

# The Ocean's least productive waters are expanding

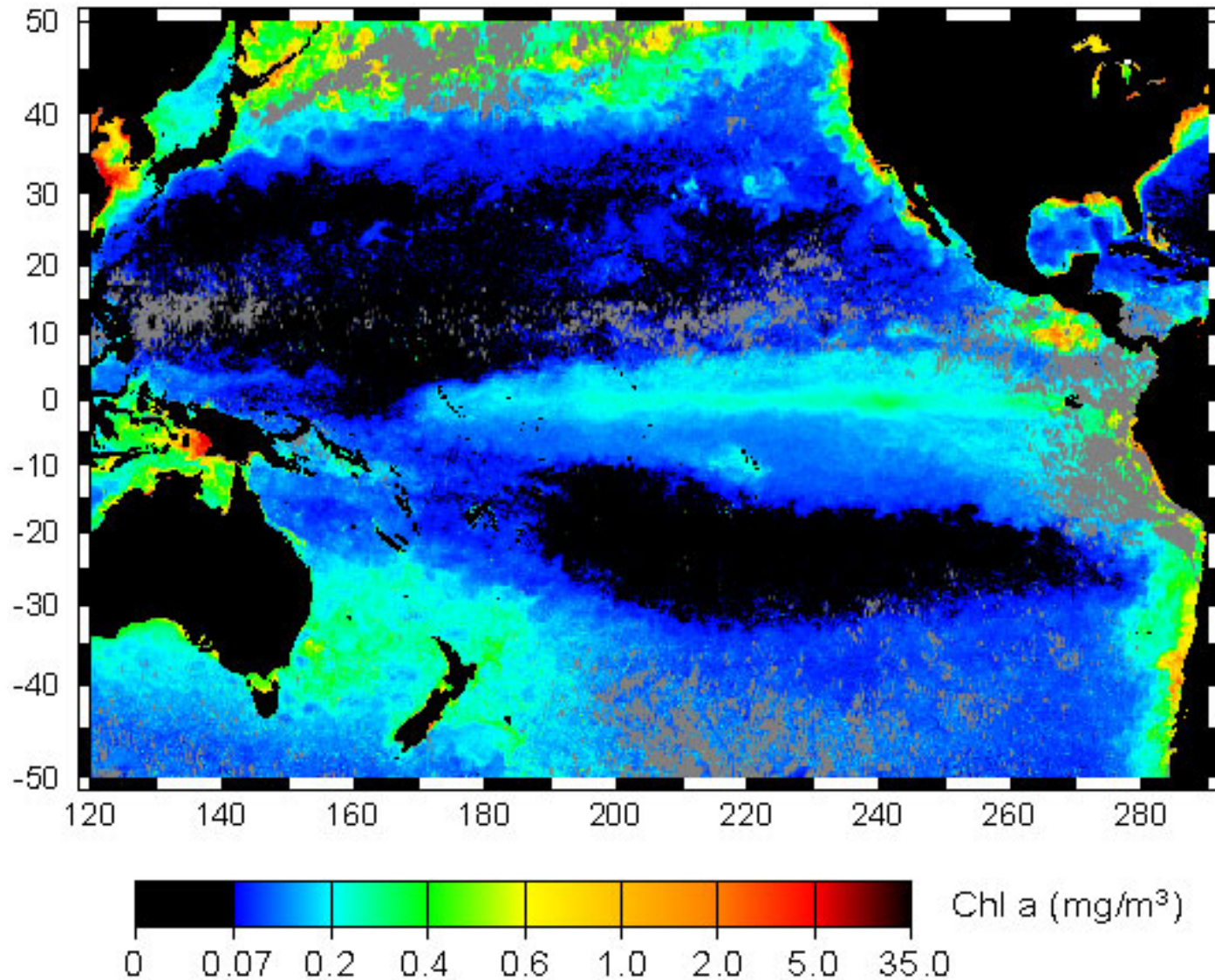
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NOAA Fisheries

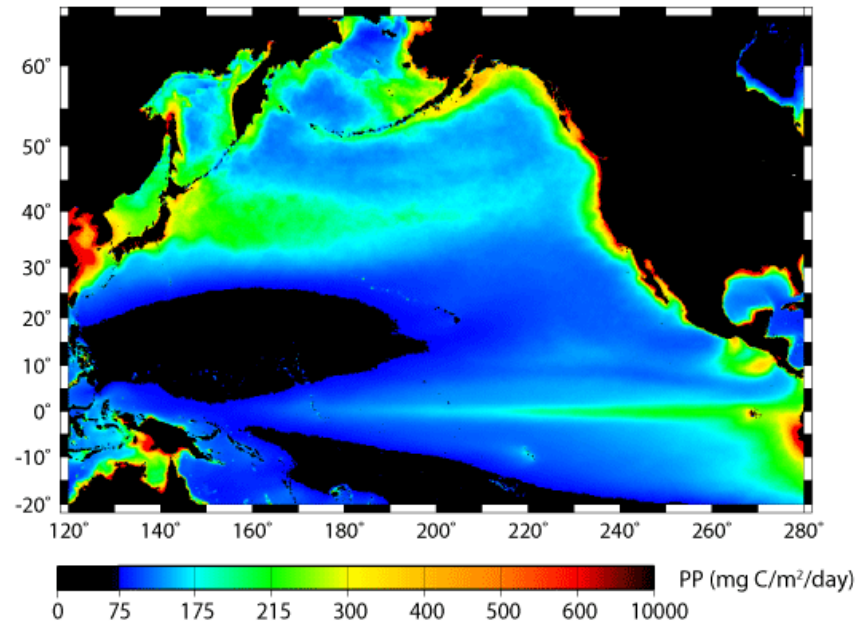
# SeaWiFS Data

- 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

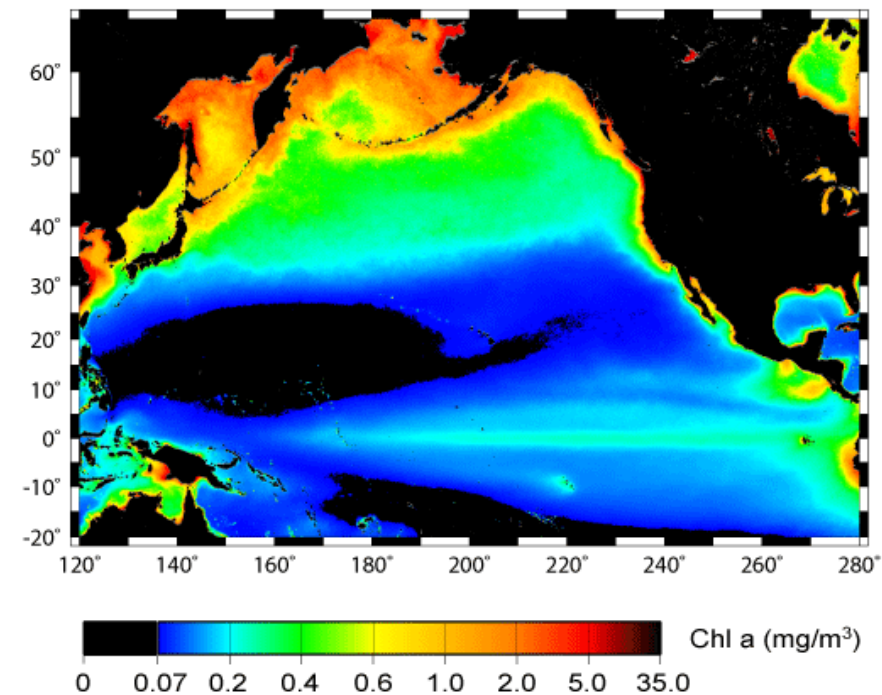
# SeawiFS surface chlorophyll August, 2003 with oligotrophic gyres in black



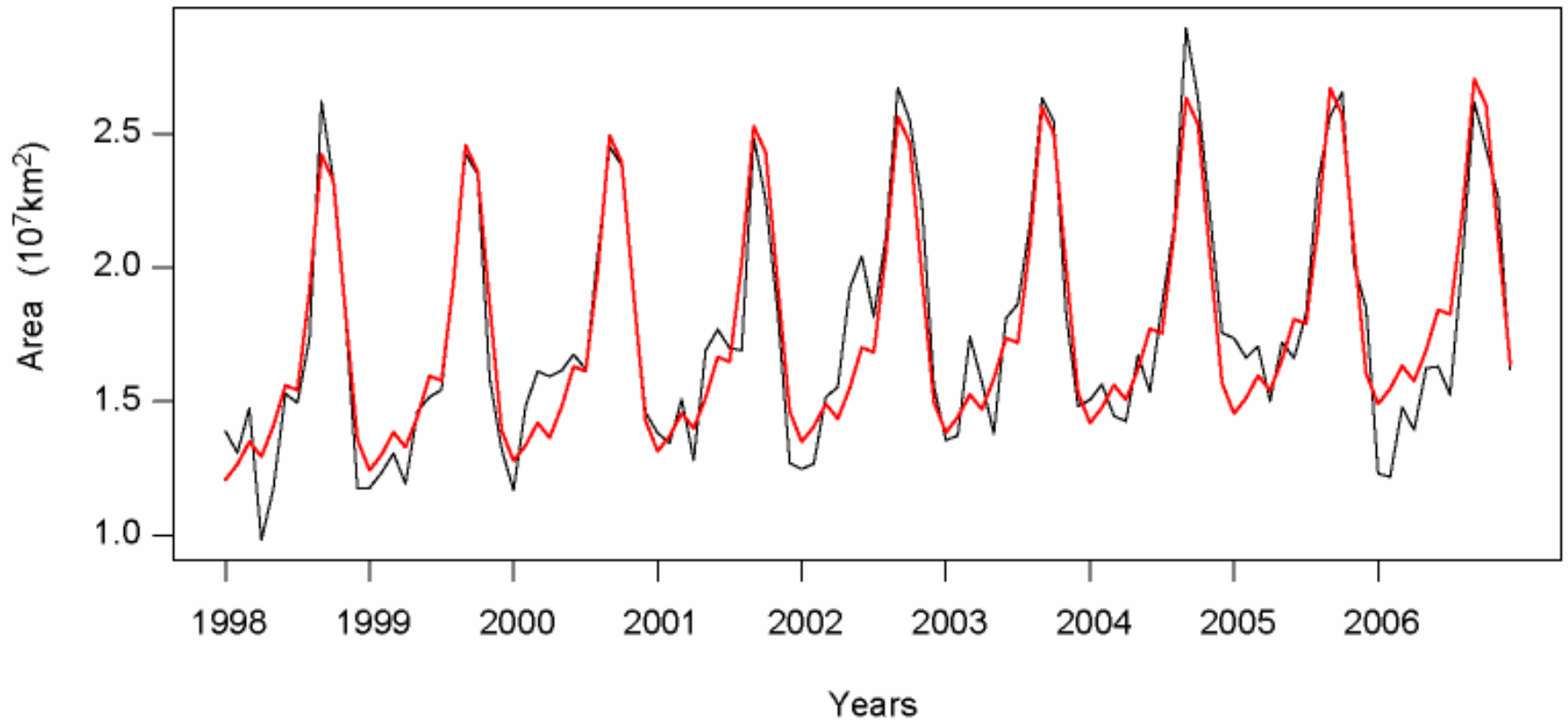
Annual mean depth integrated net primary productivity (data from Behrenfeld 2007)



Annual mean surface chlorophyll from SeaWiFS

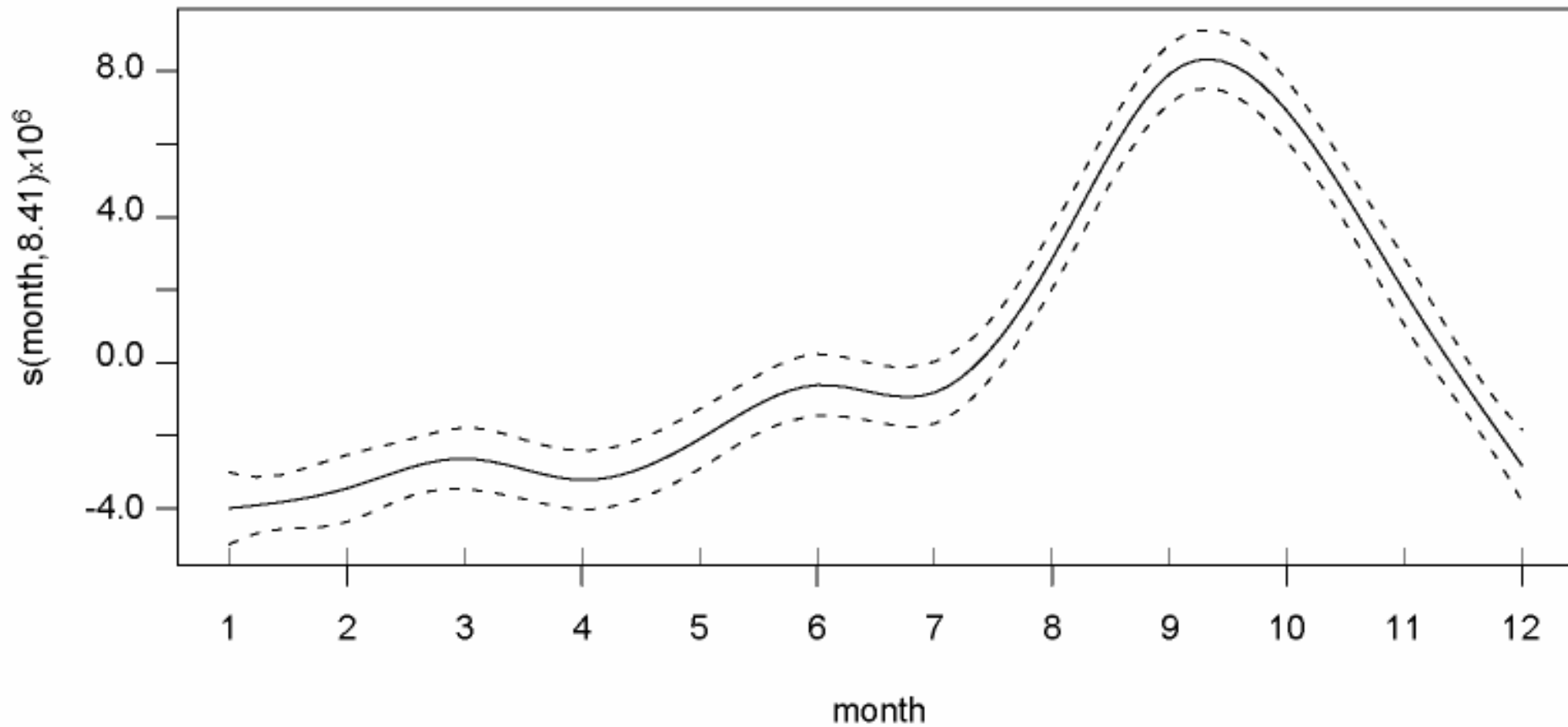


# N Pacific Monthly Area with surface chlorophyll $\leq 0.07$ mg C/m<sup>3</sup> 1998-2006 with GAM fit (red)

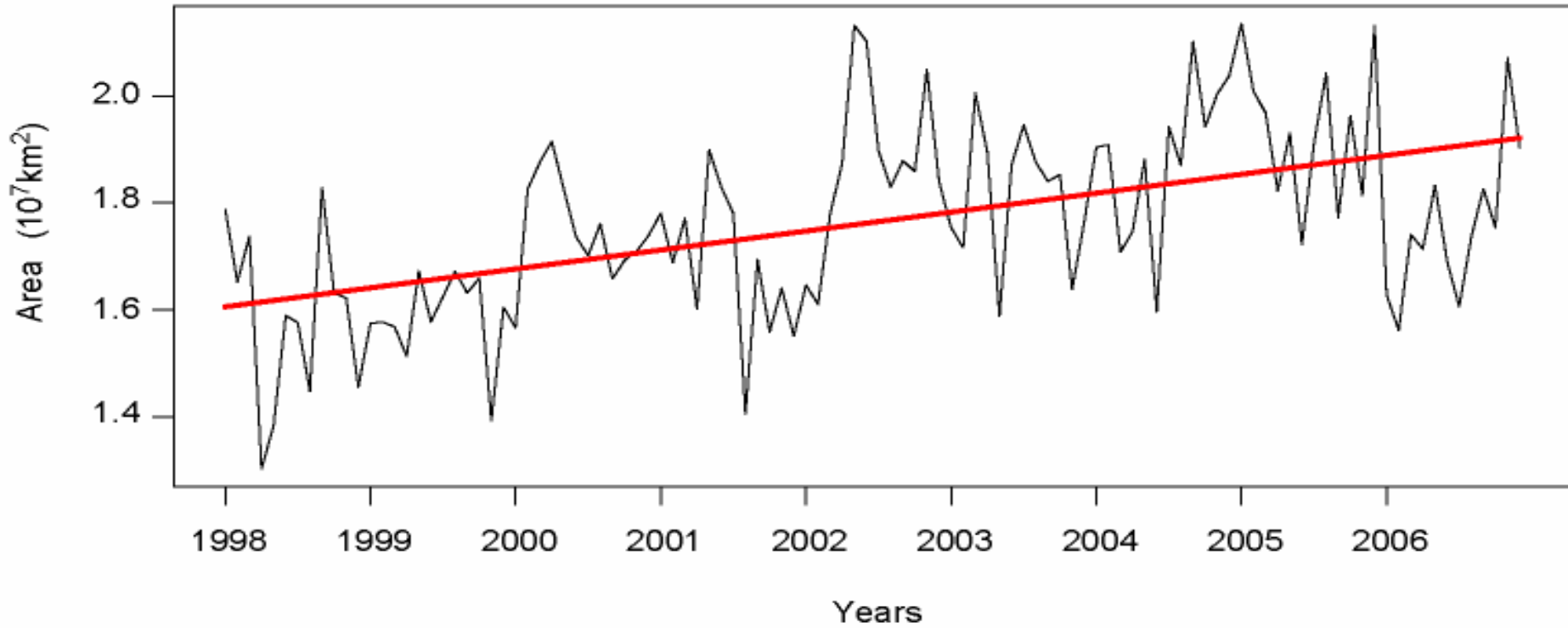


GAM: Monthly Area =  $A + B \cdot \text{time} + S(\text{Month}) + \text{error}$

# N Pacific Area GAM seasonal term

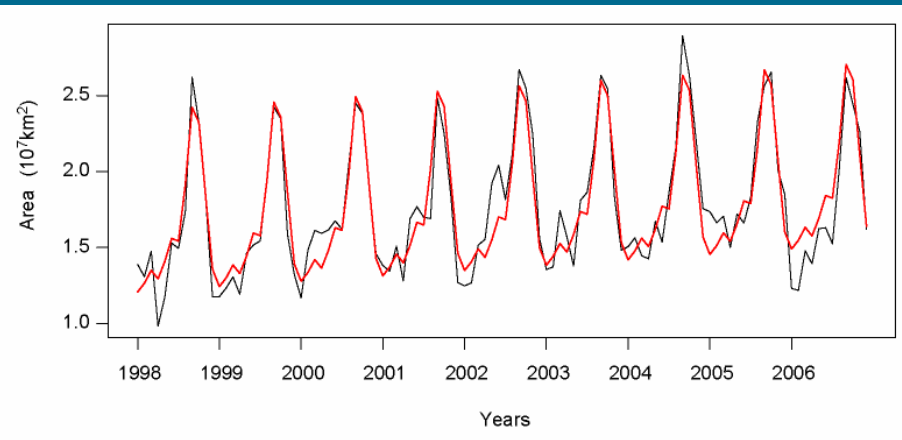


# N Pacific Area with seasonal GAM component removed, data and GAM linear term (red)

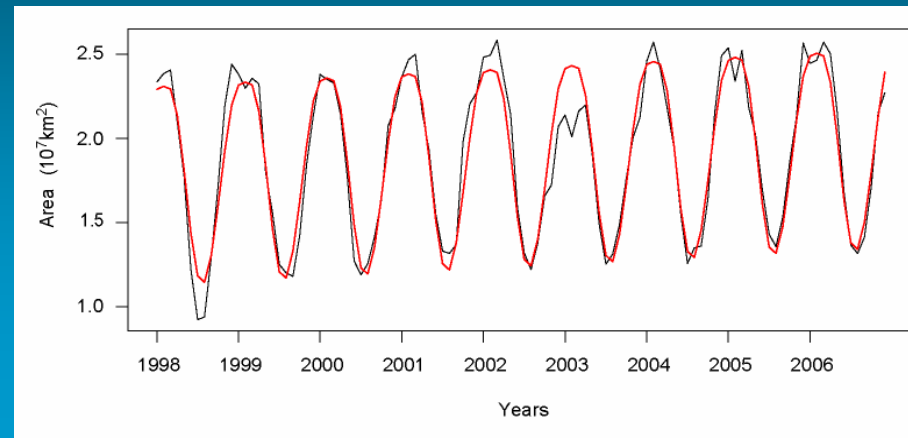


# Fit of GAM (linear plus seasonal) (red) to monthly oligotrophic gyre areas, 1998-2006.

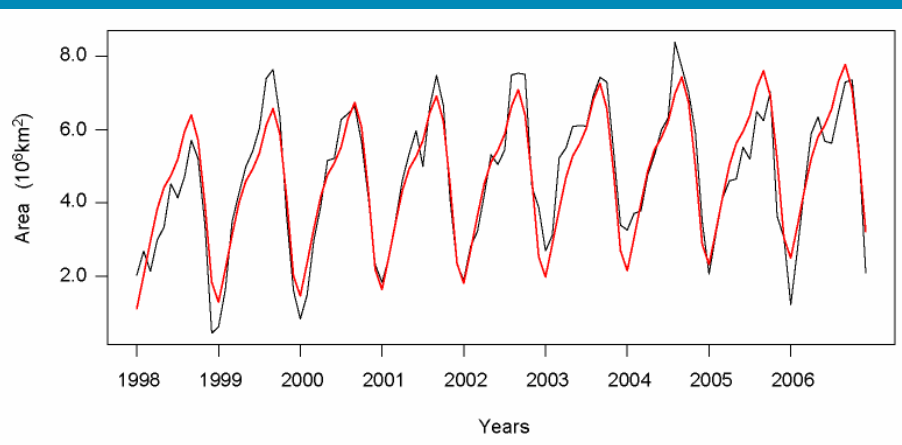
## N Pacific



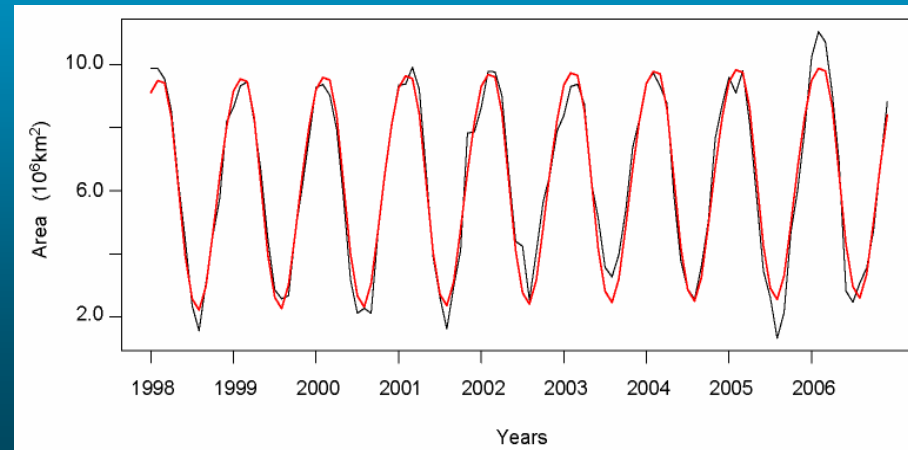
## S Pacific



## N Atlantic



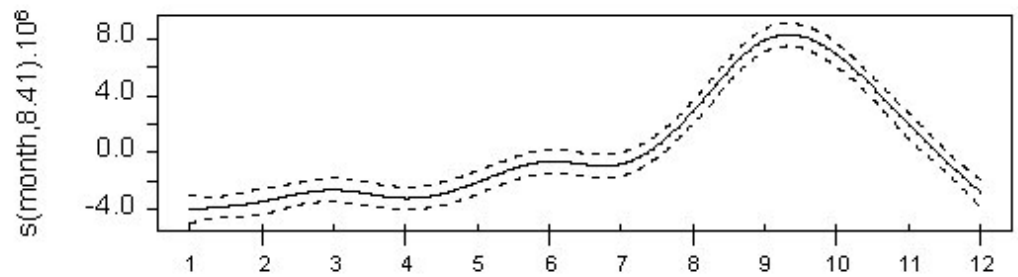
## S Atlantic



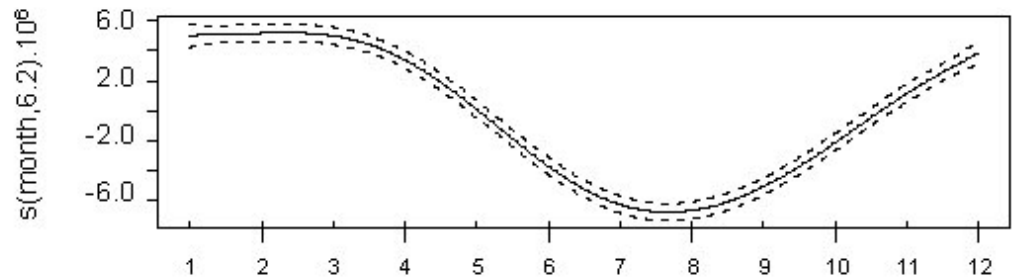


# Seasonal term

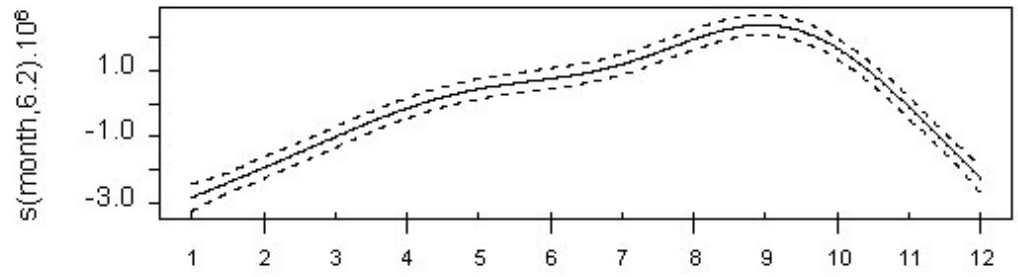
N Pacific



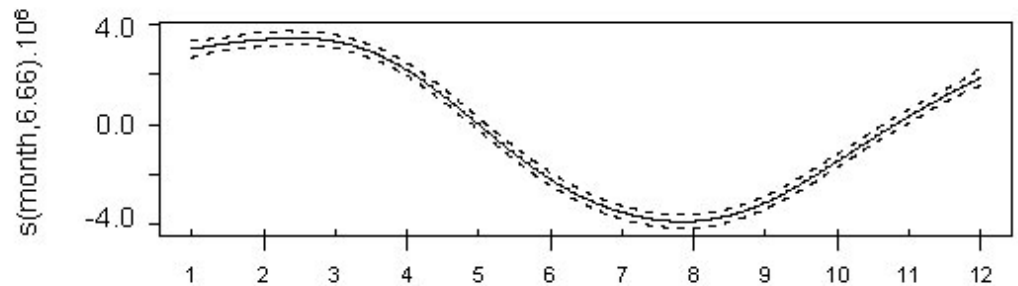
S Pacific



N Atlantic



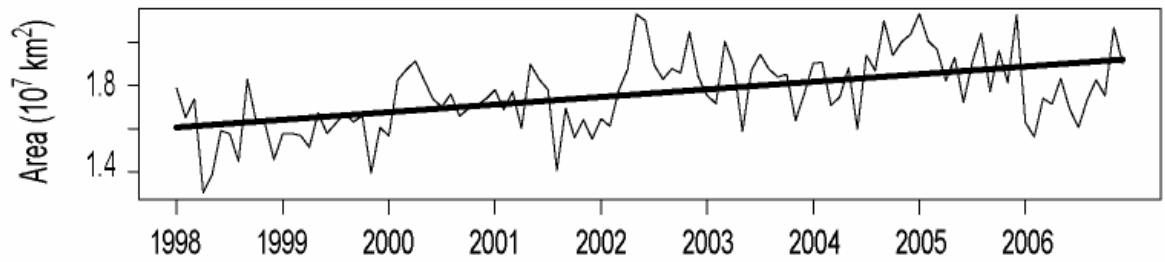
S Atlantic



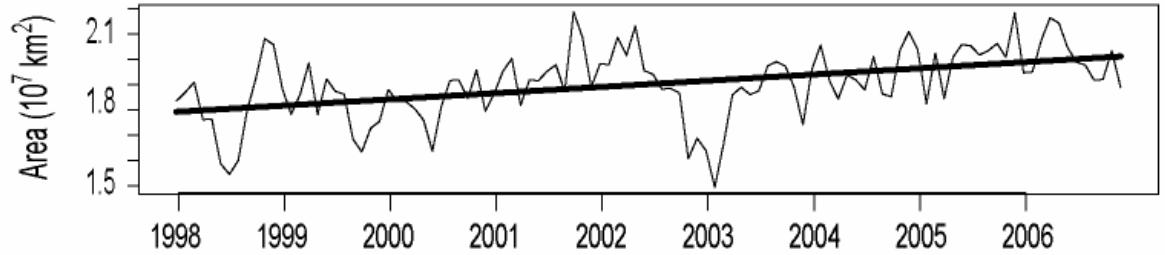
Month

Linear term

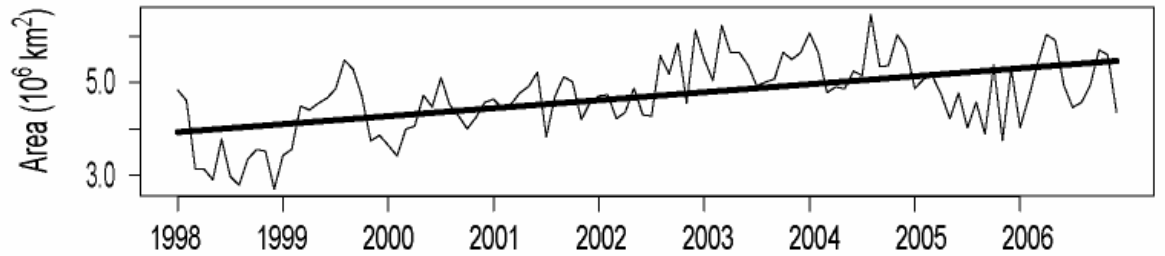
N Pacific



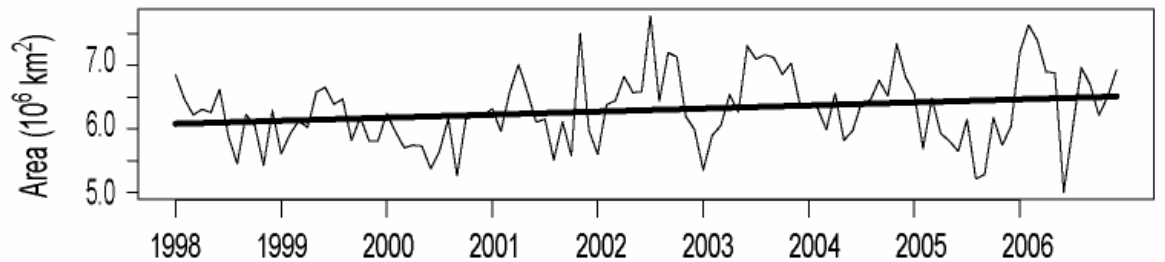
S Pacific



N Atlantic



S Atlantic

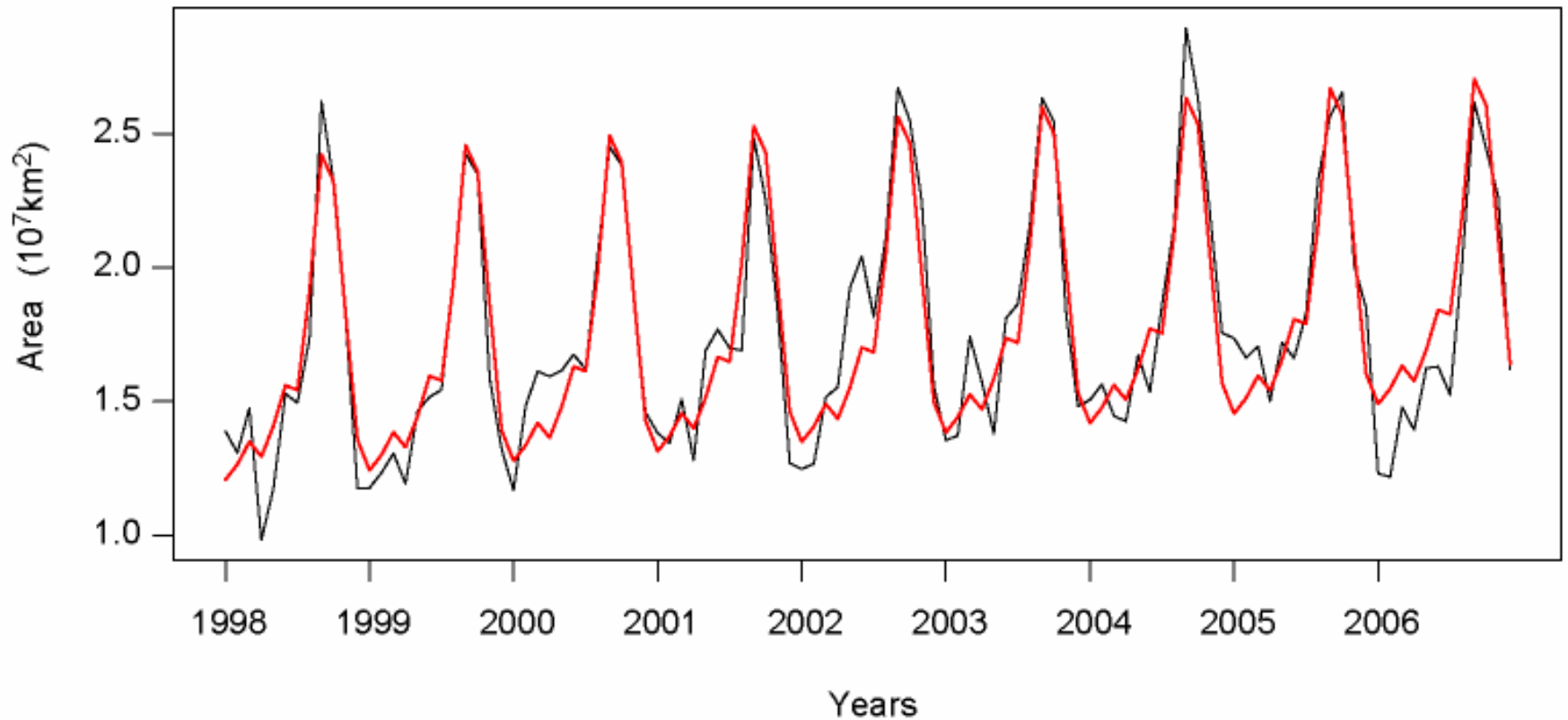


Years

# Trend in oligotrophic gyres based on GAM linear term

Ocean	1998 mean area (km <sup>2</sup> )	Increase in area (km <sup>2</sup> /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)	-

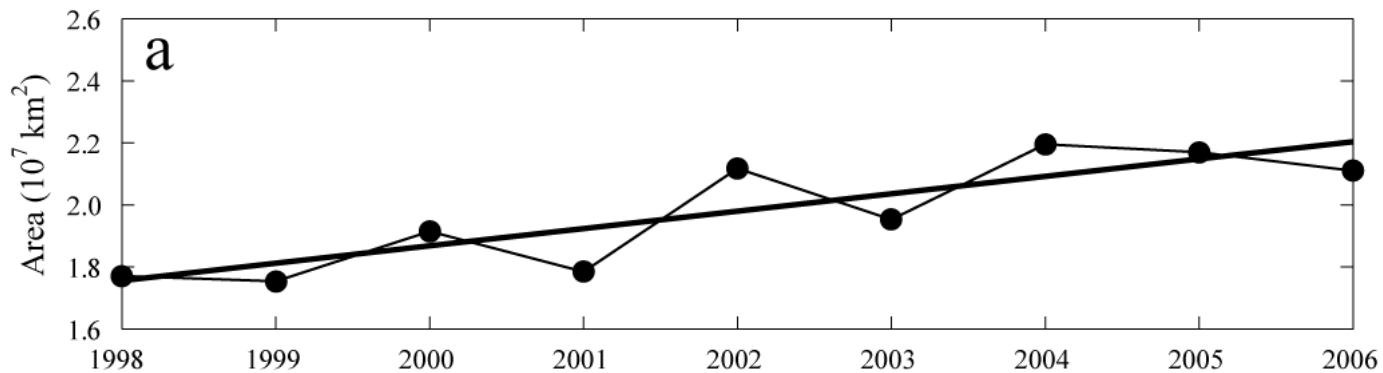
# N Pacific Monthly Area with surface chlorophyll $\leq 0.07$ mg C/m<sup>3</sup> 1998-2006 with GAM fit (red)



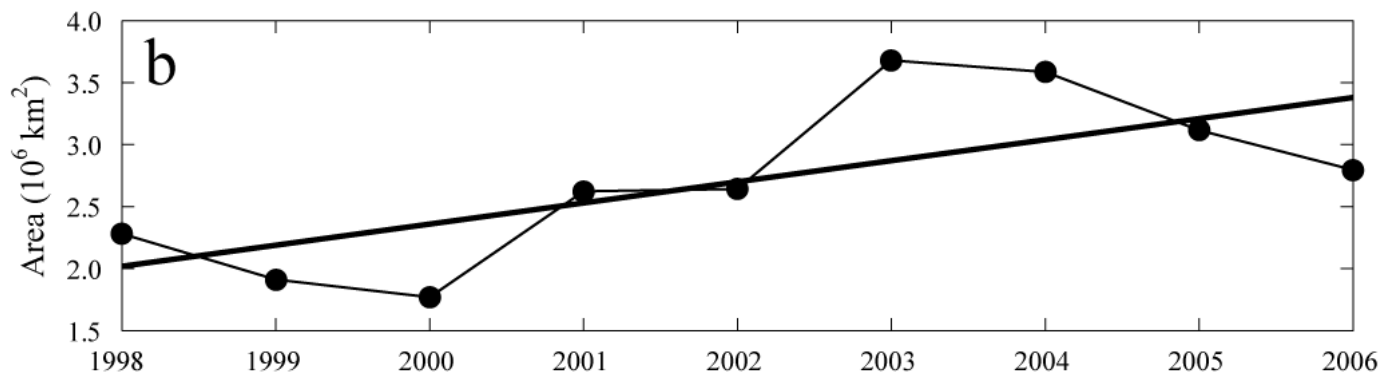
GAM: Monthly Area =  $A + B \cdot \text{time} + S(\text{Month}) + \text{error}$

# Change in mean quarterly oligotrophic gyre area

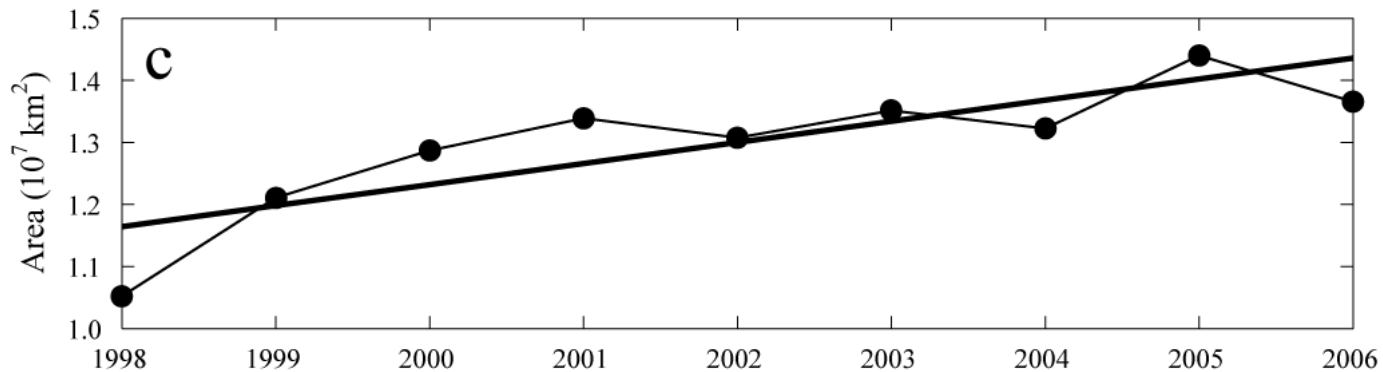
Top: North Pacific, quarter 4



Middle: North Atlantic, quarter 1



Bottom: South Pacific, quarter 3

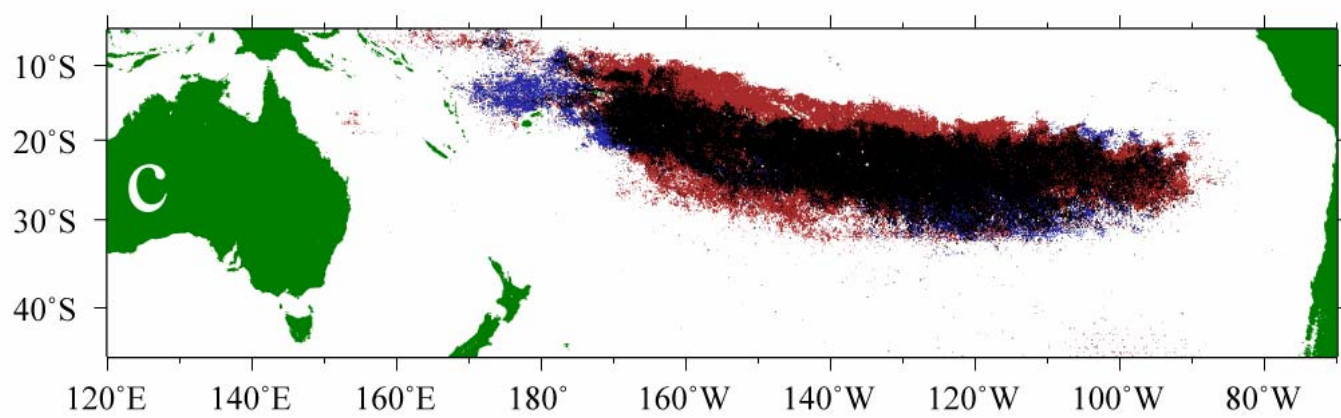
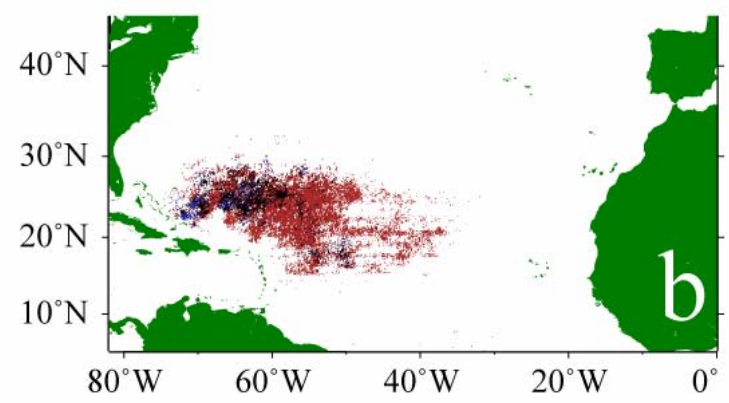
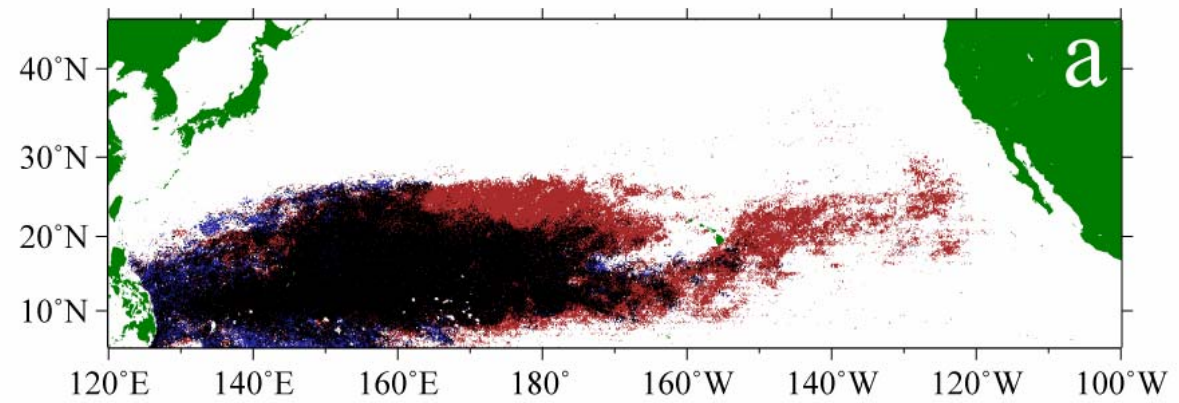


# Linear regression of quarterly mean oligotrophic gyre area vs time

Ocean	Quarter with largest rate of increase	Increase in area (km <sup>2</sup> /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 km<sup>2</sup> of oligotrophic habitat since 1998
- Oligotrophic gyres expanding faster in winter (2.5-7.0%/yr) or more than 1 million km<sup>2</sup>/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