The time is right to deliver operational ecological forecasts for use in decision-support systems.

by Dick Barber

NICHOLAS SCHOOL OF THE
ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY

March 29 to April, 2006
NASA Ecological Modeling Workshop
Asilomar Conference Center

Understanding the ocean: When, where, and how advances have been made

by Dick Barber

NOPP* Ocean Ecogenomics Workshop

Washington, DC, 7-8 March 2005

*National Oceanographic Partners for Progress

(NASA is one of the partners)

Colleagues who contributed to this talk:

Fei Chai (Univ. Maine),

Yi Chao (JPL-Cal Tech) and

Francisco Chavez (MBARI in Moss Landing, CA)

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When I say “we” I really mean it.

We think the time is right for operational ecological forecasts for managing ocean resources.

Why hasn’t this been realized before now?

What's different now?

I’ll try to answer both questions.

But first,a look at the some recent history of the Peru coastal upwelling ecosystem and its living resources.

(my view of the world is Peru-centric and ENSO-centric, which seems normal to me.)

From the CUEA proposal, May 1975:

CUEA Program Goal (The Promise)

The goal of the Coastal Upwelling Ecosystems Analysis Program is to understand the coastal upwelling ecosystem well enough to predict its response far enough in advance to be useful to mankind.

Coastal Upwelling Ecosystems Analysis *1972 - 1980*

Proposal To NSF

International Decade of Ocean Exploration (IDOE)

- absurdly over-reaching in 1970s

Now, for a look at interannual (and decadal) forcing at work

Location: coastal Peru

Time series: 1955 – 2005

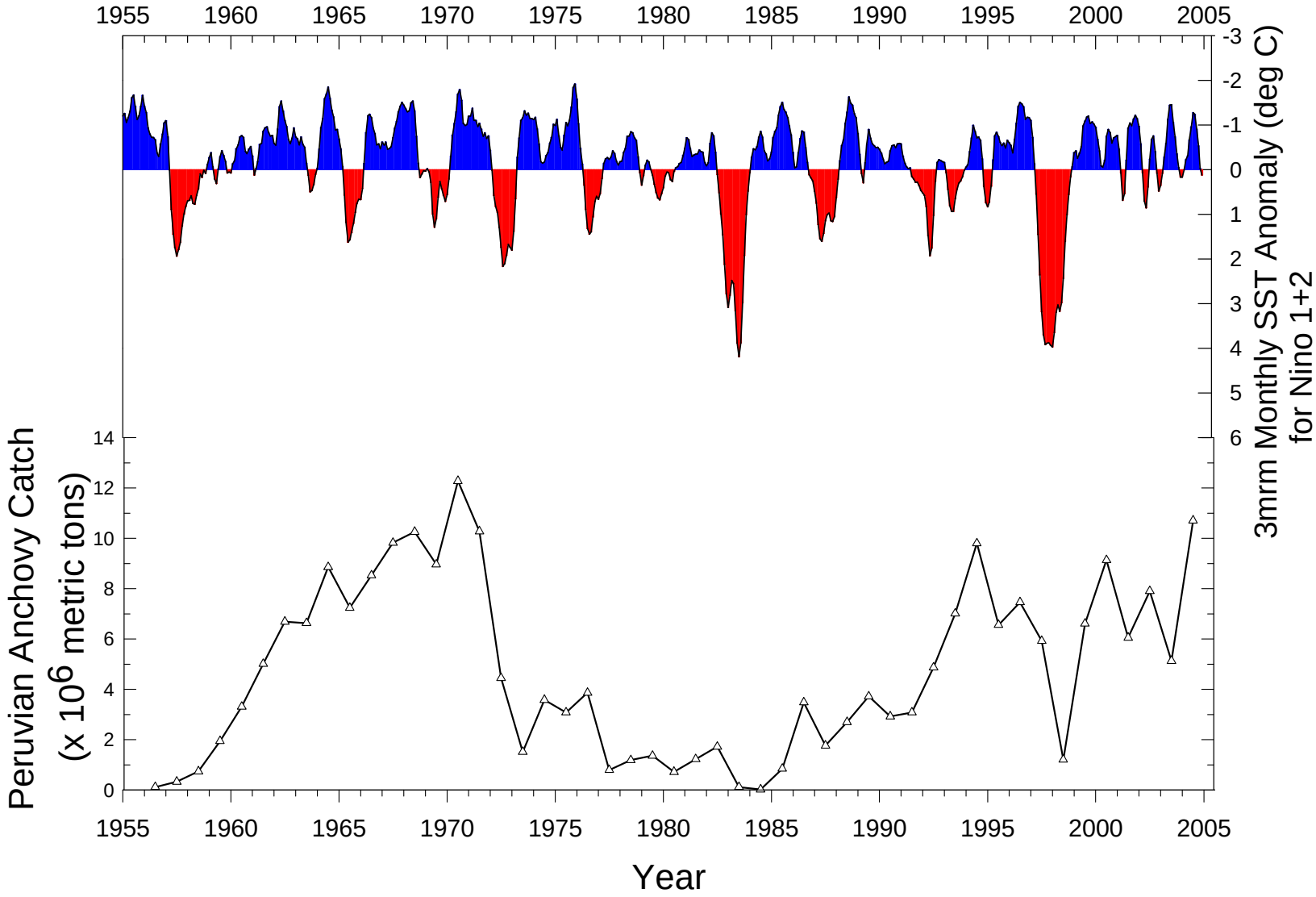
Anchovy catch by the Peruvian fishery

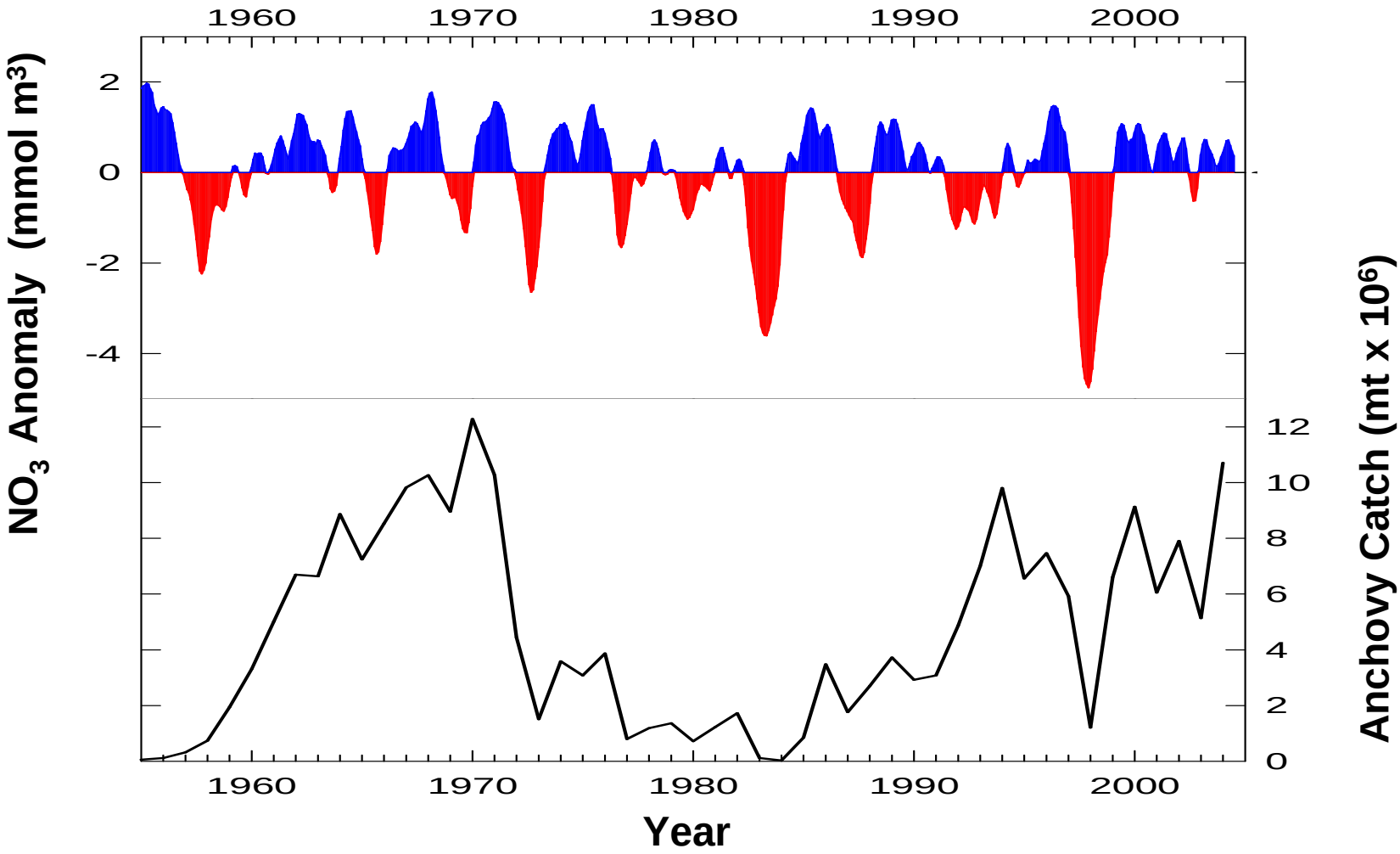
Temperature anomaly (℃) in Niño 1 and 2 regions

(3-month running mean of monthly SST anomalies)

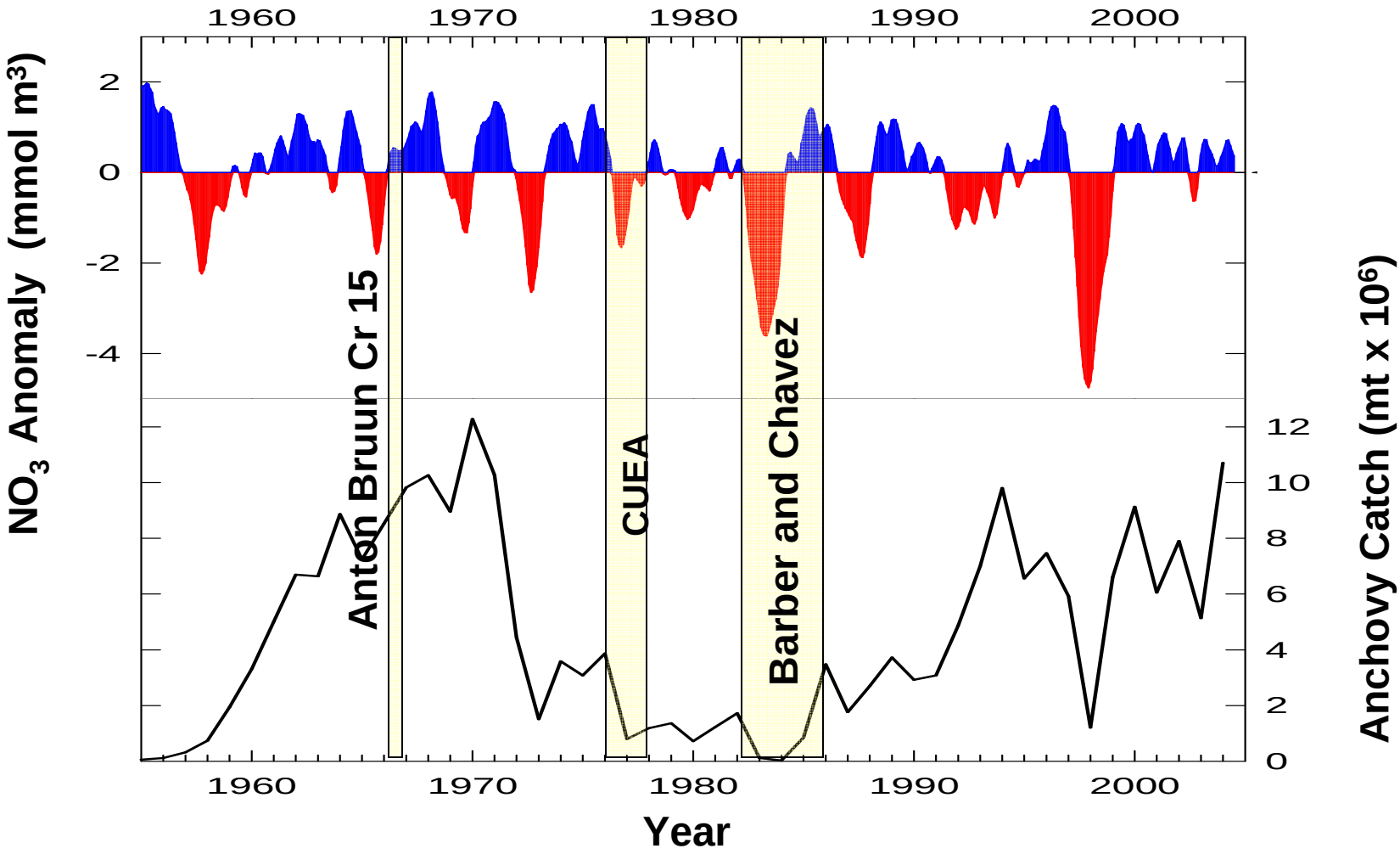
Nitrate anomaly (mmol m^3)

(using T vs NO_3 transform)


1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
-3
-2
-1
0
1
2
3
4
5
6
3mrm Monthly SST Anomaly (deg C)
for Nino 1+2
14
12
10
8
6
4
2
0
Peruvian Anchovy Catch
(x 10^6 metric tons)
Year



In this figure the Niño 1 and 2 SST anomaly is converted to a nitrate anomaly. The mean nitrate concentration is ~ 7 mmol m^3.



Anton Bruun Cruise 15: March – May 1966 (peak anchovy biomass)

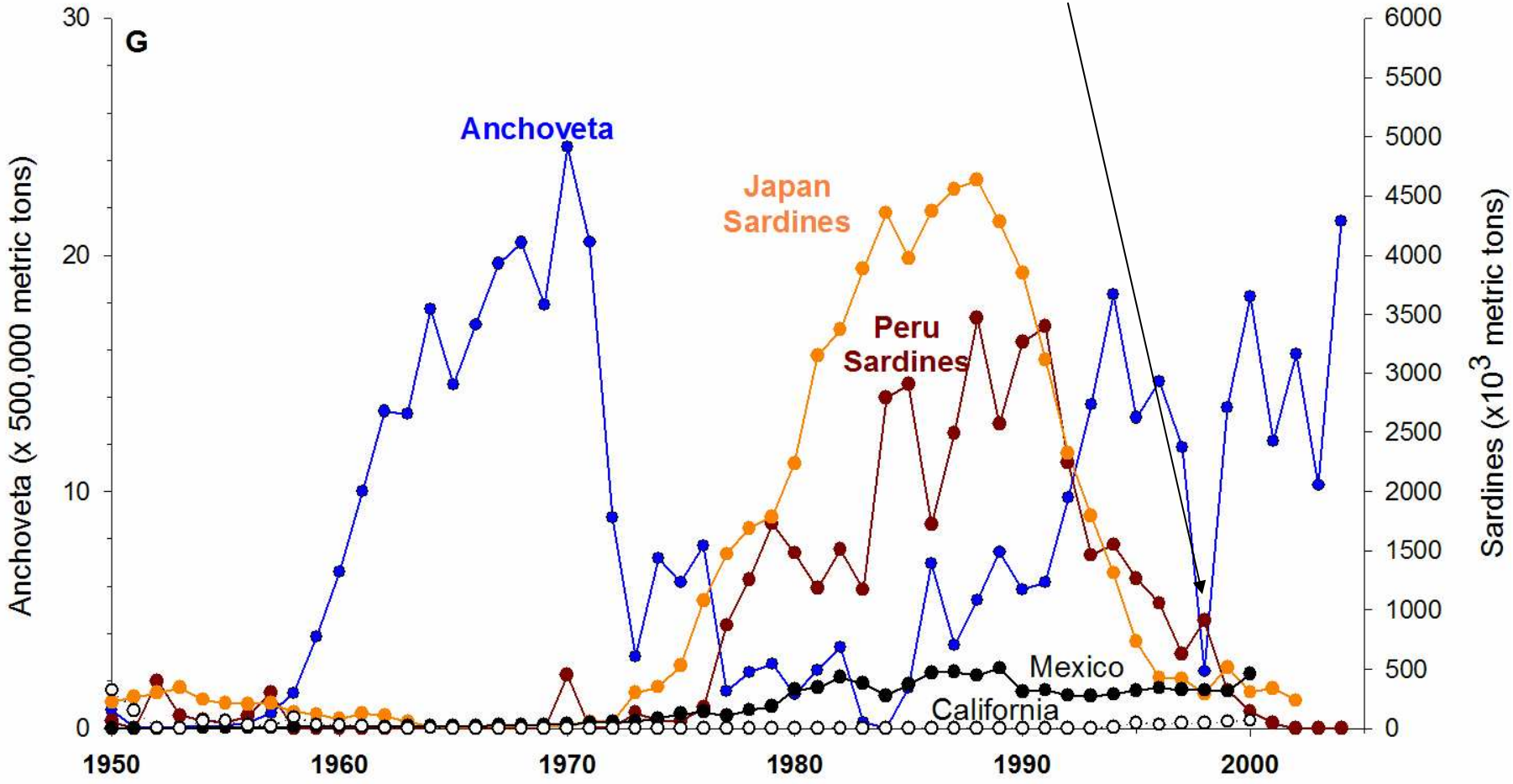
CUEA: 1976 – 1977 (onset of “anchovy to sardine” shift)

Barber: NSF project June 1982 – 1986 (onset and end of ’82-’83 El Niño)

The figures show:

1. interannual, remotely forced dynamics (ENSO) was a major driver of anchovy variability, and
2. decadal variability forced a biological shift (but not a “regime” shift) from anchovies to sardines in the period 1976 – 1985.

Look at ‘98 sardine response.



From Francsco Chavez, MBARI

Hsieh, Glaser, Lucas and Sugihara (in review) in “Distinguishing noise from catastrophic shifts in the North Pacific”
define regime shifts as:

“quasi-stationary states in measured parameters, separated by periods of rapid transition”

Sardines in these data, especially in 1998, do not show any semblance of a “quasi-stationary state” or “rapid transitions”, they simply are more successful at warmer temperatures.

Deficiencies in the 1970s:

over-simplified food web theory (need for two-path paradigm and Fe in ecological model**)**

crippling observational deficiencies (under sampling by orders of magnitude)

belief (faith) that coastal upwelling was forced by meso-scale processes alone

omission of remote forcing (ENSO) in the CUEA paradigm

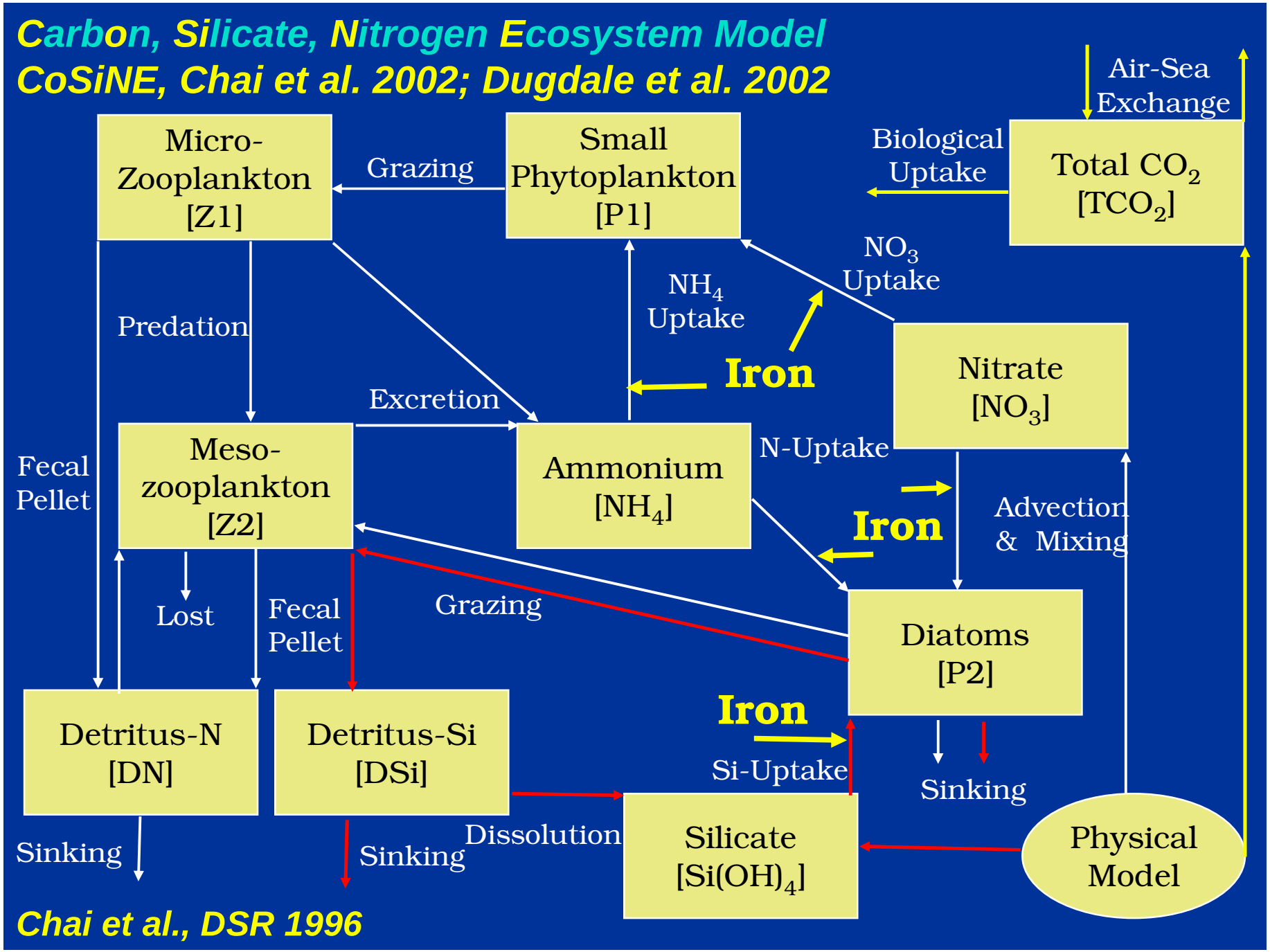
unawareness of decadal variability (PDO was not even a gleam in anyone's eye)

What's new?

1. new ideas : Fe, two-path food web and fish population models

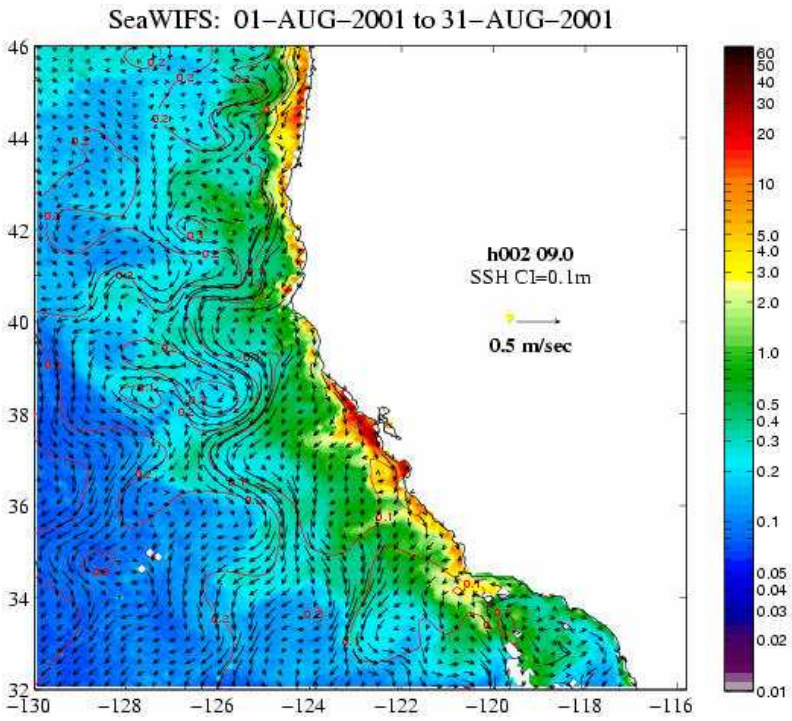
- A. Need for picophytoplankton and micrograzers, as well as Fe regulation, in ecosystem models.

- B. Need for fish population models that can incorporate high resolution physical and food web forcing.

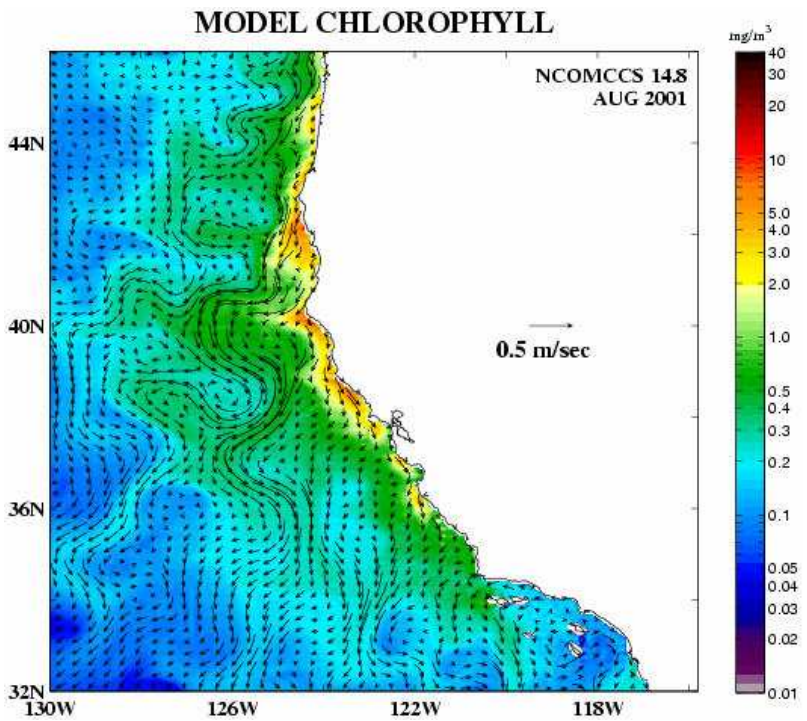

Carbon, Silicate, Nitrogen Ecosystem Model
CoSiNE, Chai et al. 2002; Dugdale et al. 2002
Air-Sea Exchange
Micro-Zooplankton [Z1]
Grazing
Small Phytoplankton [P1]
Biological Uptake
Total CO_2 [TCO_2]
NO_3 Uptake
NH_4 Uptake
Predation
Iron
Nitrate [NO_3]
Excretion
Meso-zooplankton [Z2]
Ammonium [NH_4]
N-Uptake
Fecal Pellet
Iron
Advection & Mixing
Lost
Fecal Pellet
Grazing
Diatoms [P2]
Iron
Detritus-N [DN]
Detritus-Si [DSi]
Si-Uptake
Sinking
Sinking
Dissolution
Sinking
Silicate [$Si(OH)_4$]
Physical Model
Chai et al., DSR 1996

Coupled Bio-Physical Modeling

NRL West Coast NCOM with SeaWIFS Chlorophyll

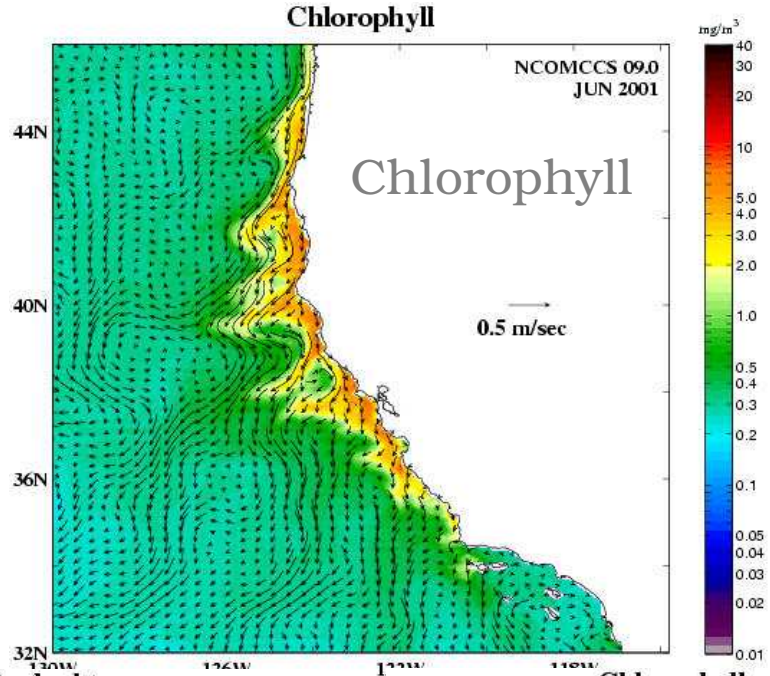


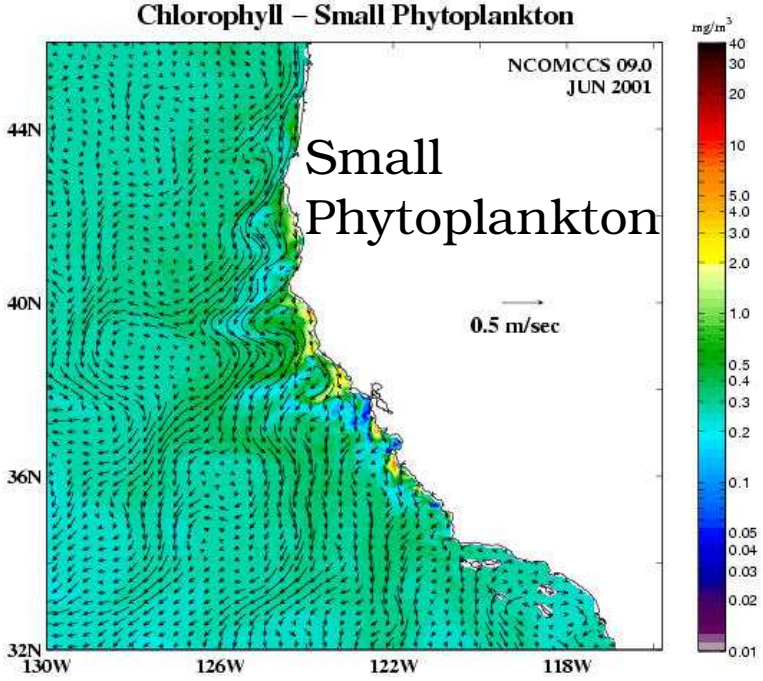
NRL West Coast NCOM with Model Chlorophyll

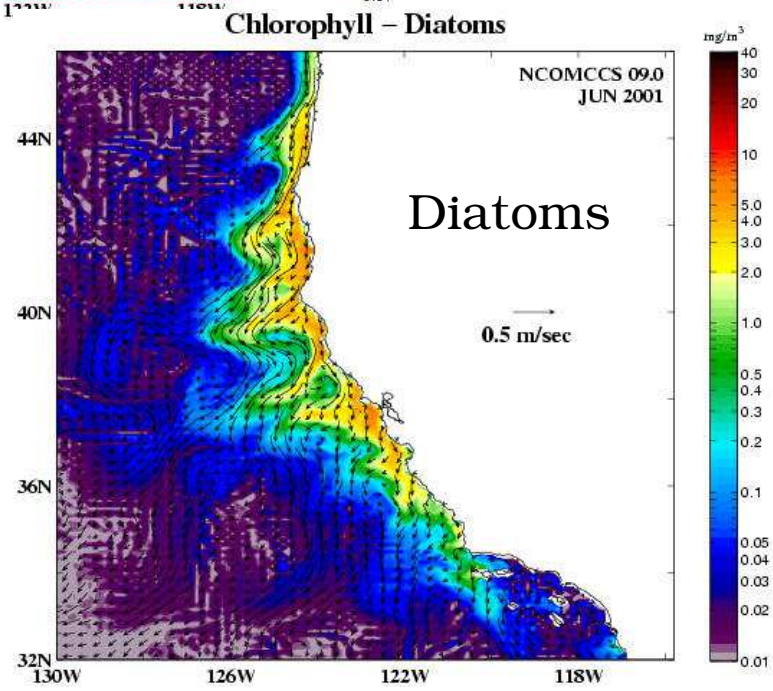


Monthly Sequence: June – August 2001

Modeled Chlorophyll, Two Phytoplankton Groups, June 2001







Why do we care (so much) about diatoms in ocean ecosystems?

…because diatoms leave a geochemical footprint of altered carbon distributions in the atmosphere, ocean and sediments.

…and because diatoms leave a biological footprint of increased fish and other higher trophic levels (squid, birds, whales, humans.)

But…to be precise, we don't actually care about diatoms.

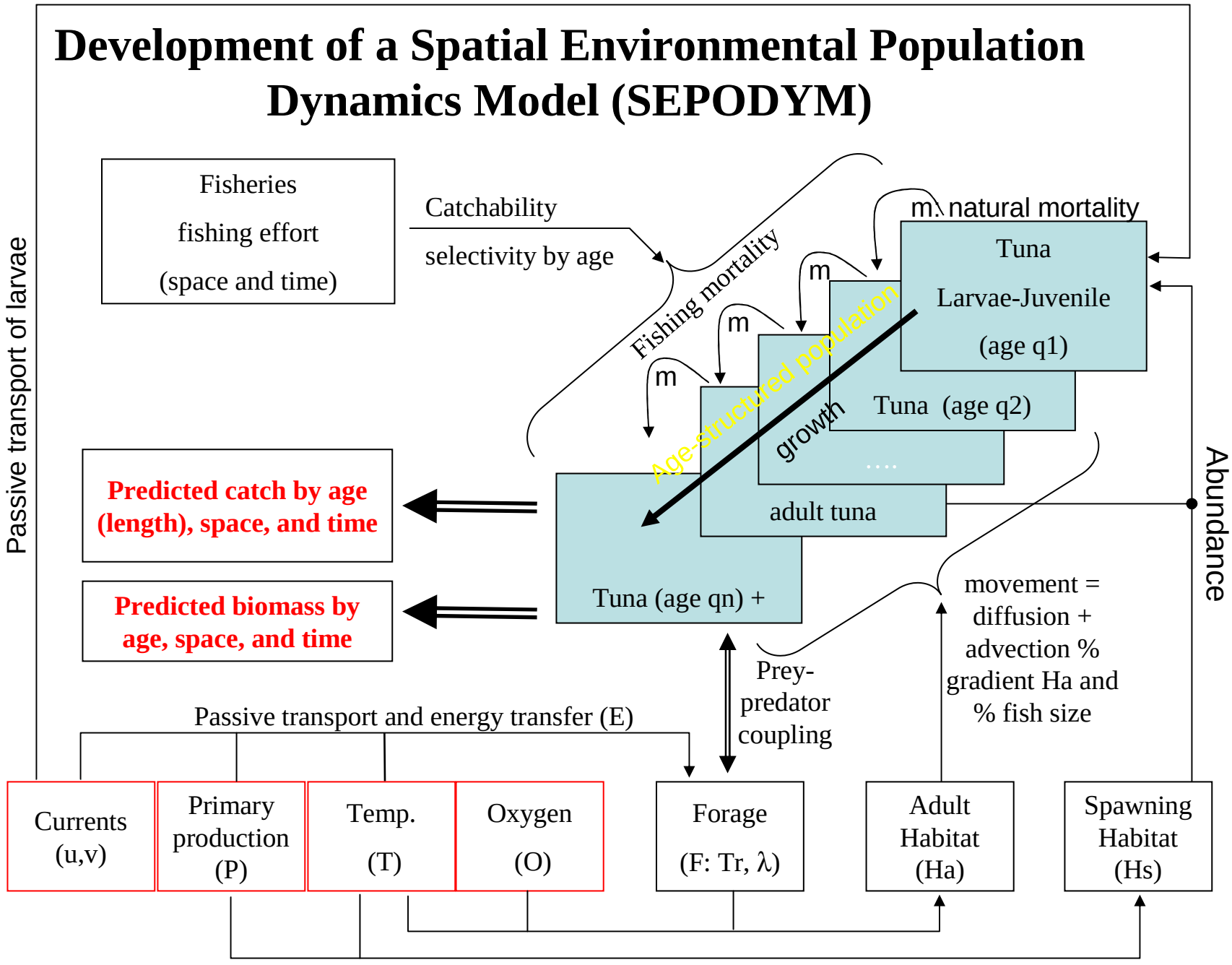
What we care about is diatom bloom formation.

Arguably, of all the earth's biological processes, diatom bloom formation has contributed most to determining the present radiative character of Earth's atmosphere.

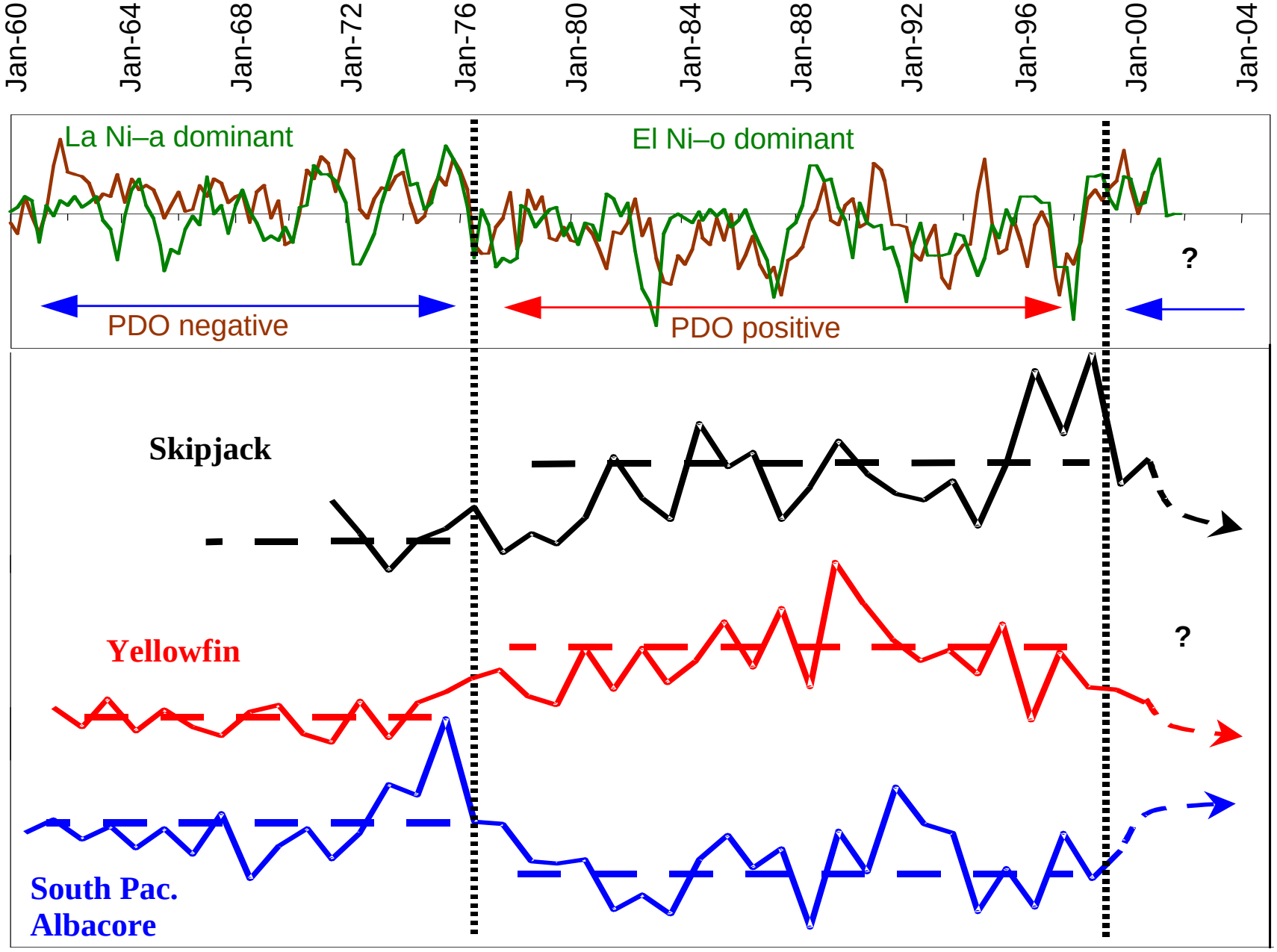
All you really need to know about diatoms

Isaiah, “All flesh is grass.”

Bigelow, “All fish is diatom.”


Development of a Spatial Environmental Population Dynamics Model (SEPODYM)
Fisheries
fishing effort
(space and time)
Catchability
selectivity by age
Fishing mortality
m: natural mortality
Tuna
Larvae-Juvenile
(age q1)
m
m
m
Tuna (age q2)
....
adult tuna
Tuna (age qn) +
Age-structured population
growth
Passive transport of larvae
Abundance
Predicted catch by age (length), space, and time
Predicted biomass by age, space, and time
movement = diffusion + advection % gradient Ha and % fish size
Prey-predator coupling
Passive transport and energy transfer (E)
Currents (u,v)
Primary production (P)
Temp. (T)
Oxygen (O)
Forage (F: Tr, λ)
Adult Habitat (Ha)
Spawning Habitat (Hs)

Decadal Links to Fish



What's new?

2. revolution in observing systems: mode, resolution, scale & quantity

Satellites

- Temperature
- Sea surface height
- Wind
- Ocean color

In Situ moorings

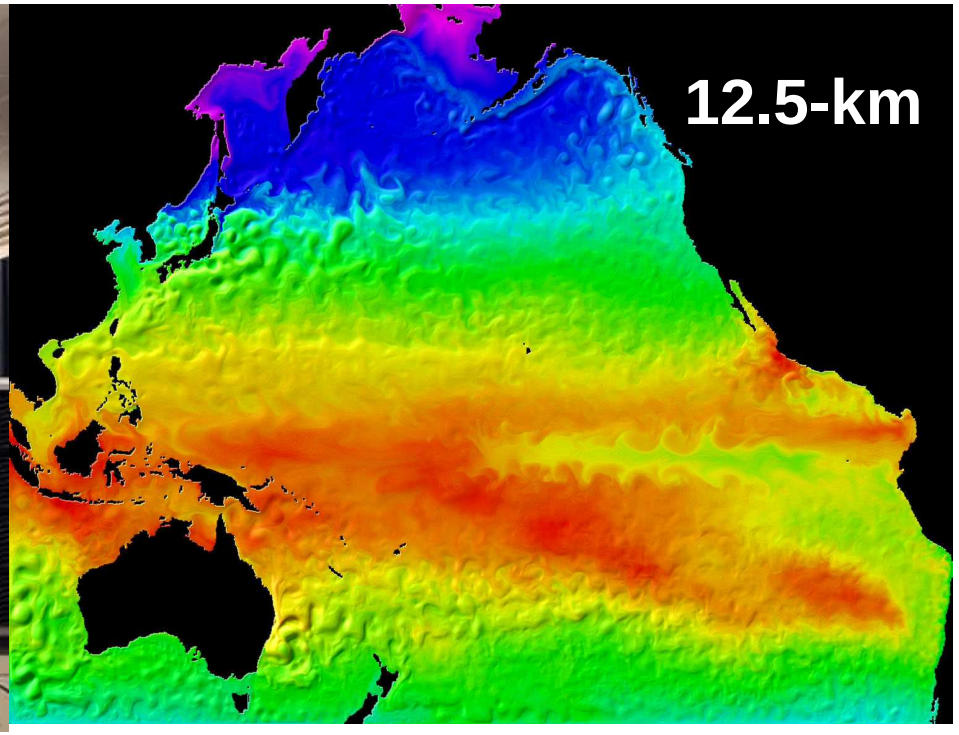
- Toga-TAO moorings along Equator
- Coastal mooring arrays

All are existing operational systems whose support is provided for other purposes.

What's new?

3. even greater revolution in computation: power, new concepts (ie, assimilation), scale convergence, scale expansion, nesting

Project Columbia: ROMS



#2 Supercomputer

20 interconnected SGI® Altix® 512-processor systems

a total of 10,240 Intel Itanium 2 processors

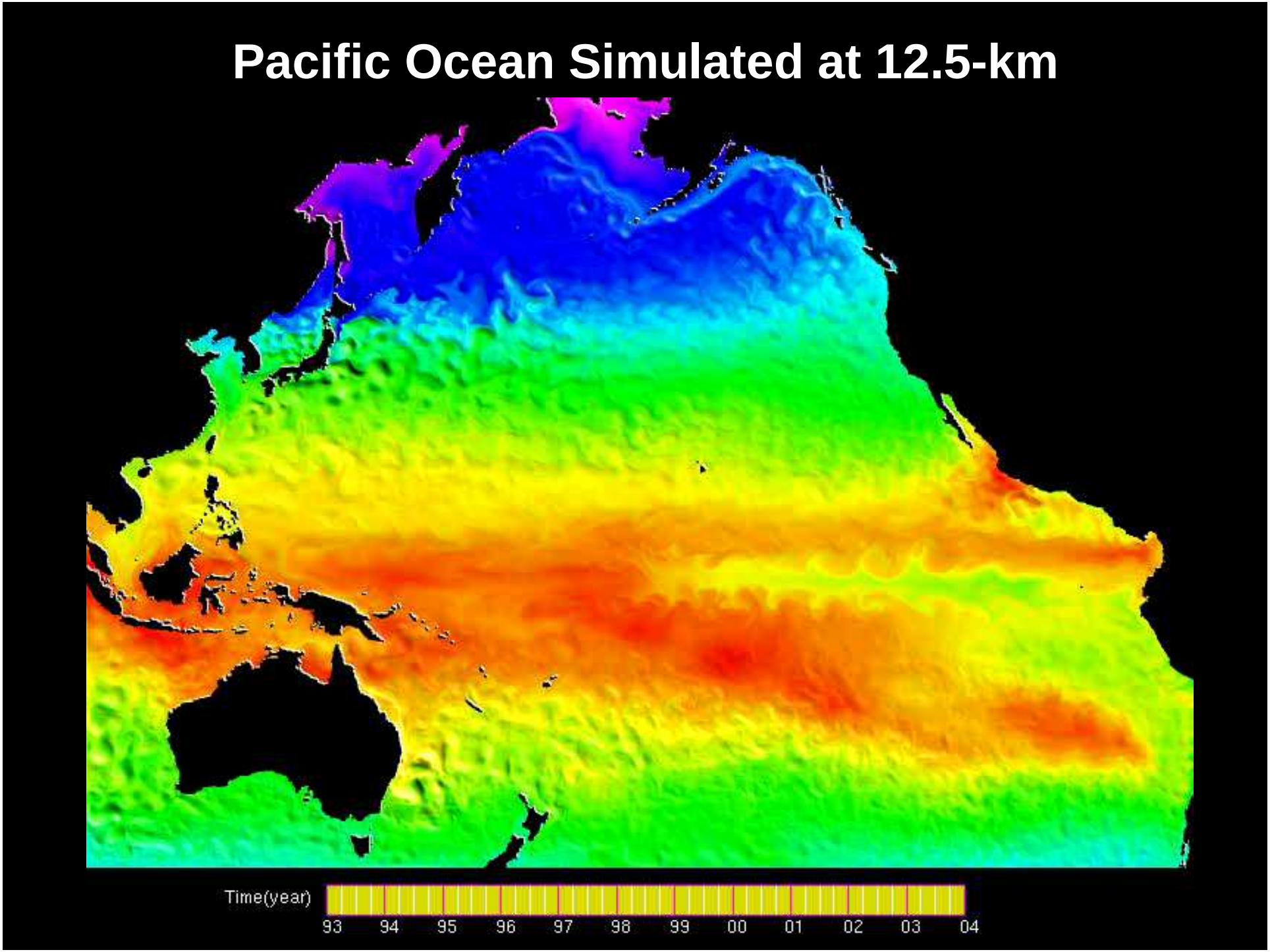
Pacific basin-scale ROMS: (1520x1088x30)

12.5-km horizontal resolutions & 30 vertical layers

50-year (1950-2000) integration

We have 100,000 processor hours for one year (as of yesterday)

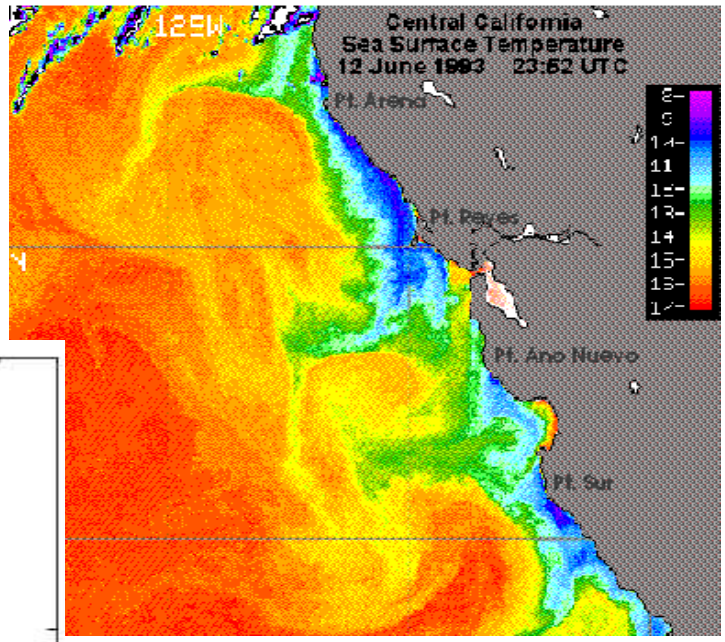
Pacific Ocean Simulated at 12.5-km

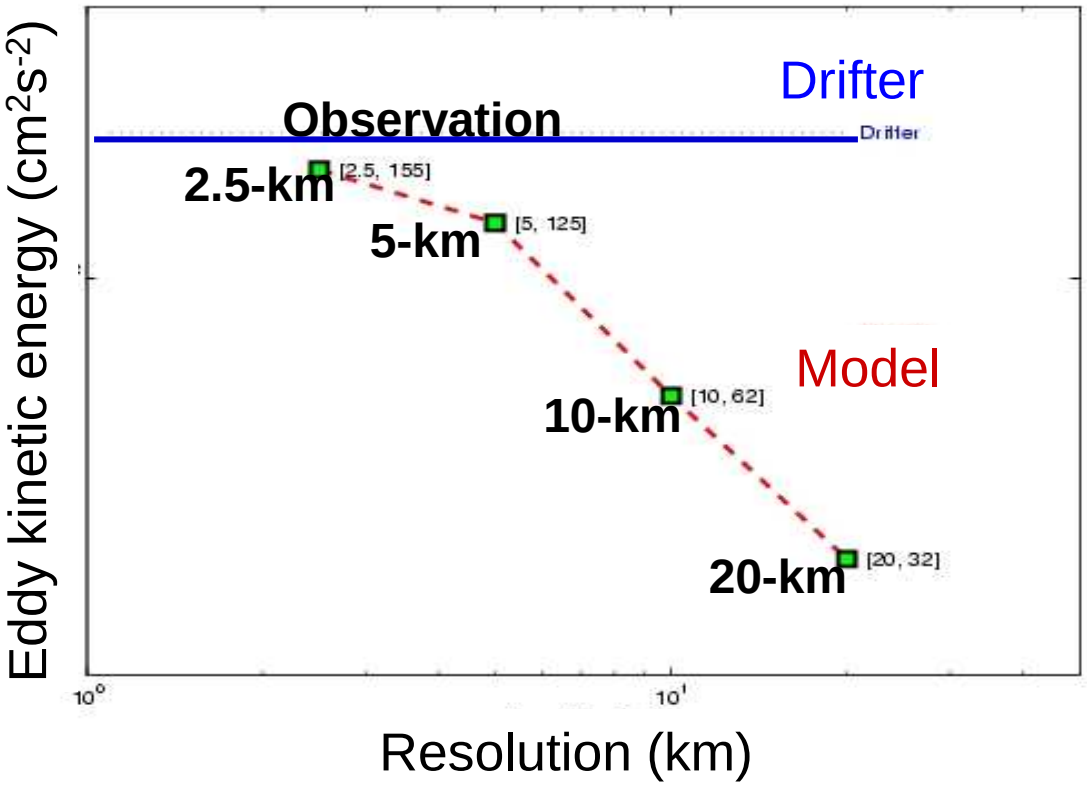


Scale convergence of eddy kinetic energy of a model and nature in a coastal upwelling system

Internal/intrinsic variability

- Features (<10 km, days)
- Model resolution (~1 km, hours)



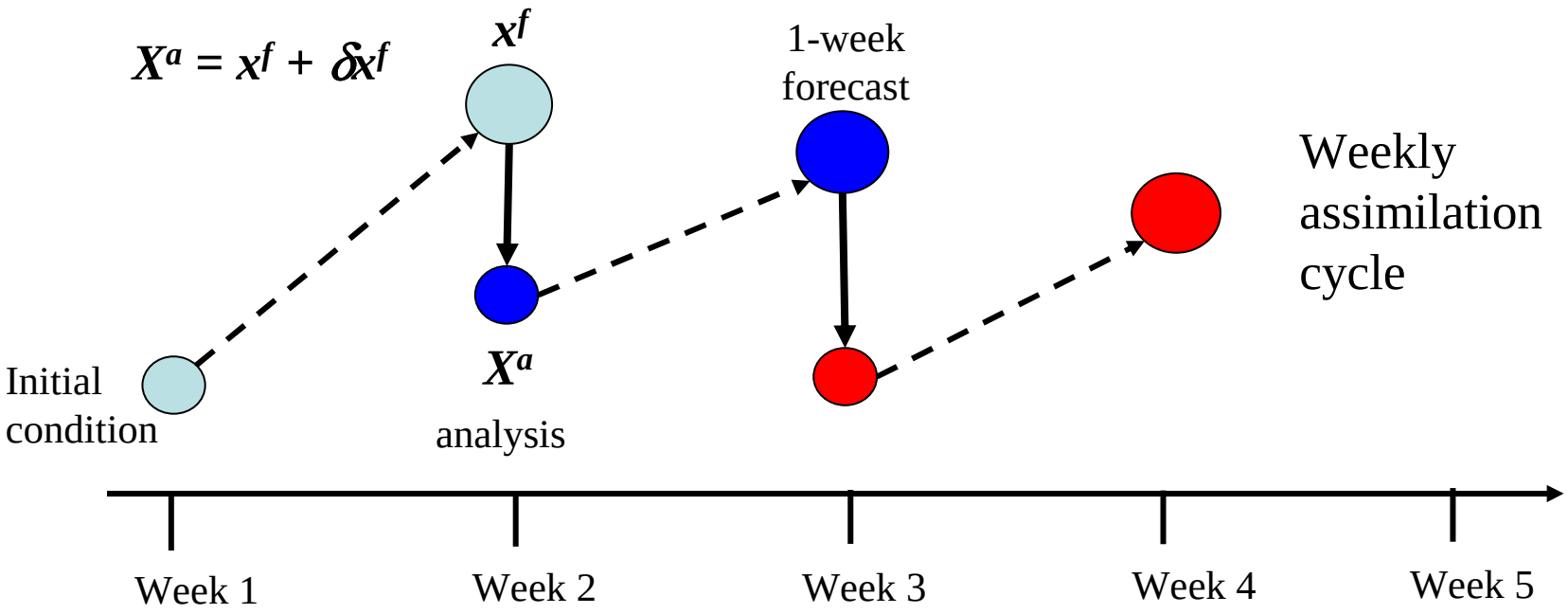


Assimilation and Initialization

3-dimensional variational (3DVAR) method:

$$J = 0.5\,(x-x^f)^T B^{-1} (x-x^f) + 0.5\,(h\,x-y)^T R^{-1} (h\,x-y)$$

y: observation
x: model



What's the record for ENSO forecasts?

- 9-month forecasts had huge societal benefits in '97/'98
- federal and state water managers in the western US prepared for the '97/'98 El Niño
- the billion-plus damage of '82/'83 on the Colorado River system dams was avoided in '97/'98
- loss of life was reduced, especially in So. California in '97/'98

So the following are available and paid for:

1. Improved food web theory (Fe and 2-path)
2. Realistic and validated physical and food web models
3. Observing tools, satellites, moorings, TOGA-TAO etc
4. Computational power needed for scale convergence, fine time steps and many model compartments
5. Operational 3,6, and 9 month ENSO forecasts

Operational ocean forecasting can:

1. Help maintain sustainability and ecosystem health of fisheries, especially high-yield fisheries, while maximizing societal benefit from the resource.

2. Contribute to conservation of threatened marine organisms (mammals, birds and turtles.)

3. Help public health systems respond proactively to outbreaks of tropical vector-borne diseases.

Neville Nicholls

Journal of Climate **1**: 418-421 (1988)

“El Niño-Southern Oscillation and rainfall variability”

Conclusions:

“Not only are fluctuations in rainfall over large areas of the globe related to ENSO, but **ENSO also amplifies**, typically by one-third to one-half for most stations, the magnitude of the **interannual rainfall variability** in these areas.

Areas affected by ENSO are truly lands “of drought and flooding rains.”

Here is an general hypothesis that accounts for the vector-borne disease outbreaks of ’97/’98;

Neville Nicholl

The Lancet **324**: 1284-1285 (1993)

“El Niño-Southern Oscillation and vector-borne disease”

The Nicholls Hypothesis:

Increases in climate variability have larger effects on the incidence of vector-borne diseases than changes in mean climate.

My corollaries to the Nicholls Hypothesis:

1. Moisture variation (1st derivative), not temperature or moisture, is the causal link in vector-borne disease outbreaks.
2. Increases in vector-borne disease associated with ENSO droughts implicate predator control of the vector as an important process.
3. Changes in ENSO *per se* have increased the geographic range of disease outbreaks through range expansion of enhanced *d* P/*d*t.

Conclusion;

ENSO-forecasts driving forecasts of precip/drought rate of change anomalies (d P/dt) in the tropics may help provide an early warning of disease outbreaks.

One forecast group could service any and all of the groups interested in tropical vector-borne diseases.

Our NASA group would like to work with you (all) on this.

1. The message:

1. Natural interannual (ENSO) and decadal (PDO,NAO) climate variability, together with fishing itself, drive large variations in fish stocks.
2. Inability to account for this externally-driven variability has limited the success of resource management.
3. Tools are now available to incorporate climate effects into ecosystem-based management models.
4. Furthermore, it is possible to provide 6 to 12 month forecasts of interannual and decadal effects.
5. Forecasts can be operational using existing hardware, ecosystem theory and models.

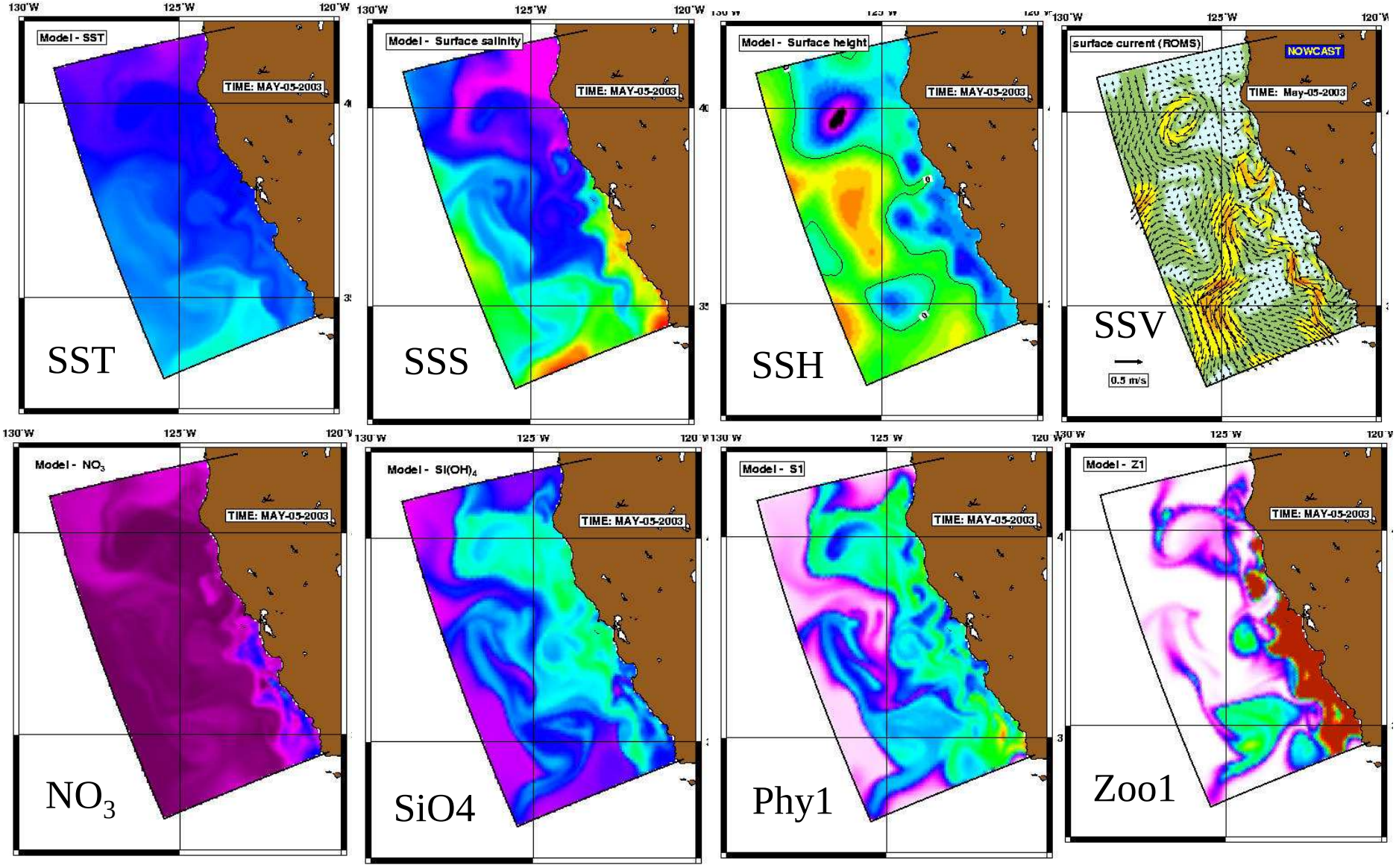
It’s time to use the tools and information that have already been paid for to provide socially useful forecasts of ocean and ocean ecosystem responses to climate forcing.

It’s time to use the tools and information that have already been paid for to provide socially useful forecasts of ocean and ocean ecosystem responses to climate forcing.

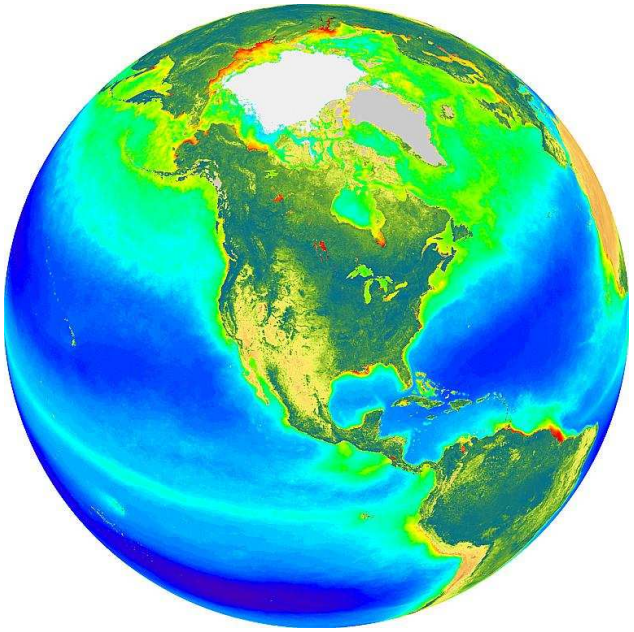
It’s time to deliver on the CUEA promise and get me off the hook.

Thank you.

Real-Time Modeling and Data Assimilation (3DVar) Coupled Physical-Ecosystem ROMS



The NASA Vision & Mission



To improve life here,

To extend life to there,

To find life beyond.

To understand and protect our home planet

To explore the universe and search for life

To inspire the next generation of explorers

. . . as only NASA can

The End

Marine conservation

Forecasts, or at least nowcasts, using habitat preference models and existing physical models of:

1) best (and worst) areas for Navy acoustic testing and exercises to minimize injury to marine mammals;

2) flexible high seas closures of longline fishing to protect threatened species, such as the leatherback turtle, while opening areas that don't have the threatened animals.

Regarding tropical disease outbreaks

Operational ocean forecasts can help deliver long lead-time warnings of the potential for outbreaks of vector-borne diseases.

First, look at a recent Scientific American article regarding global warming and tropical disease outbreaks.

Global Warming: The Hidden Health Risk

Paul R. Epstein

Scientific American 283: 50-57 (2000)

"Is global warming harmful to health?"

Introduction

"Computer models indicate that many diseases will surge as the earth's atmosphere heats up. Signs of the predicted troubles have begun to appear."

But the disease outbreaks discussed in Sci. Amer. are all associated with the ’97/’98 ENSO event, not with *global warming.*