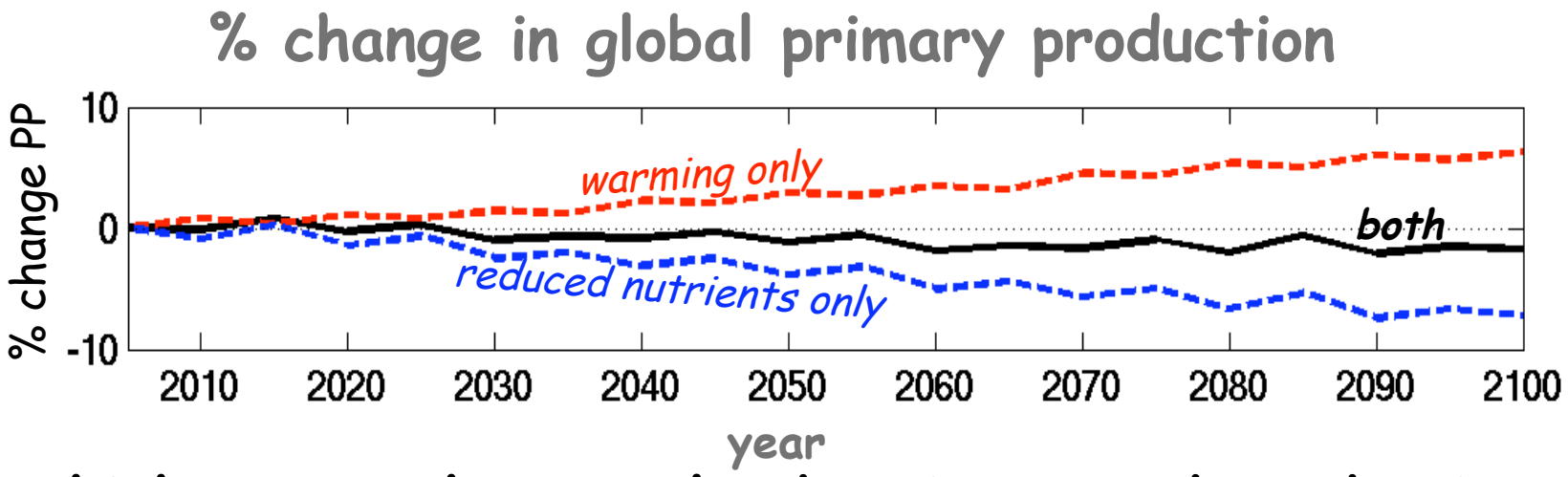


ECOSYSTEM RESPONSE: PRODUCTIVTY



Other studies have suggested both :
Increase (e.g. Sarmiento et al, 2004; Schmittner et al, 2008)
Decrease (e.g. Bopp et al, 2001, 2005; Steinacher et al 2008)

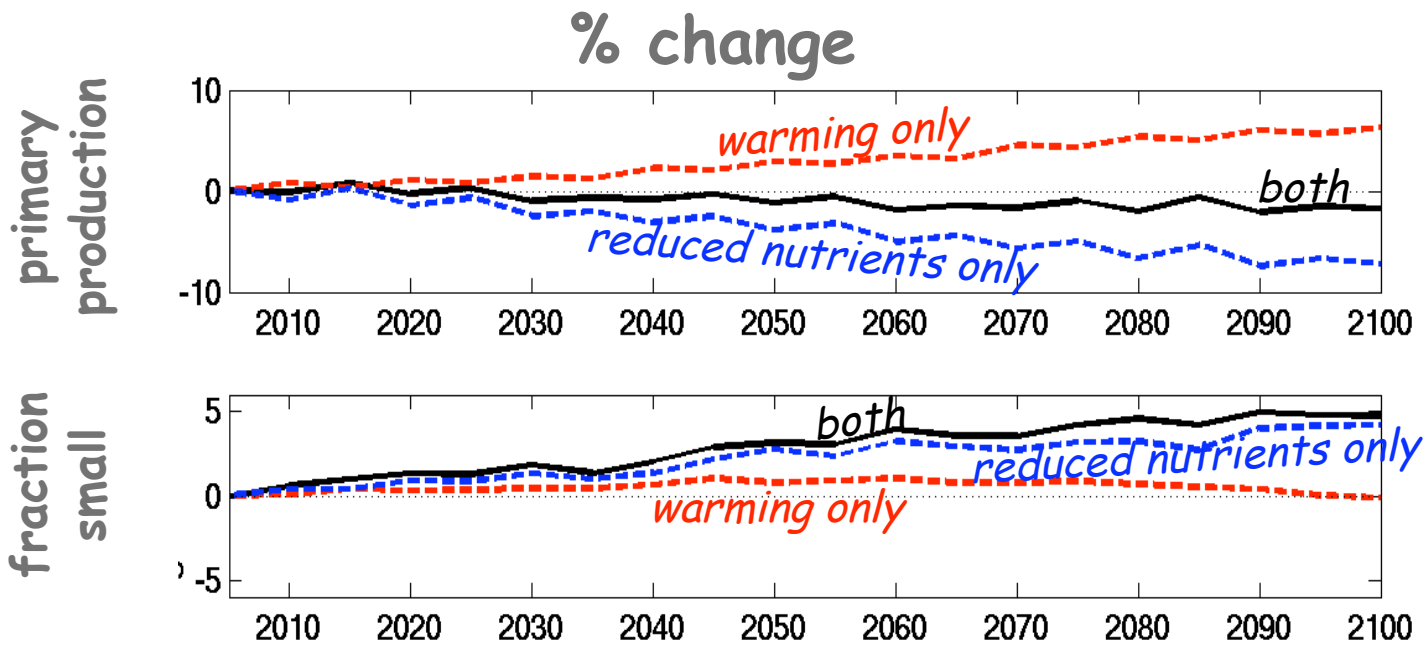
ECOSYSTEM RESPONSE: PRODUCTIVTY



- higher growth rates lead to increased production (result of higher temperatures)

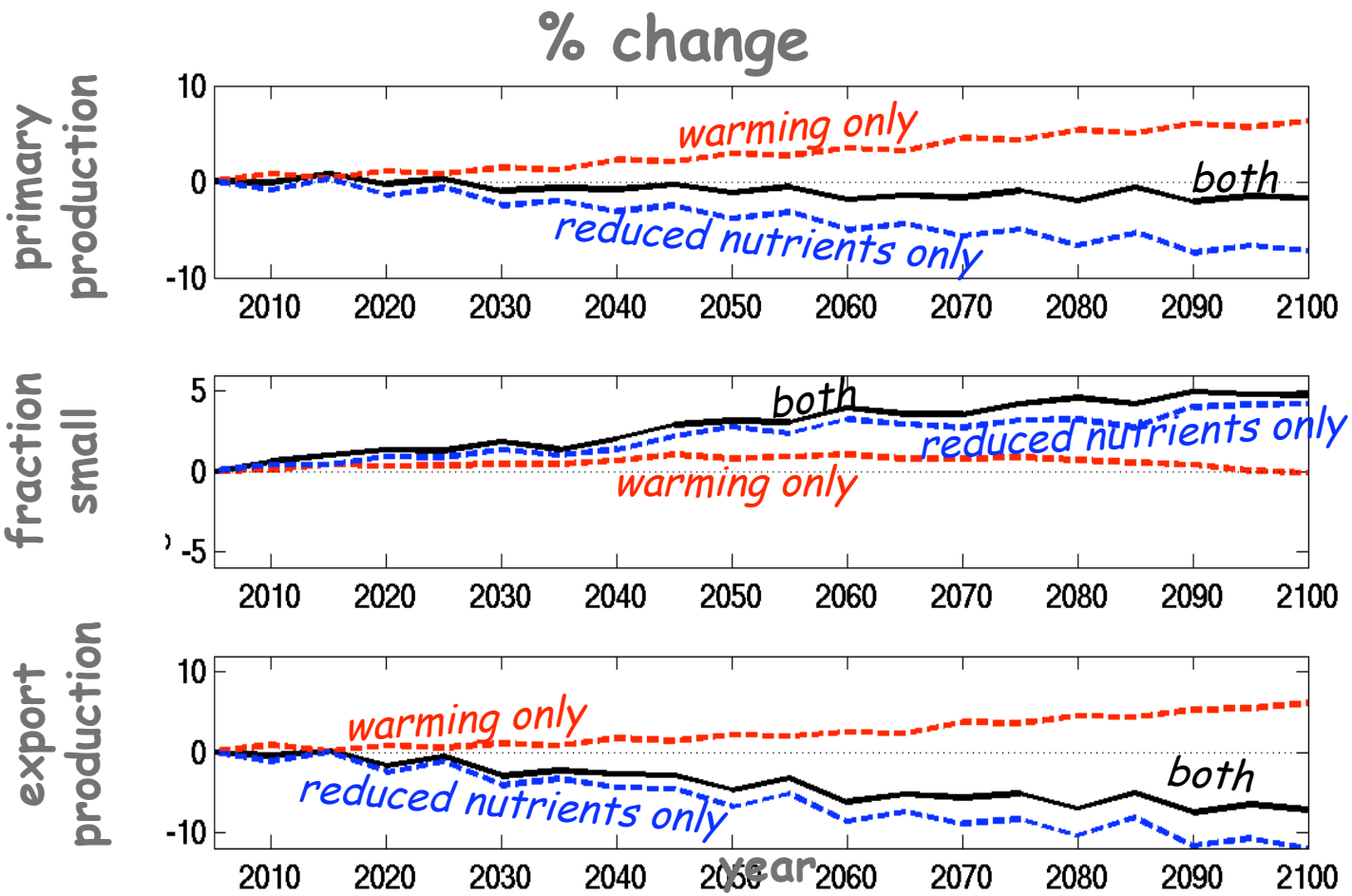
- lower nutrient supply leads to decreased production (result of increased stratification and changes to circulation)

ECOSYSTEM RESPONSE: PRODUCTIVTY



- lower nutrients favors small recycling plankton:

ECOSYSTEM RESPONSE: PRODUCTIVTY



- lower nutrients favors small recycling plankton: feedback - less export of carbon to deep ocean

SUMMARY

What processes will cause phytoplankton habitat and community structure to change in a future warmer ocean?

- **Phytoplankton habitat shifts:**
  - poleward and eastward mostly for temperature shifts, but some light environment shift in high latitudes
  - some winners, some losers

- **Community structure:**
  - increase in smaller phytoplankton driven by reduced nutrient supply

- **Productivity changes due to combination of:**
  - increase by faster biological rates, reduction by slower supply of nutrient
  - important that we model **both** these correctly to get sign of productivity change

FUTURE CONSIDERATIONS

What processes will cause phytoplankton habitat and community structure to change in a future warmer ocean?

- Importance of currently "rare" species
- In warmest regions, shifts will dependent on adaption
- How will zooplankton adapt to shift in phytoplankton
  - rise of "nuisance" species without grazer
  - link to rest of ecosystem (fish etc)