Model Linkages: Ocean/Climate Models, Ecosystem Models and Fisheries Models - What is possible?

Dick Barber

NOAA-NASA Workshop
on
Integrating Satellite Data into
Ecosystem-Based Management
of Living Marine Resources

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Can contemporary ocean science improve the management and conservation of living marine resources?

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Bob Smith, Oregon State University
Dick Dugdale, San Francisco State University

Dick Barber, Duke University

Fei Chai, University of Maine
Yi Chao, California Institute of Technology
Francisco Chavez, Monterey Bay Aquarium Research Institute

Coastal Upwelling Ecosystems Analysis (CUEA)
1972 to 1980
Northwest Africa in 1974; Peru in 1976 and 1977.

Around 1971 Bob Smith and Dick Dugdale decided that, in coastal upwelling research, physics and biology together would be more than the sum of the parts and CUEA was formed.

CUEA was so successful as an interdisciplinary basic research project that history has forgotten that CUEA failed to deliver an applied science product regarding living marine resources.

What didn't CUEA deliver and is the time is now right to deliver?

The CUEA proposal funded by NSF in May 1975 said:

"Prediction of the response of the coastal upwelling ecosystem to natural variations, man-made environmental perturbations or to different harvesting strategies is possible from a knowledge of a <u>few</u> biological, physical and meteorological variables..."

So we proposed to accomplish this:

"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 <u>useful to mankind</u>." [in the management of living marine resources].

That goal eluded CUEA in the 1970s and has yet to be attained.

Can science and technology (ever) provide *operational* living resource *forecasts* that are:

accurate,

cost-effective,

and with *enough* lead time

to improve resource management, marine conservation and optimize return on the societal investment in fisheries ?

That goal eluded CUEA in the 1970s and I don’t think it has yet been attained for any fishery anywhere.

Can science and technology (ever) provide *operational* resource *forecasts* that are:

accurate,

cost-effective,

and with *enough* lead time

to improve resource management, marine conservation and optimize return on investment ?

The answer is, almost certainly, yes.

Or, more precisely, the previous scientific and technological barriers that prevented "*useful*" ecological forecasting are now surmounted.

Its time to try and see ….

(*useful* = accurate, cost-effective and with enough lead-time)

THEN – the 1970s

Conclusions regarding "*useful to mankind*" forecasting:

1. Goal was inherently unattainable in 1972 to 1980.

2. Limitations (deficiencies) in both in theory and technology.

3. The deficiencies in theory (*food web structure, Fe, remote forcing, decadal variability*) were serious, but a lot (~75%?) of the 1972/1980 physical and biological theory was correct.

4. Technological limitations in *computation, observing systems* and *information handling infrastructure* were fatal due to the constraints they imposed (*undersampling, inadequate space and time resolution and inadequate model complexity*.)

5. These technical limitations were unconceivable at the time and had to change many orders of magnitude before "*useful*" forecasting could be done.

NOW

Conclusions regarding the present potential to provide a "*useful to mankind*" tool:

1. Theoretical deficiencies (*food web structure, Fe, remote forcing, decadal variability*) have been corrected by the orderly evolutionary advance of science.

2. Technical limitations are being removed by revolutionary, order of magnitude advances in *computing power, observing power* and *information infrastructure* driven by social forces outside of ocean science.

4. Cost to resource managers of operational ecological forecasting for fisheries management will be small [relative to the resource value] because society <u>as a whole</u> has already paid for the *computing* advances, *new observing systems* and *information infrastructure*.

We argue that there were 4 specific theory deficiencies:

food web structure, Fe, remote forcing, decadal variability

And 3 broad technical constraints:

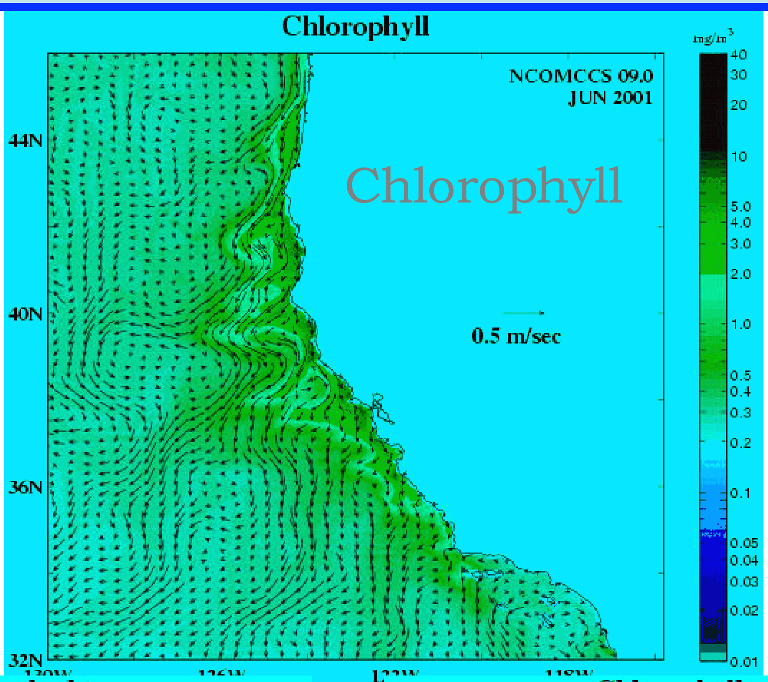
computing power, observing power (satellites) and *information handling infrastructure*

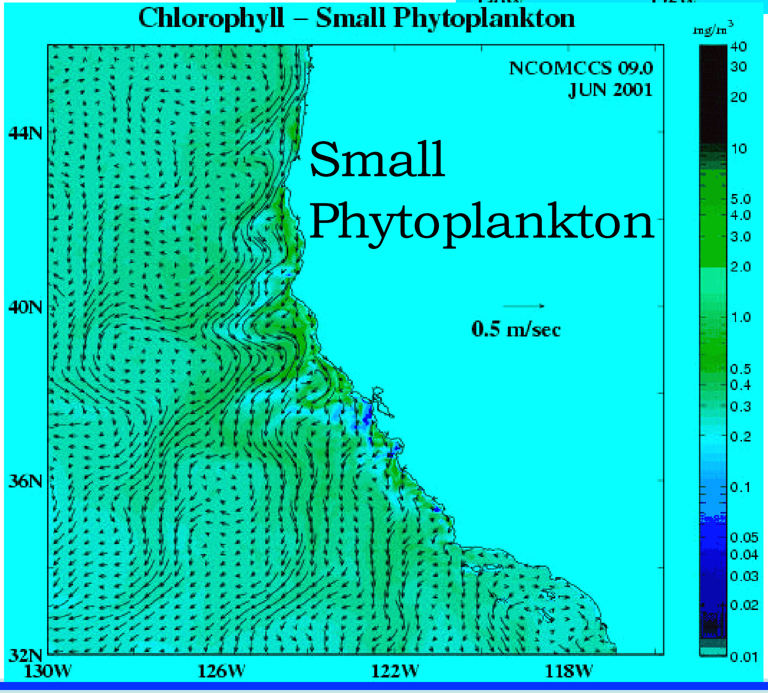
Regarding theory

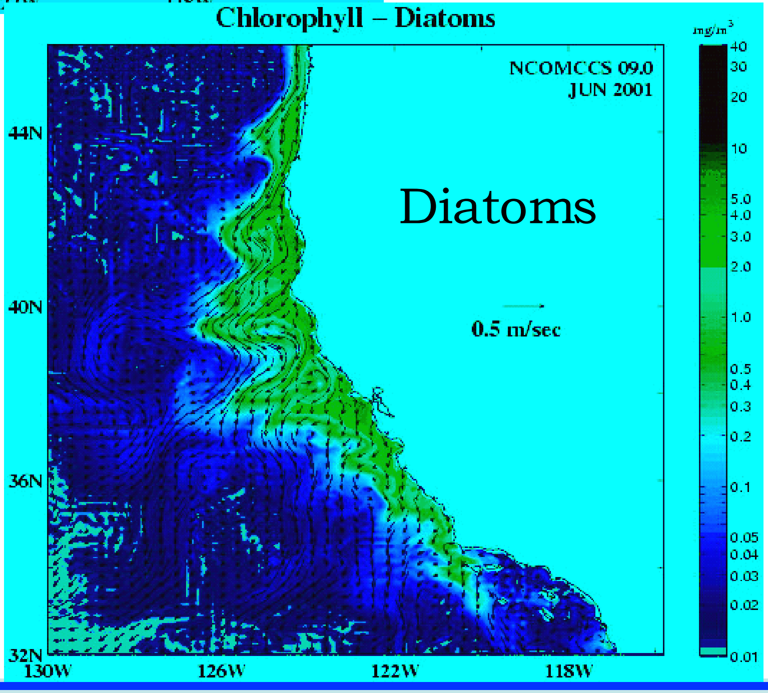
First, the fatally over-simplified (pre-microbial loop) food web, with no picoplankton, no_micrograzers,

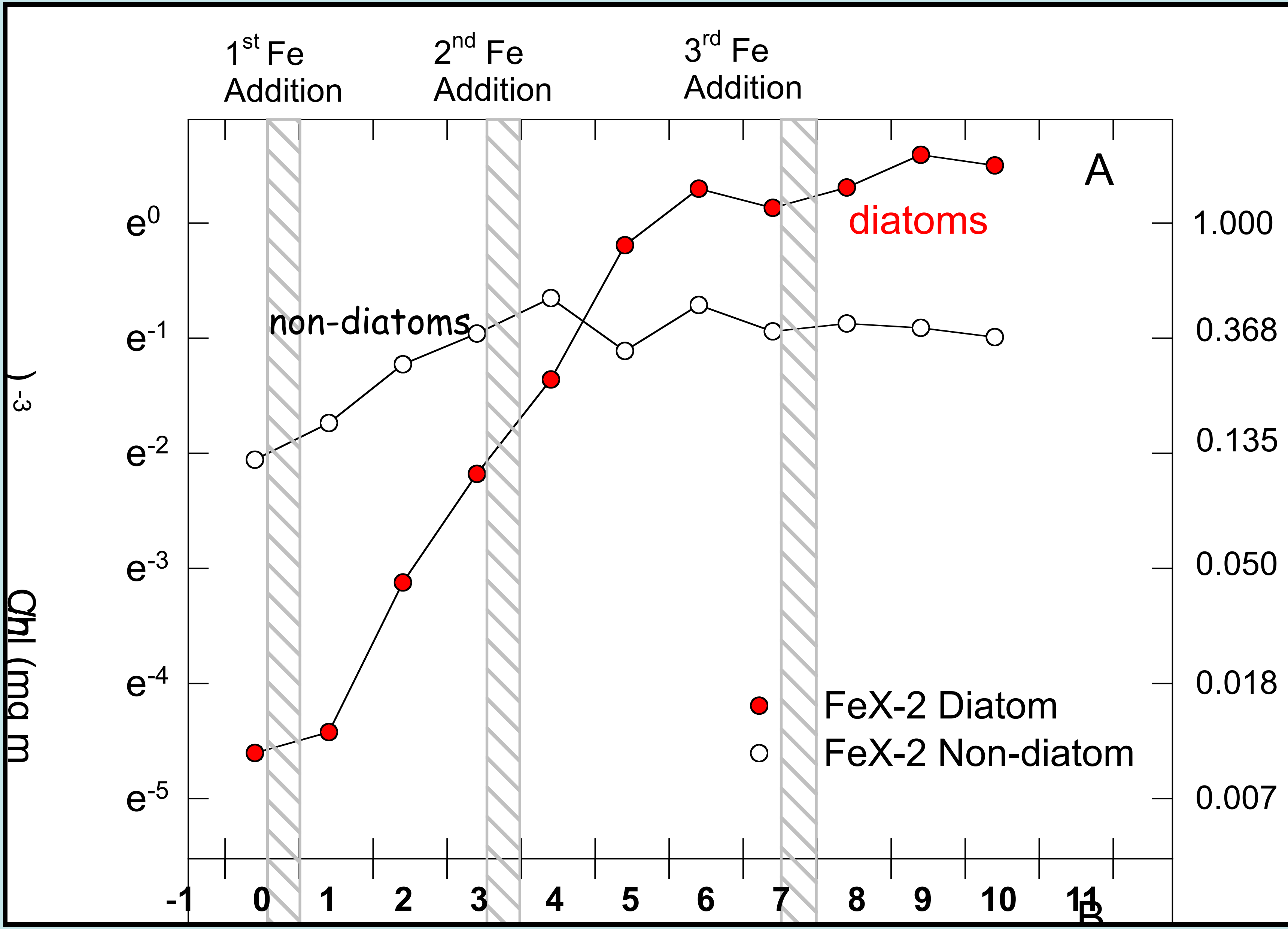
(remember this is 1972, and the first microbial loop paper was Azam et al., 1983)

Modeled Chlorophyll, Two Phytoplankton Groups, June 2001



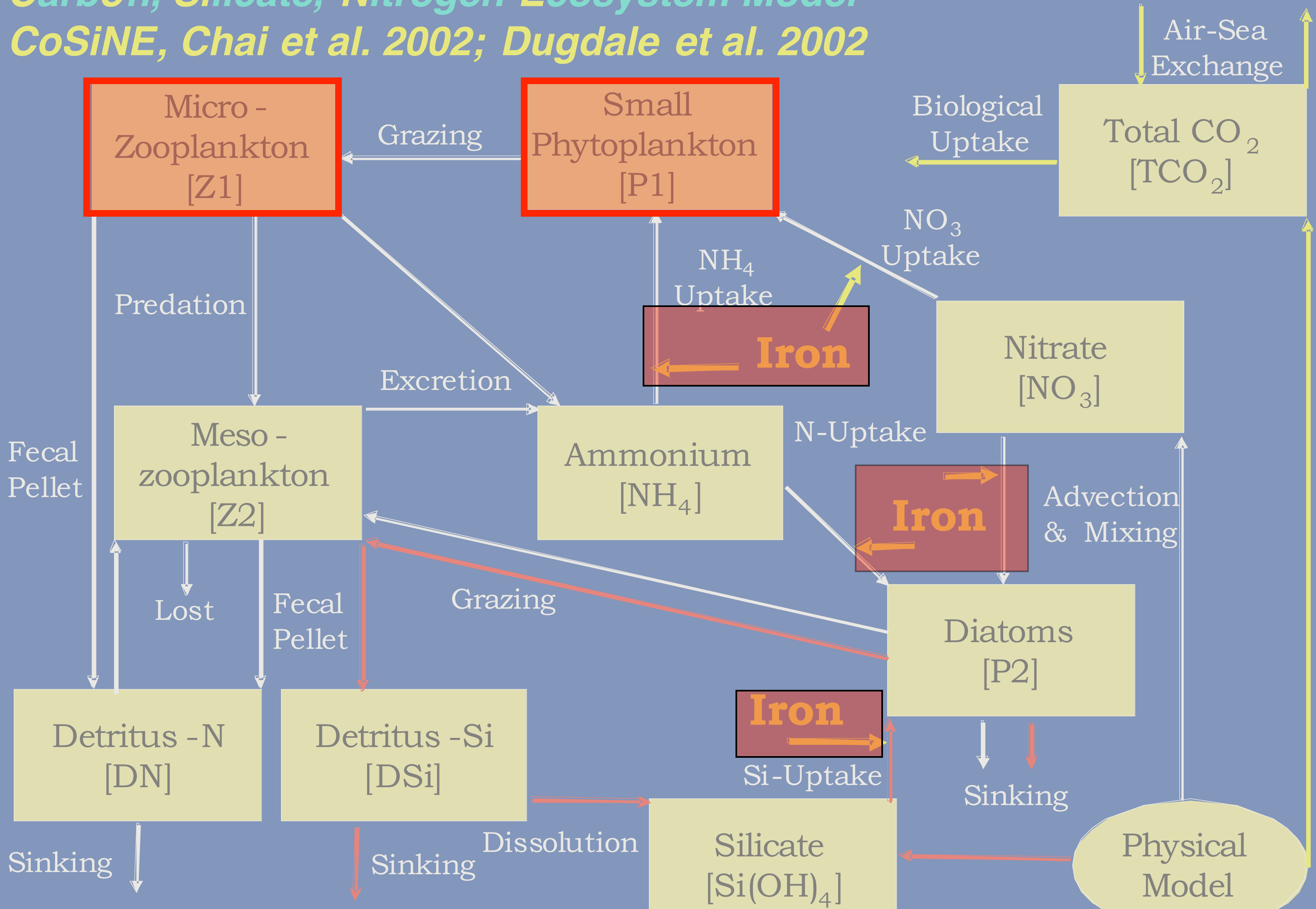




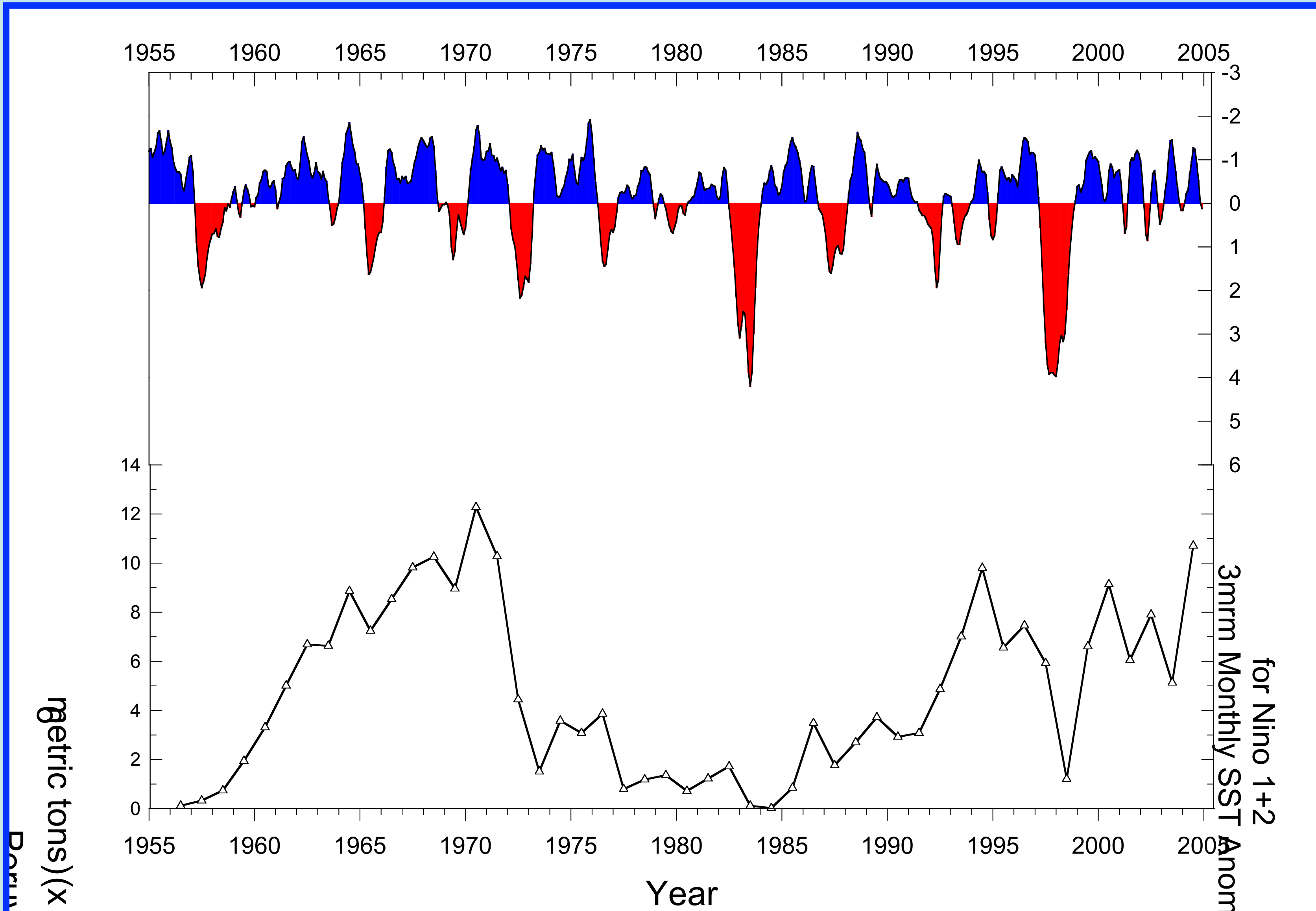


Days since first Fe fertilization

Carbon, Silicate, Nitrogen Ecosystem Model
CoSiNE, Chai et al. 2002; Dugdale et al. 2002



Chai et al., DSR 1996



1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
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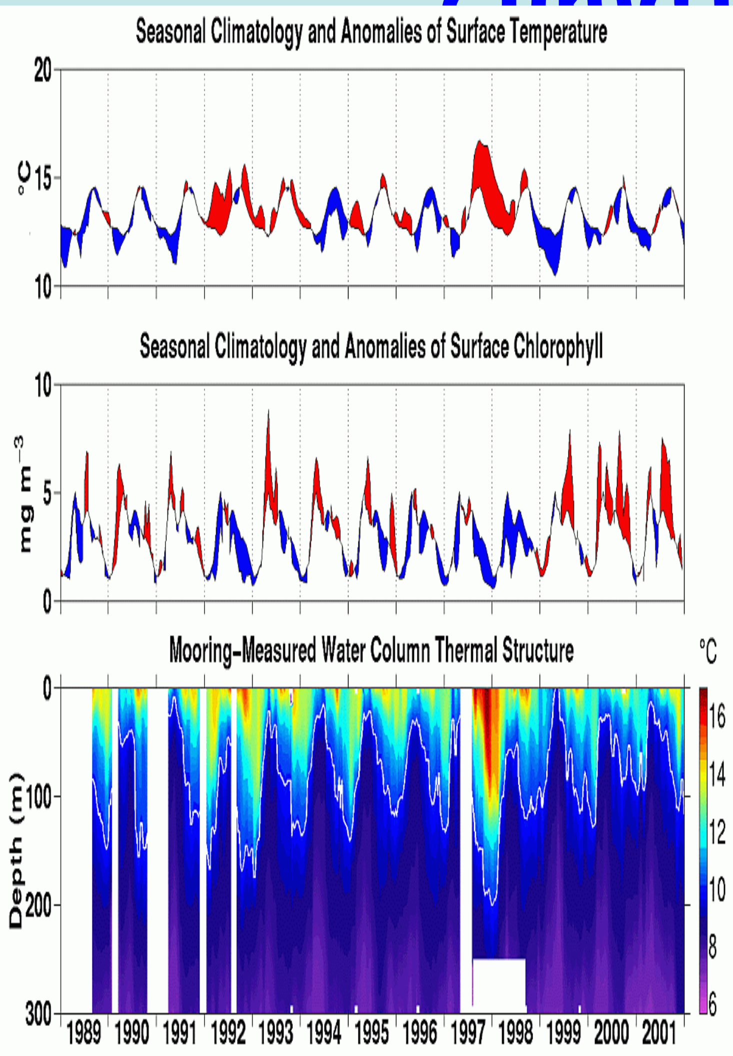
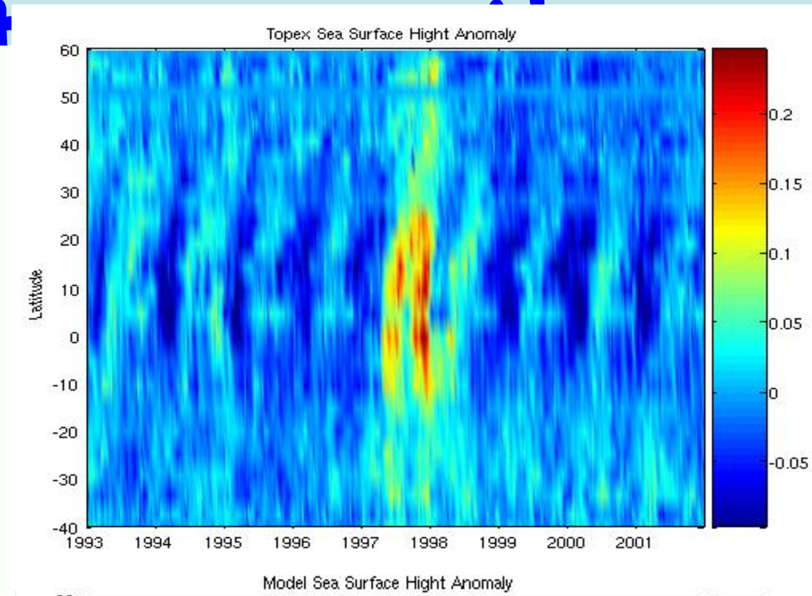
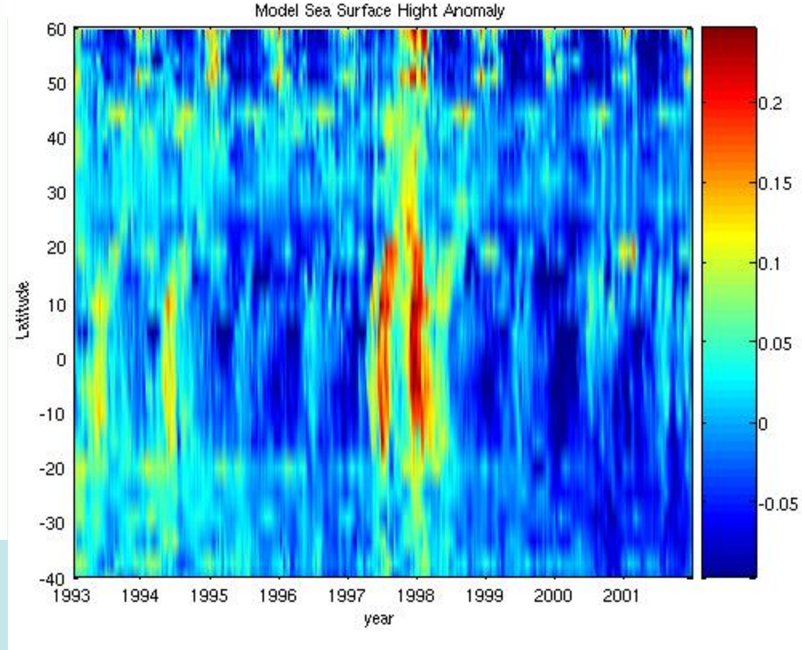
3mrm Monthly SST Anom
for Nino 1+2
metric tons)(x

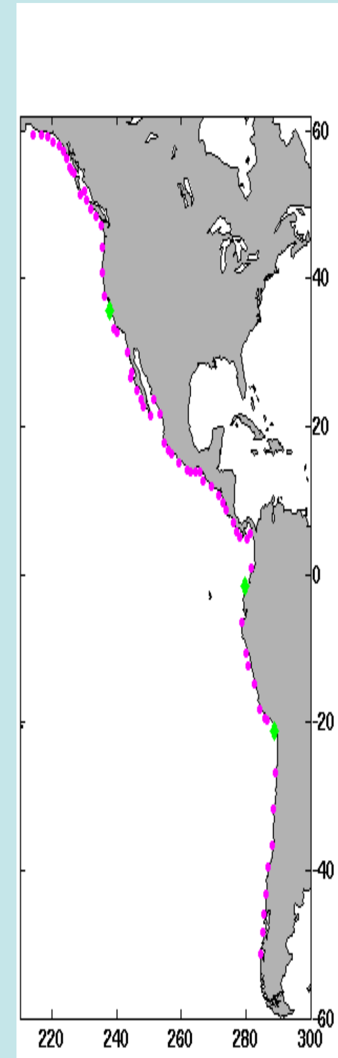
El Nino's Influence on the California Current System: climat



(MBARI)







Regarding the 3 broad technical constraints:

computing power, observing power (satellites) and */*

information handling infrastructure

Yi has discussed all three.

Let just say the consequences for operational marine resource management of Moore's Law are impressive:

increased time and space resolution,

new concepts (i.e., assimilation),

scale convergence, scale expansion, spatial nesting,

reanalysis,

model complexity, near-realtime modeling, retrospective modeling,

etc., etc., etc.

So the following are available:

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

Remaining issue:

Fish population models that couple physical and food web forcing to fish population dynamics.

Fei showed that progress is being made on this front.

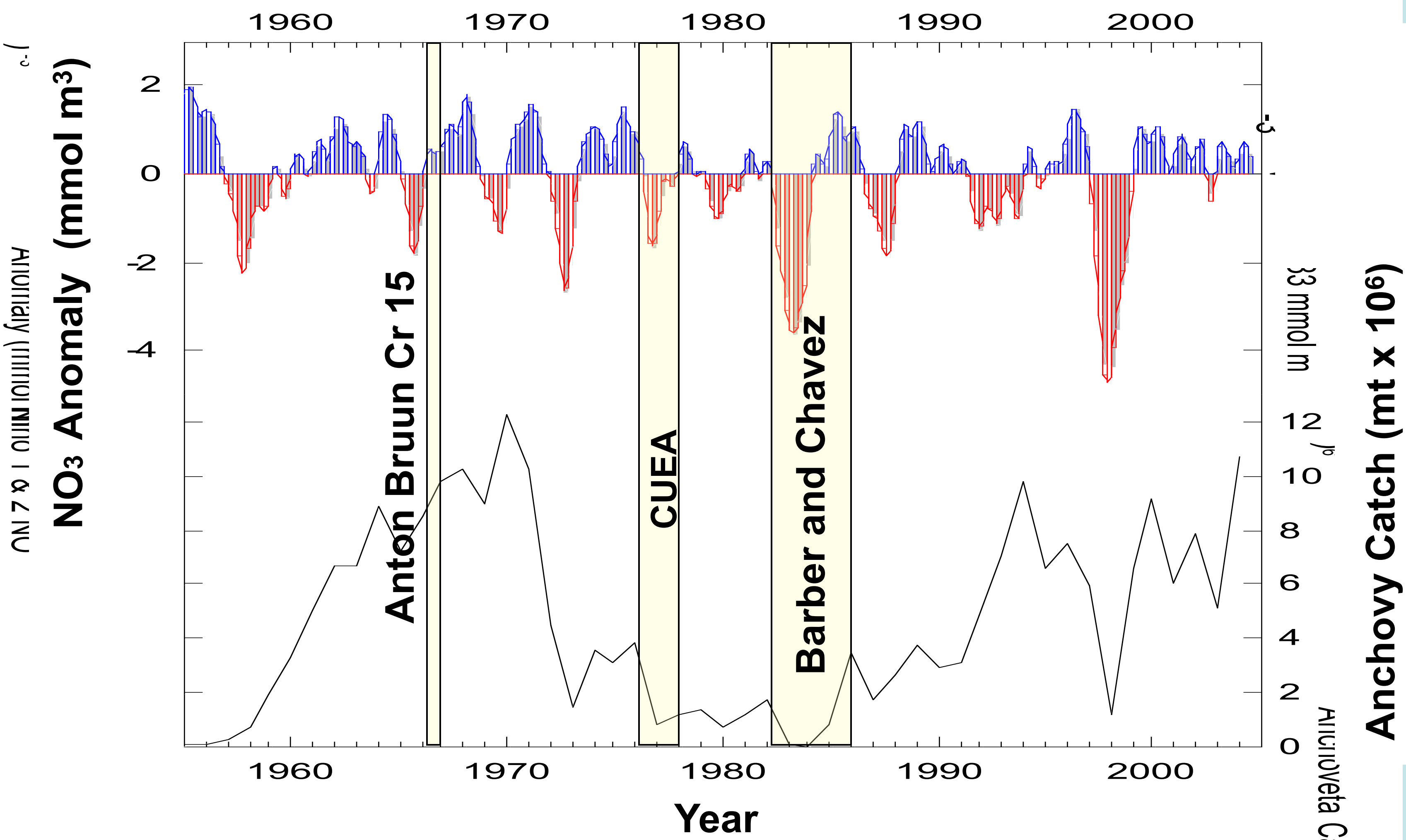
Conclusion:

The deficiencies in theory and limitations in technology that prevented “*useful”* operational marine ecosystem forecasts in the past appear to be surmounted.

Its time to try again put this new capability to work in the ecosystem-based management of living resources.

End

Extra figures for NOAA-NASA workshop.



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

CUEA: 1976 – 1977 (onset of "regime" shift)

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

REVIEW

Challenges of Modeling Ocean Basin Ecosystems

Brad deYoung,[1*] Mike Heath,[2] Francisco Werner,[3] Fei Chai,[4] Bernard Megrey,[5] Patrick Monfray[6]

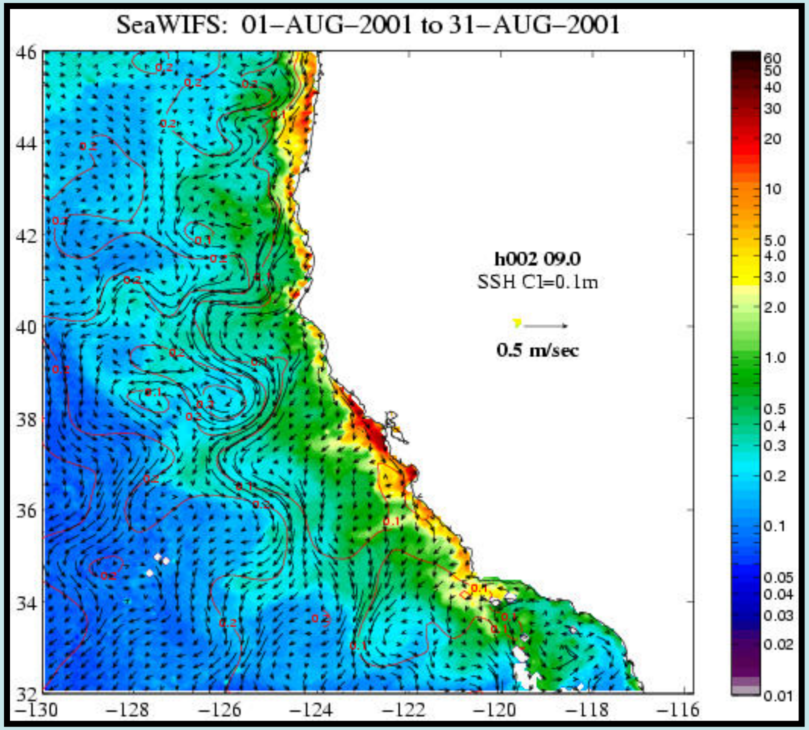
With increasing pressure for a more ecological approach to marine fisheries and environmental management, there is a growing need to understand and predict changes in marine ecosystems. Biogeochemical and physical oceanographic models are well developed, but extending these further up the food web to include zooplankton and fish is a major challenge. The difficulty arises because organisms at higher trophic levels are longer lived, with important variability in abundance and distribution at basin and decadal scales. Those organisms at higher trophic levels also have complex life histories compared to microbes, further complicating their coupling to lower trophic levels and the physical system. We discuss a strategy that builds on recent advances in modeling and observations and suggest a way forward that includes approaches to coupling across trophic levels and the inclusion of uncertainty.

deYoung et al., Science
Vol. 304, 4 June 2004

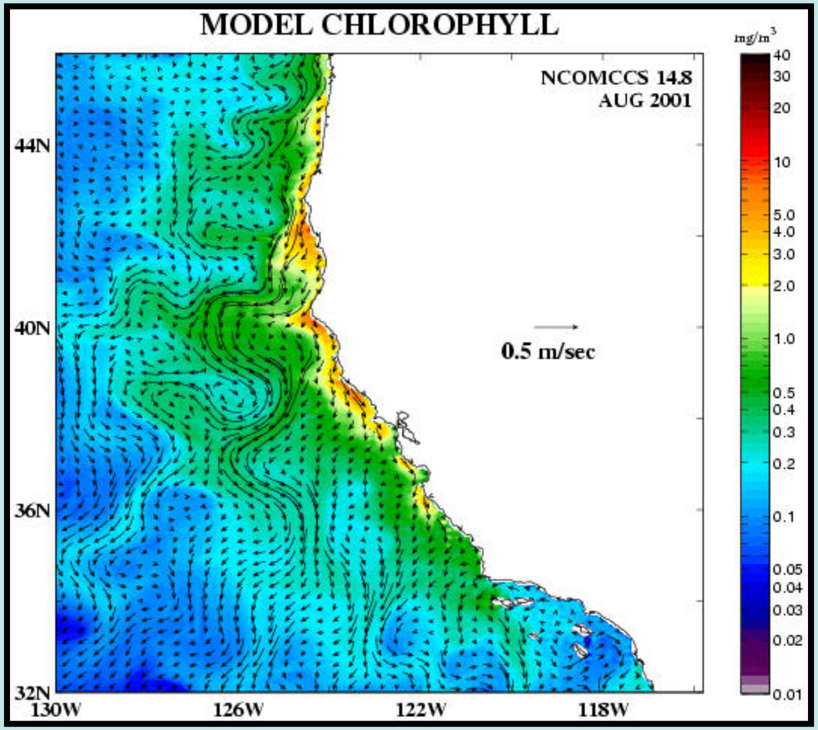
"The difficulty arises because organisms at higher trophic levels are longer lived, with important variability in abundance and distribution at basin and decadal scales."

High time and space resolution is needed

NRL West Coast NCOM with SeaWIFS Chlorophyll



NRL West Coast NCOM with Model Chlorophyll



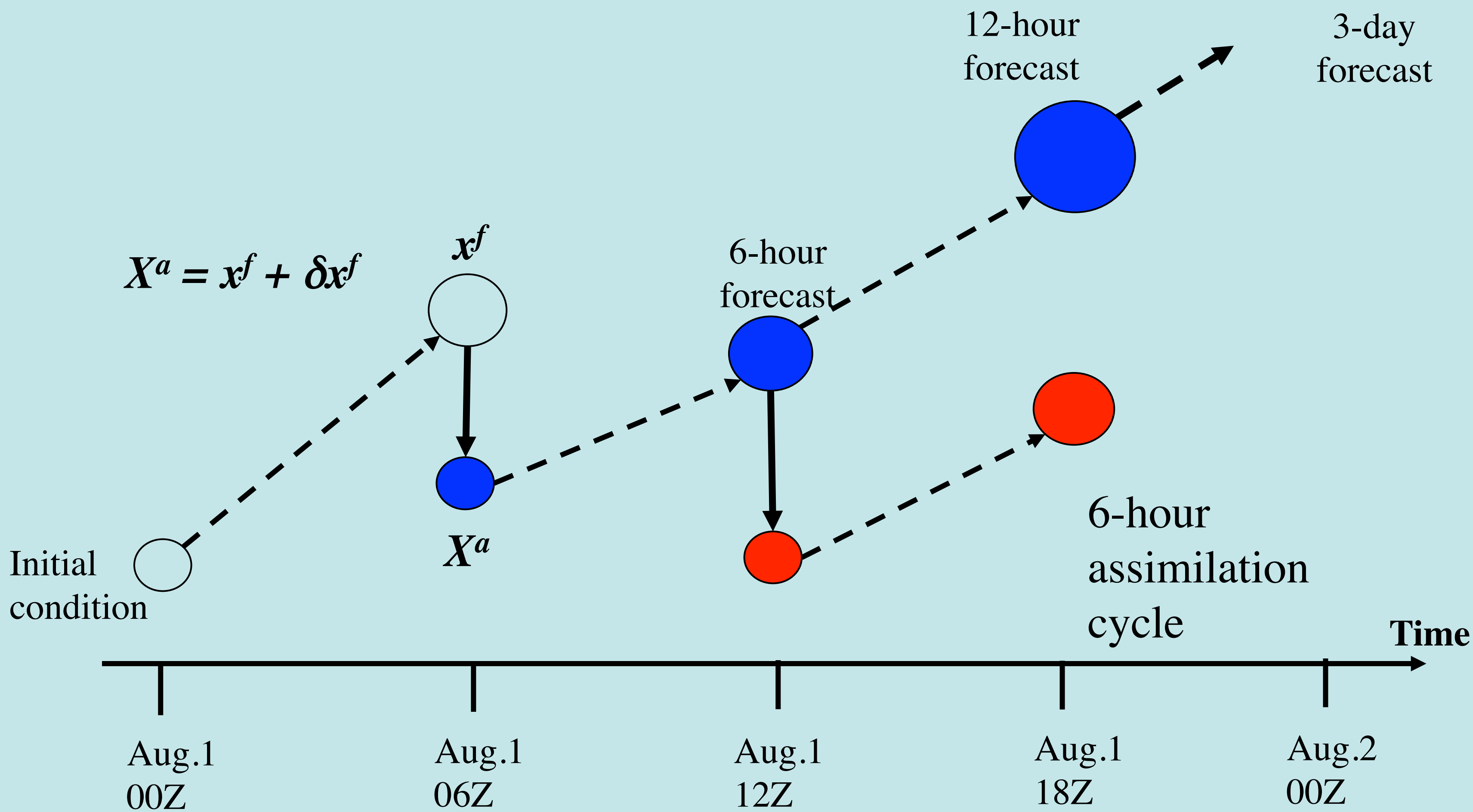
Monthly Sequence: June – August 2001

Integrating Data with Models (or Data Assimilation) for Retrospective Analysis or Real-Time Nowcast/Forecast

3-dimensional variational (3DVAR) method:

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

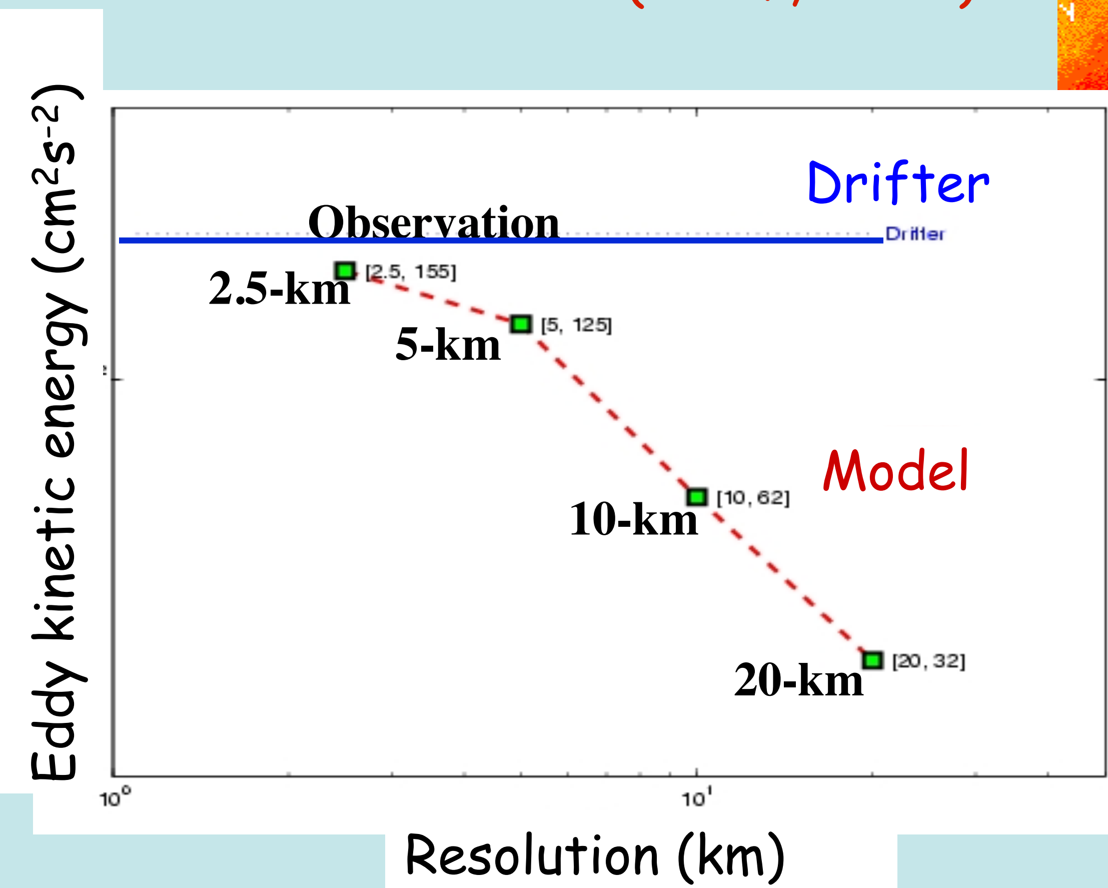
y: observation
x: model

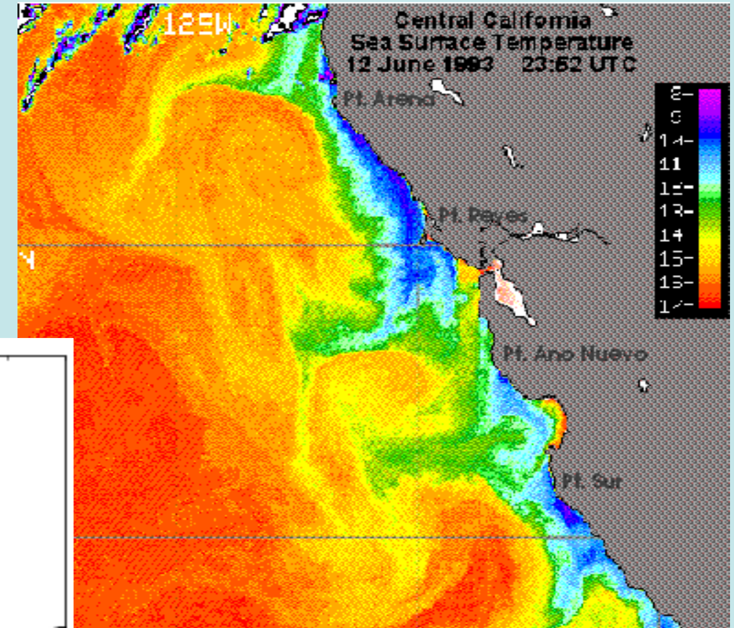


Scale convergence of eddy kinetic energy of *model* and *observations* in a coastal upwelling system

Internal/intrinsic variability

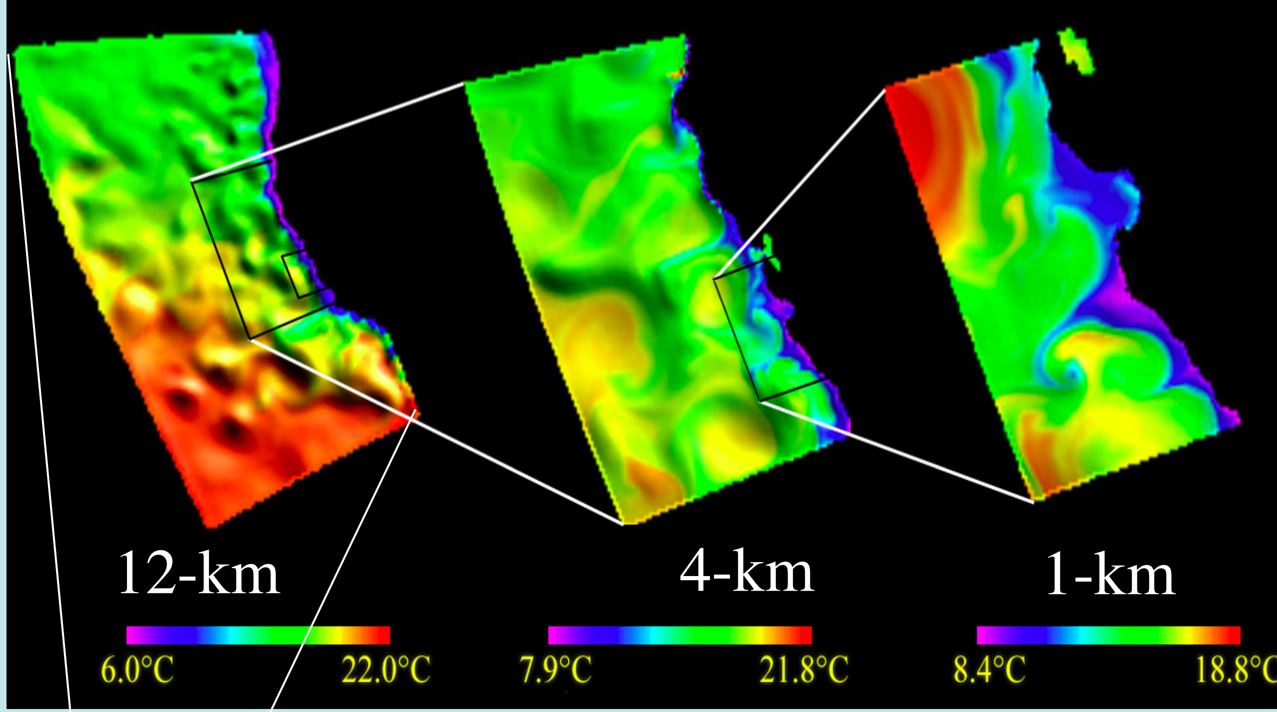
- Features (<10 km, days)
- Model resolution (~1 km, hours)

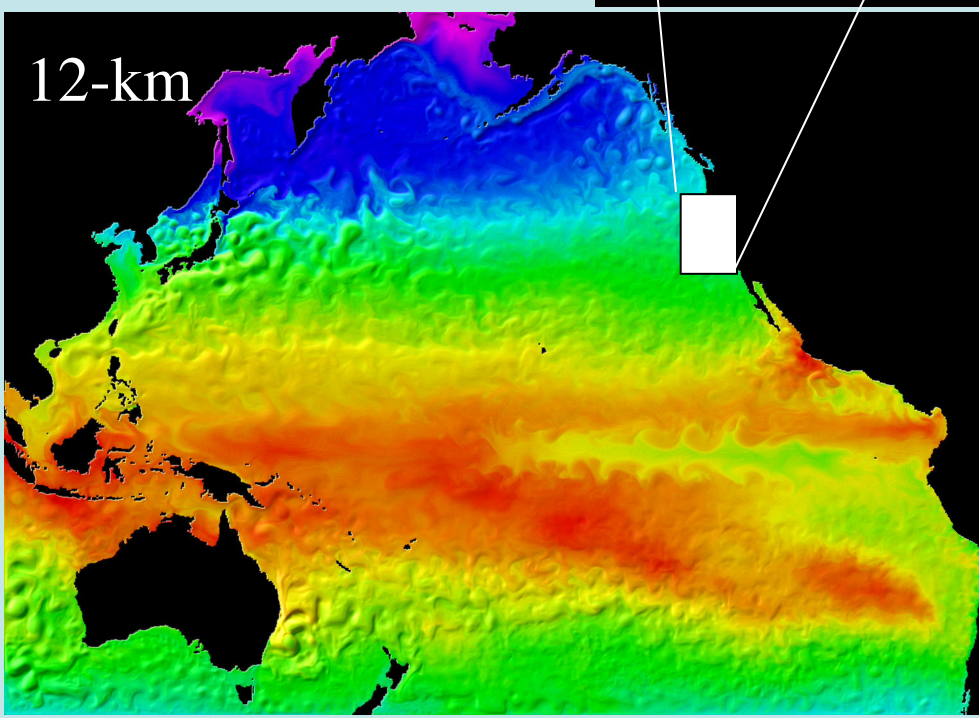




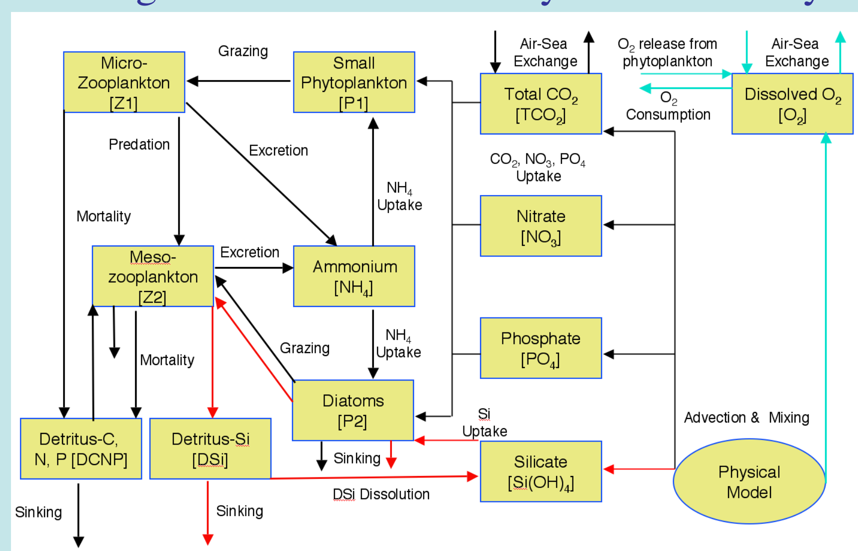
Global to Regional
&
Physics to Biology

Multi-scale (or “nested”) ROMS modeling can represent the coastal ocean at the spatial scale (e.g., 1-km) measured by satellites



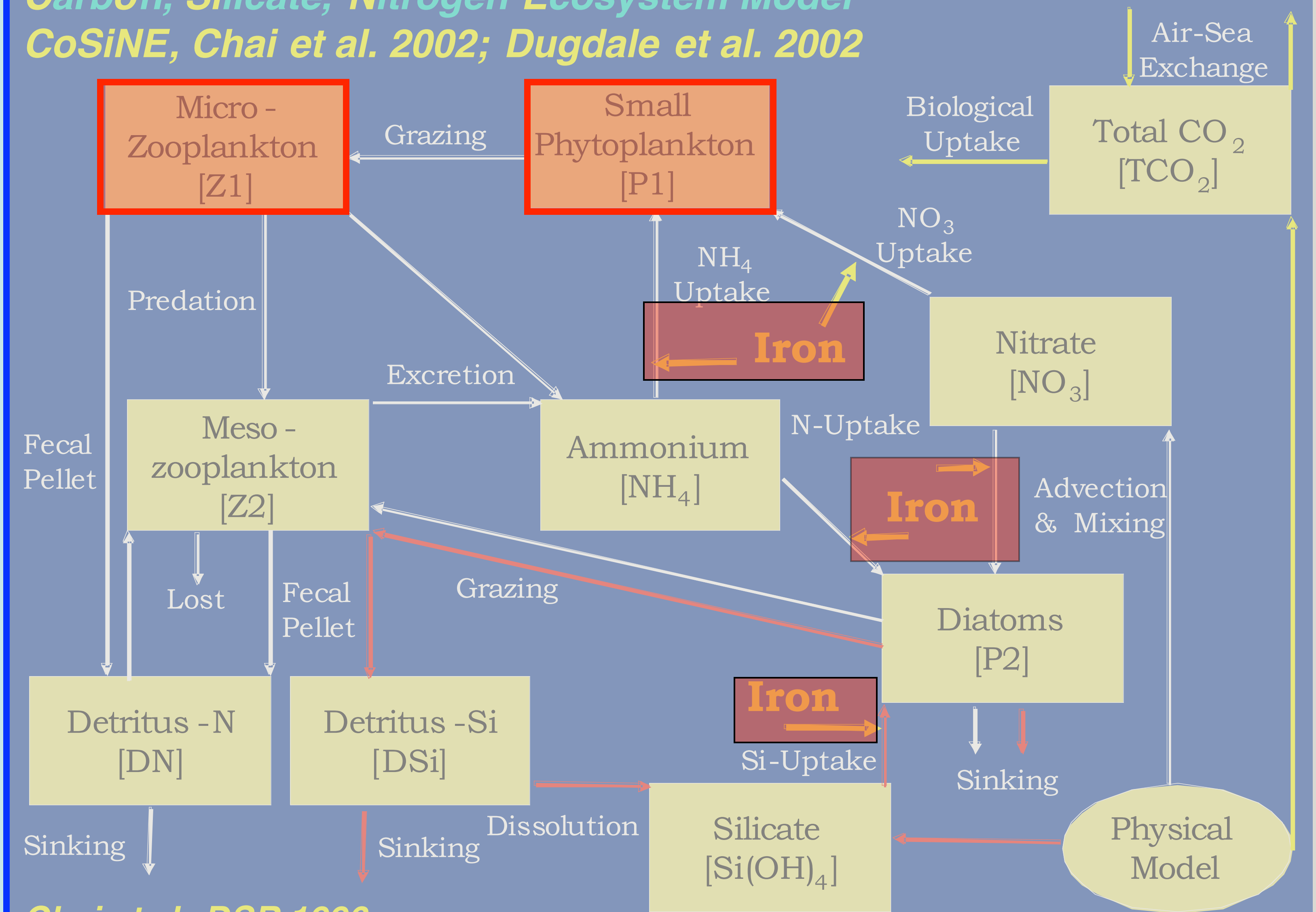


Linking Circulation with Ecosystem & Fishery



Carbon, Silicate, Nitrate Ecosystem Model (CoSINE)

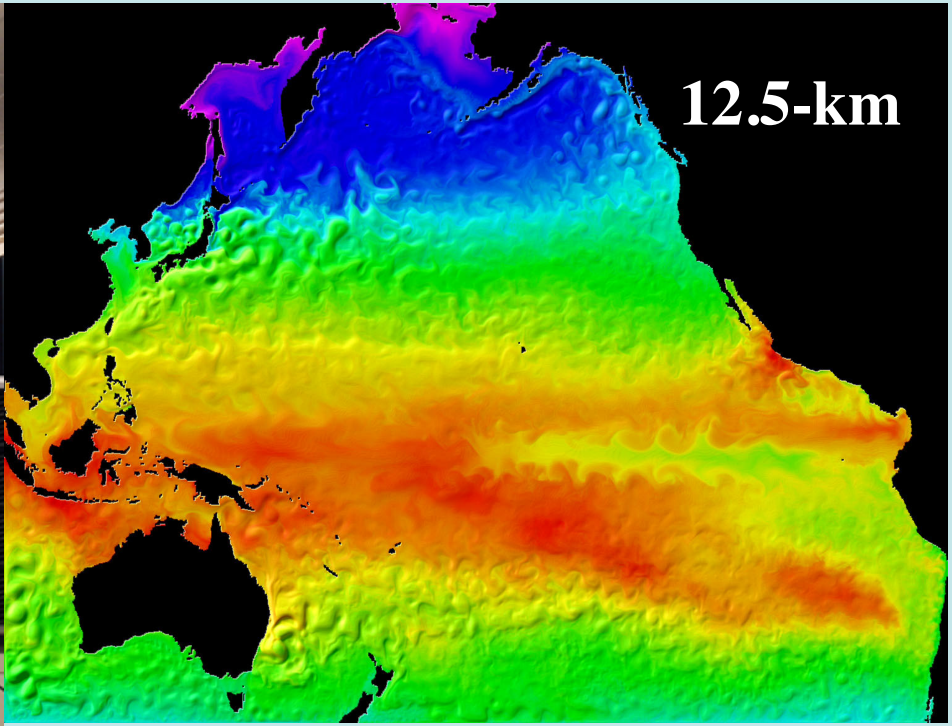
Carbon, Silicate, Nitrogen Ecosystem Model
CoSiNE, Chai et al. 2002; Dugdale et al. 2002



Chai et al., DSR 1996

NASA Biodiversity and Ecological Forecasting Team Meeting
29 – 31 August 2005 Washington, DC

Project Columbia and ROMS

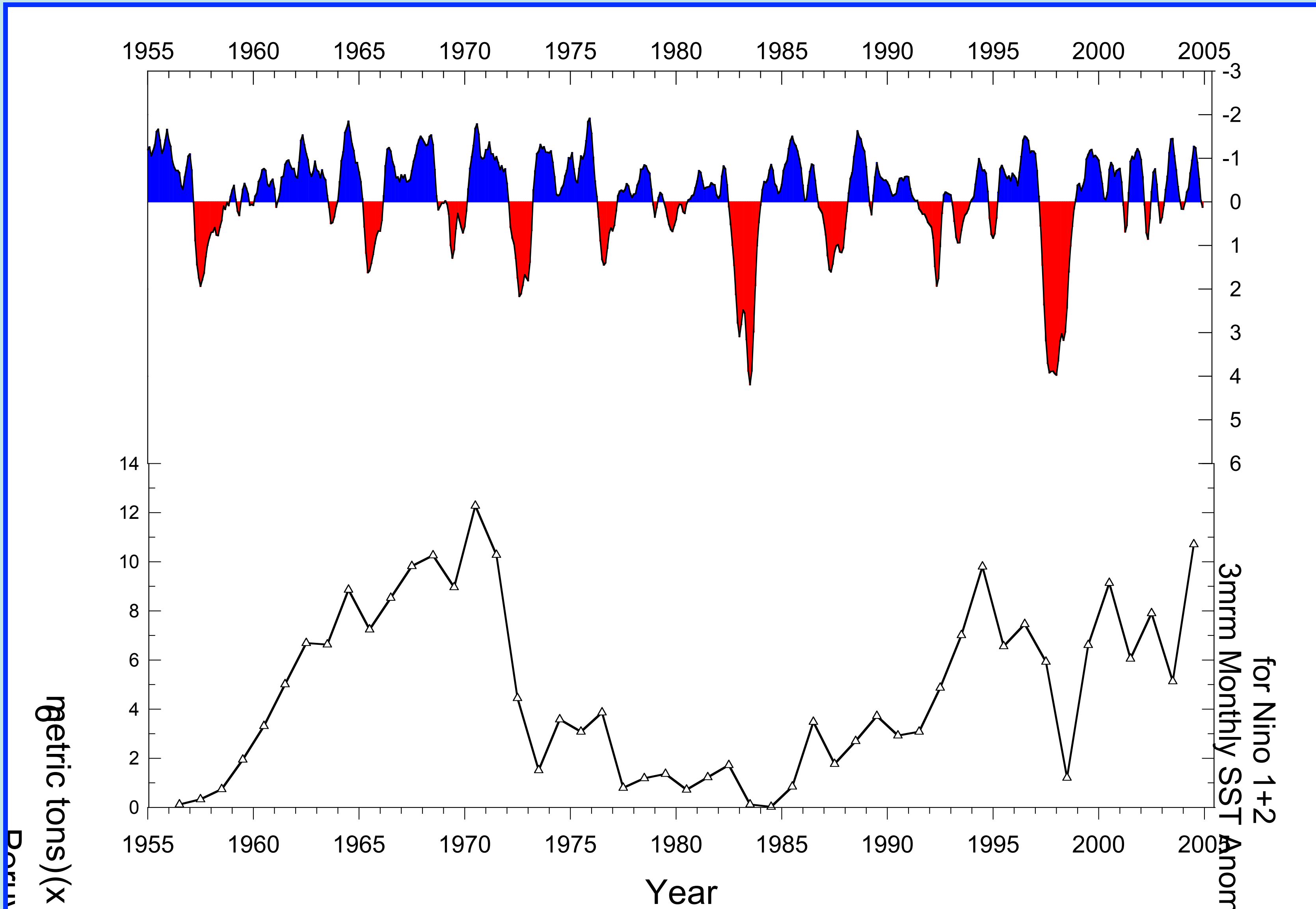


Computer at NASA Advanced Supercomputing Facility:

- 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



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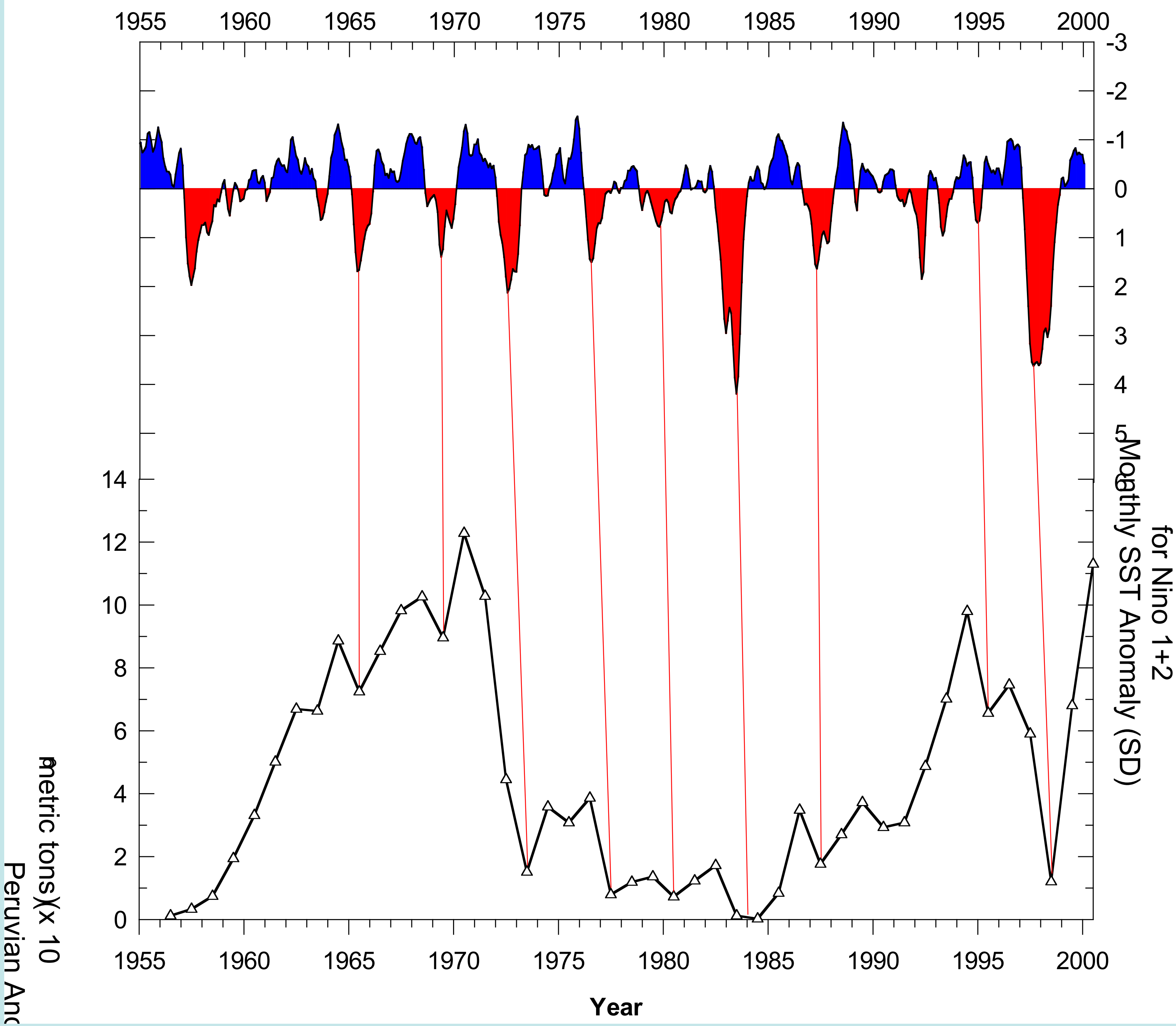

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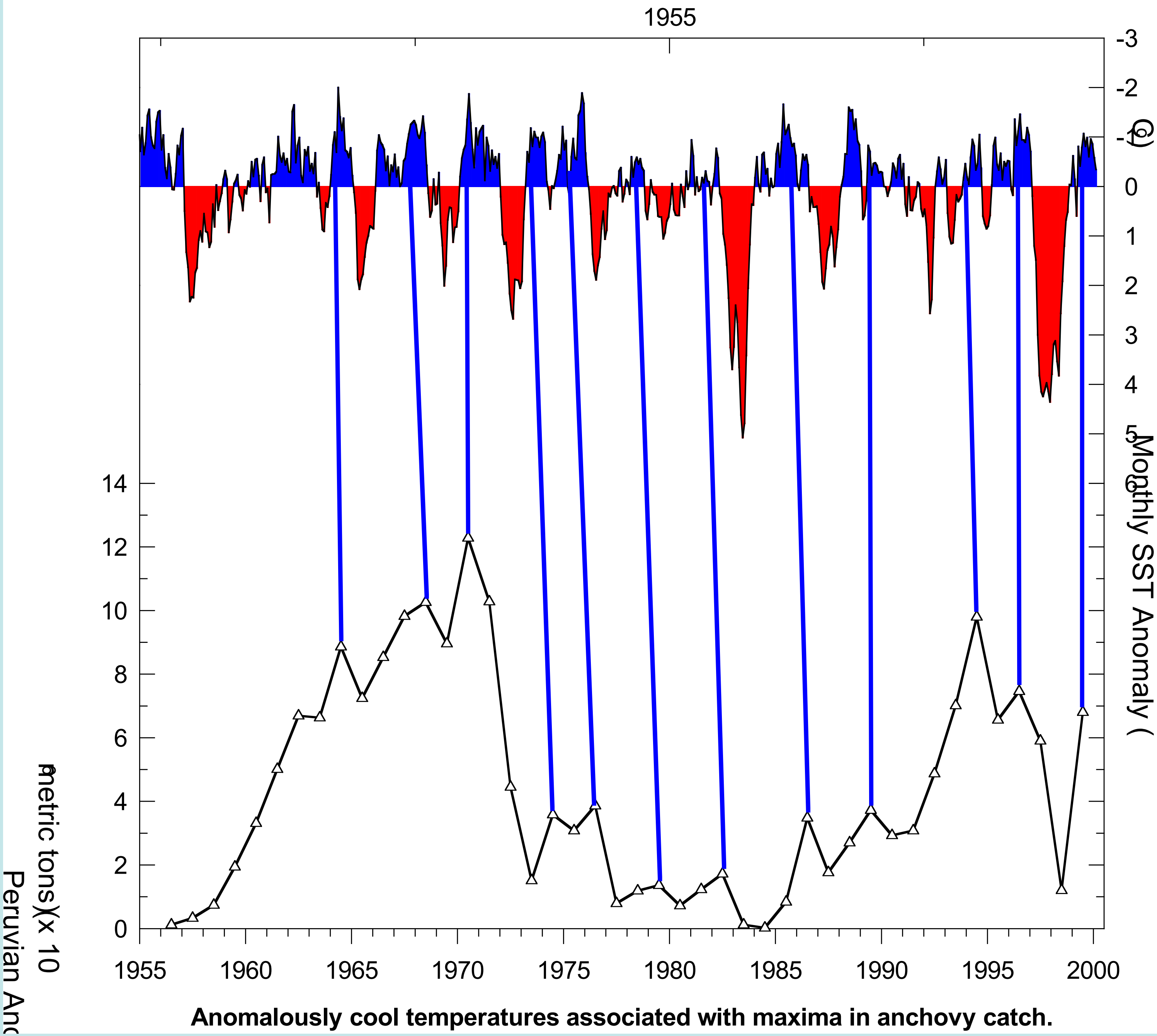

Anomalously cool temperatures associated with maxima in anchovy catch.

Assessment of weather forecasting skill

- Concept proposed in 1920s, but the major breakthrough was not made until late 1950s when the first electronic computer was used for weather forecast

- **Very short-range forecasts (0–12 hour)**
  - Considerable skill and utility, especially for predictions of the evolution and movement of large- and medium-sized weather systems

- **Short-range forecasts (12–72 hour)**
  - Forecasts of how much precipitation will fall in the 36-60-hour time frame are now more accurate than 12-36-hour predictions were during the late 1970s.
  -

- **Medium-range forecasts (3–7 days into the future)**
  - Skillful day 7 forecasts will be possible in the future given the steady improvements in computer models, observational approaches, and forecast strategies.

- **Extended-range forecasts (week 2)**
  - The predictability of the day-to-day weather for periods beyond day 7 is usually small. Statistical forecast of the mean conditions for the 8-14-day period might be possible.

- **Monthly and seasonal forecasts of weather**
  - No verifiable skill exists or is likely to exist for forecasting day-to-day weather changes beyond two weeks: “butterfly” effect (or chaos) rules,

  - ***but*** ecological forecasts of recruitment success, disease outbreaks or crop failures are climate-driven, not weather-driven.