

The Ocean's least productive waters are expanding

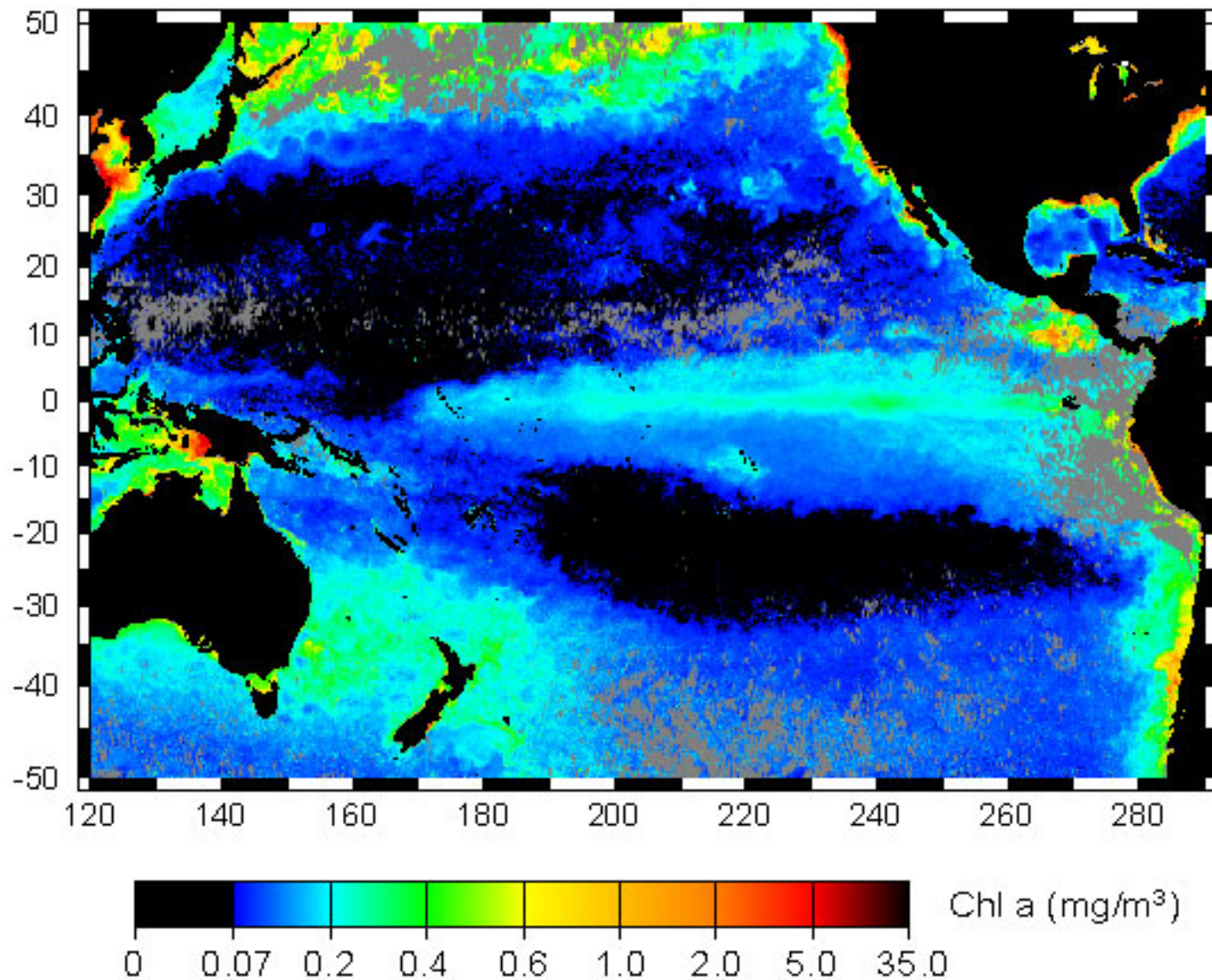
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NOAA Fisheries

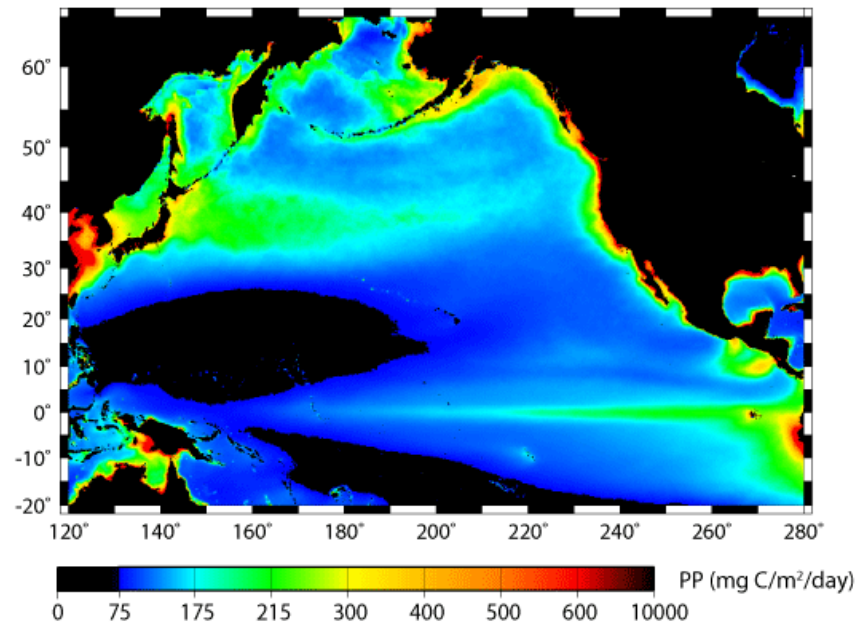
SeaWiFS Data

- Decade-long global surface Chl-a data set (9/97 to present)
- Many reprocessing to incorporate recalibrations, algorithm improvements, etc – thanks to NASA team and collaborators
- This work based on latest reprocessing July 2007, Version 5.2 to correct sensor drift and slight sensor degradation

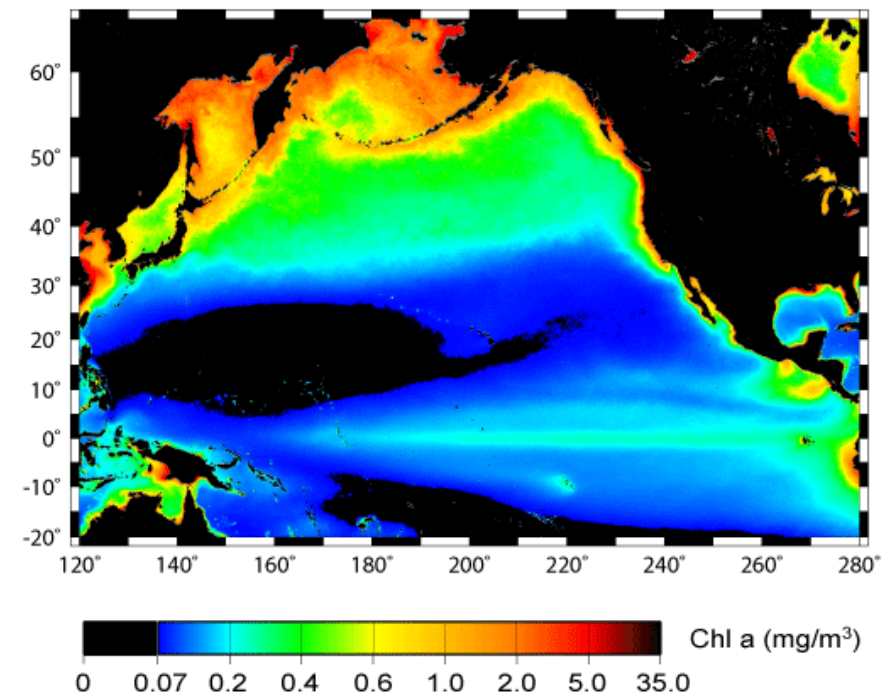
SeawiFS surface chlorophyll August, 2003 with oligotrophic gyres in black



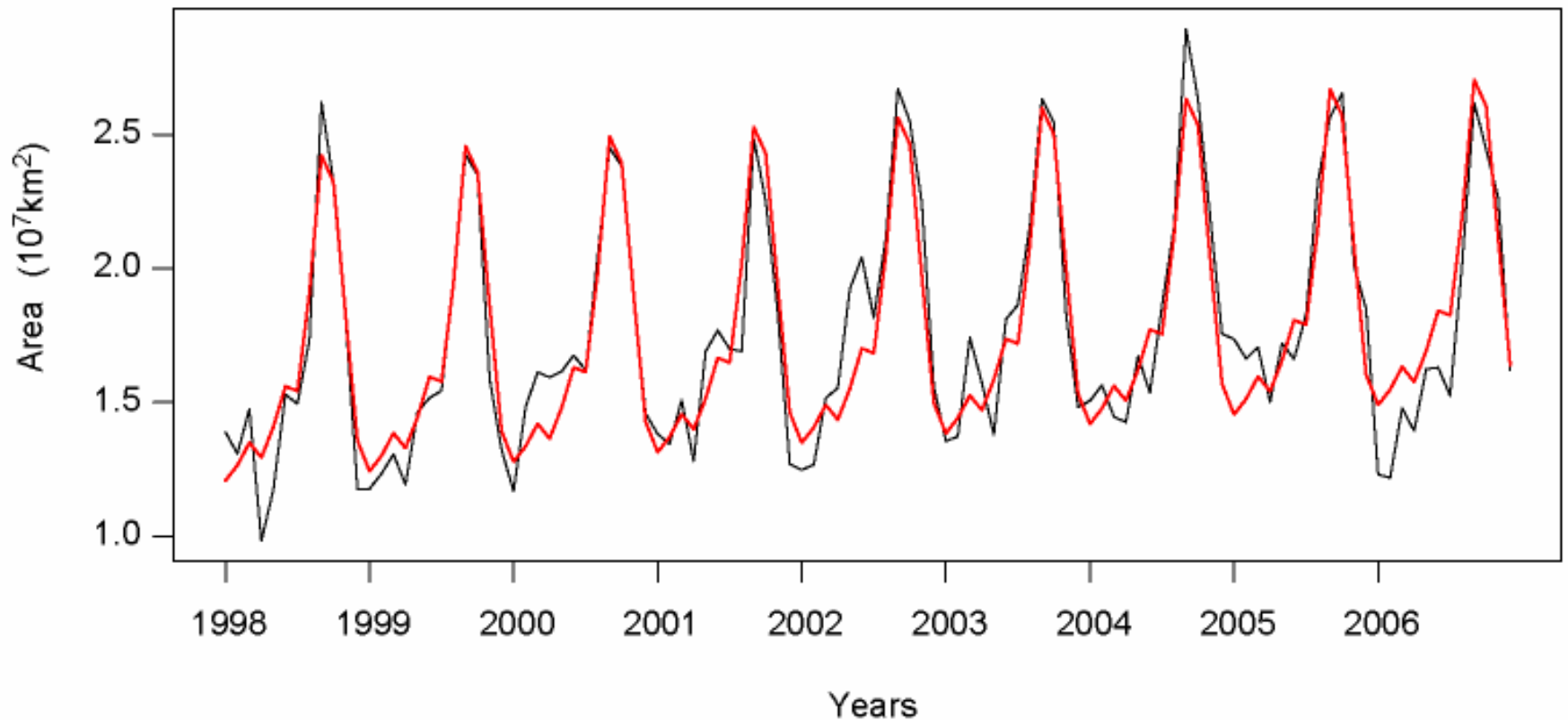
Annual mean depth integrated net primary productivity (data from Behrenfeld 2007)



Annual mean surface chlorophyll from SeaWiFS

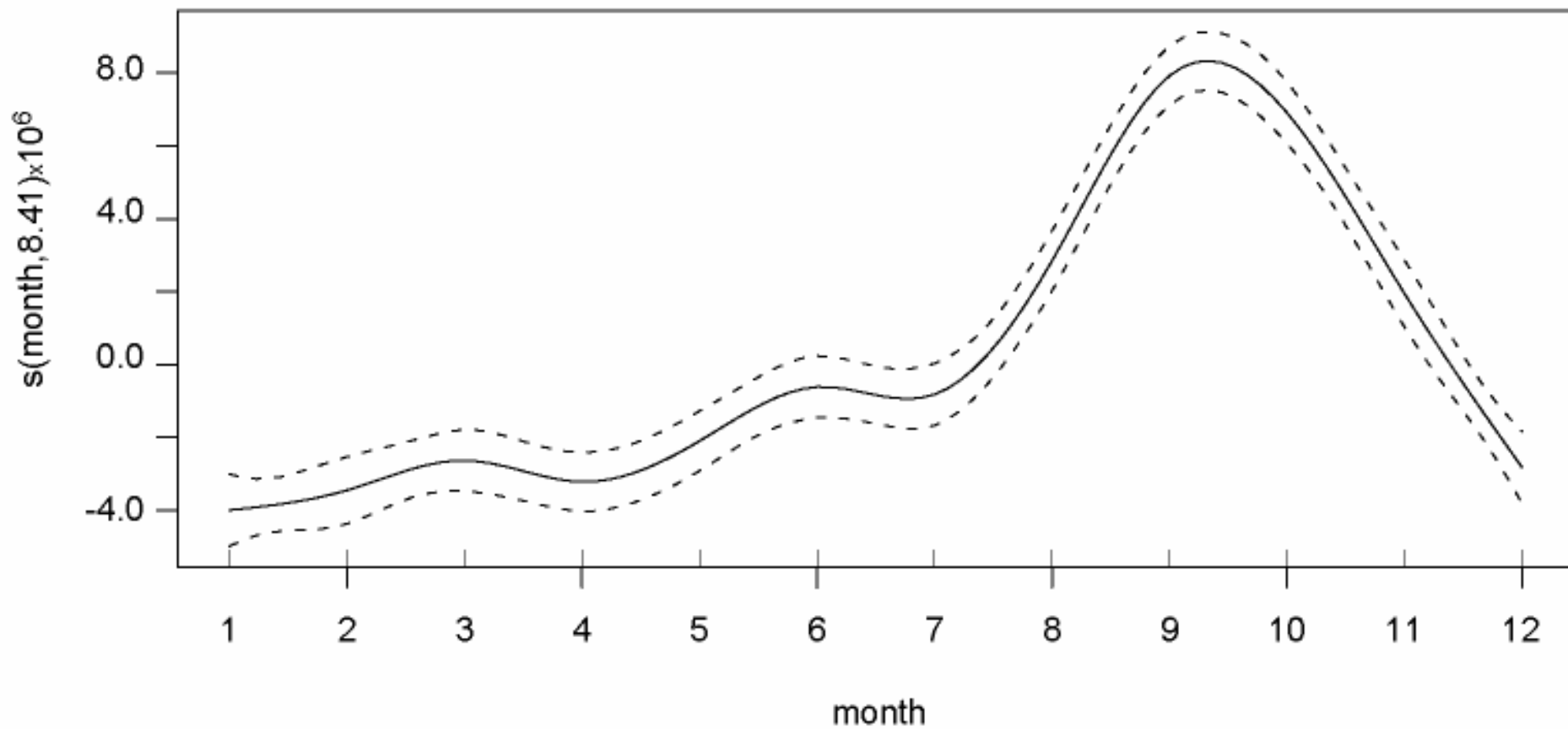


N Pacific Monthly Area with surface chlorophyll ≤ 0.07 mg C/m³ 1998-2006 with GAM fit (red)

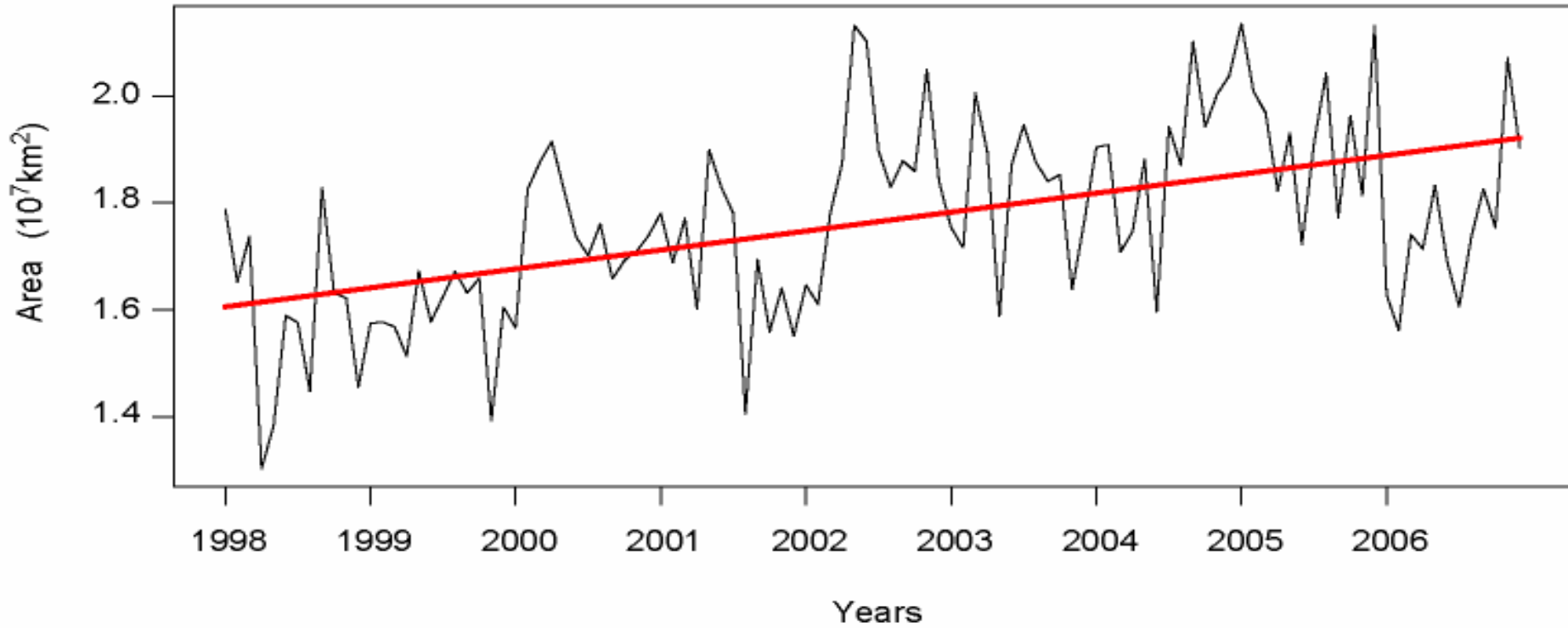


GAM: Monthly Area = $A + B \cdot \text{time} + S(\text{Month}) + \text{error}$

N Pacific Area GAM seasonal term

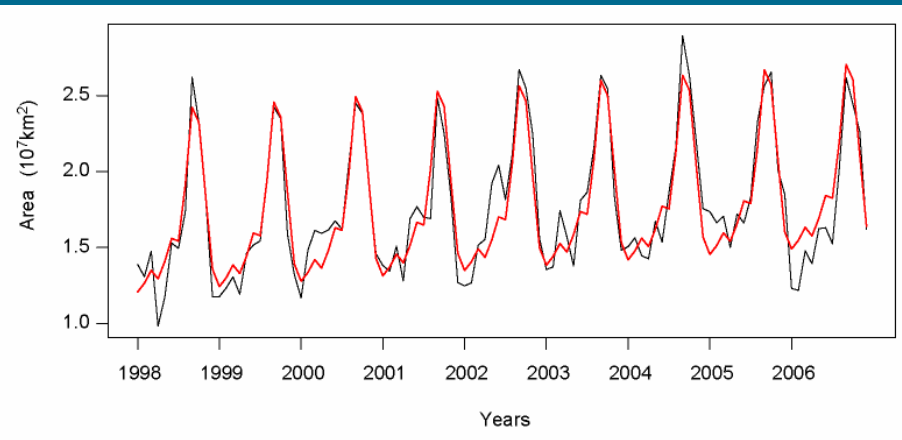


N Pacific Area with seasonal GAM component removed, data and GAM linear term (red)

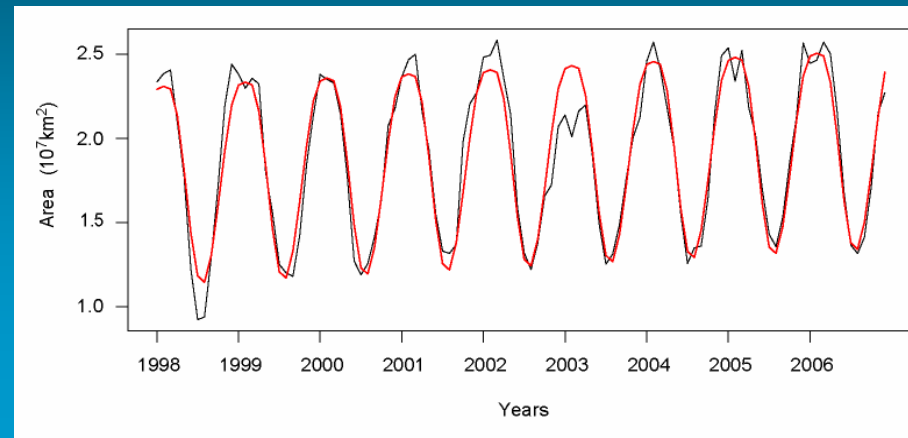


Fit of GAM (linear plus seasonal) (red) to monthly oligotrophic gyre areas, 1998-2006.

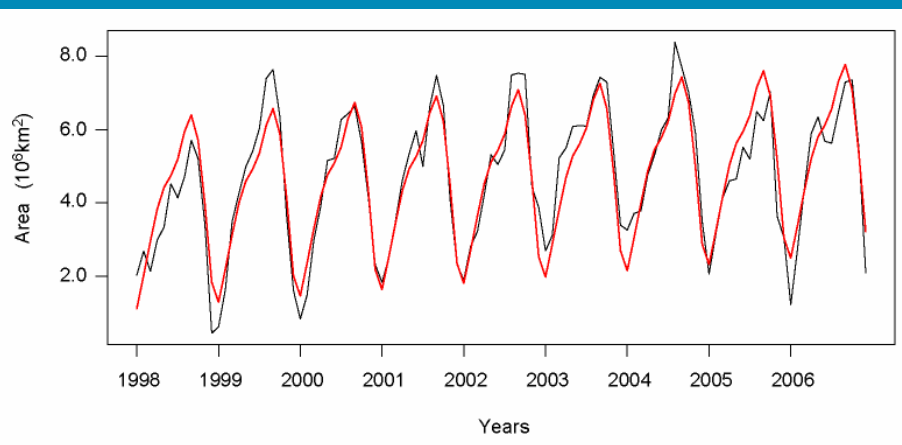
N Pacific



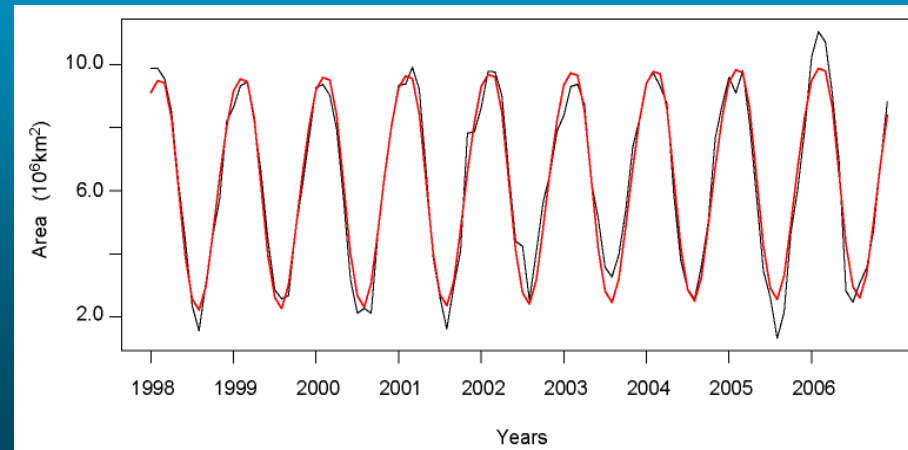
S Pacific



N Atlantic

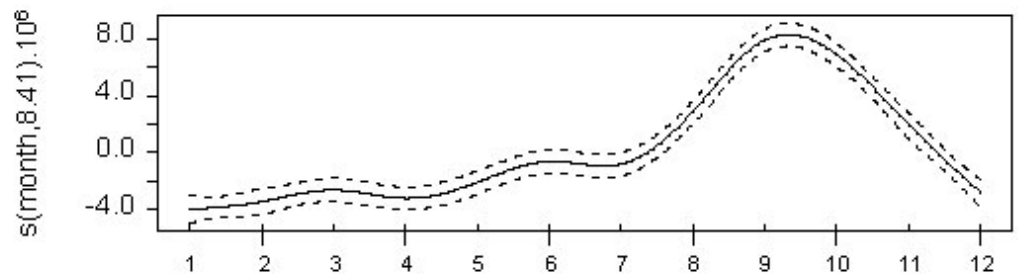


S Atlantic

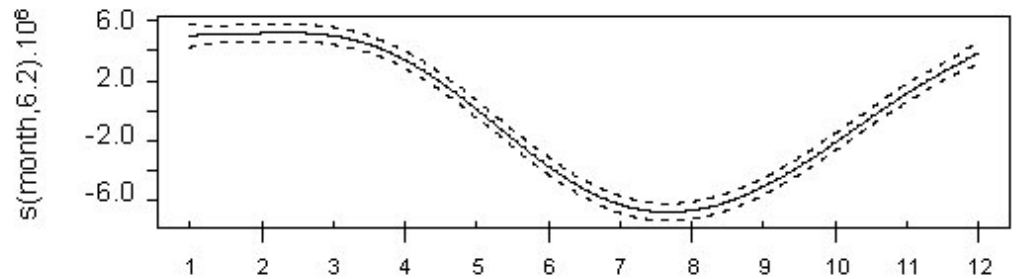


Seasonal term

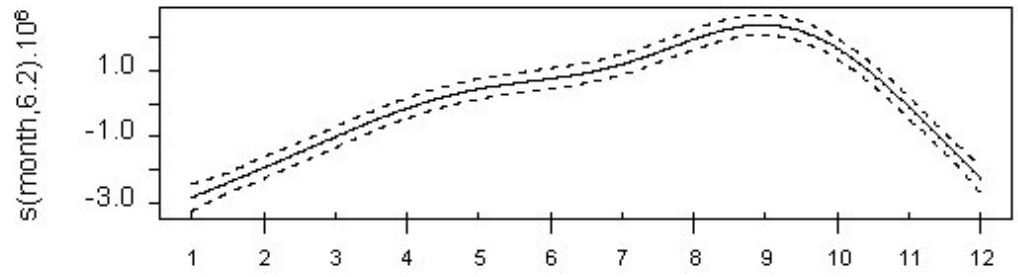
N Pacific



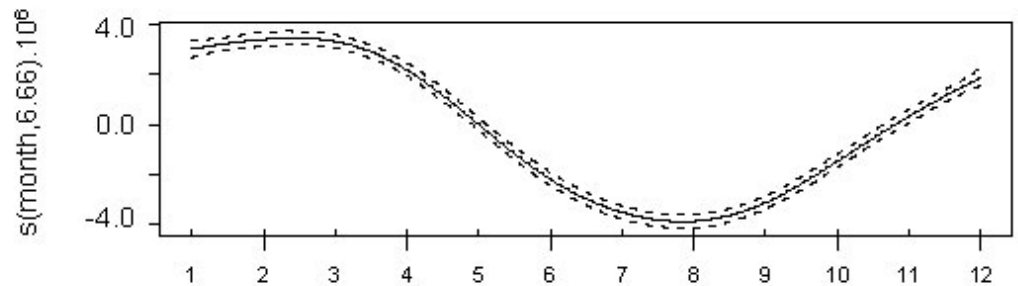
S Pacific



N Atlantic



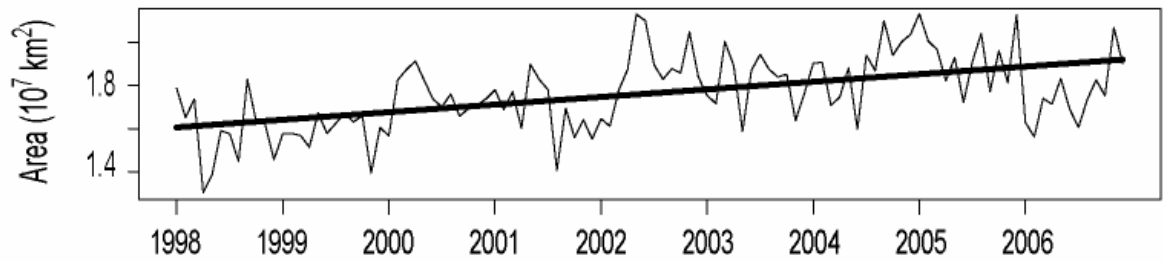
S Atlantic



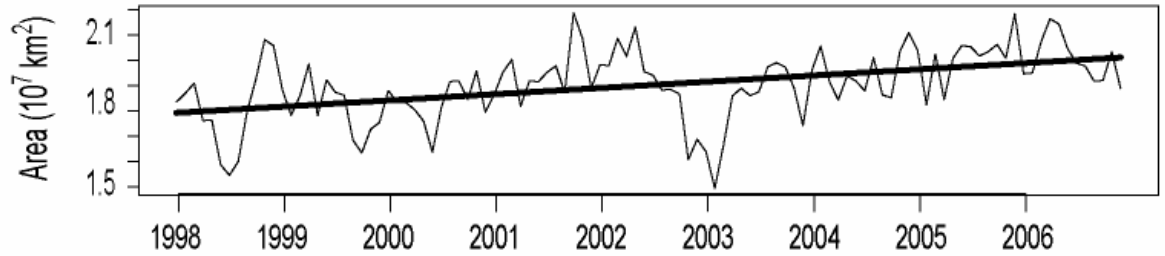
Month

Linear term

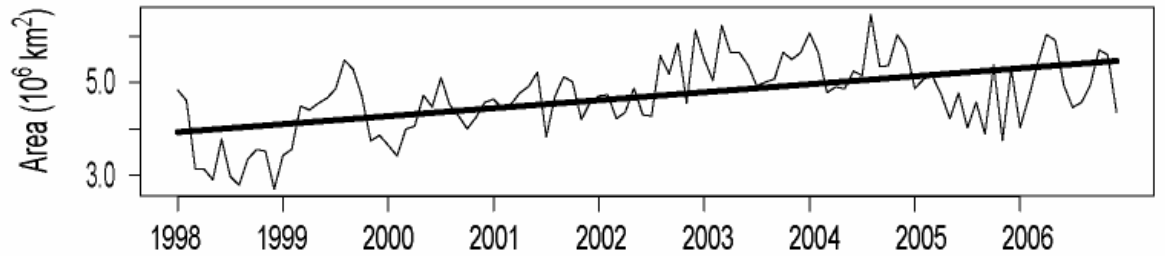
N Pacific



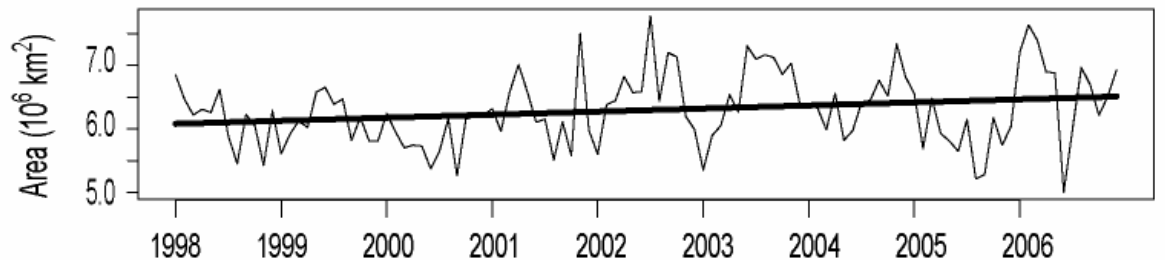
S Pacific



N Atlantic



S Atlantic

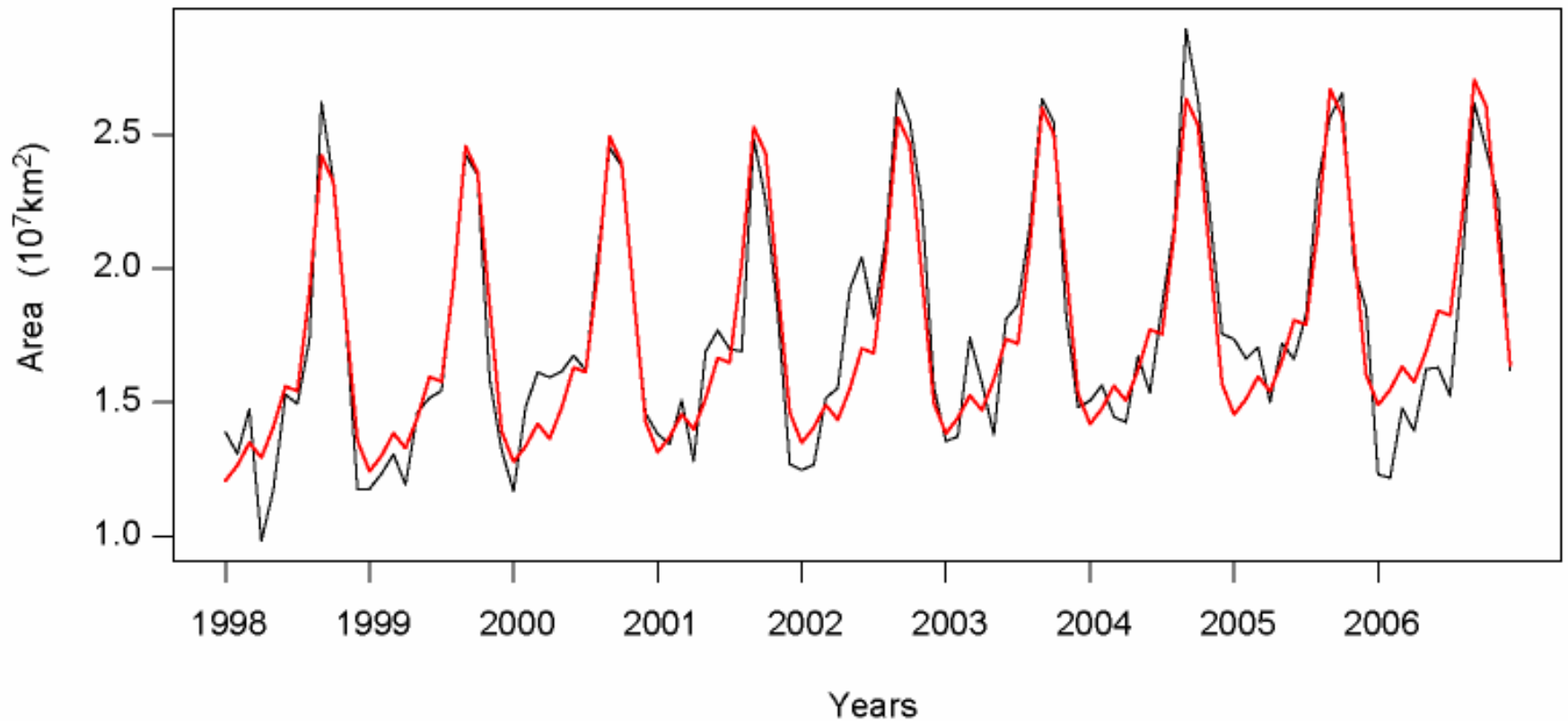


Years

Trend in oligotrophic gyres based on GAM linear term

| Ocean | 1998 mean area (km ²) | Increase in area (km ² /yr) (%/yr) | p-value |
|----------------|-----------------------------------|---|---------|
| North Pacific | 16,222,653 | 353,519 (2.18) | 2.5e-08 |
| South Pacific | 18,041,685 | 245,766 (1.36) | 1.5e-06 |
| North Atlantic | 4,010,147 | 172,455 (4.3) | 1.4e-09 |
| South Atlantic | 6,100,571 | 48,075 (0.79) | 0.026 |
| Total | 44,375,056 | 807,024 (1.85) | - |

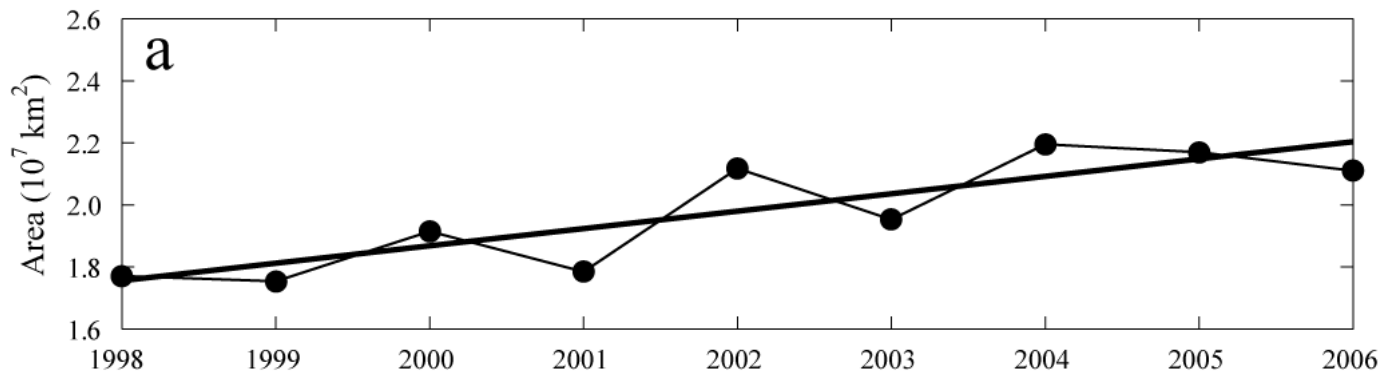
N Pacific Monthly Area with surface chlorophyll ≤ 0.07 mg C/m³ 1998-2006 with GAM fit (red)



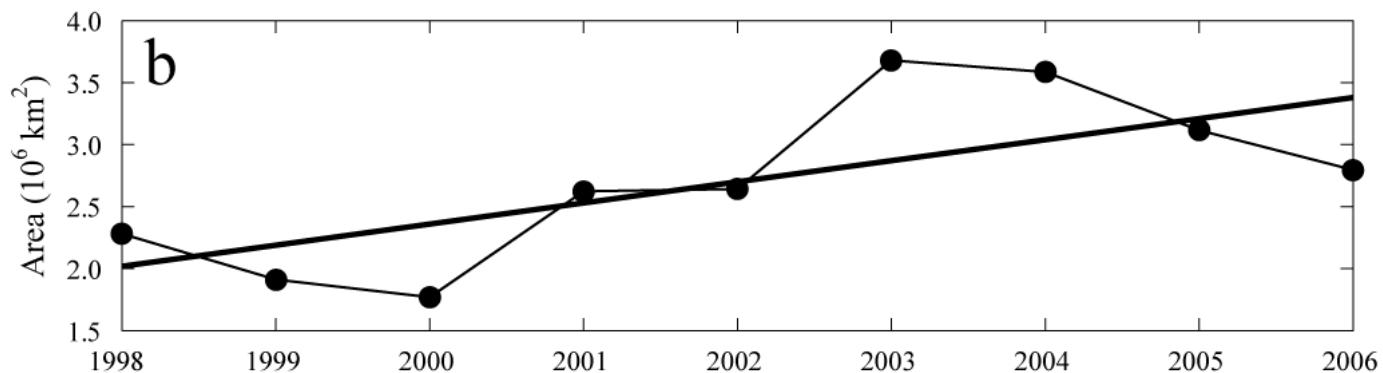
GAM: Monthly Area = $A + B \cdot \text{time} + S(\text{Month}) + \text{error}$

Change in mean quarterly oligotrophic gyre area

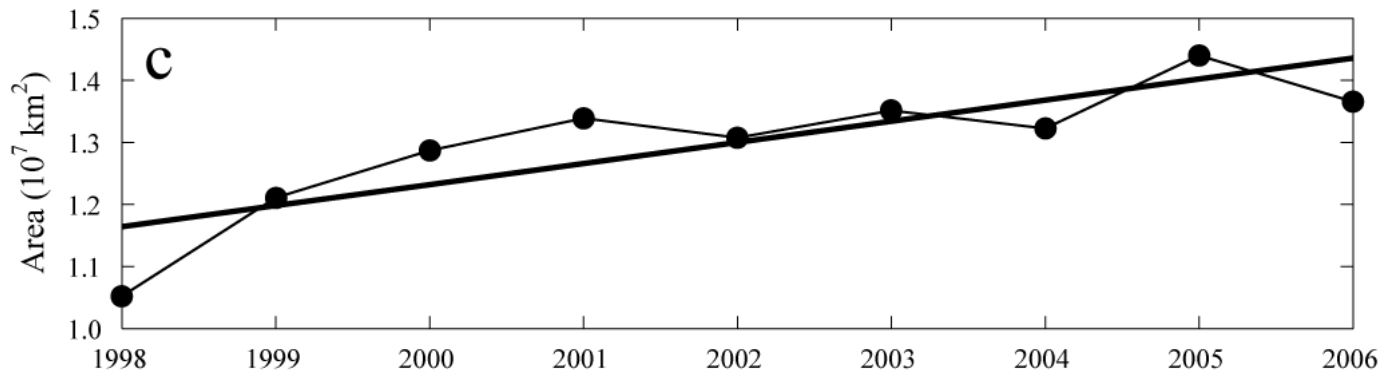
Top: North Pacific, quarter 4



Middle: North Atlantic, quarter 1



Bottom: South Pacific, quarter 3

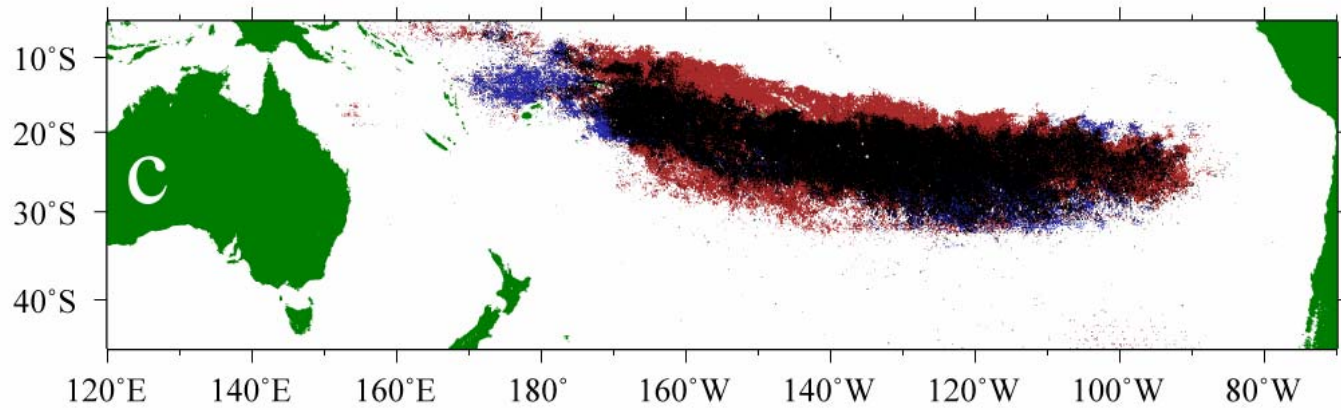
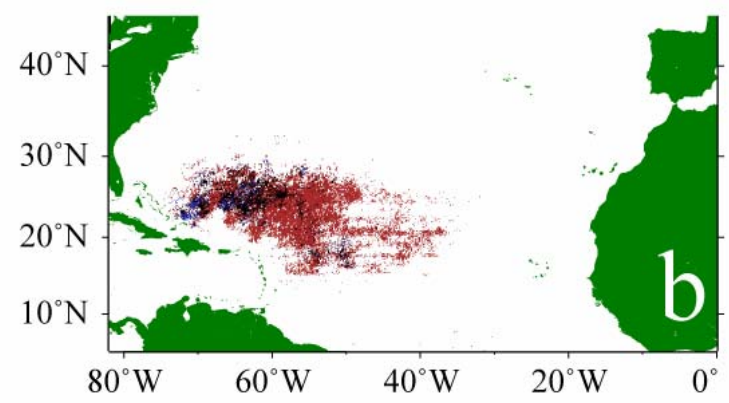
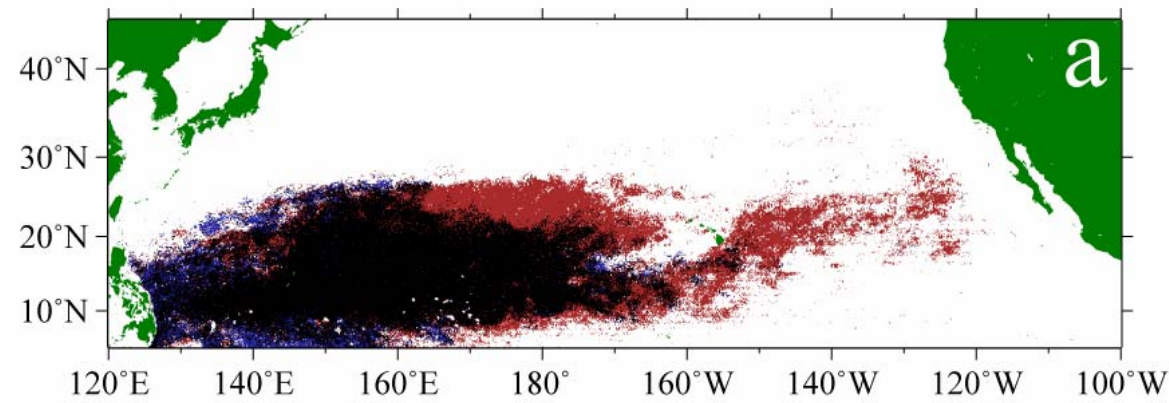


Linear regression of quarterly mean oligotrophic gyre area vs time

| Ocean | Quarter with largest rate of increase | Increase in area (km ² /yr) (%/yr) | p-value |
|----------------|---------------------------------------|---|---------|
| North Pacific | 4 | 555,875 (3.17) | 0.005 |
| North Atlantic | 1 | 172,609 (8.54) | 0.040 |
| South Pacific | 3 | 337,352 (2.90) | 0.004 |
| Total | - | 1,065,836 (3.42) | - |

Changes in oligotrophic areas between 1998-1999 and 2005-2006 in
December:

- a) North Pacific,
- b) North Atlantic,
- and August:
- a) South Pacific



Comparison to Coupled Climate Ocean models Predictions

By 2050: Permanently stratified Subtropical gyres due to global warming estimated to be:

- i) 4% larger in the Northern Hemisphere
- ii) 9.4% larger in the Southern Hemisphere

Sarmiento et al. 2004

iii) SeaWiFS results show for Pacific and Atlantic oligotrophic gyres expanding 0.79 – 4.40 %/yr (6.32-35.2% increase in 2006 compared to 1998)

vi) Ocean biology may be changing more than models predict

Summary

- Oligotrophic gyres in N Pacific, S Pacific, N Atlantic, S Atlantic show a statistically significant annual increase in area 0.79-4.40 %/yr
- Global oceans have added 6.6 million km² of oligotrophic habitat since 1998
- Oligotrophic gyres expanding faster in winter (2.5-7.0%/yr) or more than 1 million km²/yr
- Results likely due to increase in vertical stratification as already observed and predicted by climate ocean models
- Increase in oligotrophic gyre lowers the productivity and changes seasonality of the subtropical gyre resulting in ecosystem impacts