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COURSE ON CLIMATE VARIABILITY STUDIES IN THE OCEAN
"Tracing & Modelling the Ocean Variability"
16 - 27 June 2003

301/1507-17

Climate Variability & Marine Ecosystems: the Role of Forcings & Feedbacks - I & II

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Please note: These are preliminary notes intended for internal distribution only.

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Climate Variability and Marine Ecosystems: The Role of Forcings and Feedbacks

Antonio J. Busalacchi

With thanks to:
R. Murtugudde, M. Visbeck, N. Mantua,
M. McPhaden, K. Richards, D. Turk, H. Gildor

EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER
ESSIC
UNIVERSITY OF MARYLAND

Climate Variability and Marine Ecosystems: The Role of Forcings and Feedbacks

- Ocean observing platforms

- Modes of climate variability, i.e., physical climate

- Interaction between such modes and marine ecosystems
  - El Nino-Southern Oscillation
  - Pacific Decadal Oscillation
  - North Atlantic Oscillation

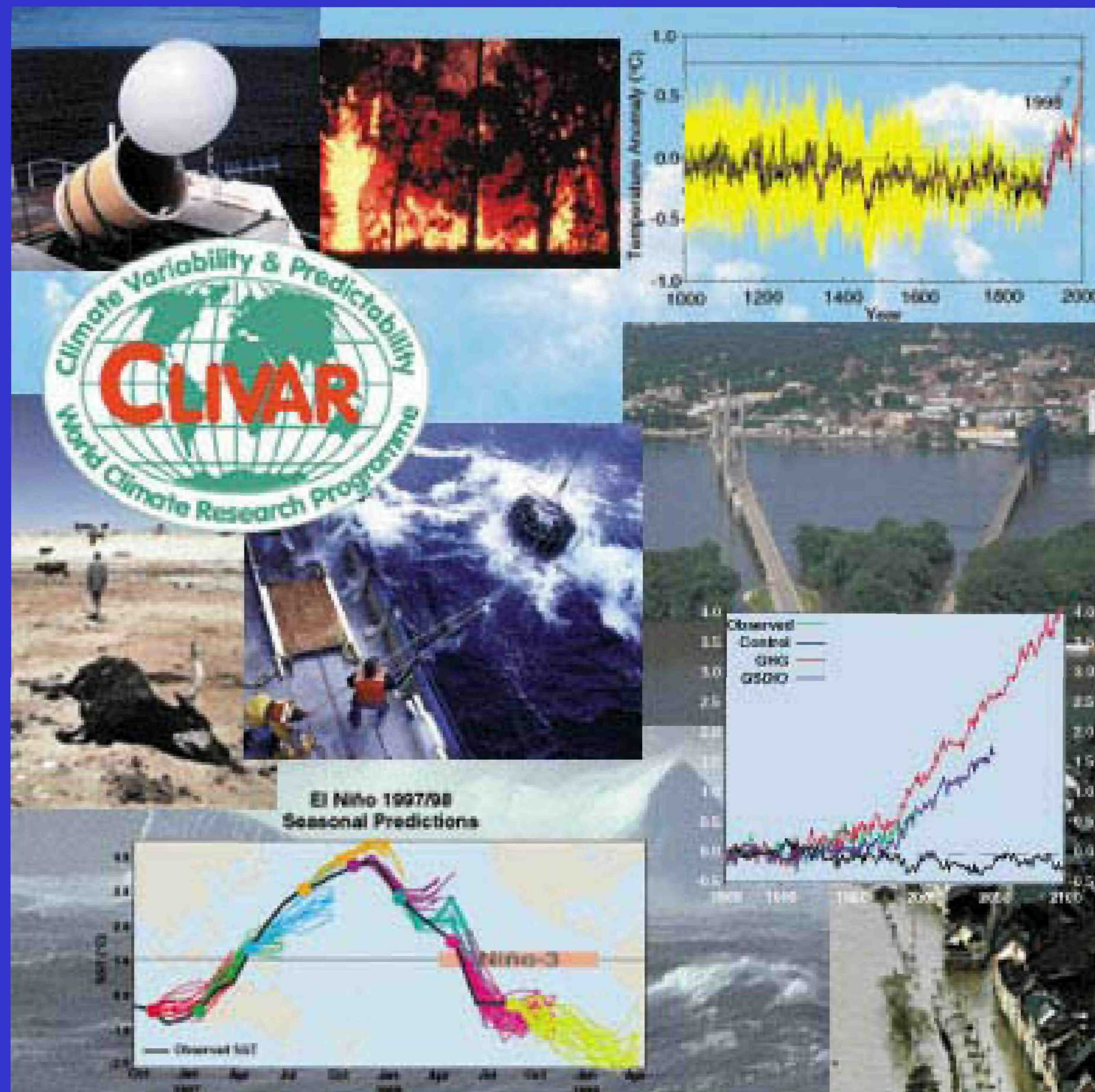
In a forcing sense, climate variability can influence:

- Circulation
- Temperature
- Stratification and Mixing
- Water mass characteristics
- Mesoscale activity
- Extreme events
- Basin-wide synchrony

CLIVAR (Climate Variability and Predictability)

CLIVAR is an interdisciplinary research effort within the World Climate Research Programme (WCRP) focusing on the variability and predictability of the slowly varying components of the climate system.

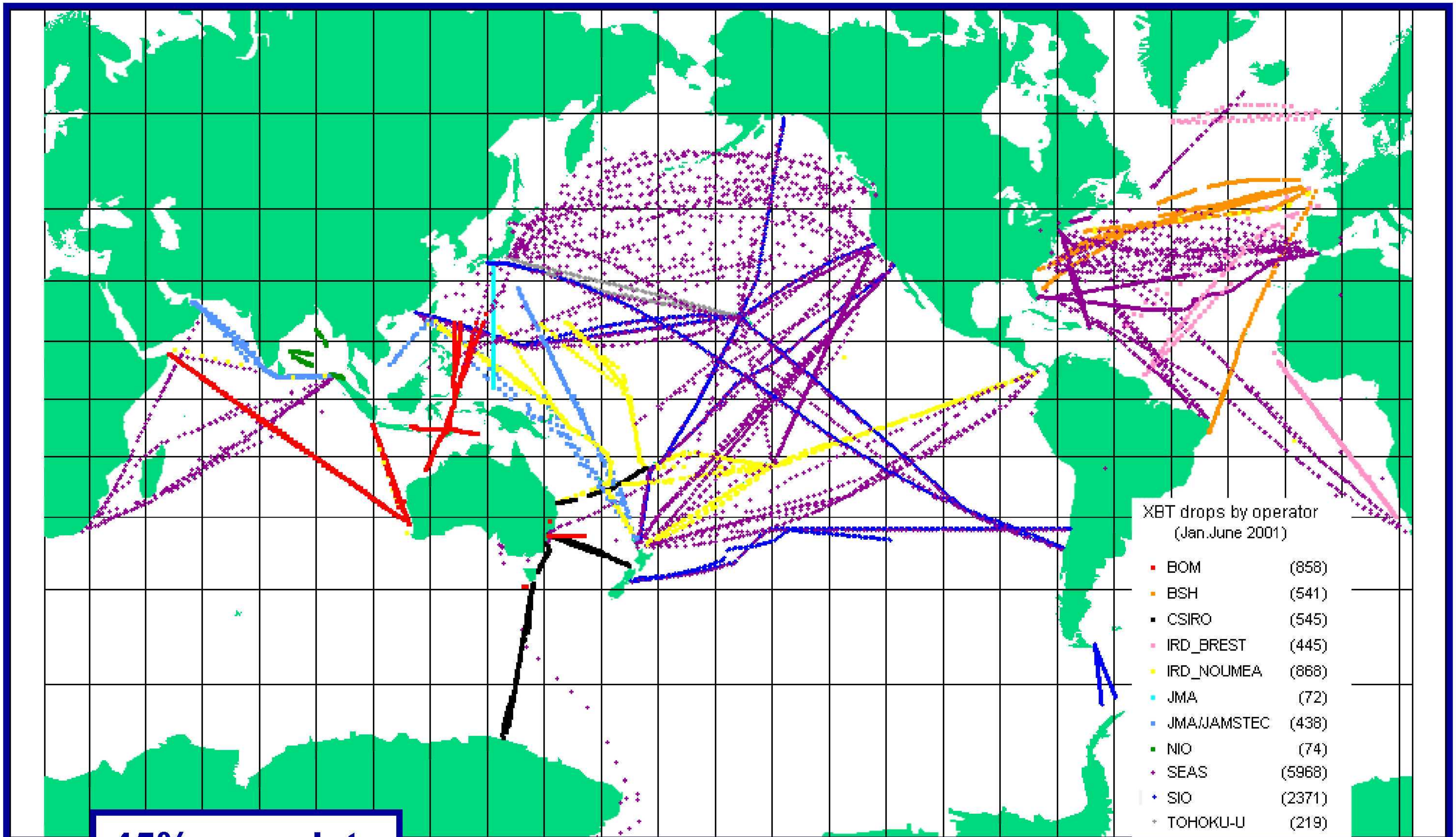
CLIVAR investigates the physical and dynamical processes in the climate system that occur on seasonal, interannual, decadal and centennial time-scales.



Advances in our knowledge of the coupled climate system require that we:

- Describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal, and centennial time-scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in cooperation with other relevant climate-research and observing programmes.
- Extend the record of climate variability over the time-scales of interest through the assembly of quality-controlled paleoclimatic and instrumental data sets.
- Extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models.
- Understand and predict the response of the climate system to increases of radiatively active gases and aerosols and to compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

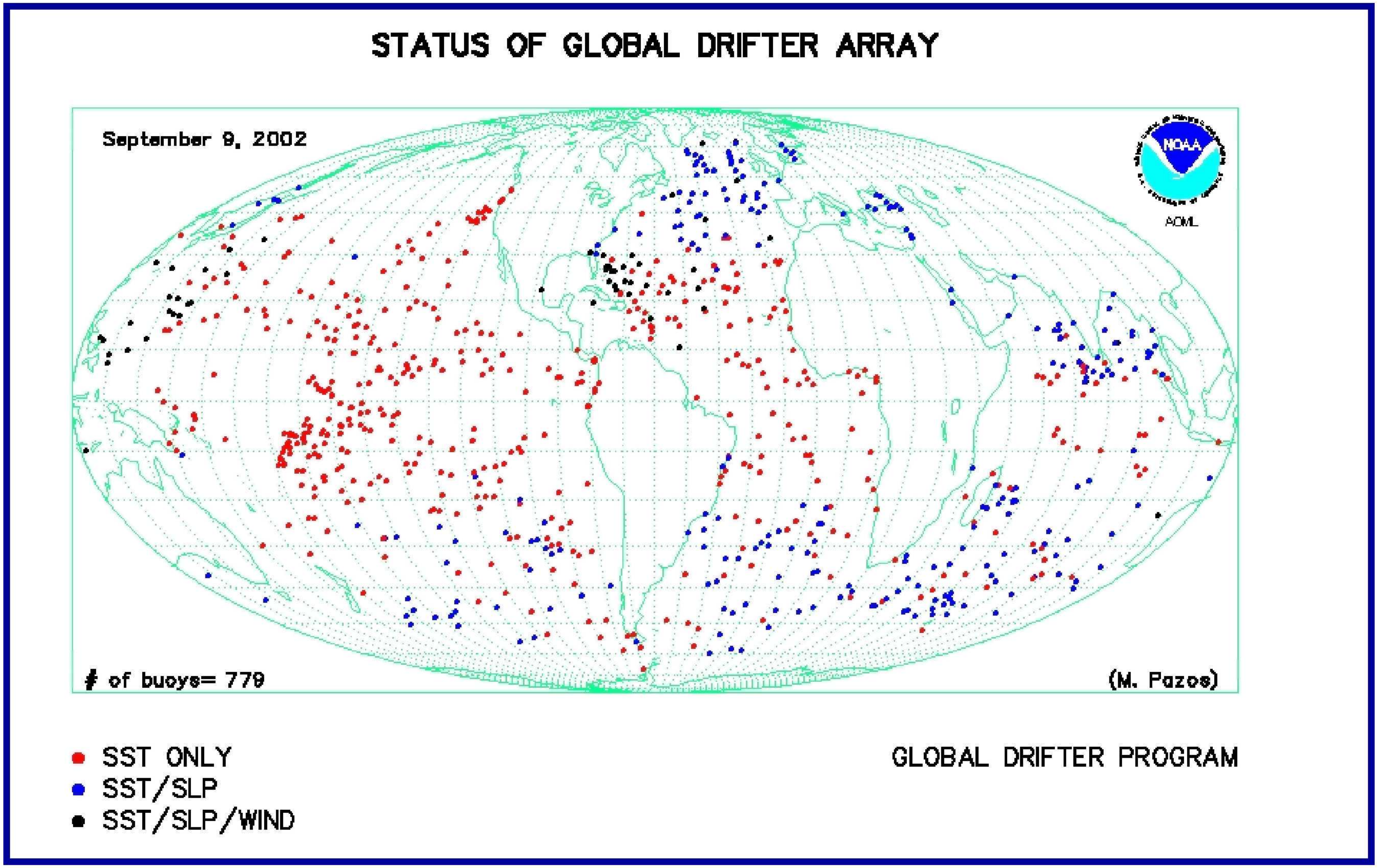
Status of the Ships-of-Opportunity Program



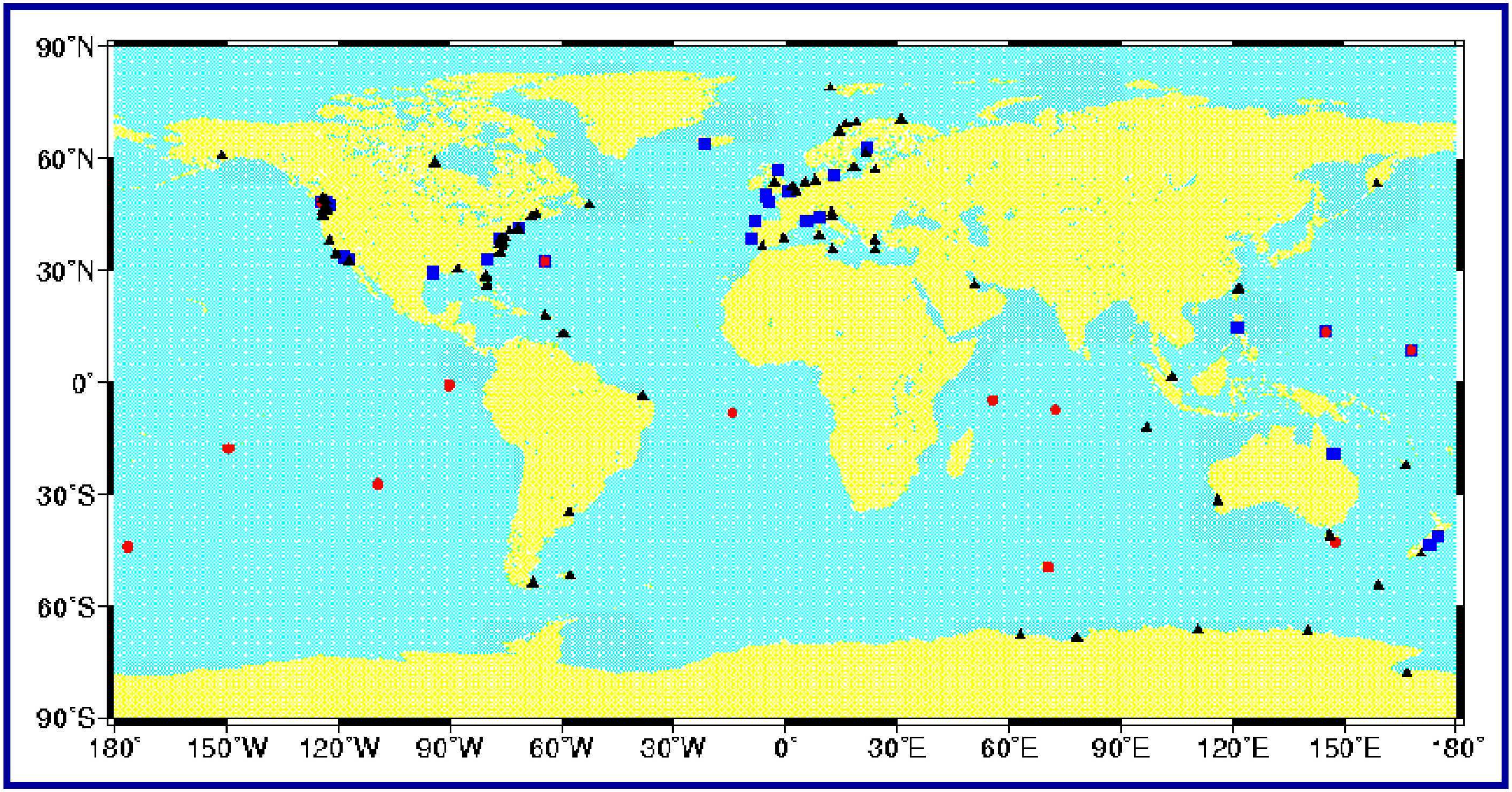
45% complete

January - June 2001

USA	8339
Partners	4060
	12399

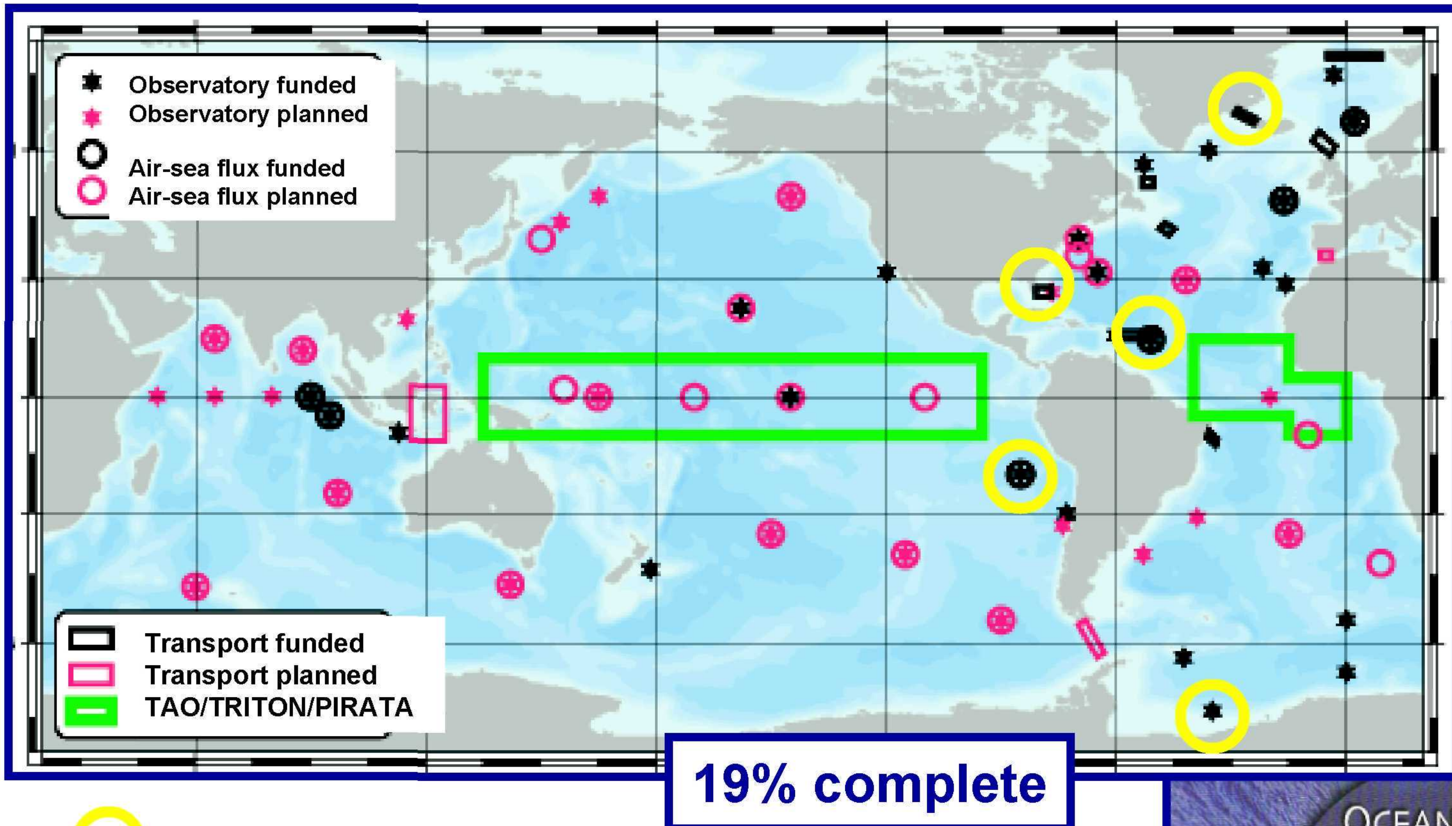

STATUS OF GLOBAL DRIFTER ARRAY
September 9, 2002
AOML
# of buoys= 779
(M. Pazos)
SST ONLY
SST/SLP
SST/SLP/WIND
GLOBAL DRIFTER PROGRAM

Status of GPS/DORIS implementation at Tide Gauge Stations

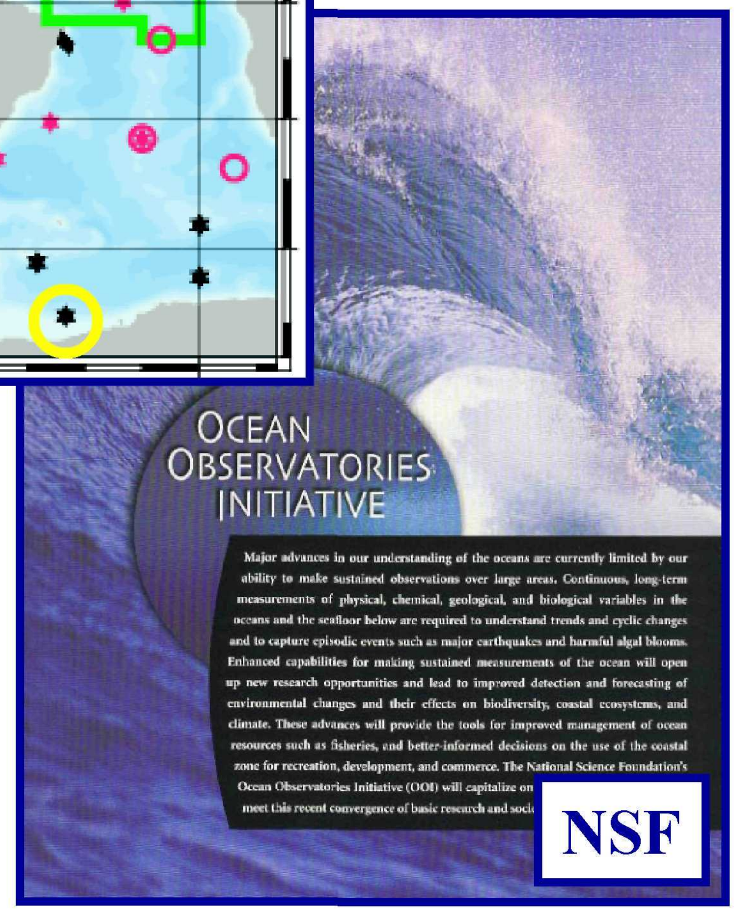


- Long Term Trends Reference Stations (27 of 62)
- Altimeter Calibration Stations (13 of 30)
- Other Stations

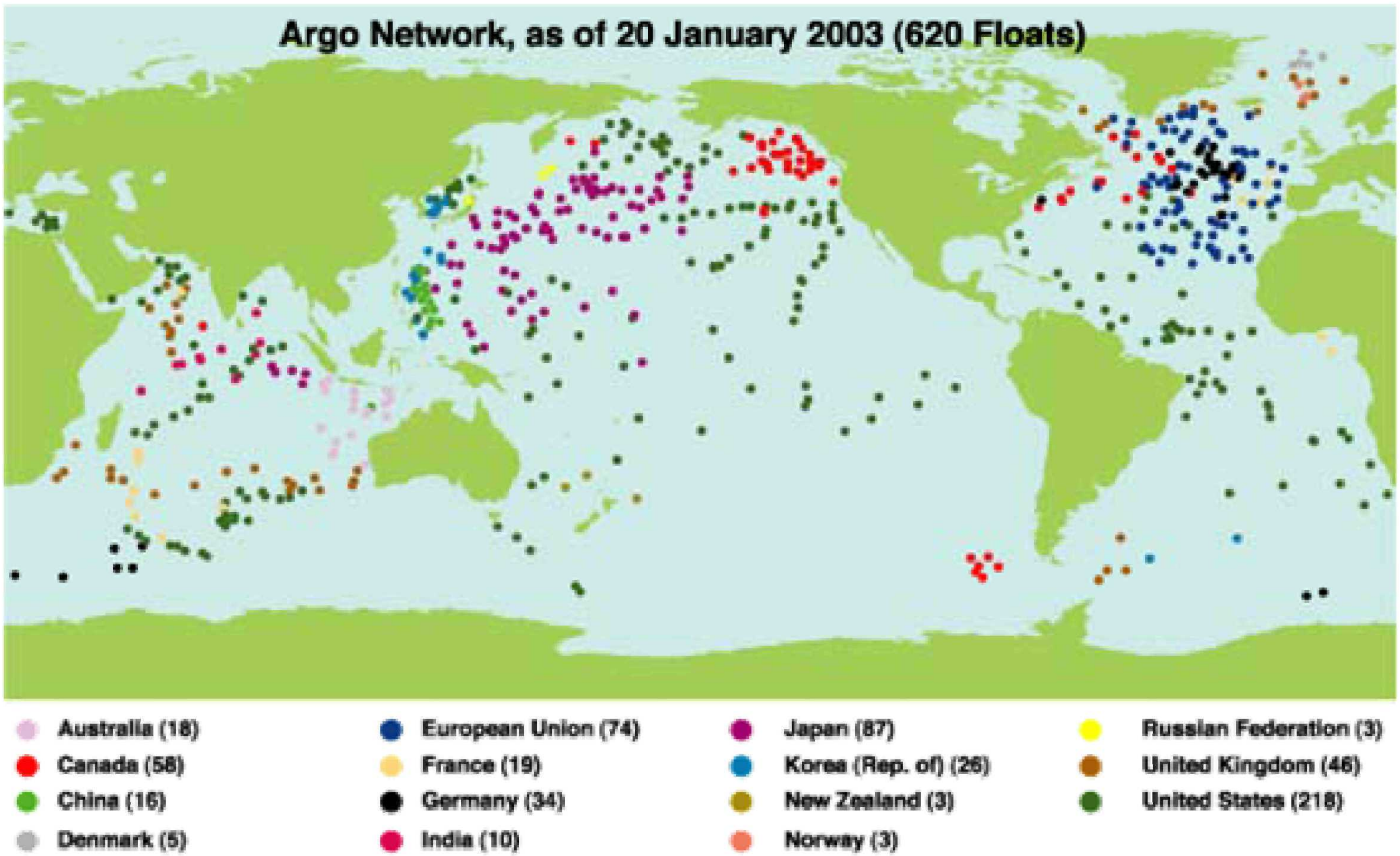
Status of Ocean Reference Stations



Present NOAA contributions

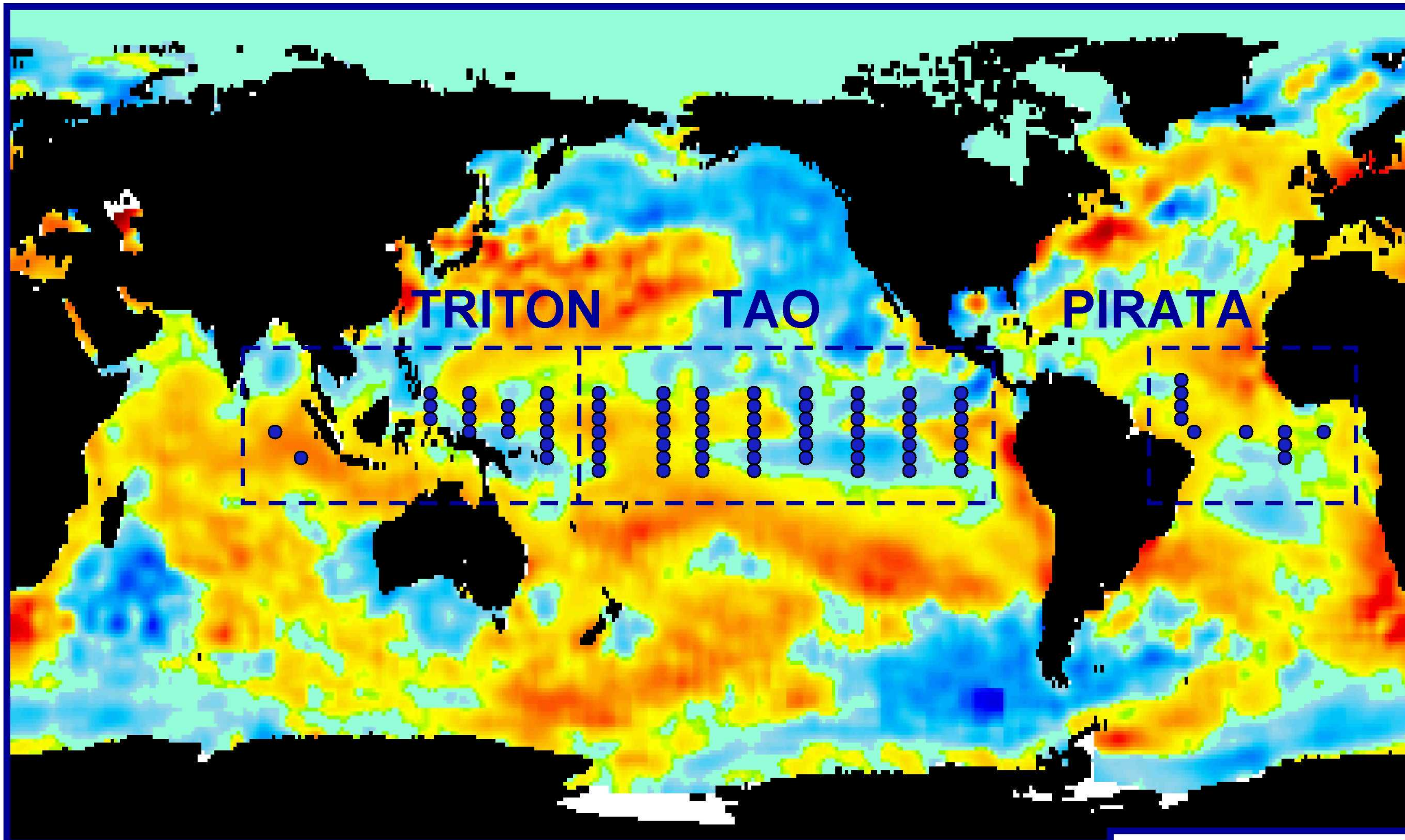


Argo Network



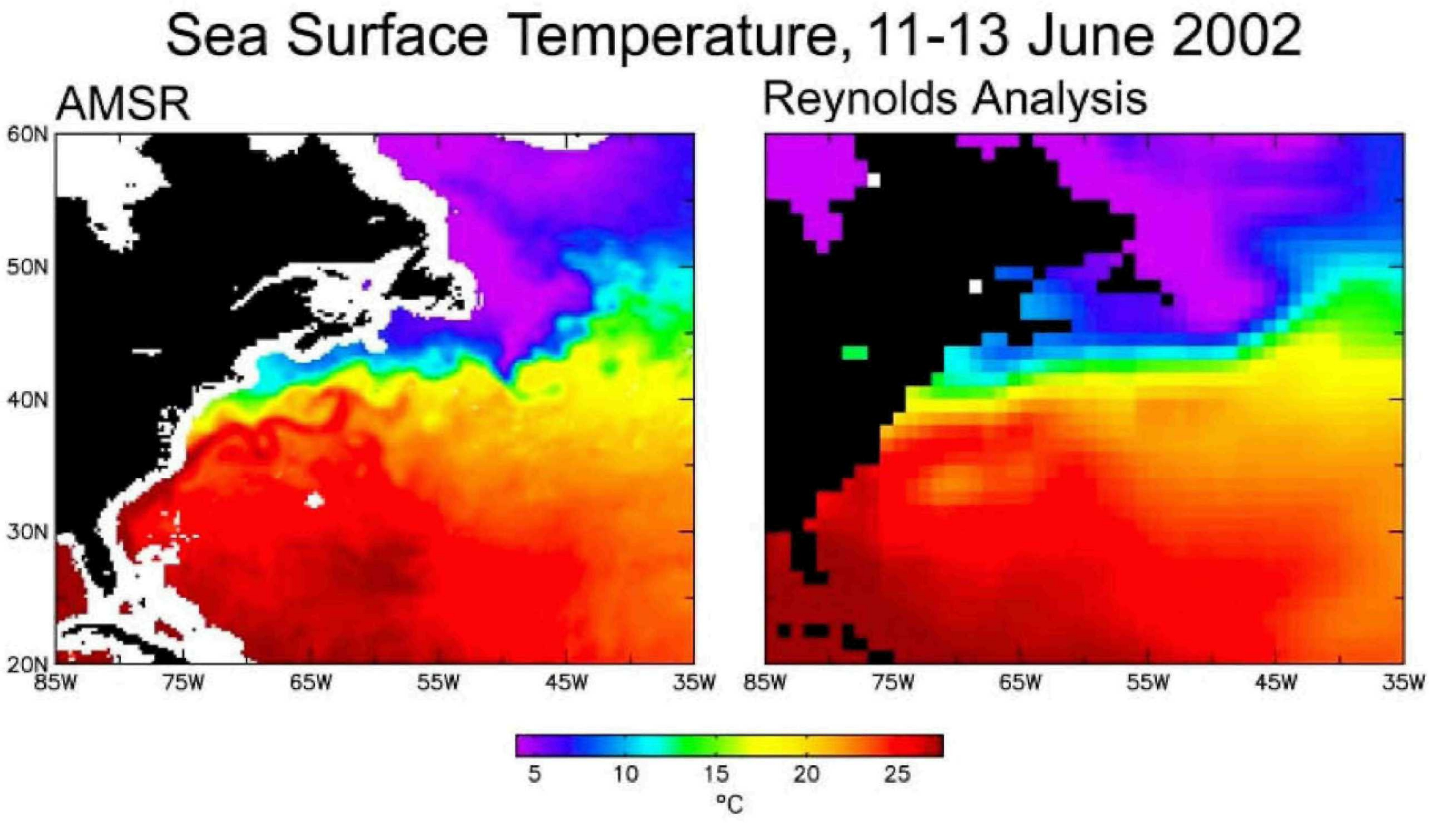
(Courtesy: D. Roemmich, SIO)

Status of the Tropical Moored Buoy Network

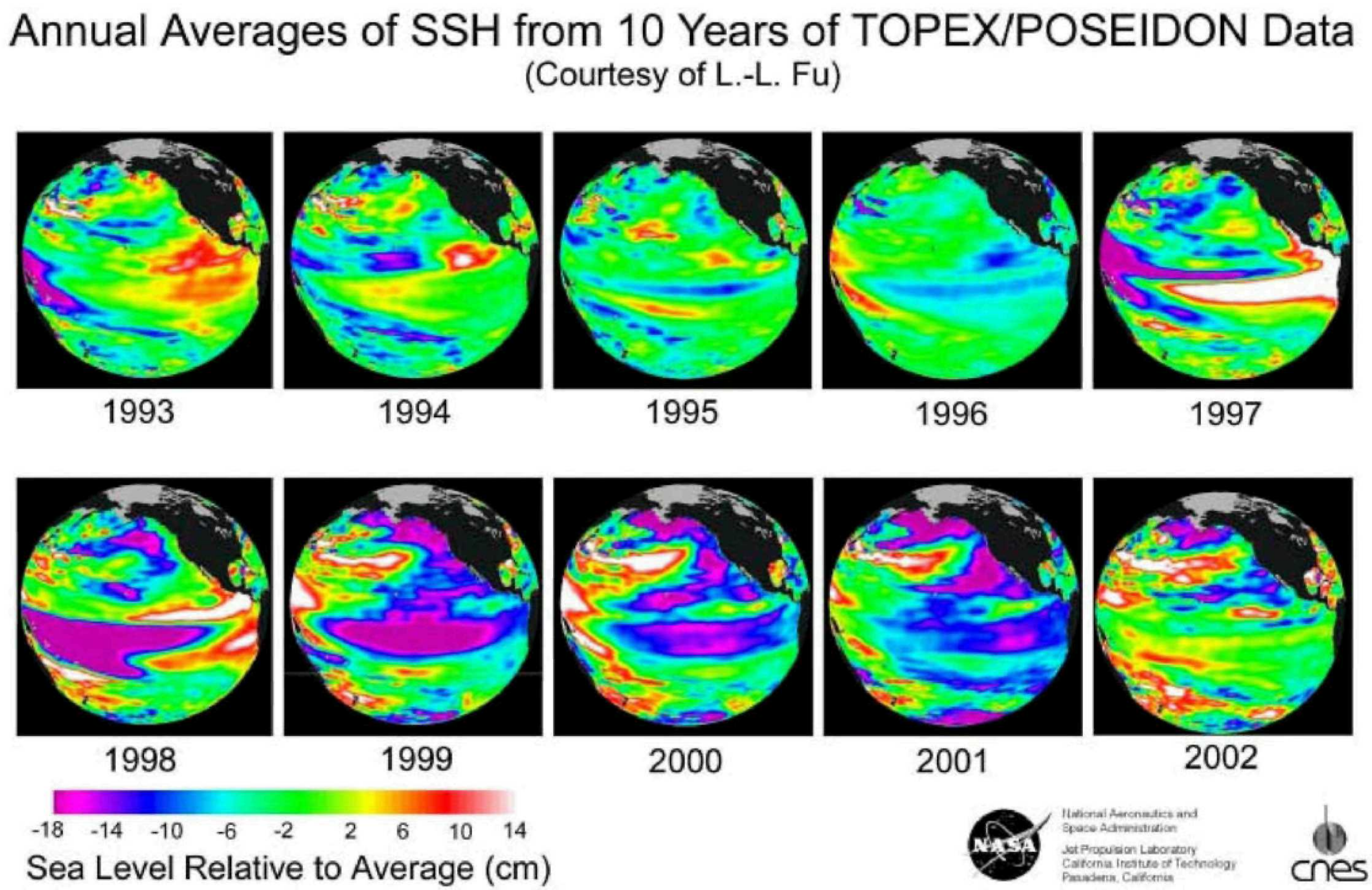


80% complete

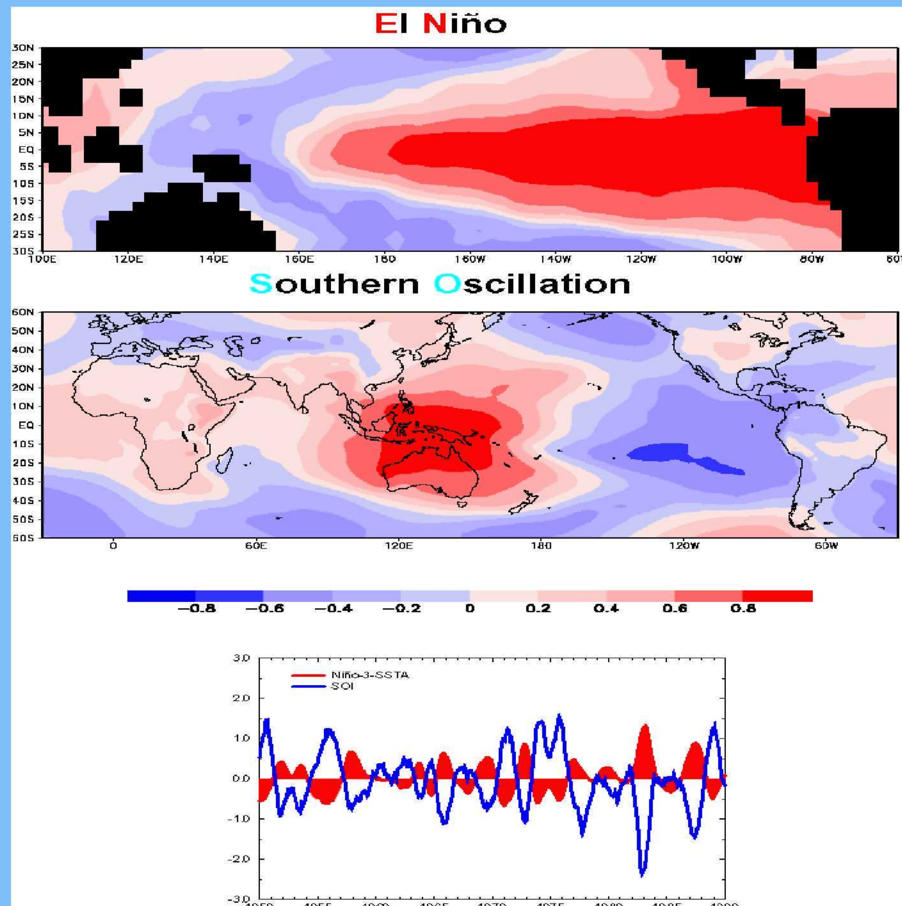
Global all-weather SST from AMSR



10-year record of sea surface topography from satellite altimeters



ENSO Fundamentals

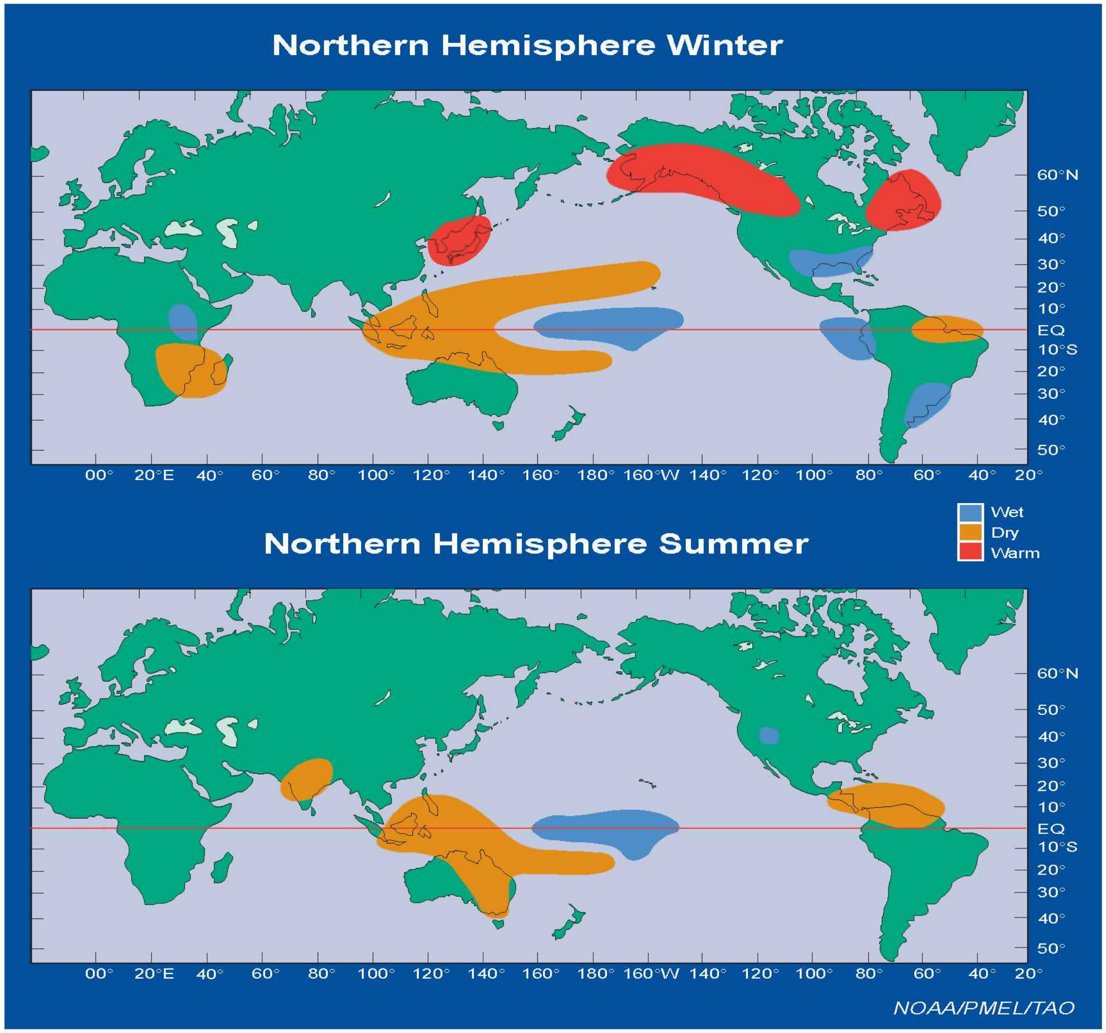


Upper panel: A typical[1] anomaly pattern for the tropical Pacific sea surface temperature (SST) associated with El Niño. Shown is the correlation of annual SST anomalies averaged over the Niño-3 region (5°N-5°S, 150°W-90°W) with all other locations. Middle: Spatial structure of the Southern Oscillation showing the global-scale nature of the phenomenon. Shown is the correlation of annual pressure anomalies at Djakarta (Indonesia) with all other locations. Lower: Time series of the Southern Oscillation Index (SOI; blue line) which measures the atmospheric sea-level pressure gradient across the tropical Pacific basin and of the anomalous SST averaged over the central equatorial Pacific (red line). Both time series are normalised by their standard deviation (courtesy of M. Latif, S. Venzke).

1. SOI pattern derived from a model simulation with ECHAM4

AV/G1/99-5

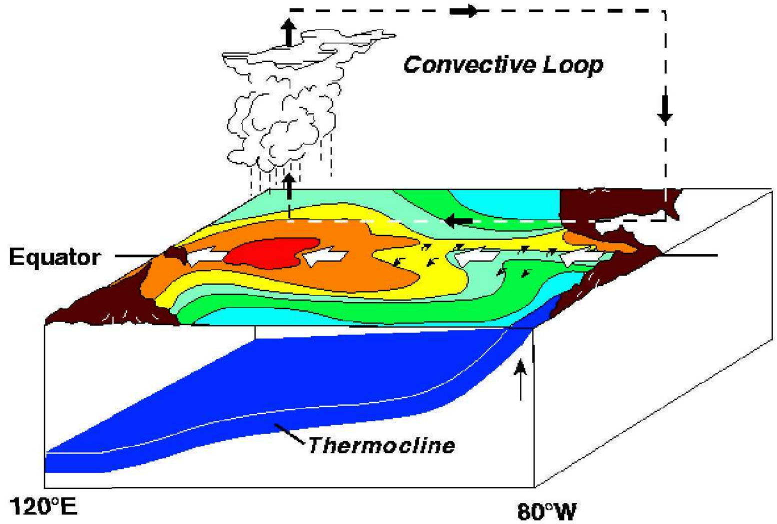
ENSO Teleconnections



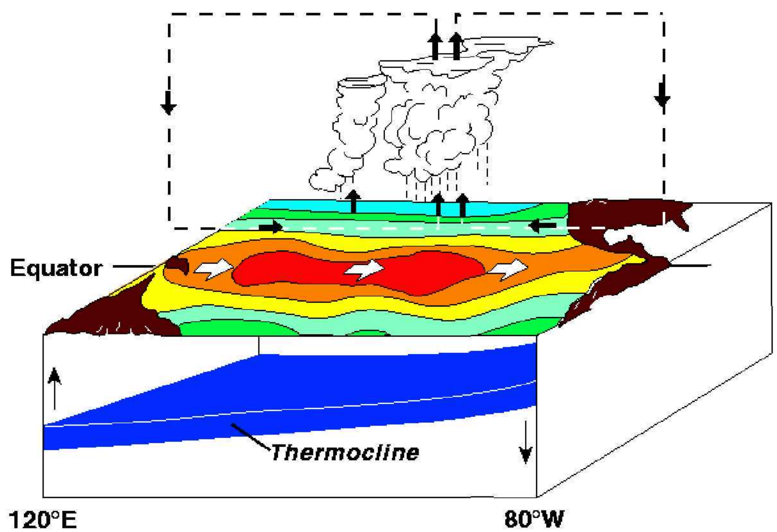
Schematic of temperature and precipitation anomalies generally associated with the warm phase of ENSO during the northern winter and summer seasons. To a good approximation, relationships with the cold phase of ENSO are simply reversed in sign. [After Halpert and Ropelewski (1992, J. Climate, 5, 577-593) and supplemented by Aceituno (1988, Mon. Wea. Rev., 116,505-525)] (courtesy of NOAA/PMEL).

LB/G1/99-2

Normal Conditions

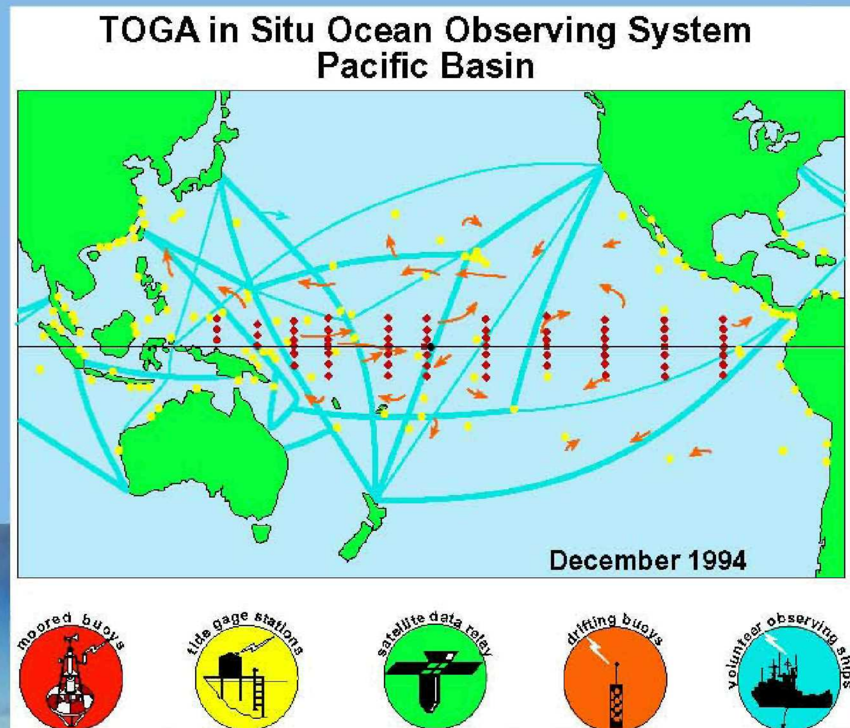


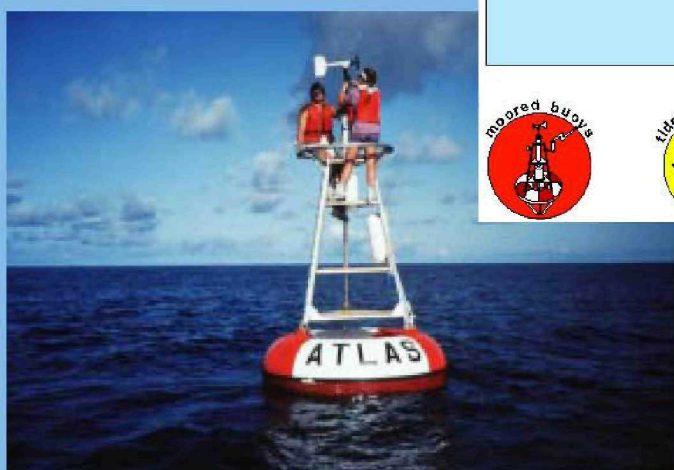
El Niño Conditions



The ENSO Observing System

The ENSO observing system build up during the TOGA period (right panel) is one of the main cornerstones for successful prediction of ENSO events. Without a continuous collection (in space and time) of different meteorological and oceanographic data using the capabilities of research vessels, ships of opportunity, surface and satellite observations and the evolving knowledge and technology of climate modelling successful forecasts of ENSO events would not be possible. Compared to the benefit of the society the cost for the maintenance of the observing system and the modelling resources are neglectable.

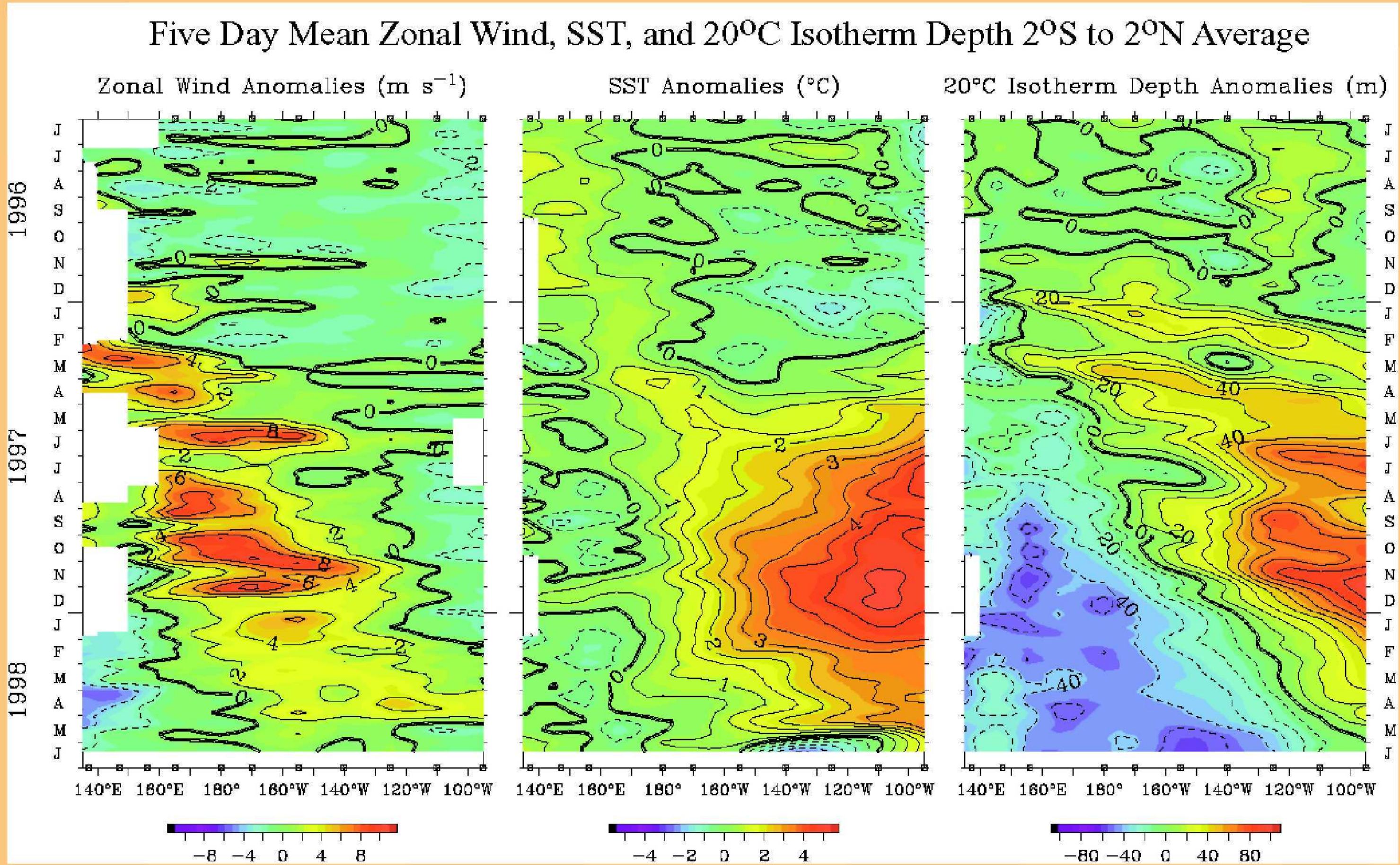




Photos: above and right: maintenance of the TAO array (courtesy NOAA/PMEL), upper right: "classical" sea surface temperature measurements (bucket) (courtesy G. Meehl)

AV/G1/99-6

ENSO 1997/98

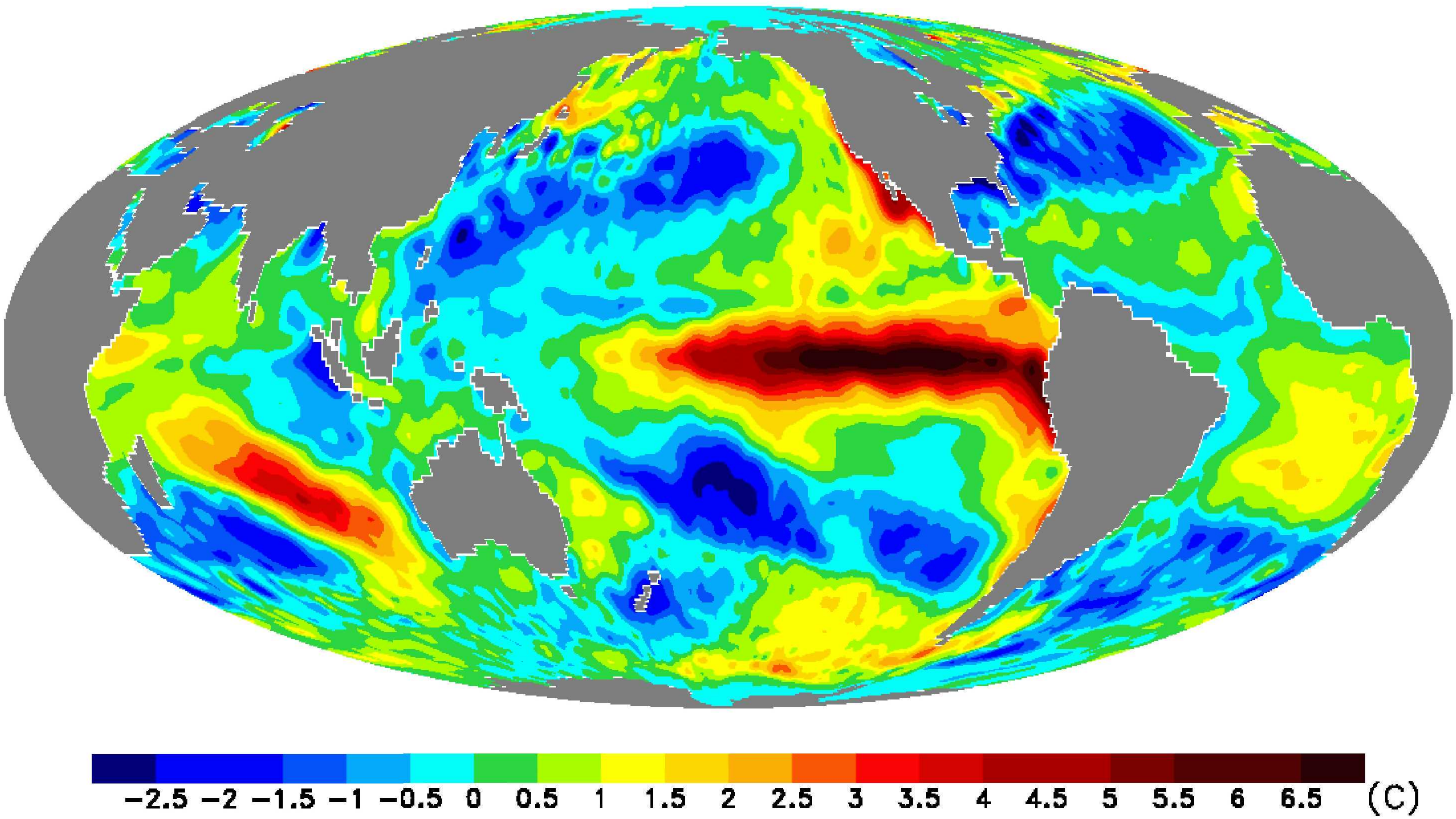


Time / longitude sections of anomalies in the surface zonal winds (in m s^{-1}), SST (in ^{o}C) and 20^{o}C isotherm depth (in m) for the past 24 months. Analysis is based on 5-day averages between 2^{o}N-2^{o}S of moored time series from the TAO array. Anomalies are relative to monthly climatologies cubic spline fitted to 5-day intervals (COADS winds, Reynolds SST, CTD/XBT 20^{o}C depths). Positive winds are westerly. Squares on the abscissas indicate longitudes where data where available at the start of the time series (top) and at the end of the time series (bottom). The TAO array is presently supported by the US (NOAA Office of Global Programs), Japan (JAMSTEC), Taiwan (NSC), Korea (STA) and France (ORSTOM). Further information is available from Dr. M.J. McPhaden (NOAA/PMEL) (courtesy of NOAA/PMEL).

AV/G1-99-7

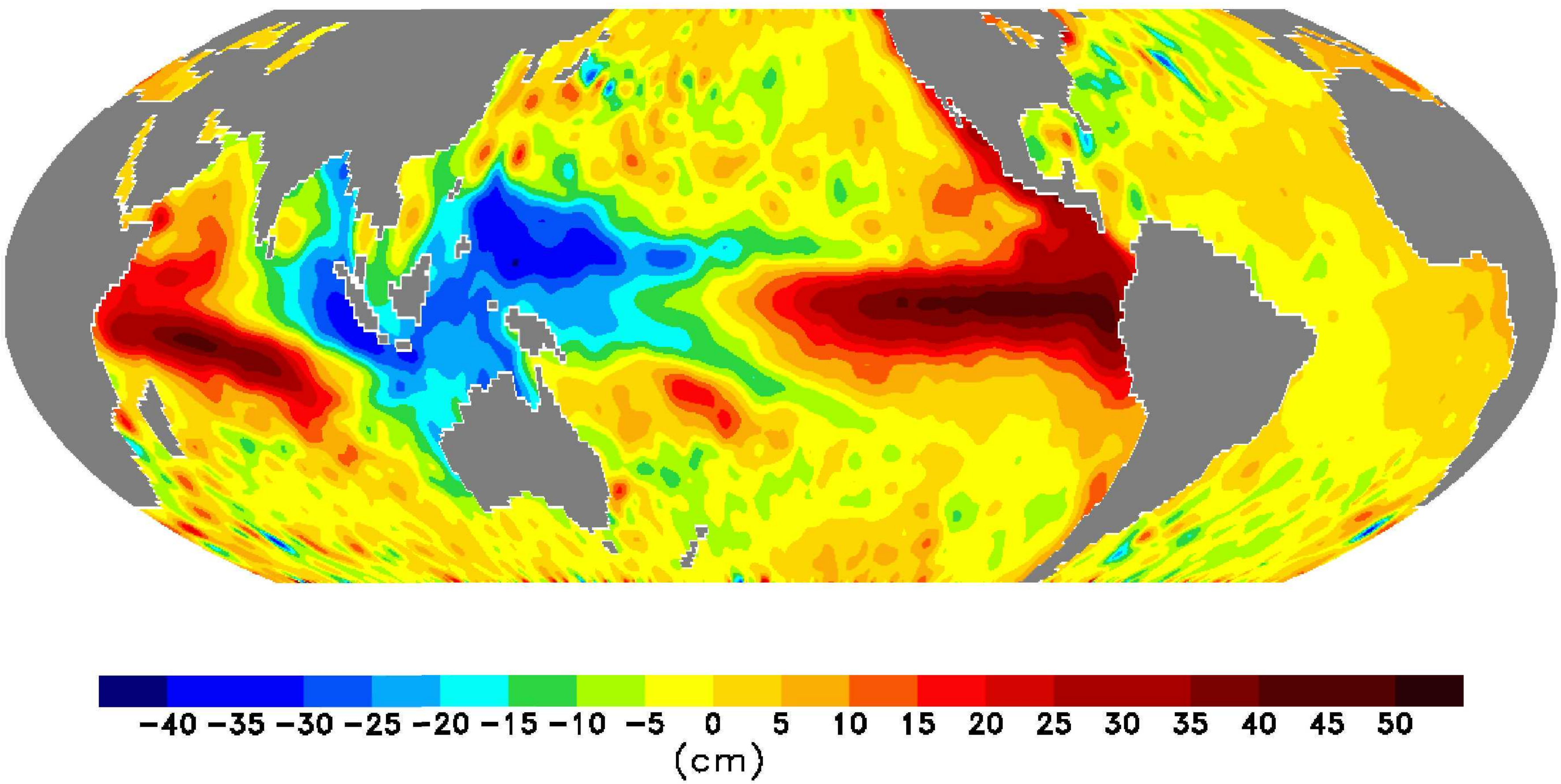
Sea Surface Temperature

Dec 1997 minus Dec 1998

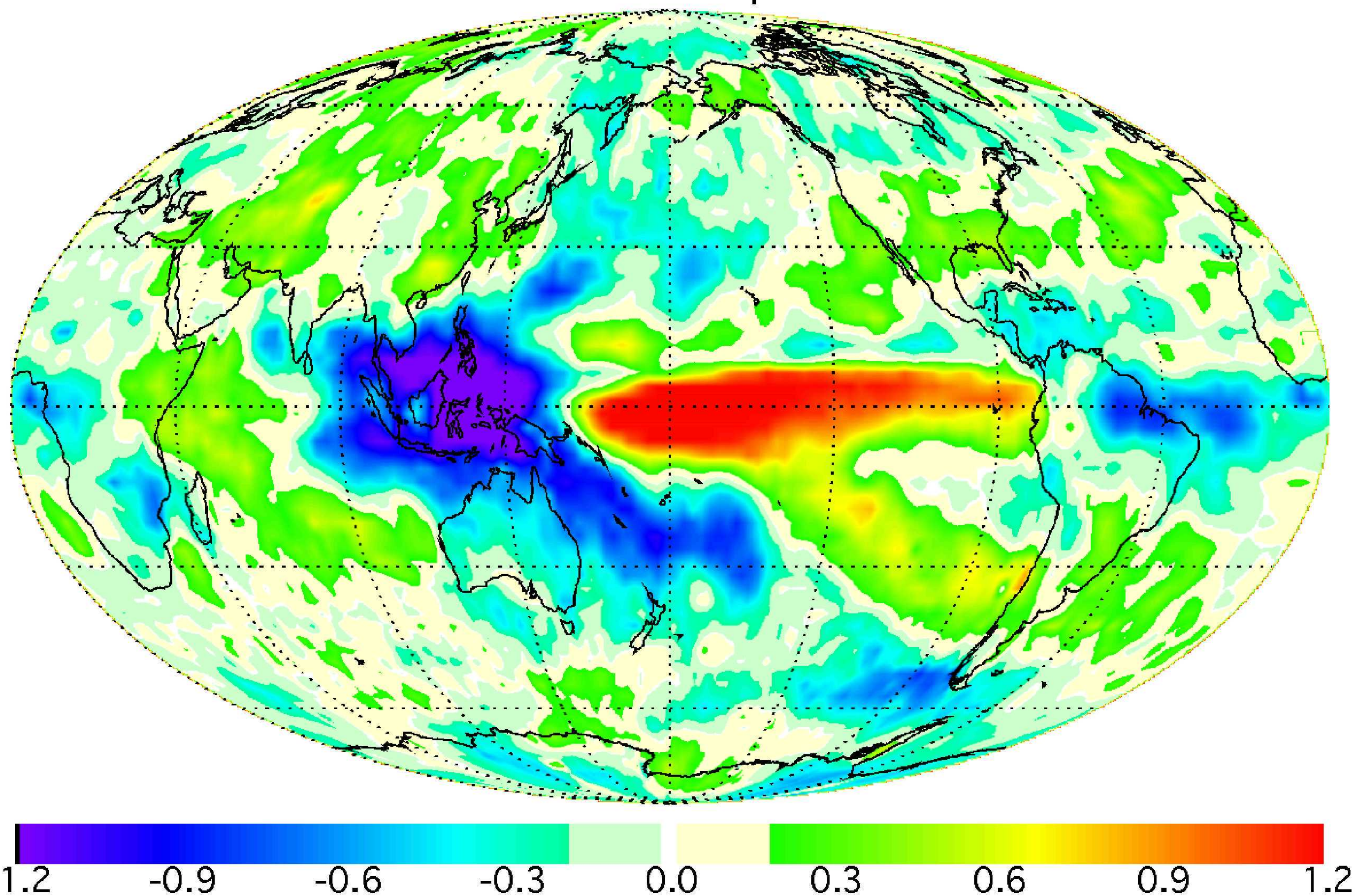


TOPEX/Poseidon Sea Level

Dec 1997 minus Dec 1998



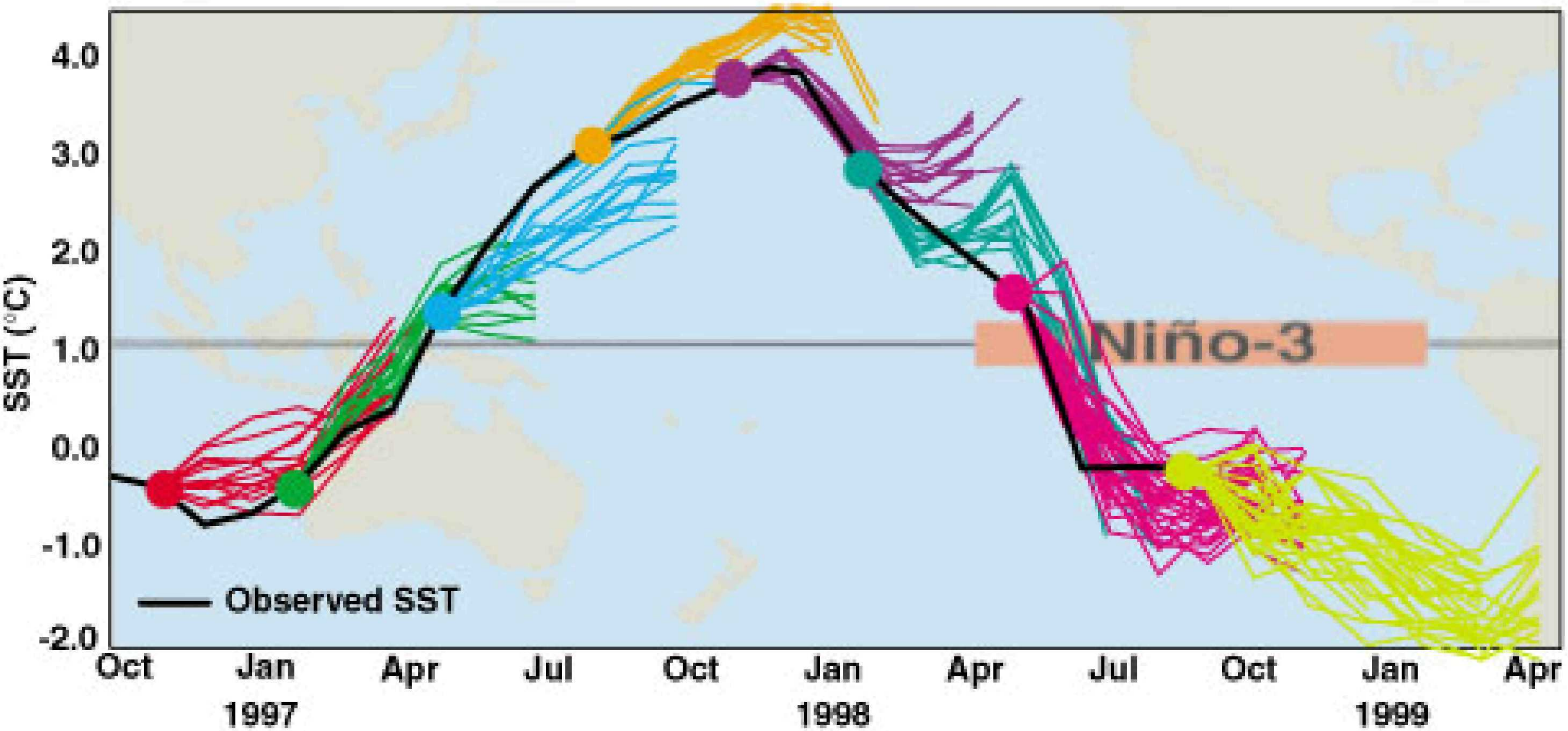
El Niño minus La Niña Composites
of Global Normalized Precipitation Anomalies



Global Precipitation Climatology Project (GPCP) 1979-99

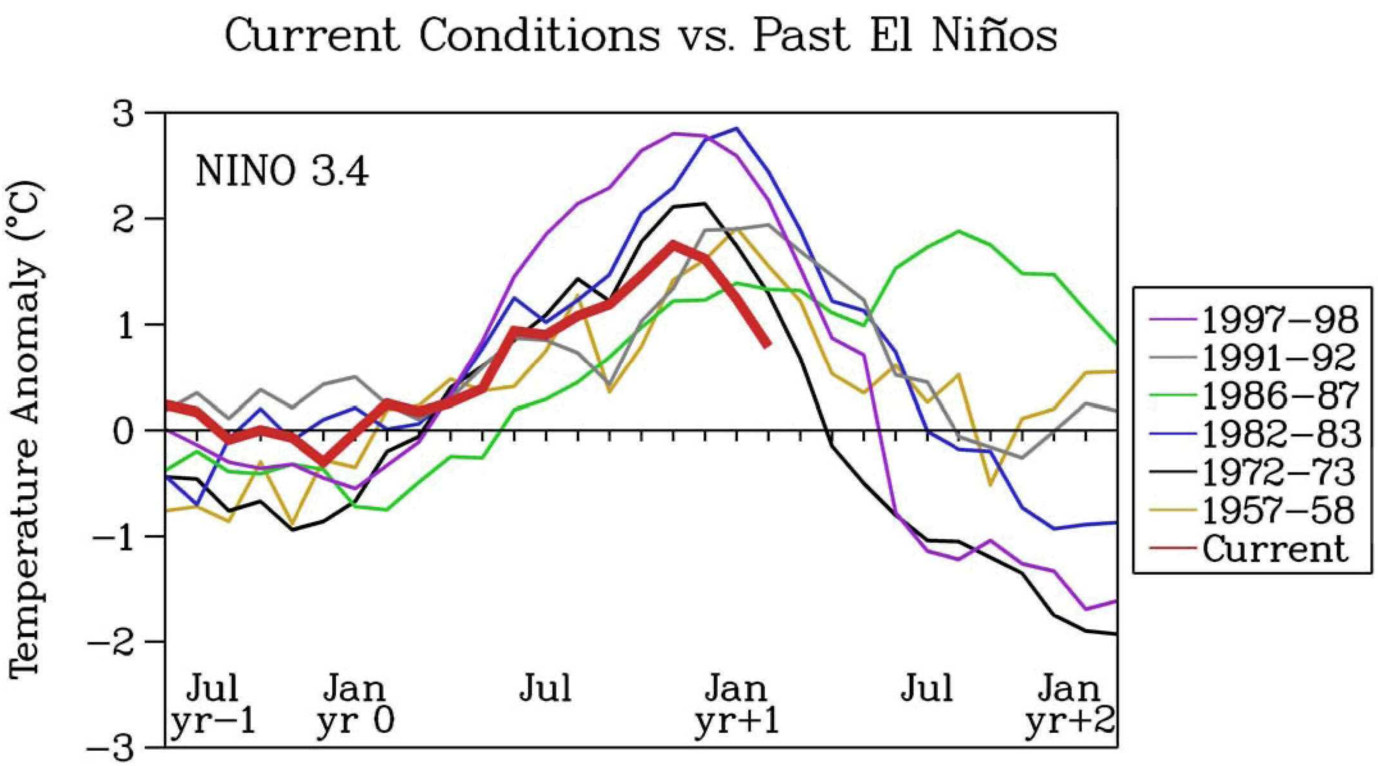
NASA Goddard Space Flight Center

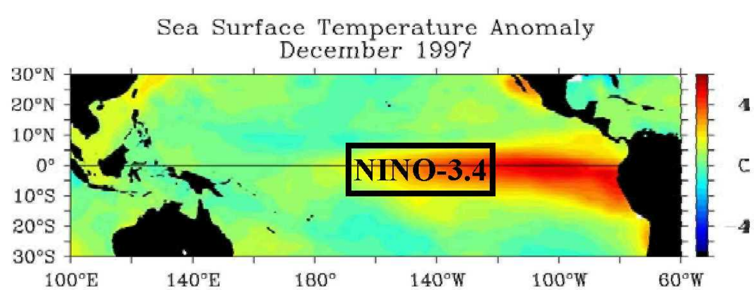
El Niño 1997/98
Seasonal Predictions



Source: ECMWF

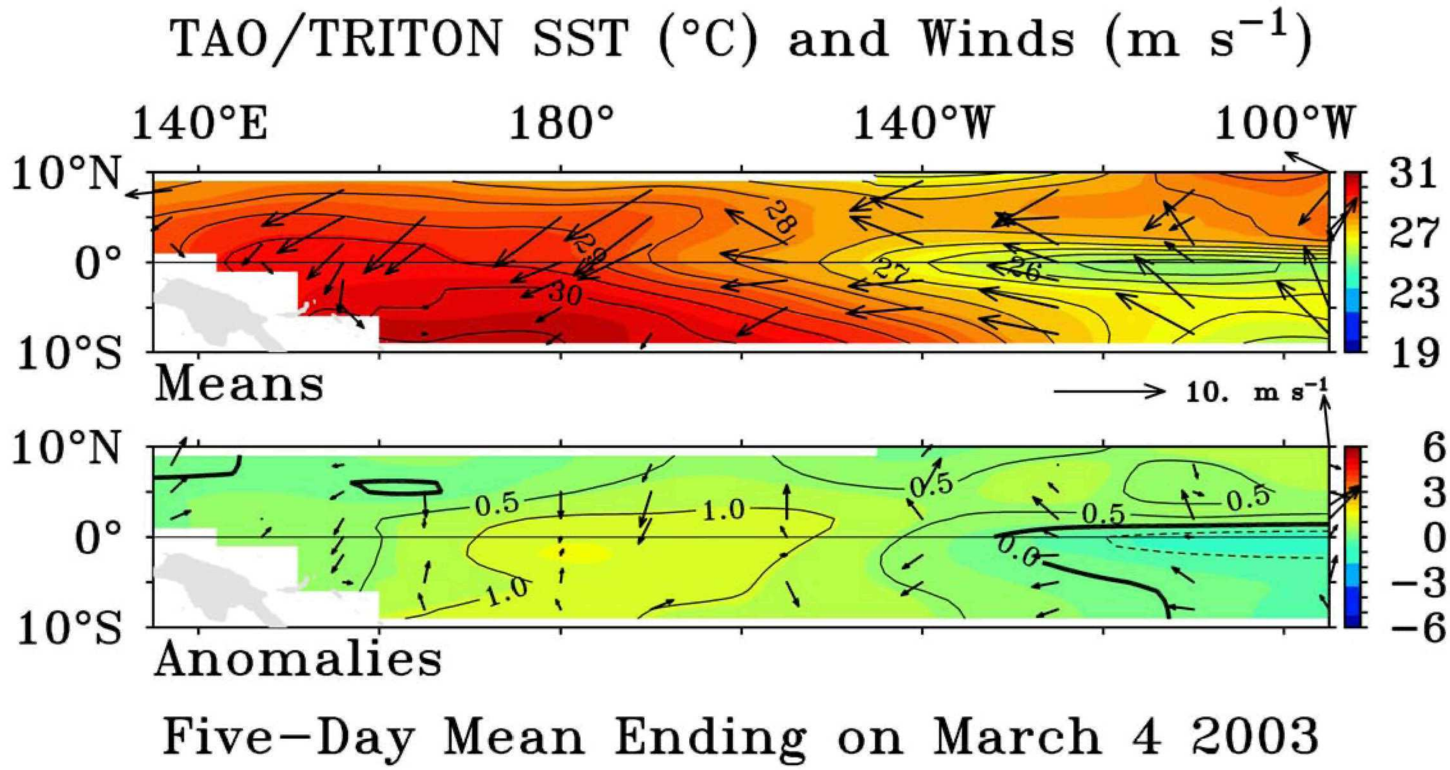
Comparison with previous El Niños

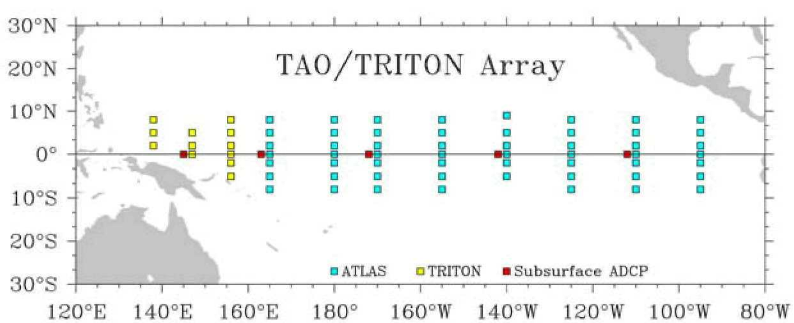




Adapted from International Research Institute

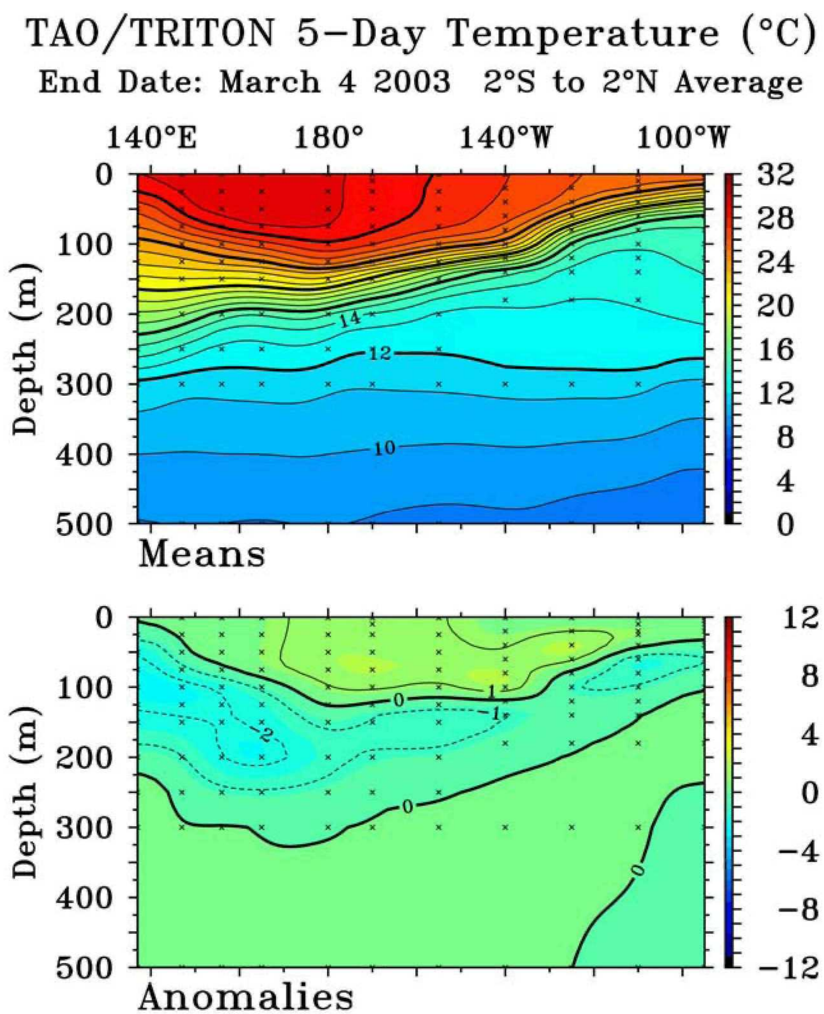
TAO/TRITON Observations





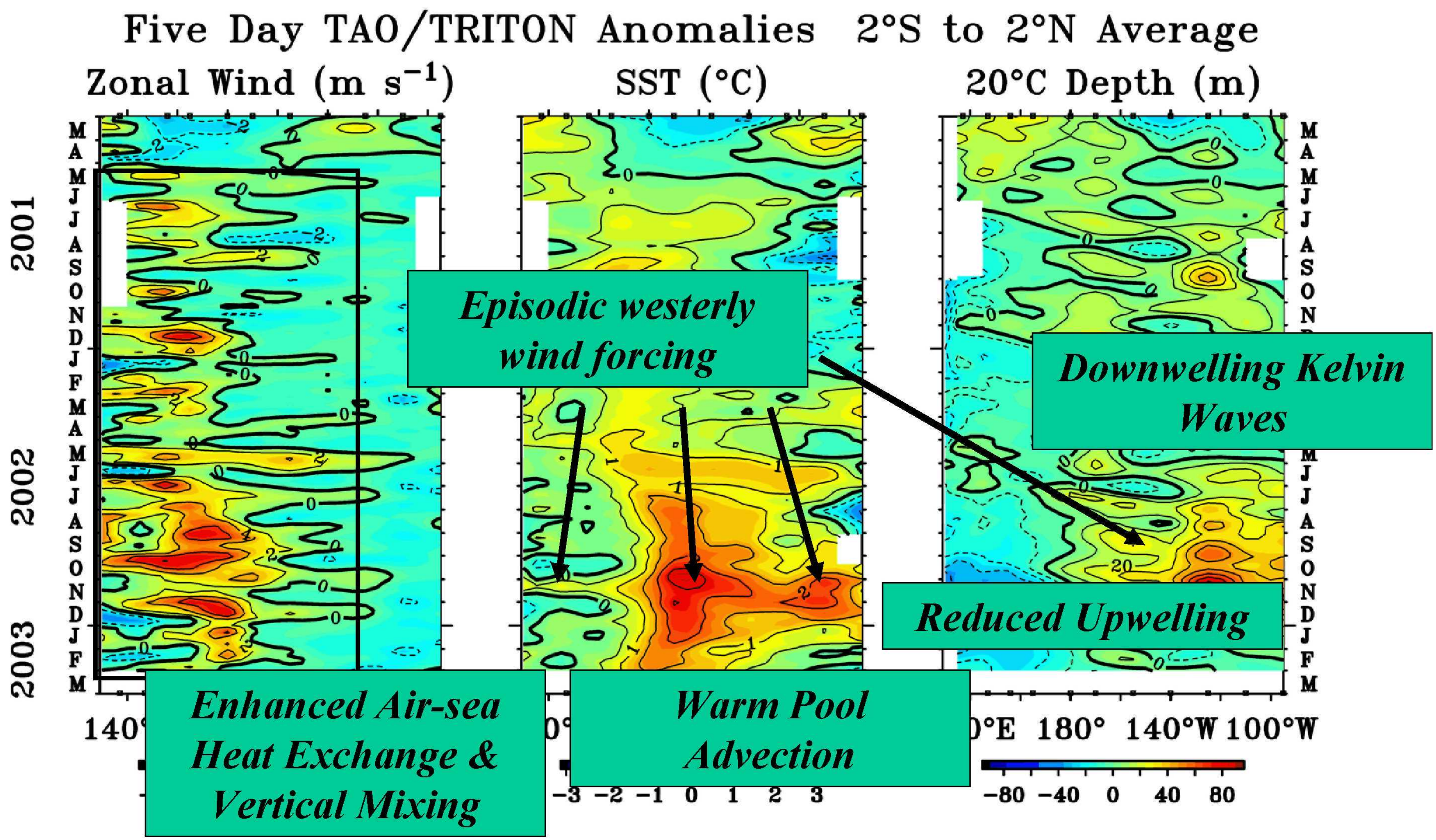
http://www.pmel.noaa.gov/tao/

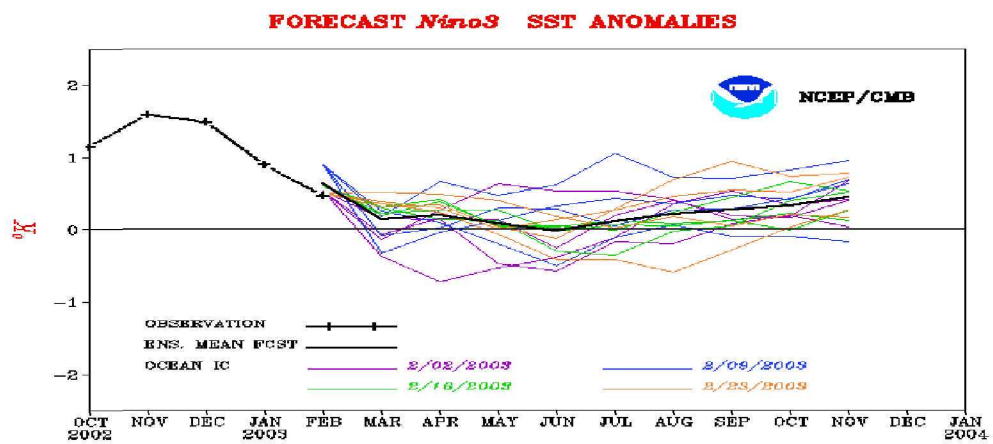
TAO/TRITON Observations

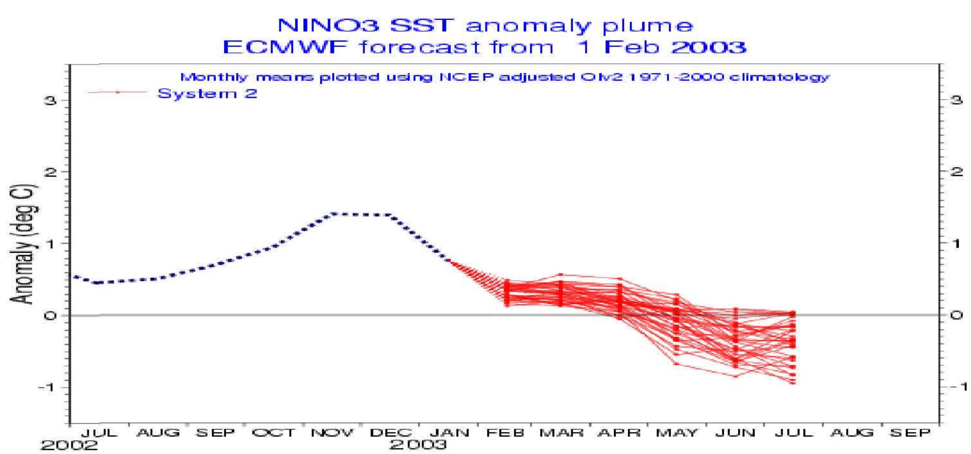


- **Thermocline slopes down to west because trade winds are near normal intensity.**
- **Residual warm anomalies persist in the upper 100 m of the central Pacific.**
- **Cold thermocline temperature anomalies across much of the basin signal the imminent demise of the event.**

March 2001-February 2003




FORECAST Nino3 SST ANOMALIES
NCEP/CMB
°K
OBSERVATION
ENS. MEAN FCST
OCEAN IC
2/02/2003
2/09/2003
2/16/2003
2/23/2003
OCT 2002
NOV
DEC
JAN 2003
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 2004


NINO3 SST anomaly plume
ECMWF forecast from 1 Feb 2003
Monthly means plotted using NCEP adjusted OIv2 1971-2000 climatology
System 2
Anomaly (deg C)
JUL 2002
AUG
SEP
OCT
NOV
DEC
JAN 2003
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

- **Observations indicated the development of warm El Niño conditions in the tropical Pacific during 2002-2003.**

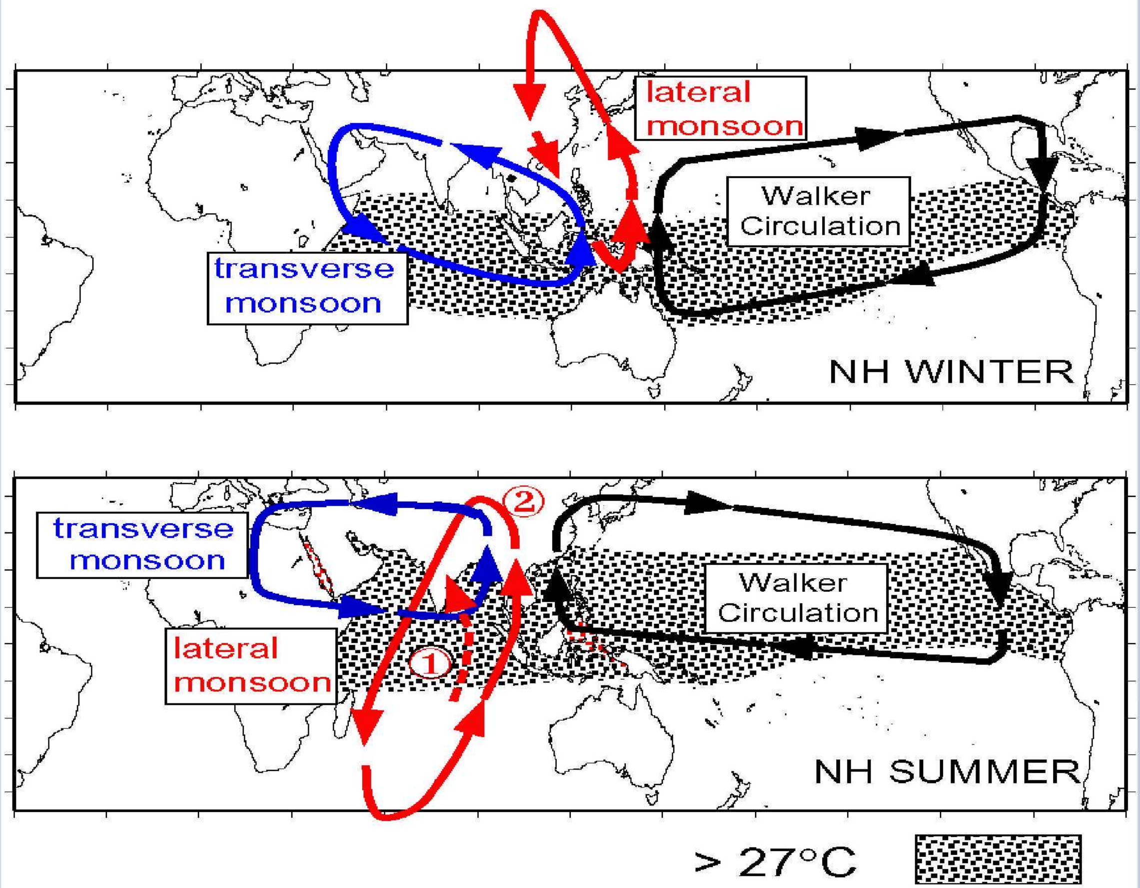
- **This warming was preconditioned by heat content build up near the equator and modulated by MJO-related intraseasonal atmospheric forcing.**

- **Both SST and heat content anomalies indicated an event of “moderate” strength.**

- **Reflected Rossby waves at the western boundary appeared to contribute to the demise of the event.**

- **The El Niño had its demise during boreal spring.**

Monsoon - ENSO Connections



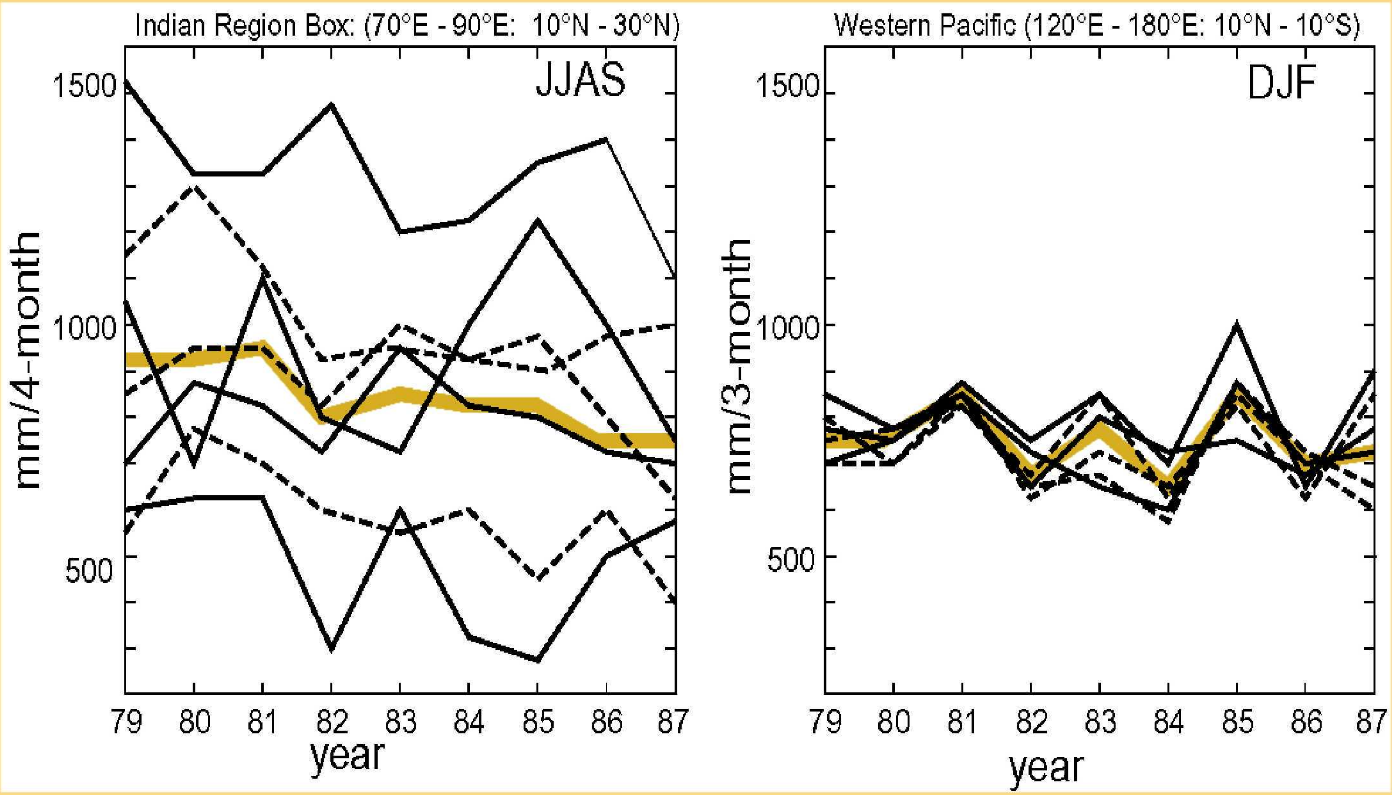
The three components of the monsoon system are tied to the heated land (both desert and pluvial areas), the tropical warm pools and the cold winter ocean and land areas. All of these conspire to produce the strongest heating gradients on the planet. There are three major circulations associated with the boreal and austral summer monsoons. These are the transverse and lateral components, and the Walker Circulation. Together these form a simplified but integrated view of the Monsoon ENSO atmospheric circulations in the Indo-Pacific Region. CLIVAR will endeavour to improve our understanding of this complex system and strive to improve on the predictions of the seasonal to interannual variability of the climate system across the whole region. (P. Webster, PAOS, 1997).

The Asian - Australian Monsoon System

The variability of the Asian - Australian Monsoon with its droughts and floods effect about 60% of the world population, global economies. Upper and left: drought in SE Asia (courtesy of G. Meehl). Right: monsoon flooding (© Photodisc), lower: TOGA IPO.

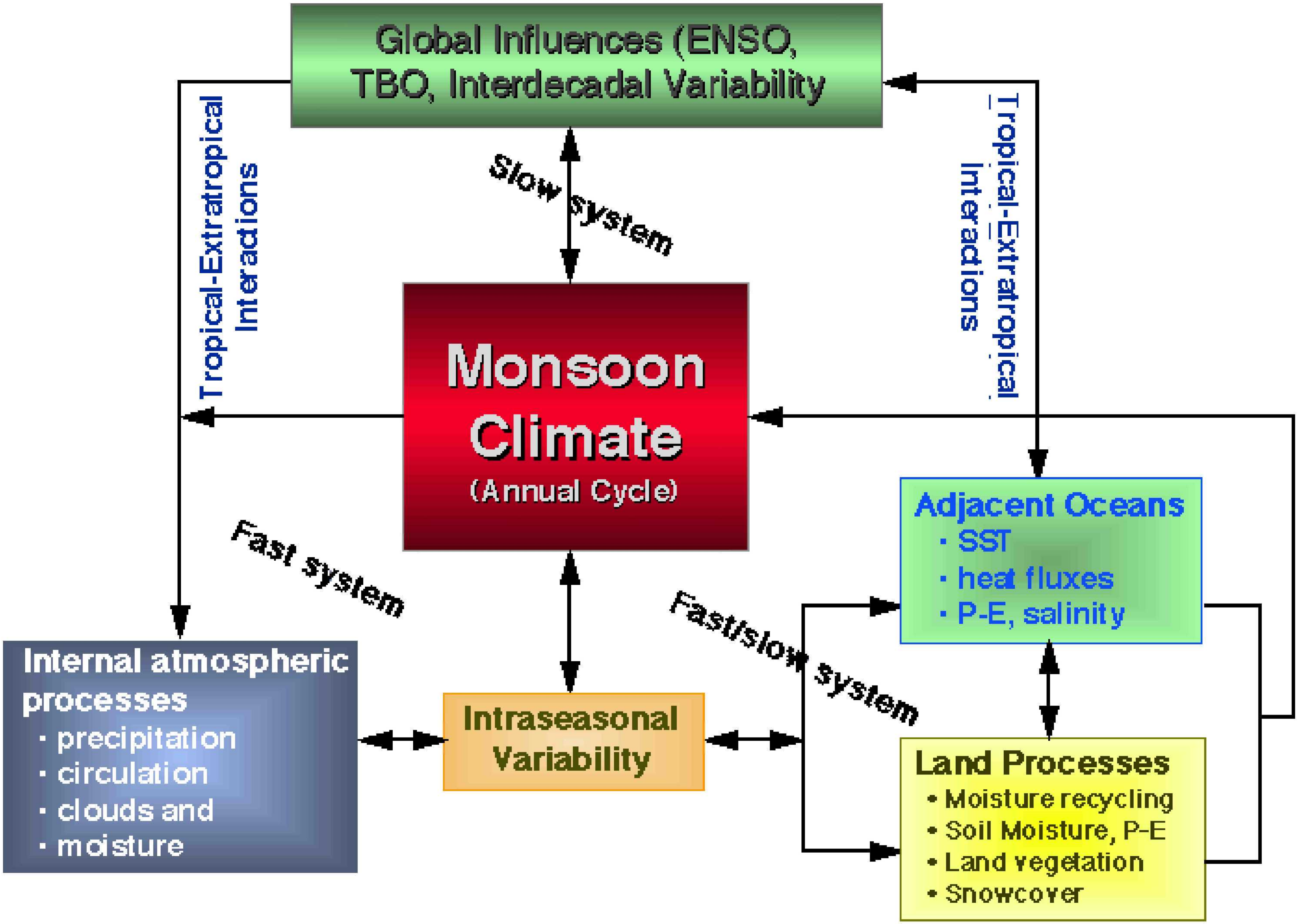
LB/G2/99-2

Modelling the Asian-Australian Monsoon



Comparison of AMIP normalized annual precipitation estimates of 8 models for (a) north India and (b) for the western Pacific Ocean warm pool. Gray curve represent the ensemble mean (Webster, 1998, pers. communication).

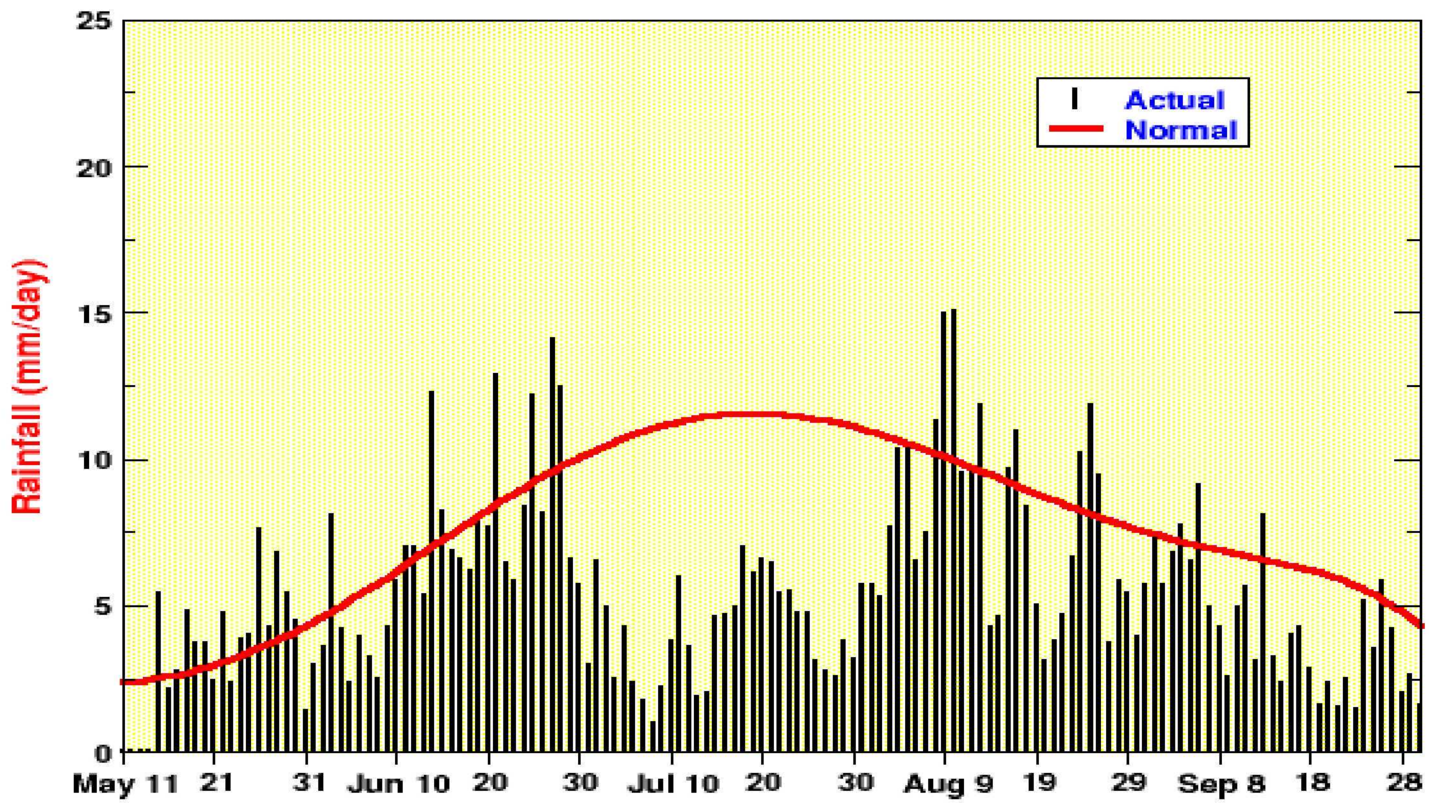
AV/G2/99-7


Global Influences (ENSO, TBO, Interdecadal Variability
Tropical-Extratropical Interactions
Slow system
Tropical-Extratropical Interactions
Monsoon Climate
(Annual Cycle)
Adjacent Oceans
· SST
· heat fluxes
· P-E, salinity
Fast system
Fast/slow system
Internal atmospheric processes
· precipitation
· circulation
· clouds and
· moisture
Intraseasonal Variability
Land Processes
• Moisture recycling
• Soil Moisture, P-E
• Land vegetation
• Snowcover

2002 monsoon

Daily evolution of all-India summer monsoon rainfall, 2002

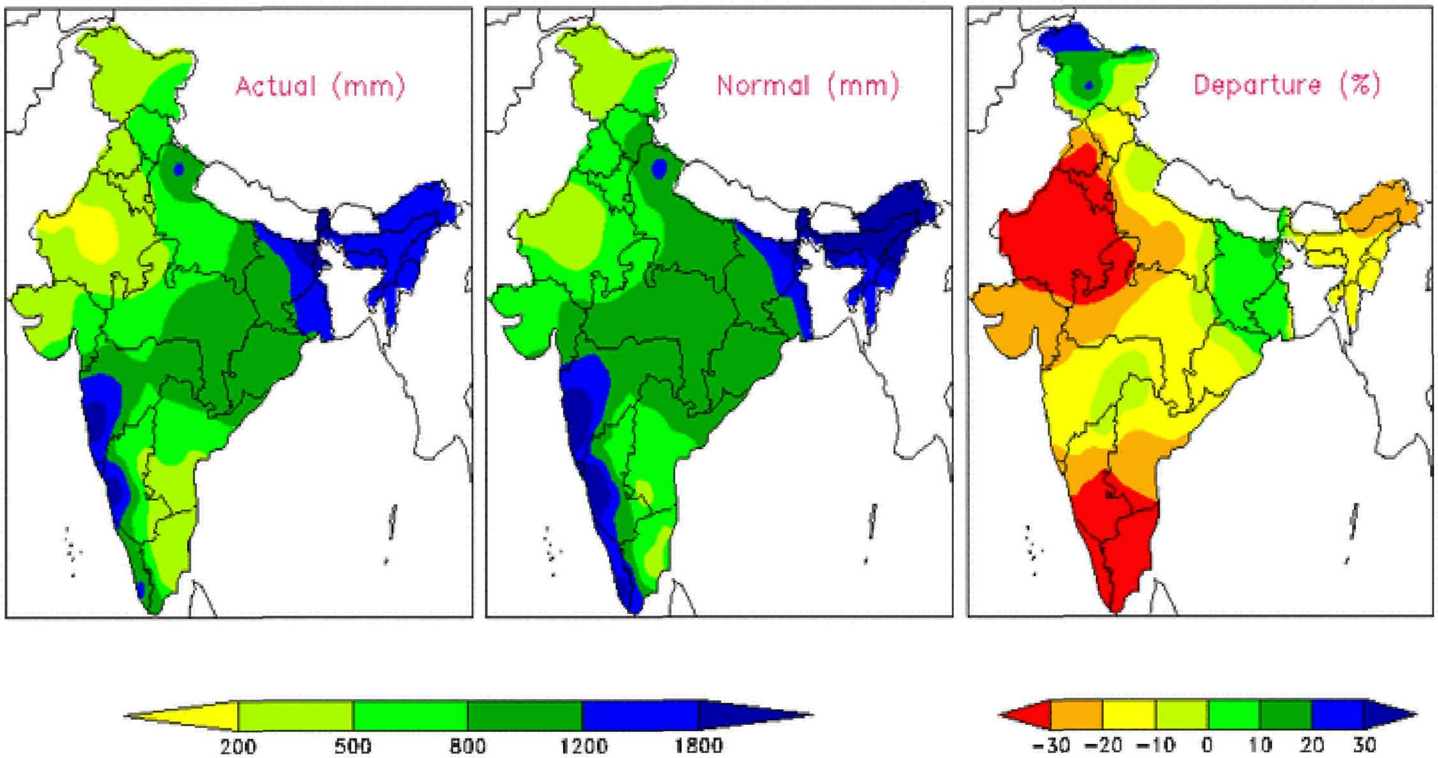
- notable deficit in July -



2002 Monsoon

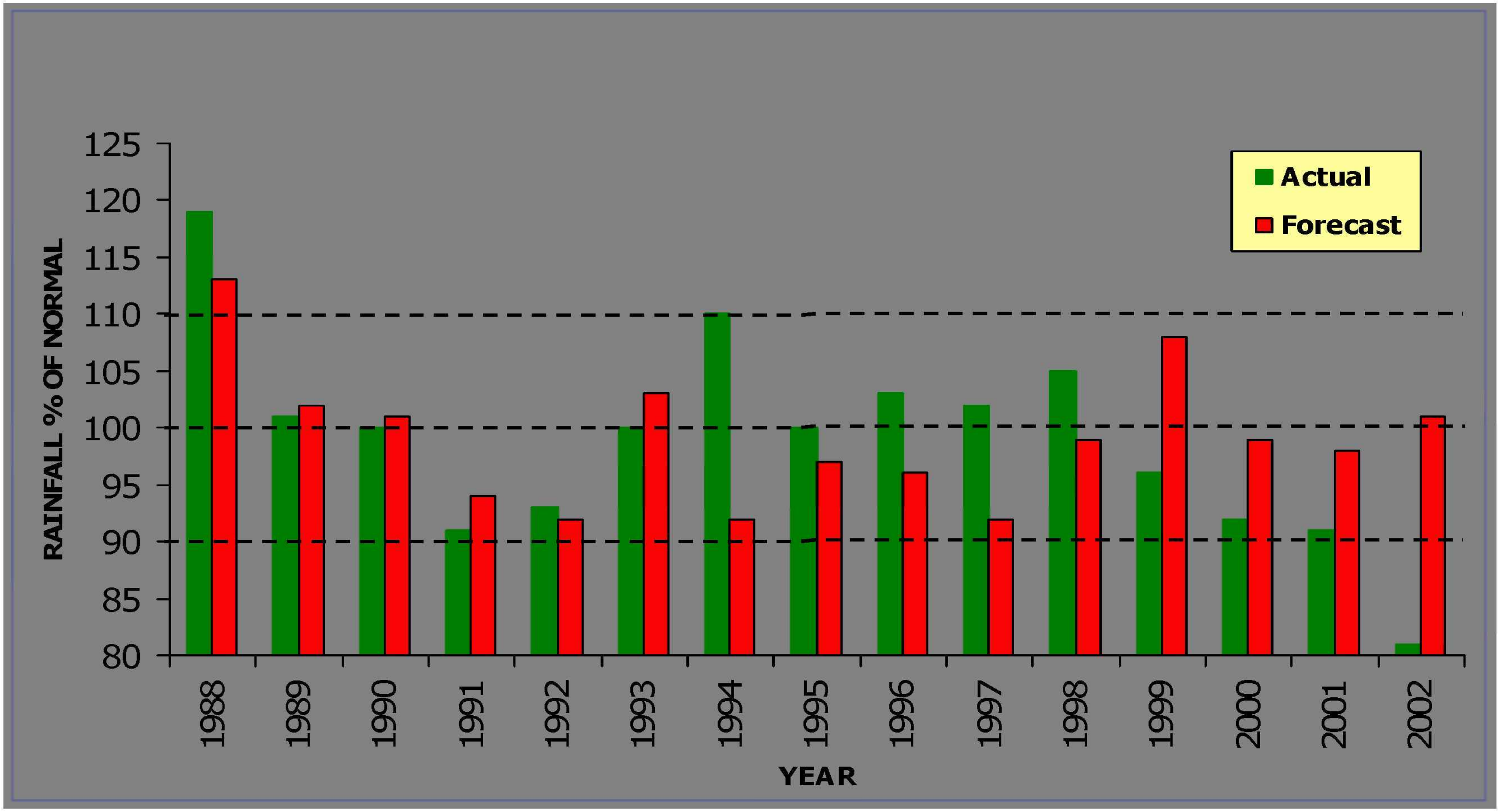
unprecedented rainfall deficit occurred in India 2002

- Seasonal total rainfall and anomaly patterns



Unusual monsoon in 2002

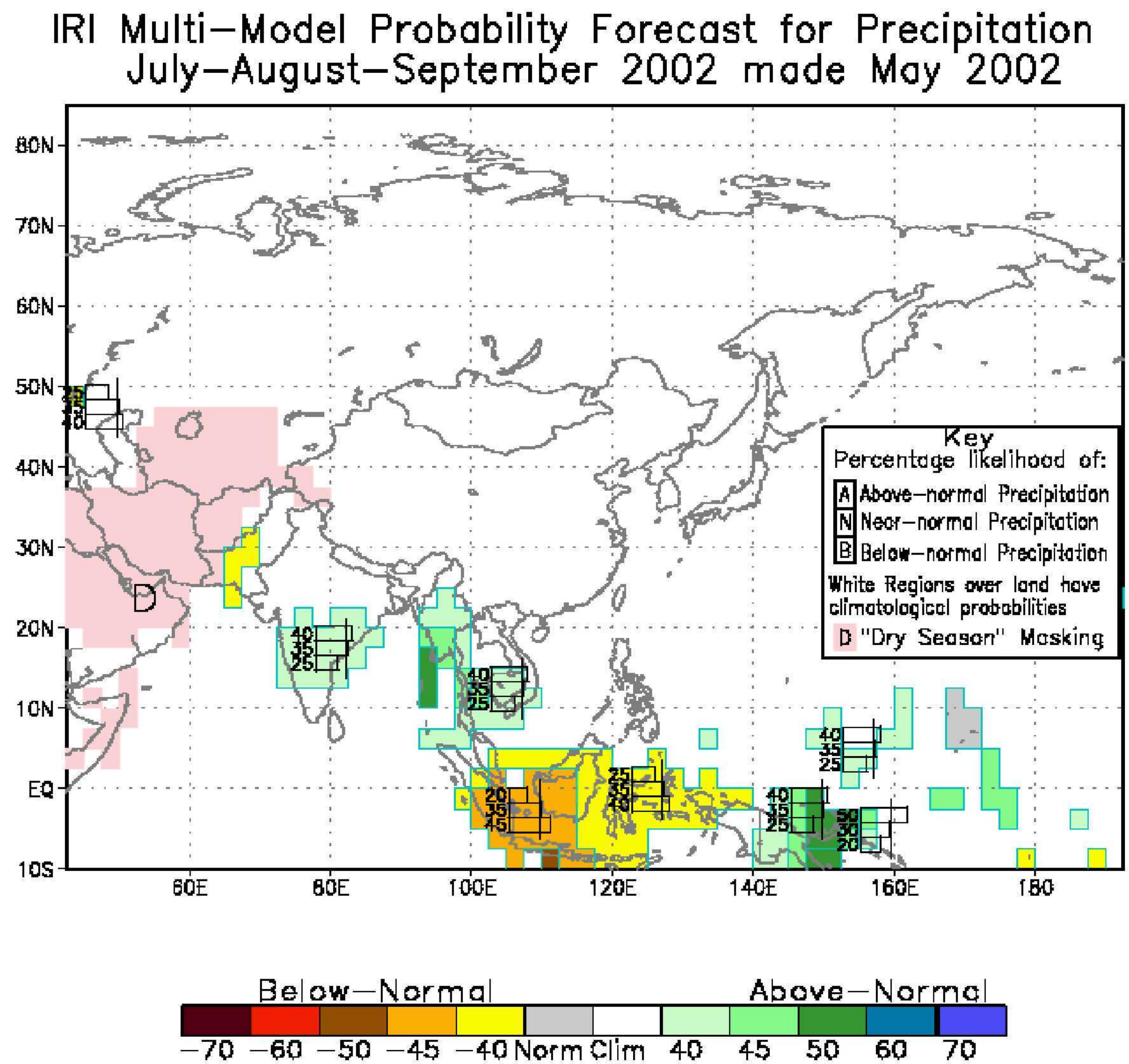
Recent Performance of Indian operational long-range forecasting model - particularly failed for 2002 -



2002 monsoon

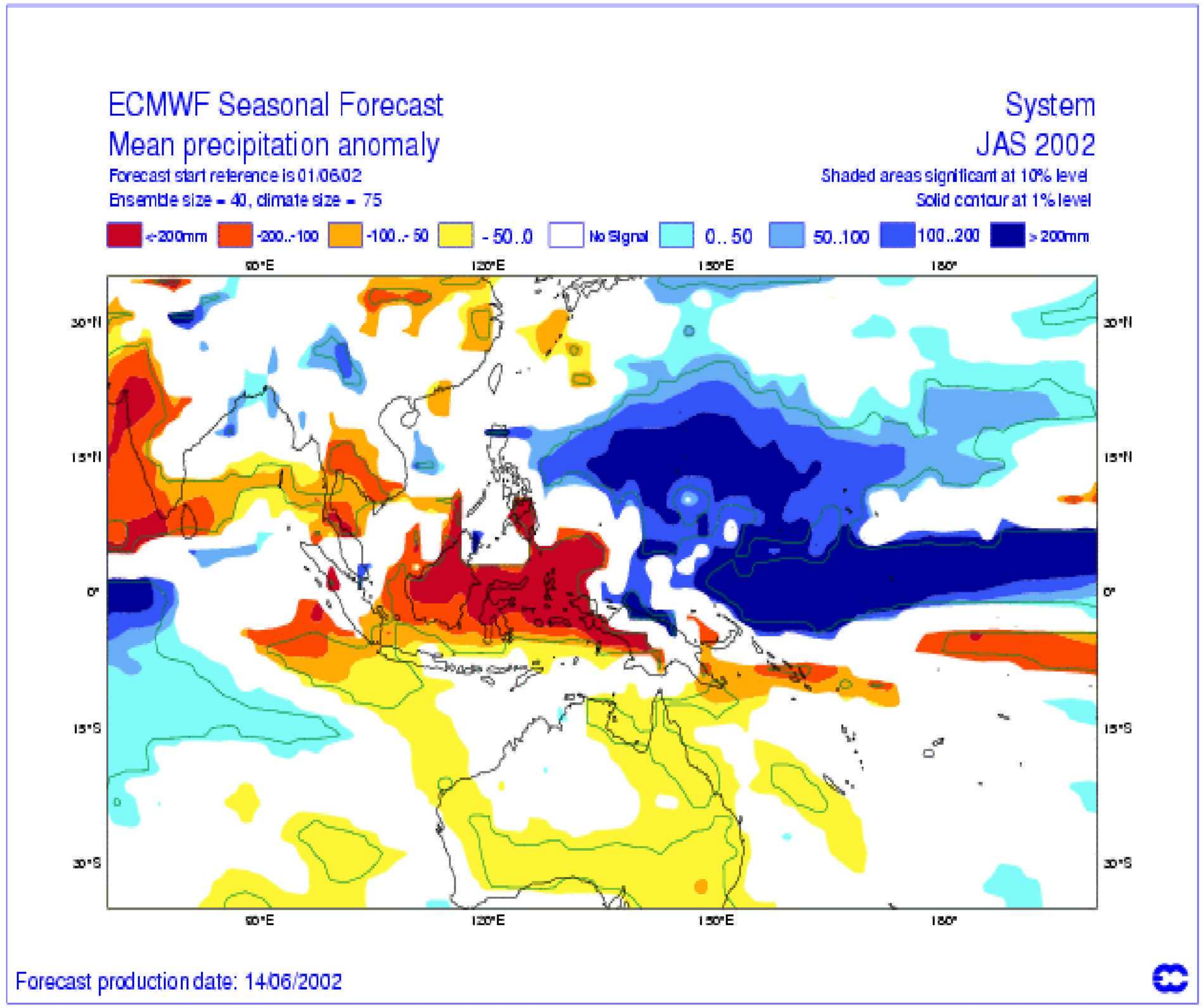
Example prediction from the IRI made in May 2002.

The April prediction had indicated drought conditions



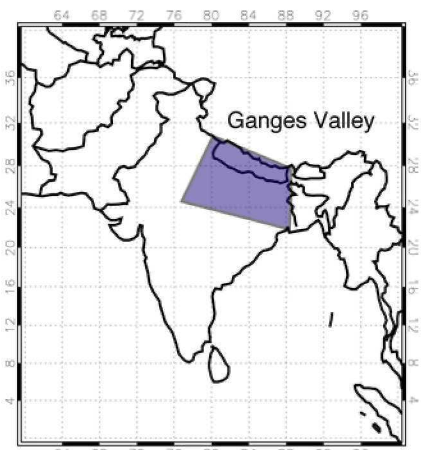
2002 monsoon

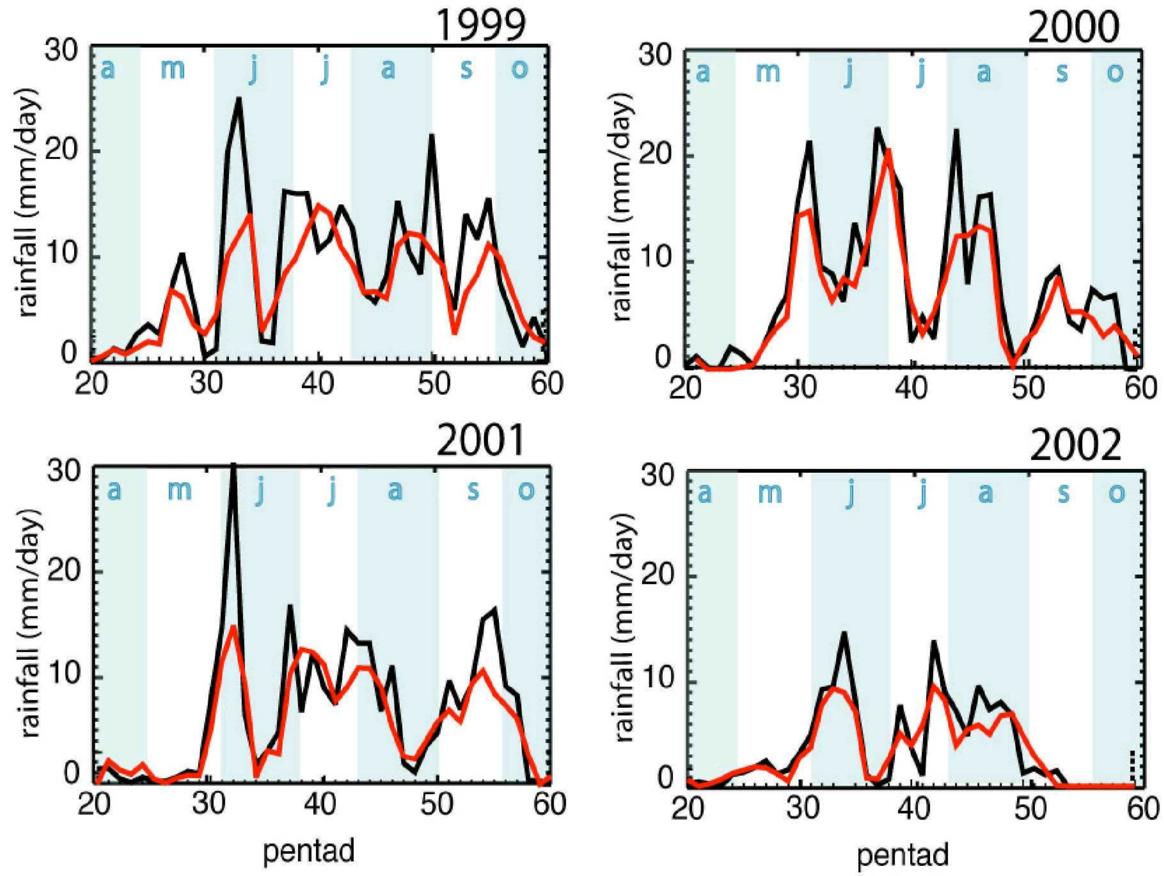
ECMWF model prediction made in June 2002



Advances in Asian-Australian Monsoon Study

Encouraging results from a physics-based empirical method for predicting intra-seasonal monsoon variability have recently been documented.



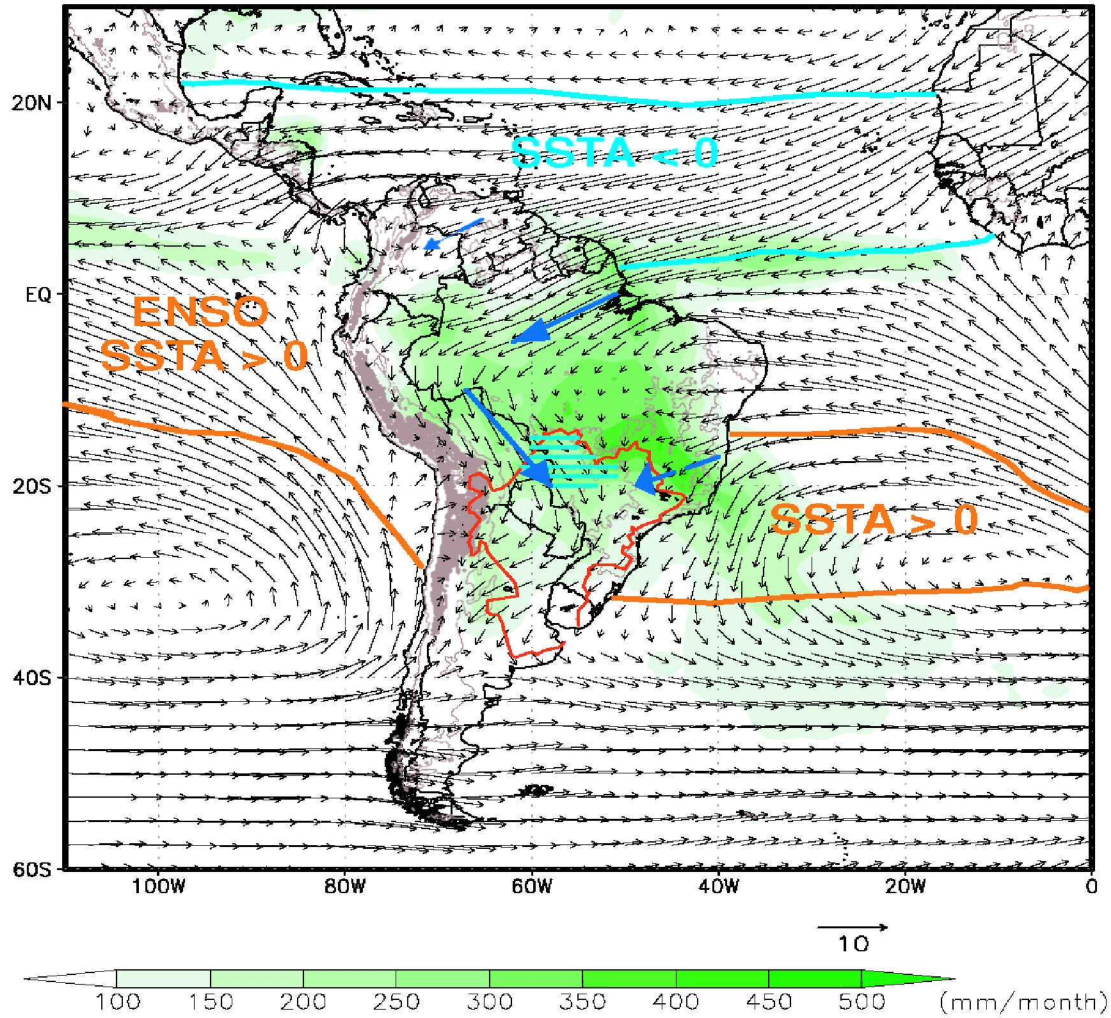


Example:
20-day forecast for Ganges Plain
(Webster 2003)

Unusual monsoon in 2002

- **No major precursor forcing indicating a poor monsoon**
- **Strong evidence suggesting that the tropical ISO triggered enhanced convection in the Pacific, leading to adverse circulation anomalies over India.**
- **The association of monsoon with global circulation features in 2002 is beyond the range of past associations used to train the empirical models.**
- **Need to find precursors for major anomalies in the active months of July and August.**
- **Need to monitor/predict the ISO over the Asia-Pacific sector and to have better understanding of its role in modulating Indian summer monsoon rainfall.**

South American Monsoon Modulation by SST Anomalies



Links between climate variability in the Rio de la Plata basin (area encircled by the red curve) and SST anomalies for the southern warm season (December-February). Green shading corresponds to precipitation (mm/month), black arrows to 925 hPa winds, thick blue arrows to maxima in vertically integrated moisture transport, and the blue hatched region to the Pantanal. The configuration of SST anomalies corresponds to enhanced precipitation in the basin (C.R. Mechoso, 2000, Exchanges No. 16, 5-7.).

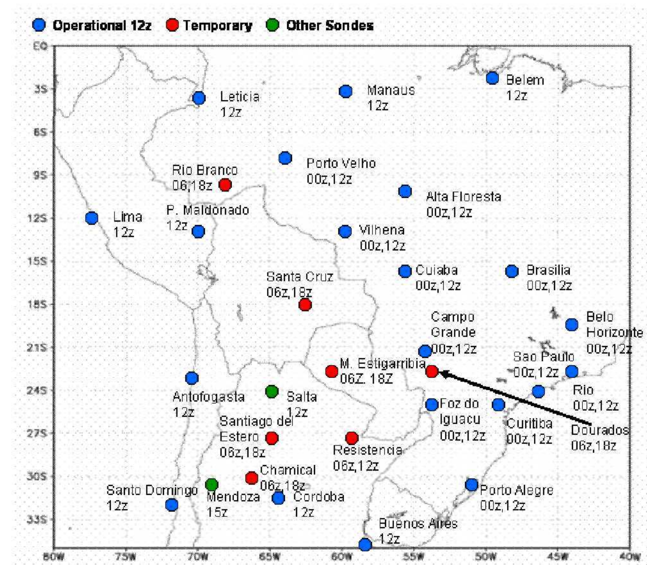
AV/G3/0102

SALLJEX UPPER-AIR NETWORK

Objective: To reduce the uncertainty in estimating the intensity and other characteristics of the tropospheric flow over a large region currently without a dense sounding network

SALLJEX PIBALS

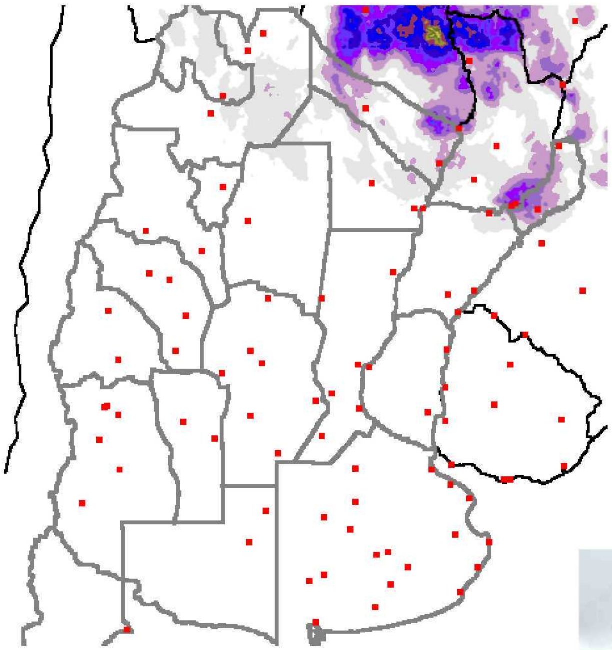
SALLJEX radiosondes (red)



SALLJEX DAILY PRECIPITATION NETWORK

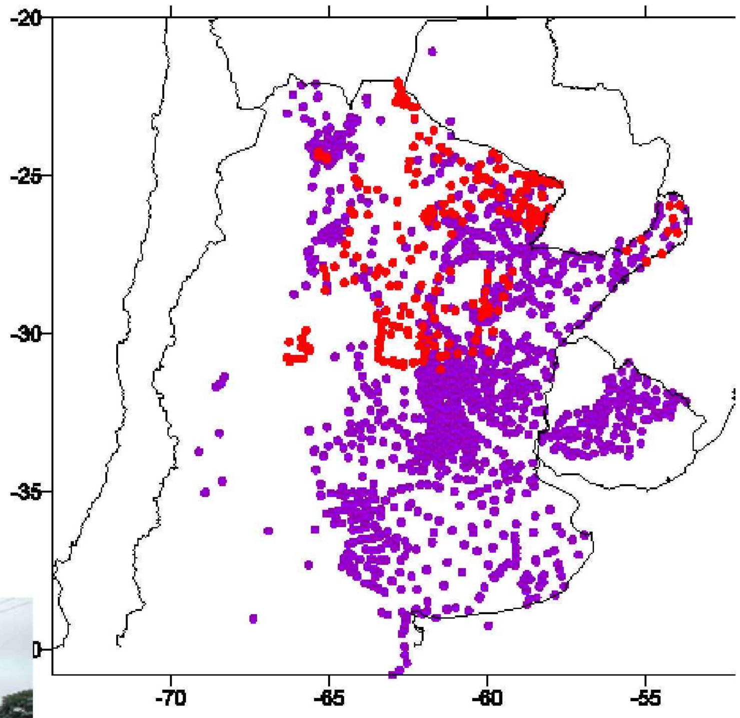
This network not only includes the new raingauges installed by SALLJEX (red) but also raingauges owned by local cooperatives and institutions (purple) that kindly accepted to participate in the experiment in an unprecedented way.

NWS operational network



Example of the SALLJEX network in Argentina

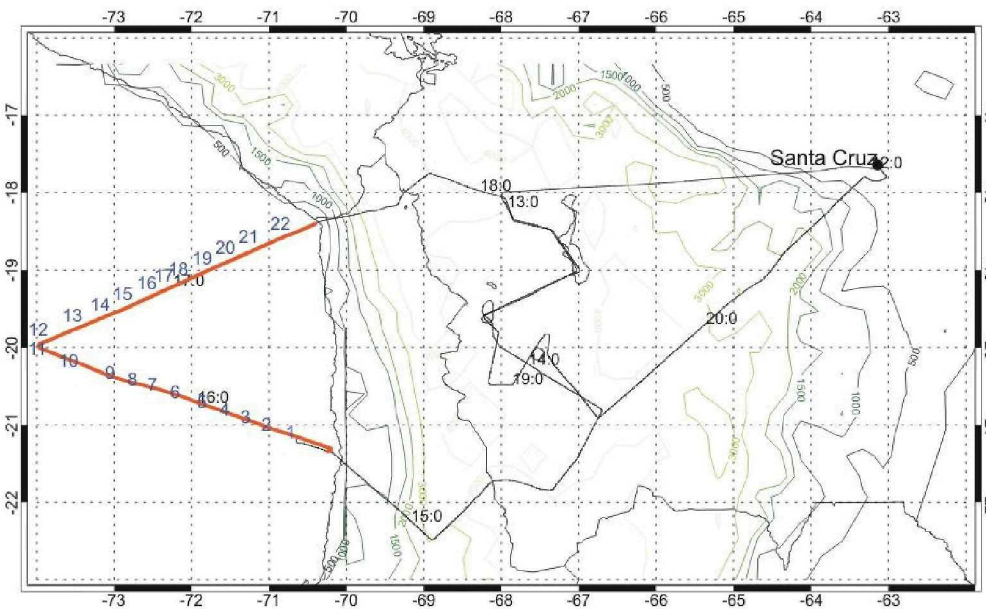
SALLJEX Network



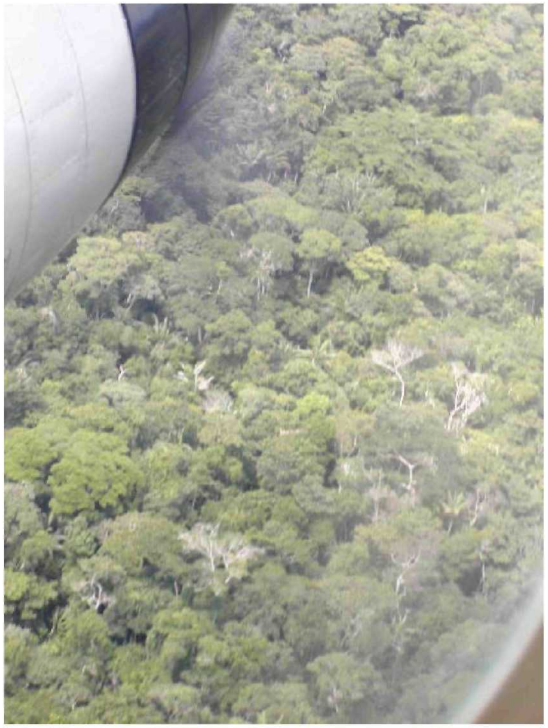
NOAA/P-3 Missions in SALLJEX

Around 120 hours were available for SALLJEX during the period between 6 January and 15 February 2003.

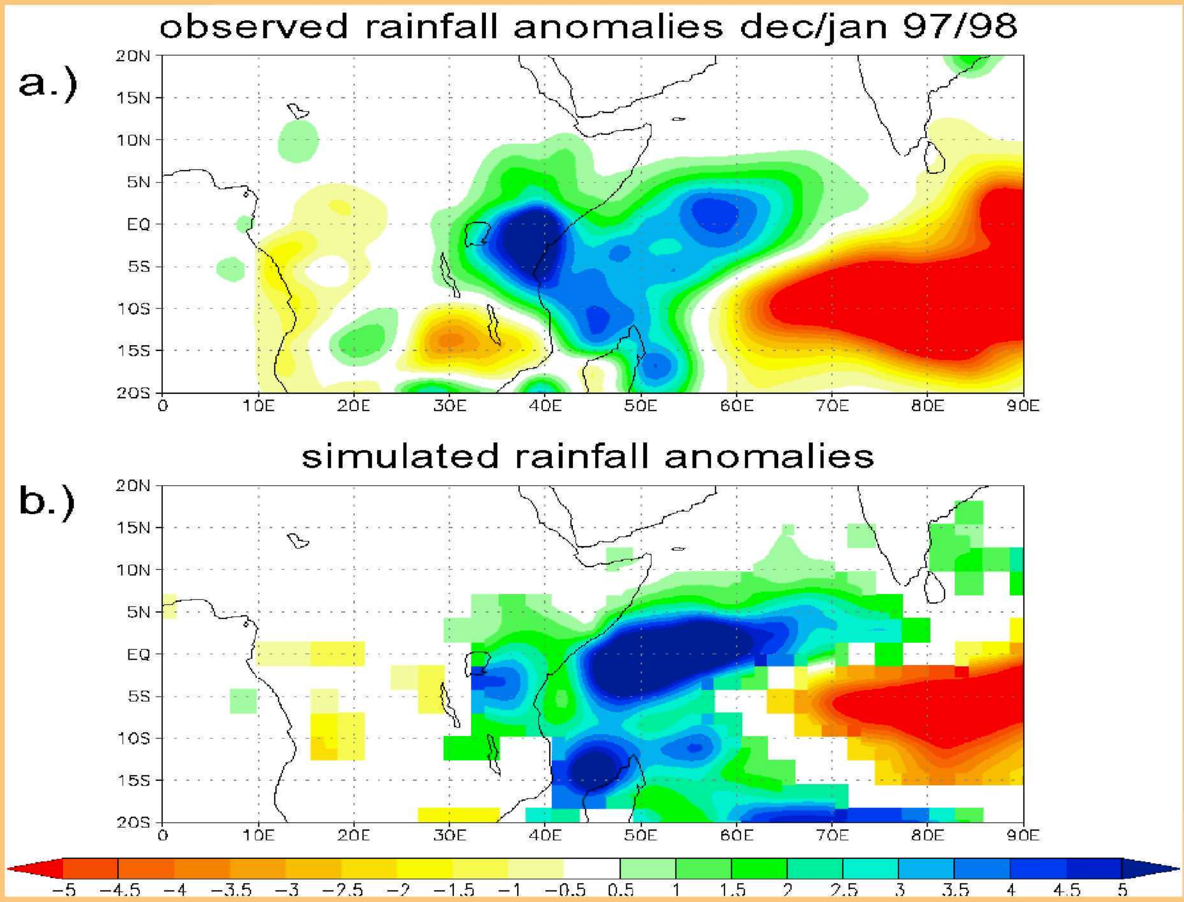
SALLJEX Flight 2003/01/28



Mission over the Altiplano & South Pacific Ocean



East African Rainfall and Indian Ocean SST's

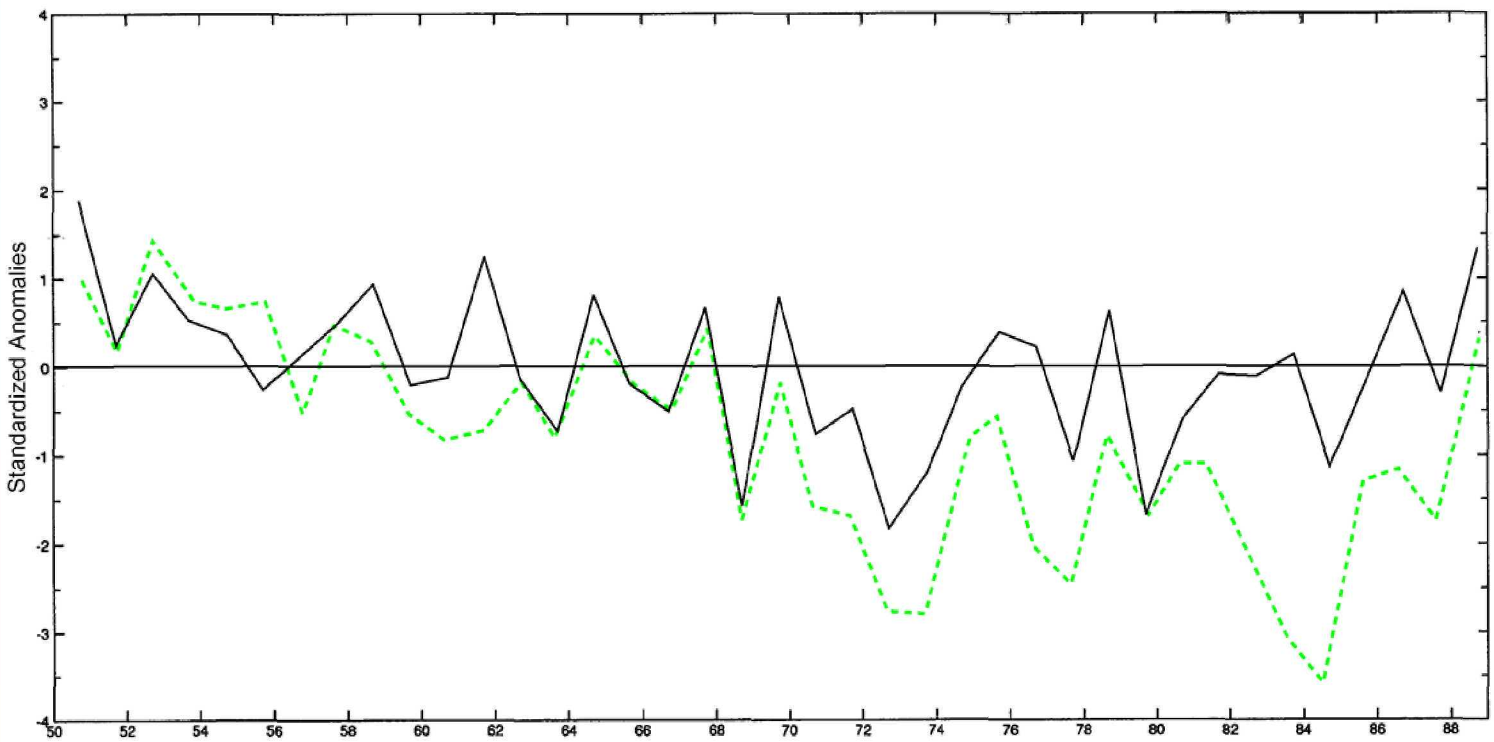


a) observed rainfall anomalies (mm/d) (after Ropelewski and Halpert, 1989, J. Climate, 2, 268-284) during the period December 1997-January 1998. b) By the atmosphere model ECHAM-3 (T42) simulated rainfall anomalies (mm/d) with Indian Ocean SST anomalies prescribed. The model response shown is the mean over five realizations. Shown are the anomalies (relative to a 30-year control run with climatological SSTs) which exceed the 95% significance level according to a t-test. (from Latif et al., 1998, MPI report No. 276, Hamburg, 12pp).

AV/G4/99-6

Variability of the Sahelian Rainfall

Anomalous Latitude of ITCZ at 17° W



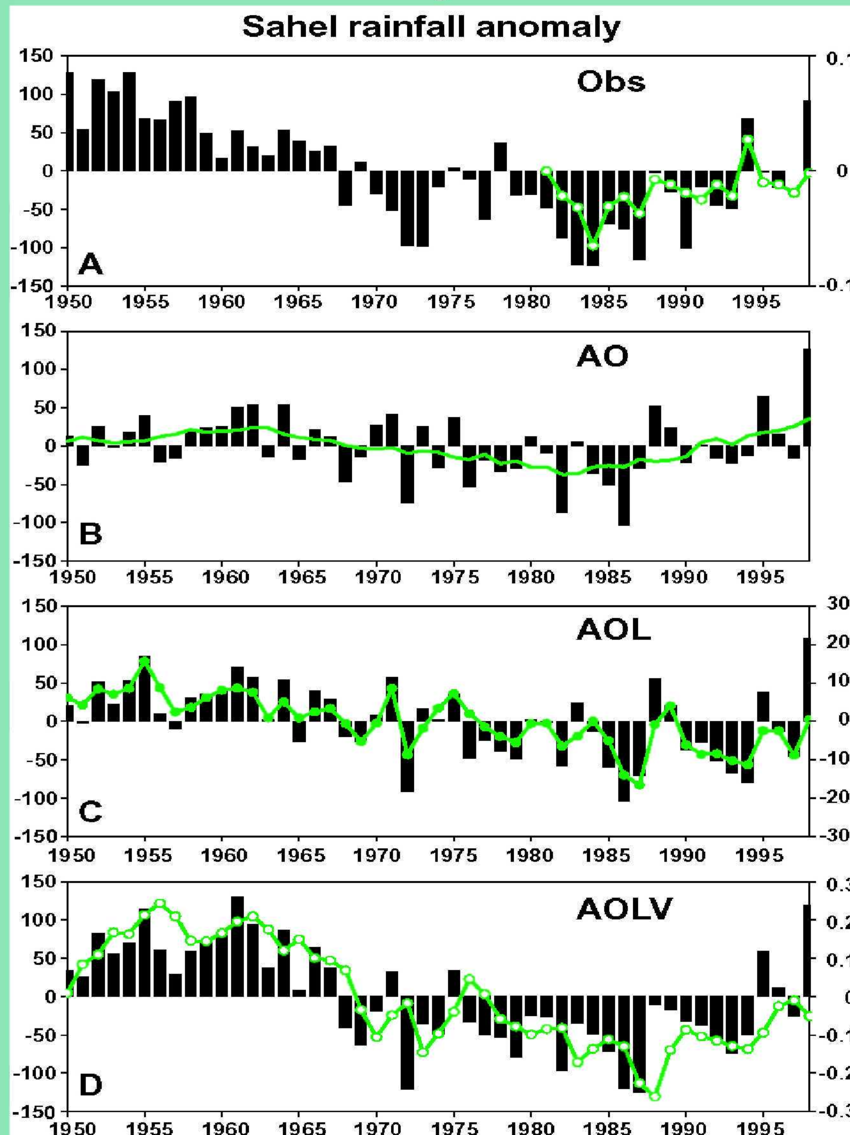
(Tourre and Lamb, 1997, pers. communication)

-------------- Sahelian Precipitation Lamb's Index

Sahelian rainfall variability is closely linked to the latitudinal position of the Intertropical Convergence Zone (ITCZ) and the meridional SST gradient in the tropical Atlantic. The latitude of the ITCZ depends upon both local conditions and remote forcings. The North Atlantic Oscillation (NAO) also generates a component of climate variability over the northern rim of the continent and over Western Africa (Tourre and Lamb, 1997, personal communication).

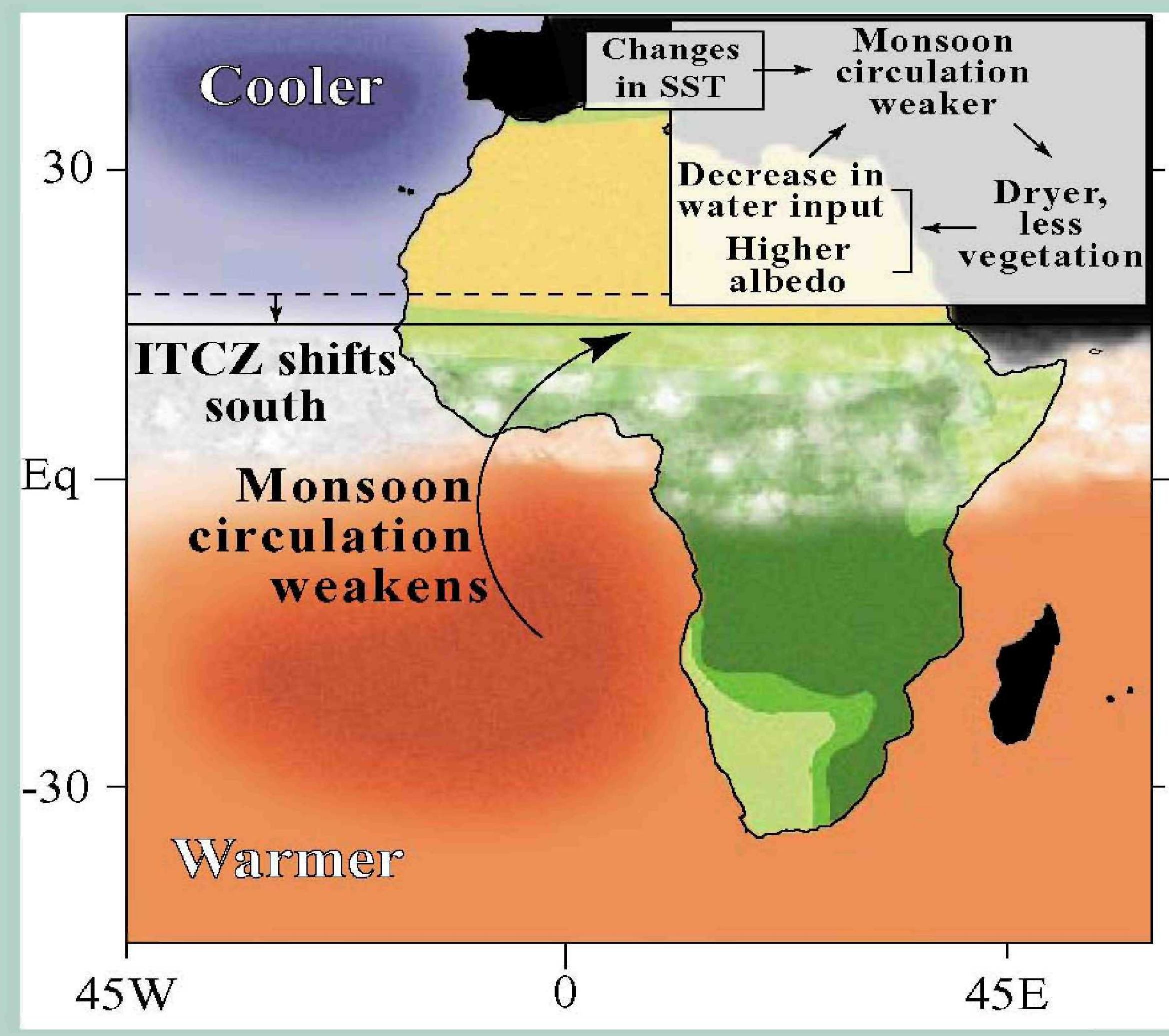
LB/G4/99-2

Decadal Variability of Sahel Rainfall



The dramatic drying trend in the Sahel from the 1950s to the 1980s is initially forced by SST (b) but amplified by soil moisture (c) and vegetation (d). Zeng et al., 1999, Science, 286, 1537-1540.

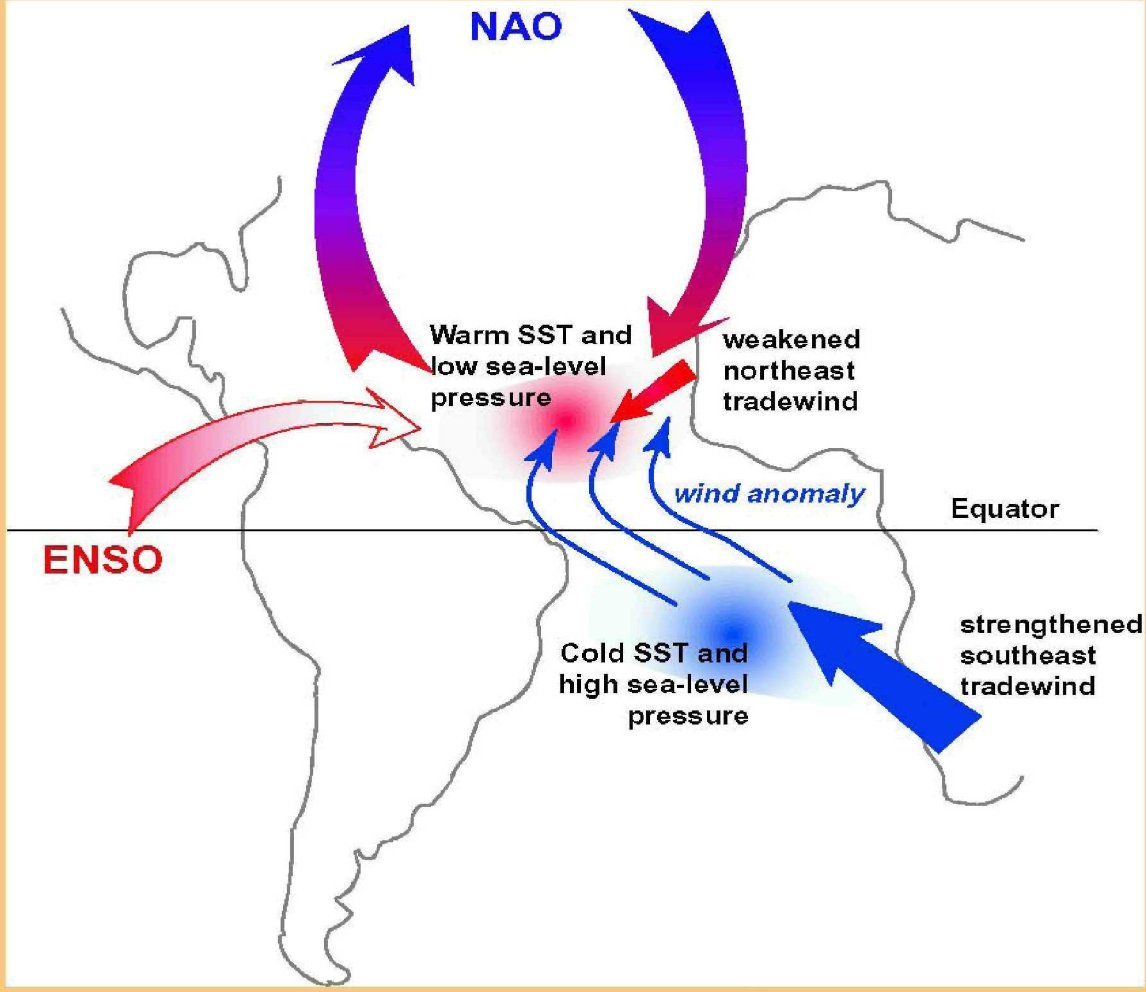
Monsoon - SST Feedback over the Sahel Region



SST - Rainfall - Vegetation feedback affecting the monsoon rainfall over the West African monsoon region. From N. Zeng, pers. communication, result after Zeng et al., 1999, Science, 286, 1537-1540.

AV/G4/0102

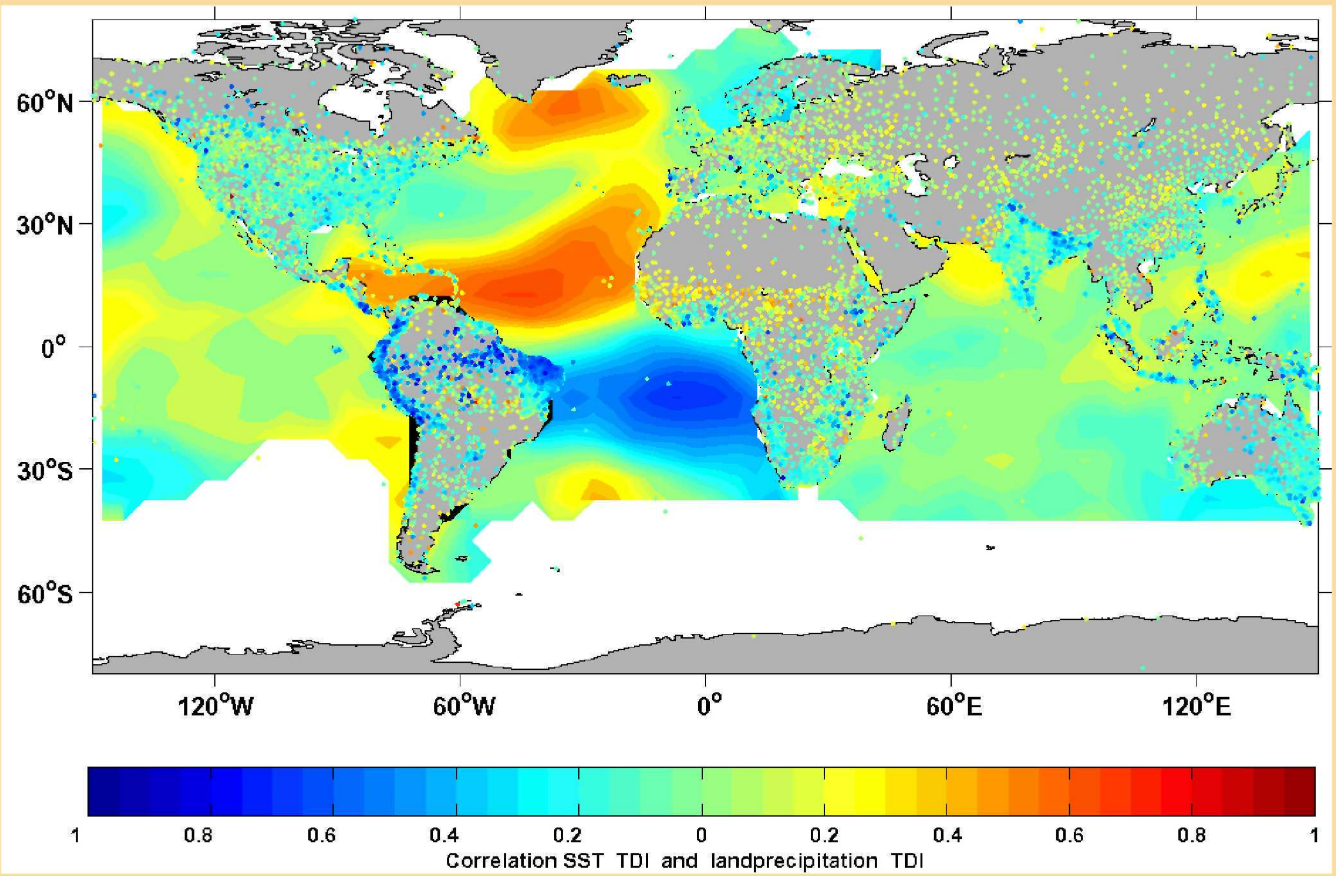
Mechanisms of Tropical Atlantic Variability



Different mechanisms explaining the variability of the tropical Atlantic SST and some teleconnections (courtesy P. Chang)

AV/D2/99-1

Atlantic SST and Rainfall

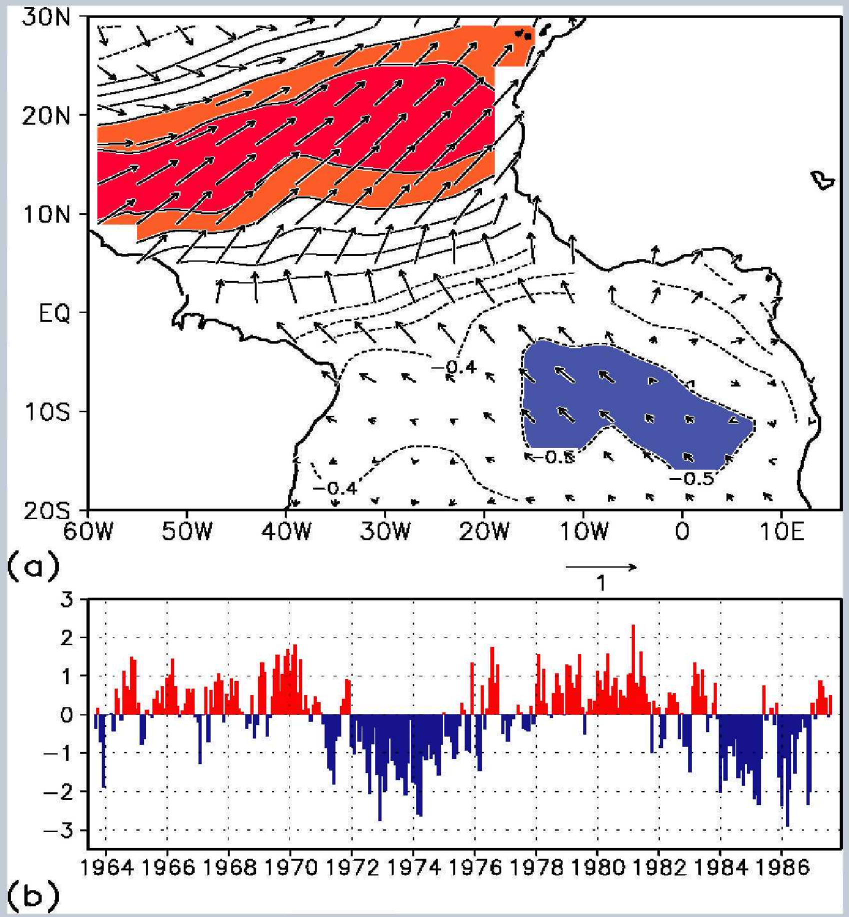


ML/G4/991

Correlation between the Atlantic cross ITCZ SST difference as defined by Servain (1991, J. Geophys. Res., 15137-15146), and station rainfall. This figure is done for annual averages of both the index and the rainfall data from 47 years. The pattern of the Atlantic SST is very similar to the NAO pattern: i.e. during strong phases of the NAO, there are strong westerlies and north-easterlies, colder SST, and thus the ITCZ is further south. When ITCZ is further south, the correlation with Tropical Dipole Index (TDI) is negative, less precipitation over the Sahel region and more precipitation along the coastline in the Gulf of Guinea, more precipitation in the Nordeste Brazil as well (Y. Kushnir and G. Krahmann, 1998, personal communication).

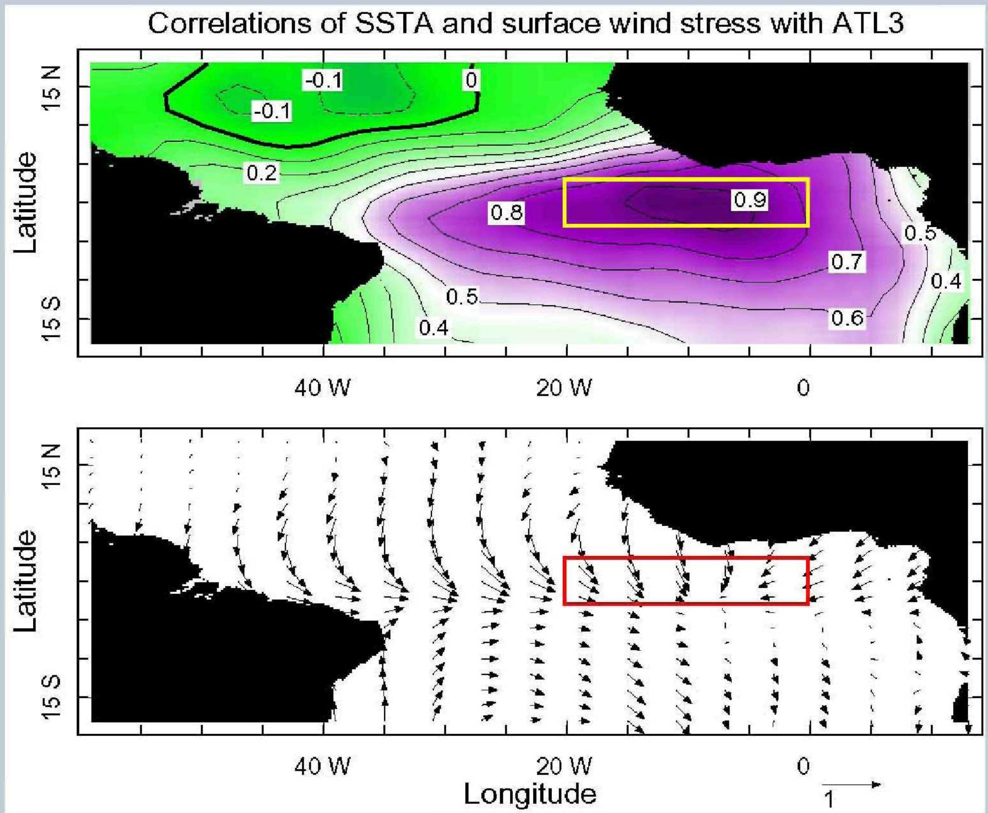
Tropical Atlantic Climate Variability

An Atlantic Dipole ?



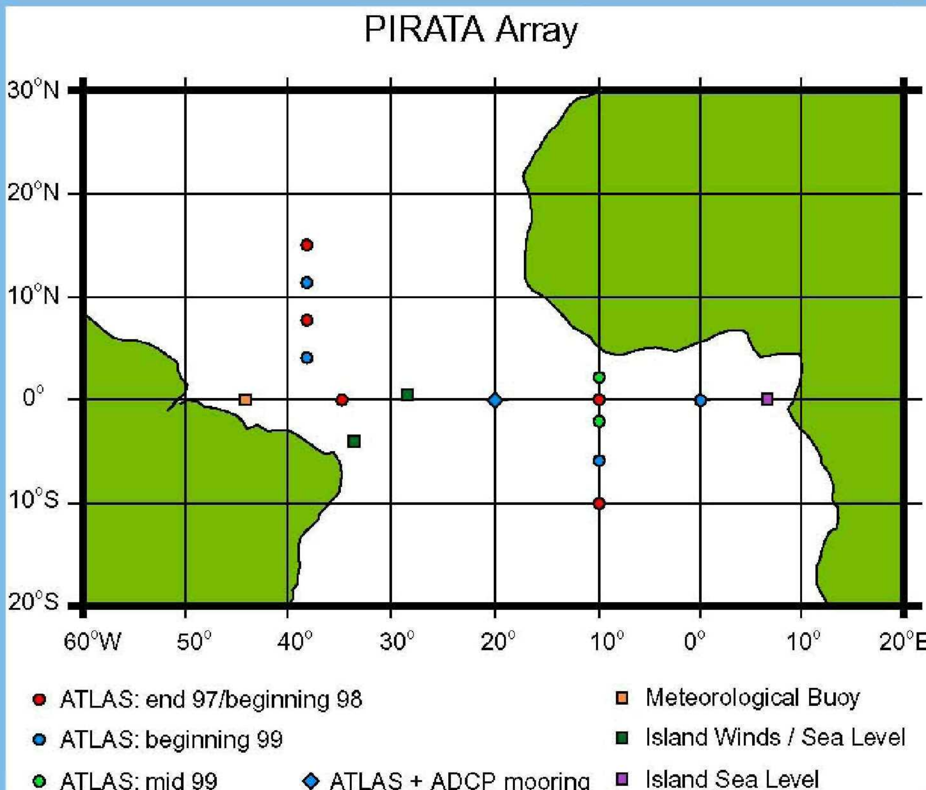
The dominant joint patterns of sea surface temperature and surface wind stress variability over the Atlantic for the period September 1963 to August 1987 and the associated time series. The time series show a dominant signal at lower frequencies but as well, there are seasonal and interannual fluctuations (Nobre and Shukla, 1996, J. Climate, 9, 2464-2479).

Observed Interannual & Decadal Variability in the Tropical Atlantic



Upper panel: correlation between the SST anomaly index ATL3 (the area-averaged SSTA in the outlined region) and SST anomalies at all points in the tropical Atlantic basin, based on the Servain et al. (1996, TOGA Atlantic pseudo-stress atlas, 1985-1994, ORSTOM, Brest, 162pp) analyses for the period 1964-1988, according to Zebiak (1993, J. Climate, 2010-2019).
Lower panel: correlation between ATL3 and the zonal and meridional pseudo-stress anomalies (plotted in vector format) based on the same analyses and observation period. (both figures: Zebiak, 1998, Bull. Meteor. Amer. Soc., 79, 2019-2031.

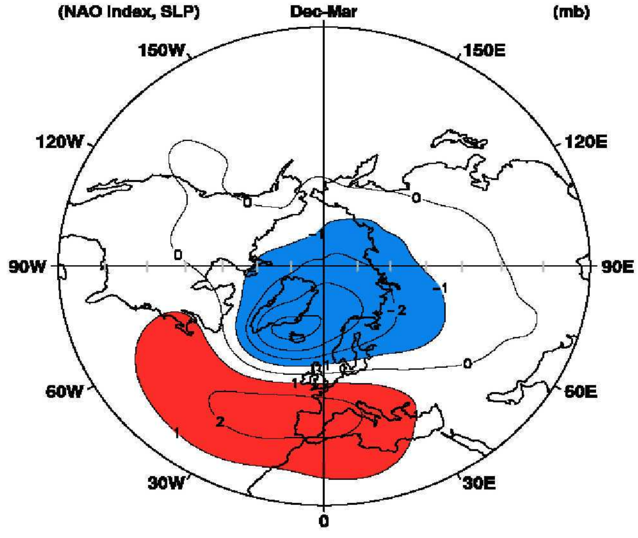
The Pilot Research Moored Array in the tropical Atlantic

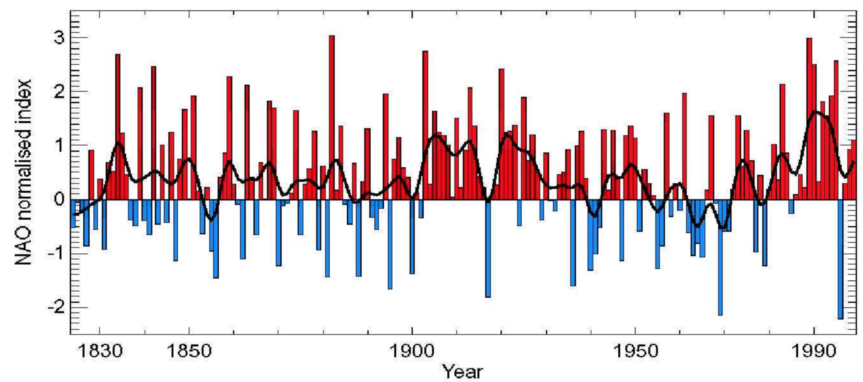


The extent of the Pilot Research Moored Array in the tropical Atlantic (PIRATA) proposed for the year 2000. In the first phase, five buoys (solid circles) were deployed in August 1997 (courtesy of J. Servain).

Deployment of ATLAS buoys during the PIRATA project in autumn 1997 (courtesy of J.Servain).

The North Atlantic Oscillation



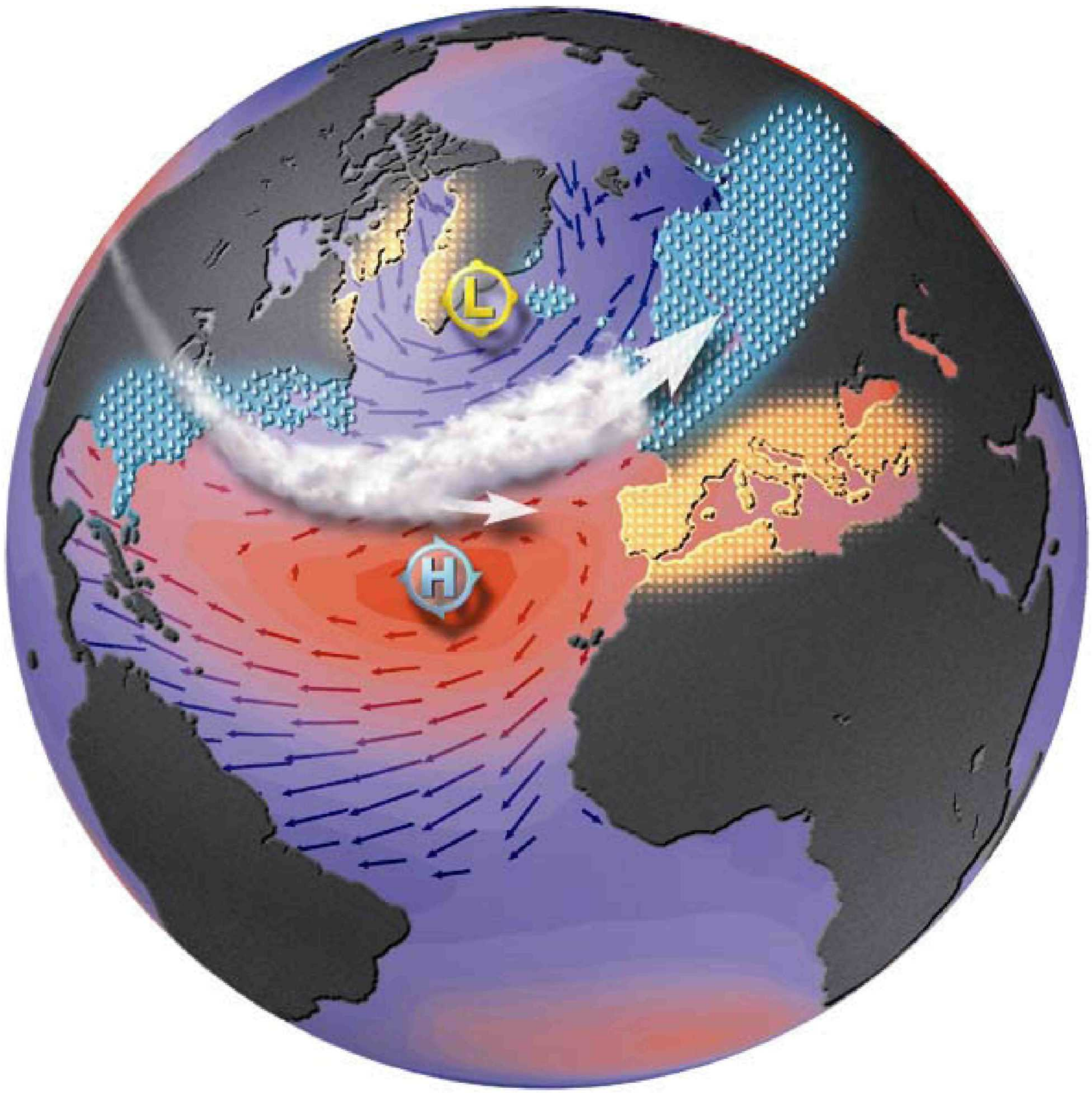


Upper panel: Observed Dec-March change in SLP associated with a 1 standard deviation change in the NAO index (after Hurrell, 1995, Science, 269, 676-679).

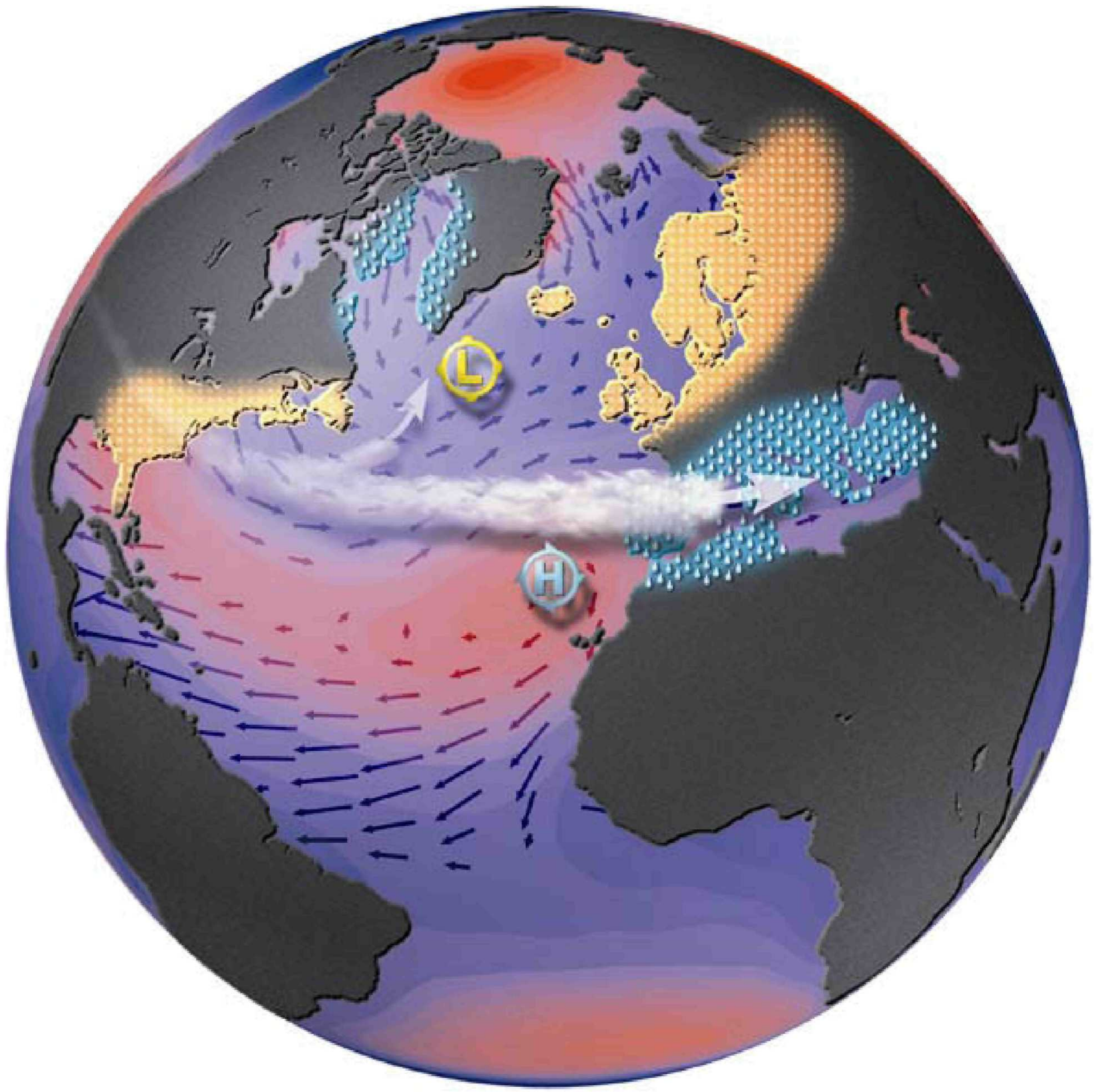
Lower Panel: Winter (December to March) index or the NAO based on the difference of normalized pressure between Lisbon, Portugal and Stykkisholmur, Iceland from 1864 to 1995. The SLP anomalies at each station were normalized by division of each seasonal pressure by the long-term mean (1864-1995) standard deviation. The heavy solid line represents the meridional pressure gradient smoothed with a low pass filter with seven weights (1,3,5,6,5,3, and 1) to remove fluctuations with periods less than 4 years (after Hurrell, 1995, Science, 269, 676-679, this version: courtesy of T. Osborn, CRU, UEA.

LB/D1/99-1

NAO Positive Phase



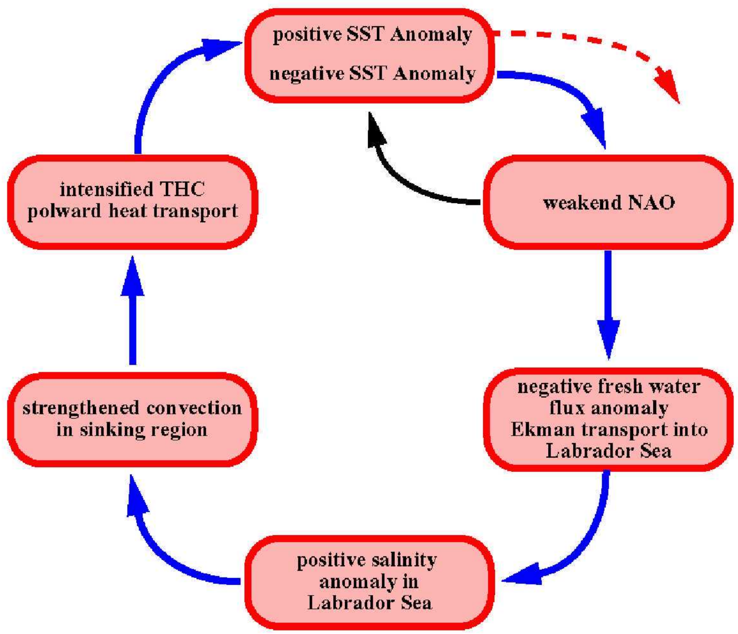
NAO Negative Phase



The NAO - A coupled mode or uncoupled mode?

- An internal atmospheric mode without surface feedback cannot explain the observed decadal variability of the NAO pattern.
- There is growing observational and modelling evidence to suggest that decadal variability over the northern ocean basins is governed by the coupled ocean-atmosphere system, including processes which might determine longer period fluctuations in the NAO.
- Different hypotheses to explain the NAO exist.

The NAO mode as descibed by Timmerman et al., 1998)

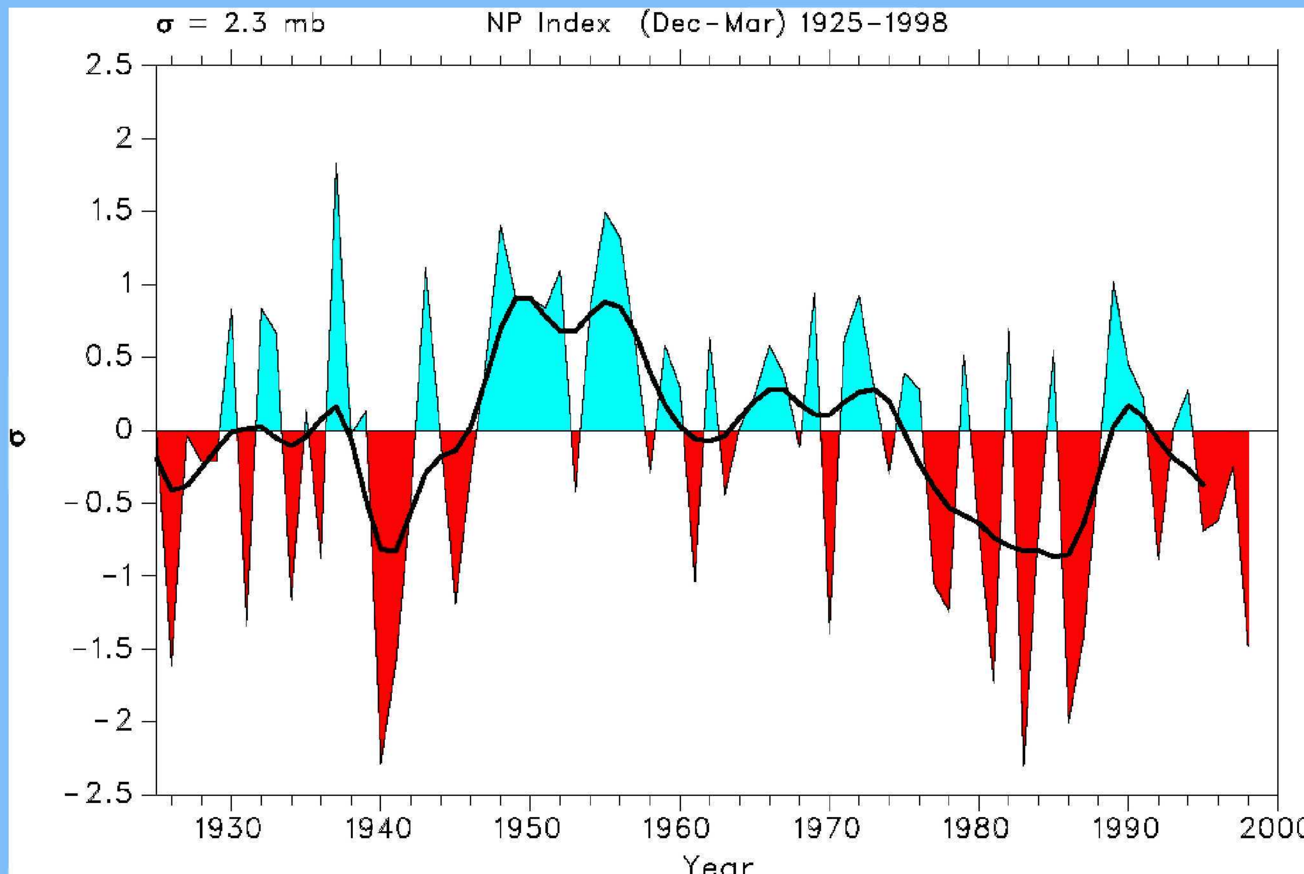


A coupled mode of the NAO as simulated by Timmermann et al., 1998, J. Climate, 11, 1906-1931).

LB/D!/99-2

Decadal Variability in the Pacific

- The North Pacific Mode -

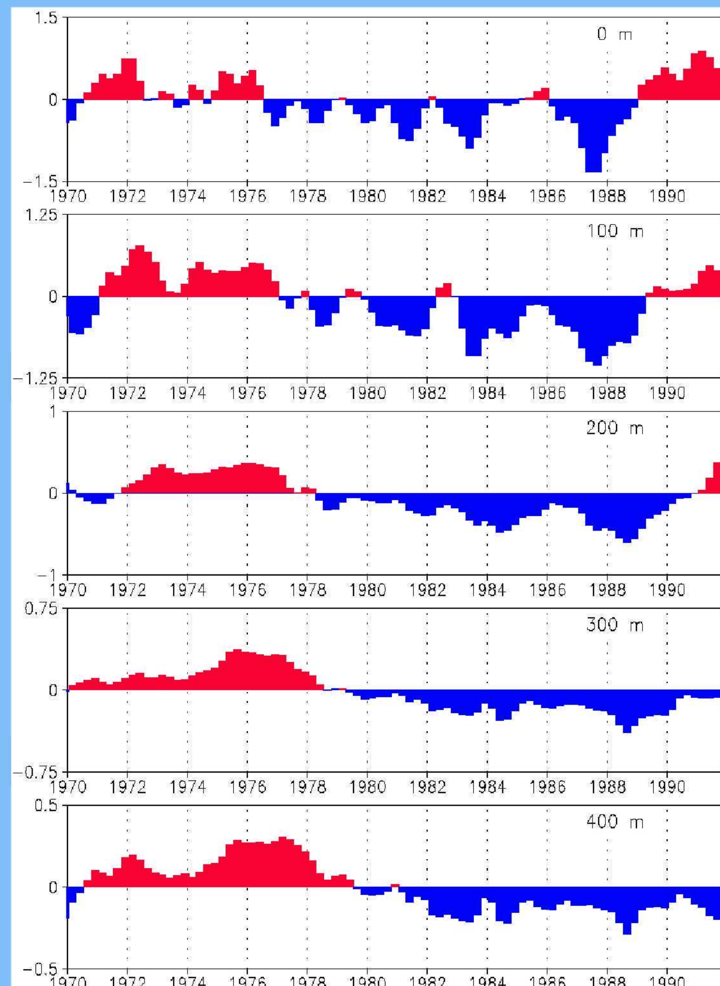


The North Pacific (NP) Index is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W and shows a high level of decadal time scale variability (after Trenberth and Hurrell, 1994, Climate Dynamics, 9, 303-319).

AV/D4/99-5

Decadal Variability in the Pacific

- Observations -

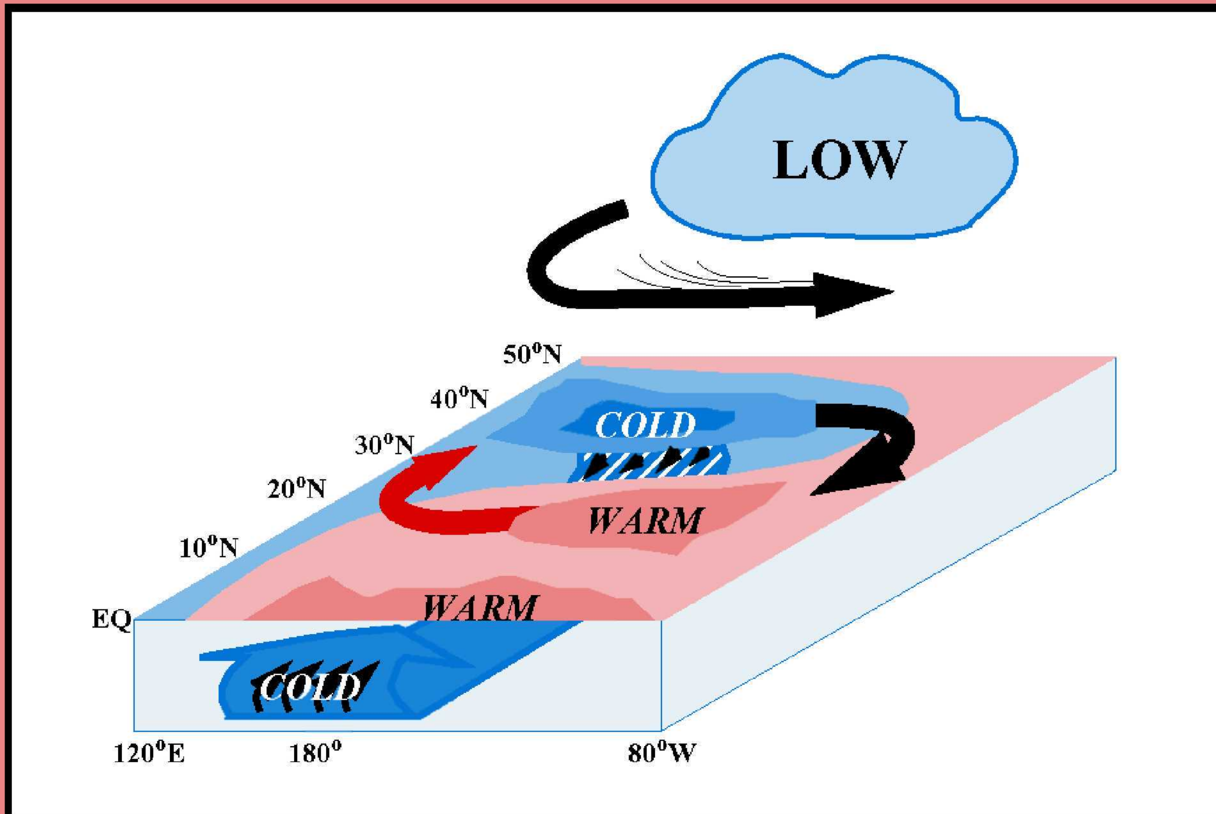


Seasonal temperature anomalies (°C) in the central Pacific region at selected depths. Note that the scale for the temperature anomalies is different for each depth (Deser et al., 1996, J. Climate, 9, 1840-1855).

AV/D4/99-4

Decadal Variability in the North Pacific

- Possible Mechanisms -

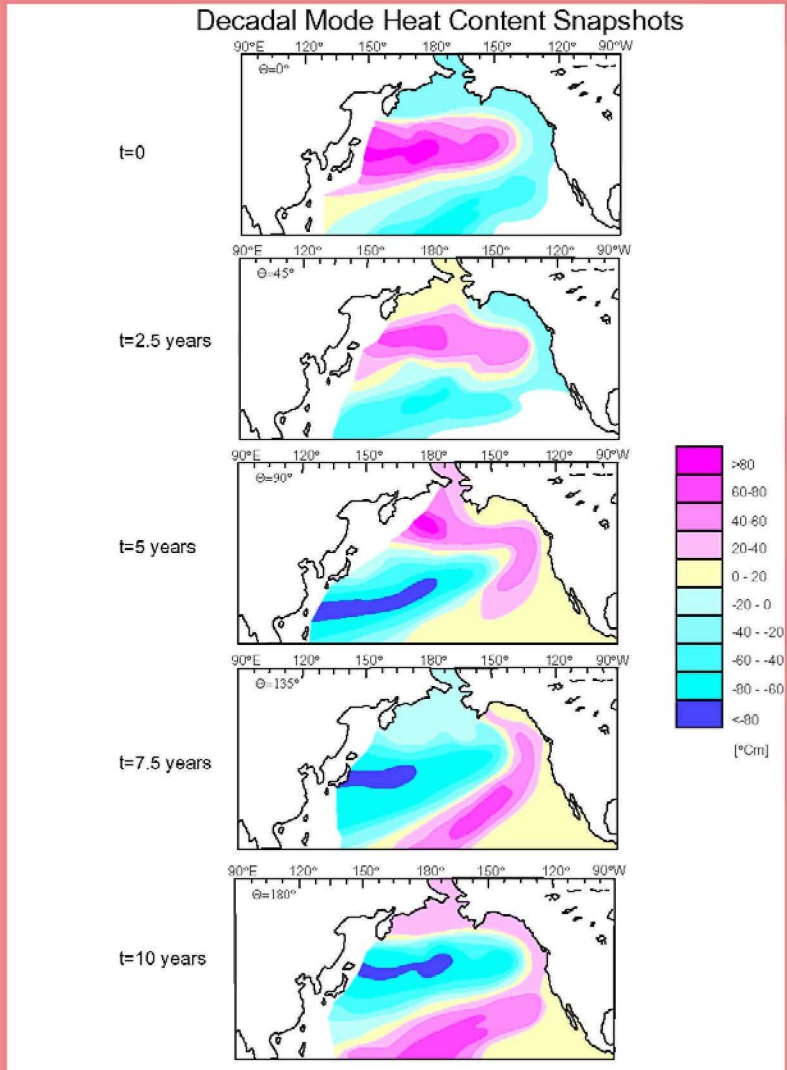


Schematic diagram of possible mechanisms of decadal climate variability. Extratropical decadal climate variability may be caused by a cycle involving unstable air-sea interactions between the subtropical gyre circulation in the North Pacific and the Aleutian low-pressure system. Long-term fluctuations of the tropical SSTs may, presumably, be induced by an influx of water from higher latitudes which subducts in the North Pacific and flows southeastward along the surfaces of constant density before equatorial upwelling brings it back to the surface. The tropical SST anomalies may in turn also affect the Aleutian low-pressure system (S. Venzke, 1998, Ocean-atmosphere interactions of decadal timescales, Thesis, Max-Planck-Institut für Meteorologie, Hamburg, 100pp).

AV/D4/99-3

Decadal Variability in the North Pacific

- The Latif-Barnett Mode-

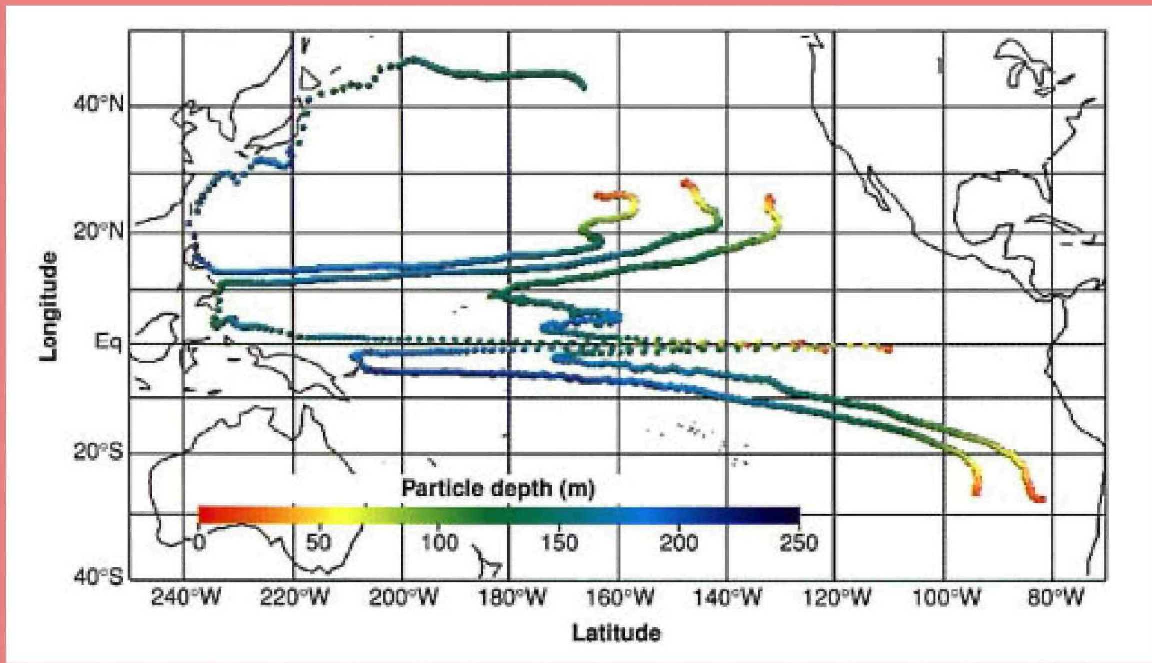


Reconstruction of anomalous heat content from the output of a coupled model run in the Pacific Ocean. The individual panels show the progression of heat content anomalies at approximately 2.5 years apart (Latif et al., 1994, Science, 266, 634-637).

AV/D4/99-1

Decadal Variability in the North Pacific

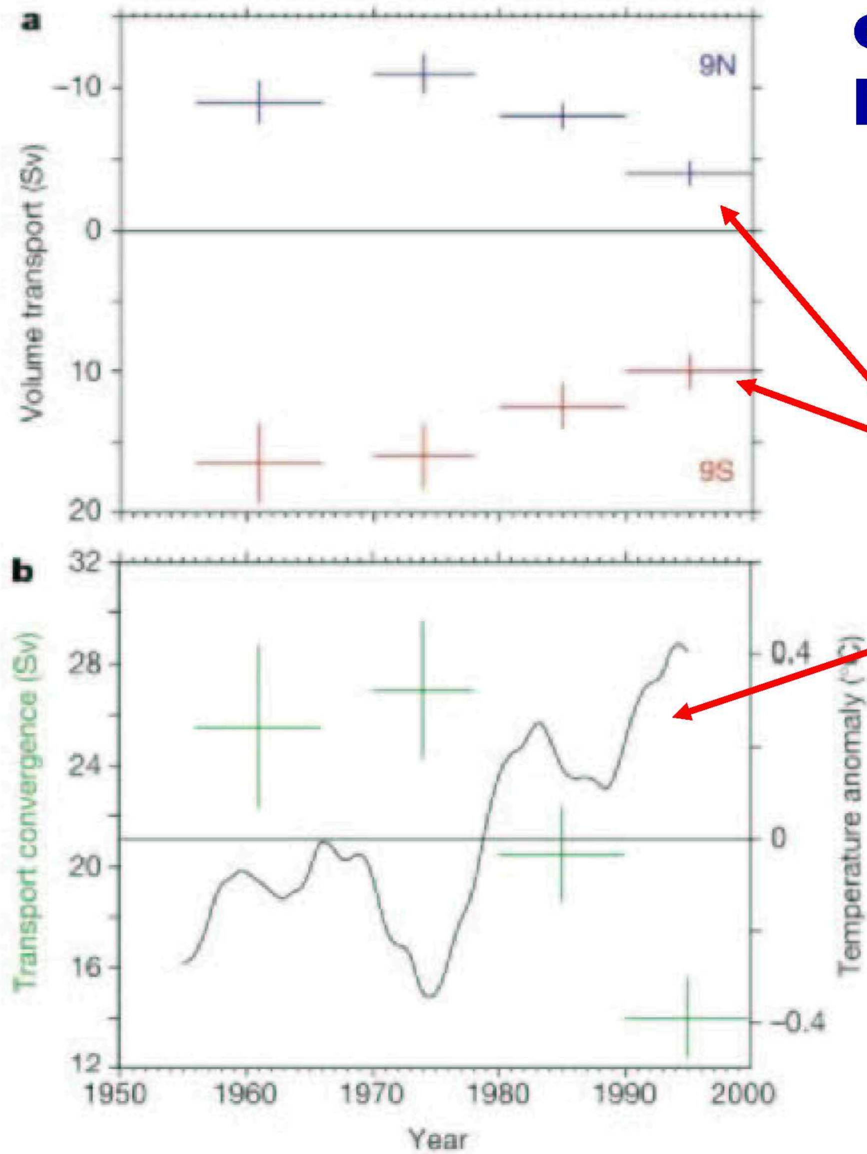
- The Subduction Hypothesis -



The paths of water parcels over a period of 16 years after subduction off the coasts of California and Peru as simulated by means of a realistic oceanic general circulation model forced with the observed climatological winds. From the colours, which indicate the depth of the parcels, it is evident that parcels move downward, westward, and equatorward unless they start too far to the west off California, in which case they join the Kuroshio Current. Along the equator they rise to the surface while being carried eastward by the swift Equatorial Undercurrent (Gu, Philander, 1997, Science, 275, 805-807).

AV/D4/99-2

Slow down of meridional overturning in upper Pacific Ocean



Reduction in volume transport of northern and southern sub-tropical cells

Associated increase in temperature anomaly

Reduction in outgassing of CO_2

McPhaden and Zhang, 2002

Summary

- Significant progress has been made in monitoring and predicting natural climate variability on a global scale.
- The largest signal of the coupled climate system is the El Nino/Southern Oscillation phenomenon. Forecast systems based on coupled ocean-atmosphere models are capable of predicting the onset of El Nino events six months in advance.
- Adaptation and mitigation strategies have been put in place around the world to take advantage of this new predictive capability.

Summary

- The long lead time of such climate forecasts rests with the memory that is inherent to the ocean.
- Observational evidence for other "modes" of the coupled climate system include the monsoons, North Atlantic Oscillation, Tropical Atlantic Variability, and the Pacific Decadal Oscillation.
- A necessary prerequisite to any understanding of the anthropogenic effect on climate requires that we be able to distinguish between the natural variability of the coupled climate system and that due to external forcing of global warming.
- During the 1980's a new era of science was initiated that considered the two-way interaction between the ocean and the atmosphere as a coupled system. During the 1990's this was extended to include land-atmosphere coupling. In the future, we will see emphasis given to coupling between the physical climate system and marine/terrestrial ecosystems

CLIVAR 2004

1st International CLIVAR Science Conference

June 21-25, 2004, Baltimore, USA

Understanding and Predicting Our Climate System

www.clivar2004.org

The international research program on CLImate VARiability and predictability (CLIVAR; www.clivar.org) under the auspices of the World Climate Research Programme (WCRP), focuses on describing and understanding variability and change of the physical climate system on time scales from months to centuries and beyond. CLIVAR's goal is to assess predictability, and develop information systems and practical prediction capabilities.

The 1st International CLIVAR Science Conference will feature:

- **Invited overviews prepared by expert teams**
- **Stimulating invited presentations and discussion forums**
- **Contributed poster presentations (with special emphasis on young scientists' participation)**

Contributions are solicited on research topics that include, but are not limited to:

- **Advances in understanding elements of the climate system**
  Seasonal-to-interannual variability, especially ENSO, monsoon systems, decadal (and longer) variability, and anthropogenic climate change
- **Looking into the past**
  Analysis of paleoclimate records; reanalyses
- **New approaches to climate prediction**
  Modeling, data assimilation, and validation
- **Improvements to the observing system**
- **Climate applications**
  Who are our clients? What products and information do they need?

Organizing Committee

A committee of international scientists is organizing the conference. Leaders of this committee include:

- Lennart Bengtsson (Max-Planck-Institut, Hamburg) – Organizing Committee Chair
- Antonio Busalacchi (Univ Maryland) – CLIVAR Scientific Steering Group Co-Chair
- Jurgen Willebrand (IFM, Kiel) – CLIVAR Scientific Steering Group Co-Chair
- David Legler (US CLIVAR Office) – Local Organizing Committee Chair

Conference contact: info@clivar2004.org

In a forcing sense, climate variability can influence:

- Circulation
- Temperature
- Stratification and Mixing
- Water mass characteristics
- Mesoscale activity
- Extreme events
- Basin-wide synchrony

In a forcing sense, climate variability can influence:

- Nutrient supply
- New and export production pathways
- Physiology (metabolic and reproductive processes)
- Age classes
- Schooling patterns
- Predator-prey interactions

Within this context,
what are the regional implications of “global change”?

Climate change → Climate variability → Regional/ mesoscale climate impacts → Extreme/ episodic events

Entrainment/mixing

Upwelling

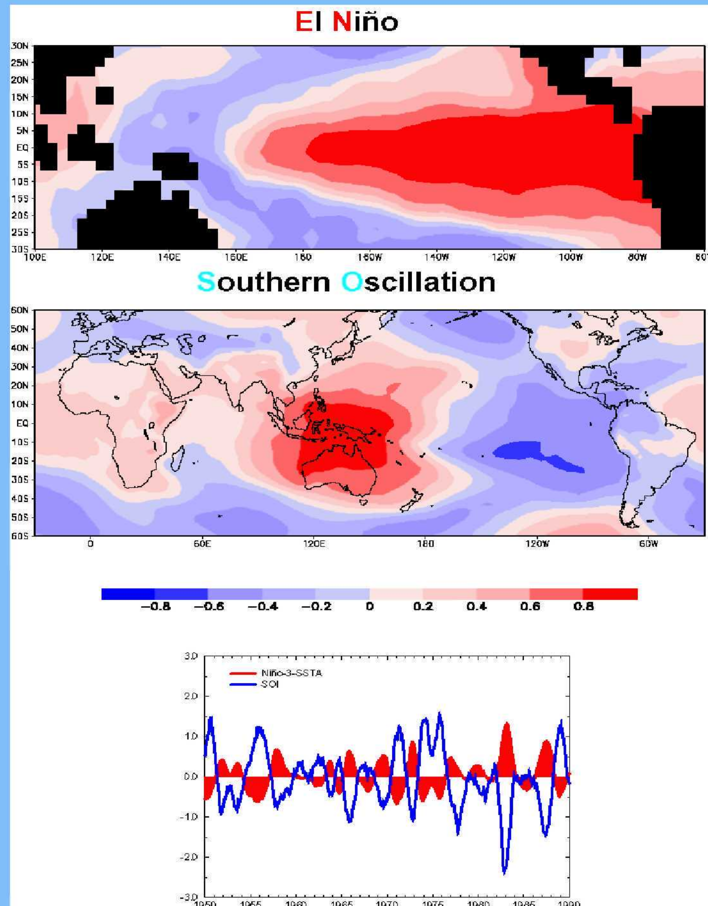
Internal waves

Eddies

Ekman pumping

Storminess

ENSO Fundamentals



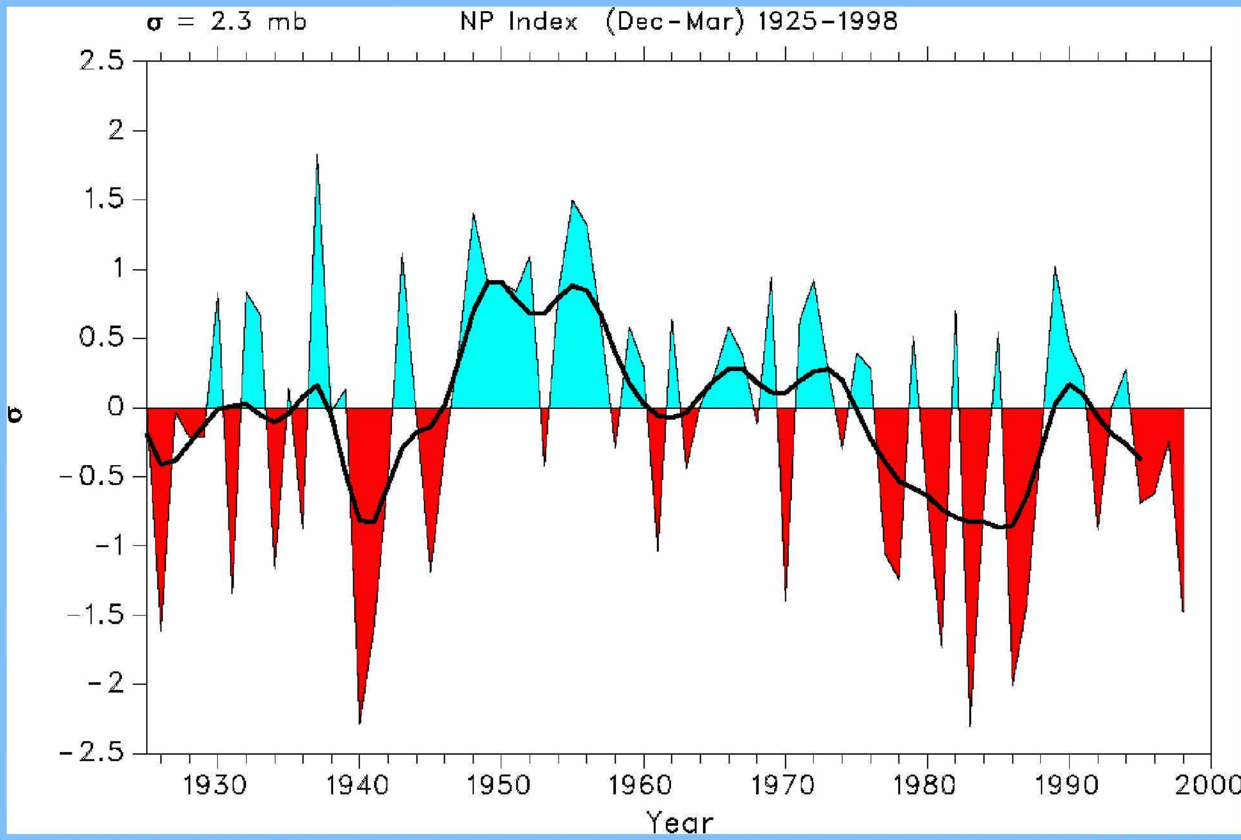
Upper panel: A typical[1] anomaly pattern for the tropical Pacific sea surface temperature (SST) associated with El Niño. Shown is the correlation of annual SST anomalies averaged over the Niño-3 region (5^{o}N-5^{o}S, 150^{o}W-90^{o}W) with all other locations. Middle: Spatial structure of the Southern Oscillation showing the global-scale nature of the phenomenon. Shown is the correlation of annual pressure anomalies at Djakarta (Indonesia) with all other locations. Lower: Time series of the Southern Oscillation Index (SOI; blue line) which measures the atmospheric sea-level pressure gradient across the tropical Pacific basin and of the anomalous SST averaged over the central equatorial Pacific (red line). Both time series are normalised by their standard deviation (courtesy of M. Latif, S. Venzke).

1. SOI pattern derived from a model simulation with ECHAM4

AV/G1/99-5

Decadal Variability in the Pacific

- The North Pacific Mode -

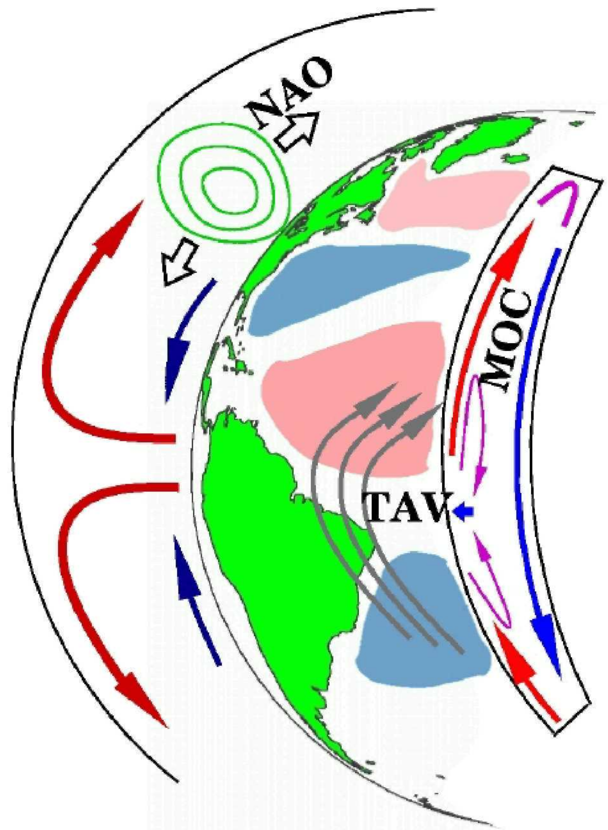


The North Pacific (NP) Index is the area-weighted sea level pressure over the region 30^{o}N-65^{o}N, 160^{o}E-140^{o}W and shows a high level of decadal time scale variability (after Trenberth and Hurrell, 1994, Climate Dynamics, 9, 303-319).

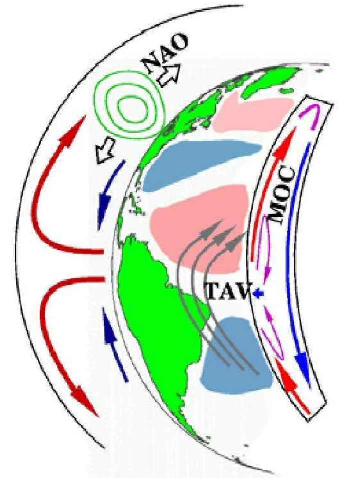
AV/D4/99-5

Climate Variability in the Atlantic Sector: The Main Phenomena

- North Atlantic Oscillation (Northern Annual Mode)
- Tropical Atlantic Climate Variability
- Meridional Overturning Circulation of the Ocean

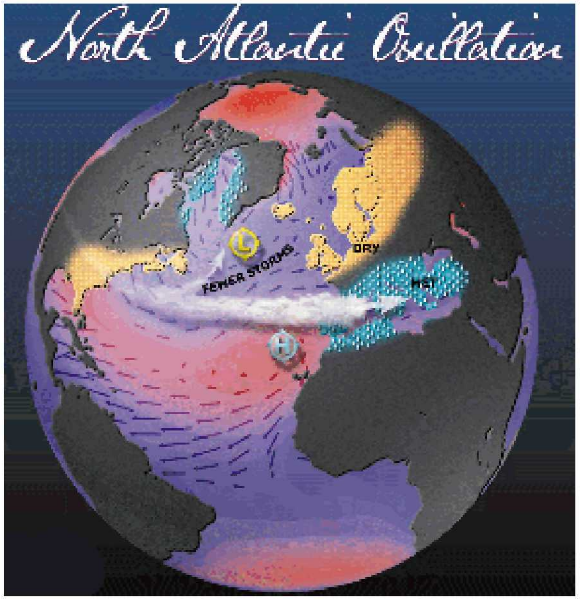


Climate Variability in the Atlantic Sector:
The North Atlantic Oscillation



Changes in the Subpolar to Subtropical Atmospheric Pressure Difference lead to:

- Changes in strength and position of the westerly winds (storm tracks)
- Phase can be described by a simple pressure based index



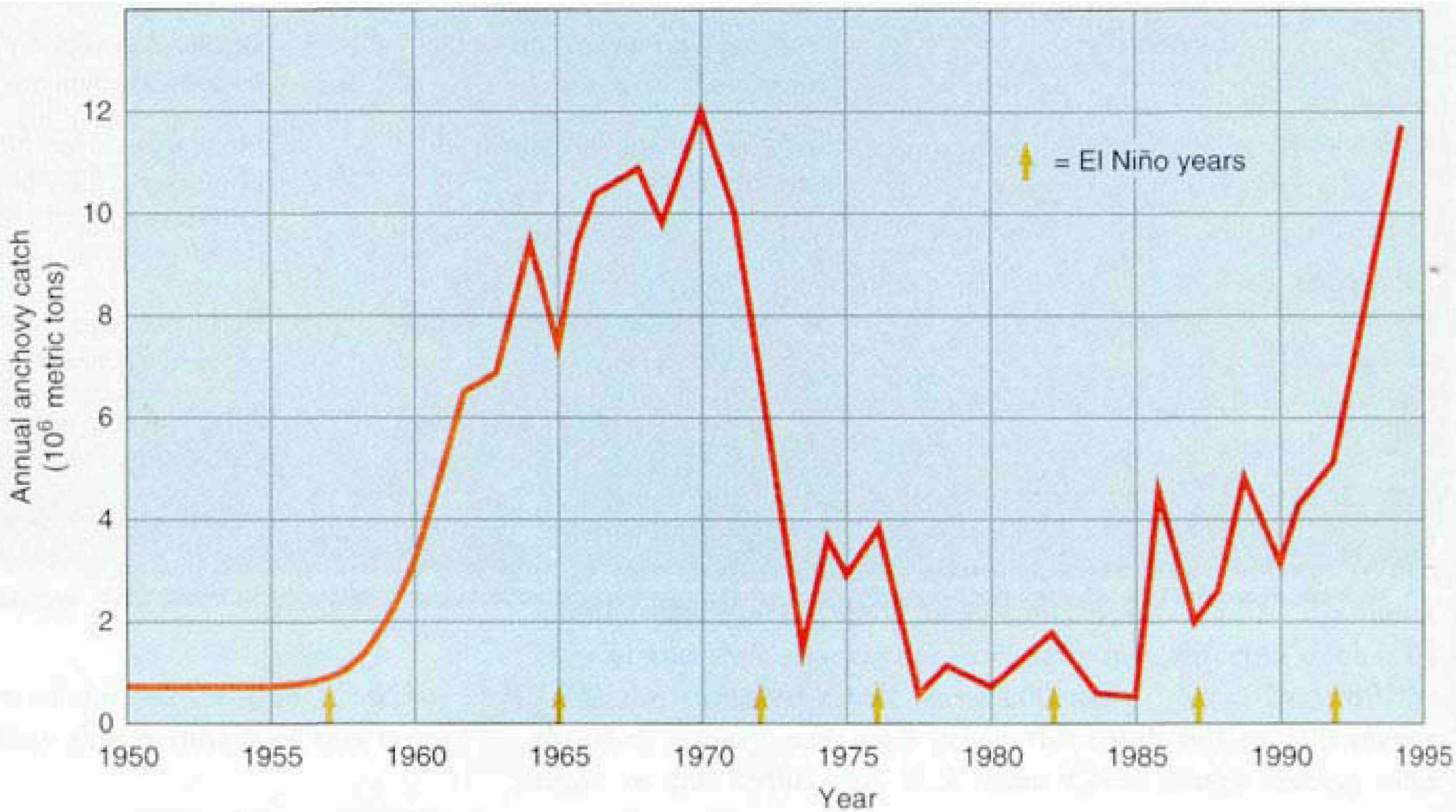
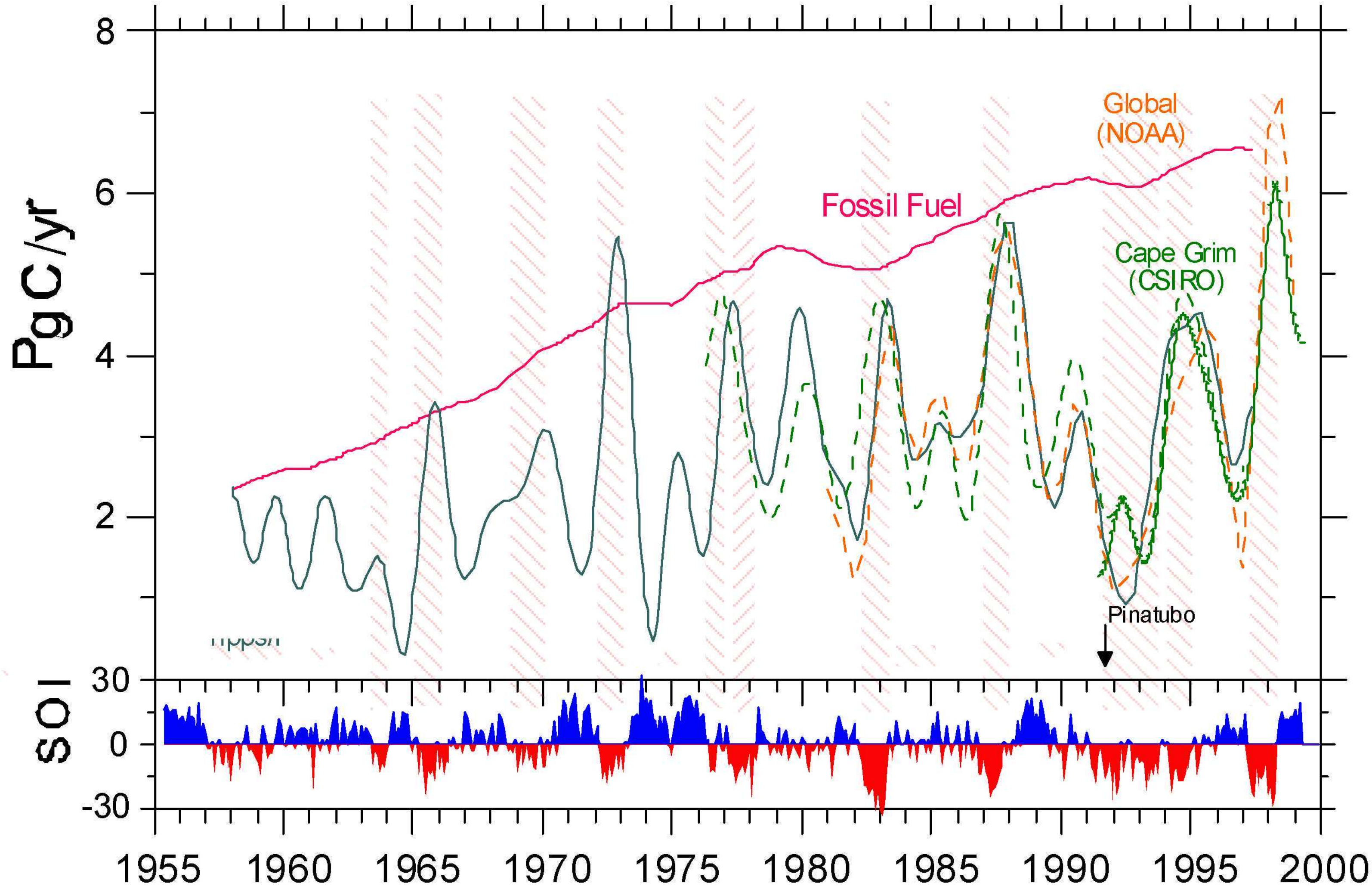
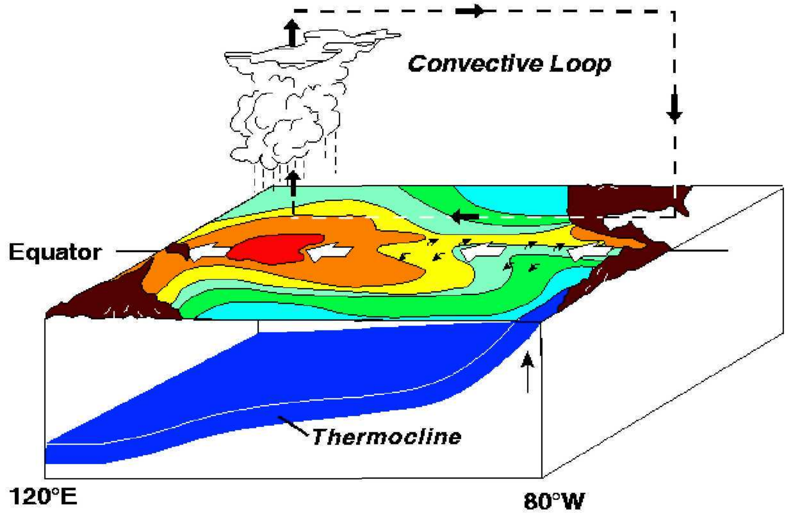


Fig.1 The anchovy catch of Peru and Ecuador by calender year given in 1×E6 tons.

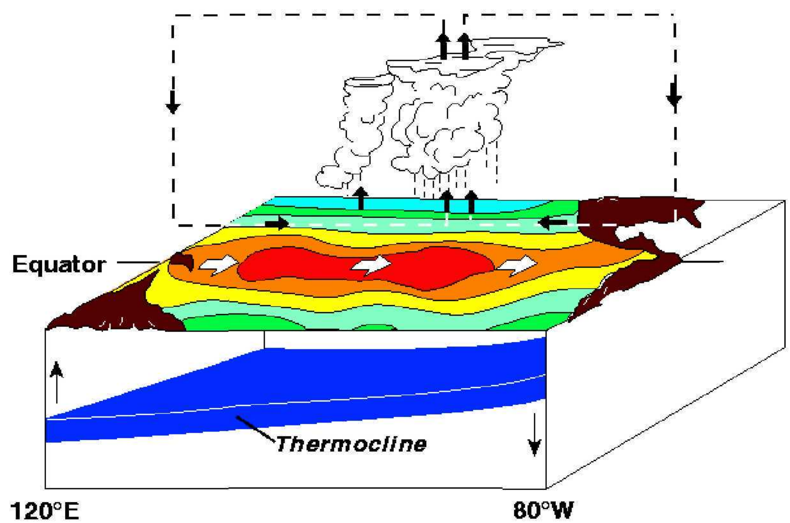


(R J Francey, pers. Com)

Normal Conditions

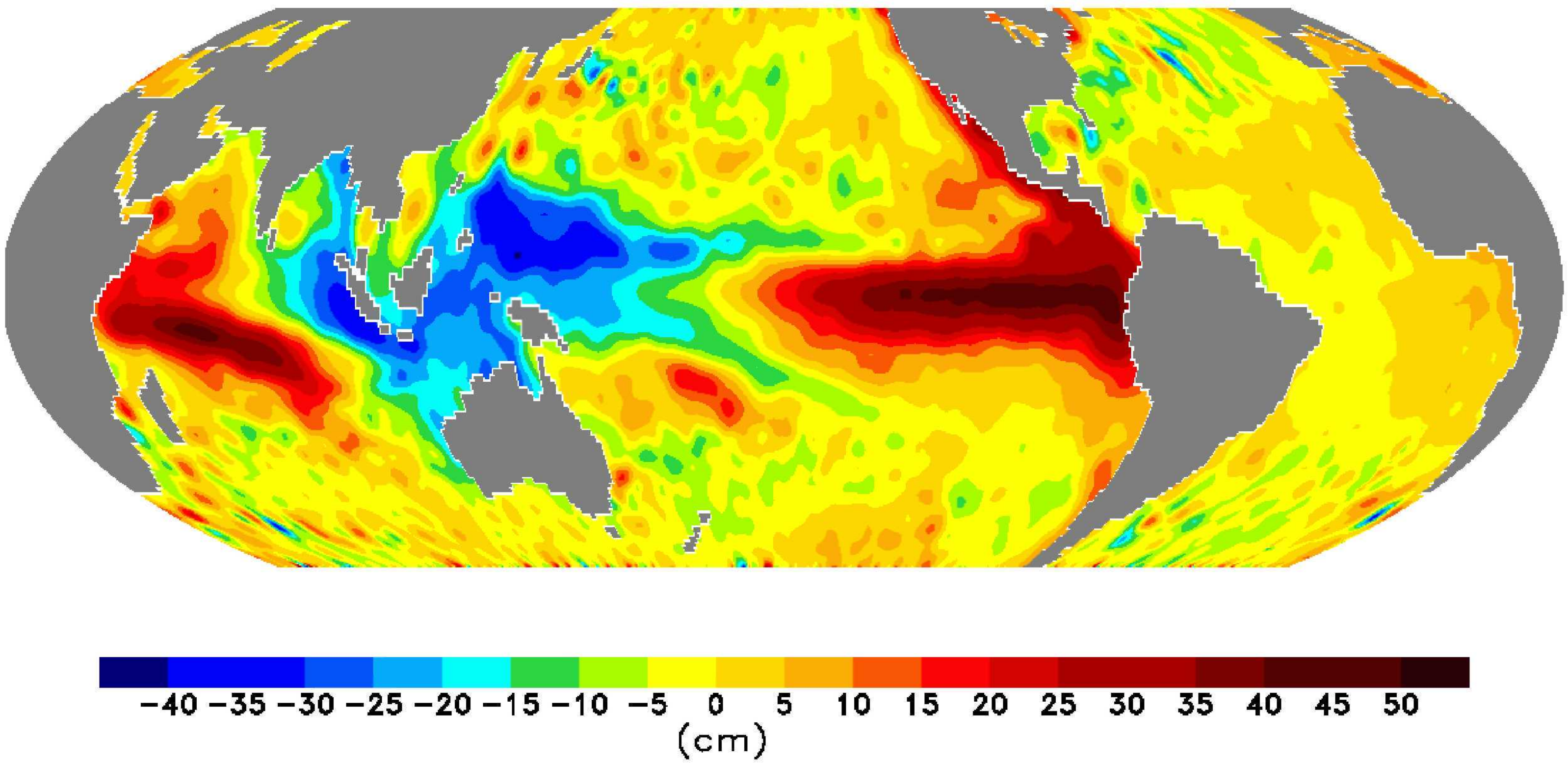


El Niño Conditions



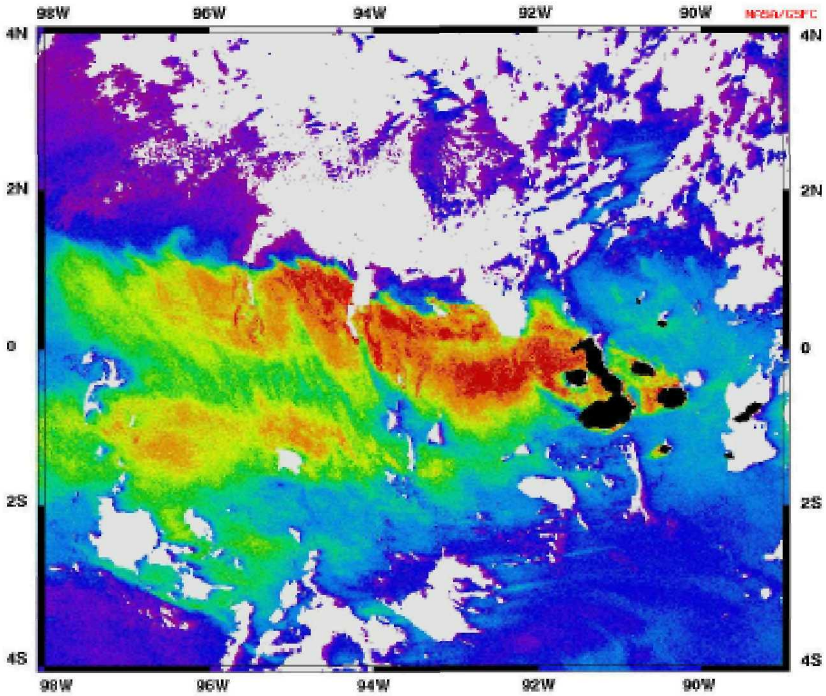
TOPEX/Poseidon Sea Level

Dec 1997 minus Dec 1998



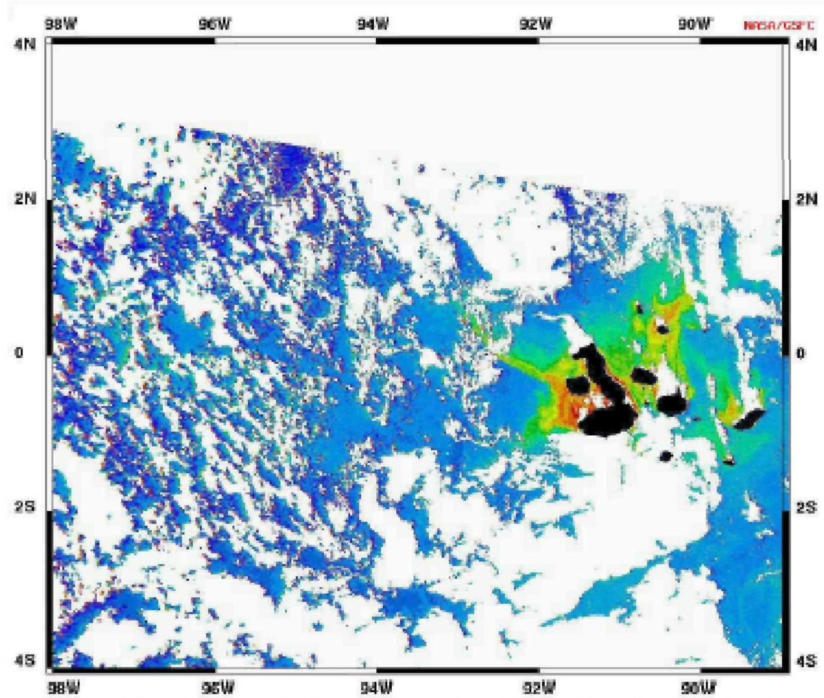
CZCS-derived Pigment Concentration

10/31/83



SeaWiFS-derived Pigment Concentration

10/31/97

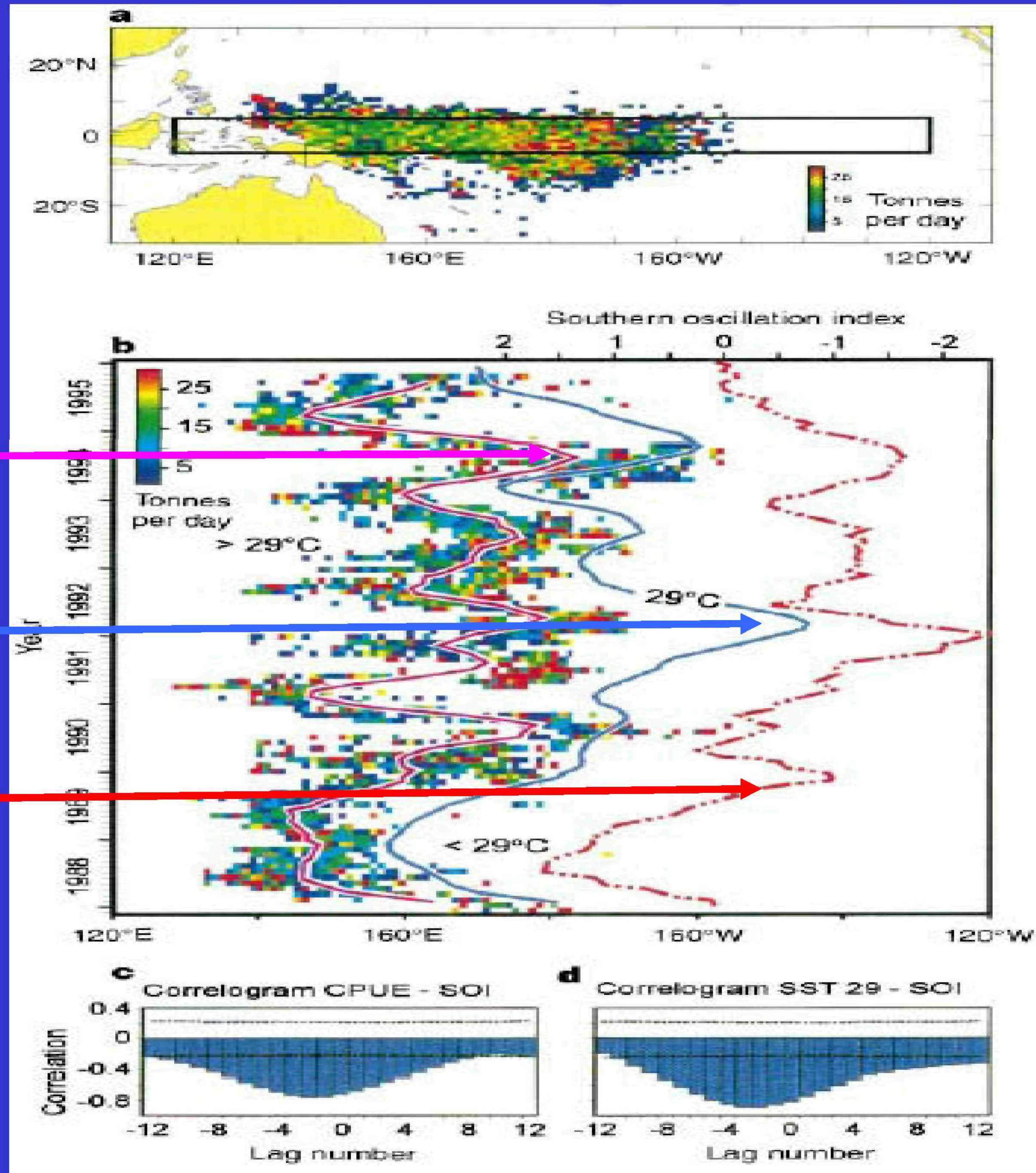


Skipjack tuna
CPUE 1988-1995

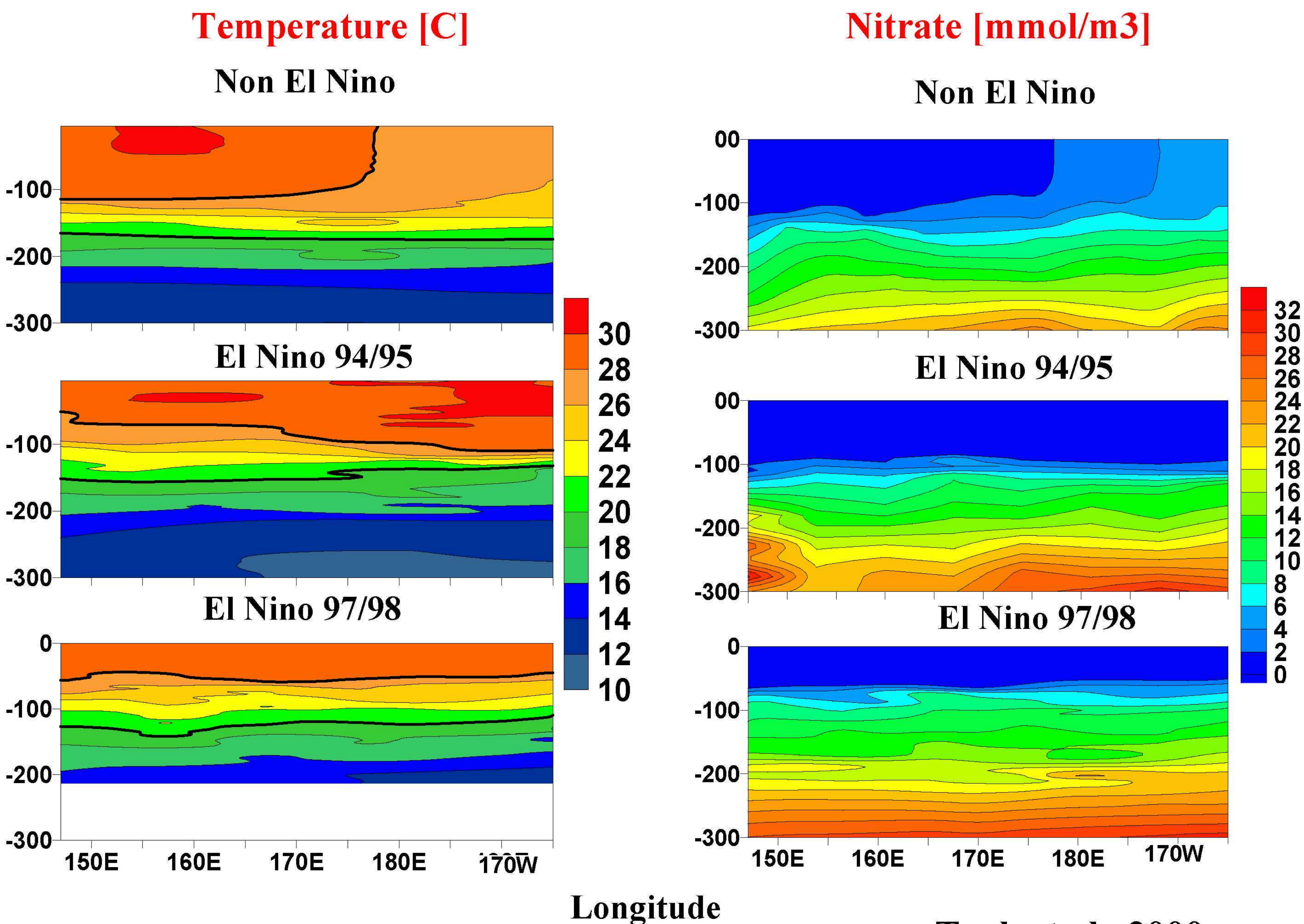
CPUE monthly
mean centroid

29°C SST

SOI

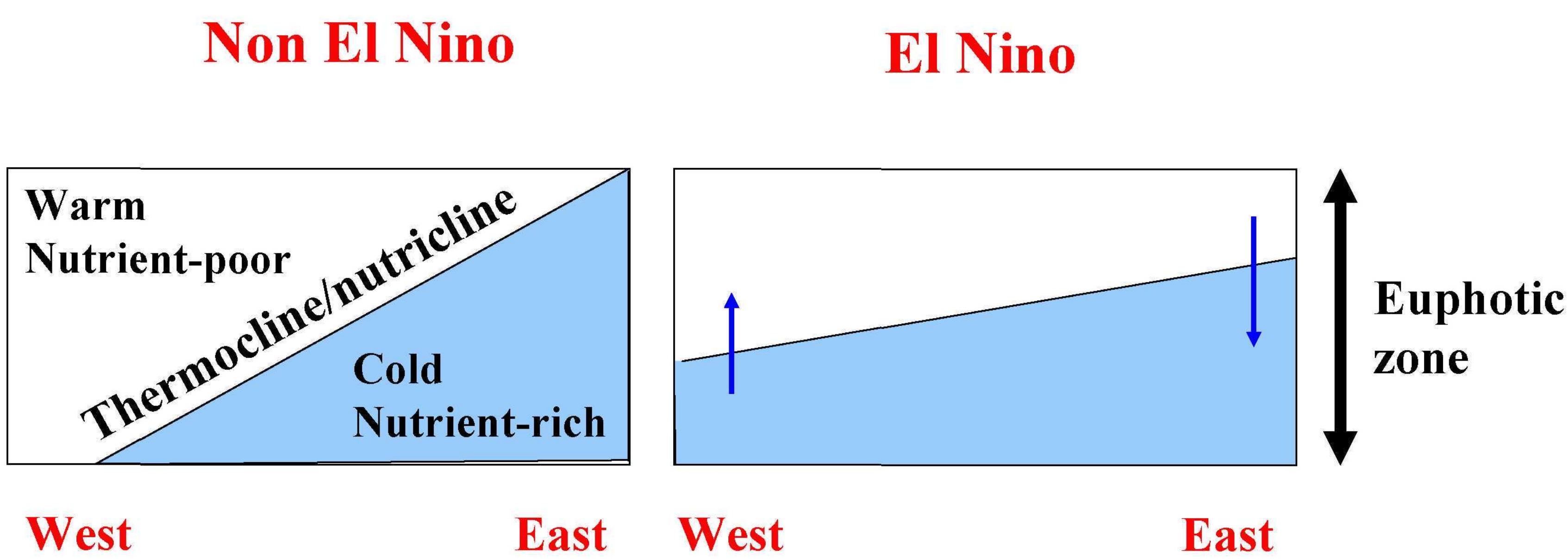


Lehodey et al., 1997

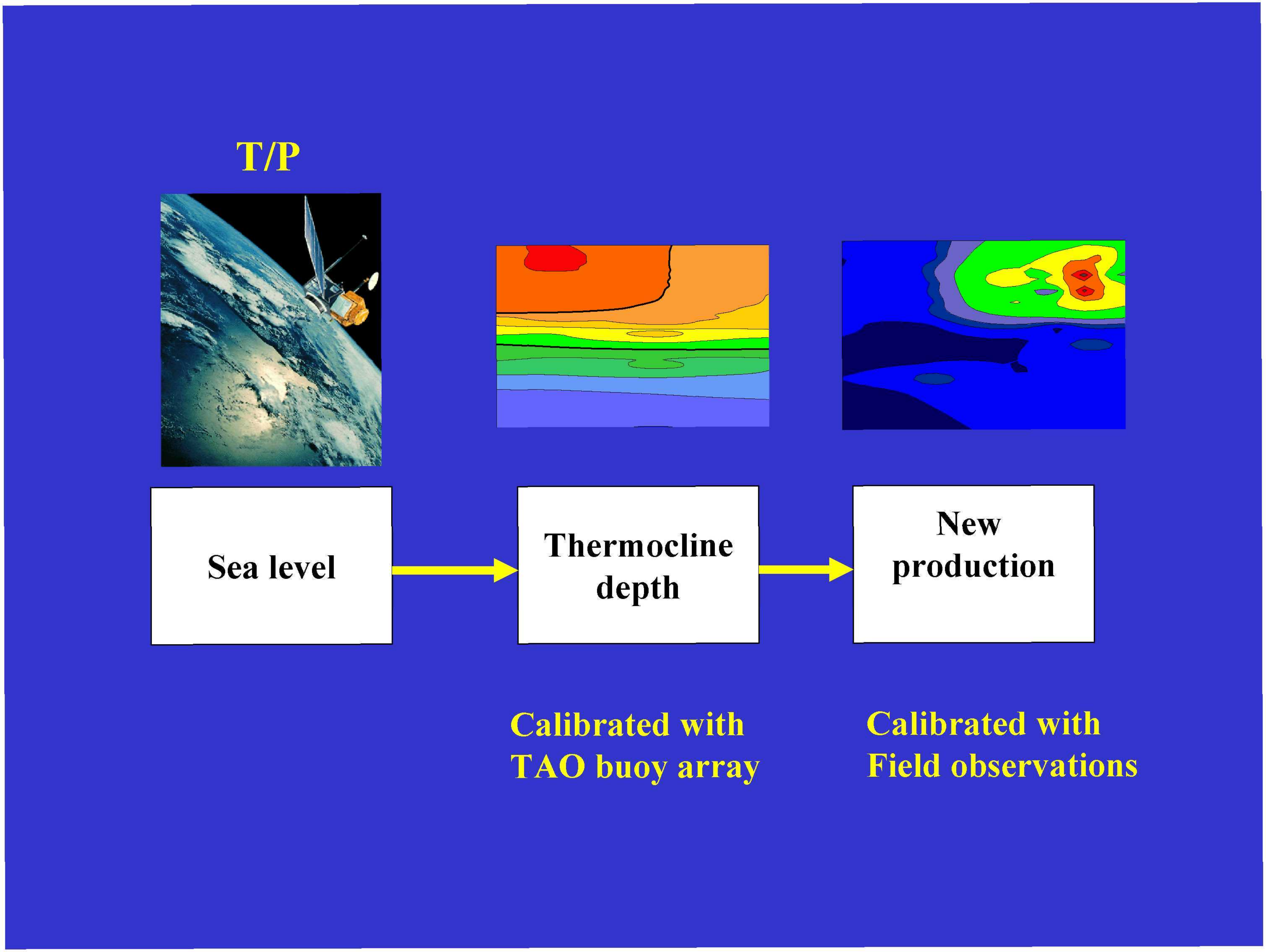


Turk et al., 2000

Relation between thermocline/nutricline depth and new production in equatorial Pacific

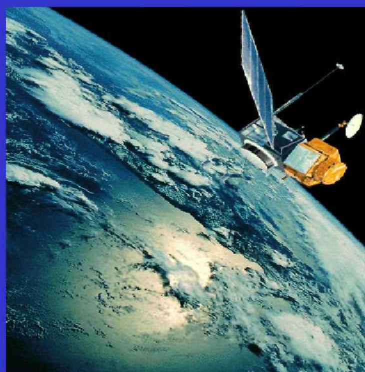


The depth of the nutricline/thermocline regulates new production on interannual time scales by changing the supply of nitrate into the euphotic zone.


T/P
Sea level
Thermocline depth
New production
Calibrated with TAO buoy array
Calibrated with Field observations

Data

T/P



• Sea Level

TAO buoy array

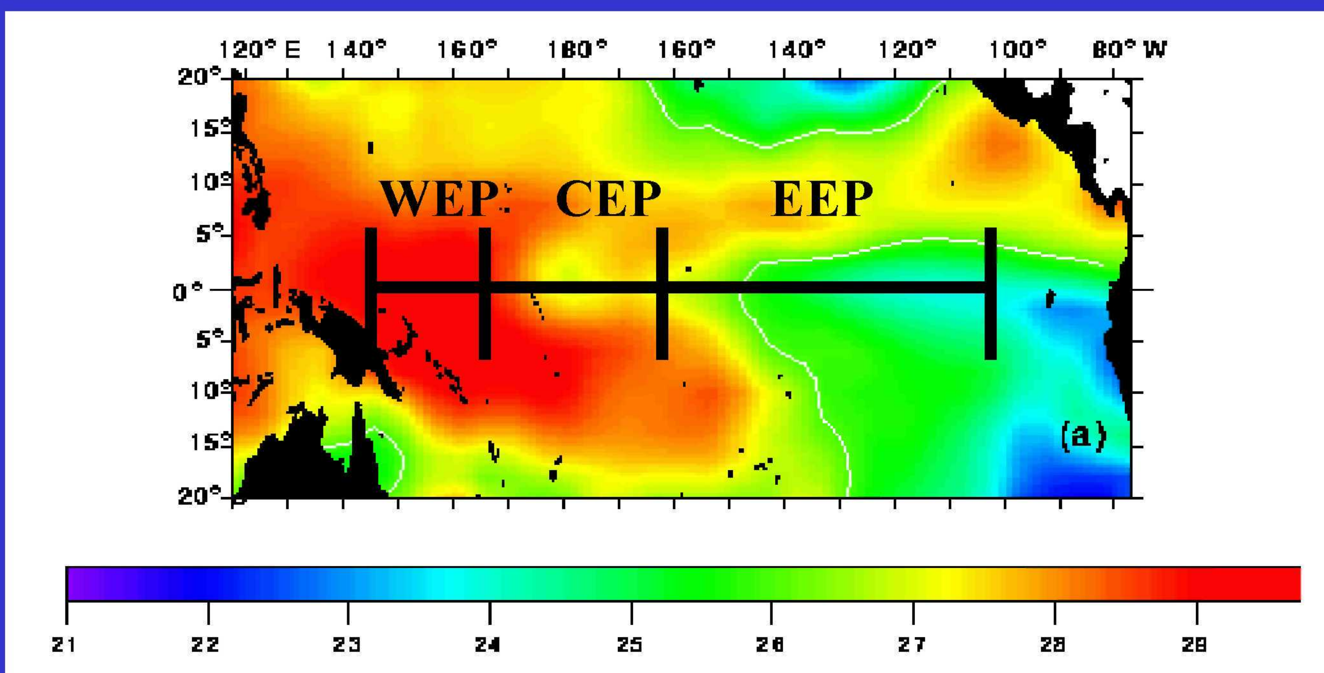
• Upper ocean temperature

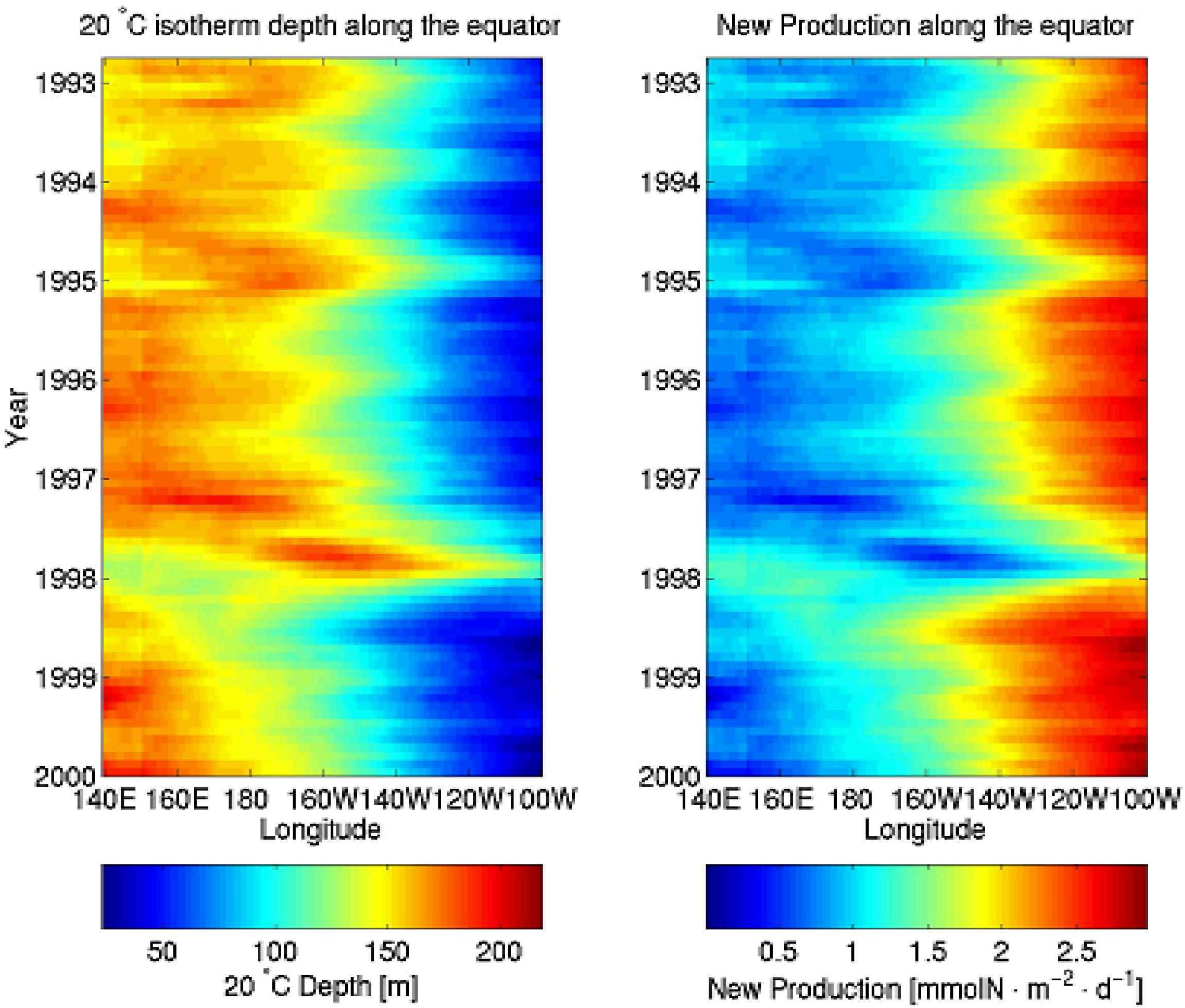
Shipboard obs.

Four cruises in WEP/CEP from 165^0 E to 165^0W along the equator.

R/V Mirai (JAMSTEC)

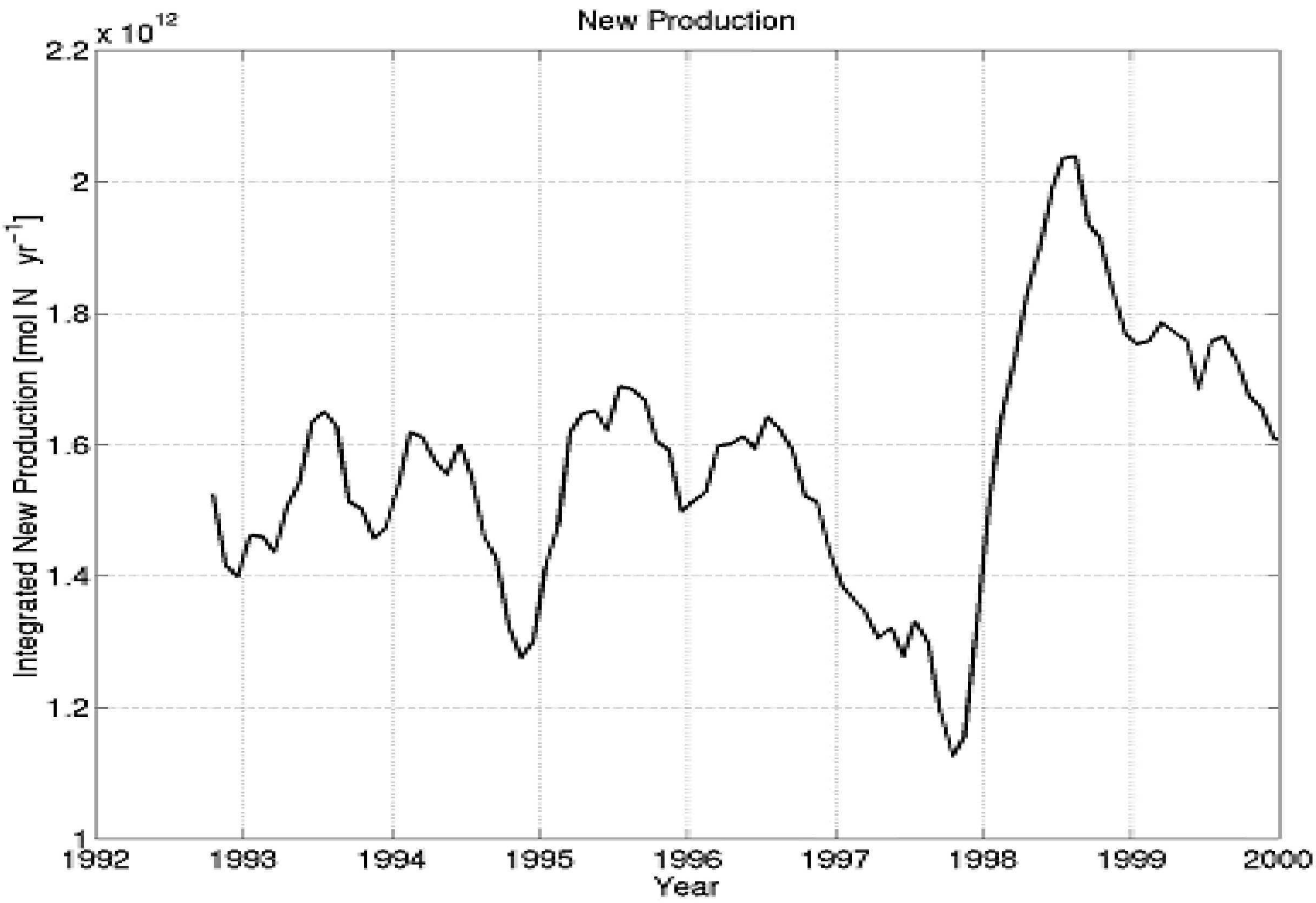
• Temperature
• Nitrate
• ^{15}N biological uptake

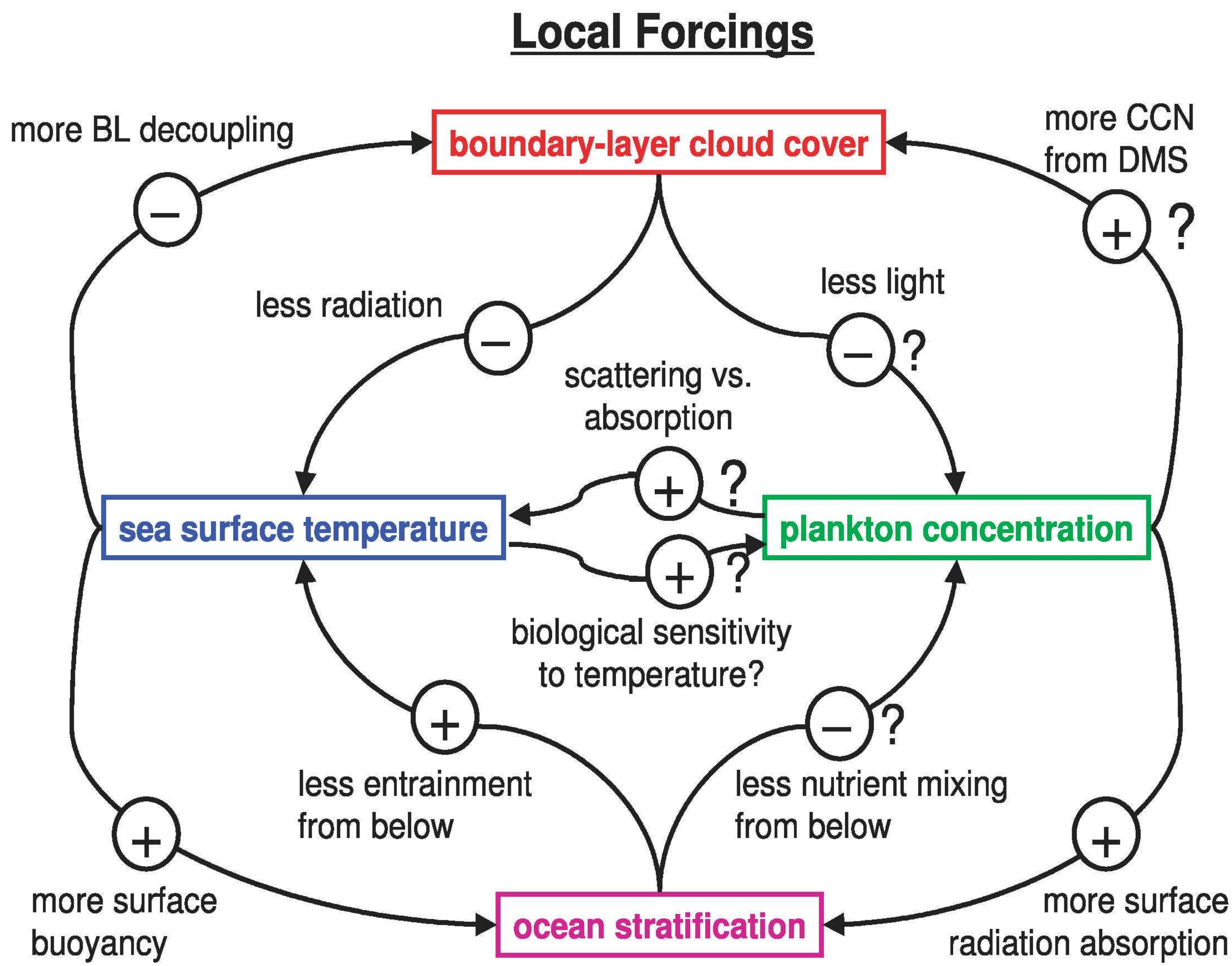




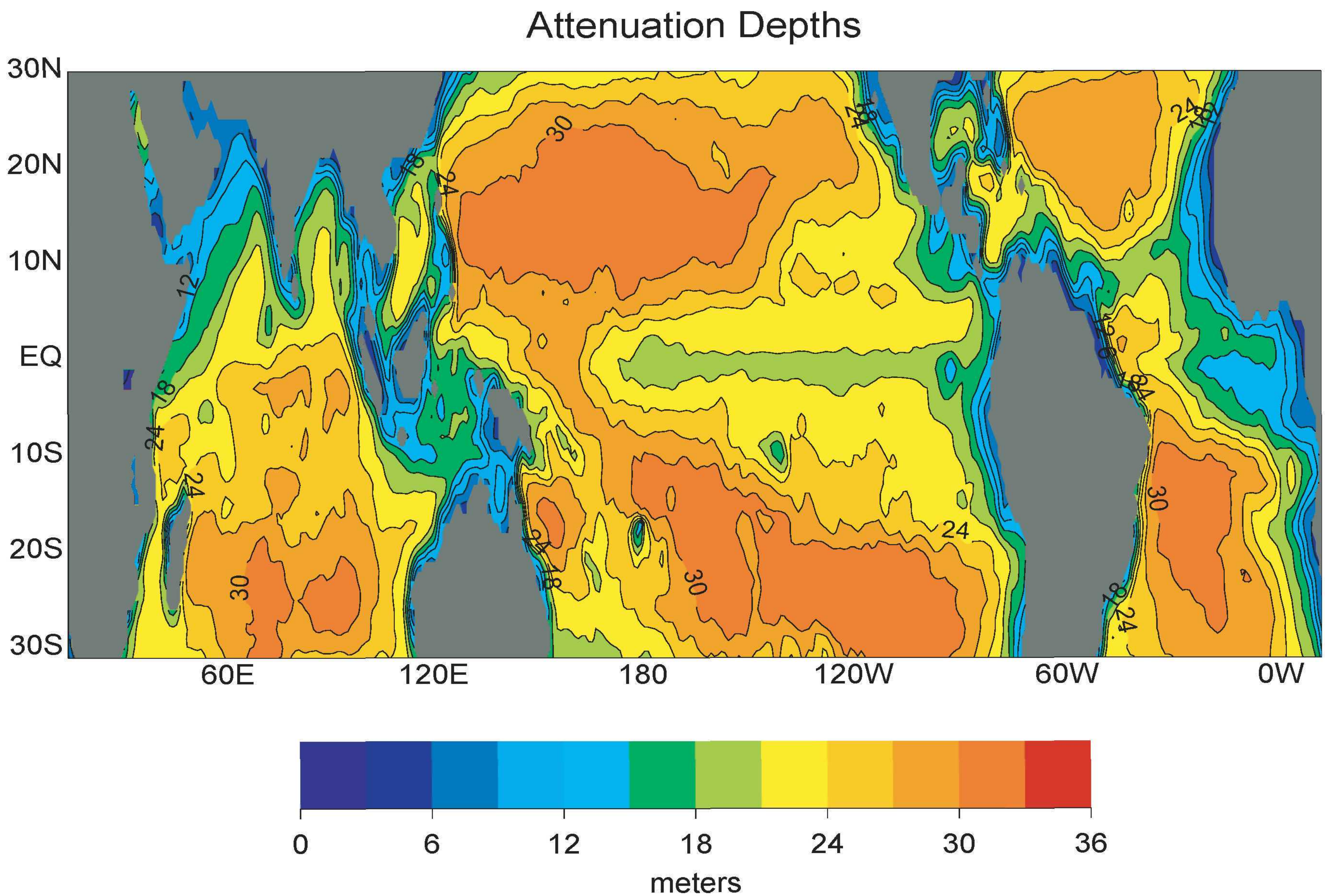
20 °C isotherm depth along the equator
New Production along the equator
Year
1993
1994
1995
1996
1997
1998
1999
2000
140E 160E 180 160W 140W 120W 100W
Longitude
50 100 150 200
20 °C Depth [m]
0.5 1 1.5 2 2.5
New Production [mmolN · m^-2 · d^-1]

Integrated new production in equatorial Pacific
(140^0E-100^0W, 1^0N-1^0S)



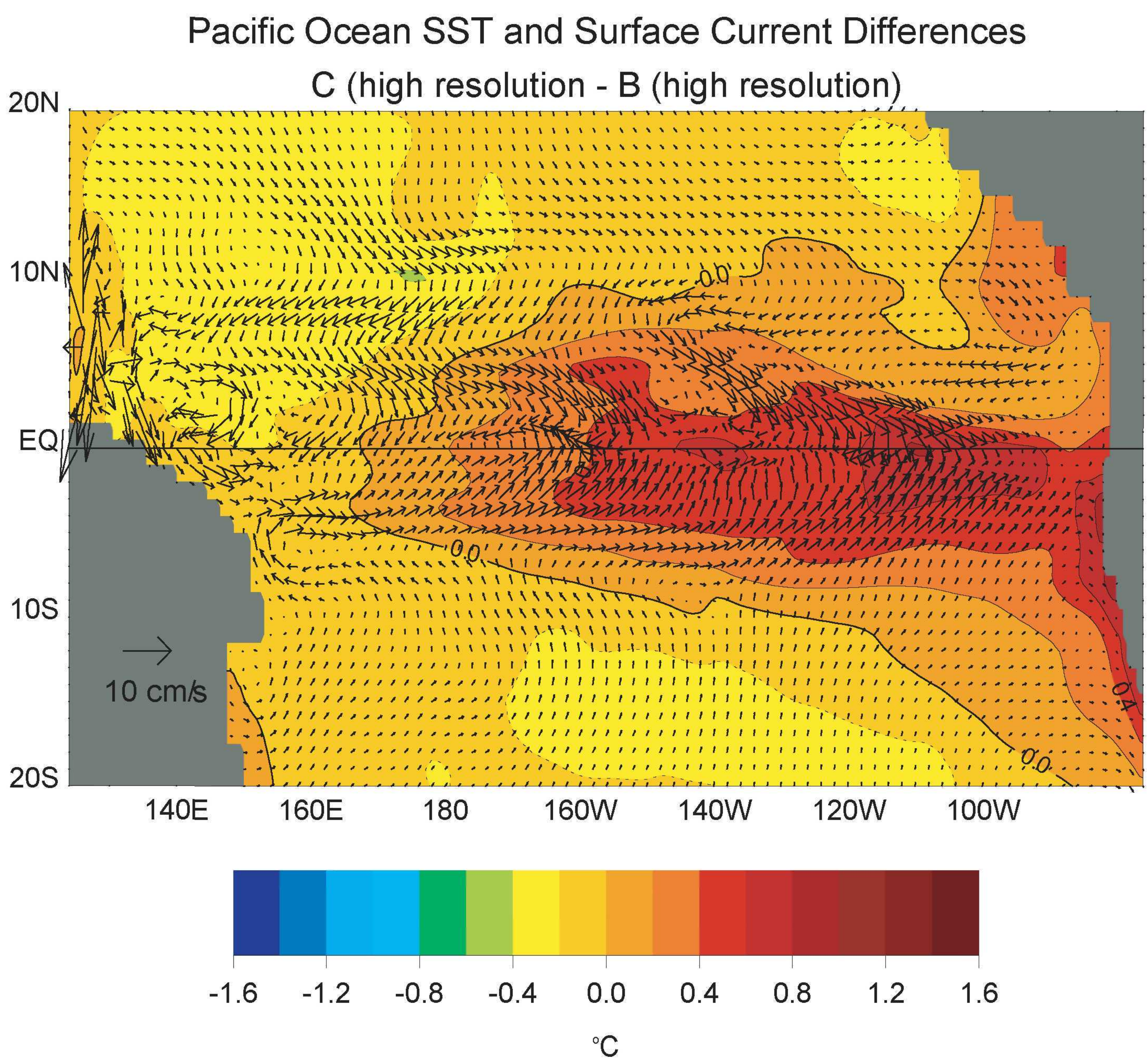


Potential feedbacks at Seasonal to Interannual time-scales

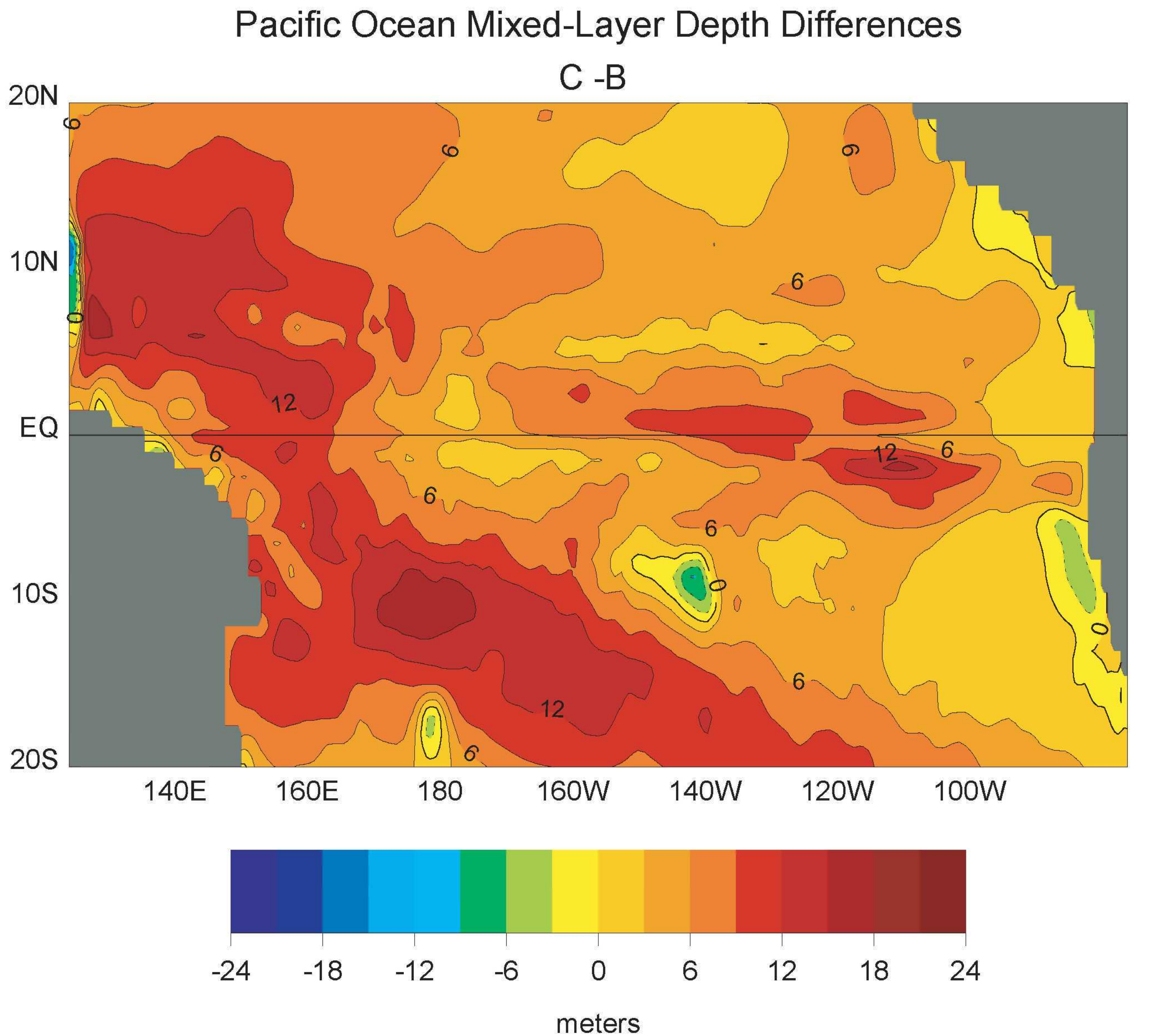


Attenuation depths from CZCS Pigments

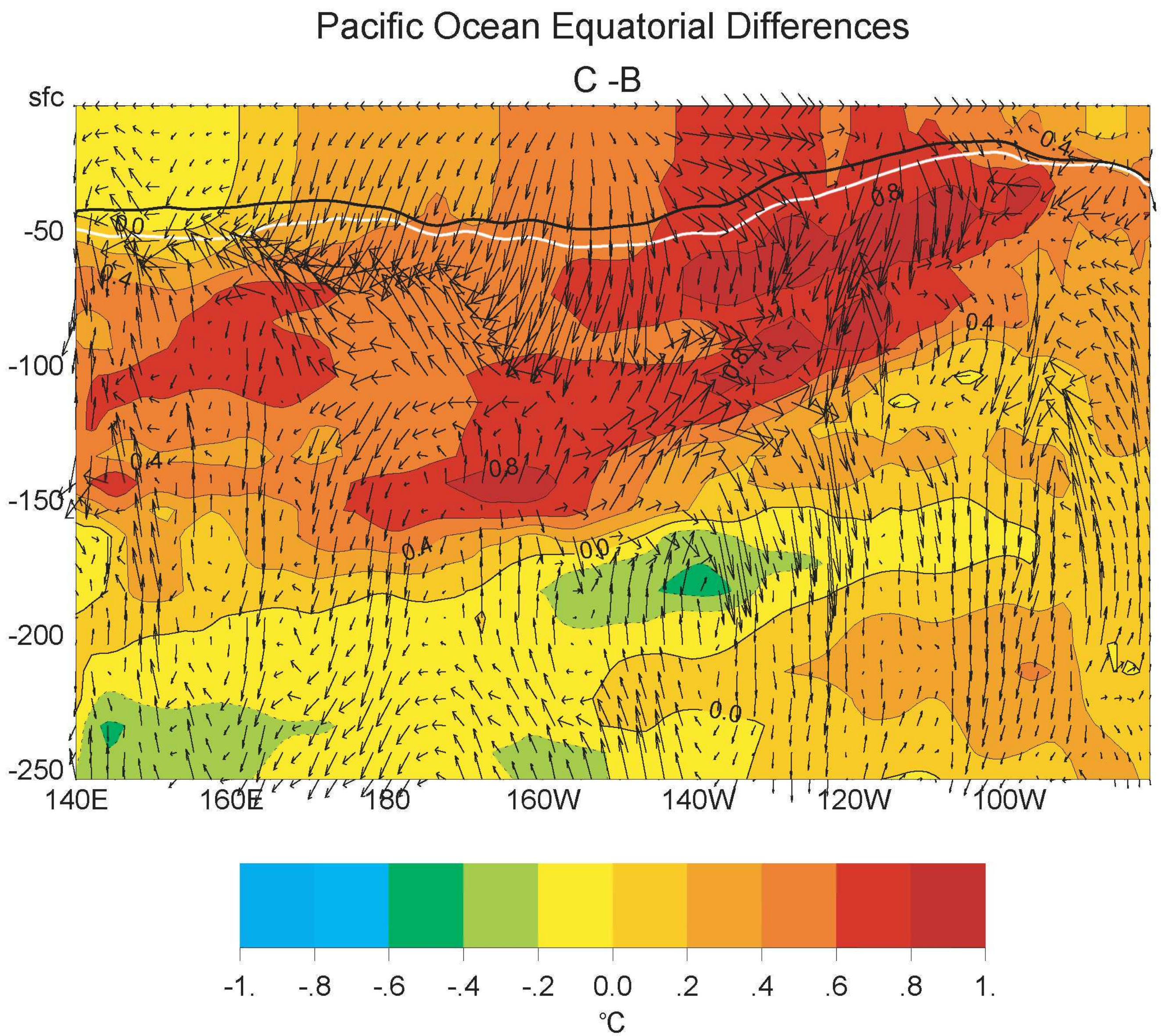
Murtugudde et al., 2002



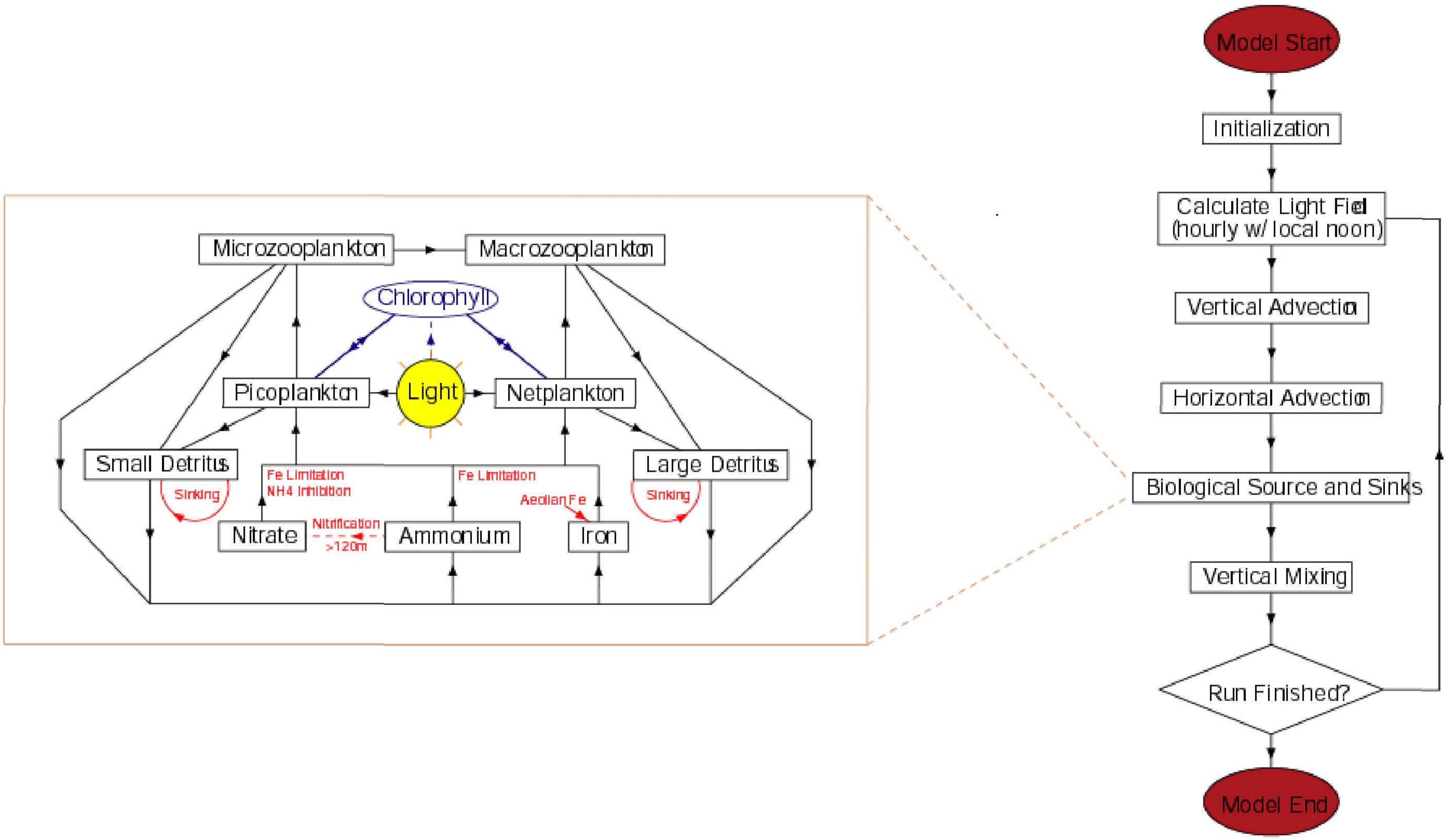
SST and surface current differences between CZCS and 17m att depth simulations.



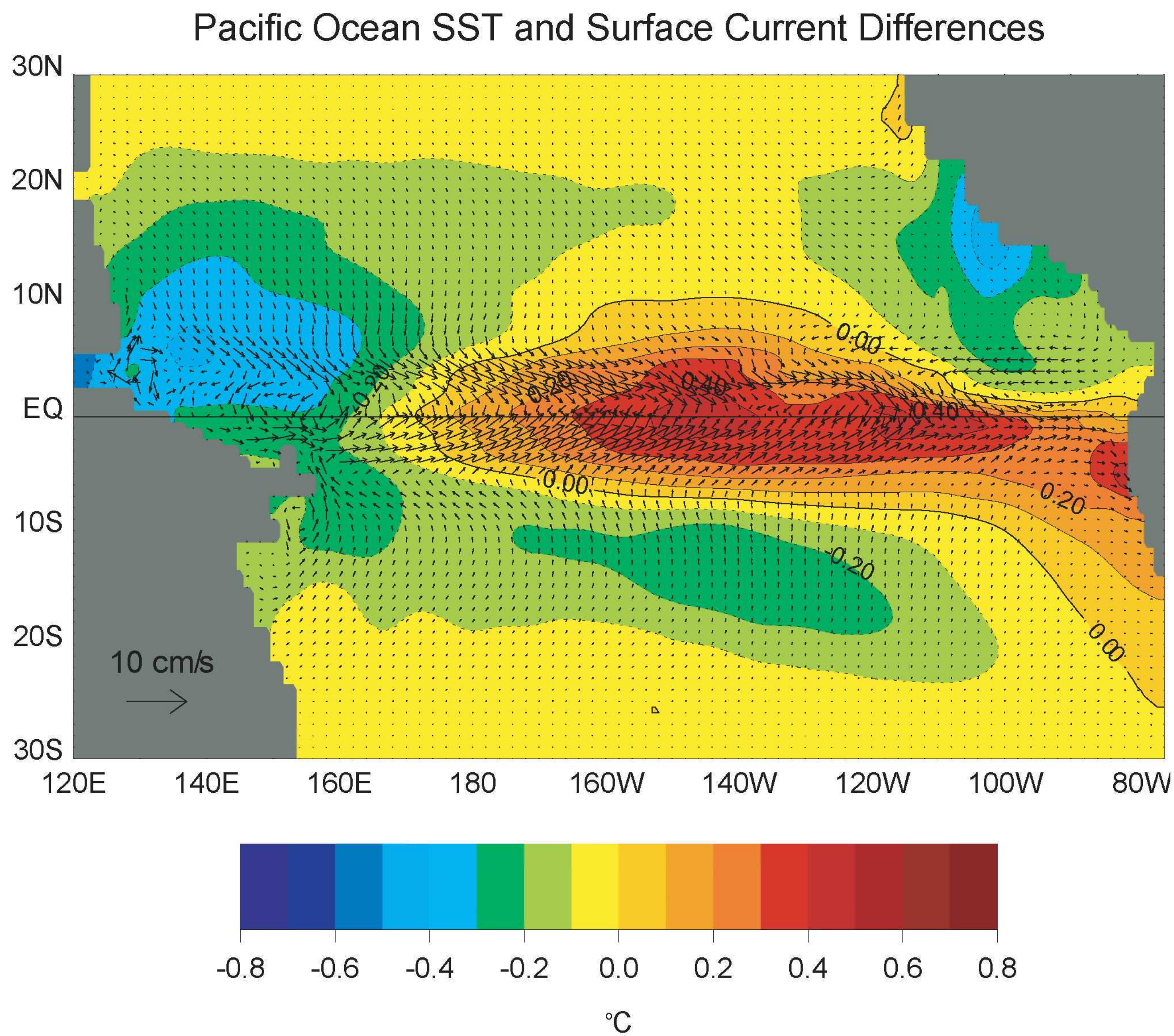
Annual mean mixed layer depth differences between CZCS and 17m att depth simulations.



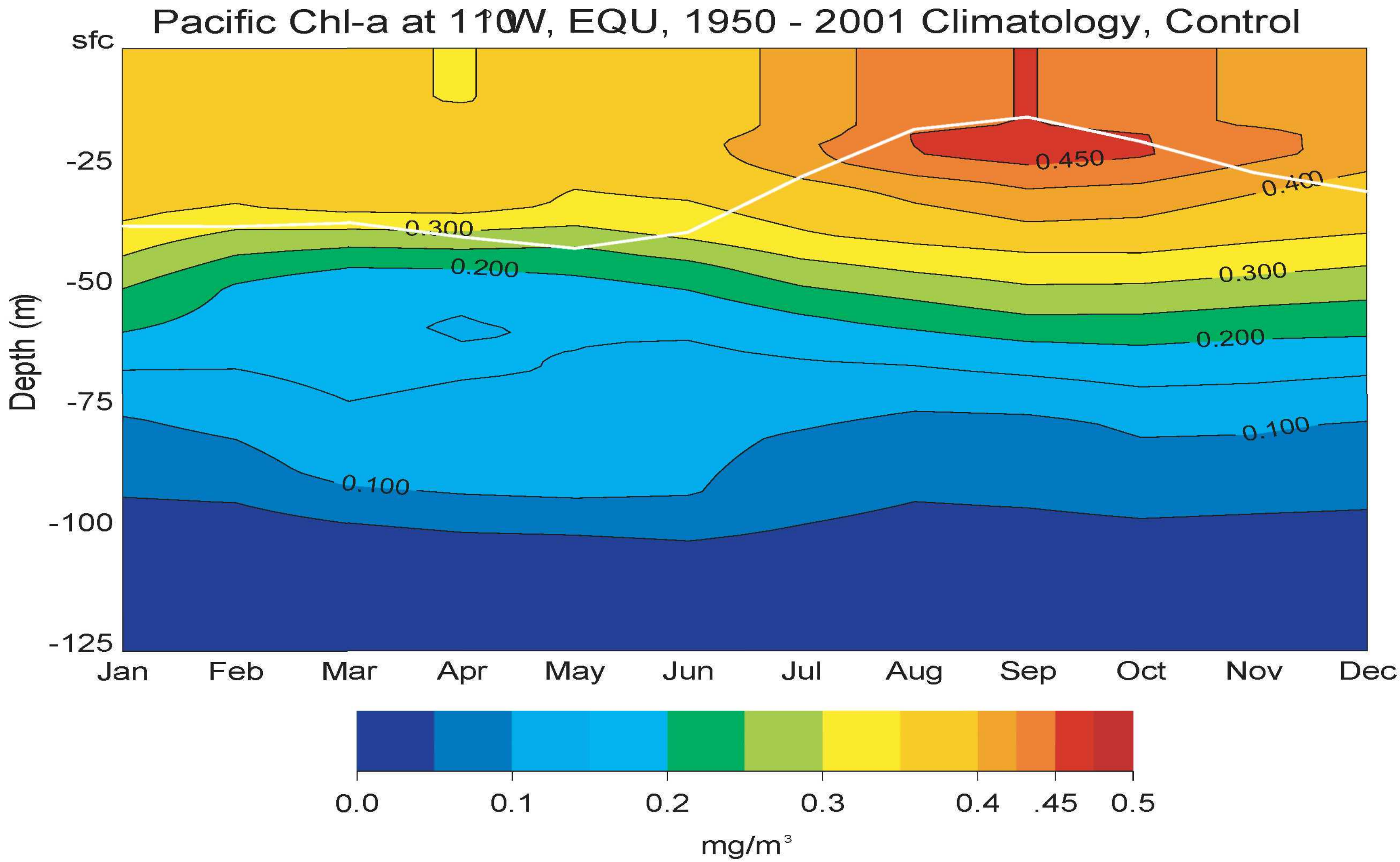
Temperature and current differences along the equator between CZCS and 17m attenuation depths.



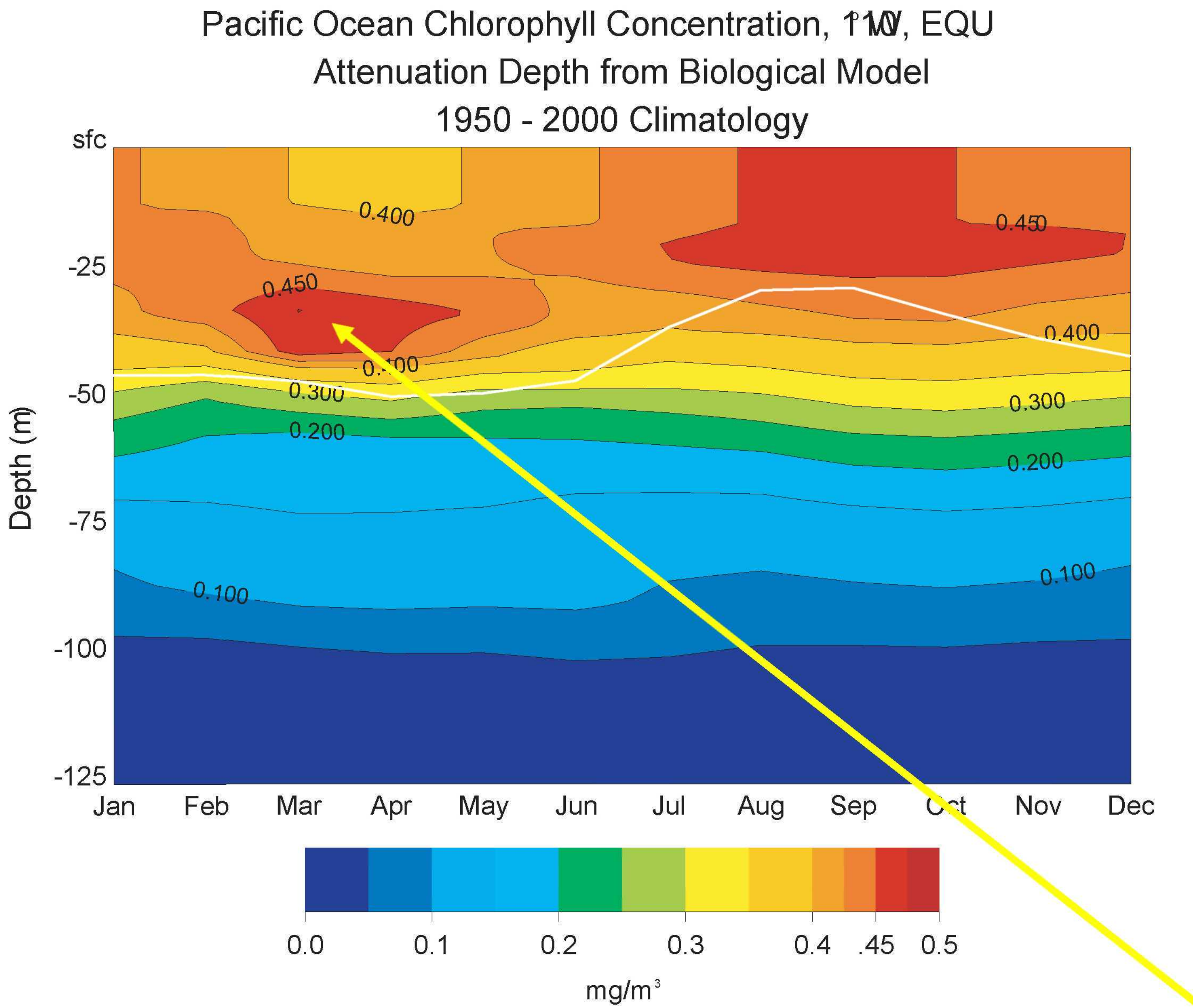
Flow chart for the ecosystem model and its coupling to the OGCM.



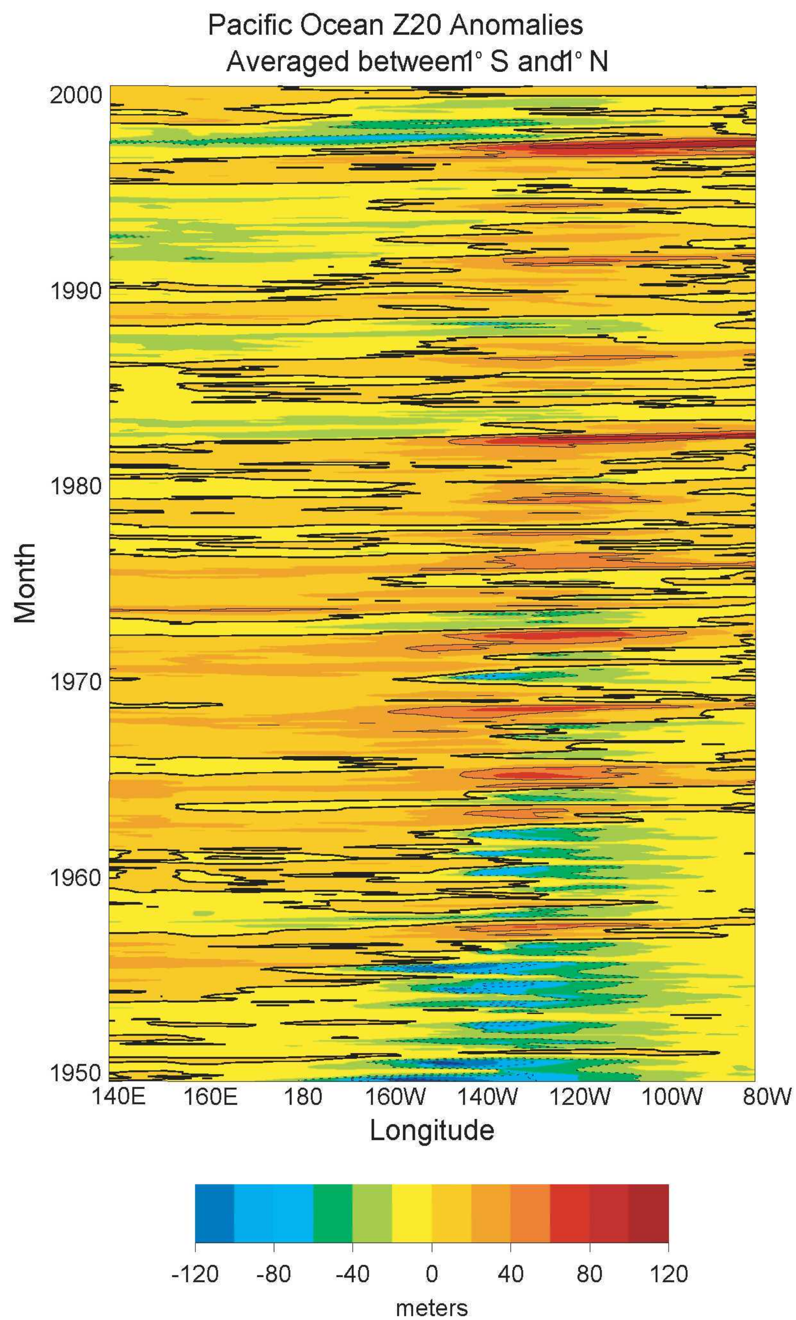
SST and current differences between runs with and without feedbacks between biology and physics.



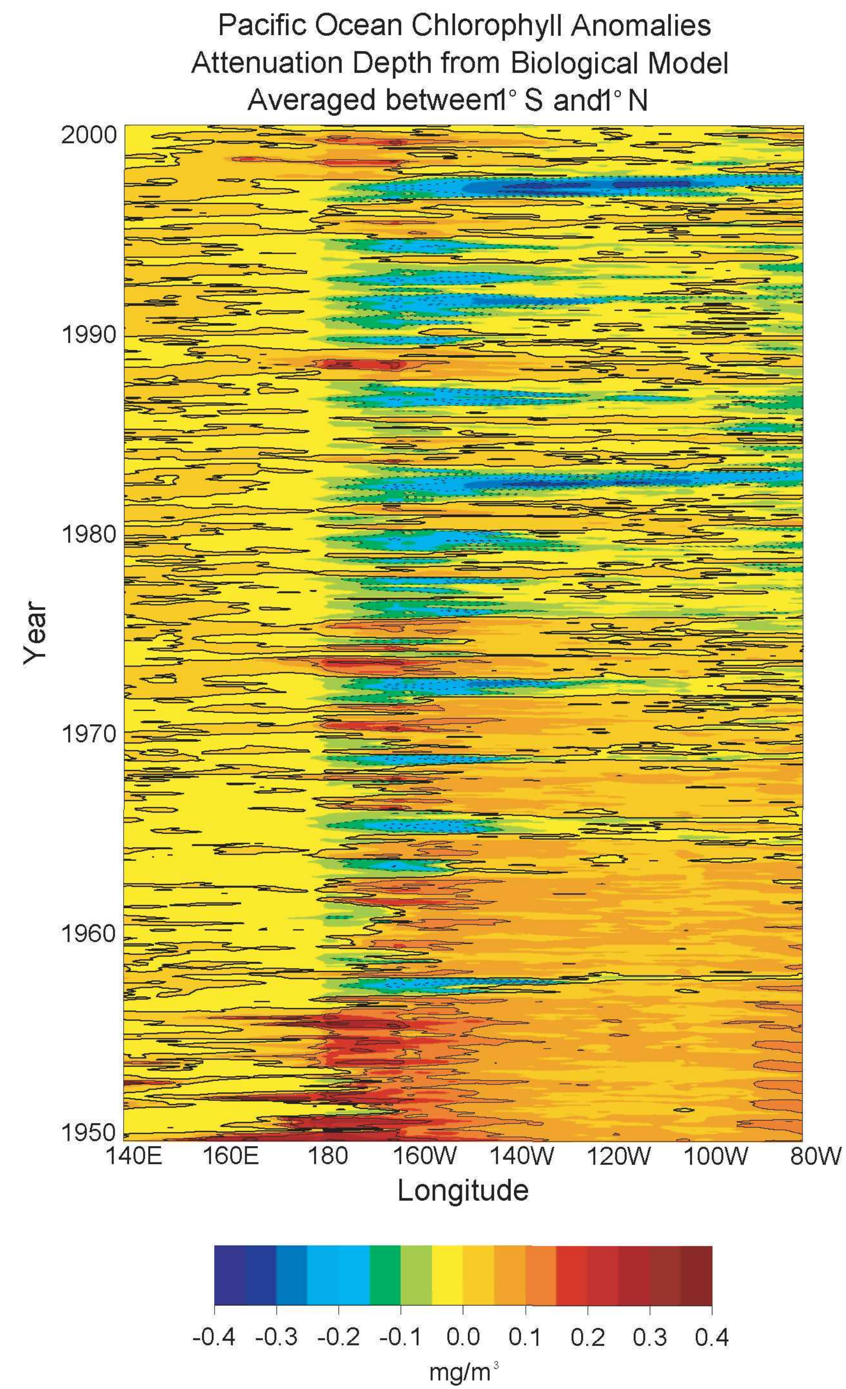
The seasonal cycle of the Chl-a is dramatically different when the feedbacks to ocean circulation are ignored.



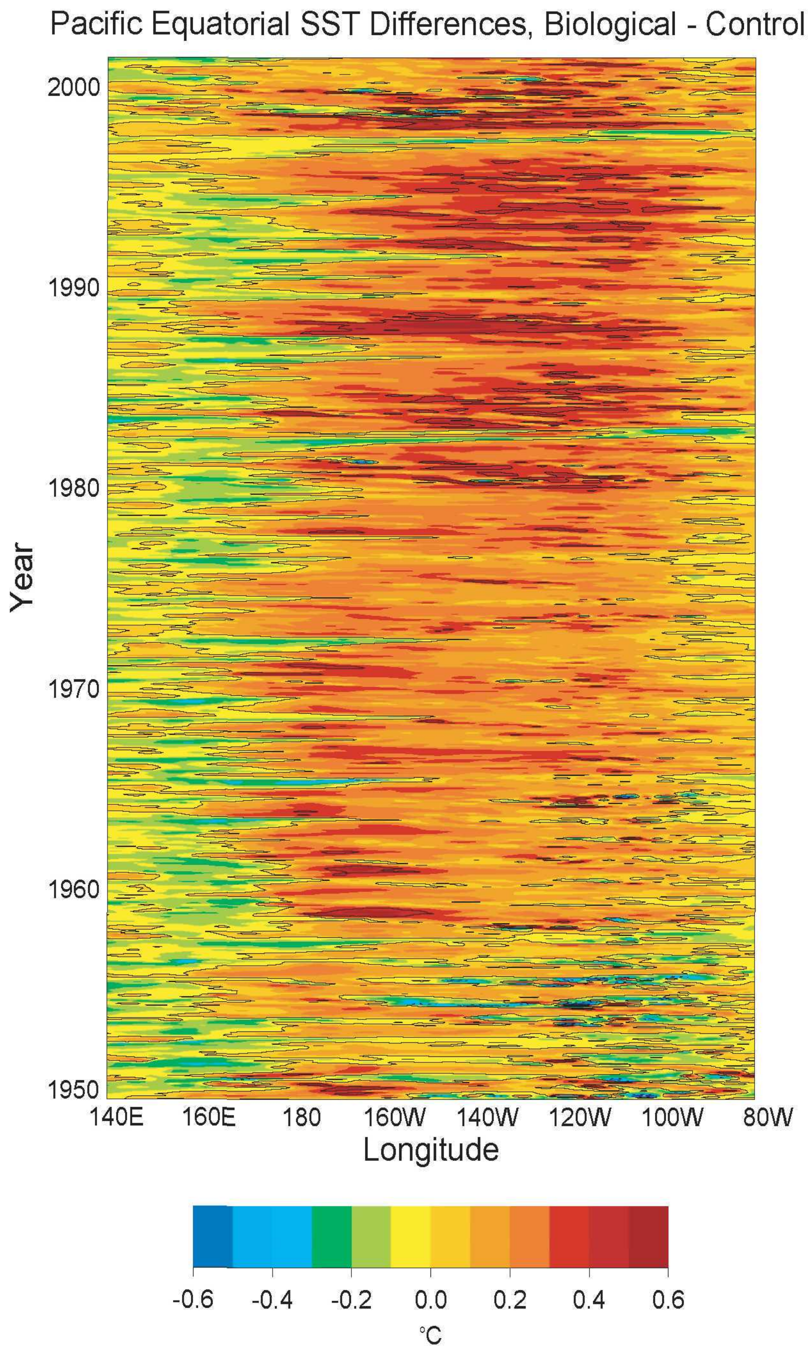
There is indeed a deep Chl-a maximum in March/April.



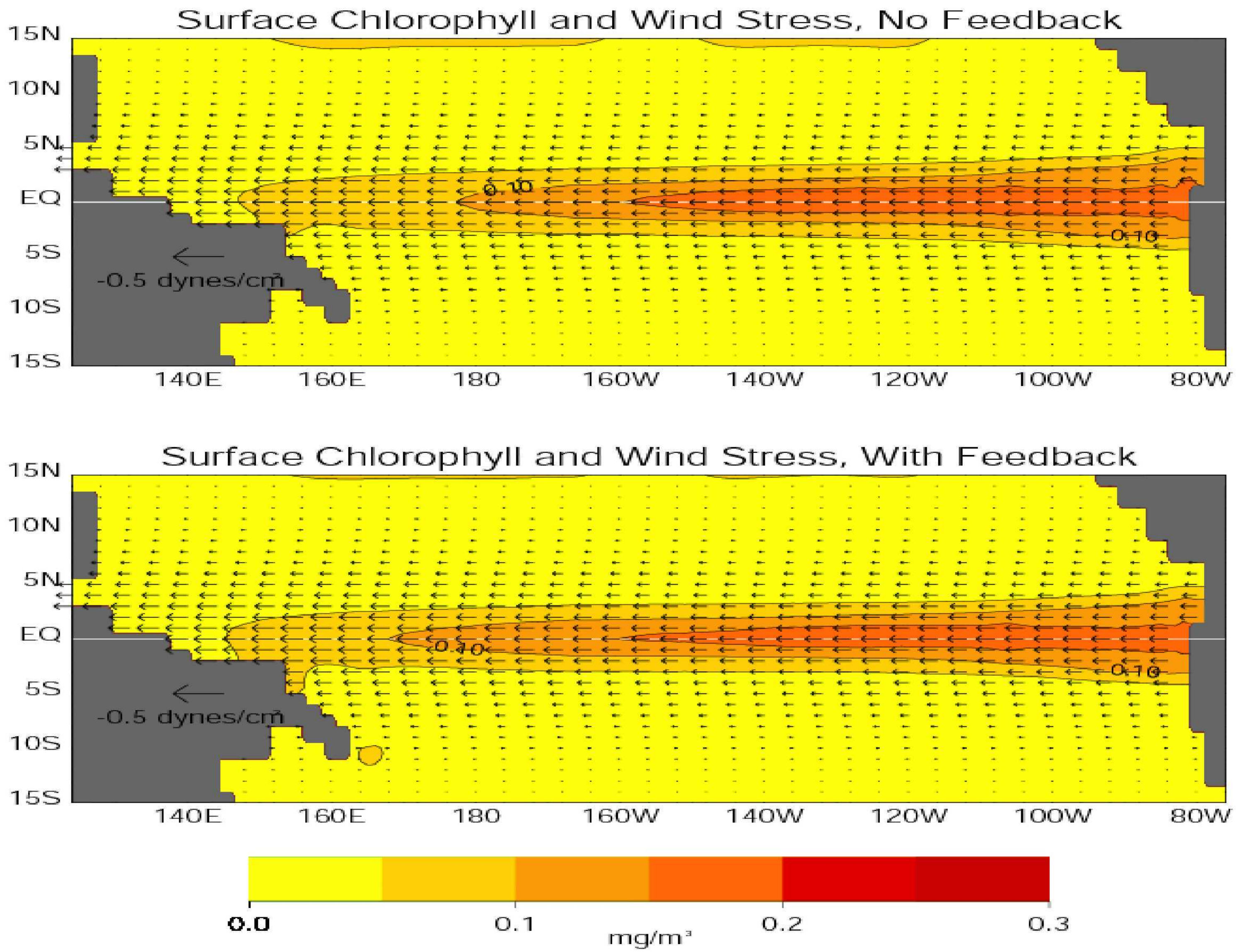
Pacific Ocean Z20 Anomalies
Averaged between 1° S and 1° N
Month
2000
1990
1980
1970
1960
1950
140E
160E
180
160W
140W
120W
100W
80W
Longitude
-120
-80
-40
0
40
80
120
meters



Pacific Ocean Chlorophyll Anomalies
Attenuation Depth from Biological Model
Averaged between 1° S and 1° N
Year
2000
1990
1980
1970
1960
1950
140E
160E
180
160W
140W
120W
100W
80W
Longitude
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
mg/m3

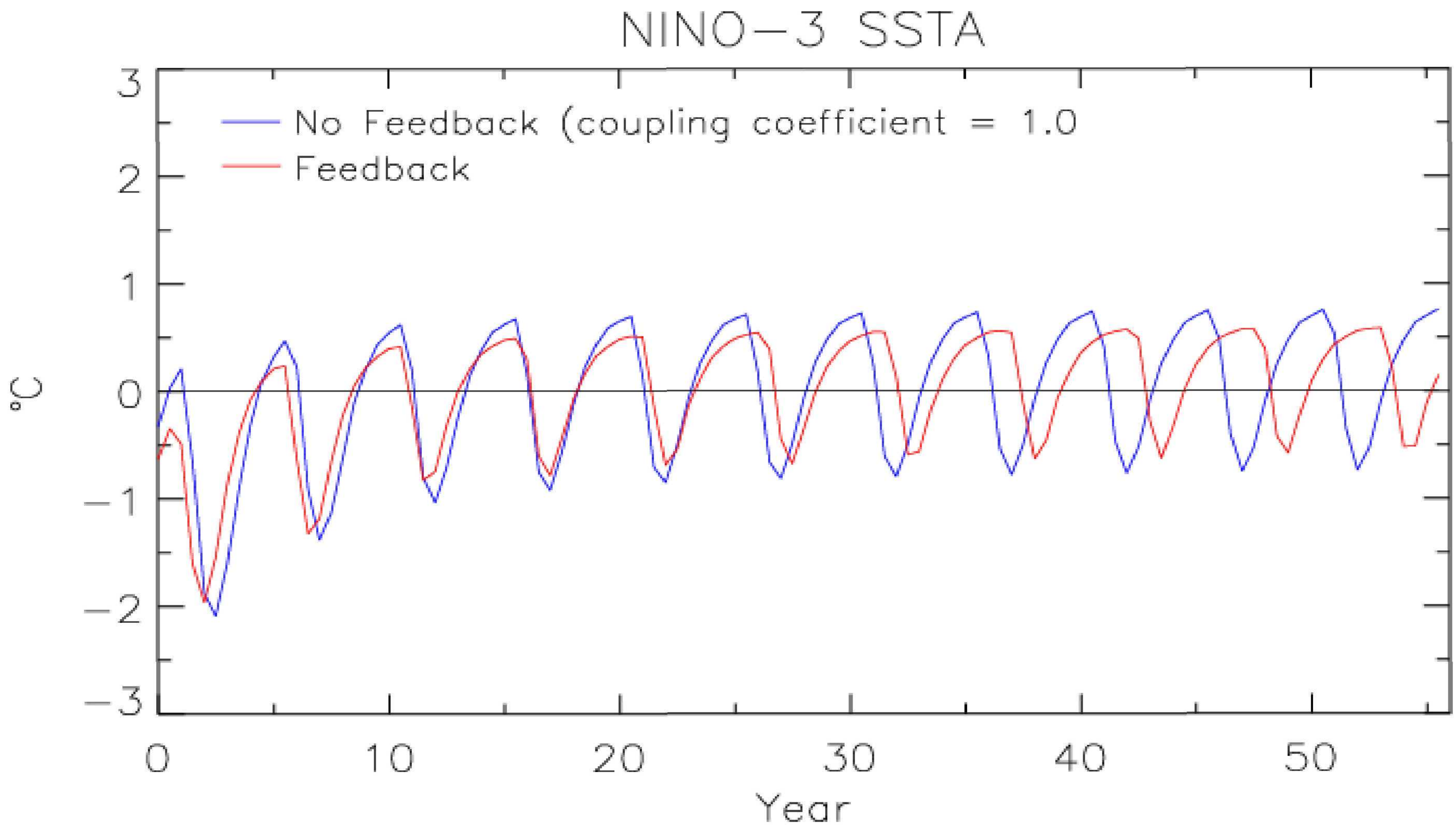


- The SST differences with and without bio-feedbacks have corresponding decadal and ENSO related variability.
- Note that individual ENSO events can produce SST warming/cooling of over 0.5C which can be important in the coupled climate system.

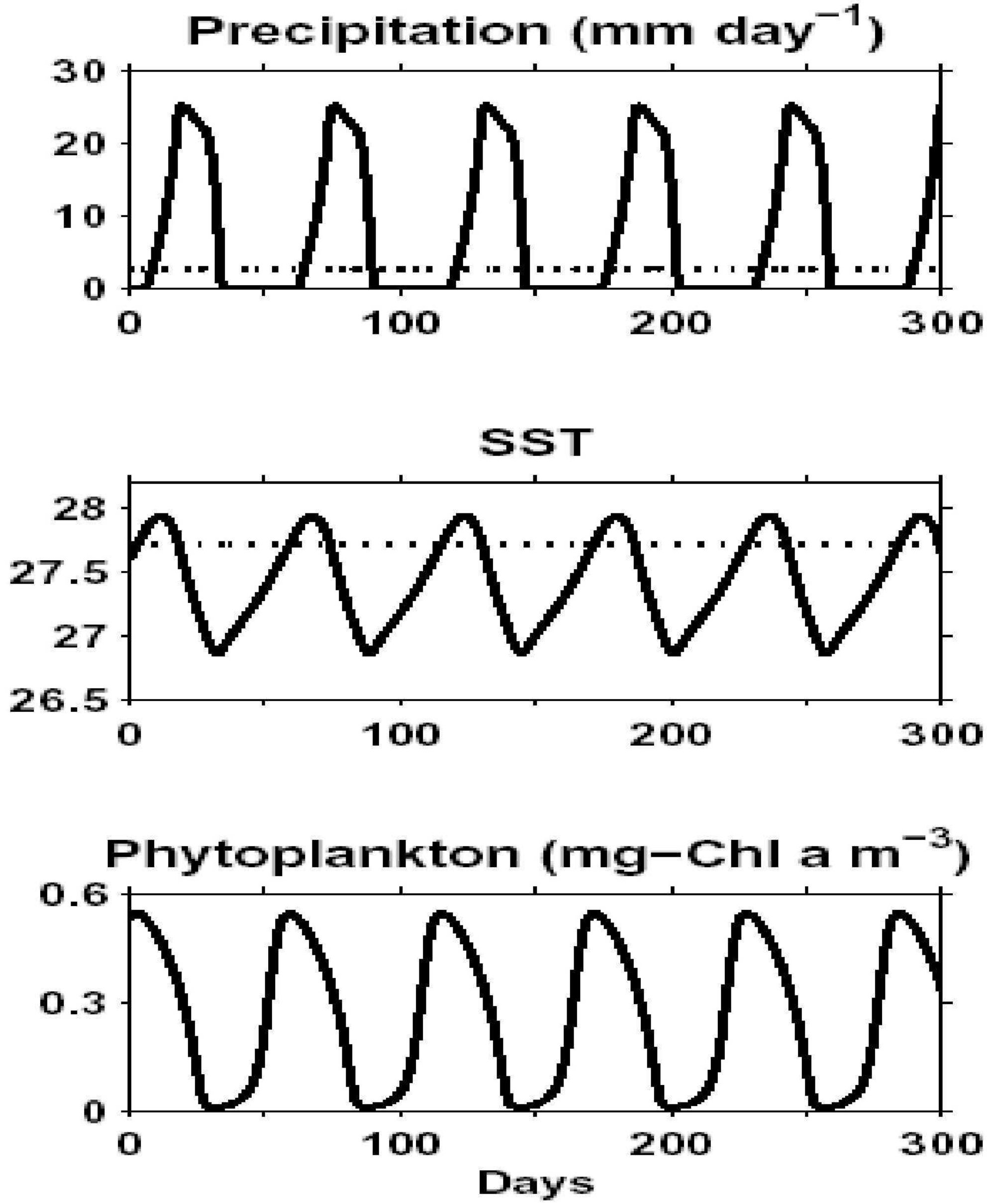


A simple wind-SST coupling allows us to study potential bio-climate feedbacks in the coupled climate system. Only zonal winds are modeled with local SST gradient.

Courtesy R. Murtugudde



The NINO3 index in this simple SST-wind coupled model display realistic interannual variability with a period of about 3 years. Allowing biological feedback leads to modulation of the amplitude and frequency of the interannual variability. Note that the feedbacks are asymmetric for warm and cold ENSO events.

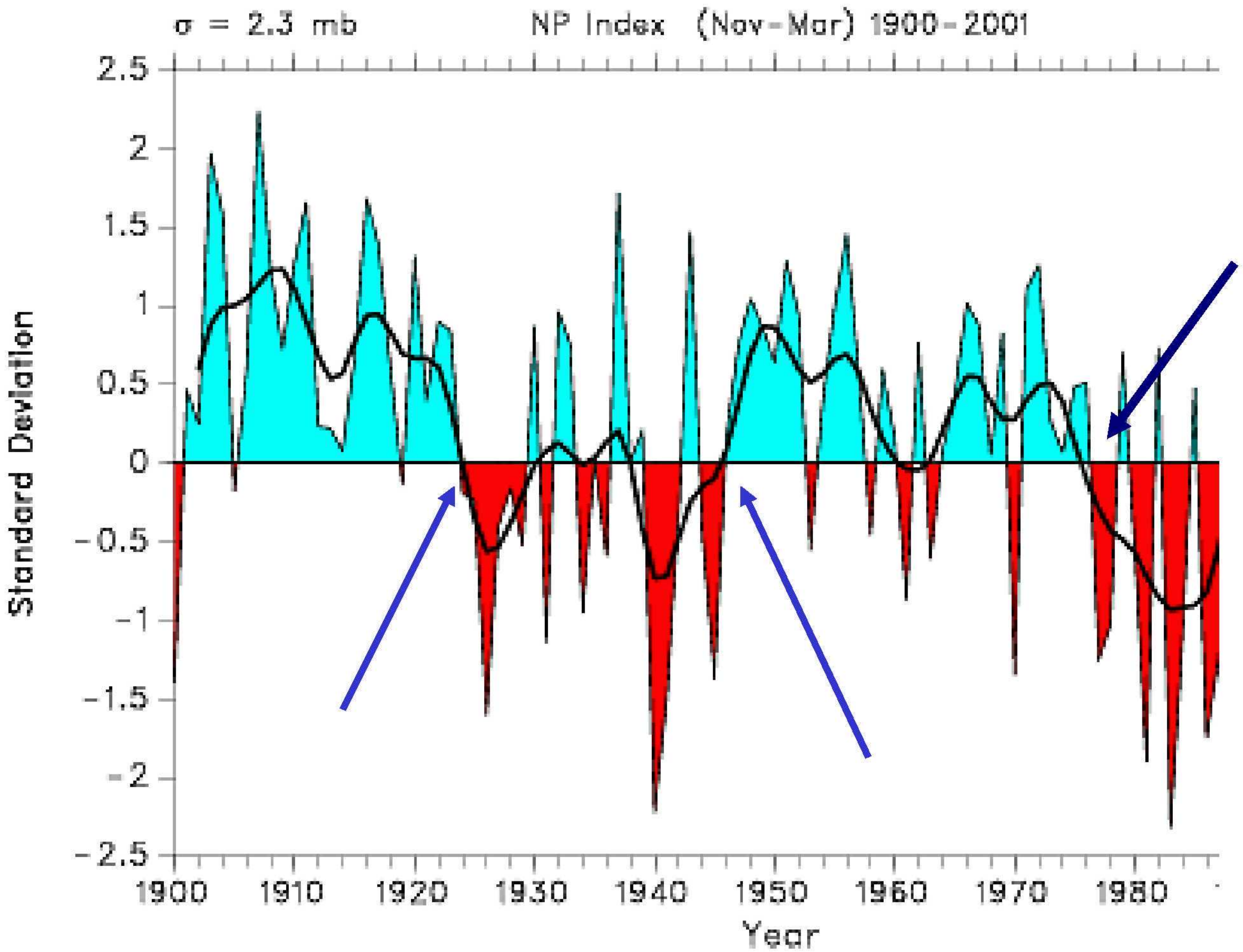


Simulation of intraseasonal atmospheric oscillations by ocean biota

Gildor et al., 2003

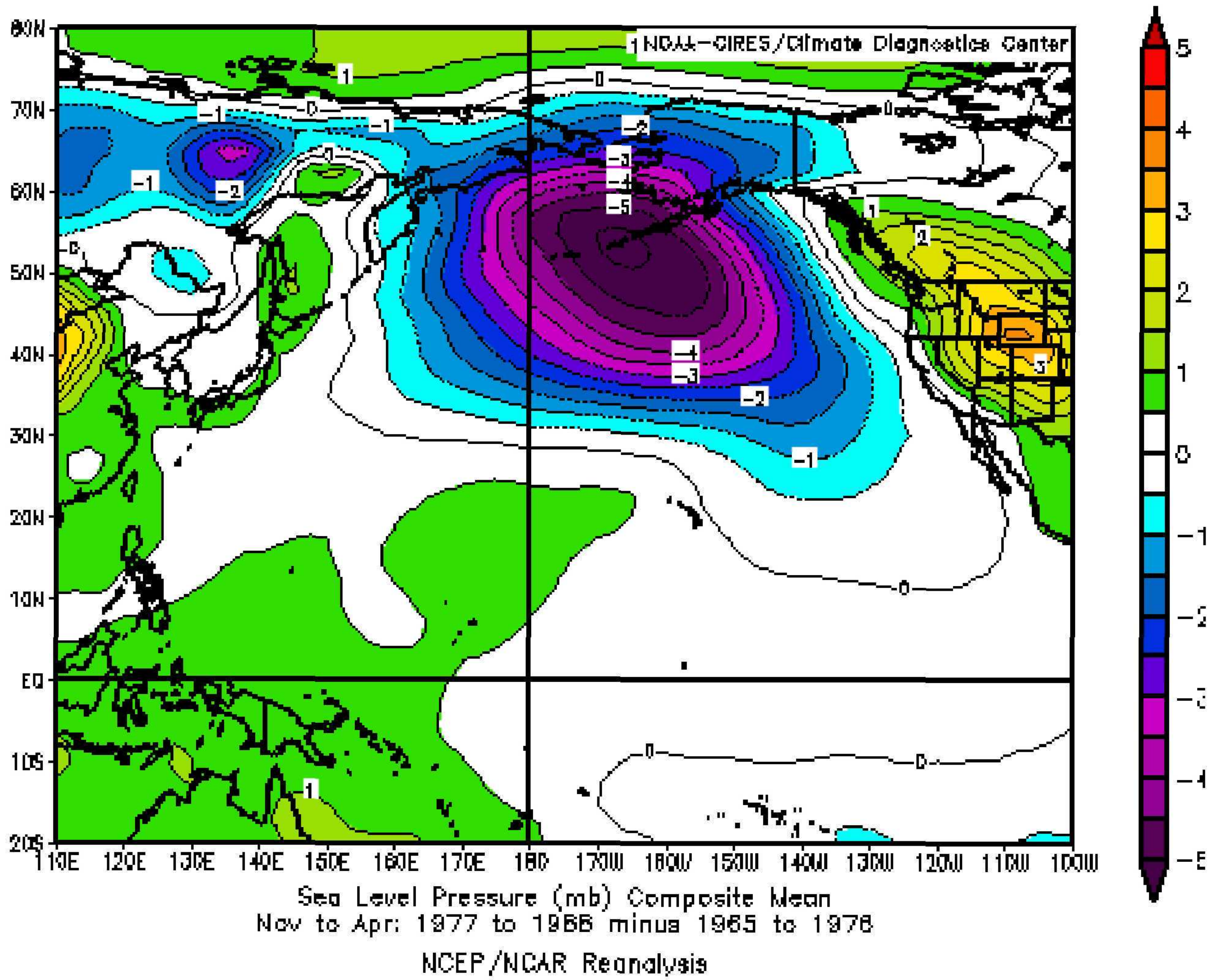
Cool season Aleutian Low variability:

(Nitta and Yamada 1989, J. Met. Soc. Japan; Trenberth 1990, BAMS)



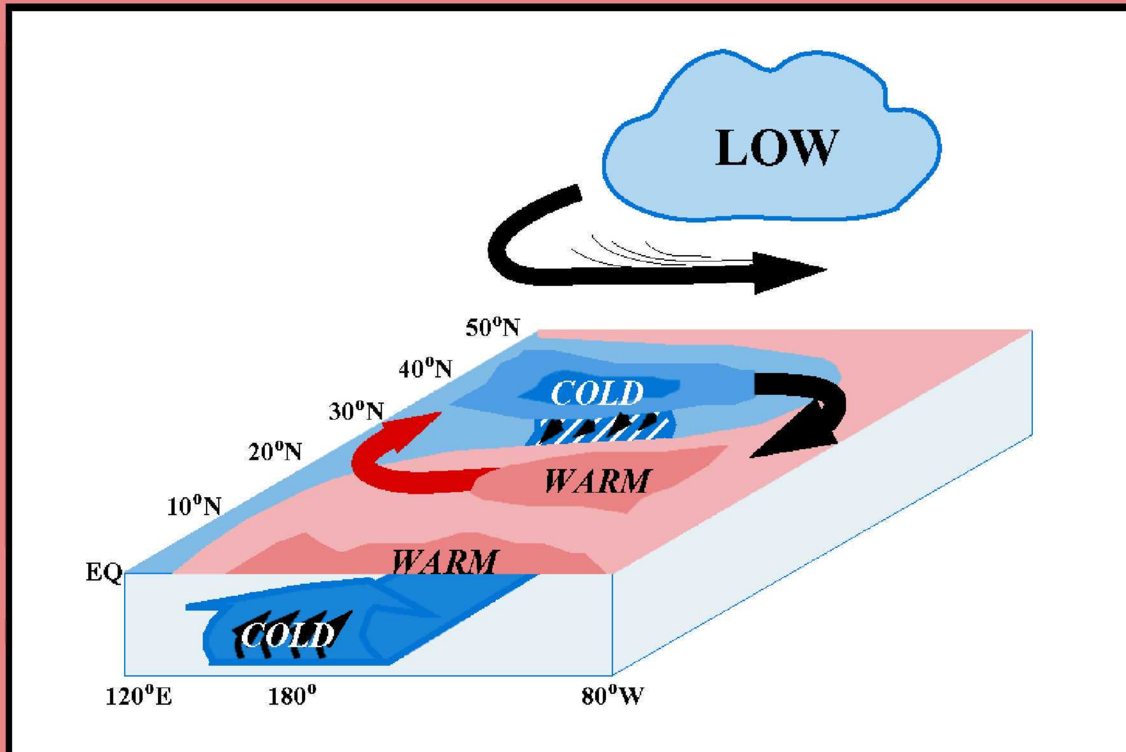
North Pacific winter climate "shifted" in 1977

November-April SLP change: (1977-88) - (1965-76)



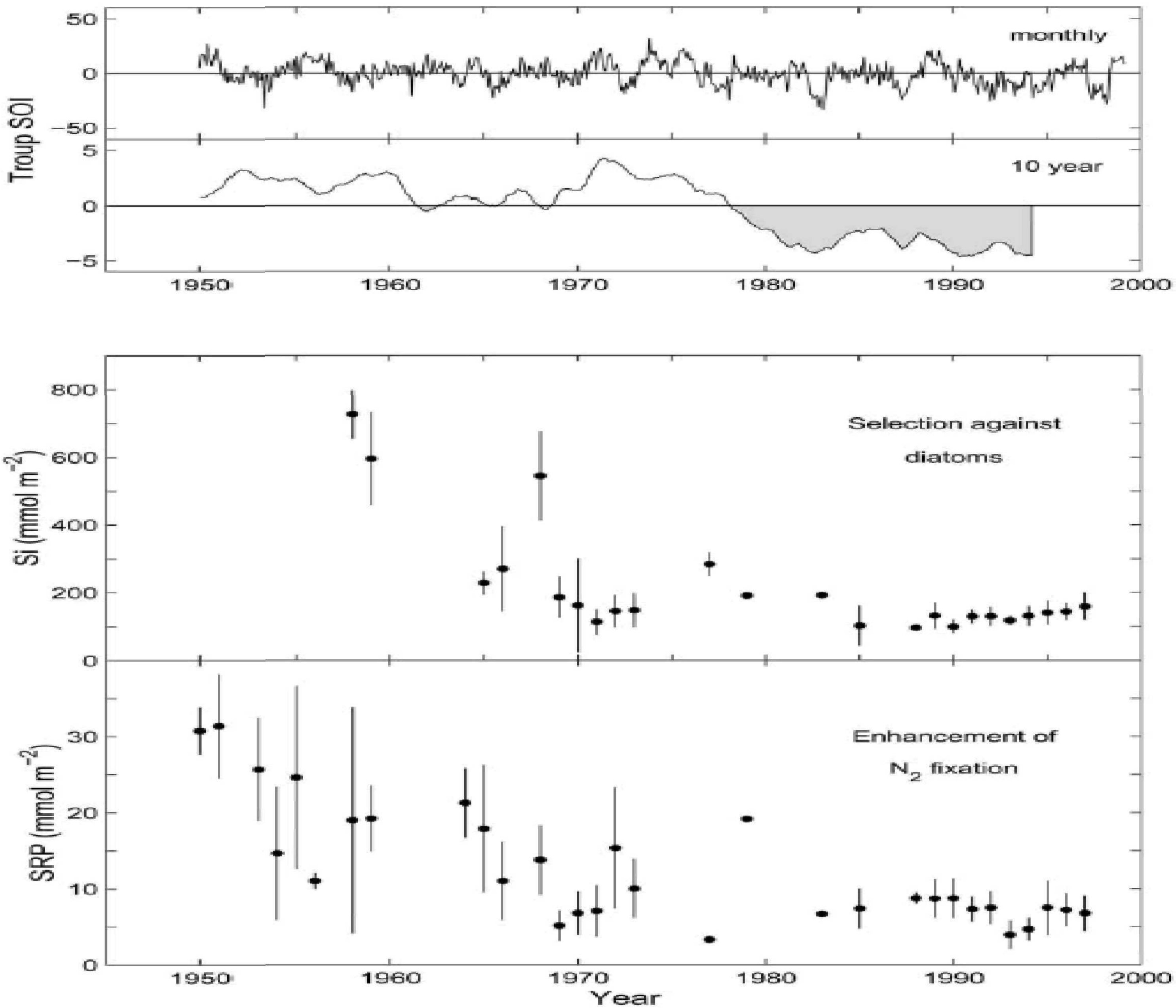
Decadal Variability in the North Pacific

- Possible Mechanisms -



Schematic diagram of possible mechanisms of decadal climate variability. Extratropical decadal climate variability may be caused by a cycle involving unstable air-sea interactions between the subtropical gyre circulation in the North Pacific and the Aleutian low-pressure system. Long-term fluctuations of the tropical SSTs may, presumably, be induced by an influx of water from higher latitudes which subducts in the North Pacific and flows southeastward along the surfaces of constant density before equatorial upwelling brings it back to the surface. The tropical SST anomalies may in turn also affect the Aleutian low-pressure system (S. Venzke, 1998, Ocean-atmosphere interactions of decadal timescales, Thesis, Max-Planck-Institut für Meteorologie, Hamburg, 100pp).

AV/D4/99-3

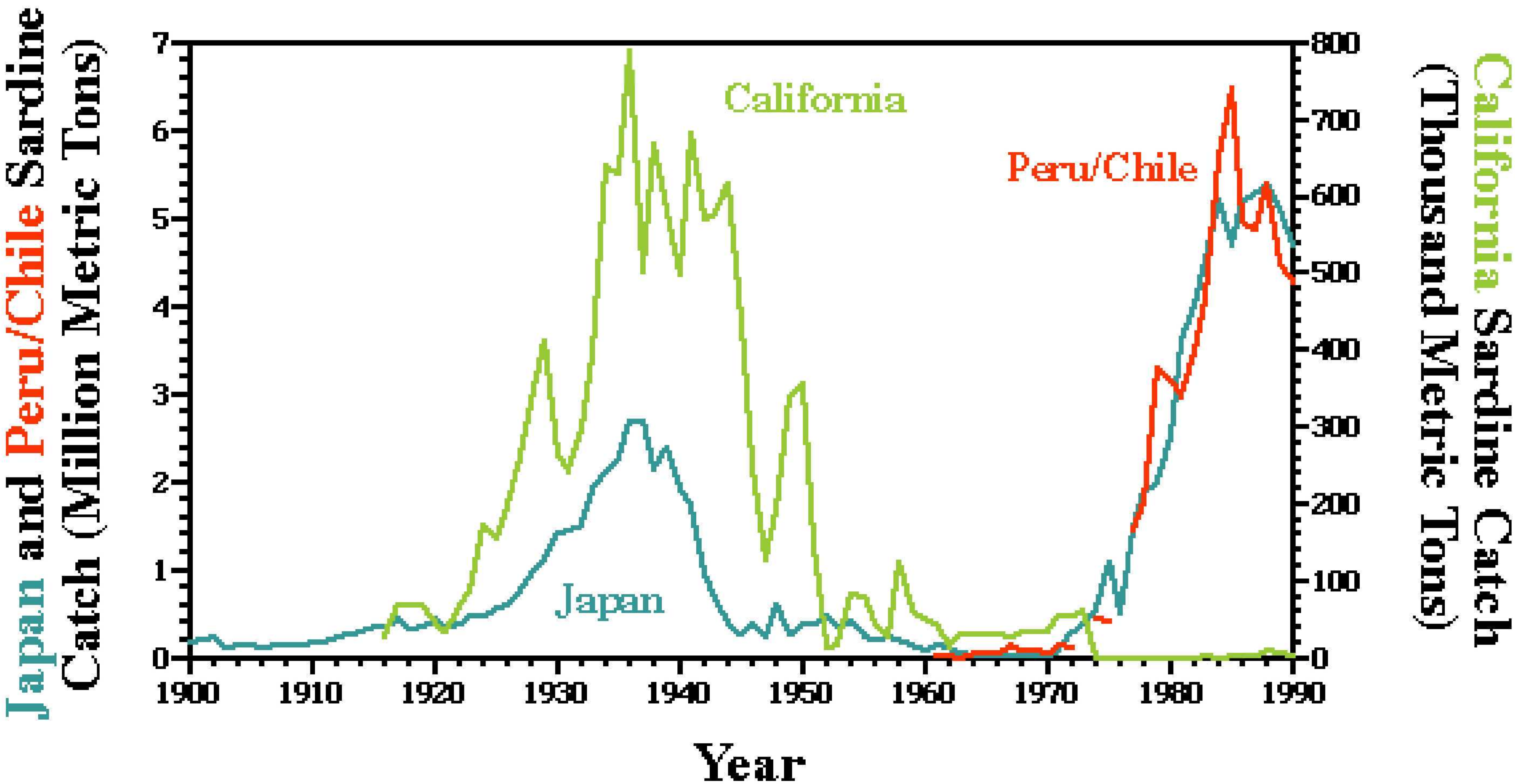


Long-term changes to dissolved silicate and phosphorus

Karl et al., 2001

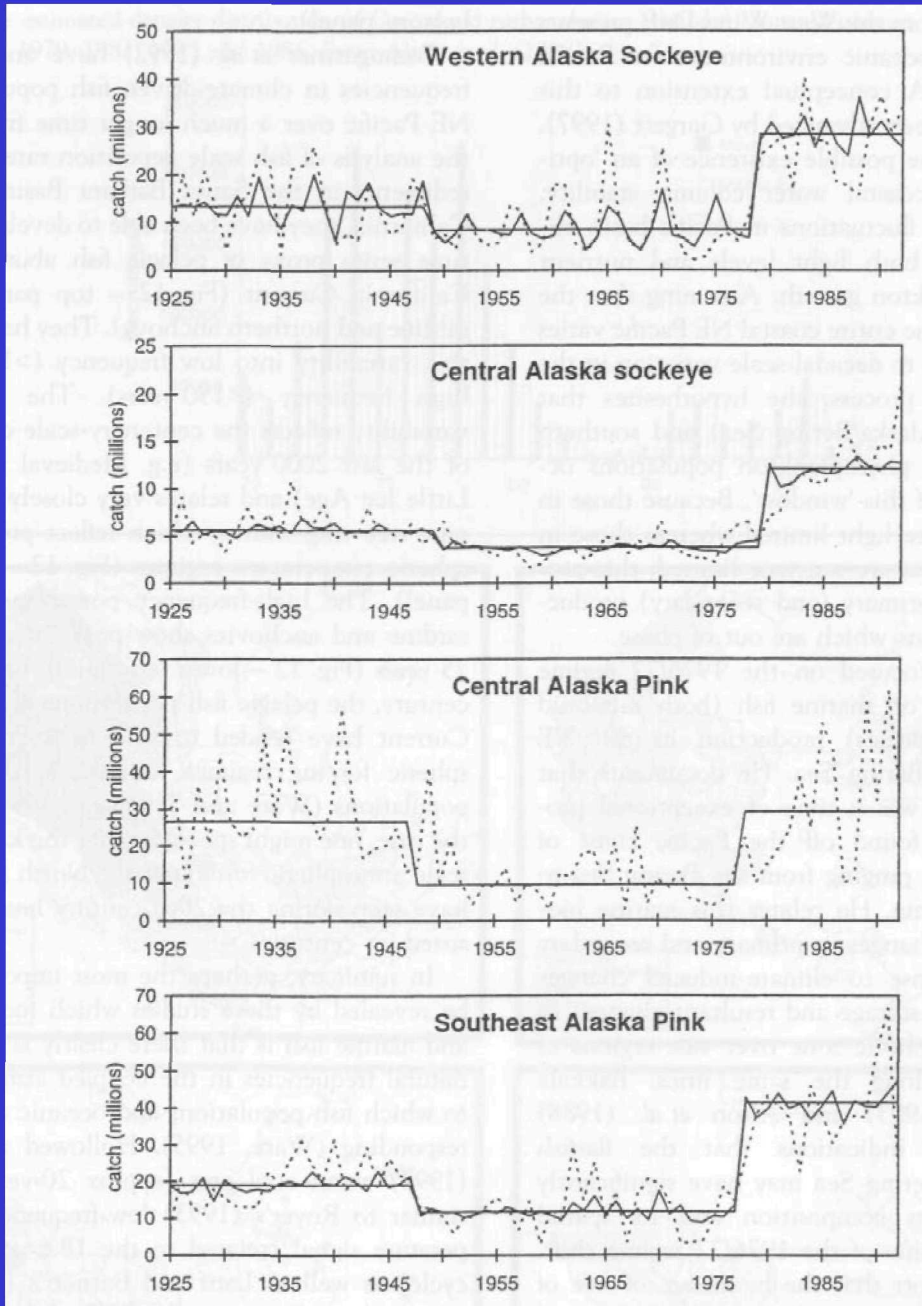
Pacific Sardines: a history of 20th Century boom and bust cycles

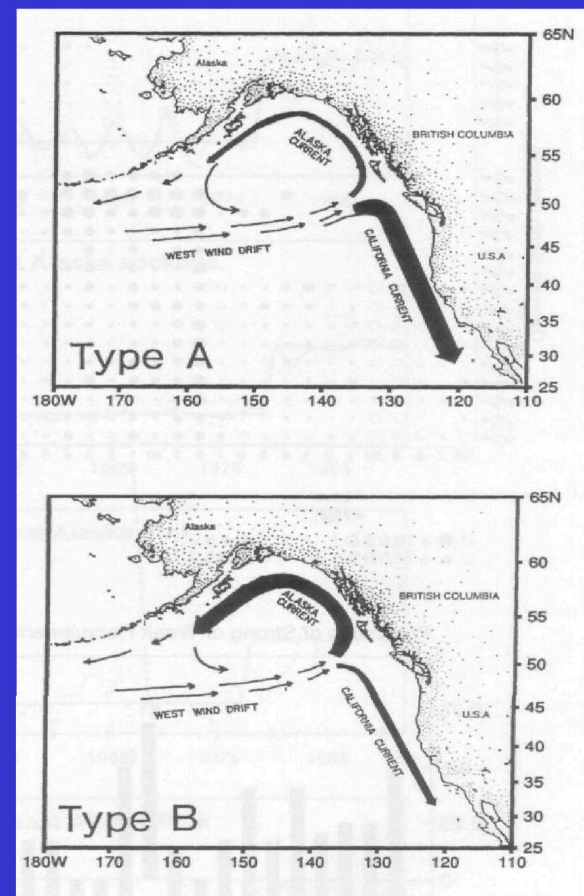
(Kawasaki and Omori 1988)



Courtesy N. Mantua

Alaska Salmon responded to 20th Century Climate Shifts (Francis and Hare 1994, Fish. Oceanog.)





(Chelton and Davis 1982, JPO)

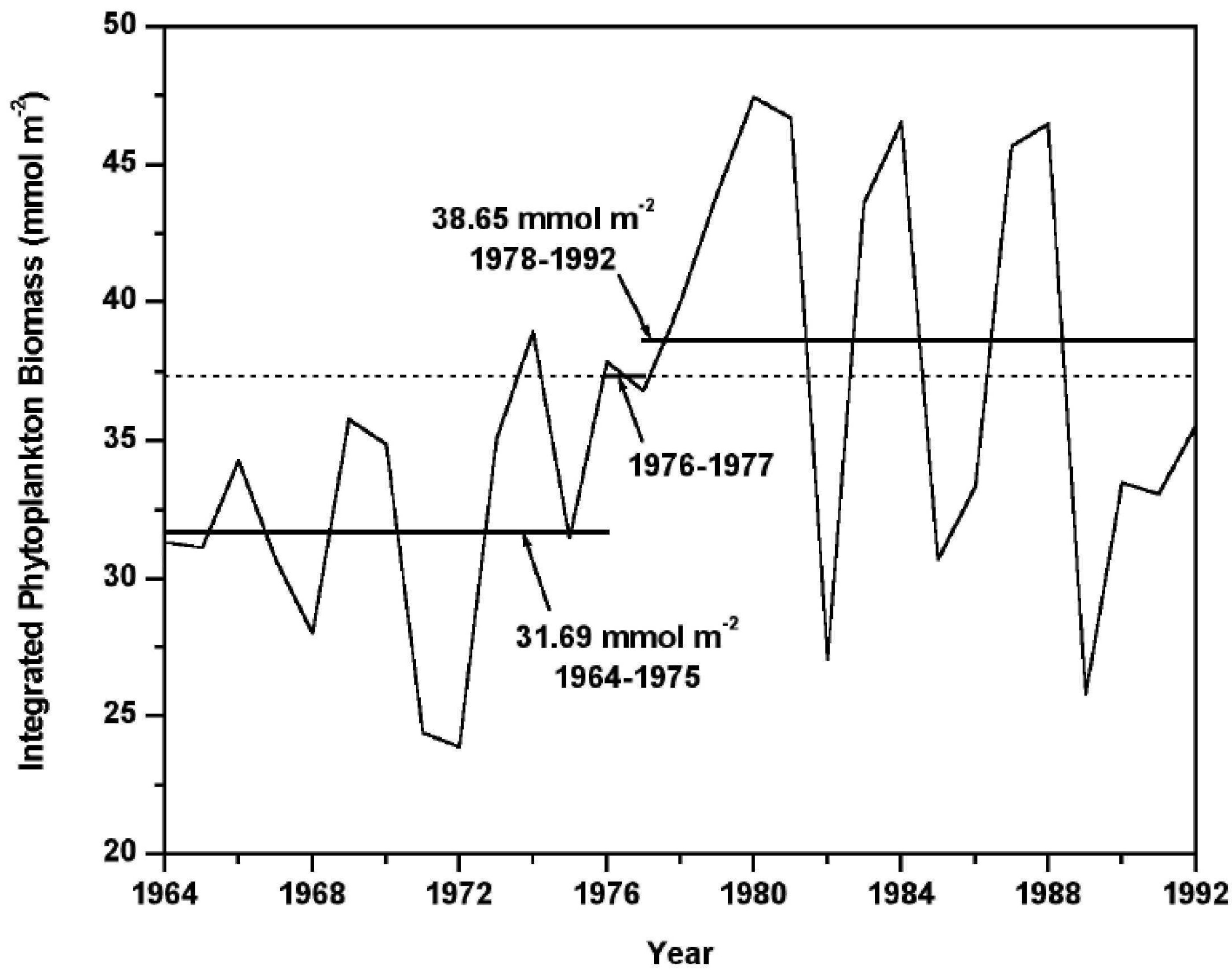
Ecosystems change

Bottom trawl surveys in Pavlov Bay, Alaska (source: Botsford et al. 1997 Science)

1960's

1970's

1980's

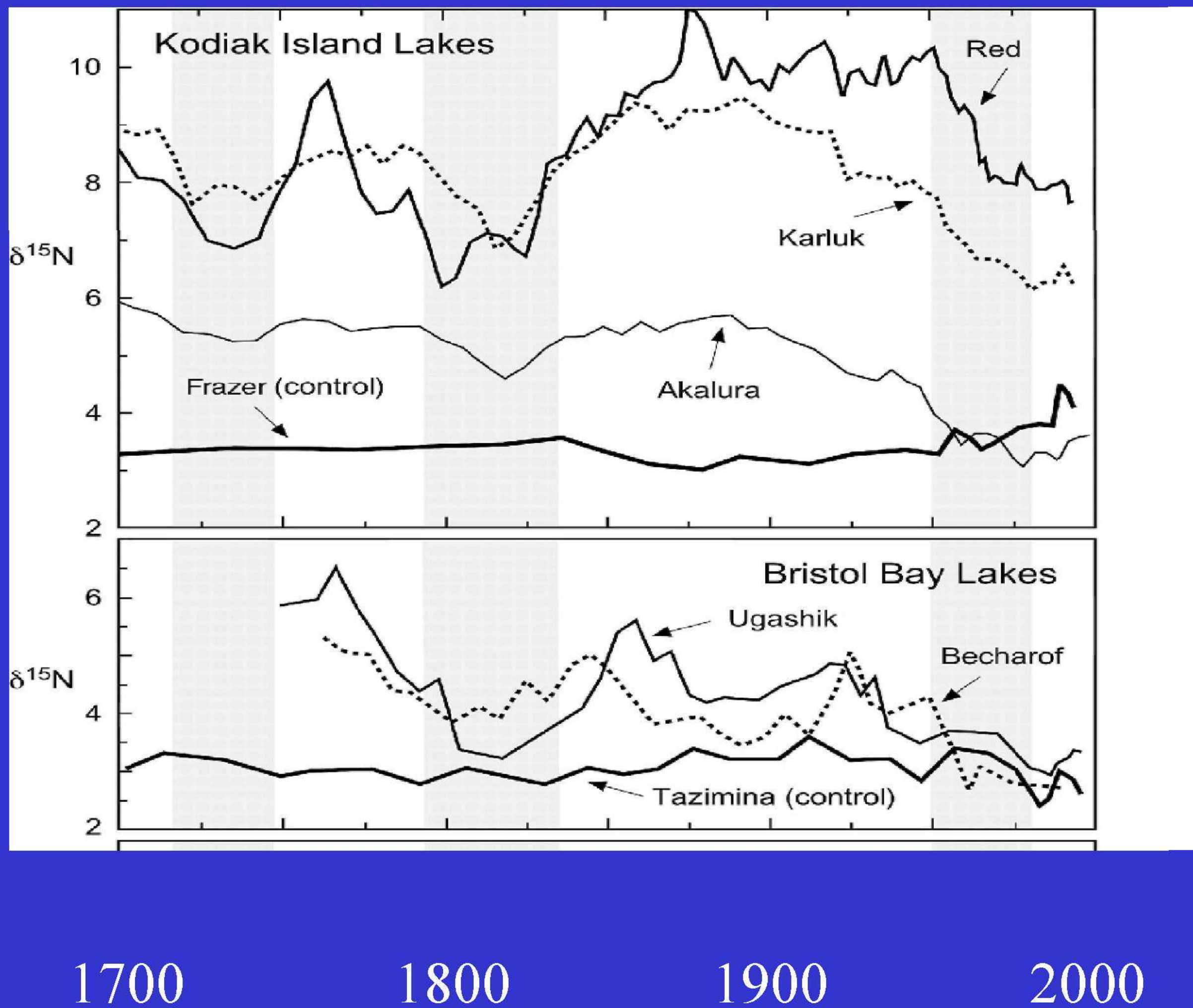


Modelled biomass in NW Pacific

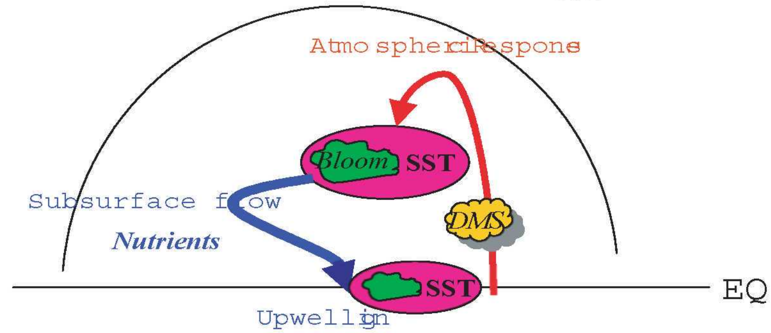
Chai et al., 2003.

Long term variability

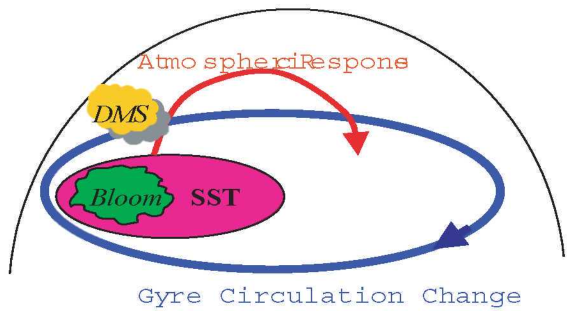
Paleo-salmon abundance estimates from lakebed sediment cores with *Salmon Derived Nutrients* (Finney et al. 2000, Science)



Subduction Mode with Biology

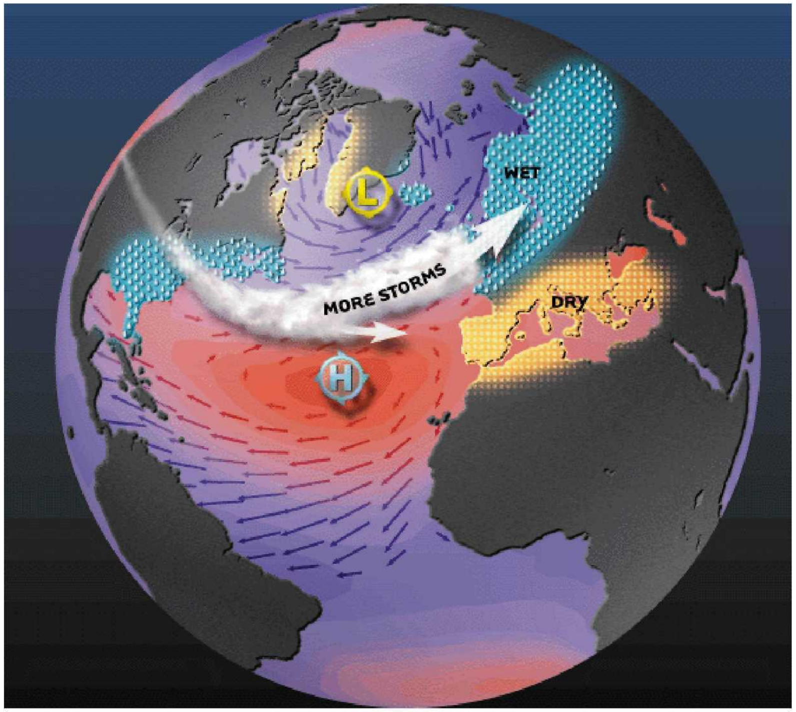


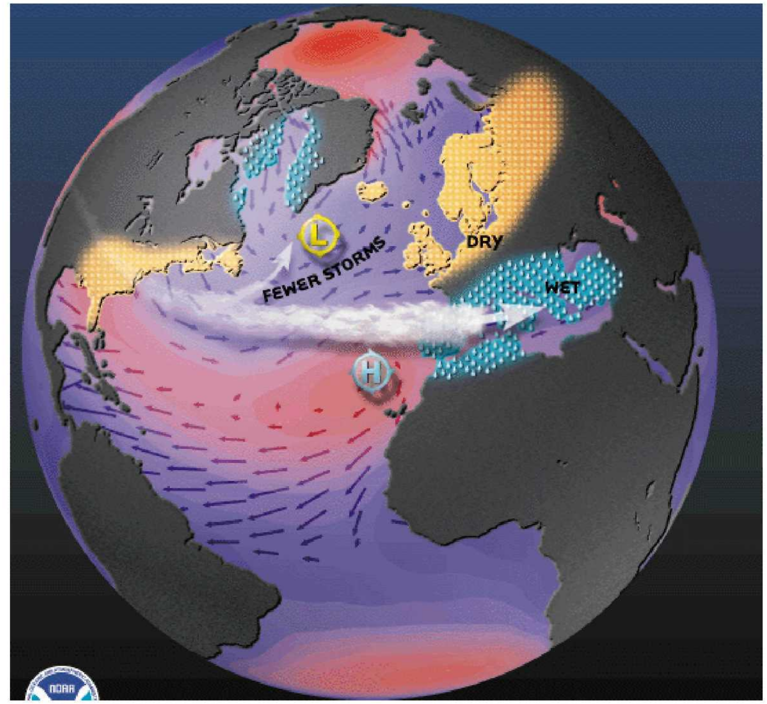
Midlatitude Gyre Mode with Biology



Modulations of the decadal variability in the Pacific

The North Atlantic Oscillation (NAO)





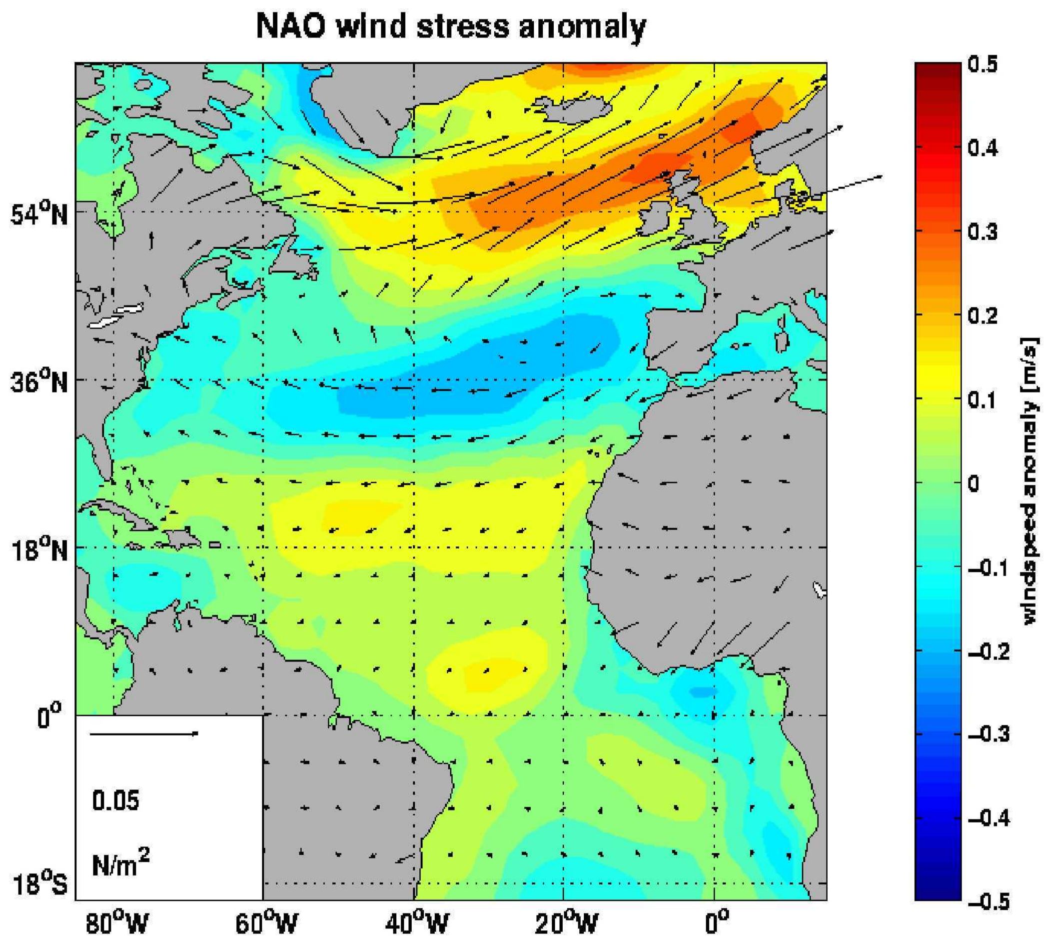
- Dominant mode of climate variability in the Atlantic in winter (van Loon & Rogers, 1972)
- Seesaw of atmospheric mass between subtropical high and subpolar low (Walker and Bliss, 1932)
- Controls the path and intensity of storm track (Hurrell, 1995)
- Spectral density of NAO weakly exists at 2-3 years (QBO), 7-10 years, also an increasing trend (Hurrell and van Loon, 1997)
- Significant impact on marine and terrestrial ecosystems

Images courtesy Martin Visbeck

Ocean's response to the NAO:

- Wind anomaly pattern
- Surface heat fluxes
- Changes in the fresh water flux
- Ekman transport anomaly
- Sverdrup transport anomaly
- Impact on the overturning circulation
- Eco-system model response

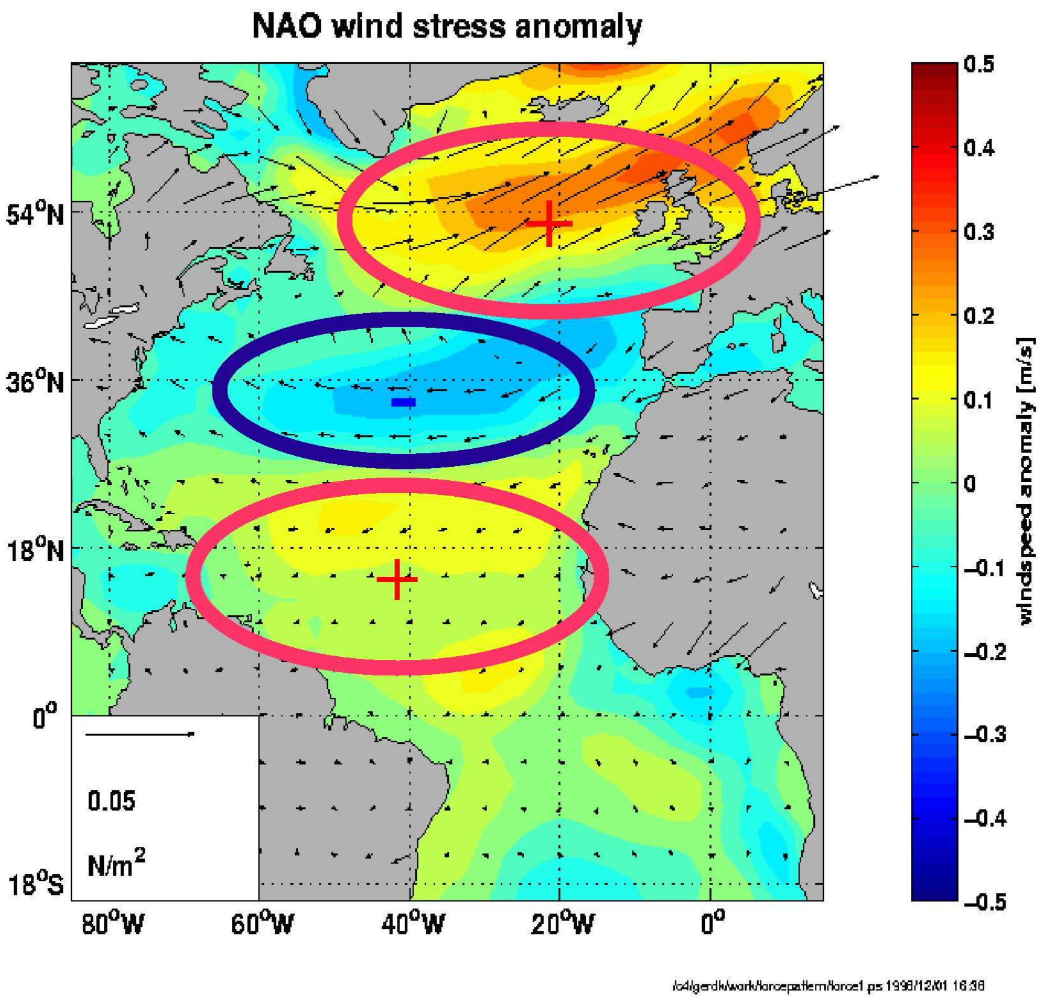
Impacts of the North Atlantic Oscillation: Changes in wind stress and wind speed



Regression of the NCEP/NACR reanalyzed wind speed and wind stress on the NAO index averaged over the winter season (DJFM)

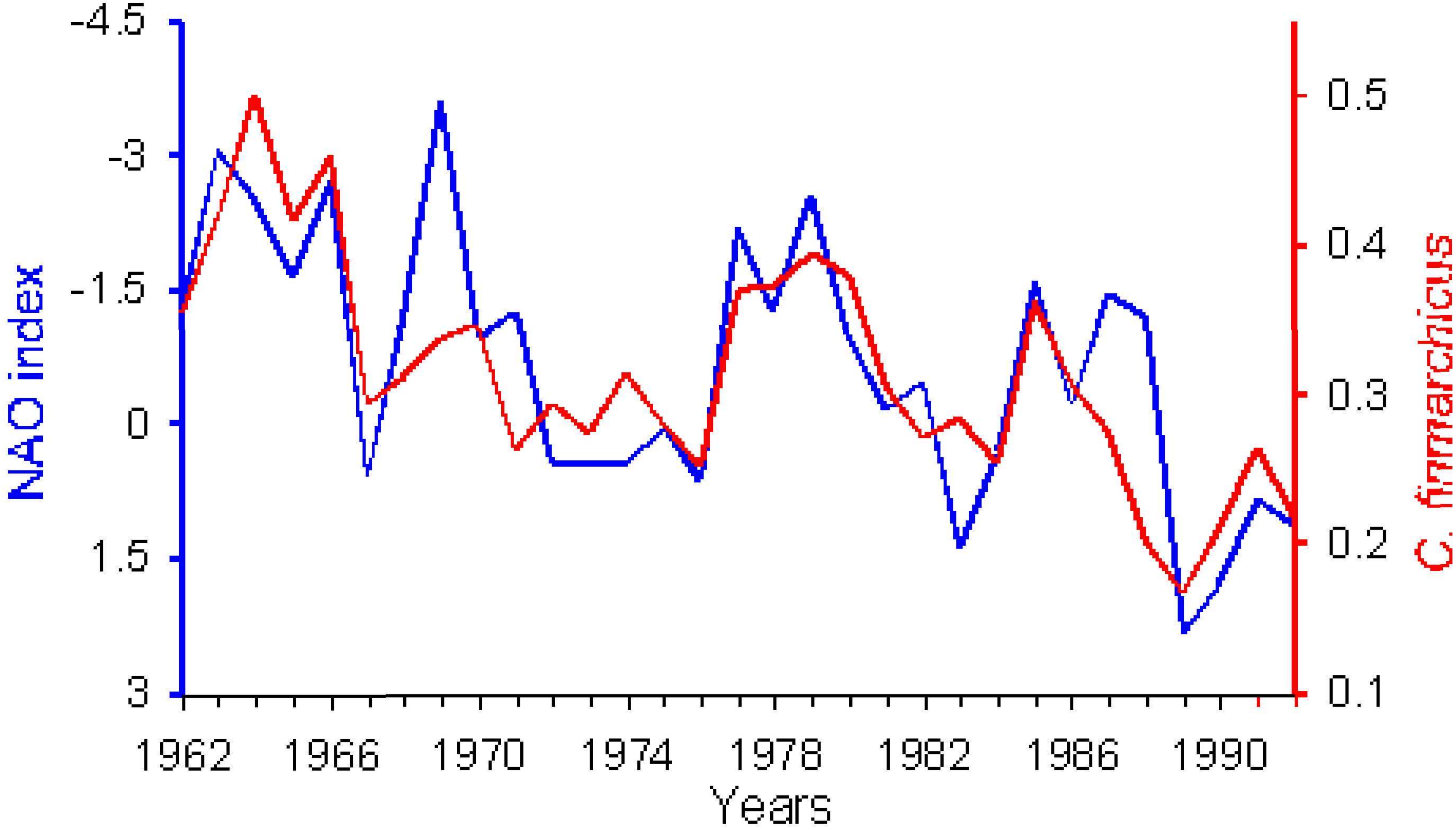
Courtesy M. Visbeck

Impacts of the North Atlantic Oscillation: Changes in wind stress and wind speed



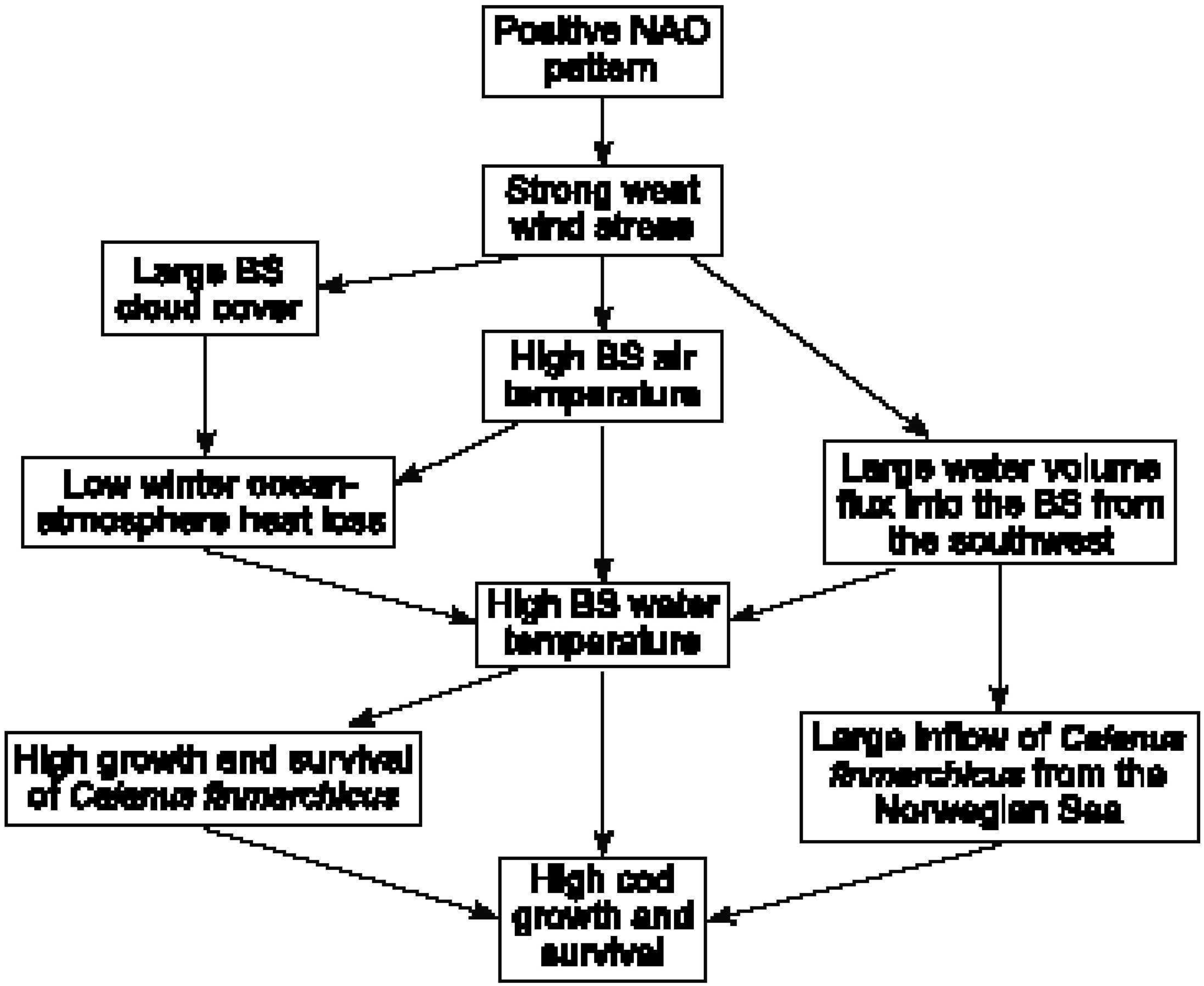
Regression of the NCEP/NCAR reanalyzed wind speed and wind stress on the NAO index averaged over the winter season (DJFM)

Note the three lobes in wind speed anomalies.



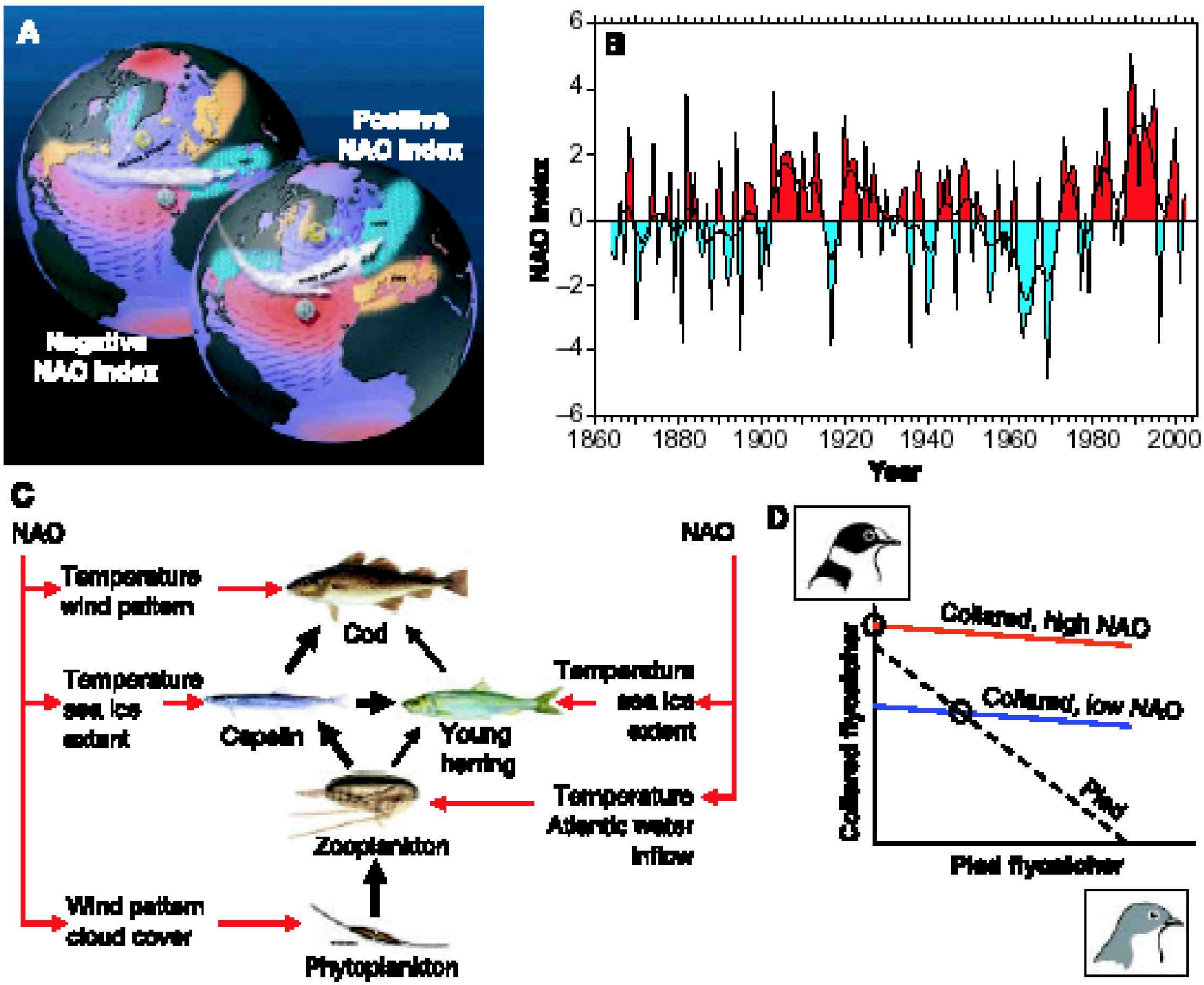
Relationship between NAO and Cal. Fin.

in NW Atlantic and northern North Sea



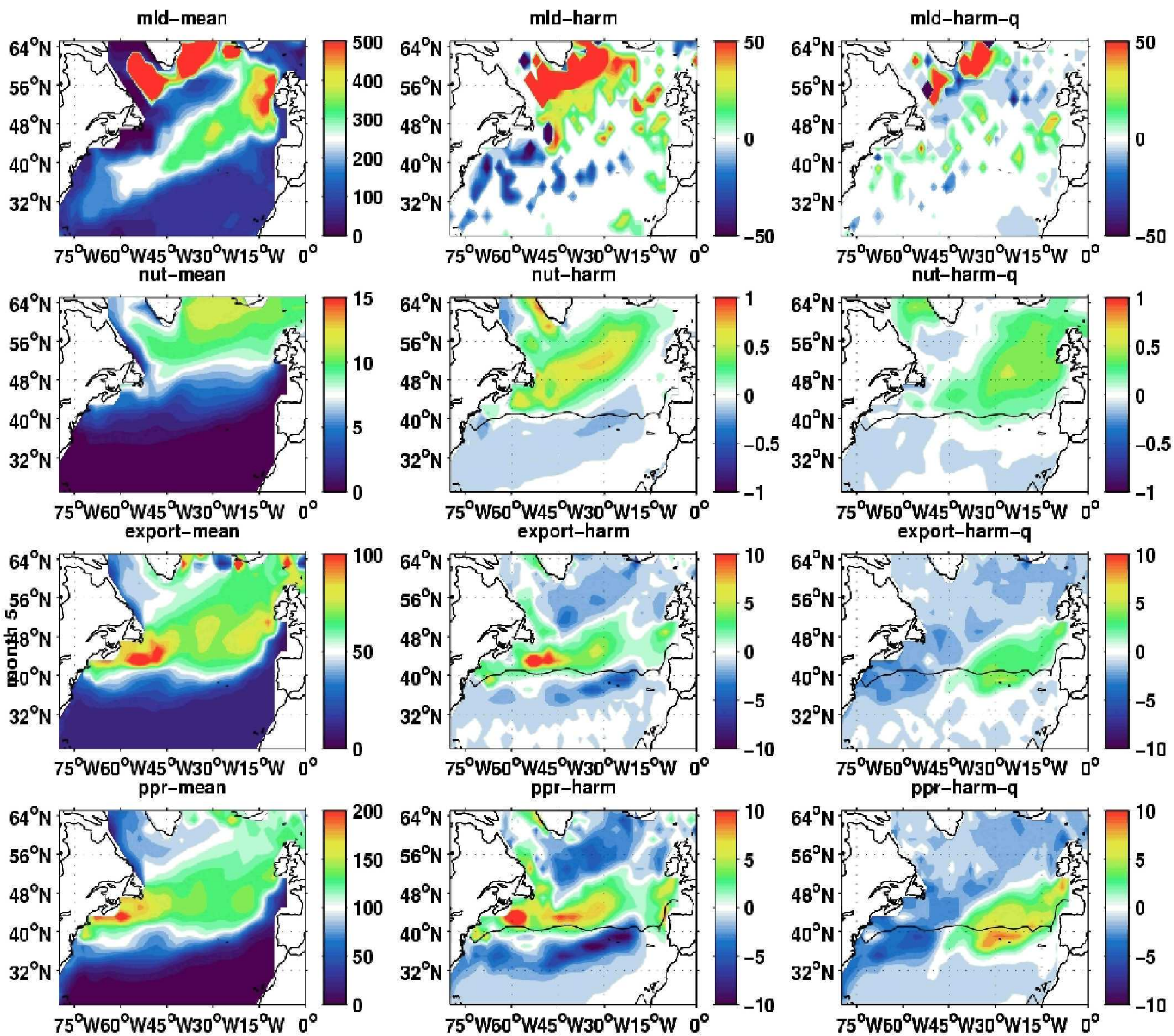
Mechanisms linking the NAO to Barent Sea oceanography and ecology

Drinkwater et al., 2002



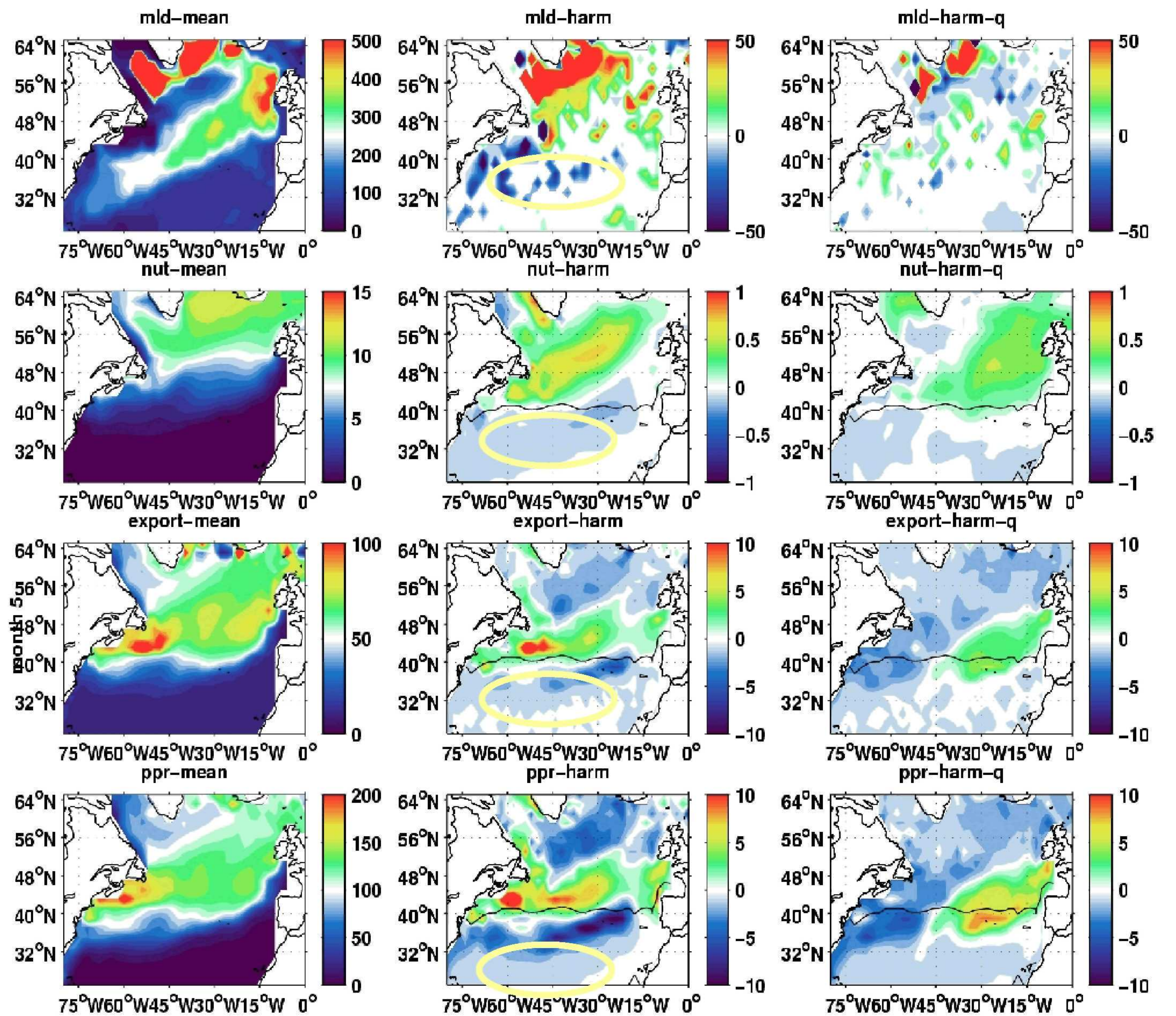
Stenseth et al., 2002

Ocean Models Eco-system response to NAO



Couple Levy's eco-system model (NPZD) to ocean model and apply the same NAO wind forcing with 8 year period.

Ocean Model Ecosystem response to NAO



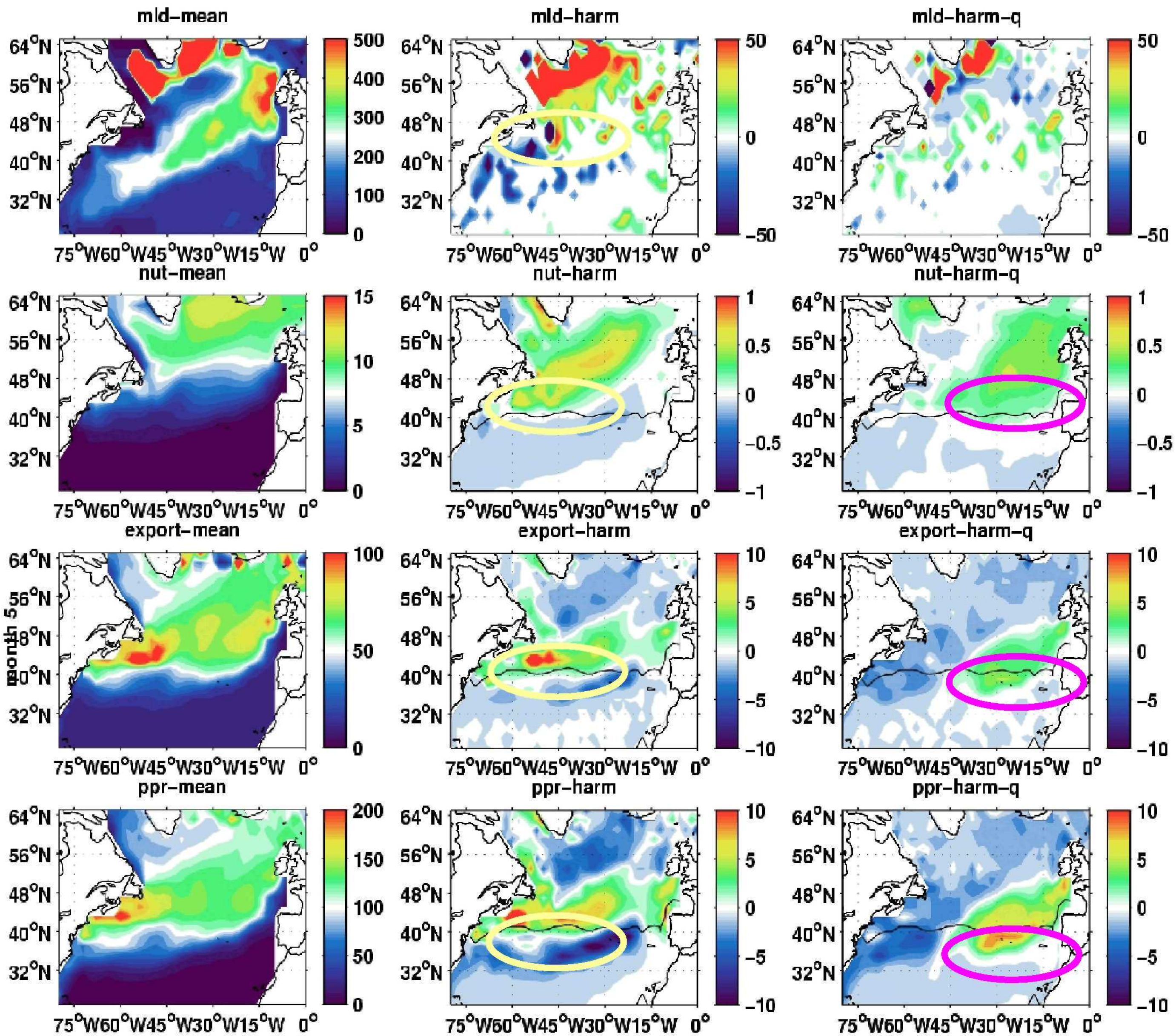
From simple nutrient limitation we expect:

a) shallow ML in subtropics

b) less winter nutrient supply

c) less productivity and export

Ocean Model Ecosystem response to NAO

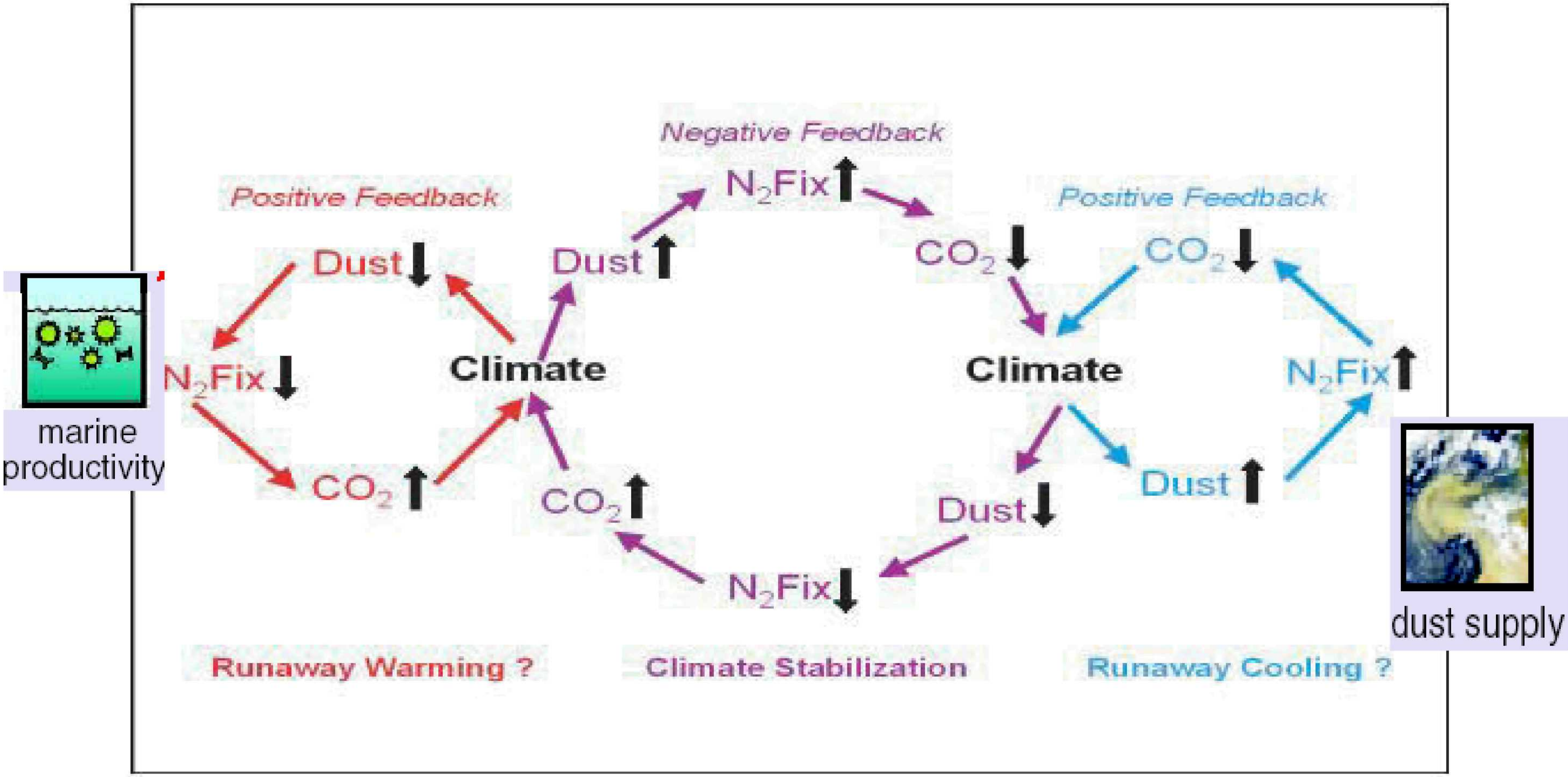


a) But what happens at 40-50N?

-ML neutral

-more productivity & export?

b) A few years after the NAO the gyre advection of nutrients is important



Potential bio-climate feedbacks on climate-change time-scale

SUMMARY

- Modes of climate variability can affect:
  Nutrient supply, primary production, species succession, and higher trophic levels

- In turn, marine ecosystems can affect:
  Depth of penetrating radiation, upper ocean stratification, and thereby coupling to the atmosphere

- If coupled ocean-atmosphere-ecosystem models cannot reproduce observed ecosystem responses to past ENSO or NAO variability, how credible are such models for global change projections of ecosystems?

- Modes of climate variability provide a means to test hypotheses and reduce uncertainty in global change projections of ecosystem response

- Climate change ➔climate variability➔regional climate impacts➔extreme events