The role of the Aleutian Low Pressure System in regulating phytoplankton biomass, primary production and export production across the subarctic Pacific Ocean basin

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Unique features of the subarctic Pacific Ocean

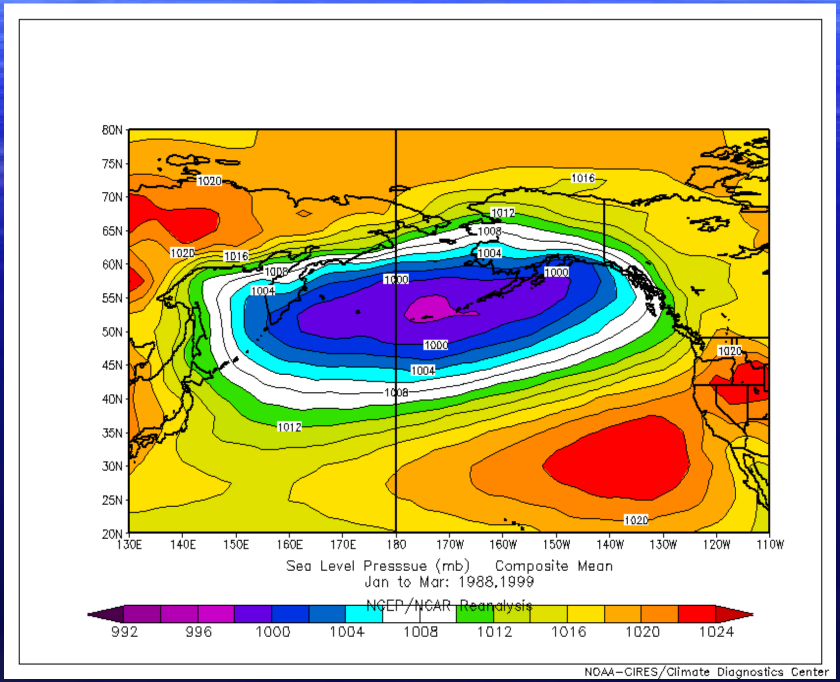
The subarctic Pacific is isolated from the rest of the North Pacific Ocean by the subarctic front

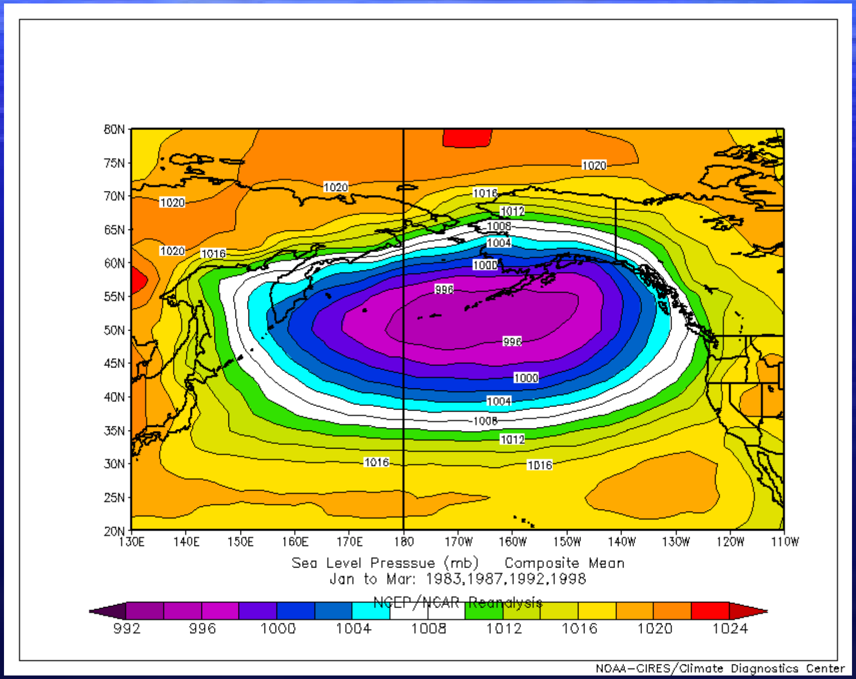
It is the world's largest ocean basin and an important sink for atmospheric CO_2

As a consequence of its positive Ekman velocity, circulation is largely driven by changes in the overlying atmosphere

Close coupling between the atmosphere, the ocean and the ecosystem of the subarctic Pacific makes it an ideal natural laboratory to observe, understand and model seasonal, interannual to decadal time scale climate variability and its consequences for carbon cycling.

The Aleutian Low Pressure System (ALPS)





Central Hypothesis

Seasonal and interannual shifts in the location and the strength of the ALPS have a major influence on the variability of phytoplankton primary and export production patterns, and gradients across the subarctic Pacific Ocean

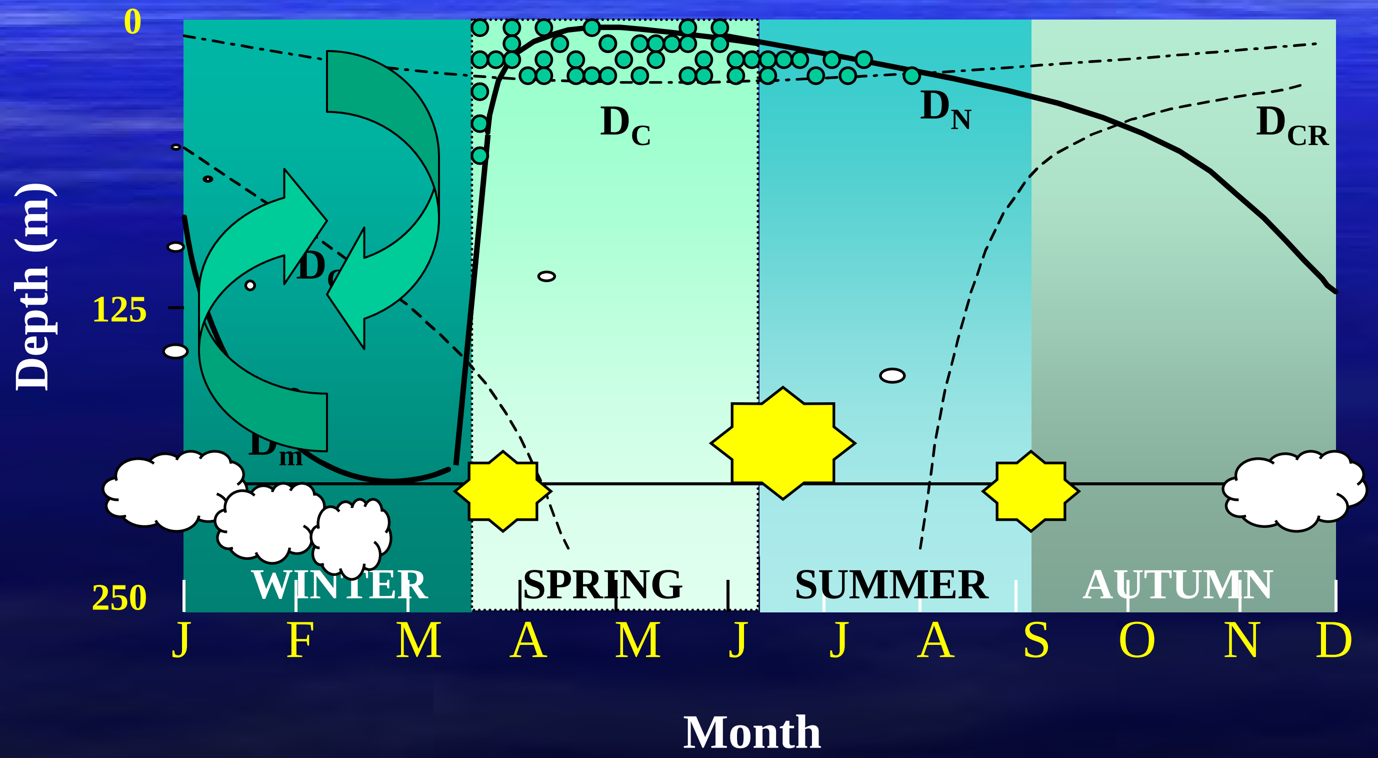
MAJOR SCIENCE QUESTIONS

How important are winds in regulating biological production and carbon export in the subarctic Pacific Ocean?

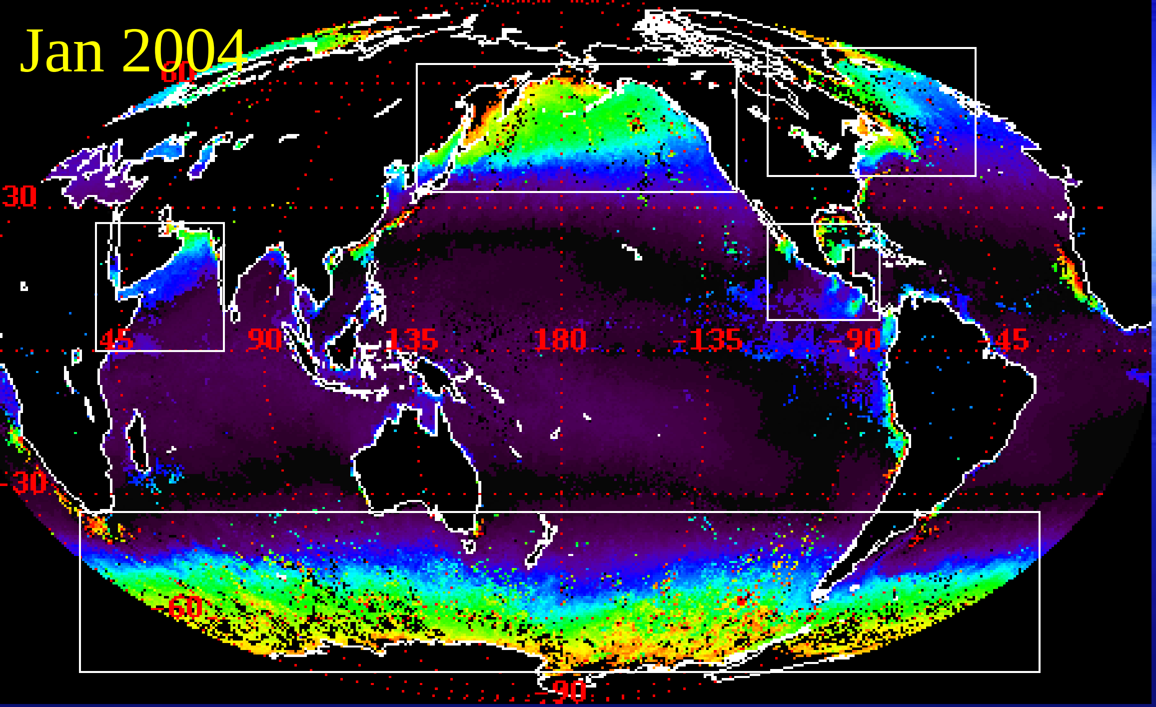
To what extent are they responsible for the large west – east gradients in biological production in the subarctic Pacific Ocean?

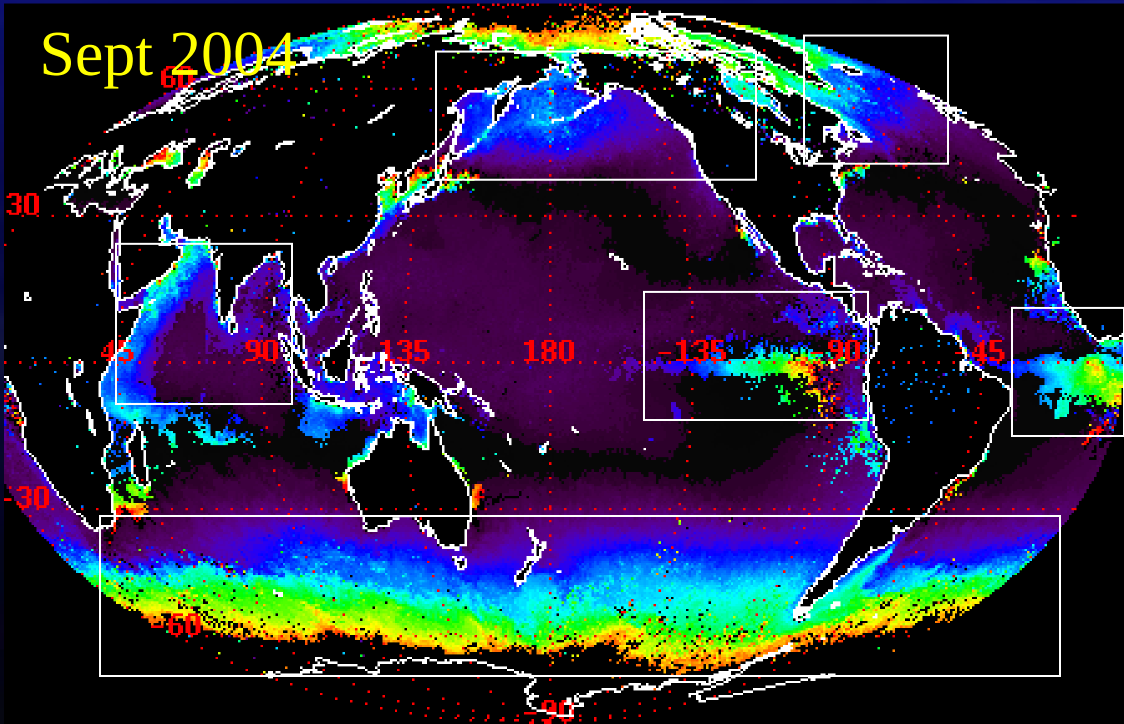
How does their variable strength over seasonal and interannual scales impact biological production in the western and eastern parts of the subarctic Pacific?

Adapted from Strass and Woods (1988)



Schematic show the seasonal evolution of the mixed layer (D_M), the compensation depth D_c and the critical depth (D_{CR}) in the subarctic Pacific Ocean. D_N indicates the depth above which nutrients are exhausted. Hypothetical distribution of those areas (dotted) in the time-depth domain within which new production is possible.

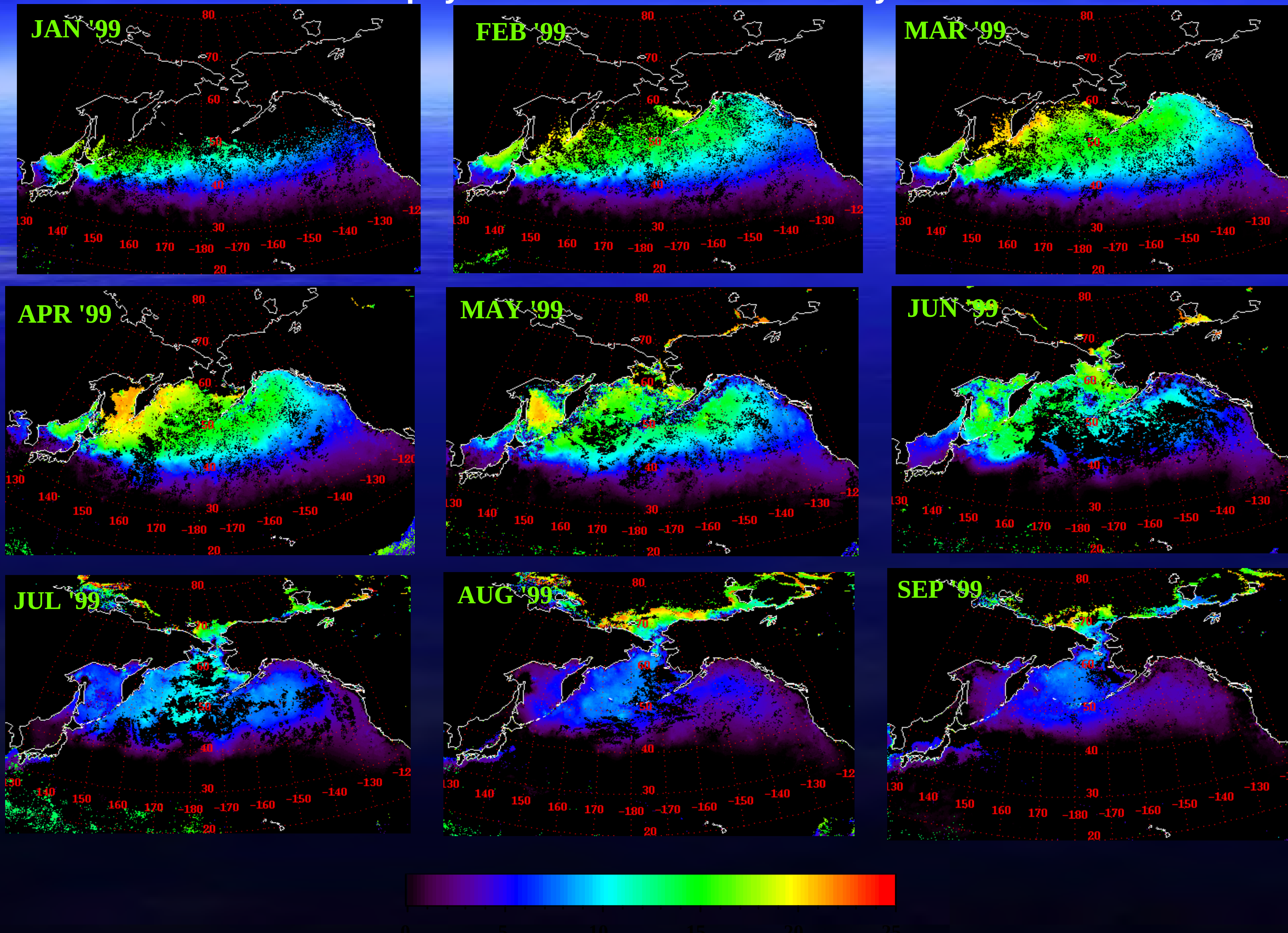


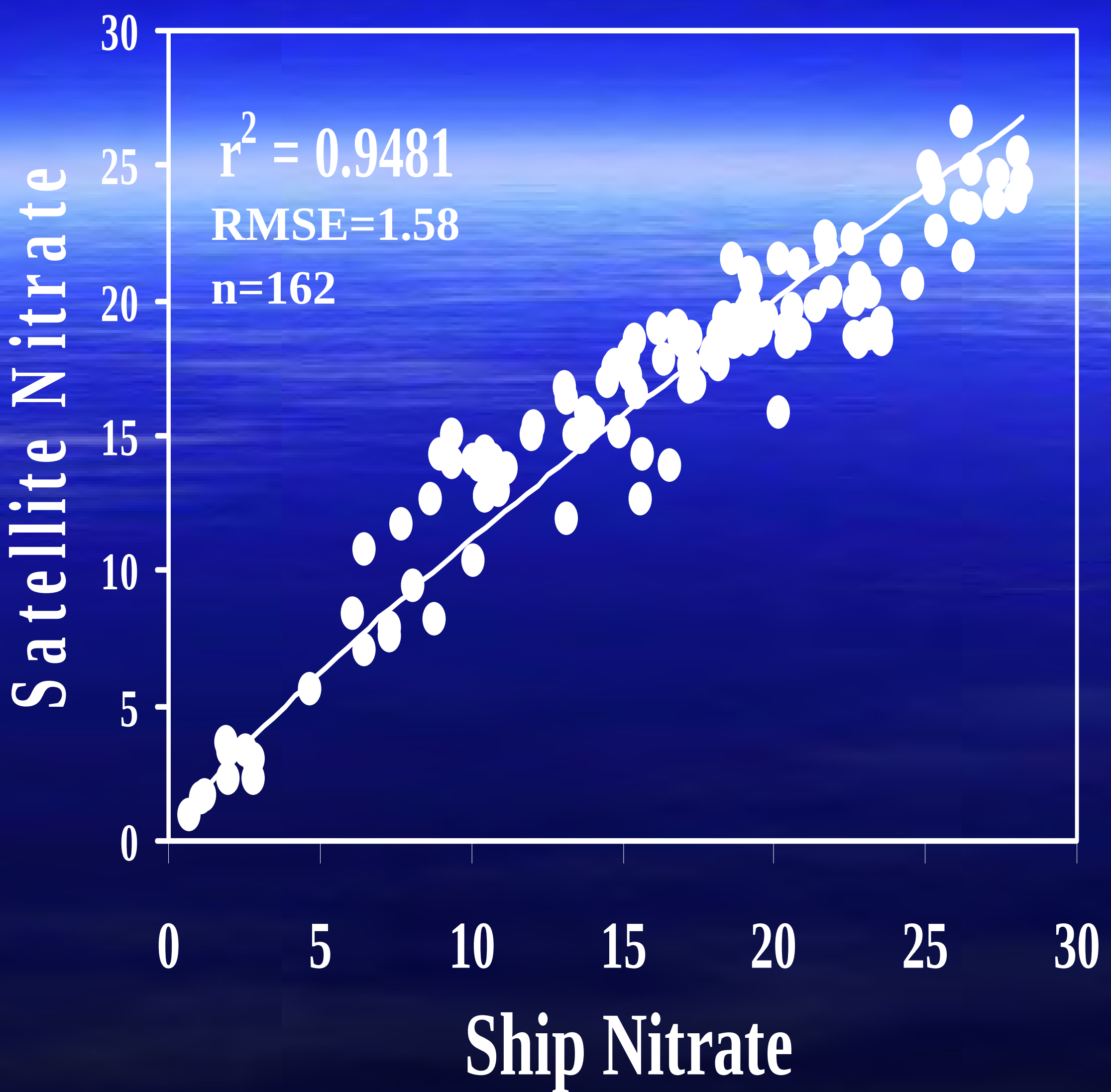


Nitrate fields generated using MODIS chl and MODIS SST

Goes et al. IEEE 1999
Goes et al., EOS 2005

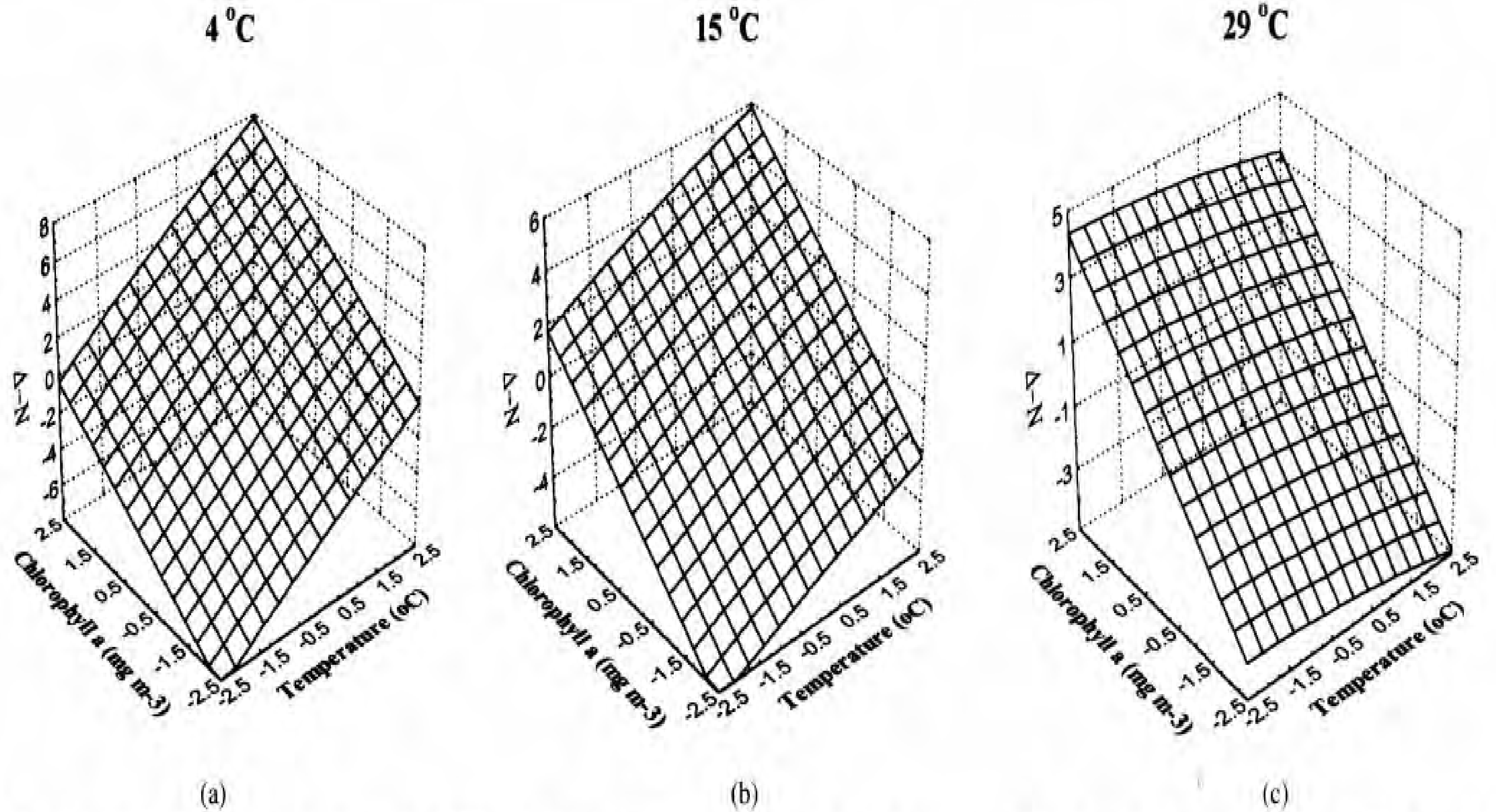
Monthly composites of sea surface nitrate concentrations derived from SeaWiFS chlorophyll *a* and AVHRR SST for the year 2000





Comparison of Alligator Hope ship nitrate and MODIS Terra satellite derived sea surface nitrate concentrations

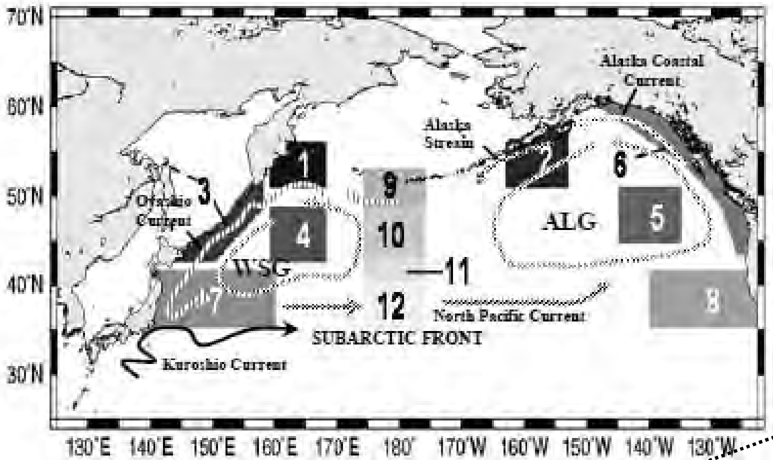
Ship data courtesy Dr. Nojiri and Dr. Wong

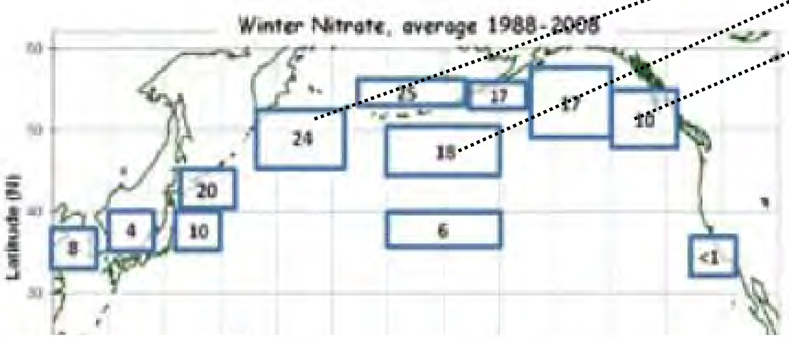


Combined effects of errors in satellite derived SST and Chl *a* on nitrate estimates at three different temperatures of seawater.

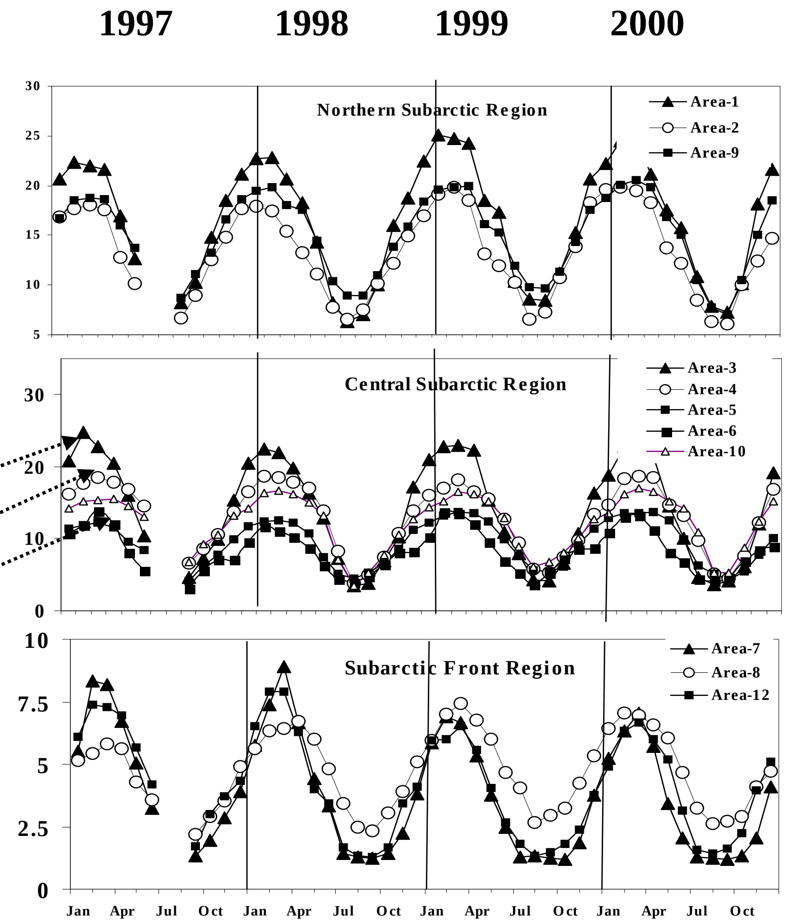
Goes et al. IEEE 1999

Spatial and temporal distribution of NO_3 in the North Pacific Ocean



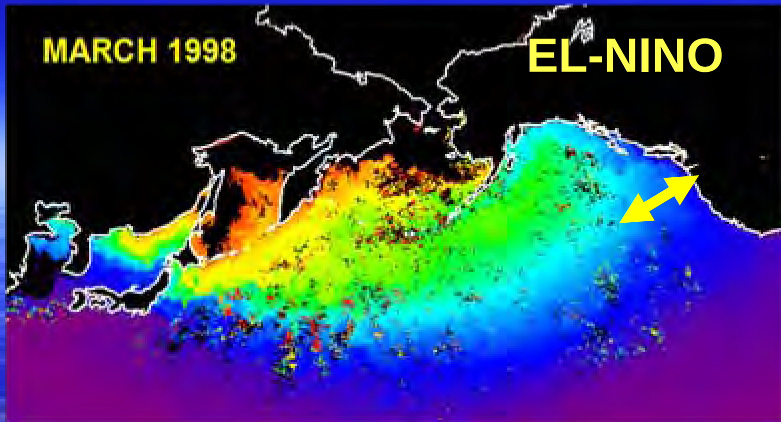


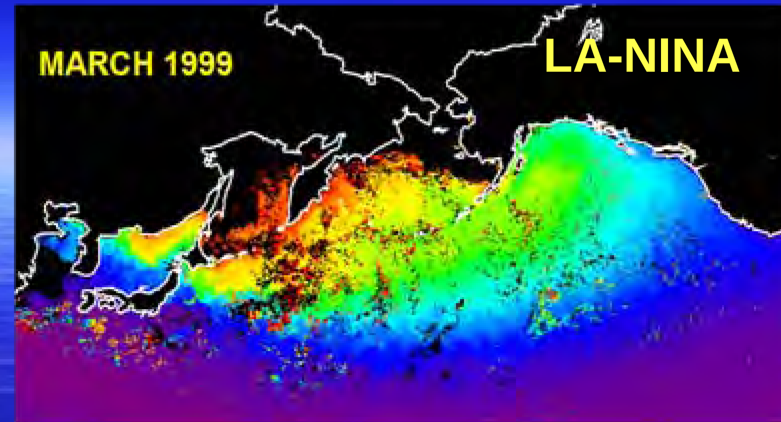
[Figure S-14] Average winter nitrate (μM) in the surface waters of the North Pacific. Yellow Sea value comes from a single survey in 2008, others are measurements made by ships of opportunity between 1988 and 2008. Tsushima Current average is for the southern portion only. Winter nutrient data are difficult to obtain in ice covered regions of the Okhotsk and Bering seas.

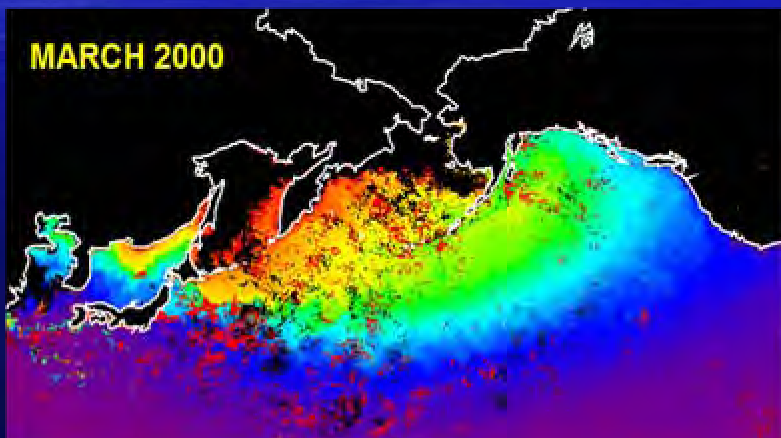


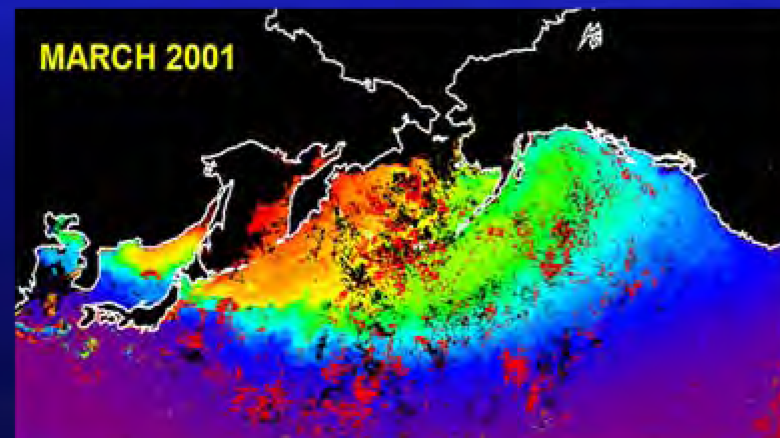
Goes et al. JOS 2004

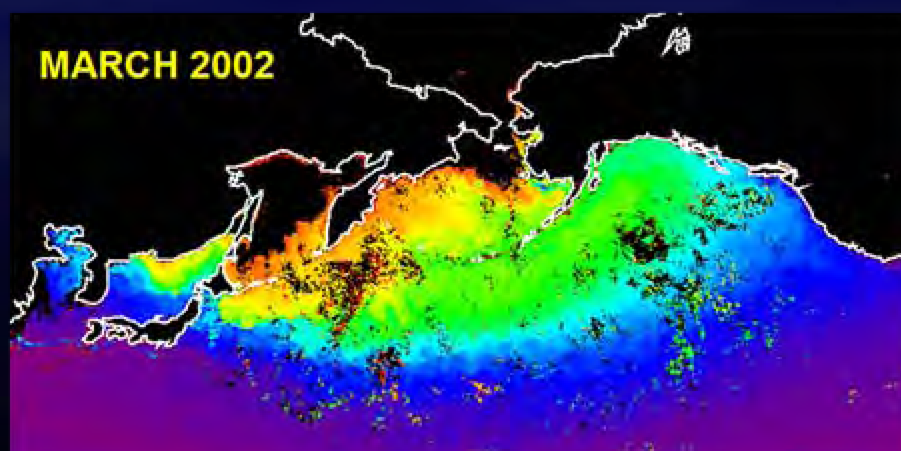
PICES, Special Publication 4
Compilation by F. Whitney

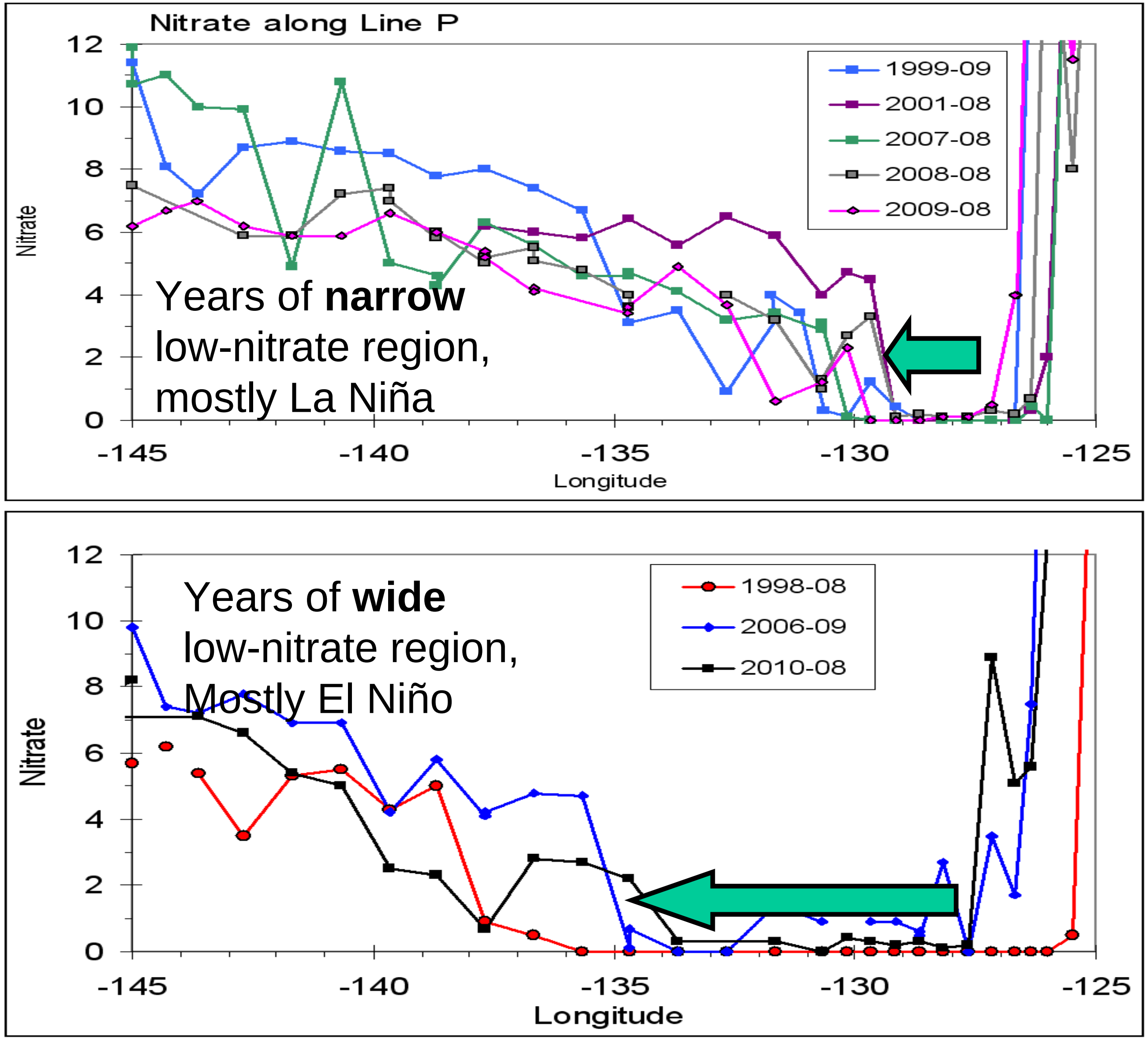

MARCH 1998
EL-NINO


MARCH 1999
LA-NINA


MARCH 2000


MARCH 2001

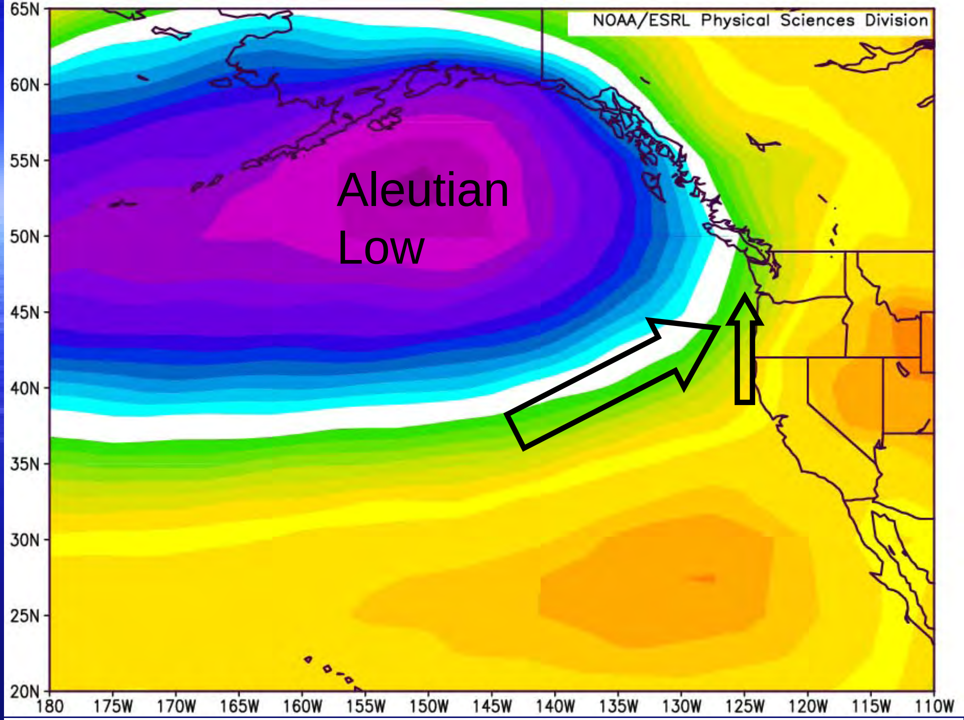

MARCH 2002



Surface nitrate concentrations along Line P. Data and slide courtesy F. Whitney and W. Crawford, IOS Canada

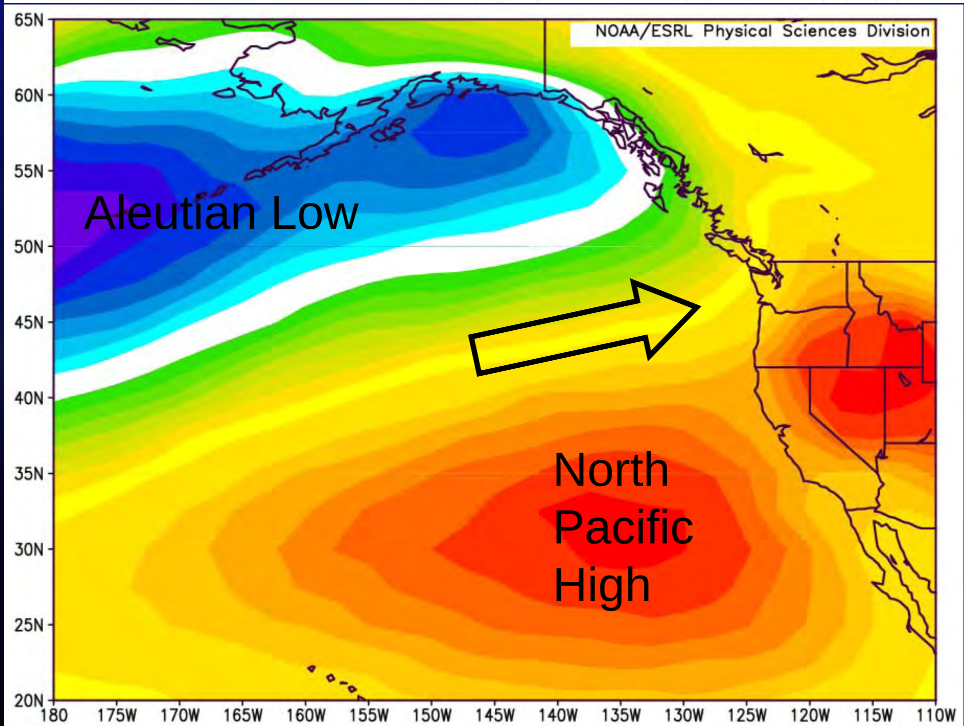
January-February
Average sea-level air pressure
1998 2006 2010
Mostly El Niño

Wide low-nitrate region

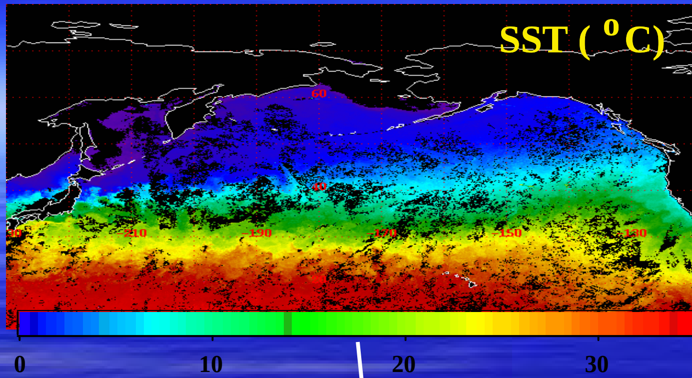


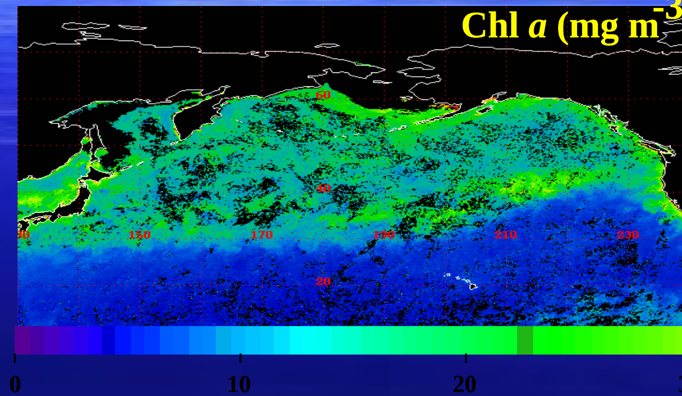
January-February
Average sea-level air pressure
1999 2001 2007 2008 2009
Mostly La Niña

Narrow low-nitrate region

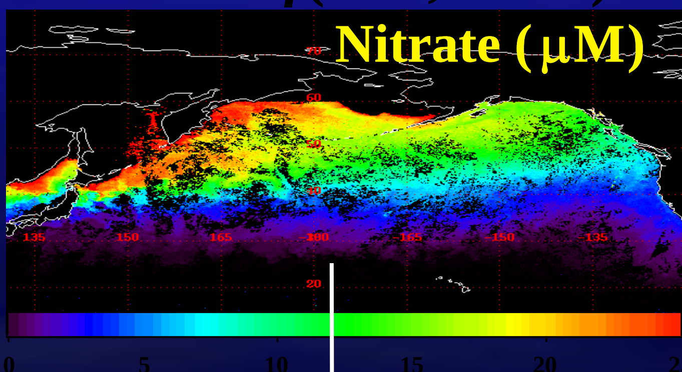


Schematic diagram showing construction of nitrate and new production maps

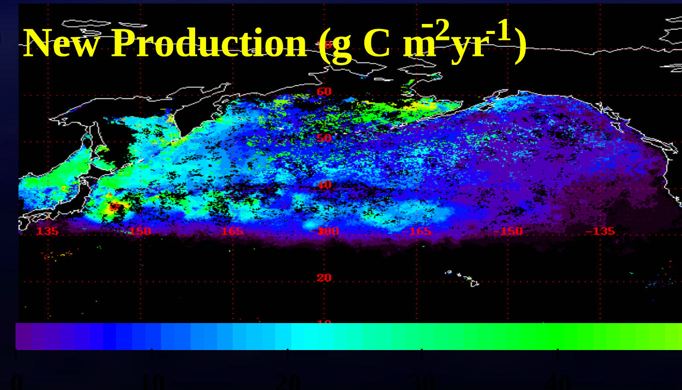




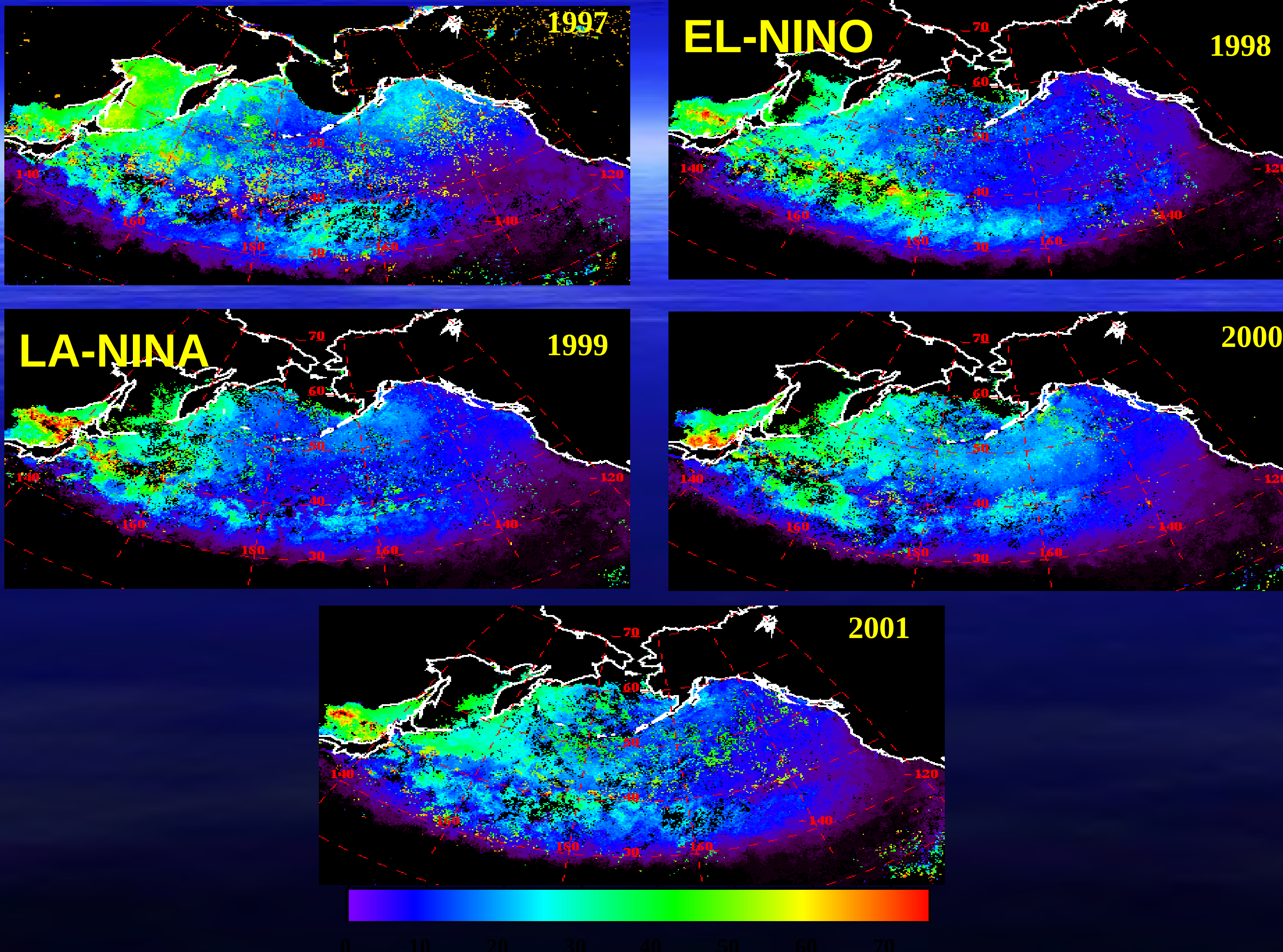
Nitrate= *f*(SST, Chl a)



New Production=*f*(ΔN, Depth of Nitracline)



Goes et al. GRL 2000

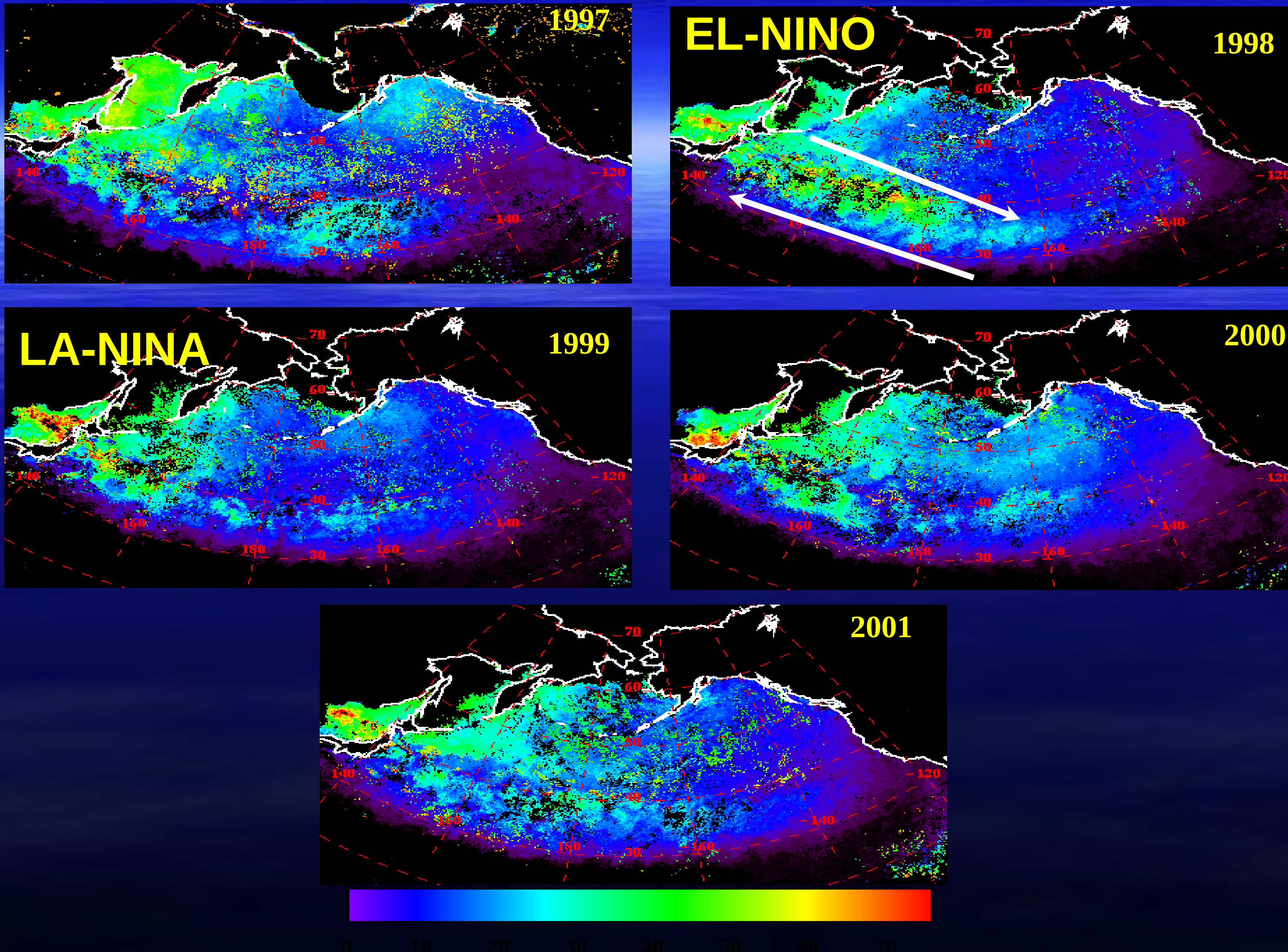


Interannual variation in New Production (gC m^{-2} yr^{-1}) in the North Pacific Ocean

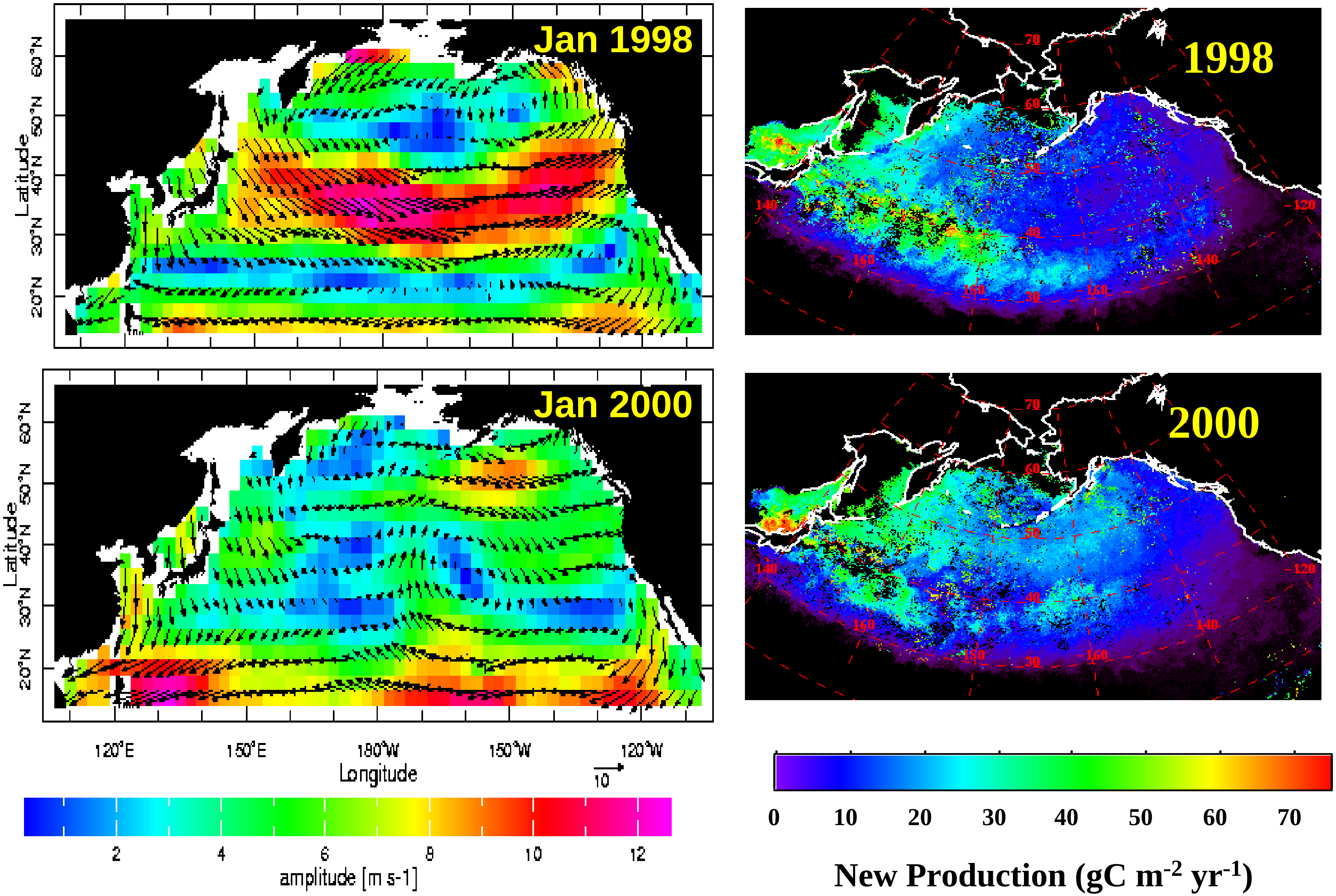
Table 1 Comparison of satellite estimates of new production with sediment trap POC fluxes (g C m^{-2} y^{-1})

Sediment trap site	Satellite Estimates (1997)	(1998)	(1999)	Measured Trap Flux	Year	Reference
50° N 145° W (PAPA)	17	19	14	18.1*	1982-1983	Honjo (1997)
48° N 175° E (NOPACCS)	17	36	24	37.4*	1993-1994	Harada (NOPACCS)
41.5° N 146.5° E (W. PACIFIC)	31	38	53	54.1**	1983	Noriki & Tsunogai (1986)
34° N 142° E (JAPAN TRENCH)	20	6	7	12.6*	1989-1990	Handa *et al* (1997)
33° N 139° W (VERTEX)	2	6	8	12.95	1981-1984	Martin & Knauer (1987)
30° N 175° E (NOPACCS)	3	10	7	6.48	1993-1994	Harada (NOPACCS)

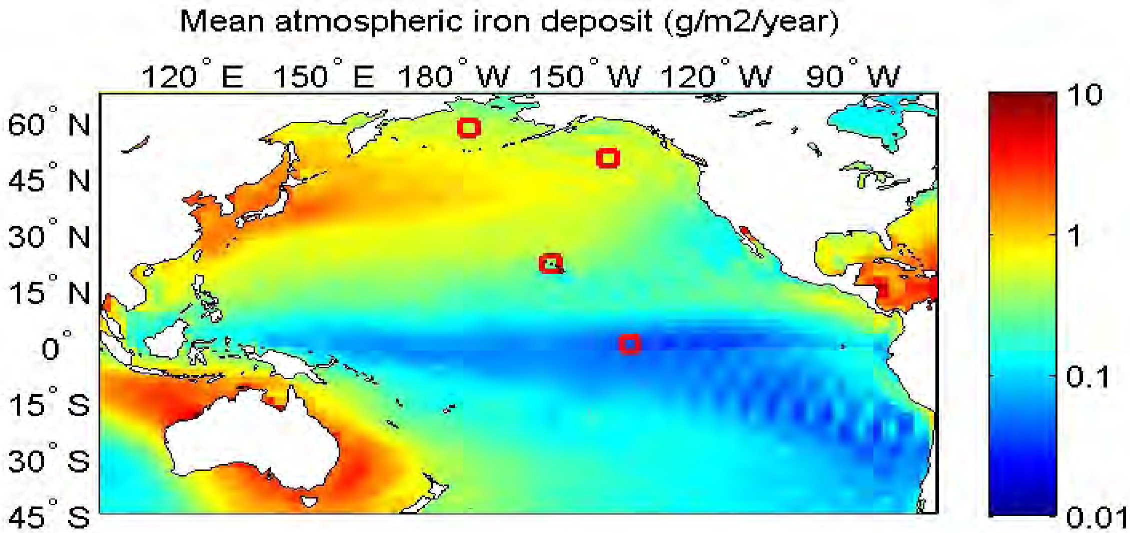
* Referenced to 100 m using formulation of Martin et al., 1987
Referenced to 150 m using formulation of Martin et al., 1987
** Value based on sediment trap data from mid Aug. to mid Sept. 1983
Reference depths chosen to reflect maximum depths of euphotic column

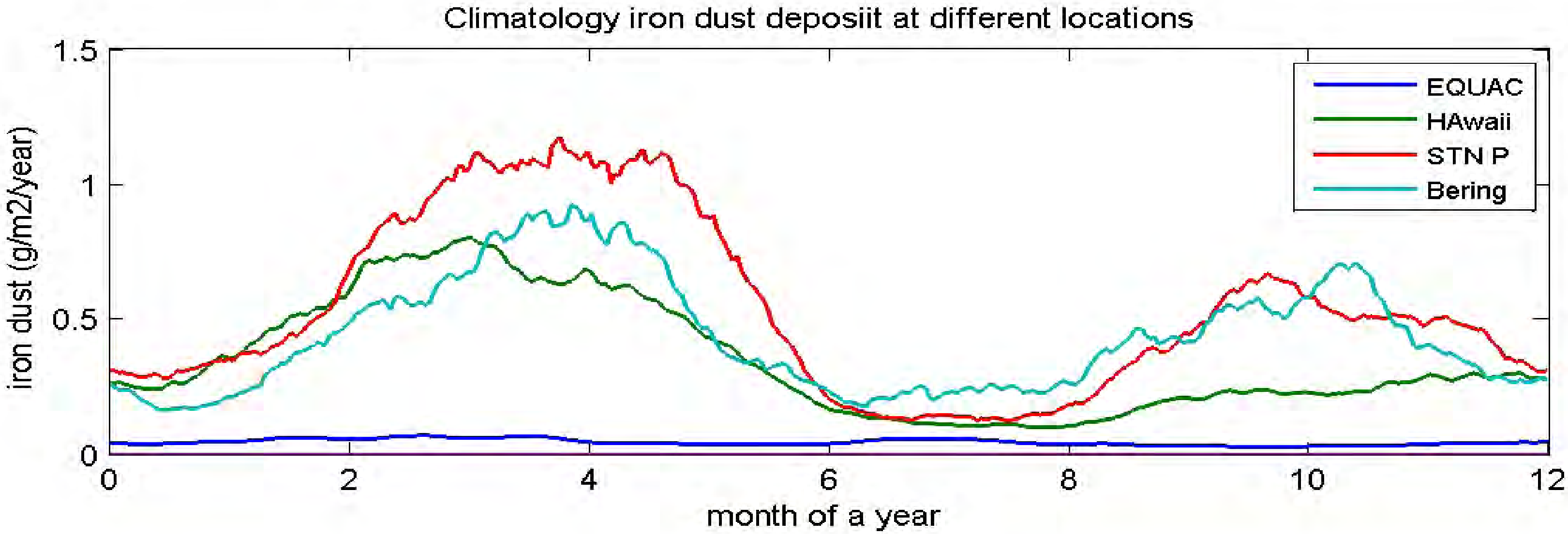


Interannual variation in New Production (gC m^{-2} yr^{-1}) in the North Pacific Ocean

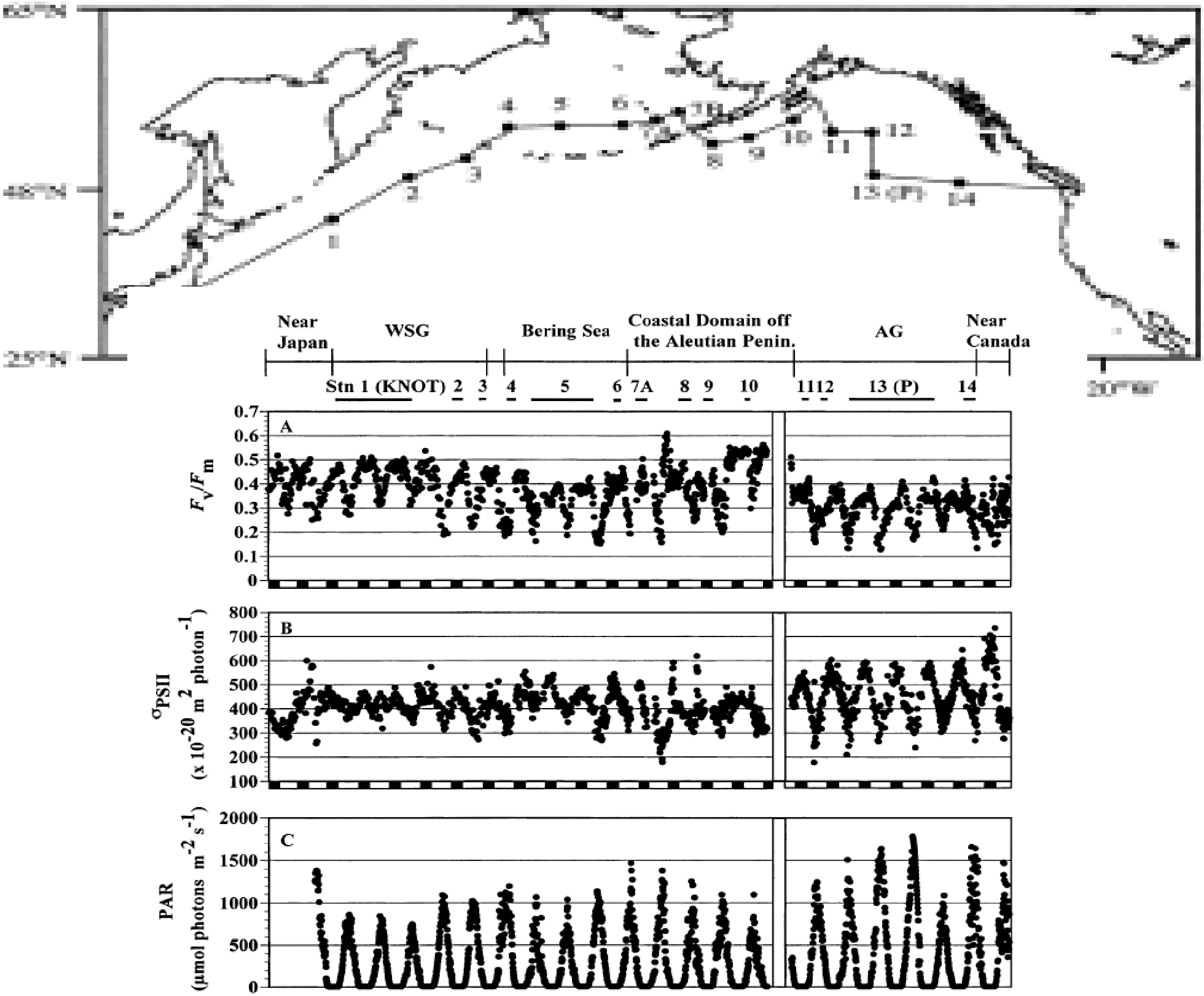


Jan 1998
Jan 2000
Latitude
20°N
30°N
40°N
50°N
60°N
120°E
150°E
180°W
150°W
120°W
Longitude
10
2
4
6
8
10
12
amplitude [m s-1]
1998
2000
0
10
20
30
40
50
60
70
New Production (gC m^{-2} yr^{-1})





Atmospheric iron dust deposition in the Pacific Ocean. Model output data from N. Malhowald. Slide courtesy F. Chai.



East-West gradients in the photosynthetic competency of surface phytoplankton from the North Pacific Ocean. Suzuki et al L & O (2002)

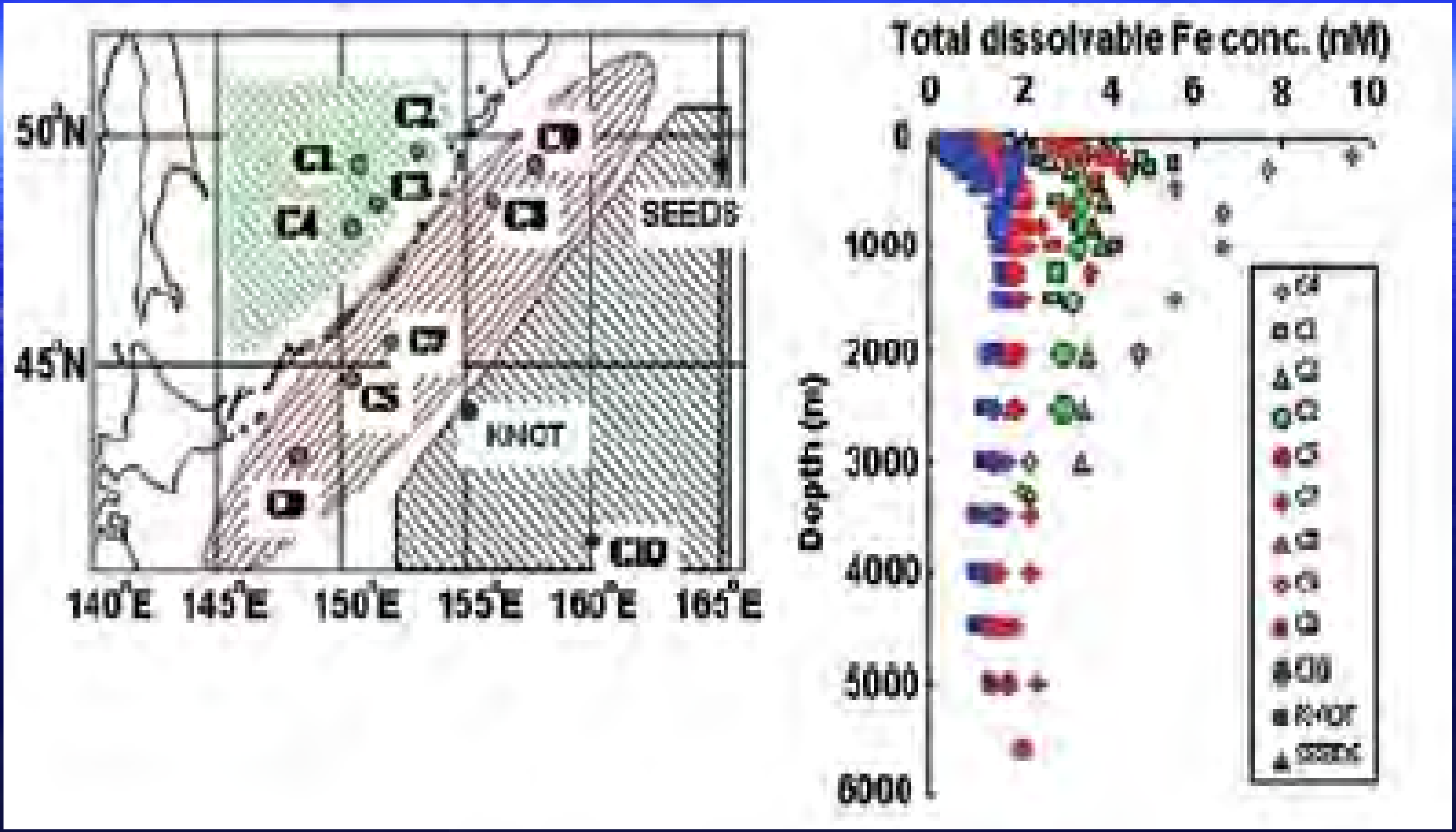
Table 1. Photosystem II and photosynthesis irradiance parameters and phytoplankton growth rate within the surface mixed layer during the cruise. Values indicate means ± SD.

Parameter	WSG	Bering Sea	Coastal domain off the Aleutian Penins.	AG	Reference
F_v/F_m*	0.45±0.03	0.38±0.04	0.43±0.05	0.33±0.02	This study
σ_{PSII}* ($\times 10^{-20}$ m^2 photon^{-1})	445±26	482±30	430±59	542±34	This study
P^B_{max} (mgC mg Chl a^{-1} h^{-1})	2.39±0.72	2.45±0.32†	2.95±0.42†	2.00±0.27†	Yoshikawa (2002)
α^B (mg C [mg Chl a]$^{-1}$ h^{-1} [μmol photons m^{-2} s^{-1}]$^{-1}$)	0.0131±0.0087	0.0110±0.0026†	0.0125±0.0032†	0.0096±0.0033†	Yoshikawa (2002)
Phytoplankton growth rate (d^{-1})	0.33±0.12	0.41±0.16†	0.45±0.10†	0.20±0.13	Liu et al. (2002*a*)

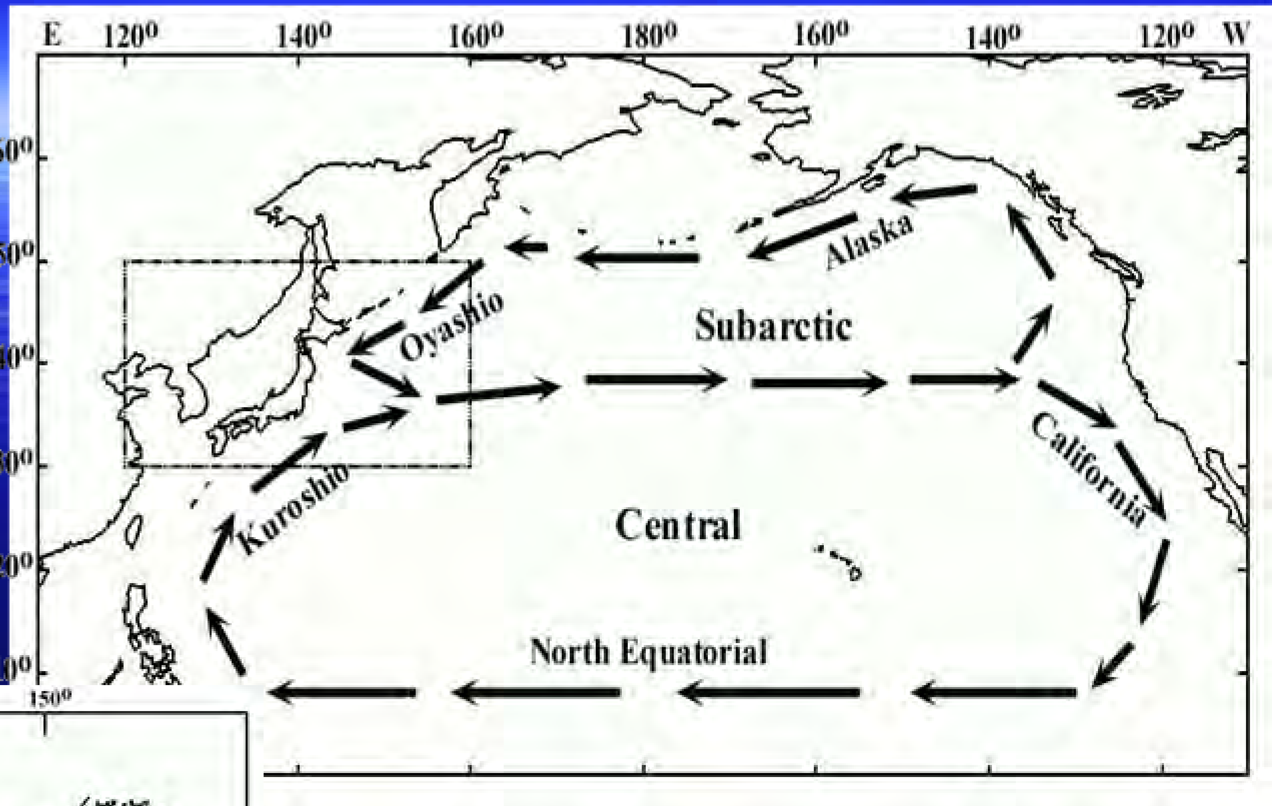
* Only nighttime data were used.

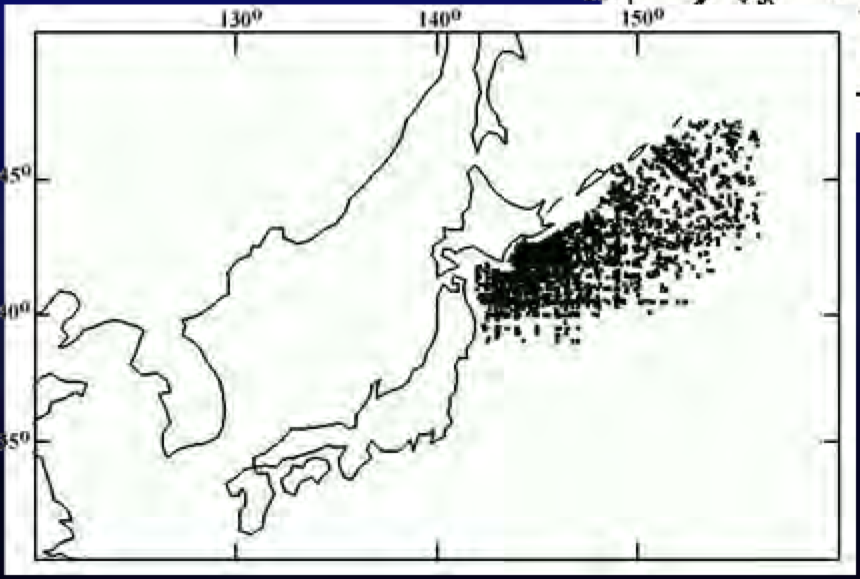
† The data were calculated after their original data had been reclassified into the hydrographic regime of this study (*see text*).

East-West gradients in the photosynthetic competency of surface phytoplankton from the North Pacific Ocean. Suzuki et al L & O (2002)

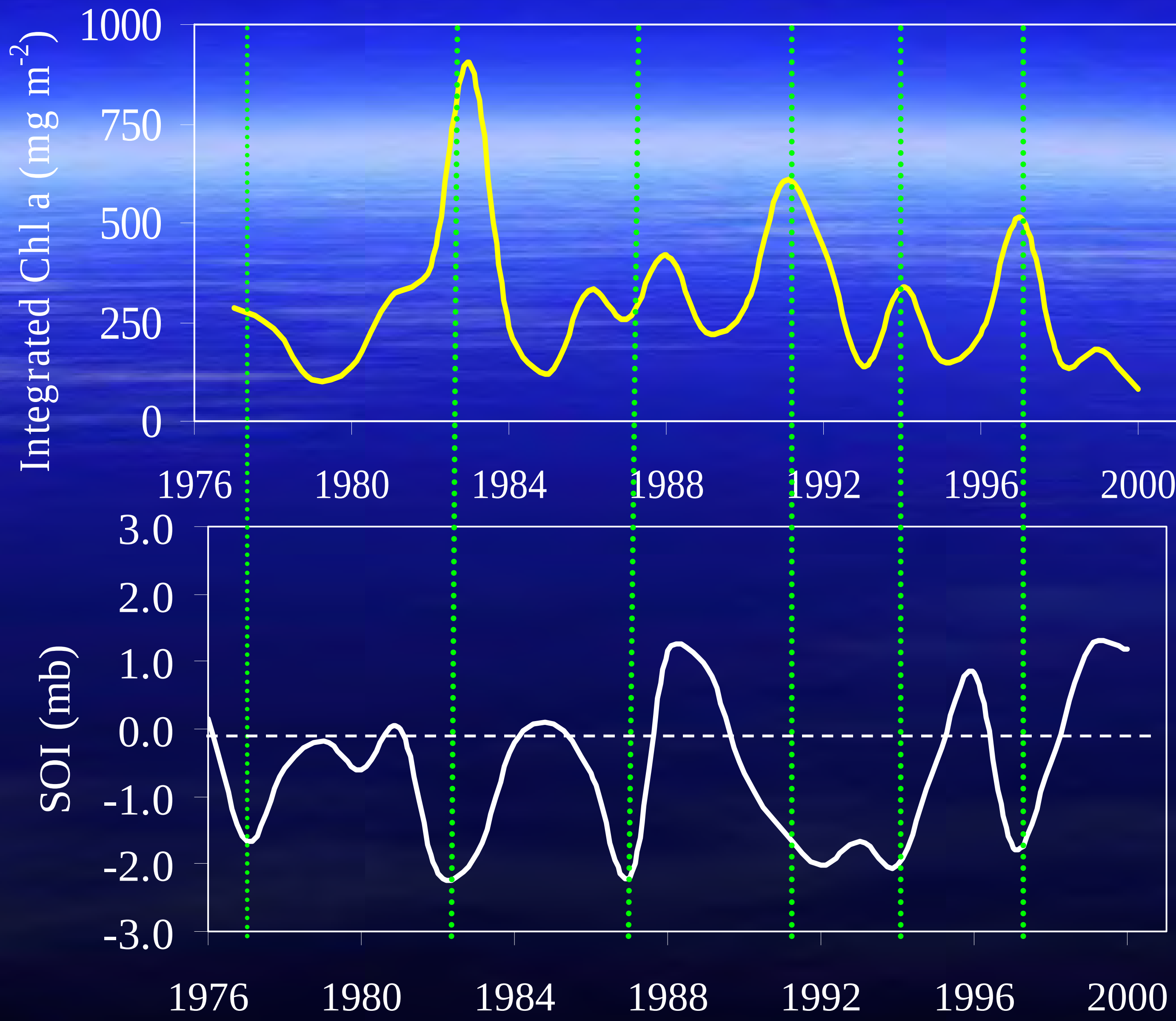


Vertical profiles of total dissolvable iron around the Kuril Islands. Green symbols - Sea of Okhotsk, Red symbols – Oyashio, Blue symbols - oceanic regions of the western Subarctic Pacific. Source Nishioka, J. from PICES special Volume 4

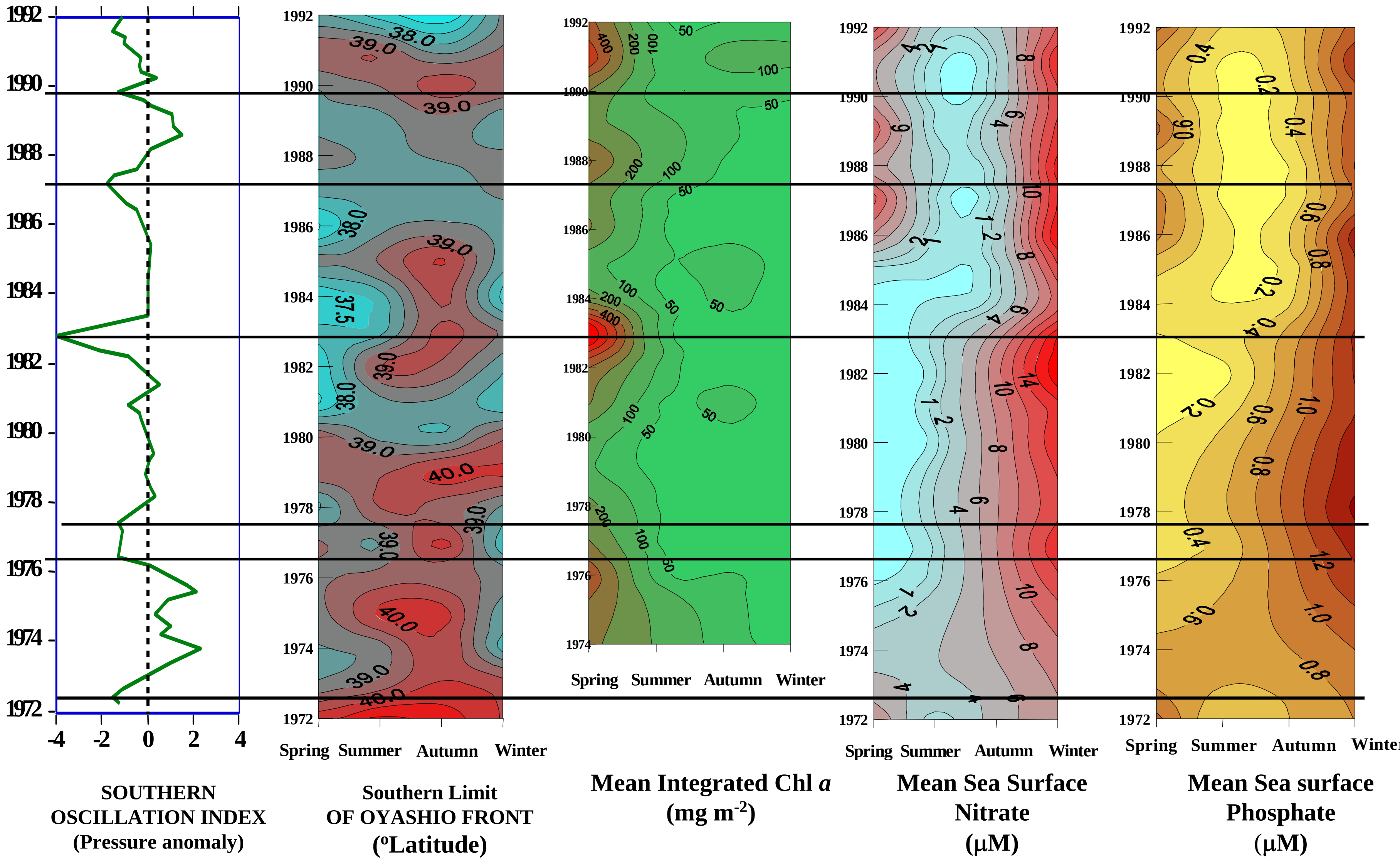




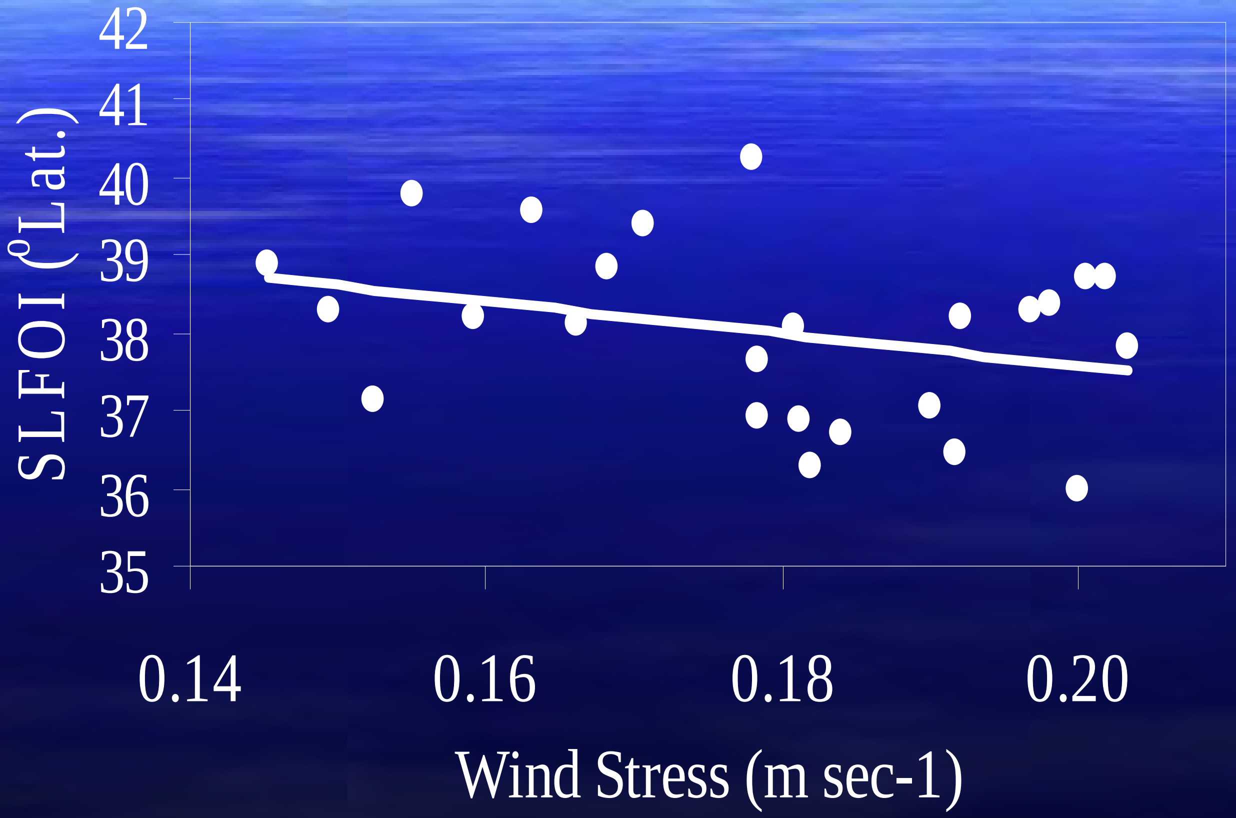
Location of shipboard data (1976-2000). All data collected by research vessels from Japan



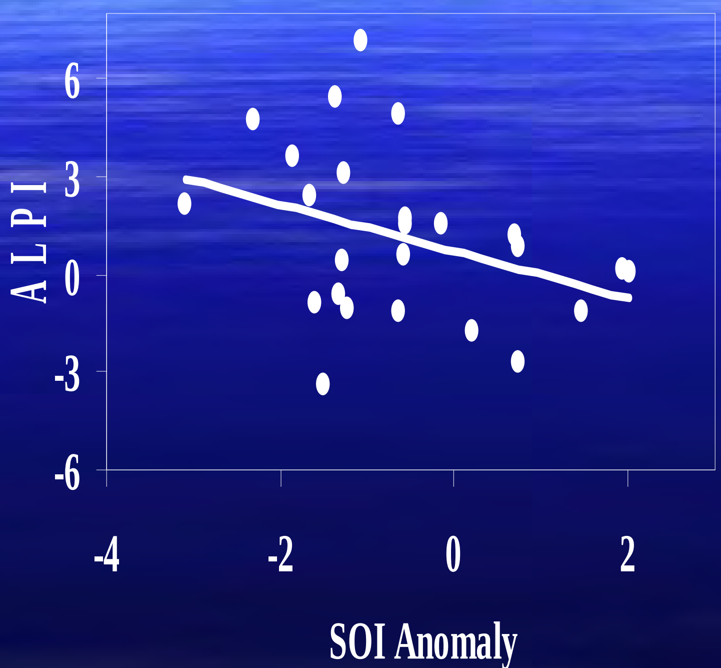
Interannual variation of phytoplankton biomass in the western North Pacific Ocean and relationship to the southern oscillation index

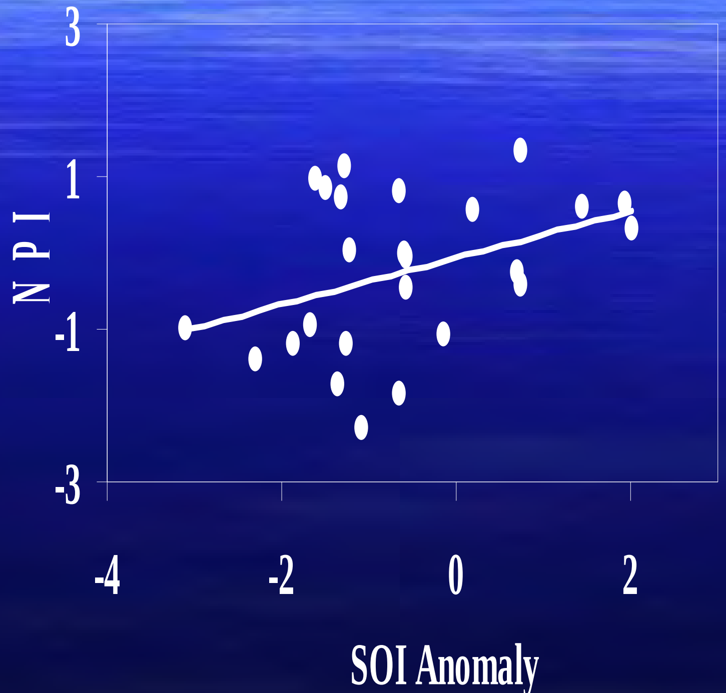


Seasonal and interannual changes in oceanographic conditions in the western North Pacific Ocean in relation to changes in the Southern Oscillation Index.

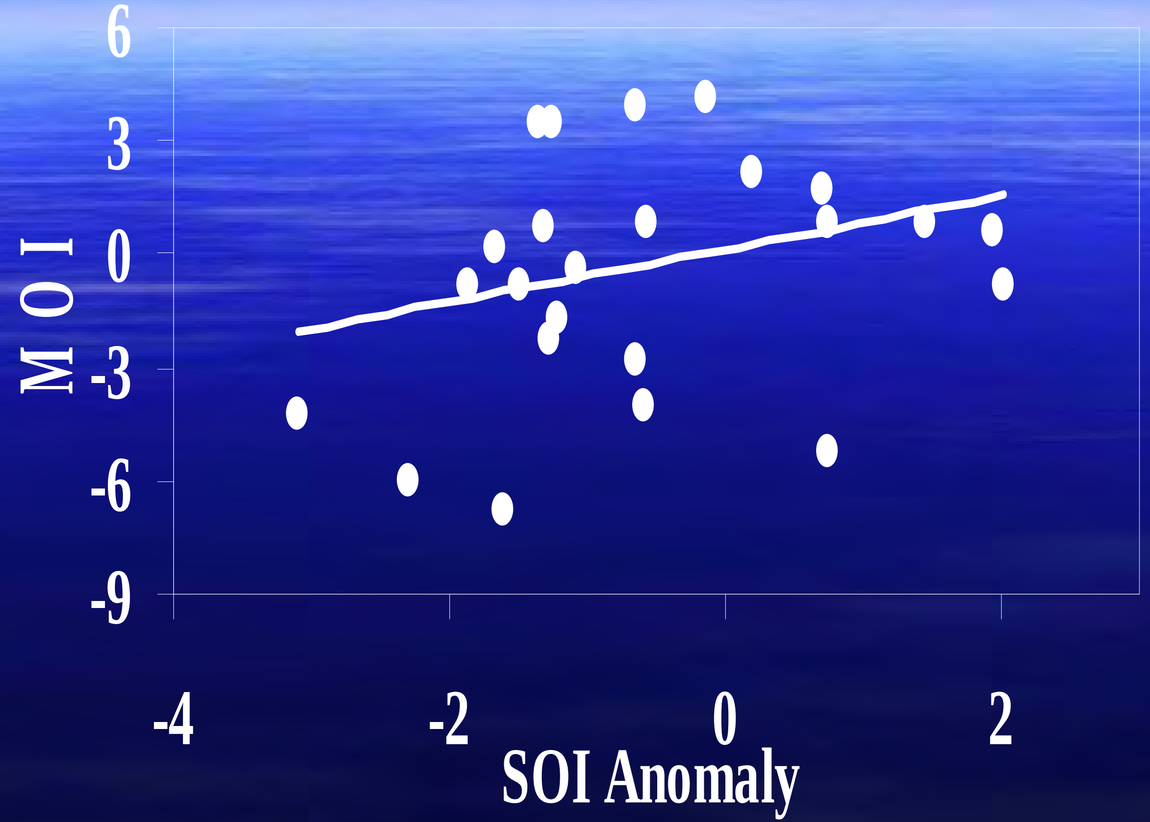


Impact of wind stress on southern limit of the Oyashio Front

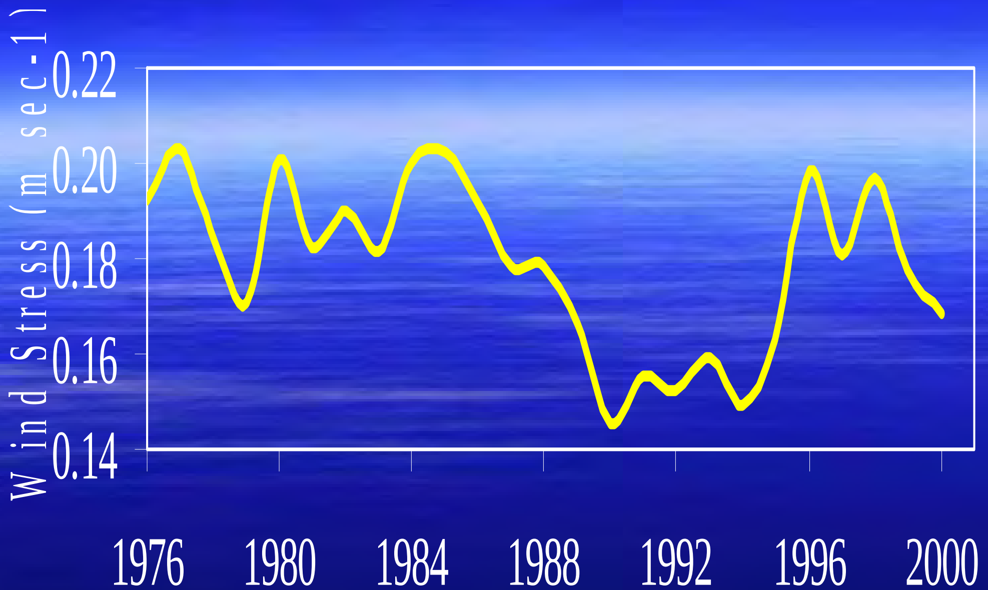


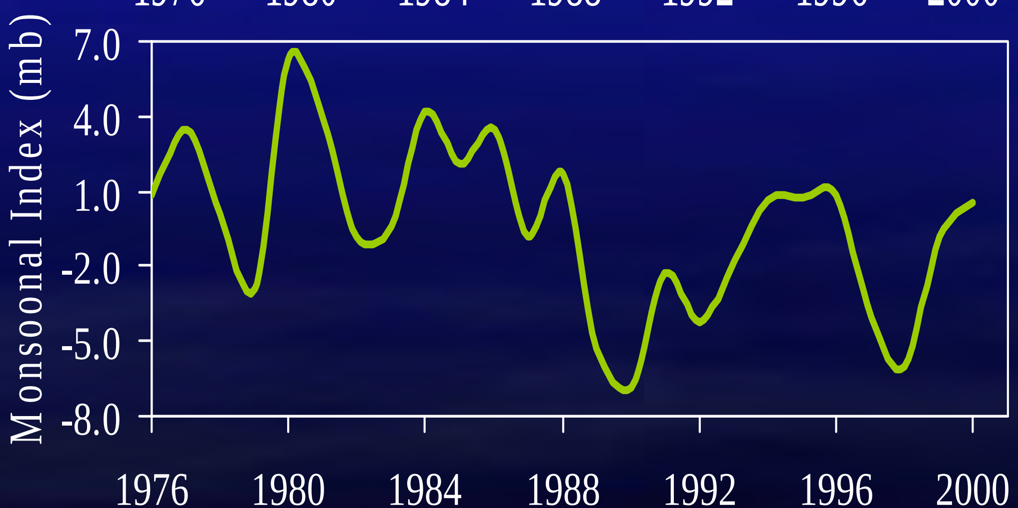


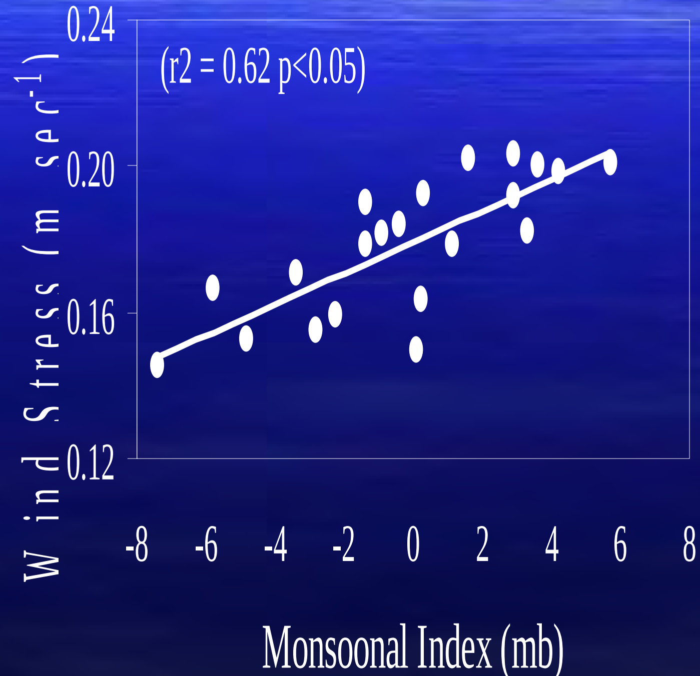
Relationship between SOI and indices describing the Aleutian Low Pressure System



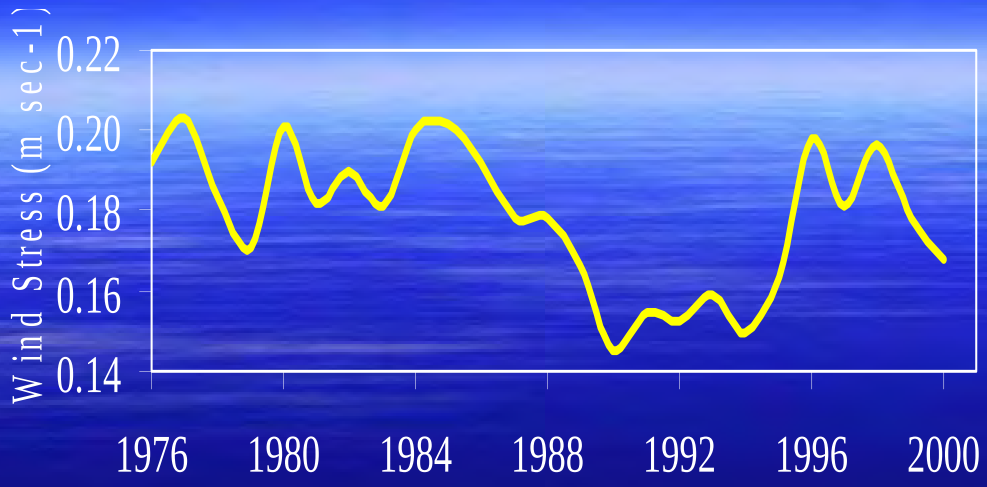
Relationship between the Monsoonal Index (MOI) and the SOI. The MOI is defined as the difference in SLP between Irkutsk (52.2º N, 104.2º E), Russia and Nemuro (43.0º N, 145.5º E), Japan

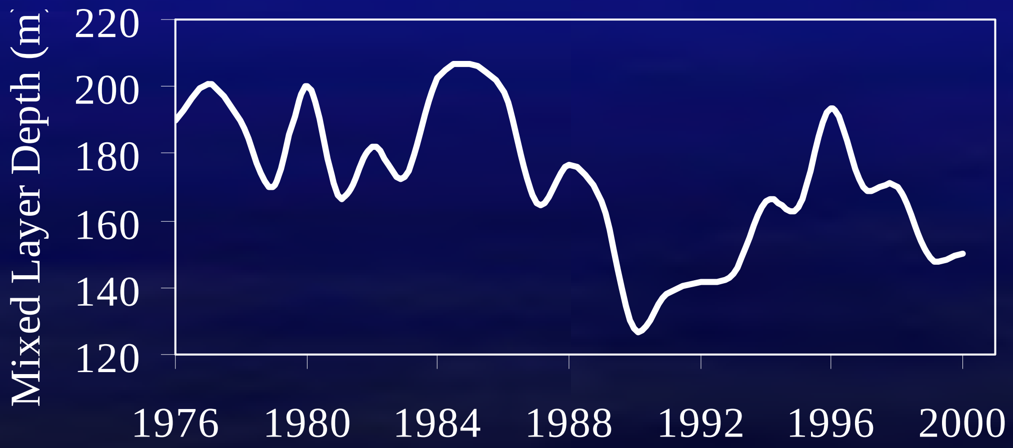


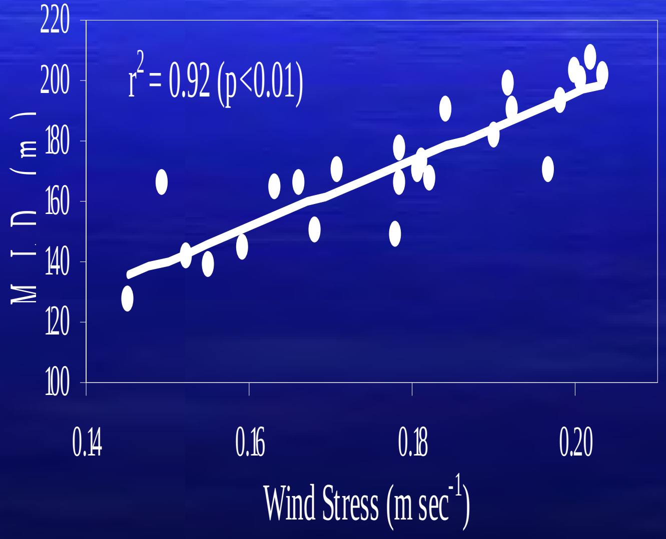




Interannual variation of winter time wind stress in relation to the MOI

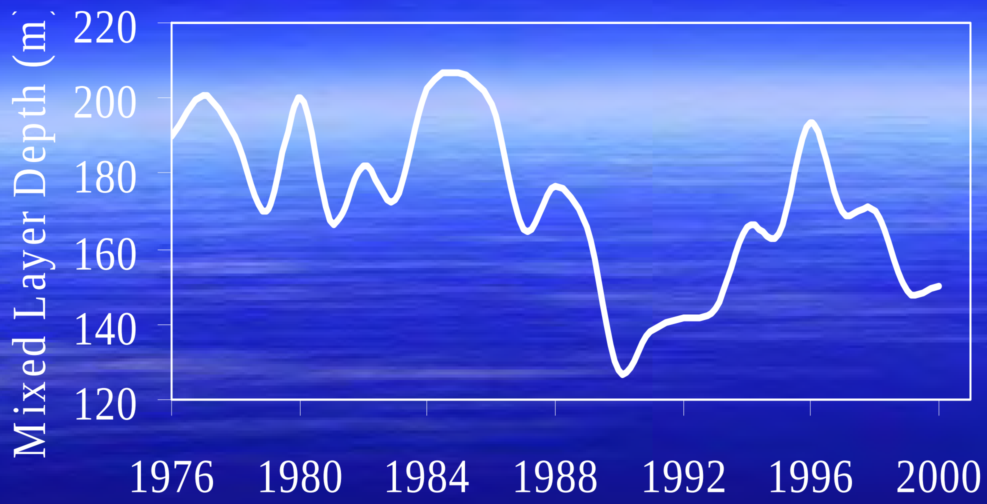


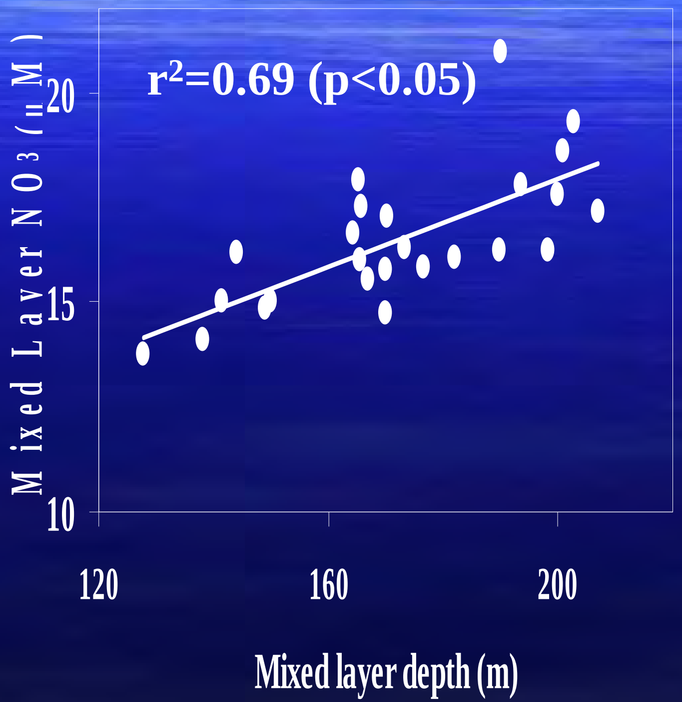




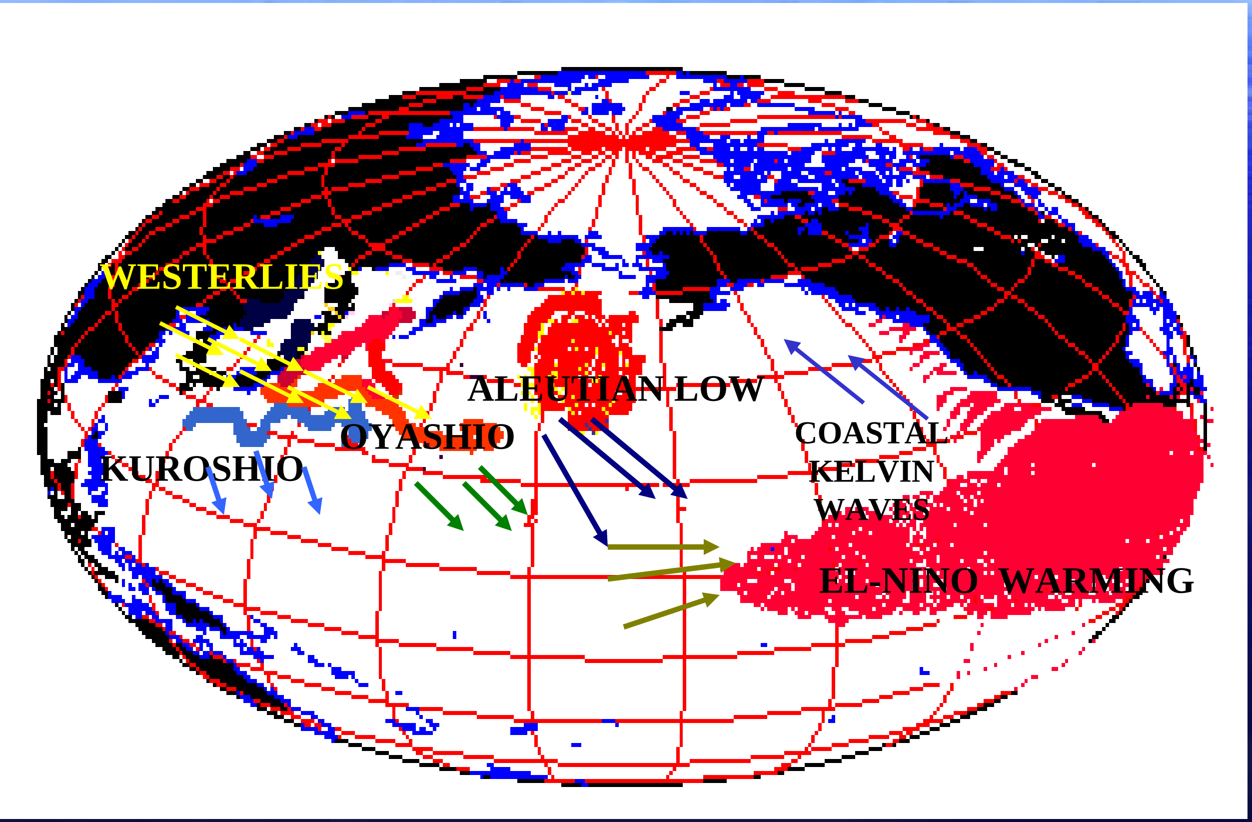
Interannual variation of winter time wind stress and its effect on mixed layer depths in the western North Pacific Ocean

Goes et al. 2004



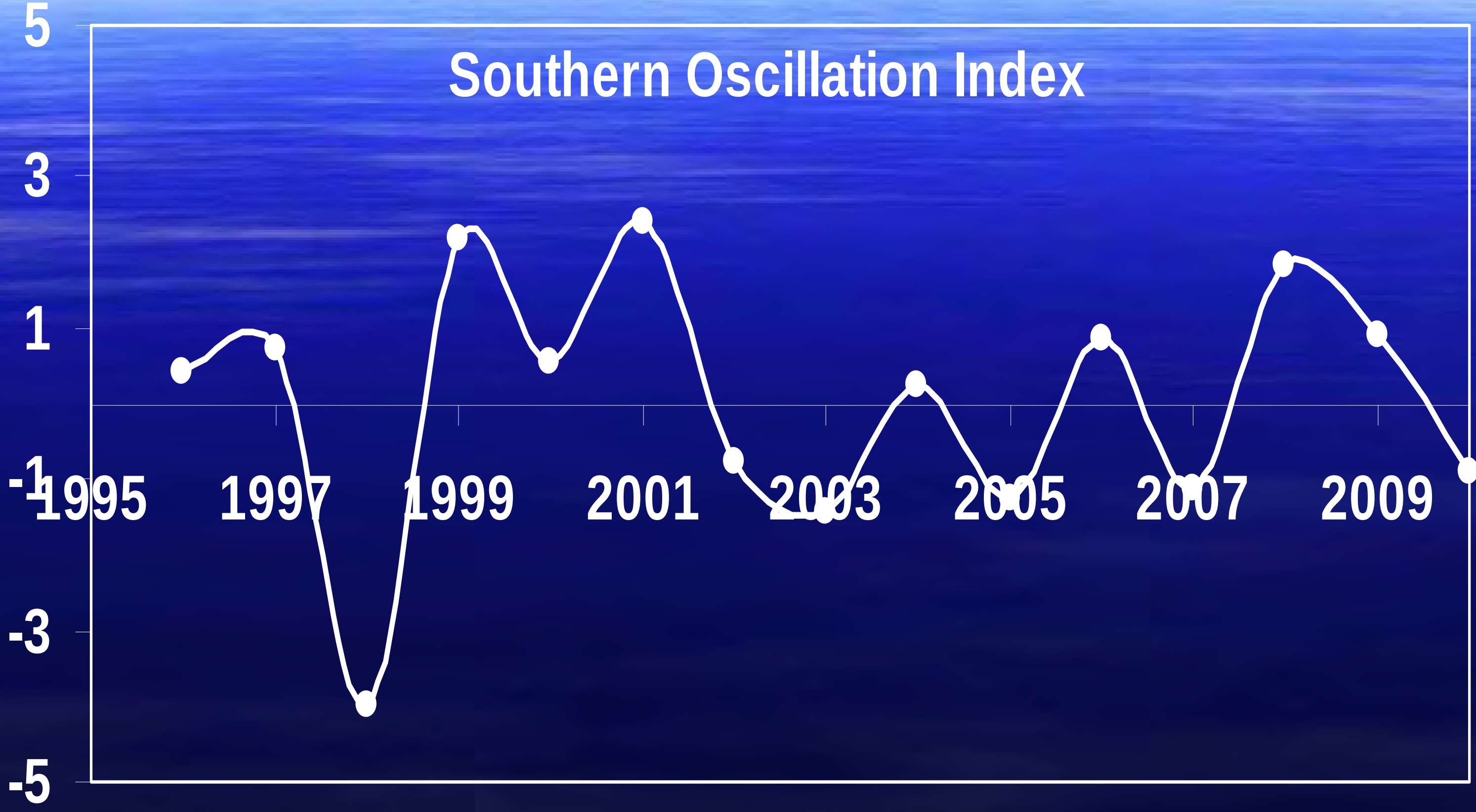


Relationship between the mixed layer depth and mixed layer nitrate concentrations in the western North Pacific Ocean

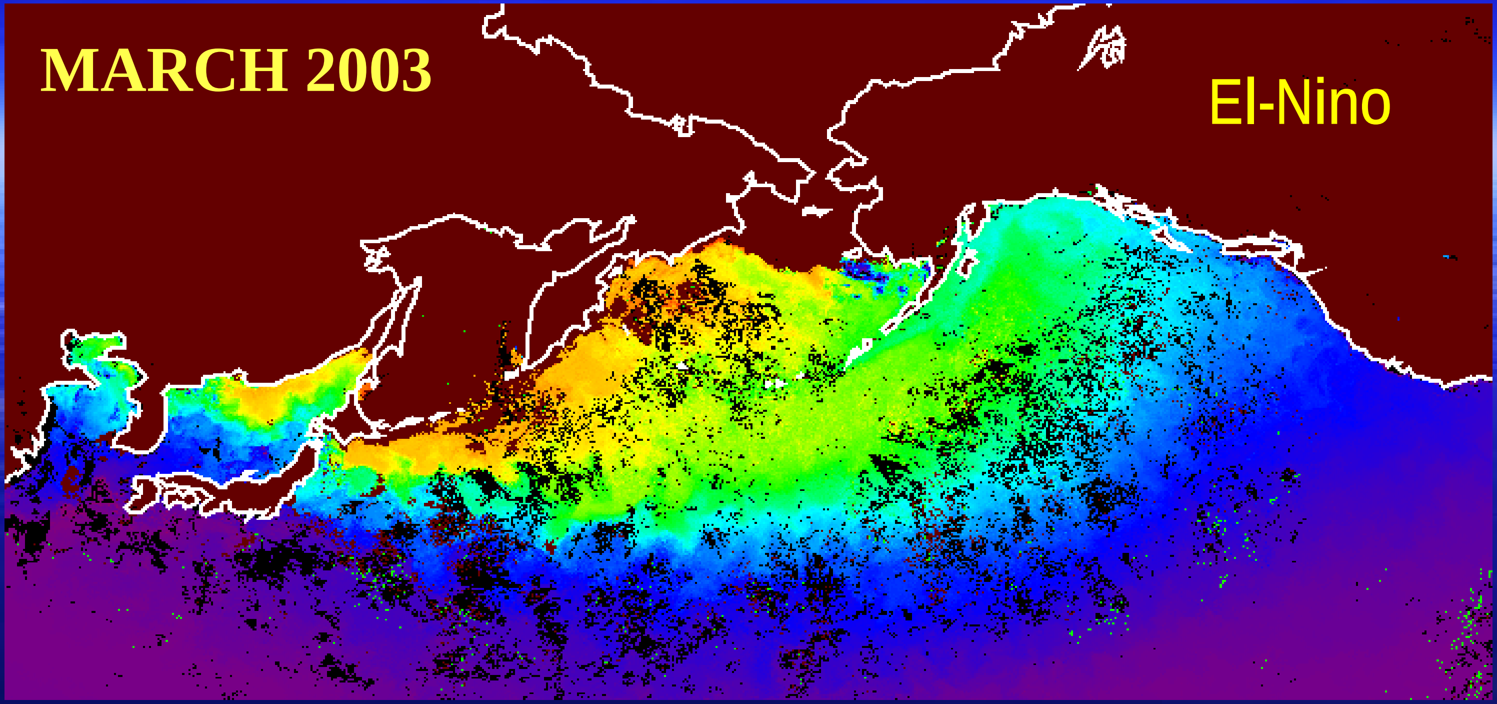


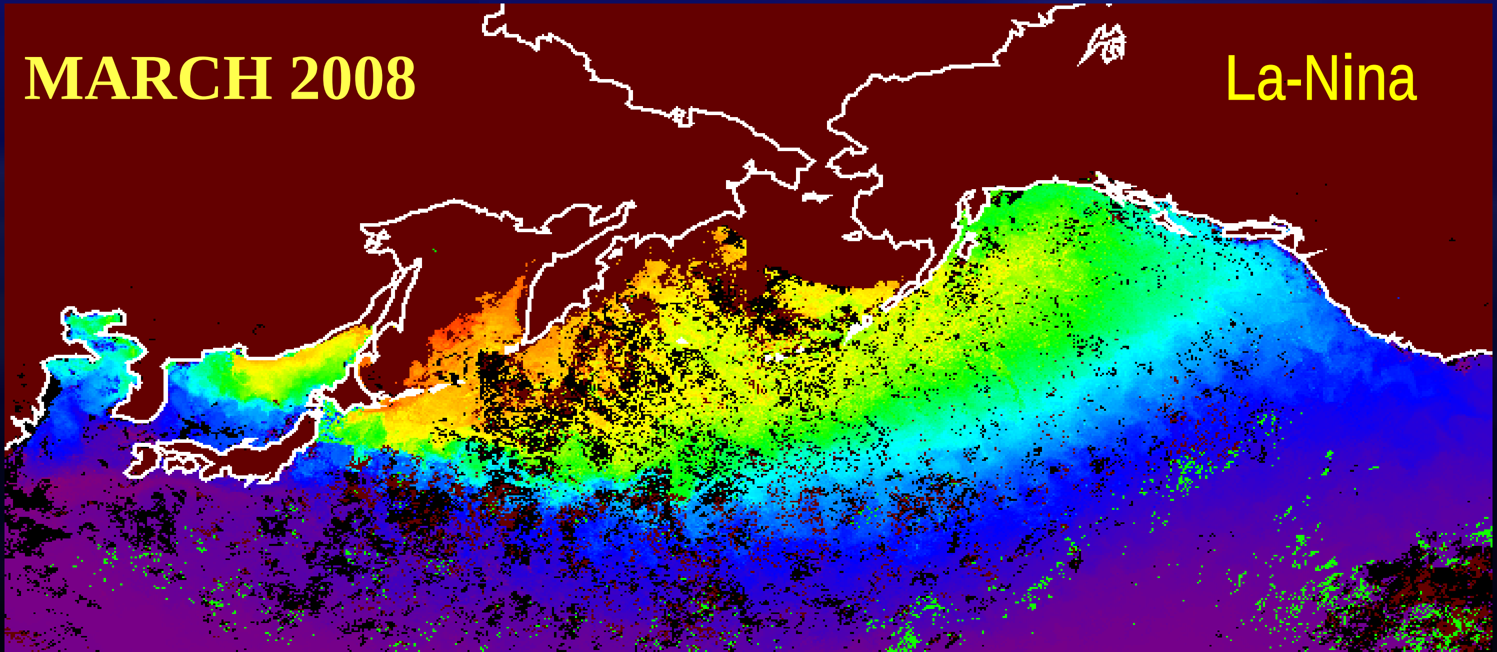
SCHEMATIC DIAGRAM SHOWING CHANGES IN ATMOSPHERIC AND OCEANOGRAPHIC CONDITIONS IN THE NORTH PACIFIC OCEAN FOLLOWING AN ENSO EVENT IN THE TROPICS.

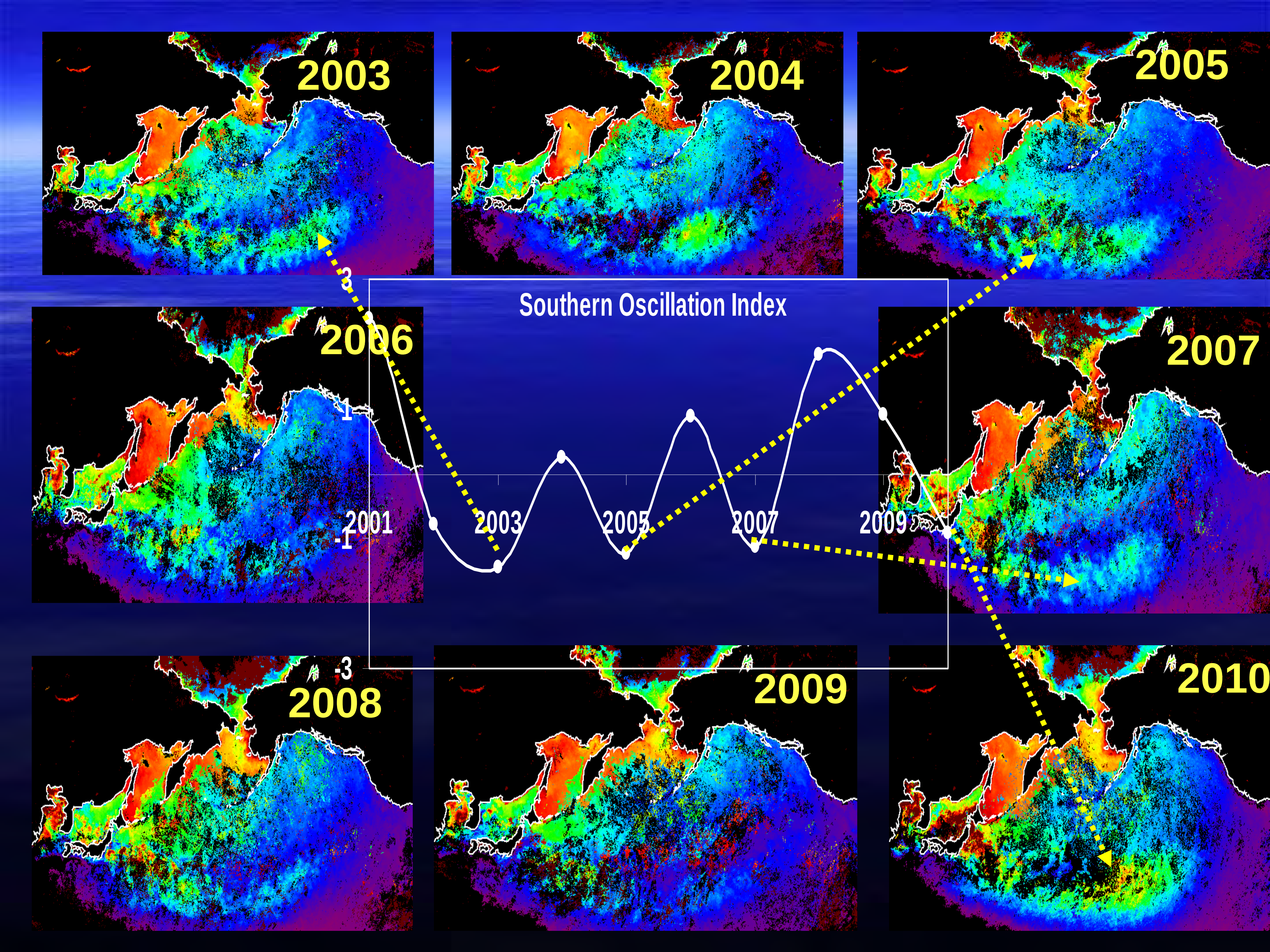
Goes et al. Prog. Oceanogr. 2000

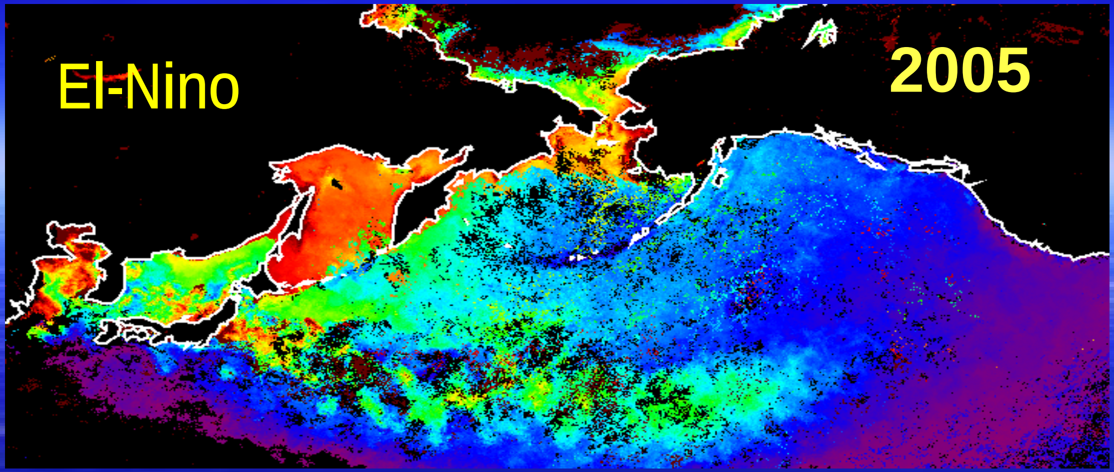
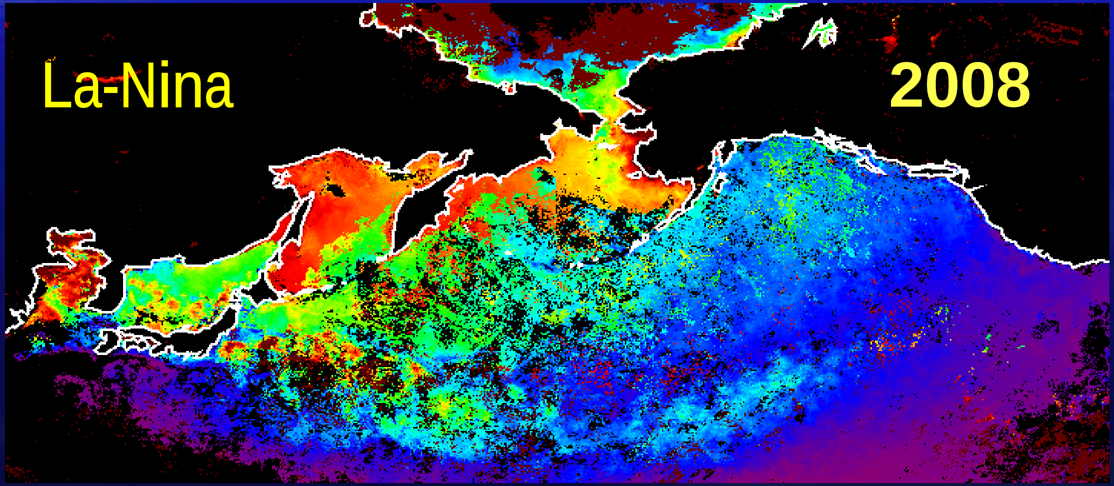
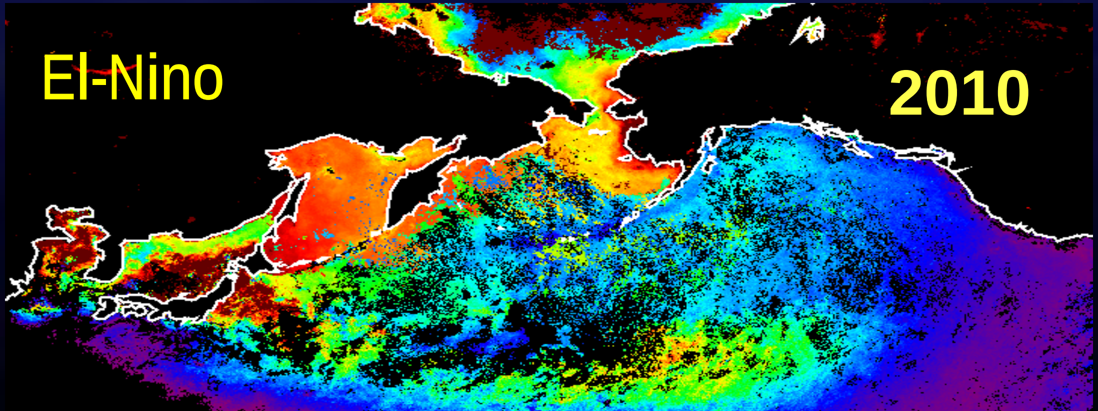


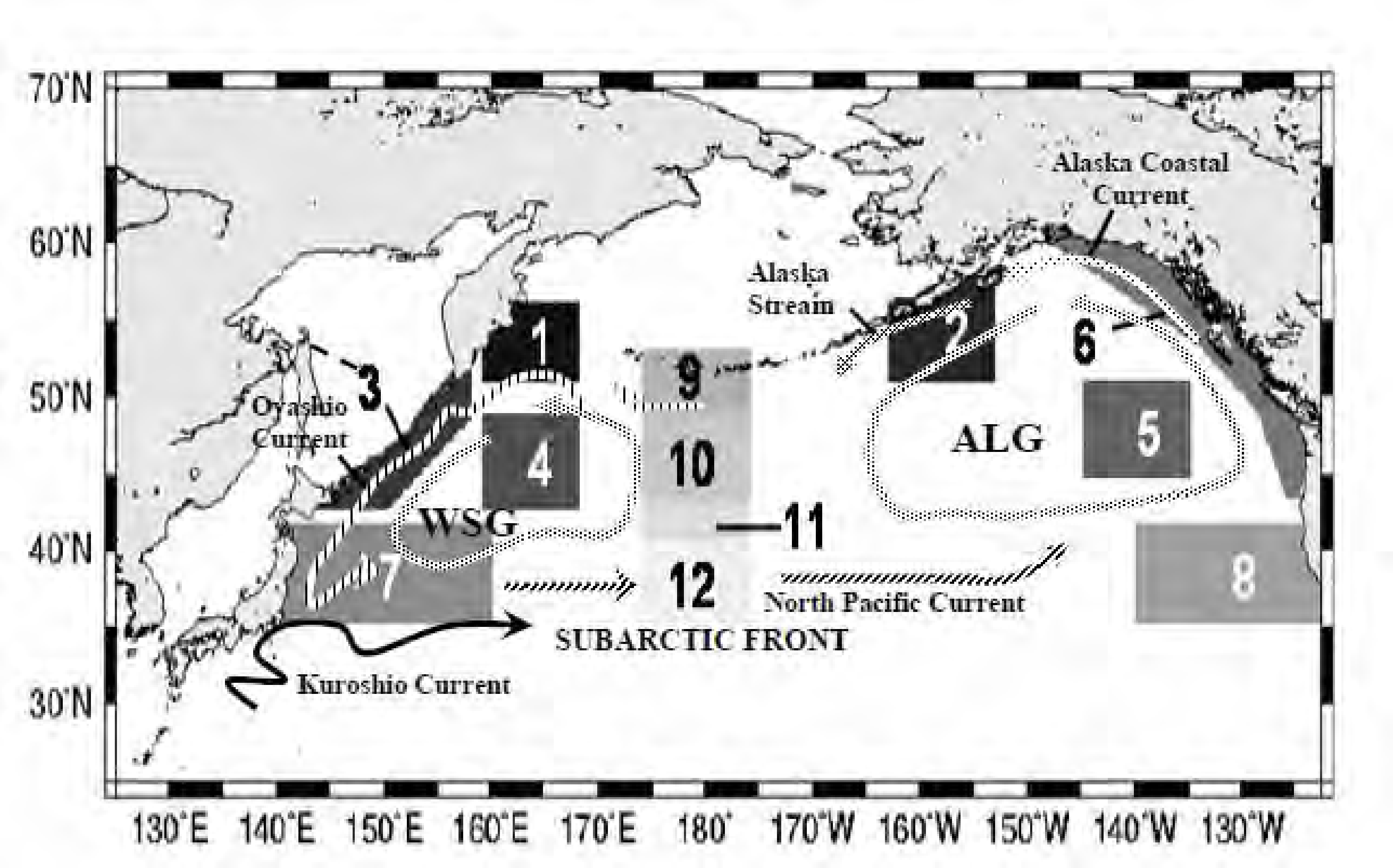
Interannual variation of the SOI


MARCH 2003
El-Nino


MARCH 2008
La-Nina


2003
2004
2005
2006
2007
2008
2009
2010
Southern Oscillation Index
3
1
-1
-3
2001
2003
2005
2007
2009


El-Nino
2005

La-Nina
2008

El-Nino
2010



Goes et al. 2004

Coefficients of determination and beta coefficients from multiple regression analysis of primary production versus predictor variables, sea surface winds and PAR. Beta coefficient values in bold are significant at $p < 0.01$ level, with exception of value shown in * which is significant at $p < 0.02$.

SUB-AREA	R^2	Wind β	PAR β
Western Subarctic Gyre			
WSGC-1	**0.79**	**-1.1**	-0.28
WSGC-2	**0.70**	**-1.2**	-0.33
WSGO	**0.62**	**-0.89**	-0.13
WSGF	0.25	-0.11	0.40
Central Subarctic Pacific			
CSAC	**0.72**	**-0.76**	0.11
CSAO-1	**0.68**	**-0.8**	0.03
CSAO-2	**0.62**	**-0.76**	0.03
CSAF	0.10	-0.15	0.18
Alaskan Gyre			
ALGC-1	**0.89**	0.37	**0.76**
ALGC-2	**0.83**	-0.39	**0.56**
ALGO	**0.65**	**-0.49***	0.35
ALGF	**0.78**	-0.09	**0.94**

Goes et al. 2004

Summary

El-Nino events in the tropics have a profound impact on primary production and export production gradients across the subarctic Pacific Ocean through impacts on the location and strength of the ALPS and consequently the strength of winter monsoonal winds and winter-time convective mixing

Over large parts of the central and eastern subarctic Pacific, phytoplankton photosynthetic competency, and hence primary production and carbon export rates are regulated by iron, whose availability could be regulated by the strength of winter-time winds.

There is an urgent need to examine rates of iron dust deposition, its solubility in seawater and bioavailability for phytoplankton.

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