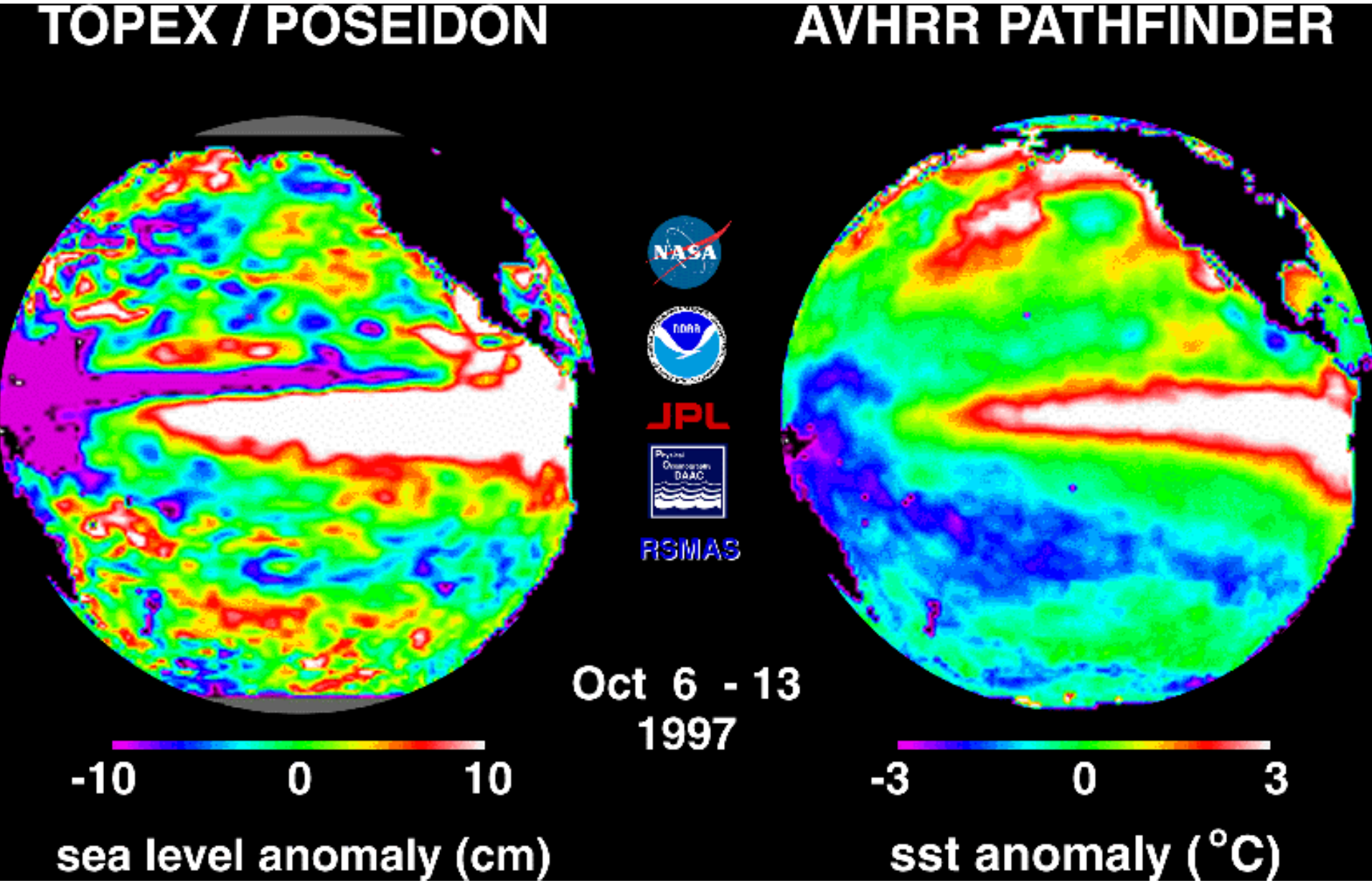
# Ocean Biogeochemistry Using MODIS

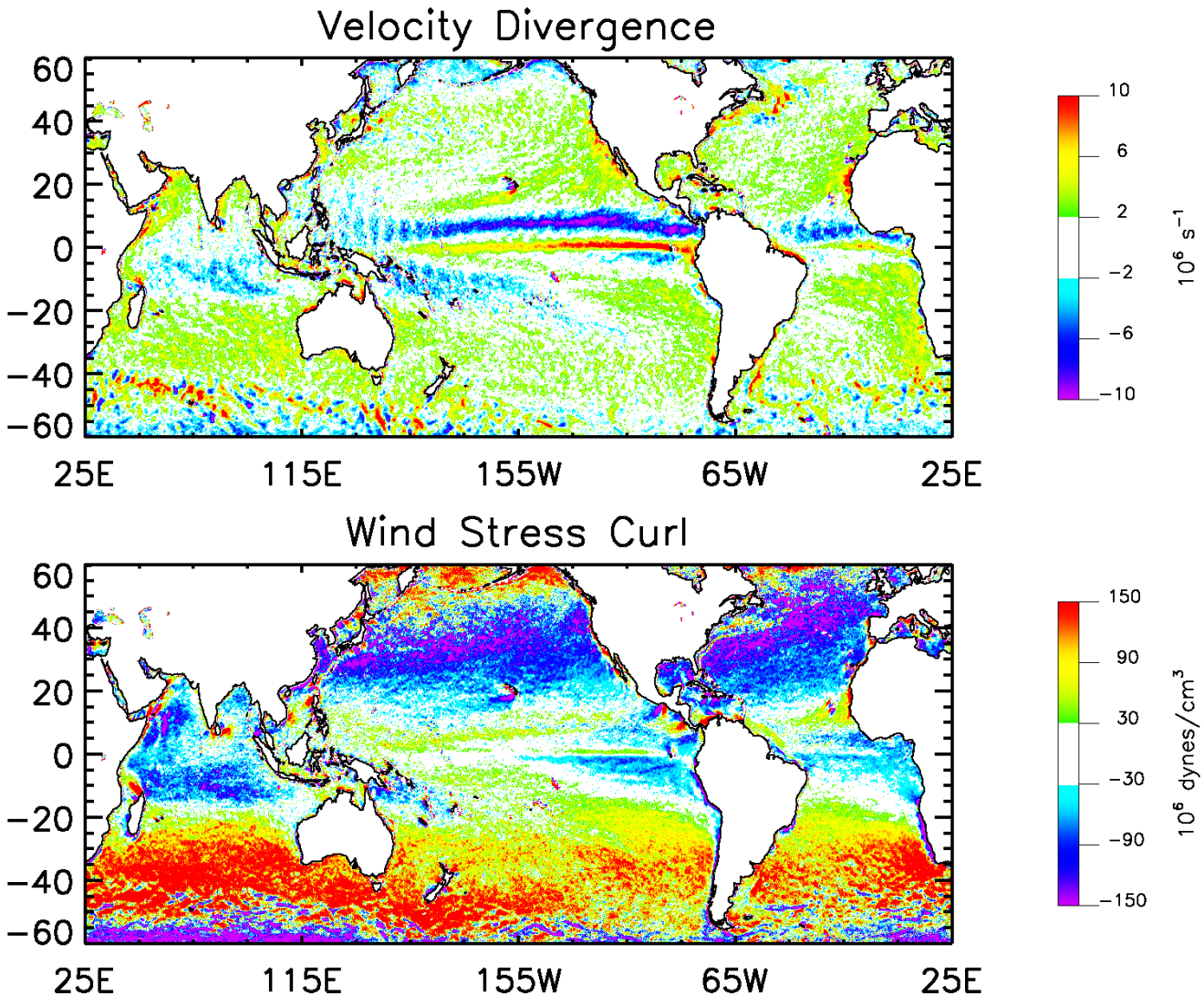
# Challenges and Opportunities

Mark R. Abbott
College of Oceanic and Atmospheric Sciences
Oregon State University

# El Niño


TOPEX / POSEIDON
AVHRR PATHFINDER
NASA
NOAA
JPL
Physical Oceanography DAAC
RSMAS
Oct 6 - 13
1997
-10
0
10
sea level anomaly (cm)
-3
0
3
sst anomaly (°C)

# Global Wind Fields

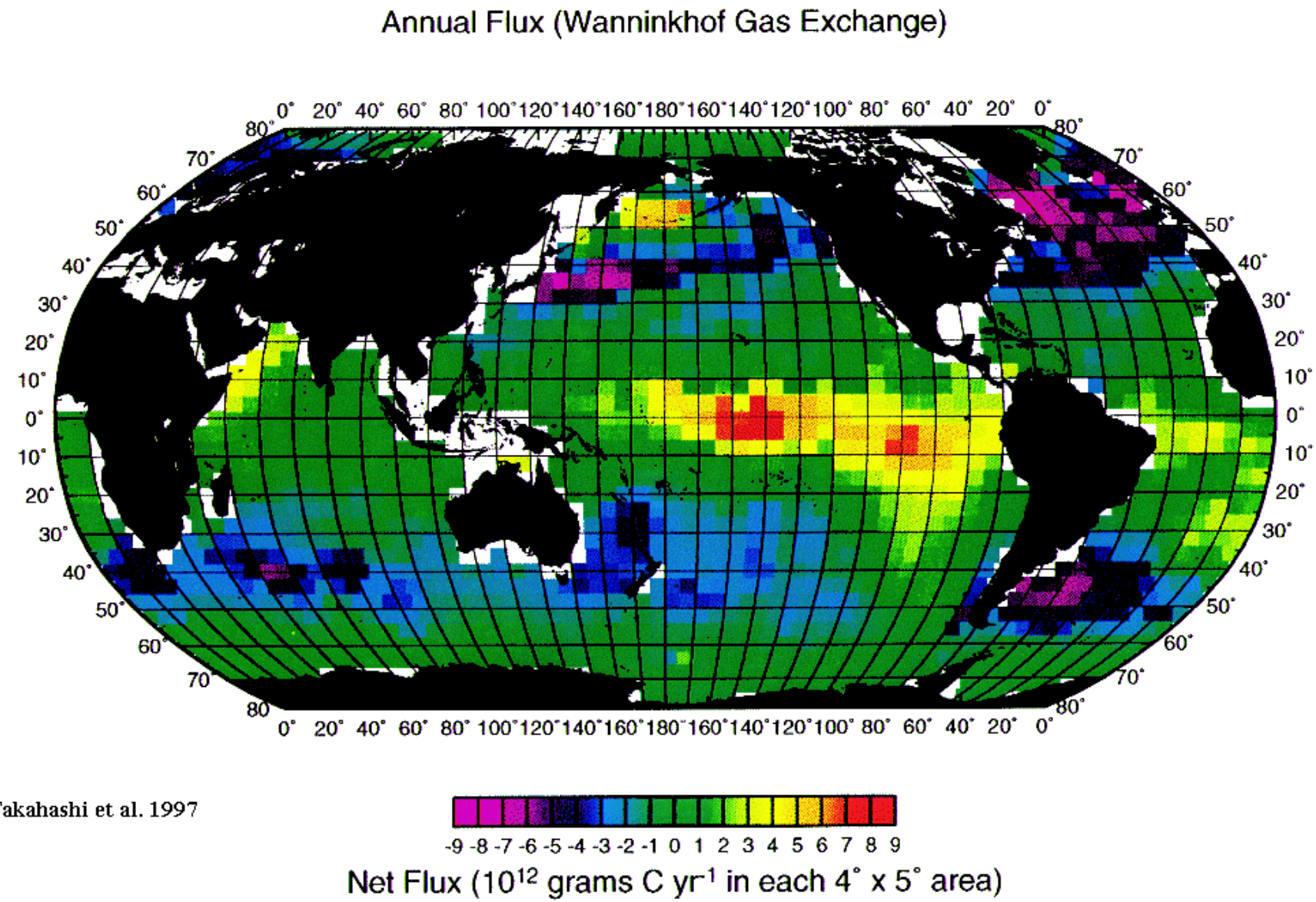



Courtesy Mike Freilich, OSU

# Oceans and the Carbon Cycle

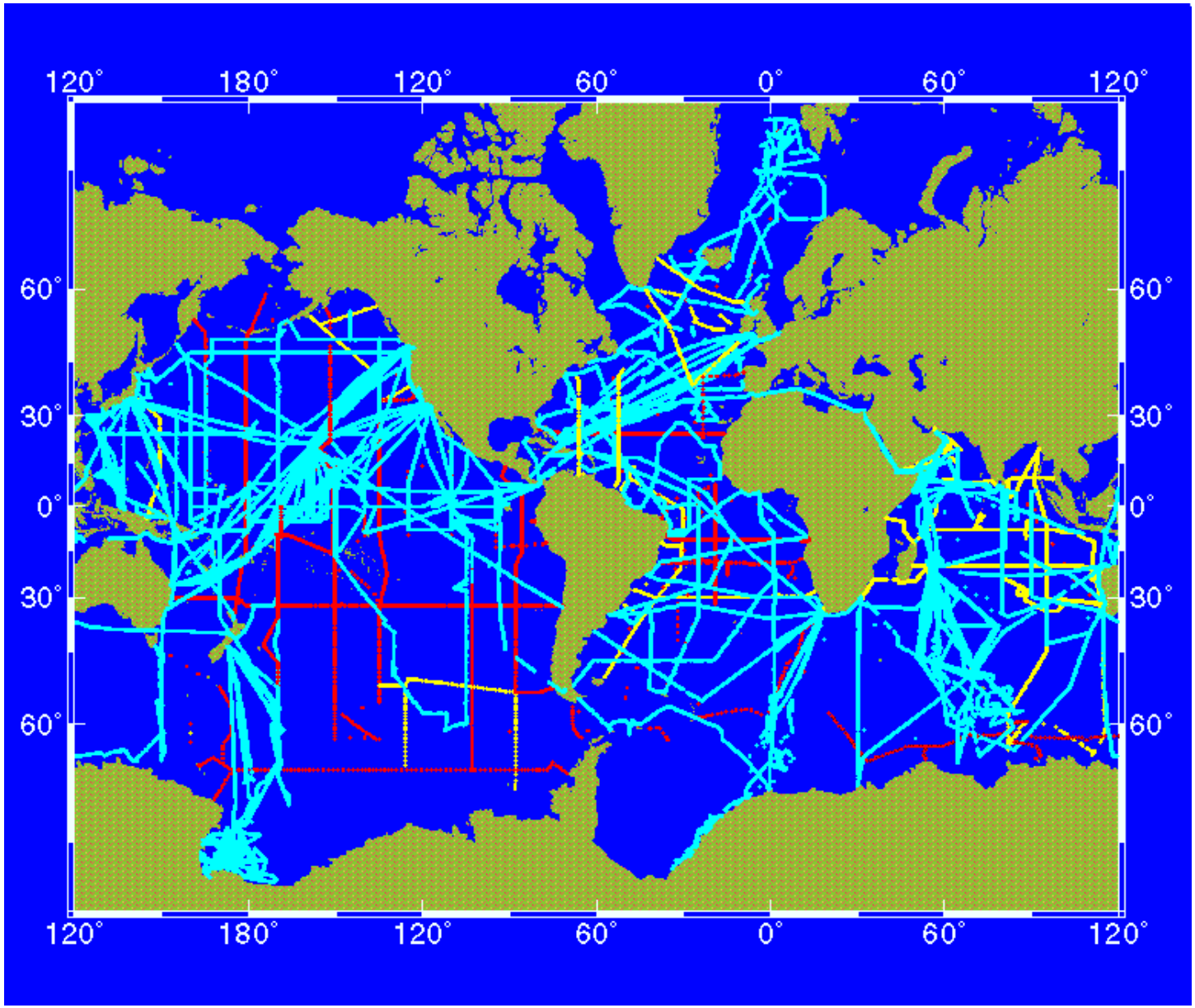
- Separation of upper ocean and deep ocean
  - Total $CO_2$ and alkalinity reduced by organism uptake in upper ocean
  - Chemical gradients maintained by:
    - Downward flux of sinking biogenic particles
    - Upward mixing and advection of nutrient, carbon, and alkalinity-enriched deep waters
  - Sinking particles are dissolved or remineralized in deep ocean, thus closing cycle
- Atmospheric $pCO_2$ about 3-4 times lower than if ocean were completely mixed

# Atmosphere/Ocean $CO_2$ Flux




Takahashi et al. 1997

# Locations of Ship-based $CO_2$ Measurements



# Box Model Assumptions

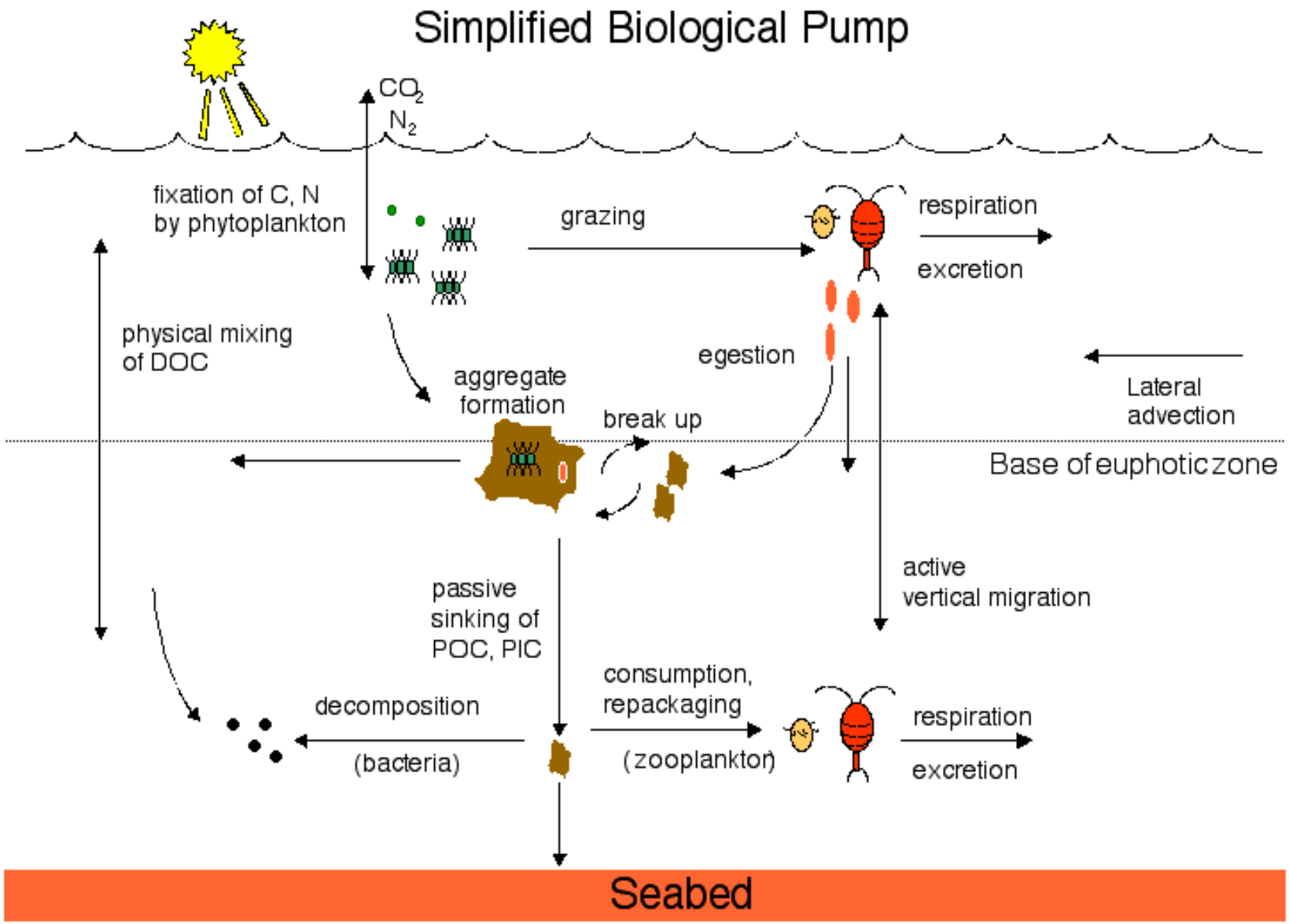
- All nutrients move at Redfield ratios
  - Includes uptake and export
- Physical processes are steady
  - Do not need to consider episodic processes
- No external changes in fluxes
  - No $N_2$ fixation etc.
  - No luxury consumption
- We do not need to know details of boxes
  - Everything stable and in equilibrium

# Are these reasonable assumptions?

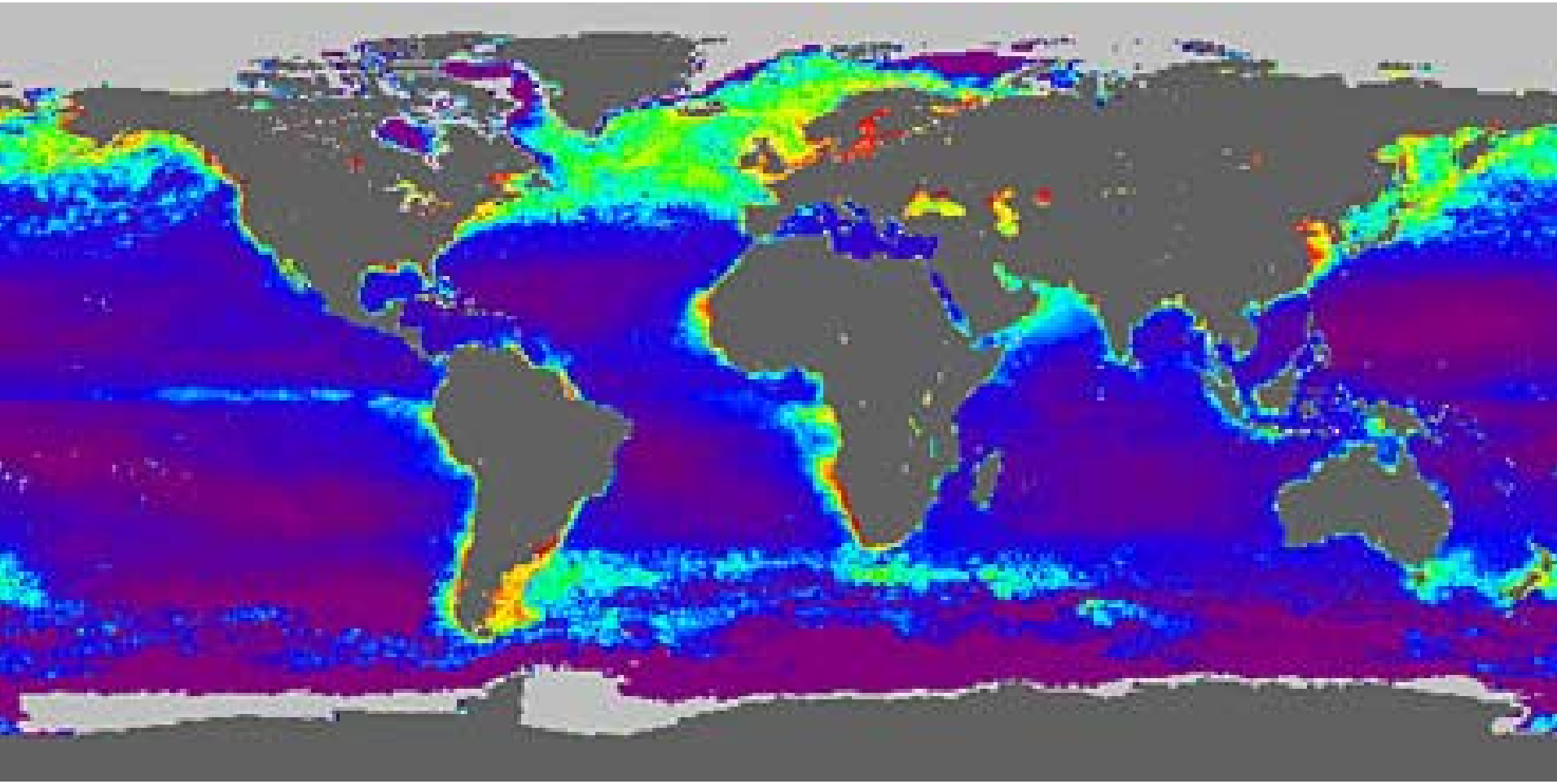
- Changes in ecosystem structure
  - Export/production
  - Shifts in nutrient uptake ratios
  - Shift from organic/silica-walled organisms to carbonate
  - Changes in midwater ecosystems
- Changes in physical processes
  - Deep water formation, sea ice
  - Thermohaline circulation
- Interaction of ecology and physics

# What is the role of ocean biota?

- Cannot react directly to increase in atmospheric $CO_2$
  - Ocean ecosystems not limited by carbon
- Indirect response is more complicated
  - Do ecosystems always process nutrients in the same way?
  - Do physical processes stay the same?
  - Do nutrient ratios stay the same?

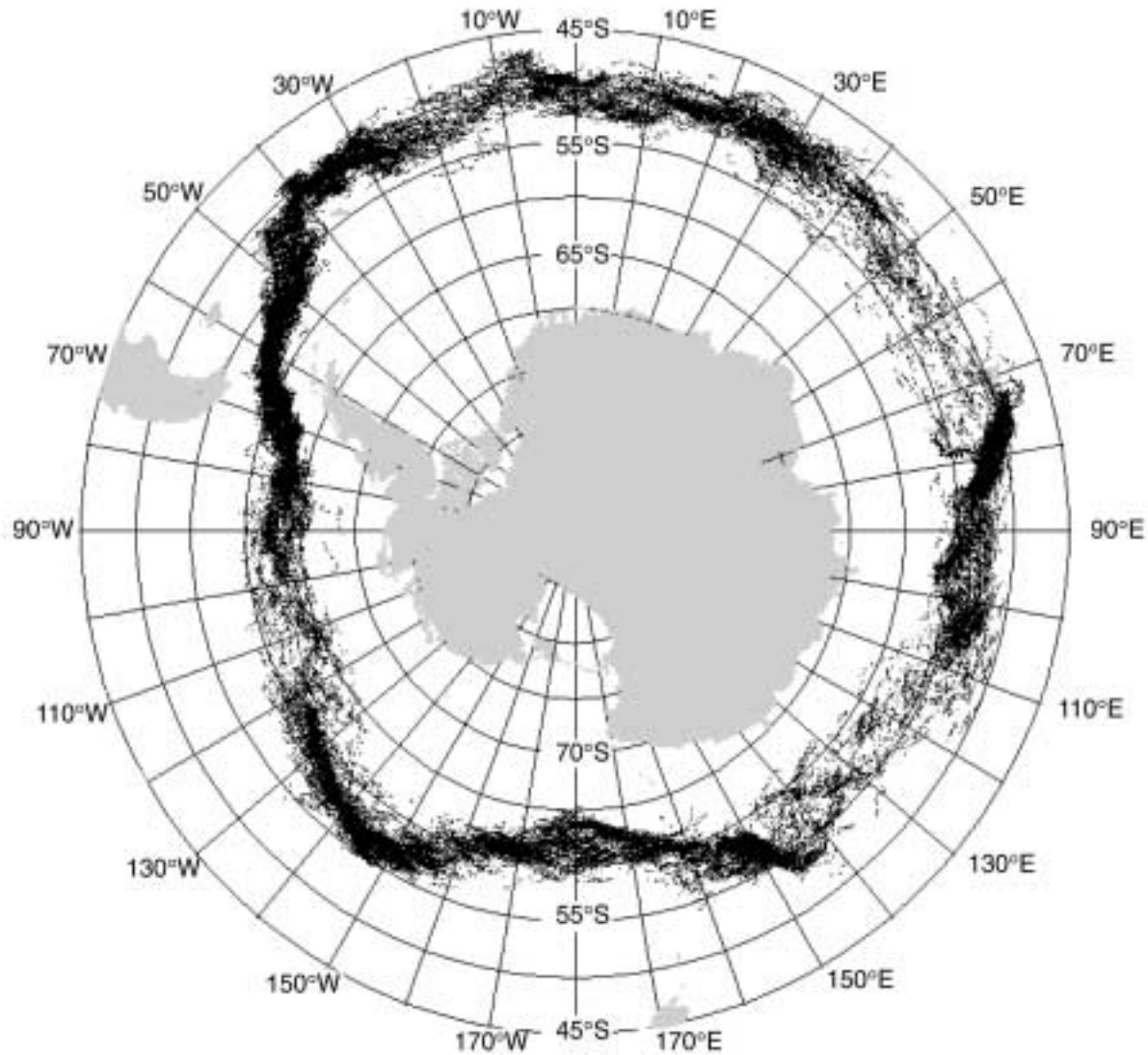



From OCTET workshop report



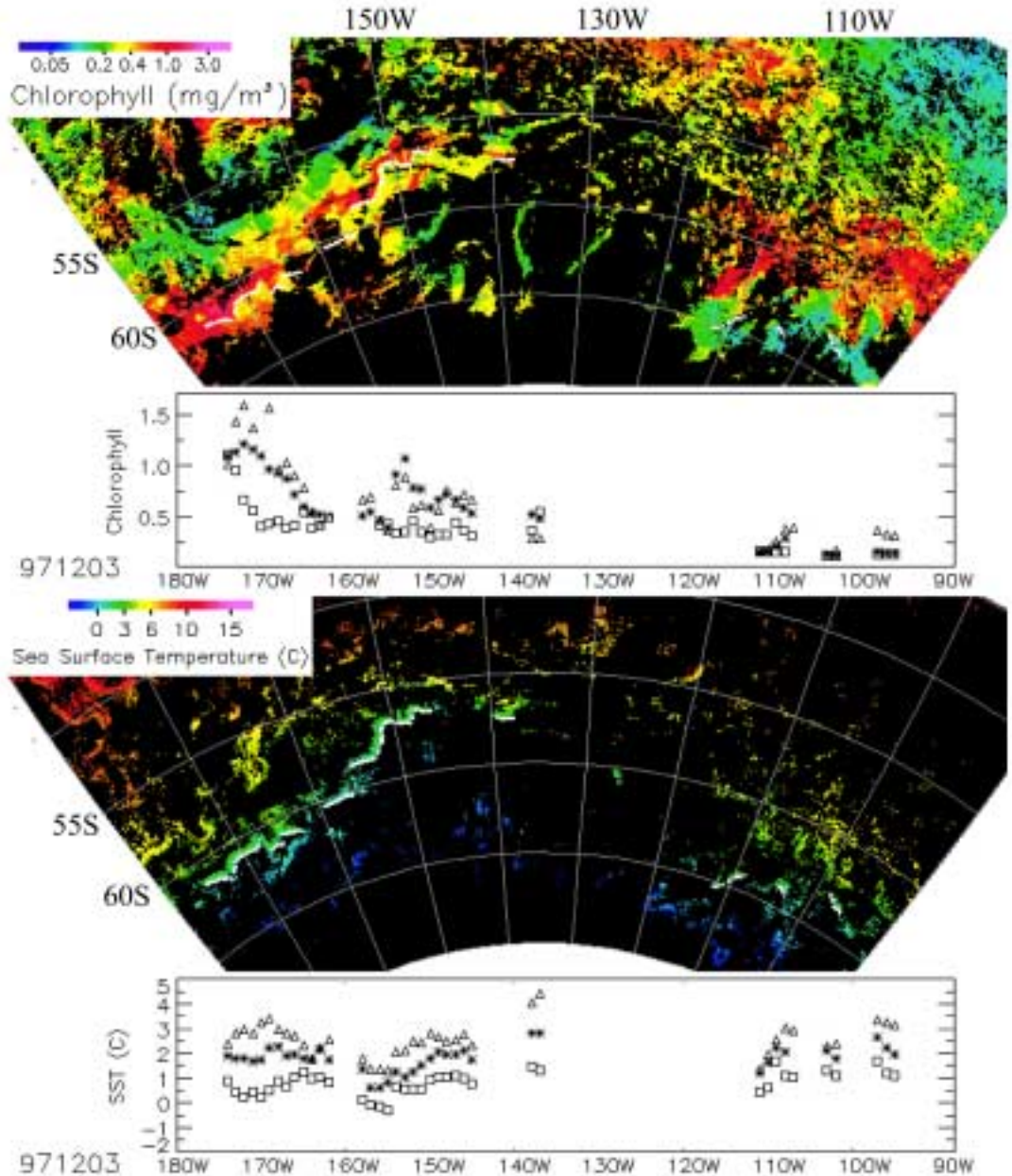
Estimate of carbon flux based on model of Laws et al. (2000) using SeaWiFS data

# Variations in the Position of the Polar Front, 1987-1998



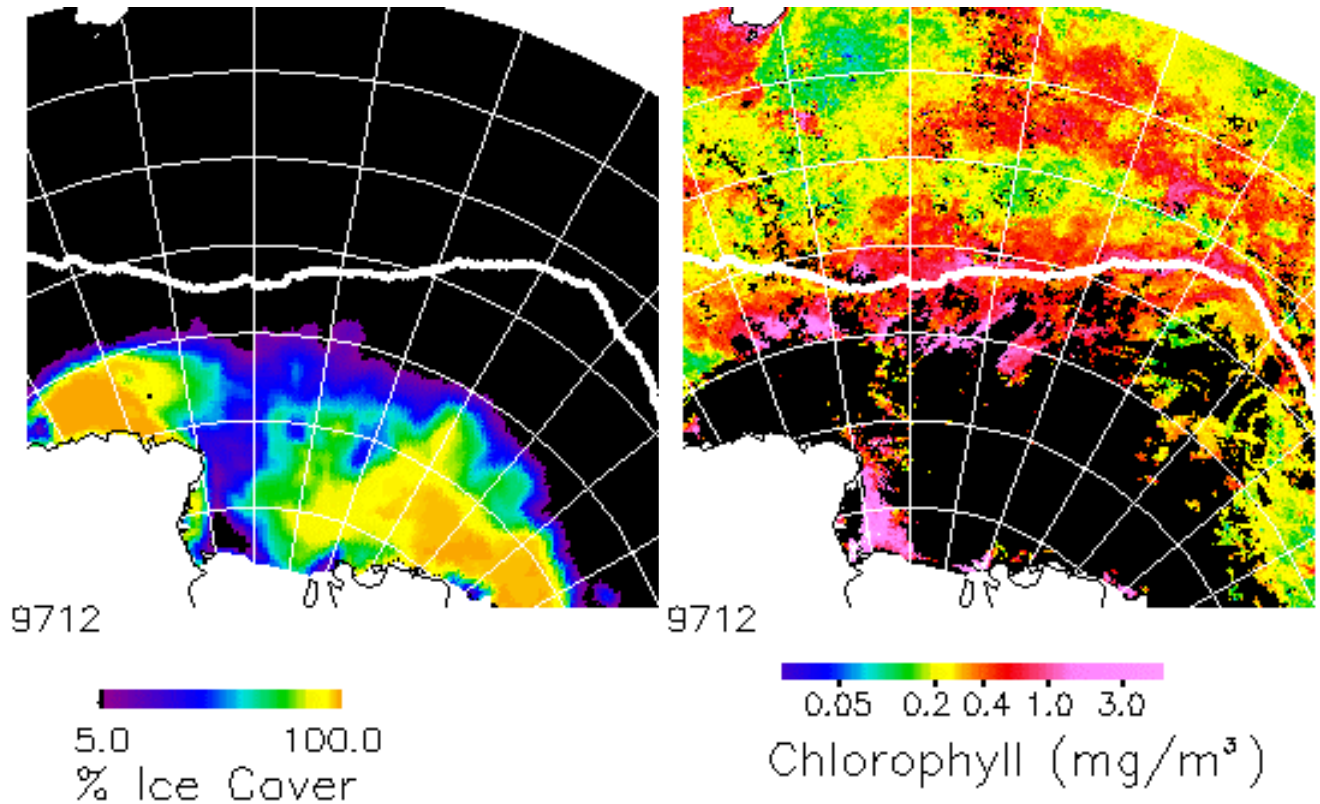

Moore et al. (2000)

SST and chlorophyll in the US JGOFS region

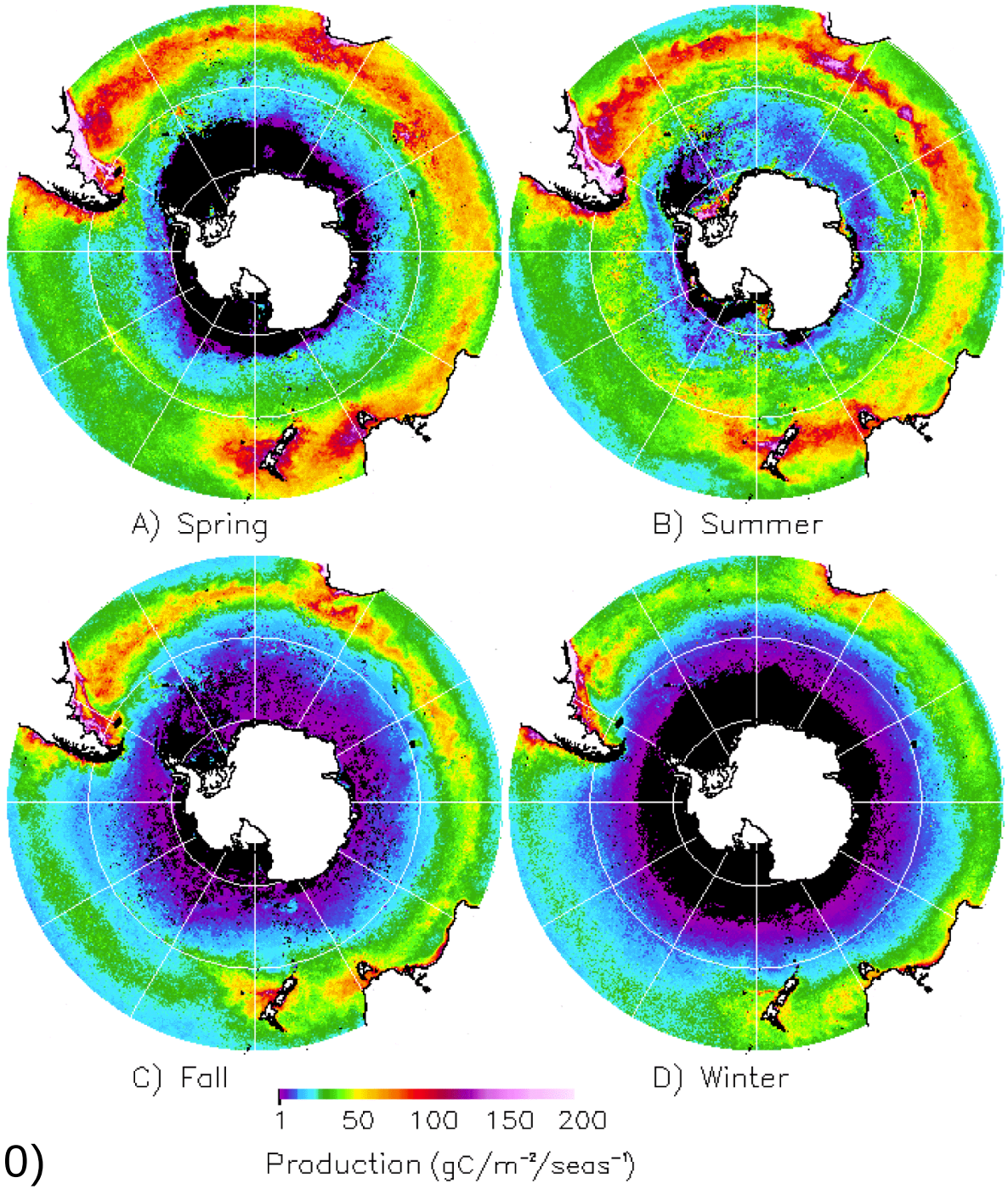



Moore and Abbott (2000)

# Ice Edge and Chlorophyll – Dec. 1997



SeaWiFS-estimated primary productivity




Moore and Abbott (2000)

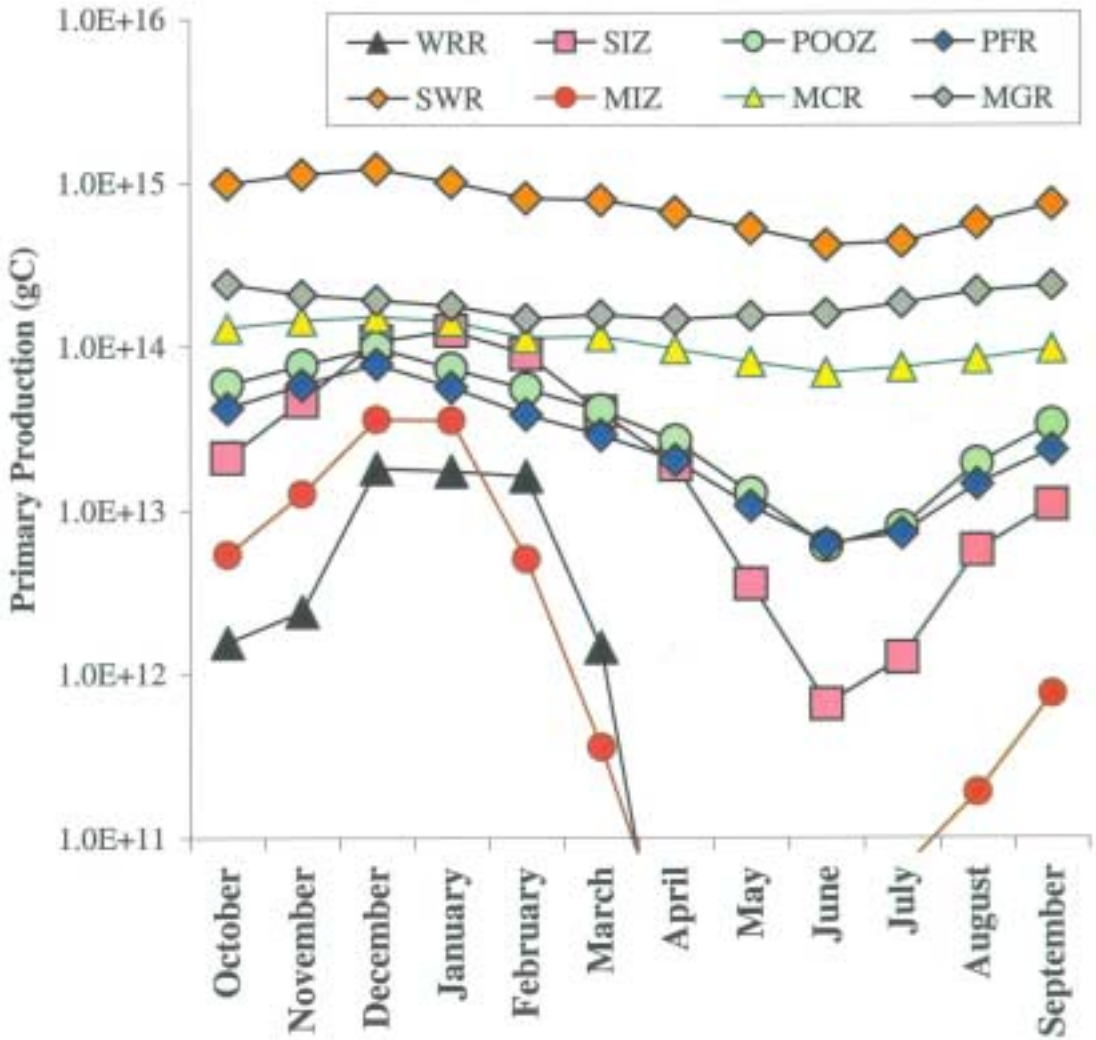
# Satellite-based Estimates of Primary Productivity

| Study | $50^{o}$-$90^{o}$ S |
|---|---|
| Longhurst et al. (1995) | 4 Pg C/yr |
| Behrenfeld and Falkowski (1997) corrected by Arrigo et al. | 4.8 |
| Antoine et al. (1996) | 5.9 |
| Arrigo et al. (1998) | 3.2 - 4.4 |
| Moore and Abbott (2000) - SeaWiFS | 2.9 |

# The Iron Hypothesis

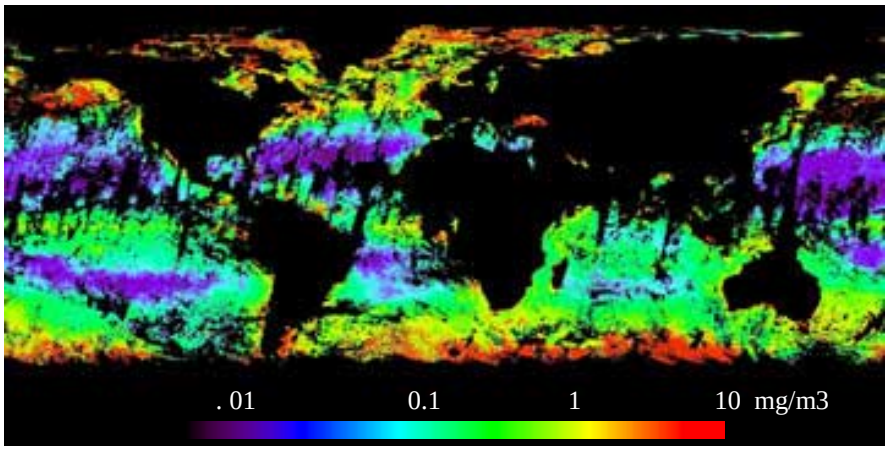
- Ocean productivity largely limited by iron
- High nutrient, low chlorophyll (HNLC) regions
  - Equatorial Pacific, Subarctic North Pacific, Southern Ocean
  - Underutilized nutrients represent possible sink of $CO_2$
- "Give me enough iron and I can create an ice age"

# Productivity by Ecological Region

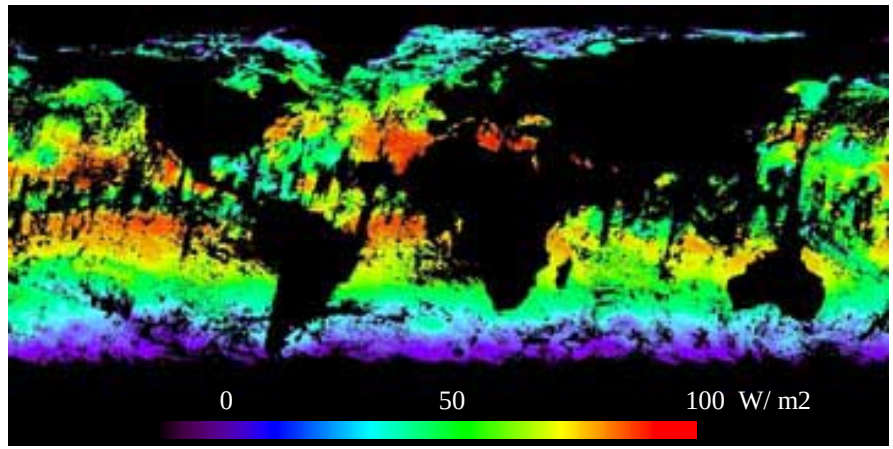



Moore et al. (2000)

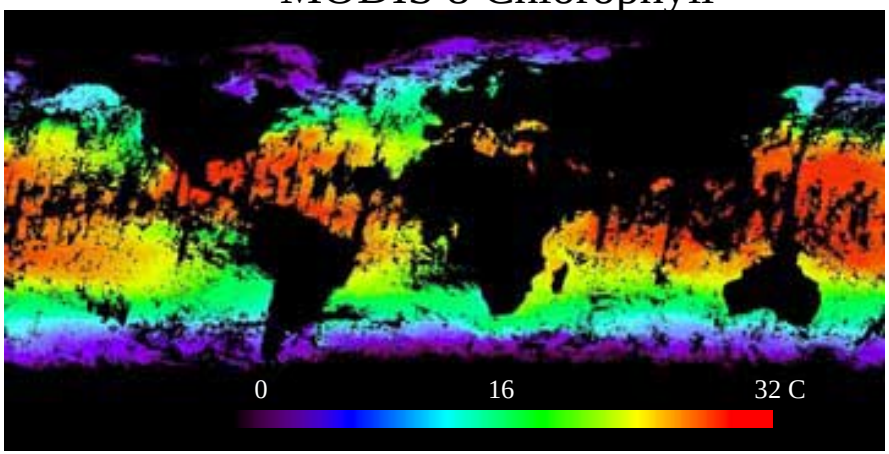
# Ocean Weekly Productivity Index Inputs



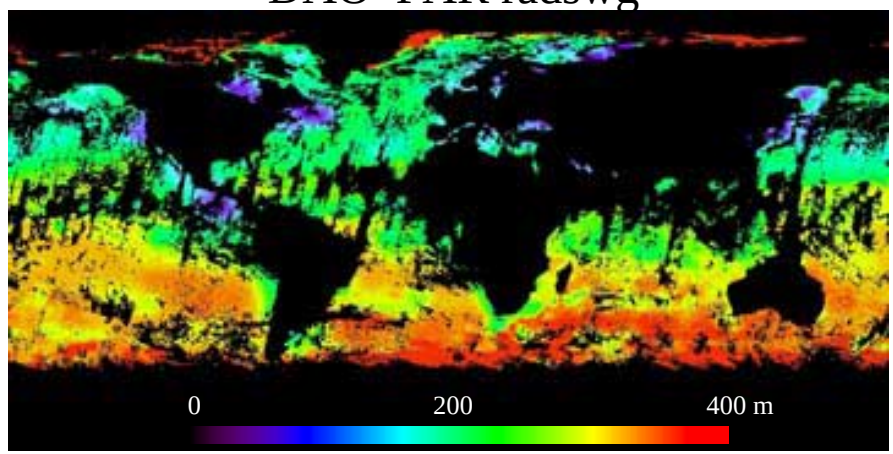

MODIS 8 Chlorophyll




DAO PAR radswg



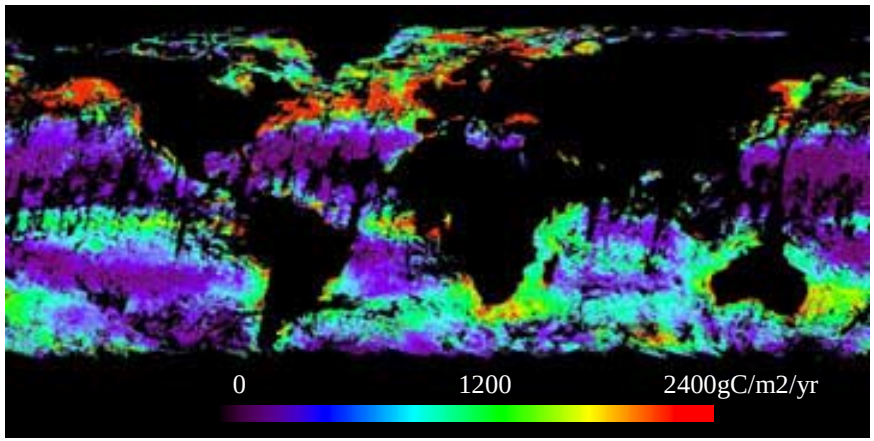

MODIS SST 11-12 µm Day



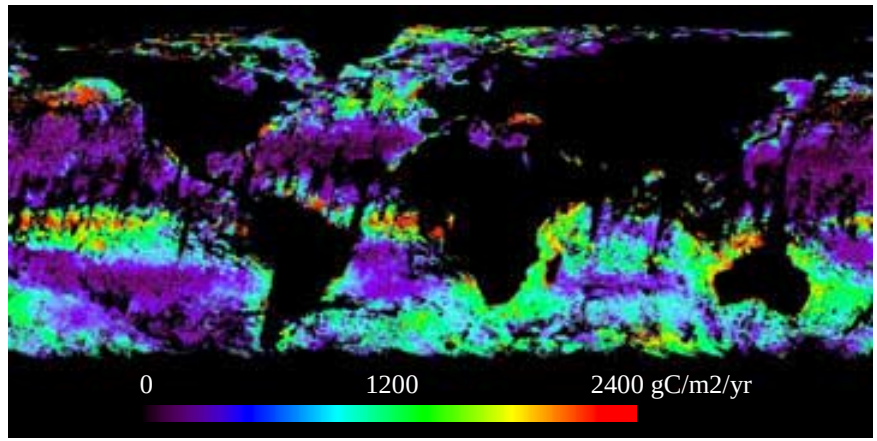

FNMOC Mixed Layer Depth

Esaias, Iverson, Turpie

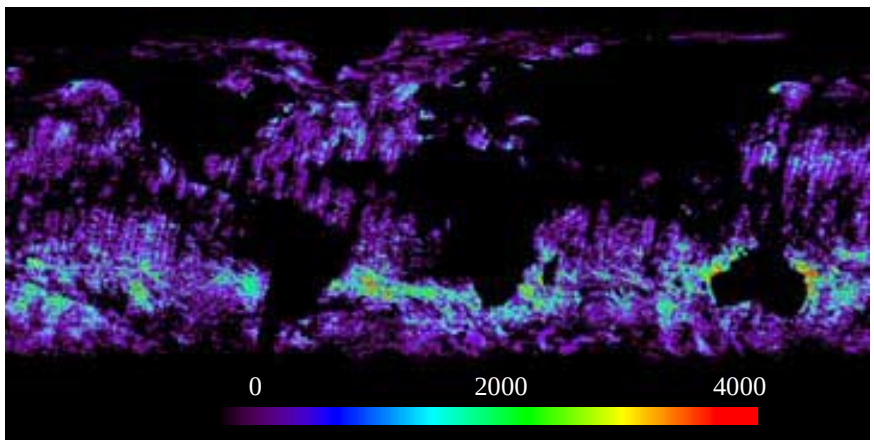
# L-4 Weekly Ocean Productivity Indices



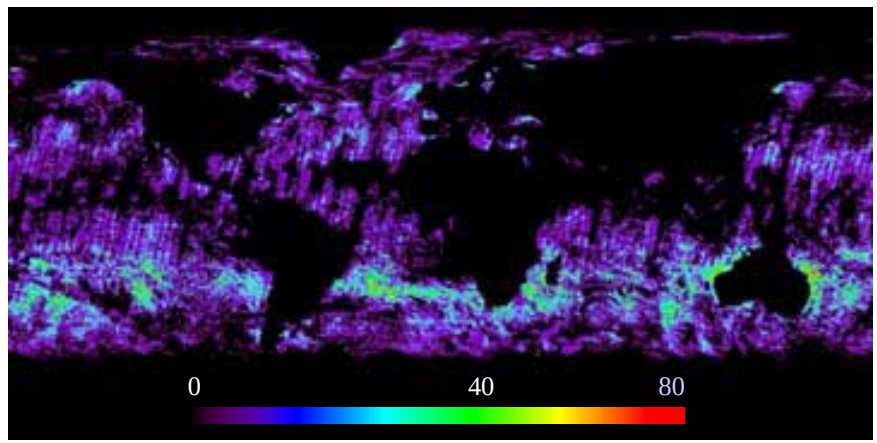

Ocean Productivity P1 (B/F)




Ocean Productivity P2 (H/Y/R)




Number of pixels

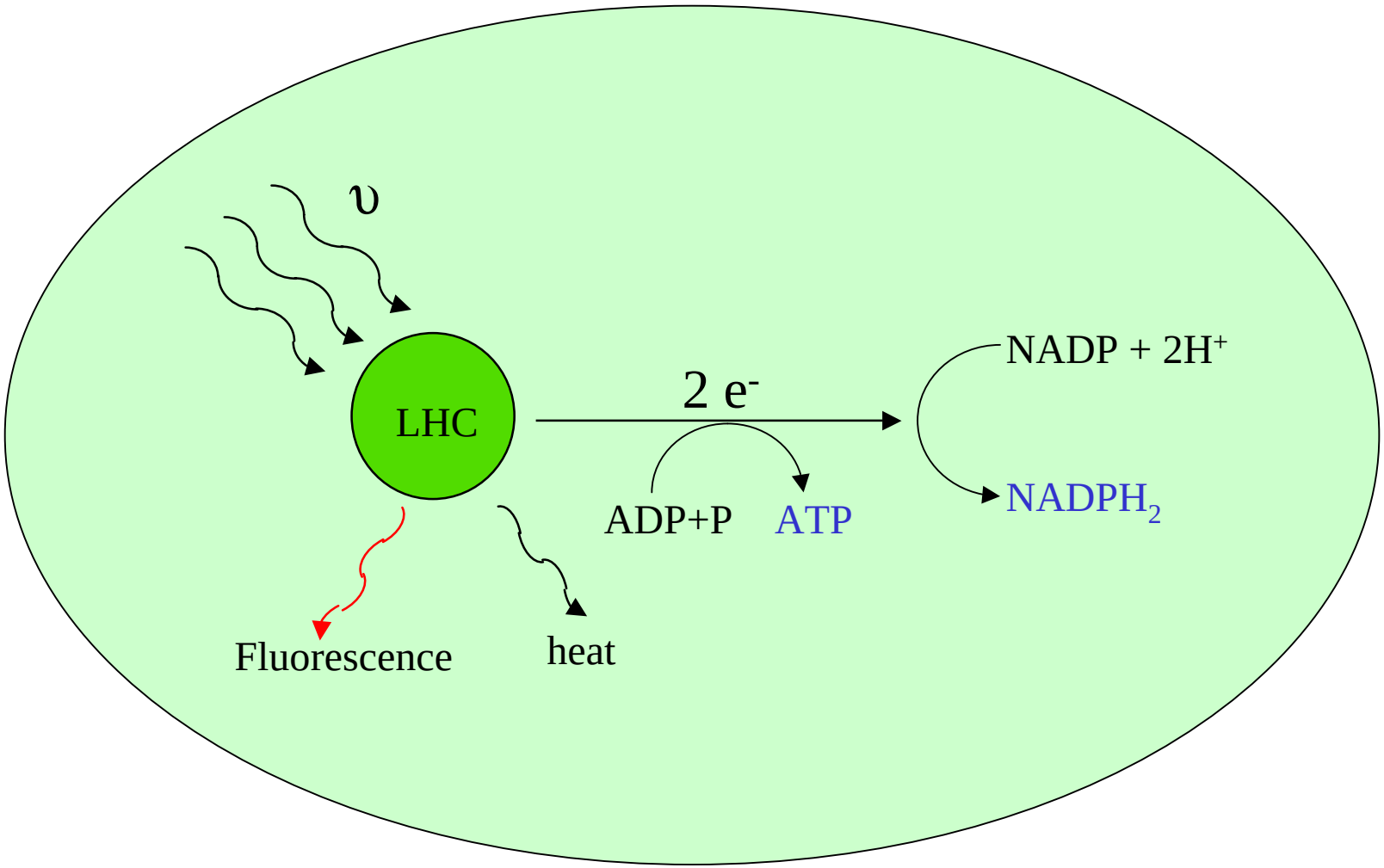



Number of granules

Test - Unvalidated, for Week 233, 2000, 36 km

Esaias, Iverson, Turpie

# Photon Pathways



# Fluorescence and Productivity

- $F = [chl] \times (PAR \times a^*) \times \phi_F$

  where F = fluorescence

  [chl] = chlorophyll concentration

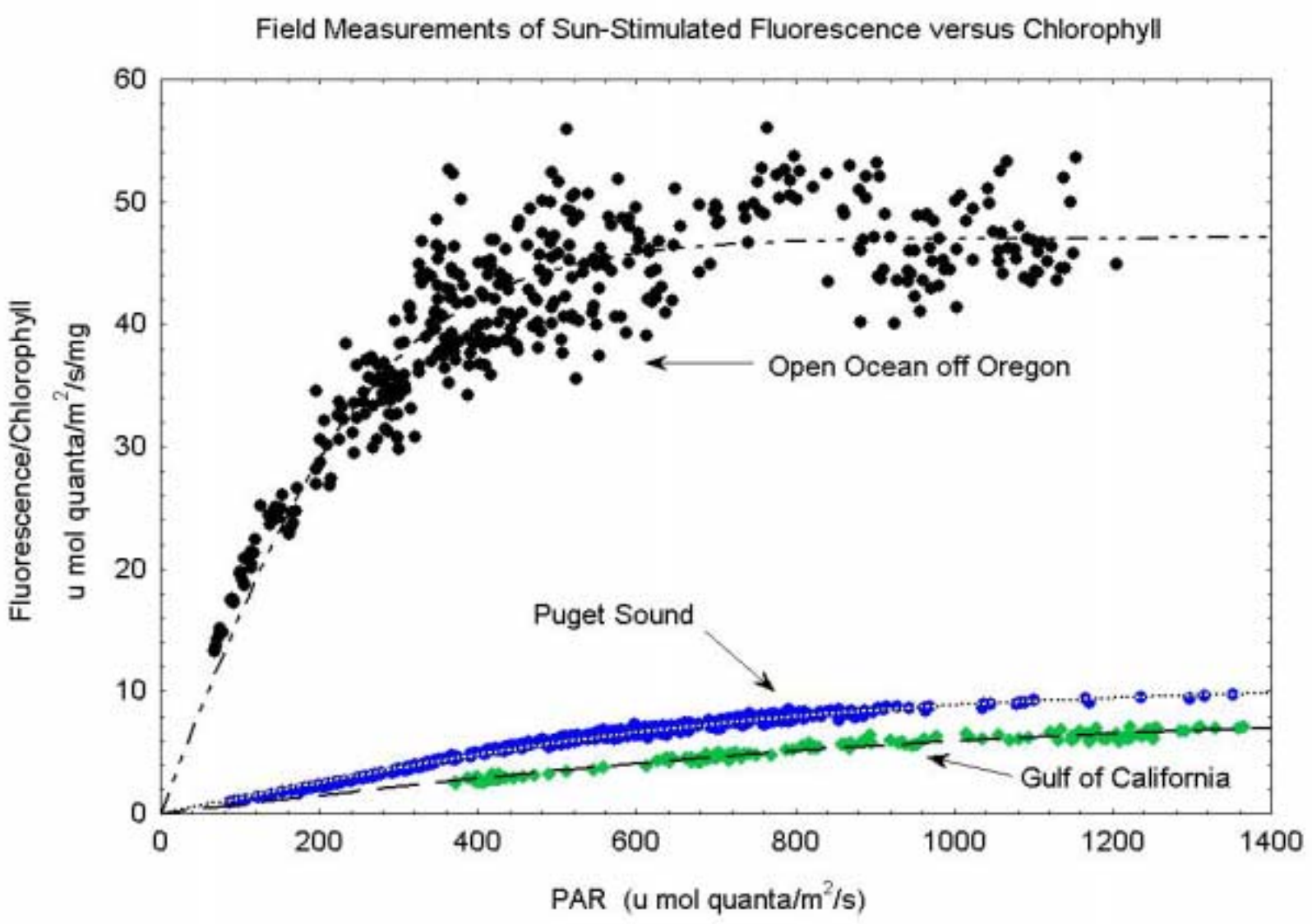
  PAR = photosynthetically available radiation

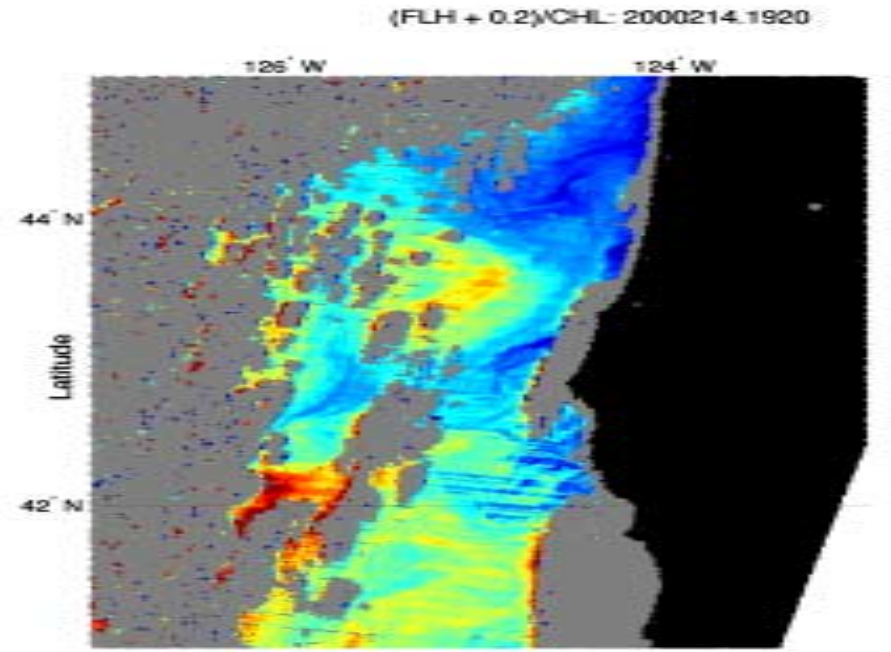
  $a^*$ = chlorophyll specific absorption

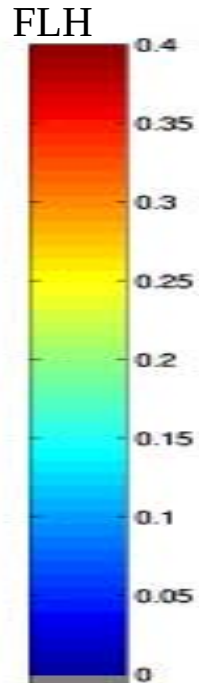
  $\phi_F$ = fluorescence quantum yield

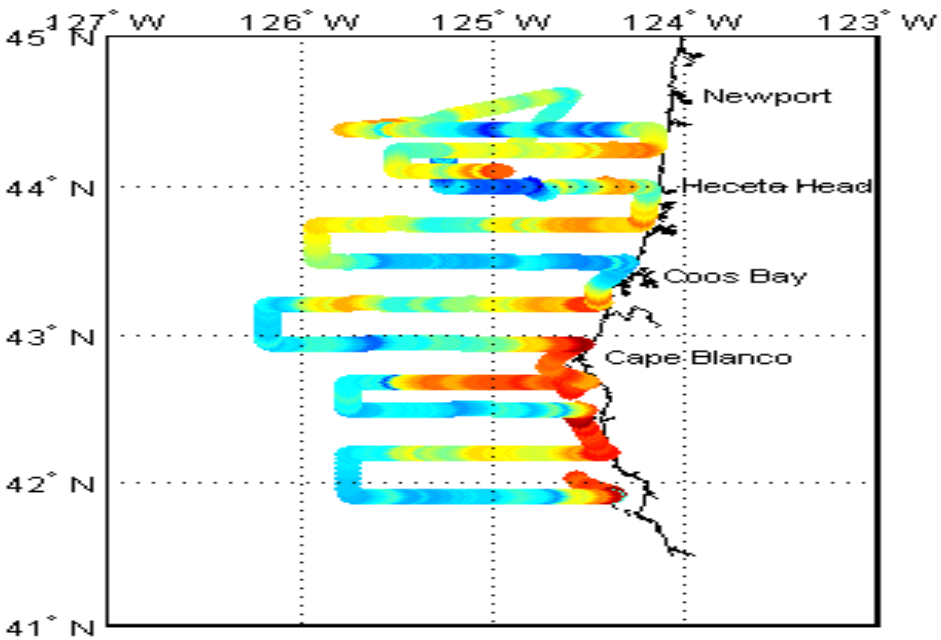
- We can rearrange as F/[chl] to estimate $\phi_F$
- Next-generation ocean color sensors will measure fluorescence
  - MODIS, MERIS, and GLI

# In Situ Observations of F/[chl]



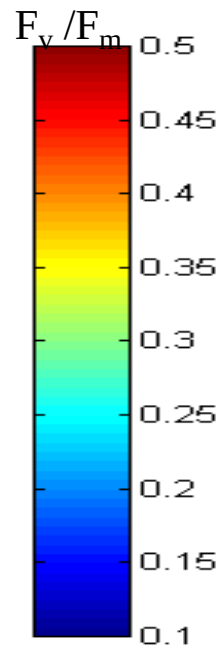


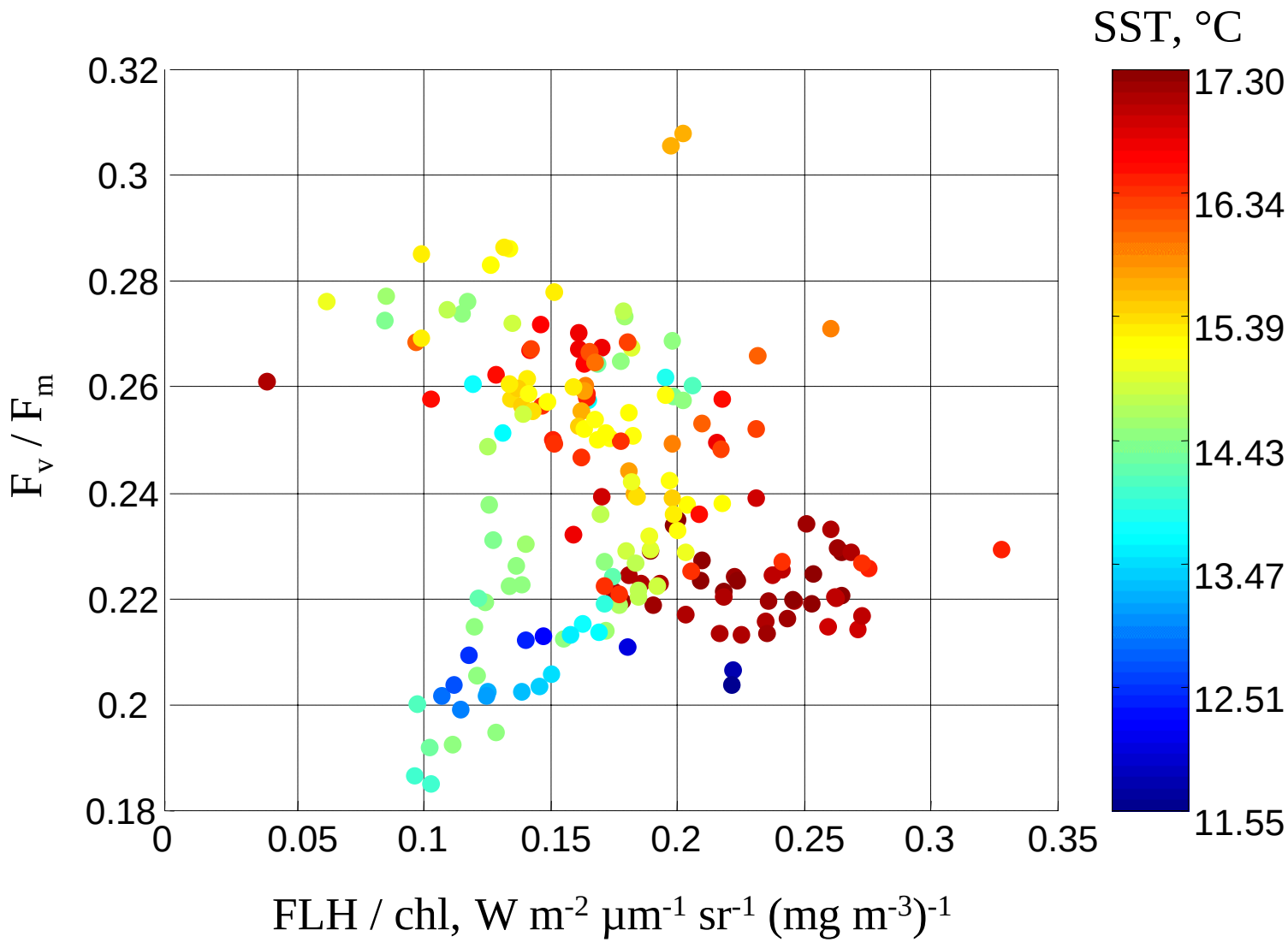




Latitude

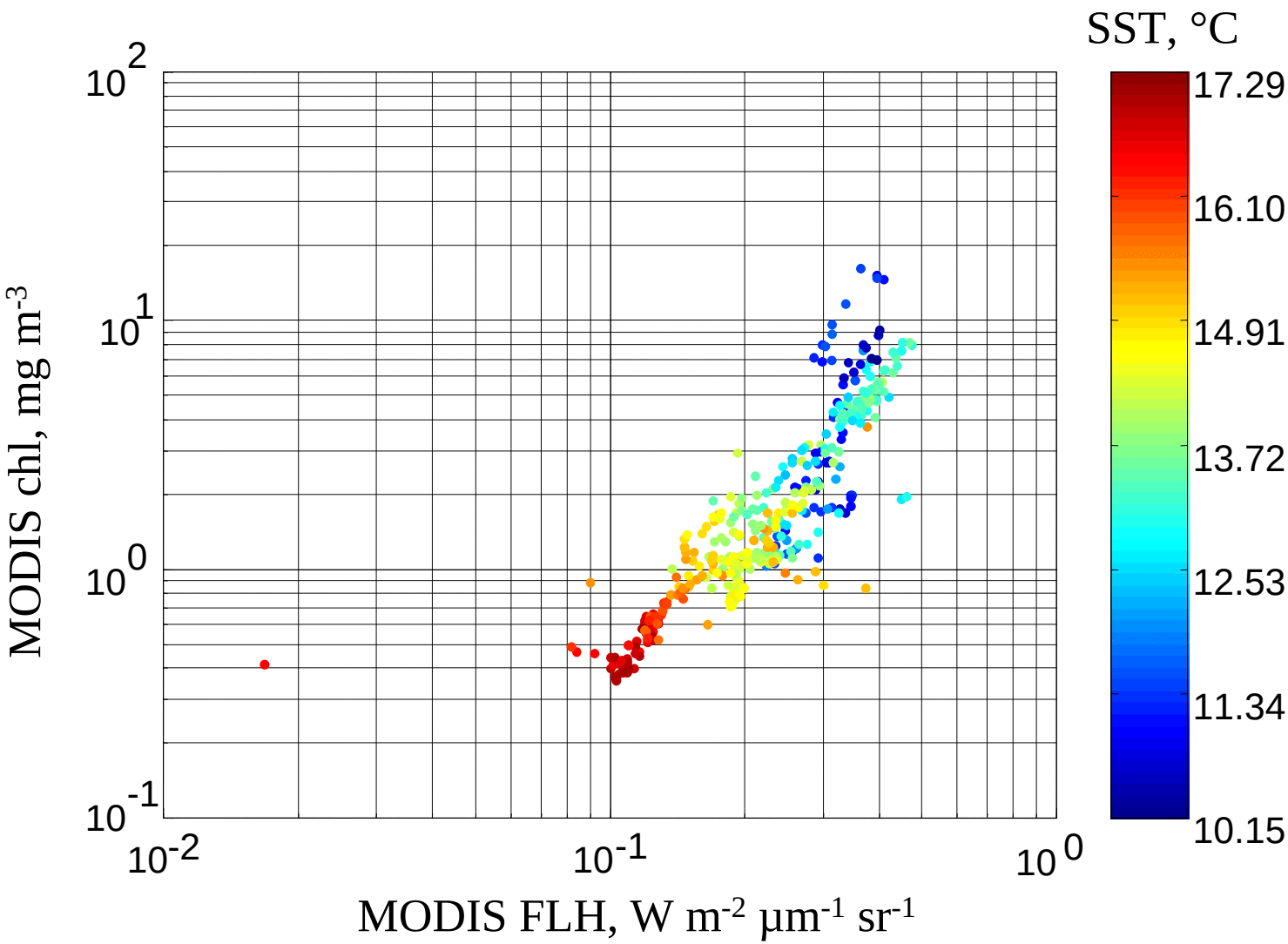
Longitude



# Photosynthetic Capacity vs. FLH/chlorophyll



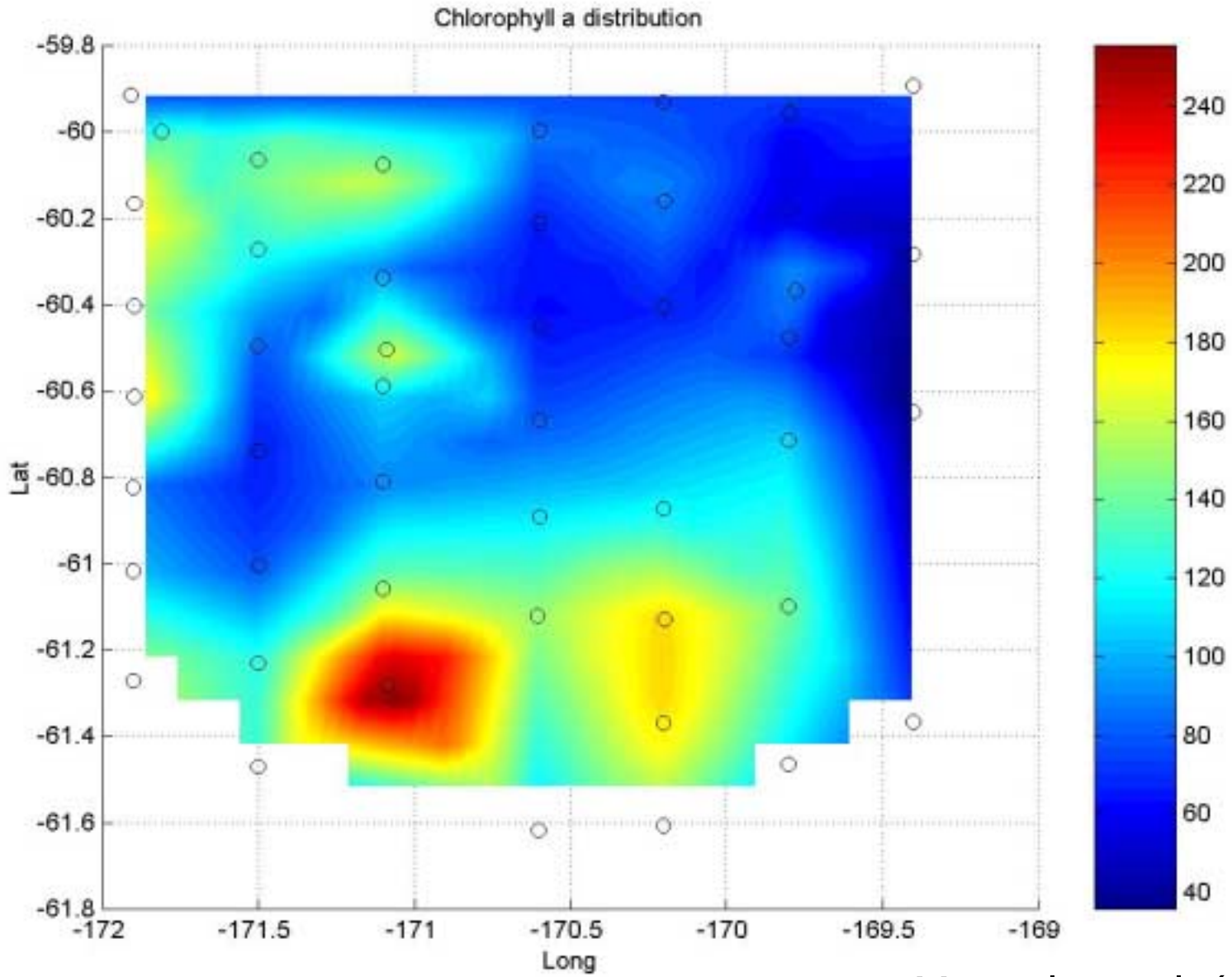
# MODIS FLH and Chlorophyll



# How Can the Fluorescence Signal be Used?

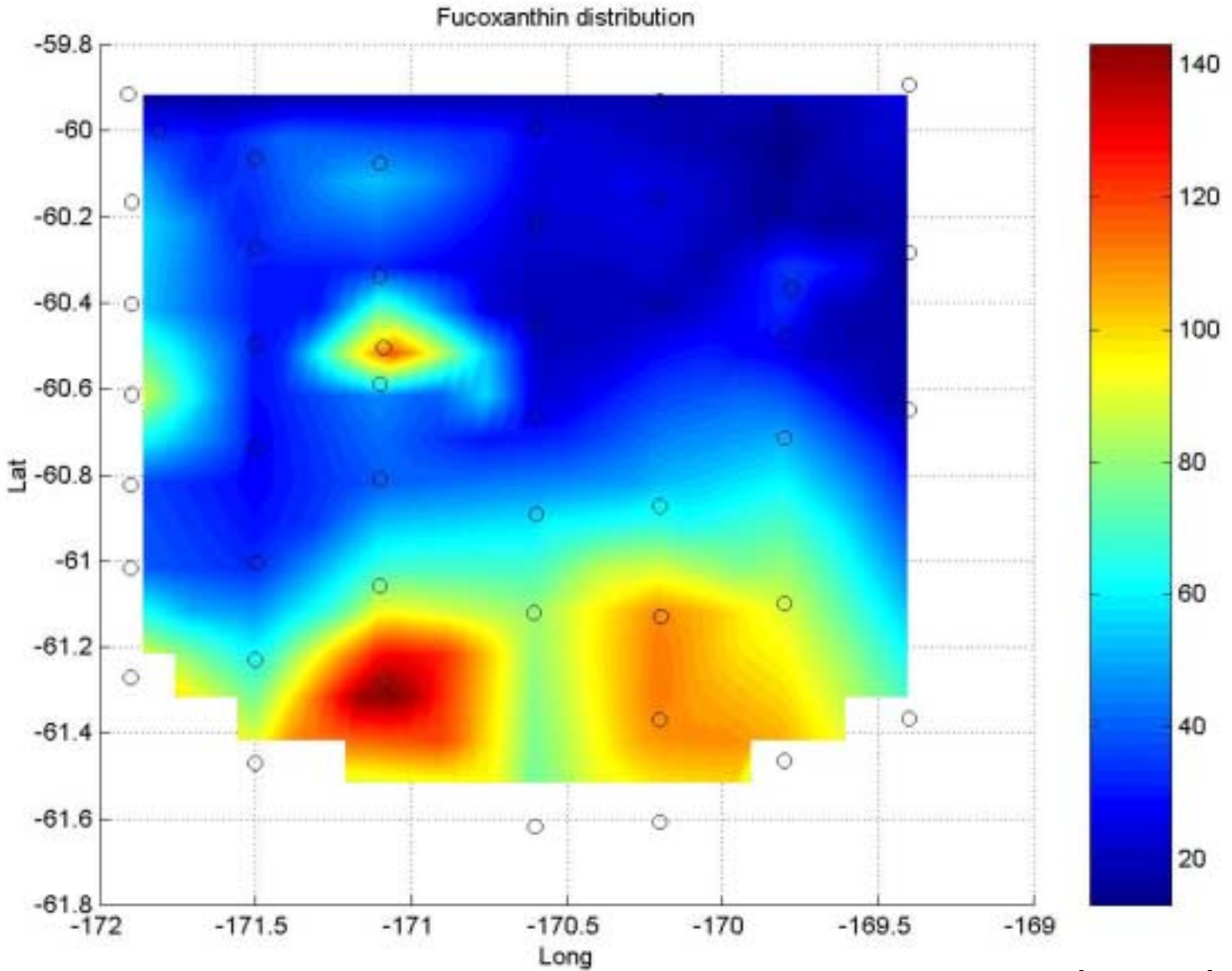
- Field and laboratory measurements suggest that there is useful information
- Challenge is to understand relationship between F/[chl] and photosynthetic potential
  - Time and space scales
  - Unlikely that instantaneous measurements will work
- Chemostat studies of phytoplankton response

# Surface Chlorophyll at the Polar Front



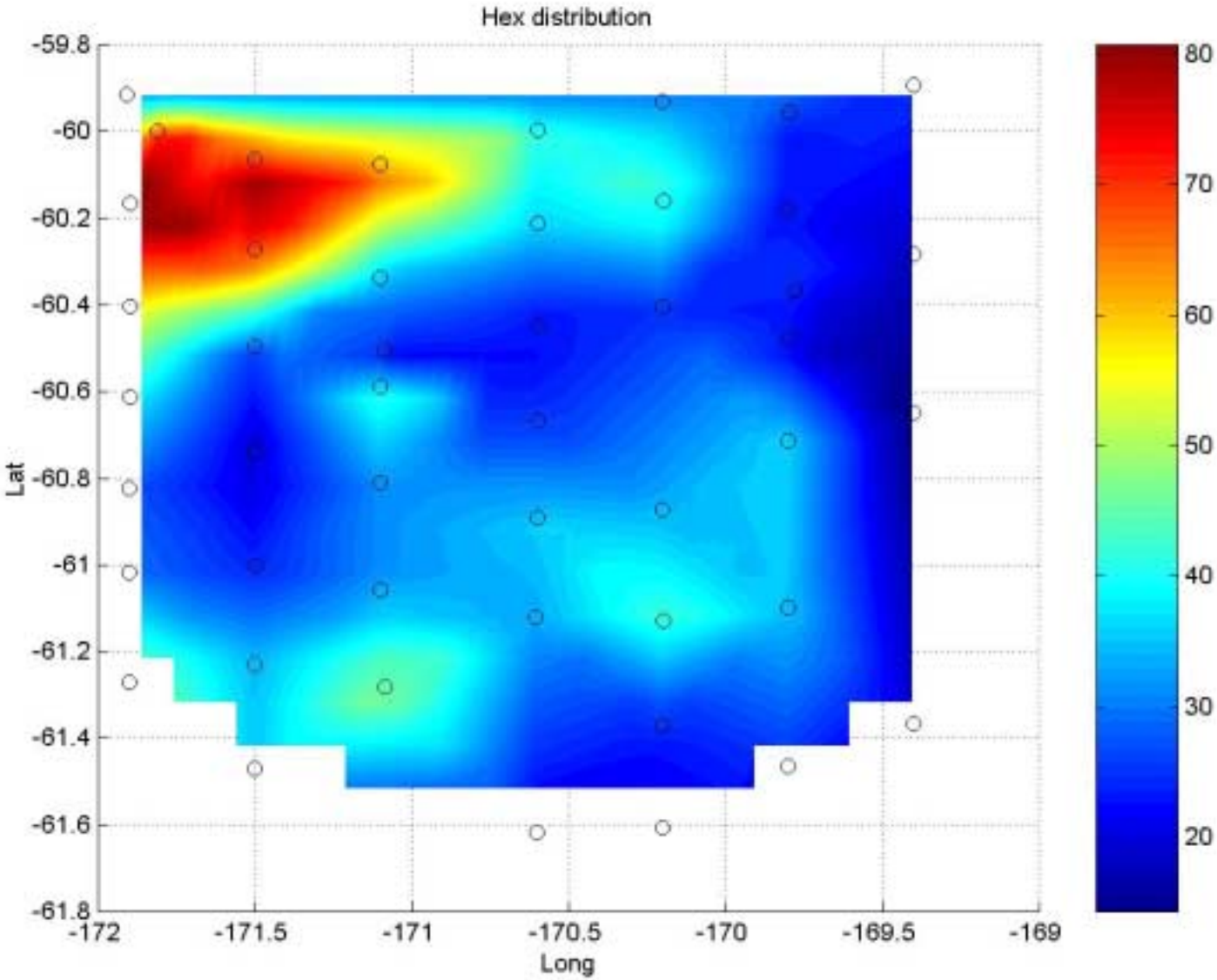

Mengelt et al. (2001)

# Pigments Associated with Diatoms

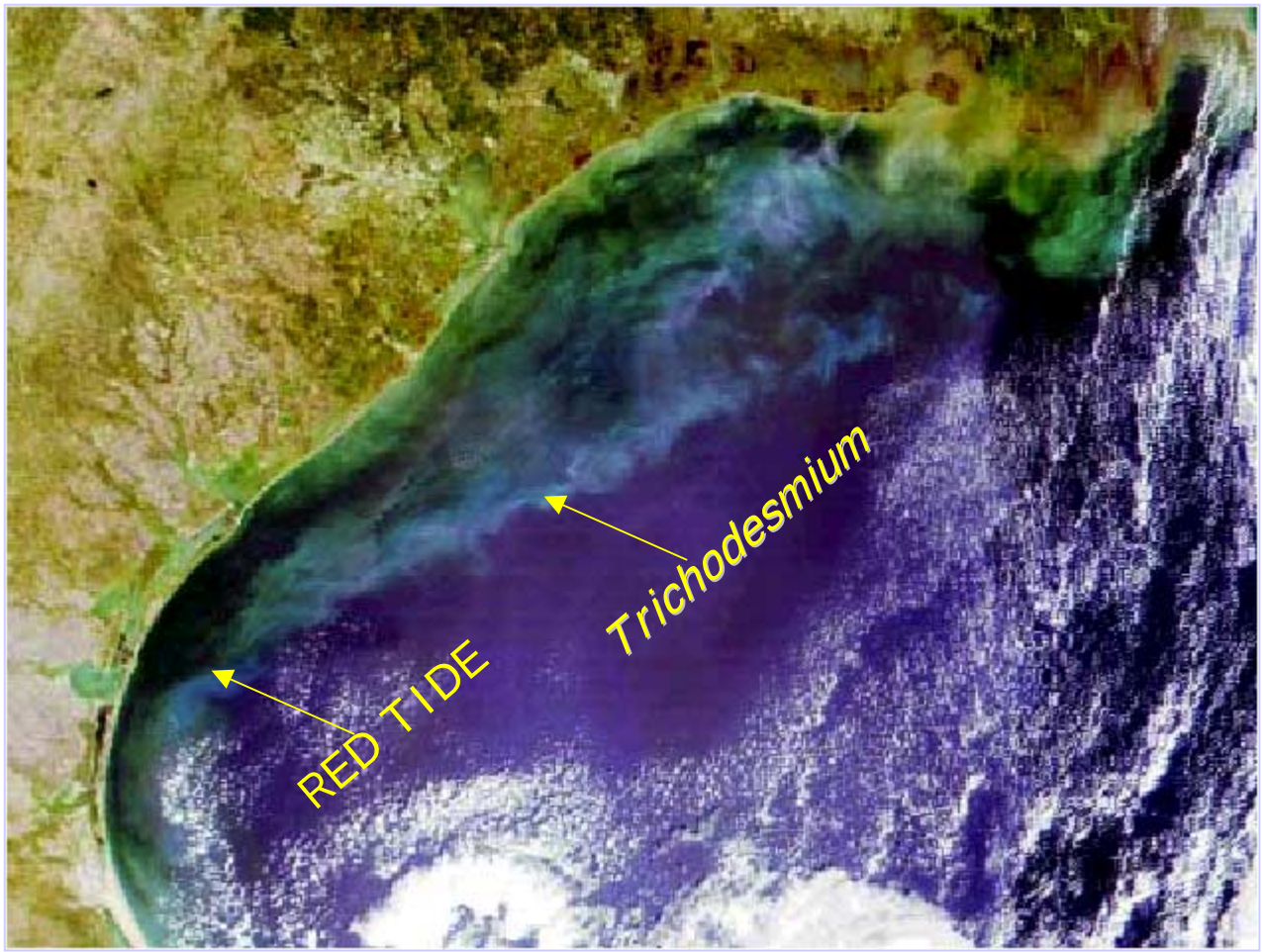



Mengelt et al. (2001)

# Pigments Associated with Prymnesiophytes




Mengelt et al. (2001)




Red tide (black) and *Trichodesmium* (aqua), 29 September 2000

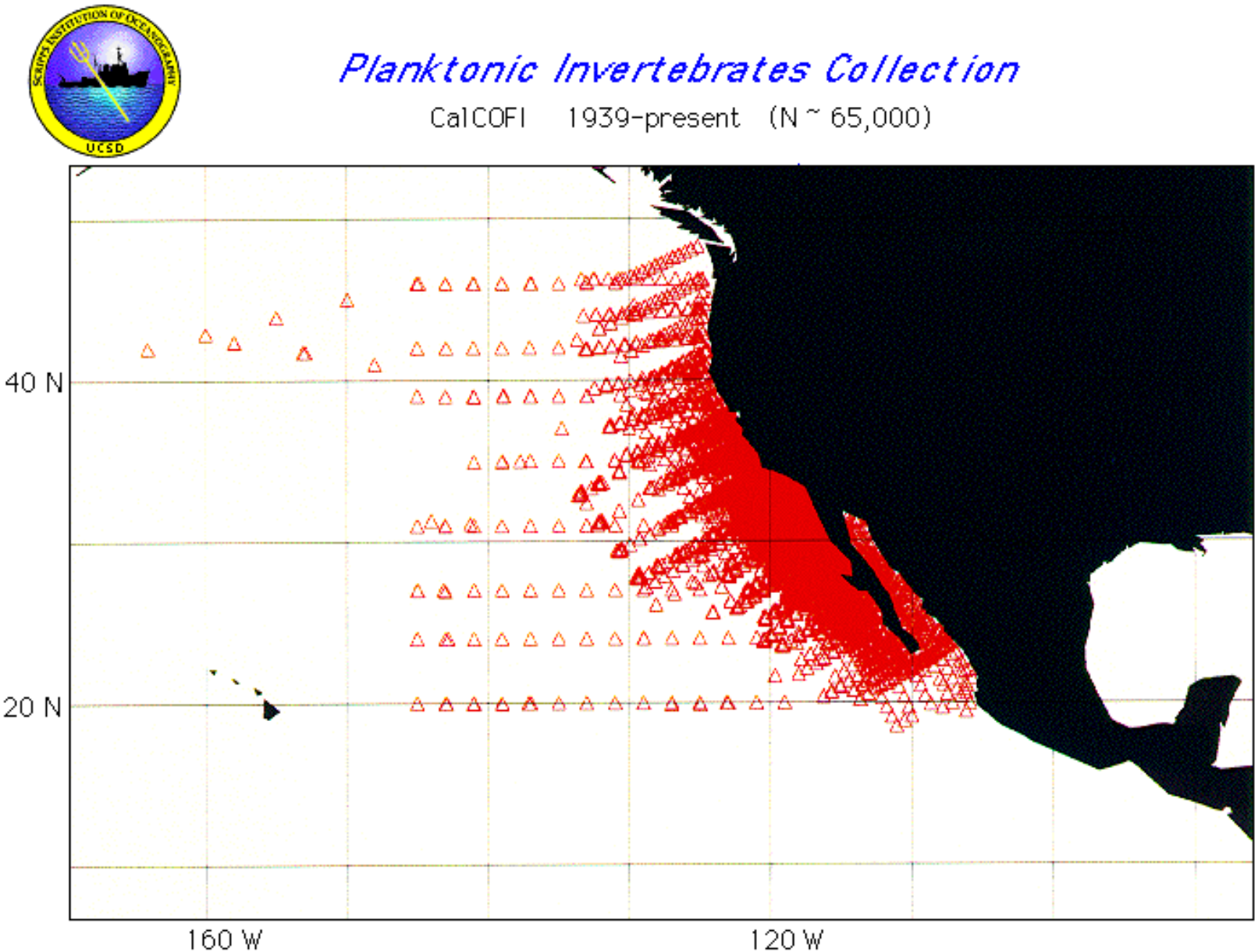
# Putting it all together

- Strong biological/physical coupling at mesoscales
- Need for long time series
- Good prospects for improving estimates of primary productivity
- But satellites will always “miss” some scales and some processes
- Models and field measurements are critical components as well

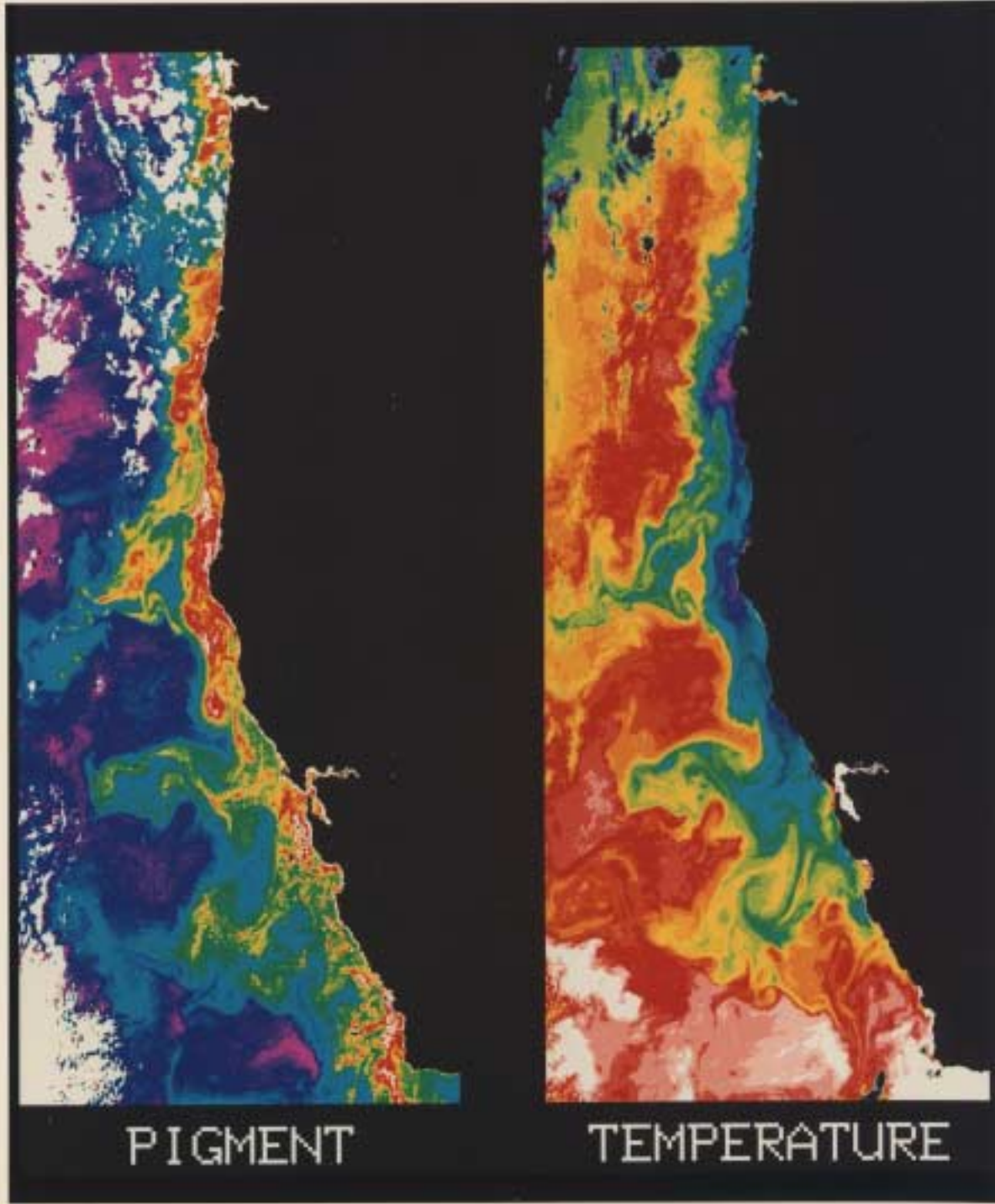
# Future Directions

- Programs such as CLIVAR, GODAE, and GOOS emphasize an operational strategy
- But programs such as JGOFS have shown that much research remains, especially in ecology and physical coupling
  - What processes need to be included?
  - What scales do we need to observe?
  - How do we parameterize for models?
- Are ocean sciences ready for monitoring?
  - We do need long-term, carefully-calibrated series

# CalCOFI Sampling Grid



Despite 40 years' of sampling, CalCOFI missed one of the dominant features of the California Current!



# Summary

- Changes in ocean's role in global carbon cycle a key element of the US Carbon Cycle Science Plan
  - Importance of both physical and biological processes
- Need for better time/space dependent estimates of primary productivity
- MODIS will play a critical role in this research