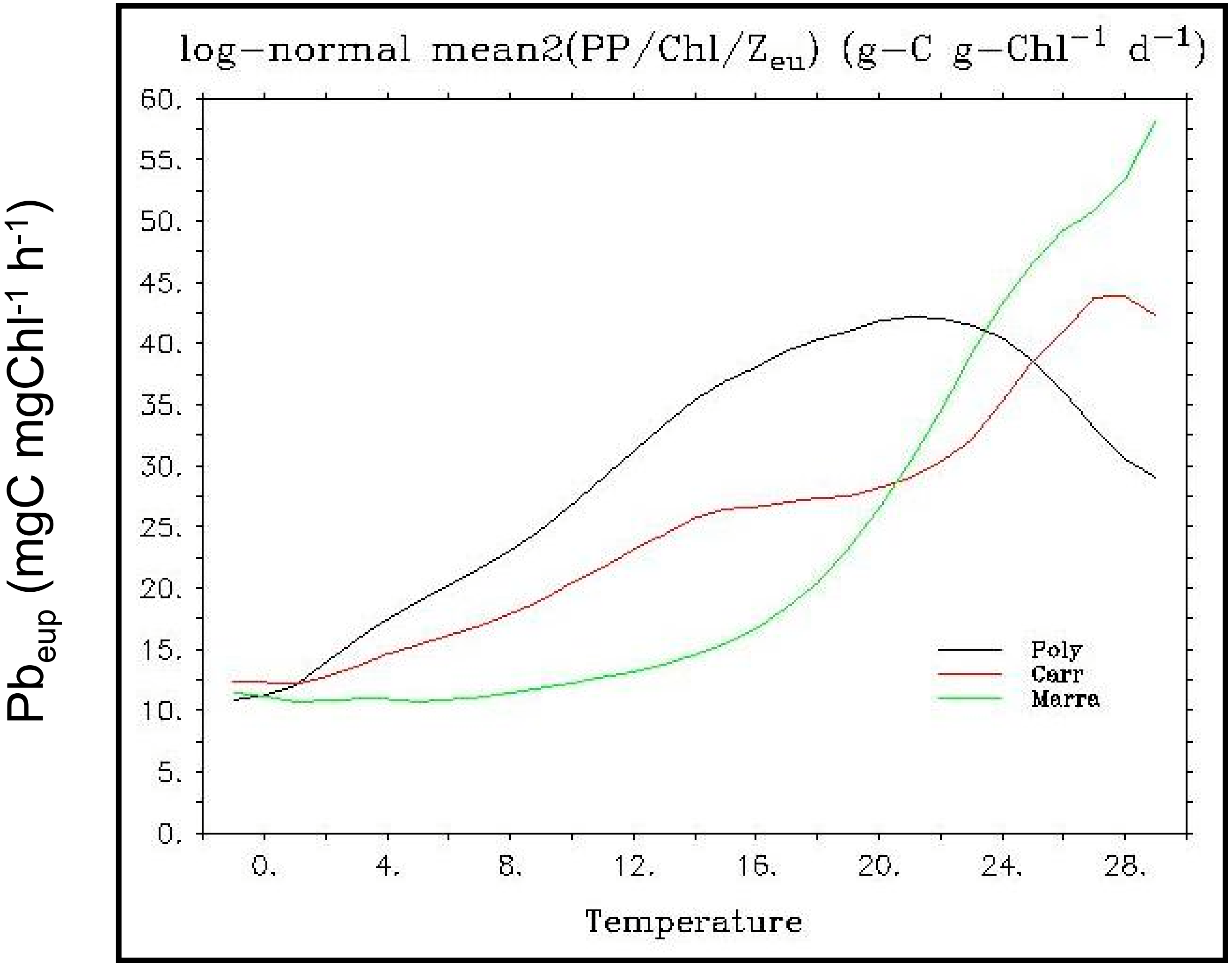
“RESPONSE OF OCEAN ECOSYSTEMS TO CLIMATE WARMING”

by

, J. Sarmiento, R. Slater, R. Barber
L. Bopp, S. C. Doney, A.C. Hirst,
J. Kleypas, R. Matear,
U. Mikolajewicz, P. Monfray,
J. Orr, V. Soldatov, S. Spall, R. Stouffer

In press in Global Biogeochemical Cycles



log-normal mean2(PP/Chl/Z_{eu}) (g-C g-Chl^{-1} d^{-1})
Pb_{eup} (mgC $mgChl^{-1}$ h^{-1})
60.
55.
50.
45.
40.
35.
30.
25.
20.
15.
10.
5.
0.
0.
4.
8.
12.
16.
20.
24.
28.
Temperature
Poly
Carr
Marra

Future Directions in Science

Dick Barber
Duke University

Ocean Color Research Team Meeting
14-16 April 2004 – Washington, DC

Real Title:

Future Directions in Science that involve Ocean Color Research and NASA's entire armory of Remote Sensing and Computational Power

Dick Barber

Duke University

A better title might be:

A look ahead based on
the experiences * of
a lucky person, 1957 to 2004

* WHOI in late 50's: Odum's Chl Hypothesis, ^{14}C, Assimilation No., Ryther & Yentsch,etc,etc

WHOI in late 60's: Giff Ewing & Charlie Y.'s first remote "color" signal in summer of '67, Ryther's AEC Cycle of Carbon…, rise of team sci , NSF support for interdisc. sci, rise of alphabet culture: IGBP, IDOE, GARP, FGGE, GEOSEC, CUEA, etc

plus late 70's: big sci, CZCS, climate, planning….

Comments from a proposal, May 1975:

… 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 few biological, physical and meteorological variables…

Program Goal

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 useful to mankind.

Coastal Upwelling Ecosystems Analysis

Renewal Proposal To NSF,

(International Decade of Ocean Exploration, IDOE)

Volume 1, Page 6.

In today's language the CUEA goal would be:

To empower decision makers to practice proactive ecosystem management in an ocean forced by varying climate and anthropogenic activities.

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To empower decision makers to practice proactive ecosystem management in an ocean forced by varying climate and anthropogenic activities.

Obviously this goal was widely over-reaching in 1975.

Our enormous underestimation of the degree of difficulty is interesting, but for now the issue is, ***can this goal ever be achieved?***

Our = Dick Barber, Bob Smith, Jim O'Brien, Dave Halpern, Dick Dugdale, John Walsh and Jim Kelley writing for 30 PI's

Why be optimistic now?

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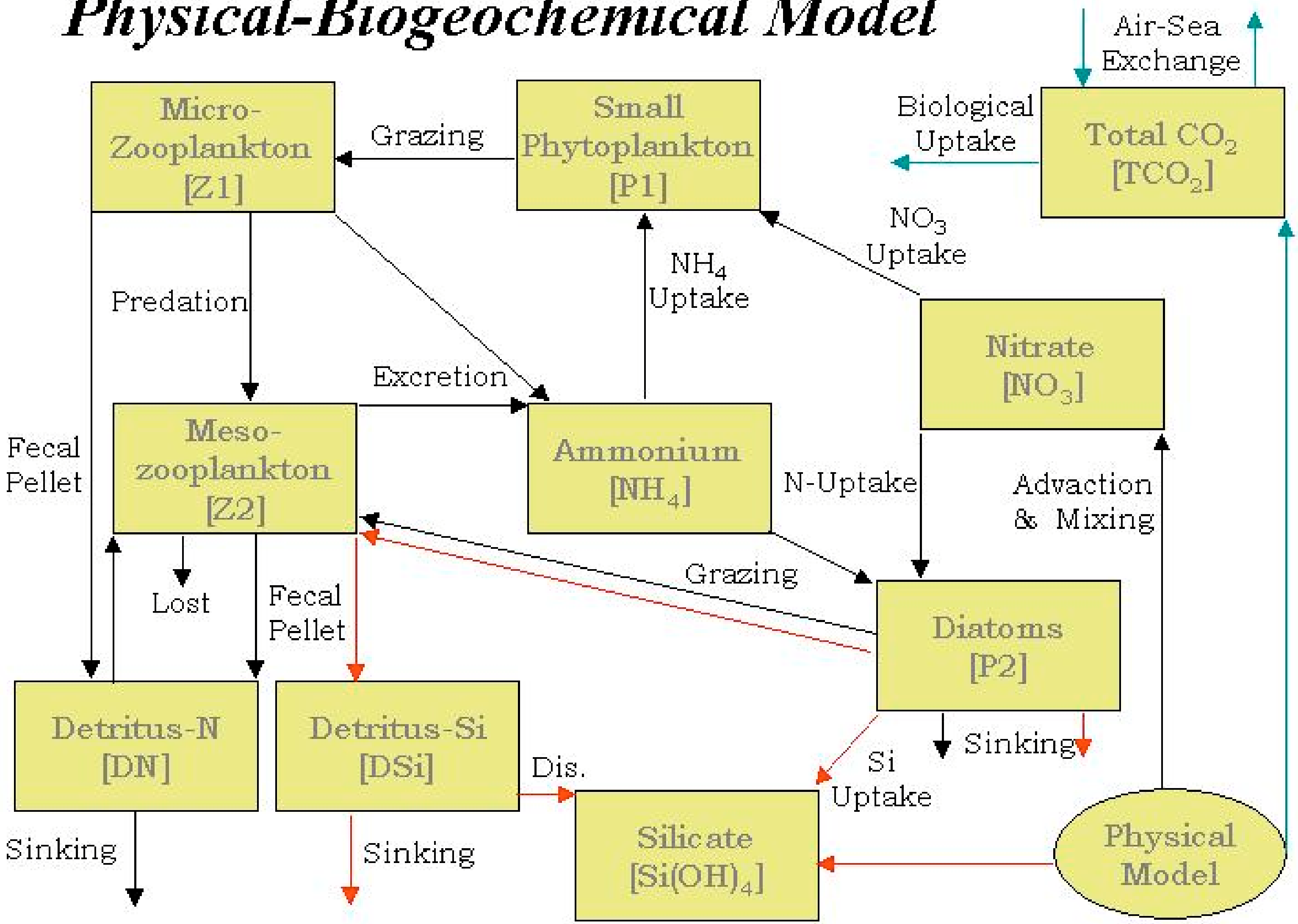
Since 1975:

- A few new ideas; ie, Fe and Two-path food web (need for picophytos & micrograzers in ecosystem models), etc

Physical-Biogeochemical Model



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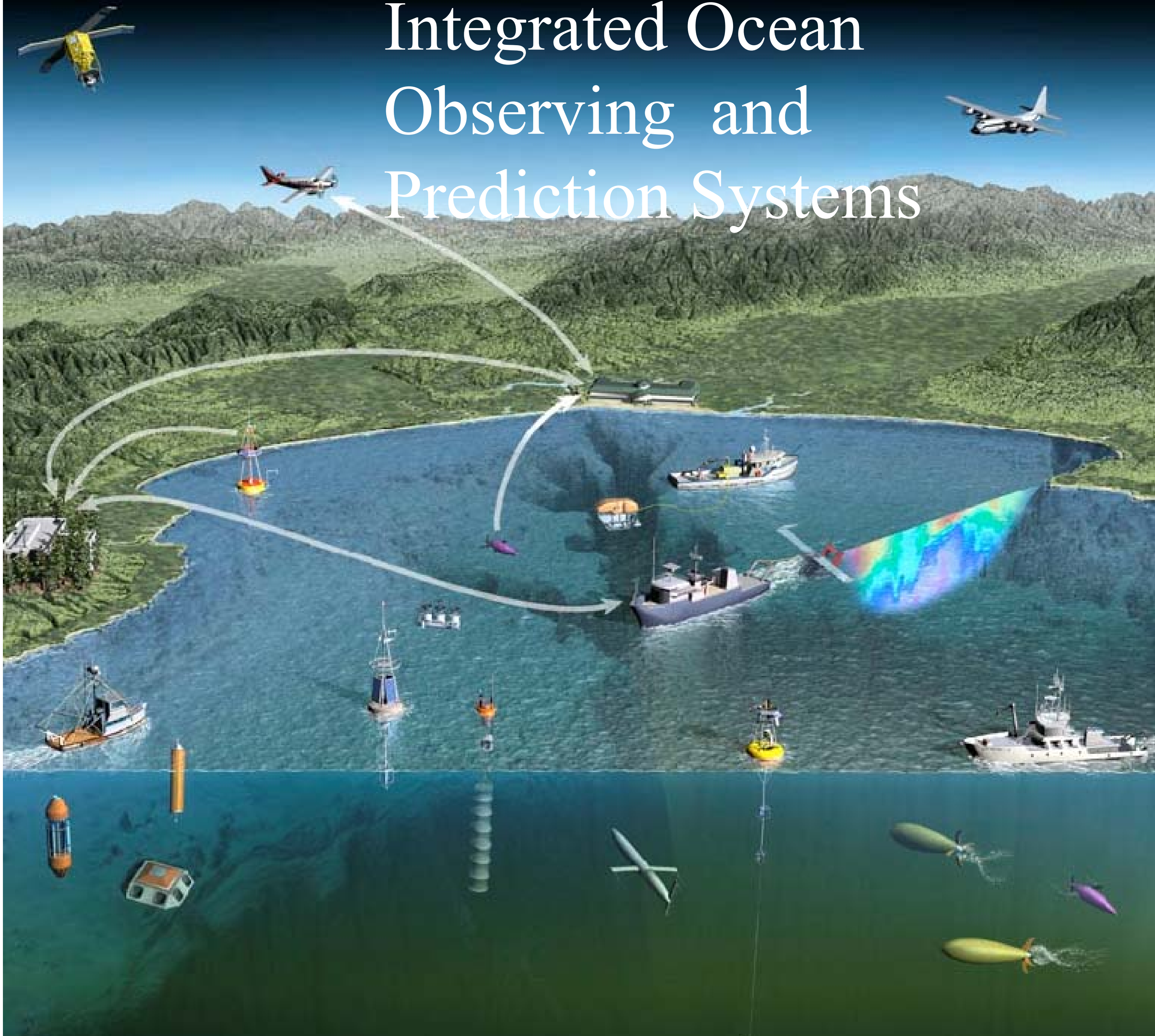
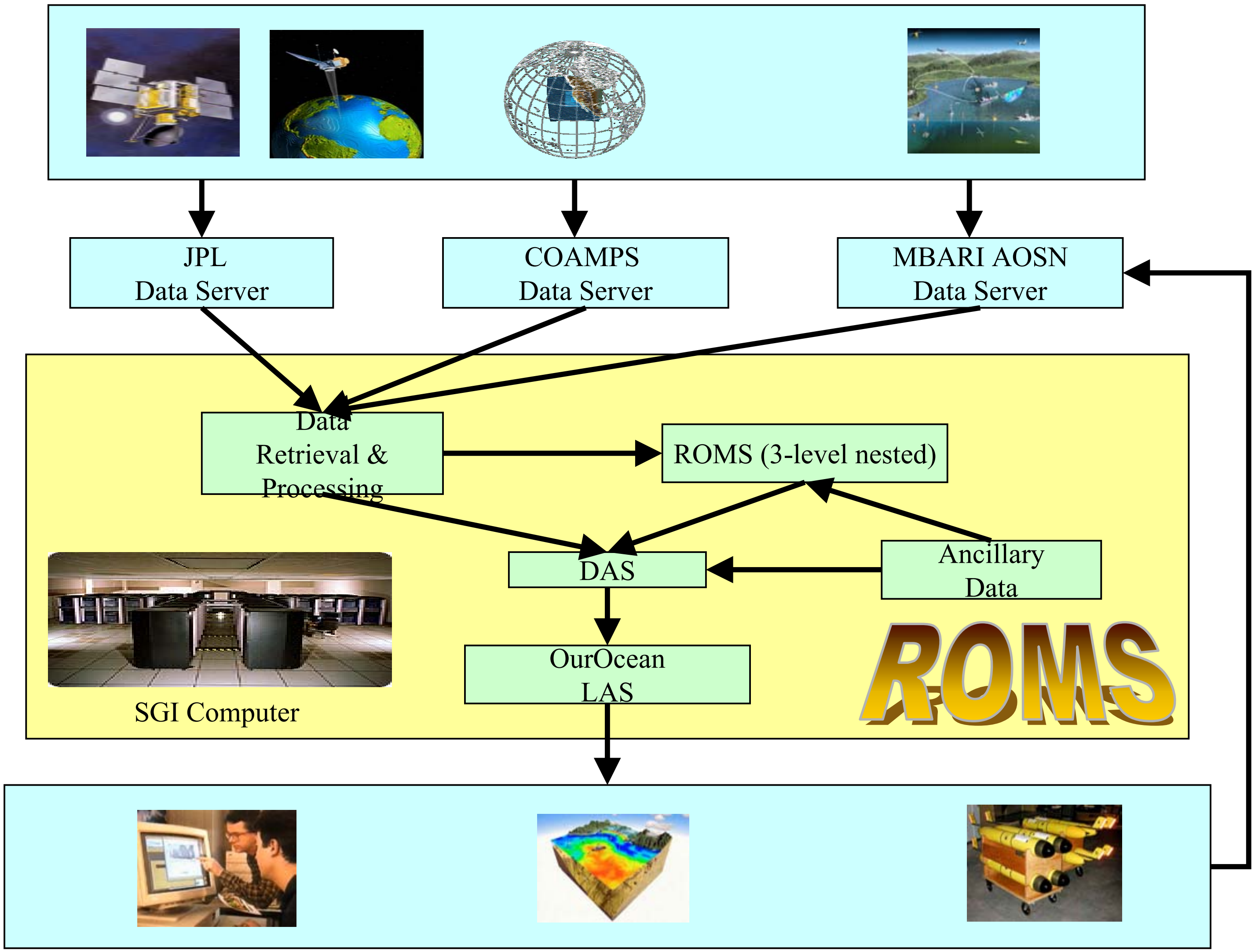
2. The revolution in observing systems; mode, resolution & quantity (approaching over-determination?)

Integrated Ocean Observing and Prediction Systems



Monterey Bay Forecasting System using ROMS (Regional Ocean Modeling System)



AOSN ROMS Team:

PI: Yi Chao (JPL)

Co-PI: Jim McWilliams (UCLA)

ROMS Physics:

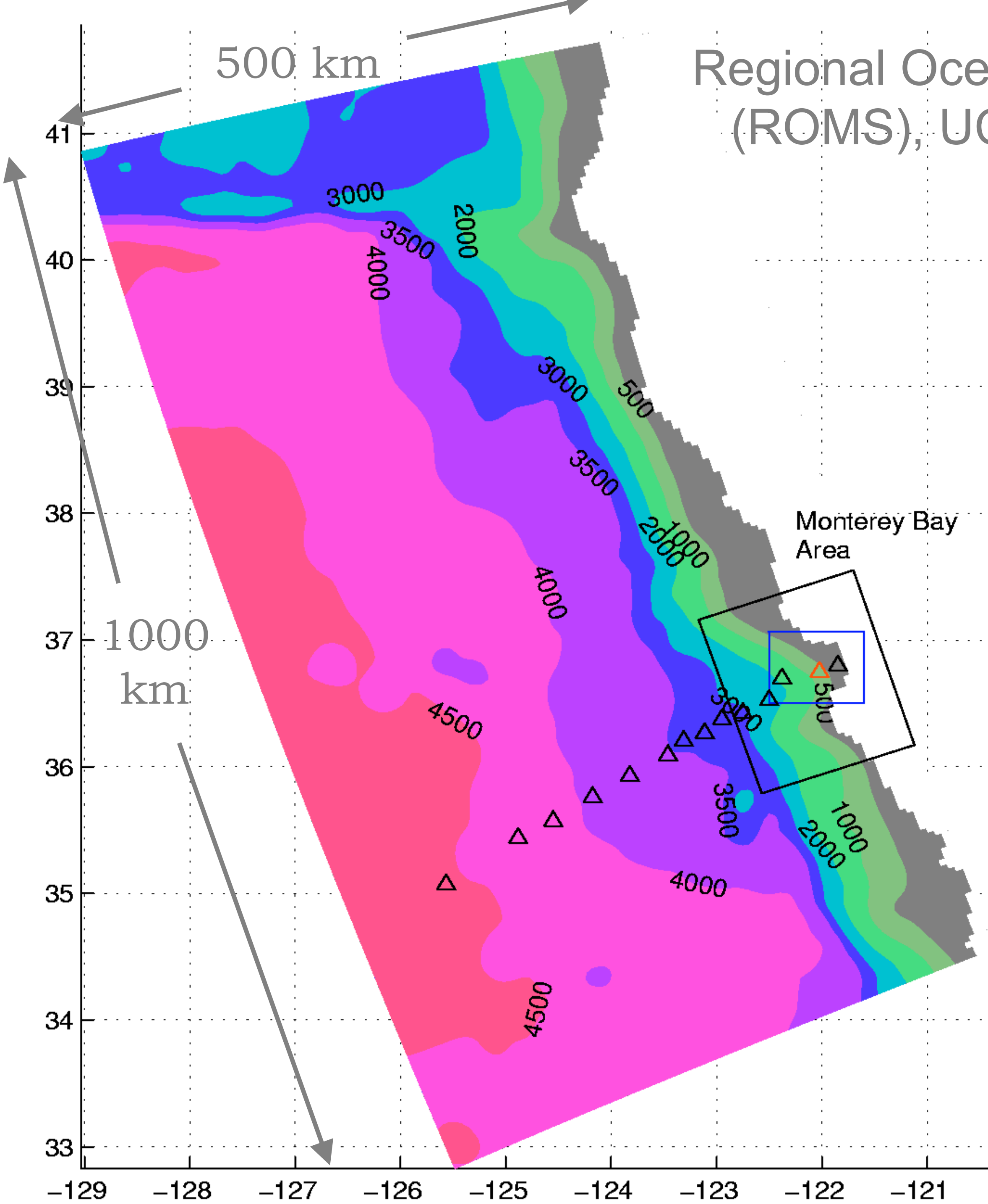
JPL:
- Zhijin Li
- Jei Choi
- Peggy Li

UCLA:
- Patrick Marchesiello
- Xavier Capet
- Kayo Ide

ROMS Ecosystem:

Francisco Chavez
Fei Chai
Niki Gruber

Regional Ocean Modeling System (ROMS), UCLA and JPL/NASA



5 km model resolution

a) 100 km COADS Monthly Forcing

b) 9 km COAMPS Daily Forcing

Seasonal and Upwelling Event Time Scale

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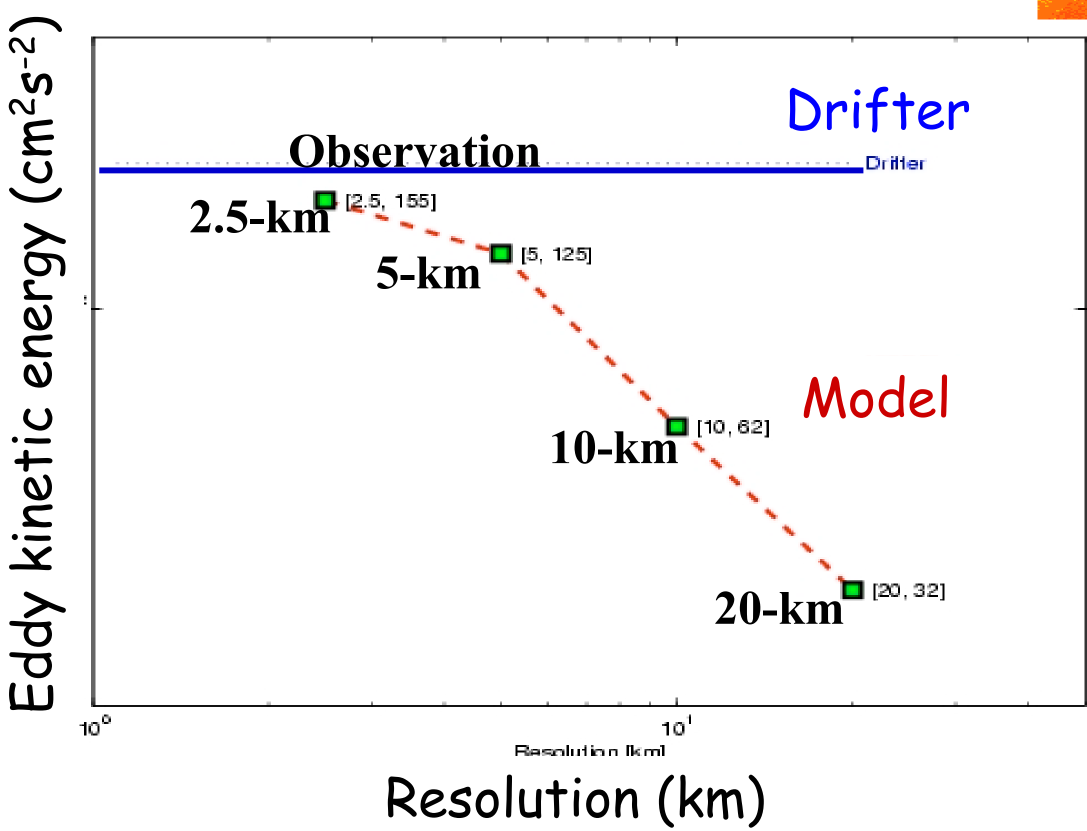
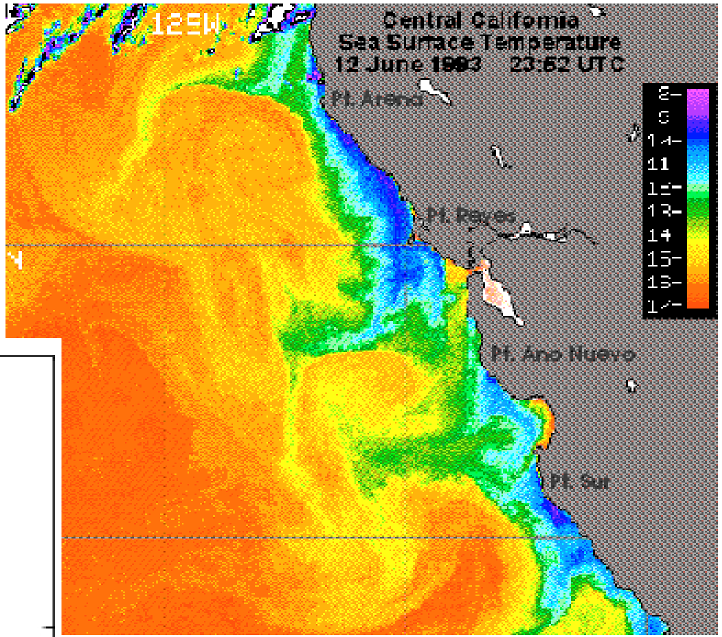
3. The even greater computational revolution; power, new concepts (ie,assimilation), scale convergence,

Seeing the Variability of the California Current System (for the first time)

Internal/intrinsic variability

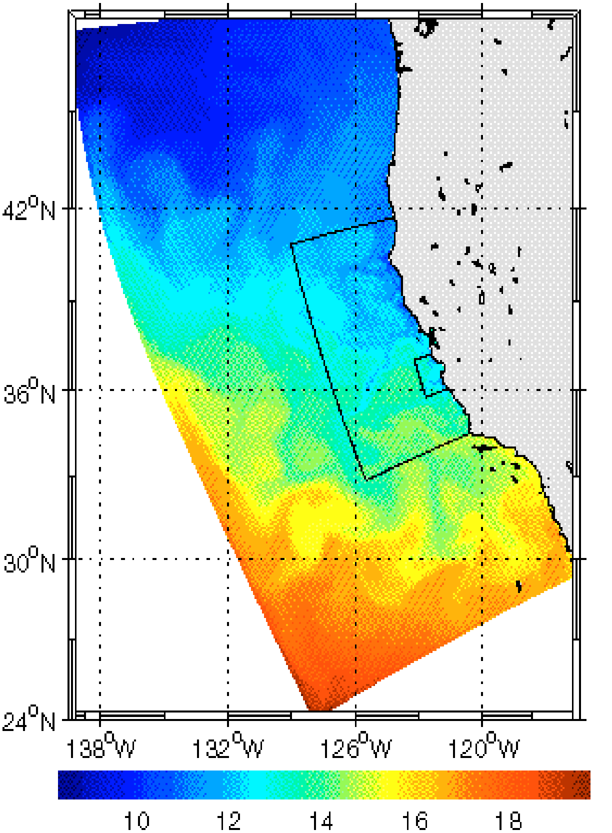
- Features (<10 km, days)
- Model resolution (~1 km, hours)





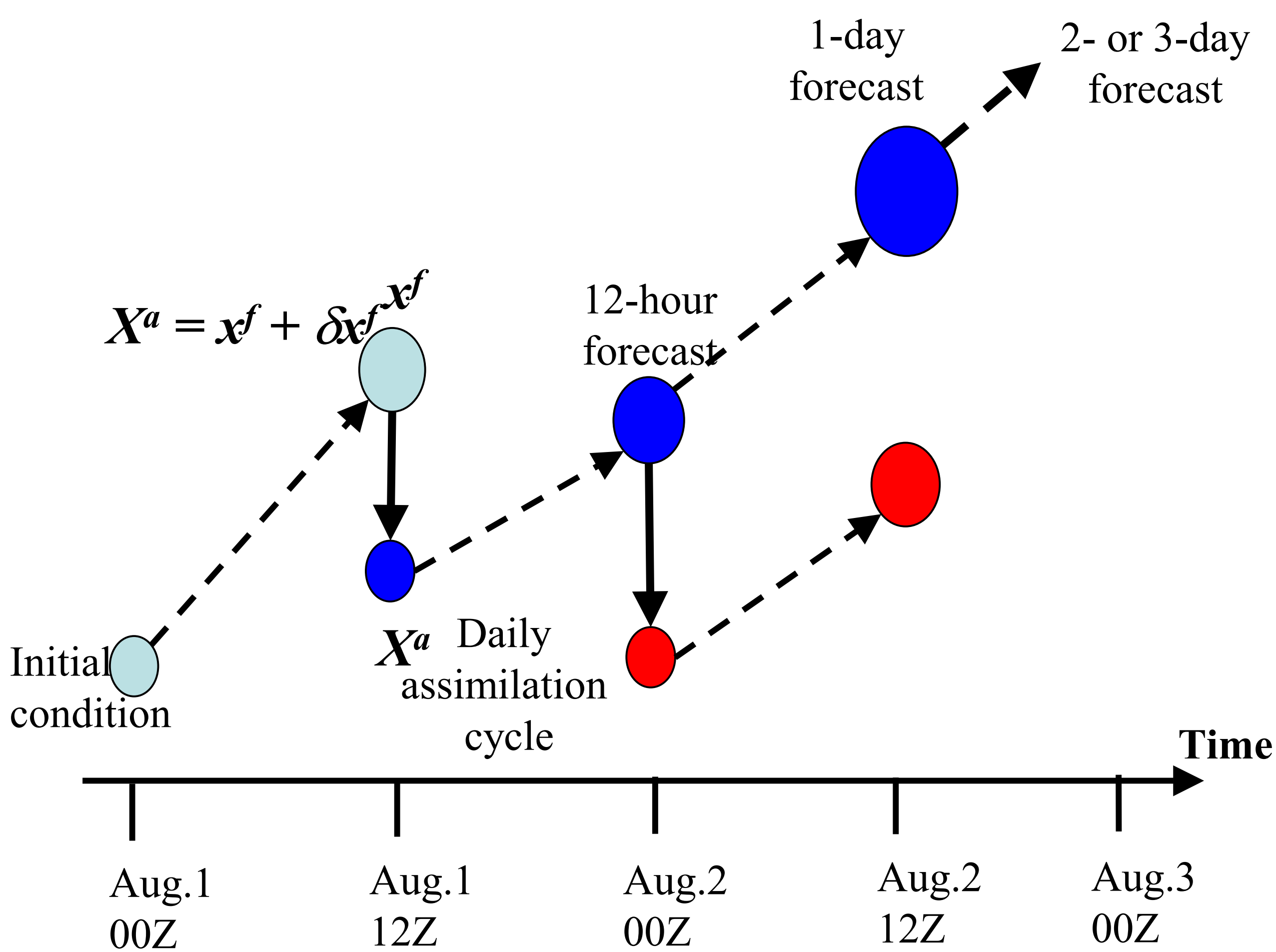
Summary of ROMS and Data Assimilation System

3-level ROMS: 15/5/1.5 km



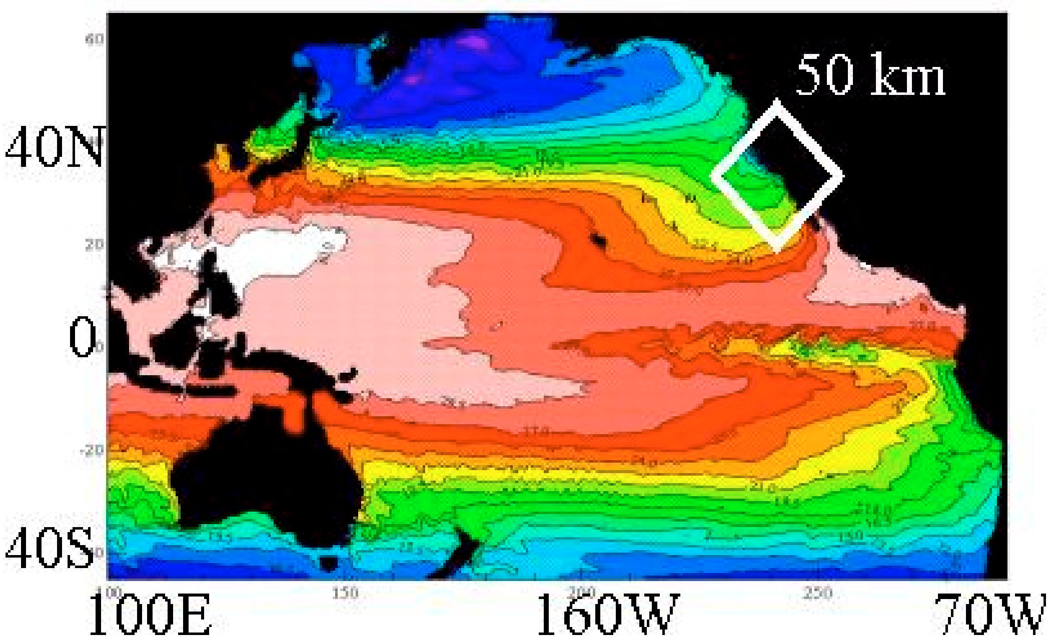
3-dimensional variational (3DVAR) method:

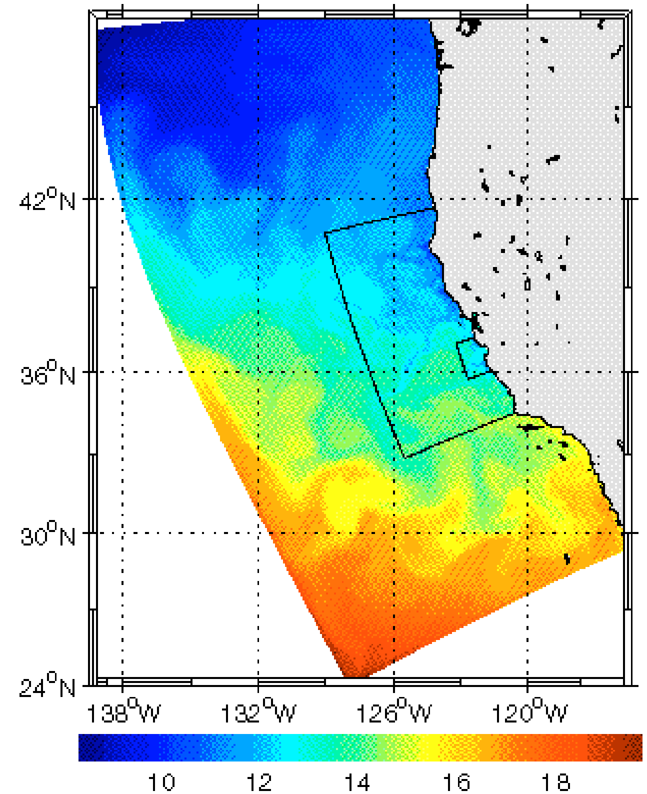
$$J = 0.5\,(x-x^f)^T\,B^{-1}\,(x-x^f) + 0.5\,(h\,x-y)^T\,R^{-1}\,(h\,x-y)$$



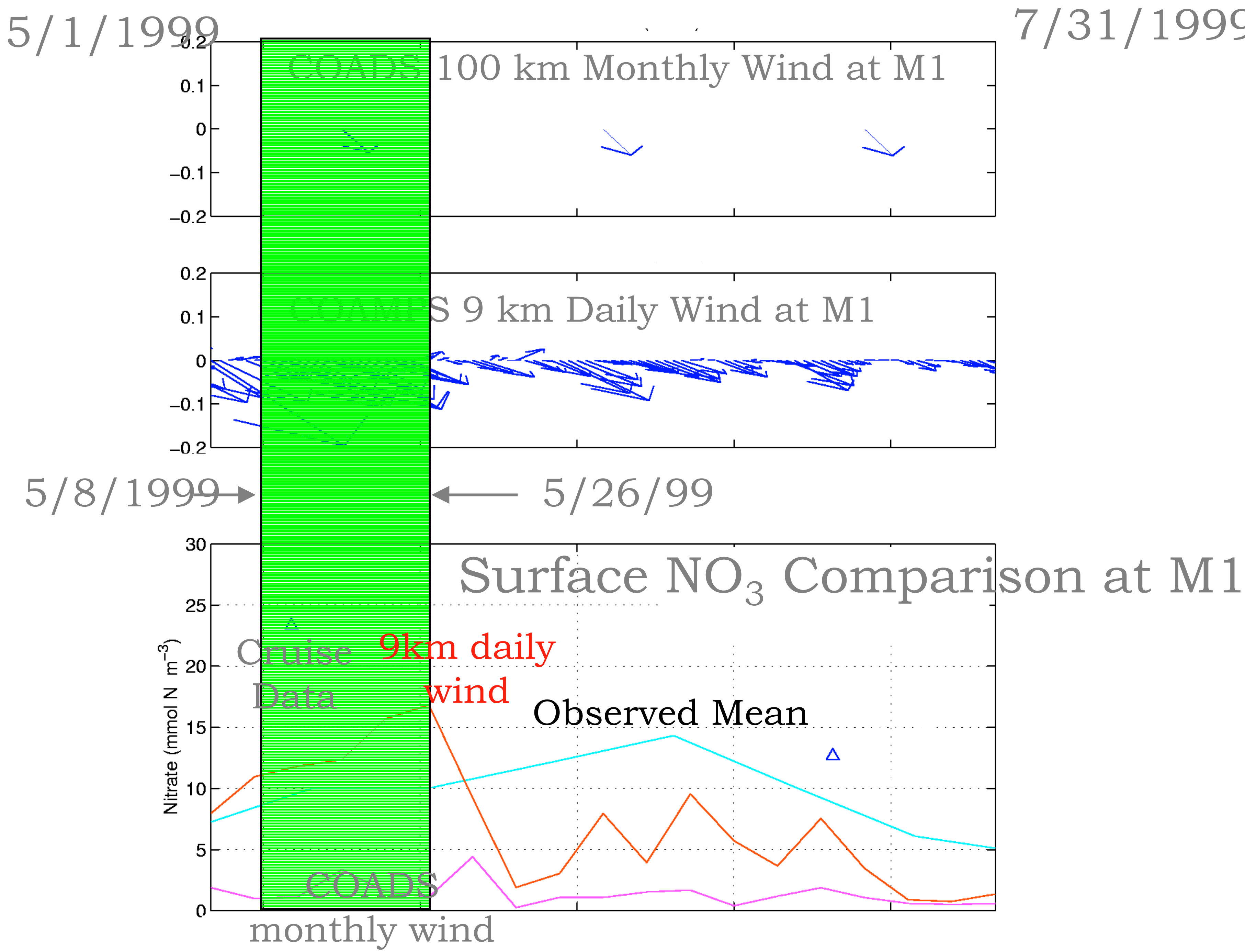
During August, the assimilation window was 24 hours; Now we reduce it to 12 hours, and will further reduce it to 6 hours soon.

Nested Modeling from Pacific to Monterey Bay

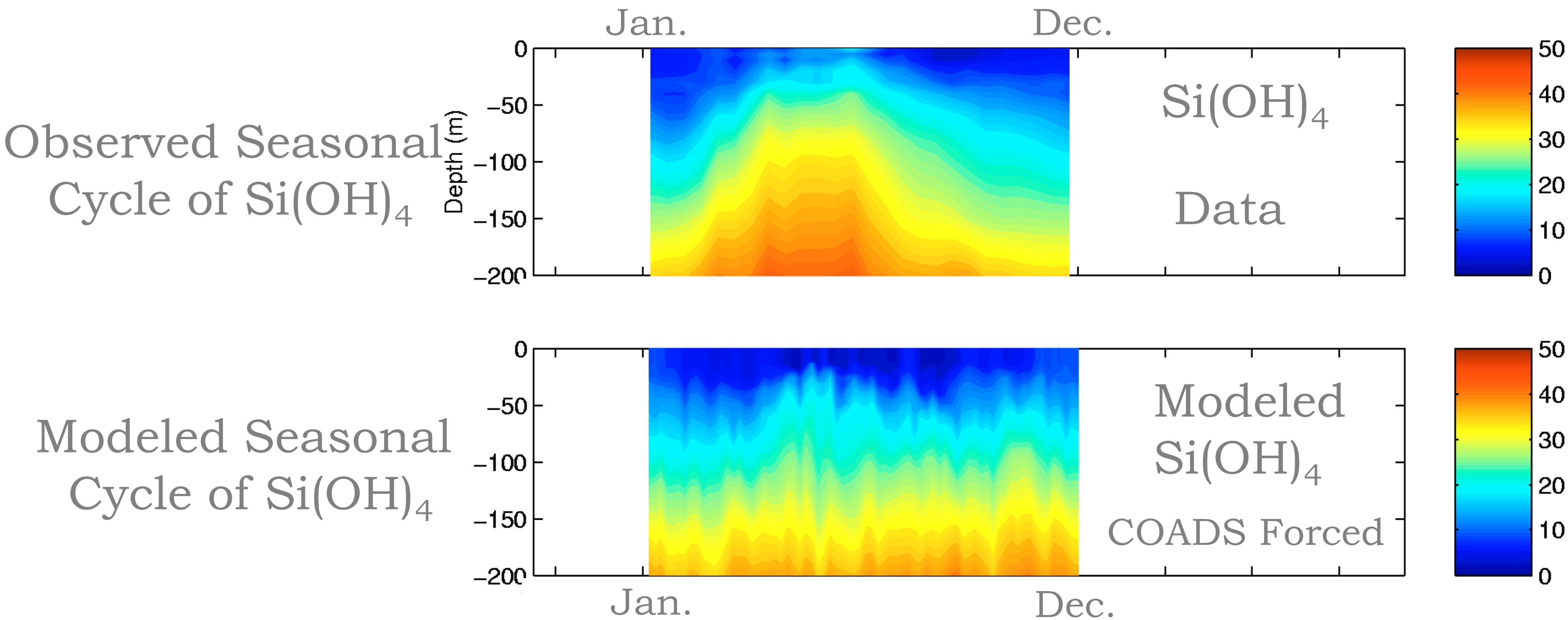




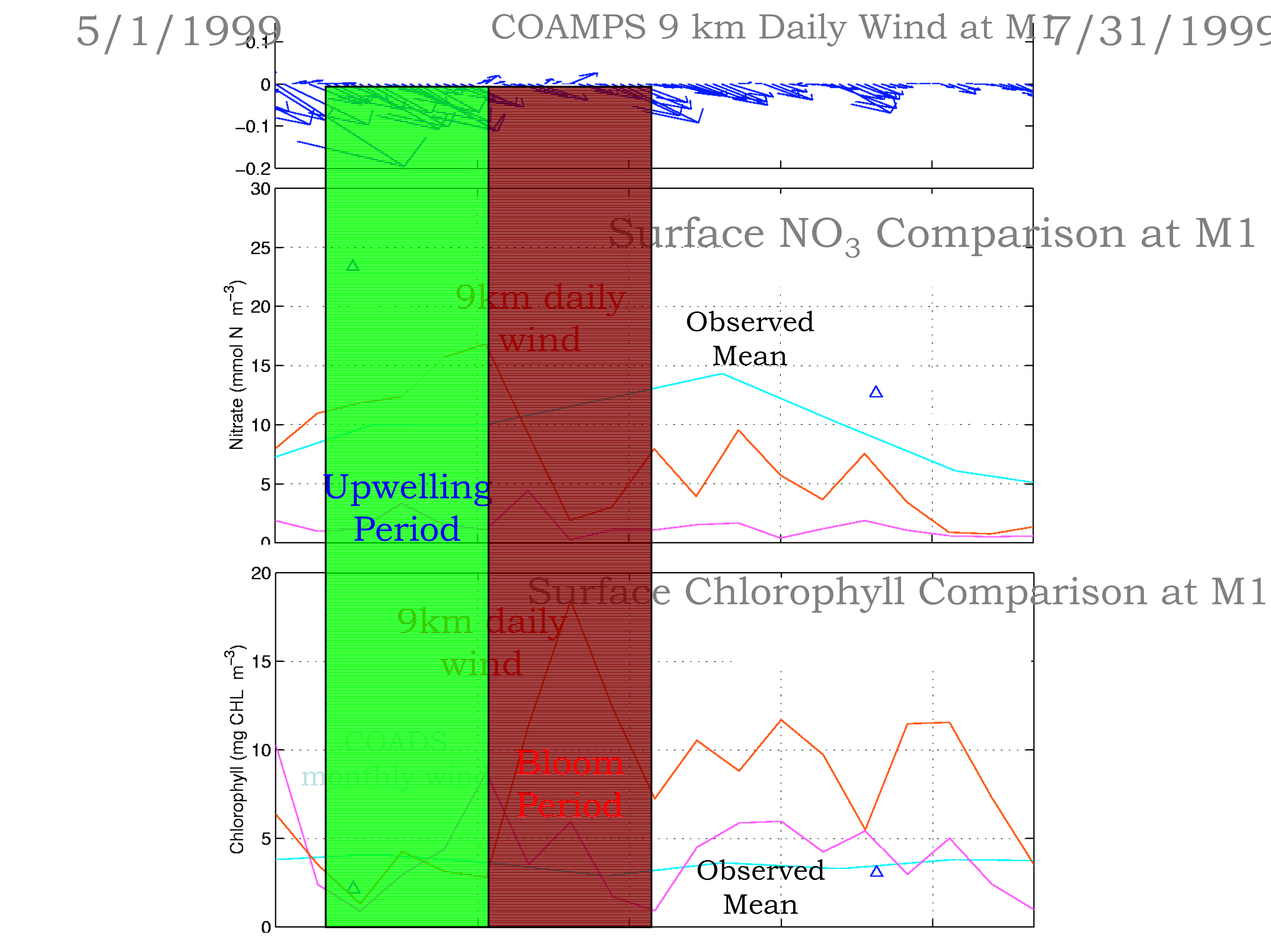
15/5/1.5-km



5/1/1999
7/31/1999
COADS 100 km Monthly Wind at M1
COAMPS 9 km Daily Wind at M1
5/8/1999
5/26/99
Surface NO_3 Comparison at M1
Nitrate (mmol N m^{-3})
Cruise Data
9km daily wind
Observed Mean
COADS monthly wind

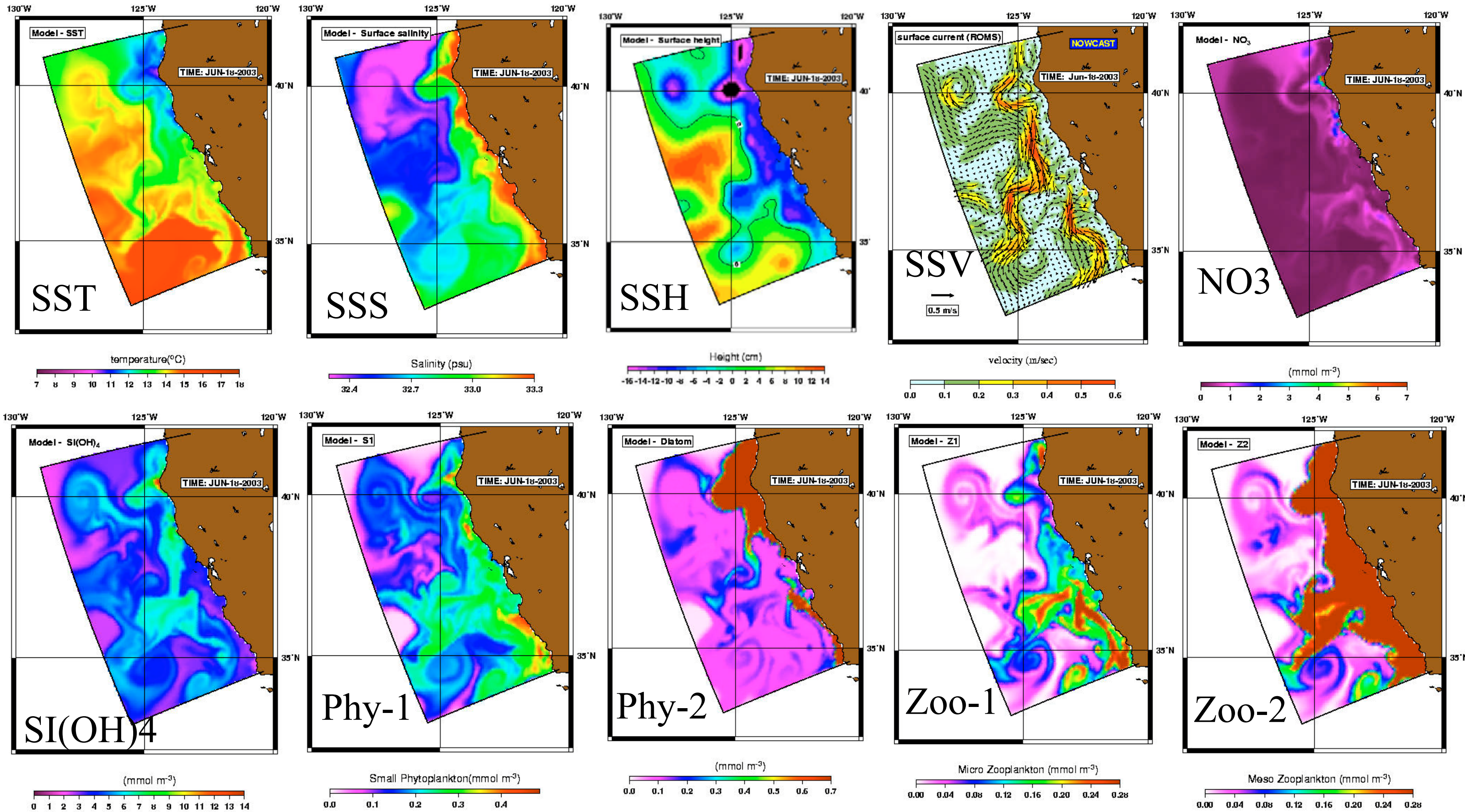


Observed Seasonal Cycle of $Si(OH)_4$
Jan.
Dec.
Depth (m)
0
−50
−100
−150
−200
$Si(OH)_4$
Data
50
40
30
20
10
0
Modeled Seasonal Cycle of $Si(OH)_4$
Modeled $Si(OH)_4$
COADS Forced



5/1/1999
COAMPS 9 km Daily Wind at M1
7/31/1999
Surface NO$_3$ Comparison at M1
Nitrate (mmol N m^{-3})
9km daily wind
Observed Mean
Upwelling Period
Surface Chlorophyll Comparison at M1
Chlorophyll (mg CHL m^{-3})
9km daily wind
COADS monthly wind
Bloom Period
Observed Mean

Real-Time Simulation of Coupled Physical-Ecosystem



(http://OurOcean.jpl.nasa.gov)

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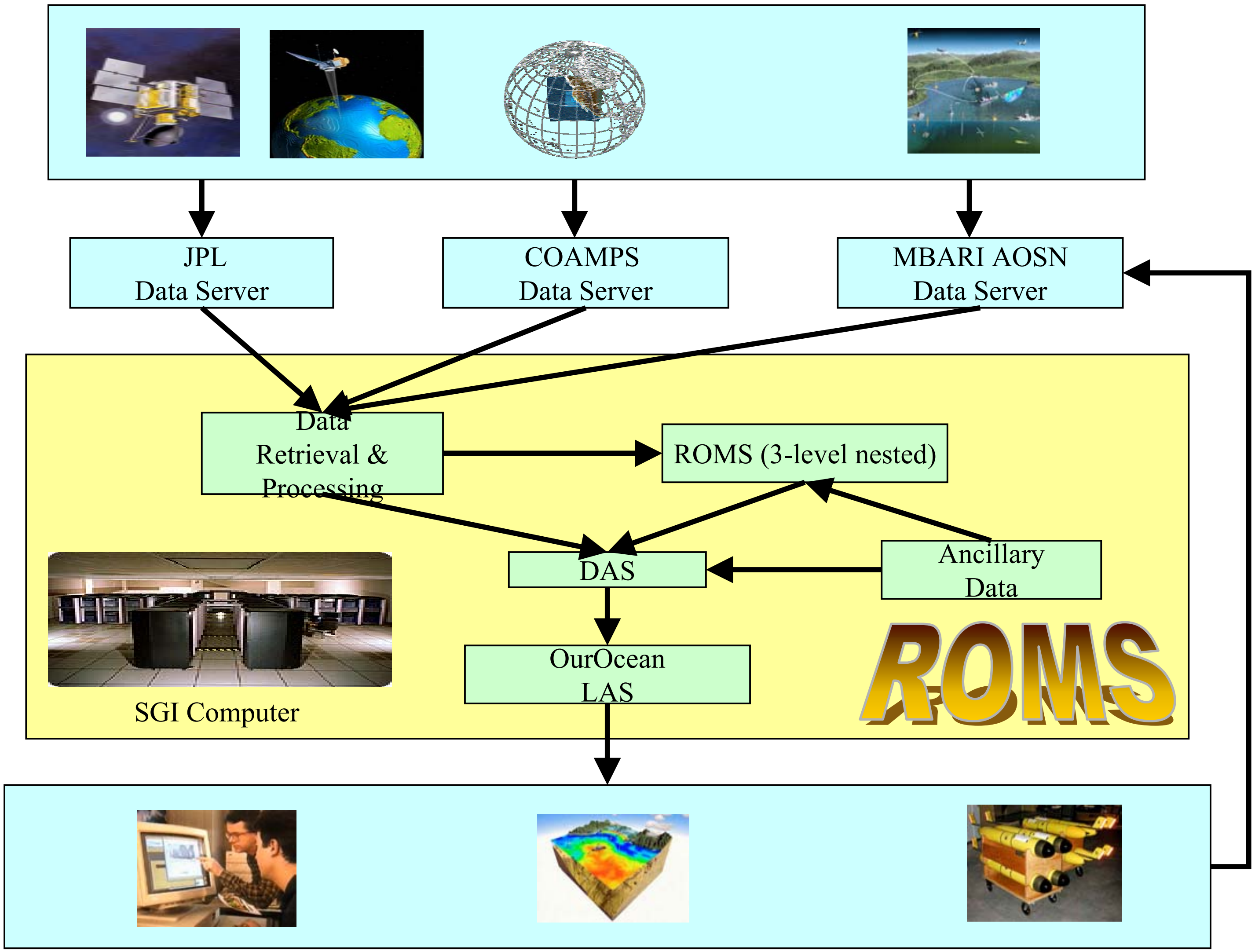
Anna Hilting and I identified milestones in our field in Barber and Hilting (2002) The history of the study of plankton productivity. In: *Phytoplankton Productivity*, P. J. leB. Williams, D. N. Thomas and C. S. Reynolds (eds.)

Gran (1912) is a major milestone laying out the ideas that were the intellectual framework for CUEA; from Gran (1912) to CUEA (1975) there is evolutionary continuity. Gran could easily work in CUEA!

Between CUEA (1975) and today there have two revolutions : observing and computational.

The Monterey Bay Forecasting System (2003) depends, in part, on a new kind of scientist or engineer (as well as individuals with Gran's almost supernatural feel for ocean ecosystems.)

Monterey Bay Forecasting System is vision of the future



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Good news: revolutionary progress and capability,
(and Bad) but only evolutionary response of our institutions

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(and Bad) but only evolutionary response of our institutions

Needed: a social revolution to exploit the technological revolution;

ie, better ways for humans to collaborate, synthesize, integrate & communicate

END

Sarmiento, J., Princeton University, Princeton, NJ, USA
Barber, R. T., Duke University, Beaufort, NC, USA,

CSIRO:
Hirst, A. C., CSIRO Atmospheric Research, Victoria, Australia
Matear, R., CSIRO Marine Research, Hobart, Australia

GFDL:
Slater, R., Princeton University, Princeton, NJ, USA
Stouffer, R., Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA

Hadley:
Spall, S., Hadley Centre for Climate Prediction and Research, Berkshire, UK

IPSL:
Bopp, L., Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France
Monfray, P., Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France
Orr, J., Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France

MPI:
Mikolajewicz, U., Max-Planck-Institut fur Meteorologie, Hamburg, Germany
Soldatov, V., St. Petersburg State University, St. Petersburg, Russia

NCAR:
Doney, S. C., Woods Hole Oceanographic Institution, Woods Hole, MA, USA
Kleypas, J., National Center for Atmospheric Research, Boulder, CO, USA

STRATEGY

Part 1

- Six GCMs with CO_2 using the consensus scenario IS92a for CO_2 increase.
- Model period roughly 1850 to 2050 with control and increased CO_2.
- Define six dynamic domains, look at eight properties in each domain.
- Analyze patterns.

Part 2

- Develop empirical model to estimate Chl from physical properties.
- Check six model estimates vs SeaWiFS observations.
- Estimate 2050 Chl.

Part 3

- Use 2050 Chl and Temp estimates to estimate 2050 Prim Prod.
- Analyze 2050 prim prod patterns.

DOMAINS

Marginal Ice Zone – Polar Zone:

area covered by seasonal sea ice

Subpolar Gyre – Seasonally Stratified:

net upwelling; cyclonic gyres

Subtropical Gyre – Seasonally Stratified:

net downwelling; anticyclonic

Subtropical Gyre – Permanently Stratified:

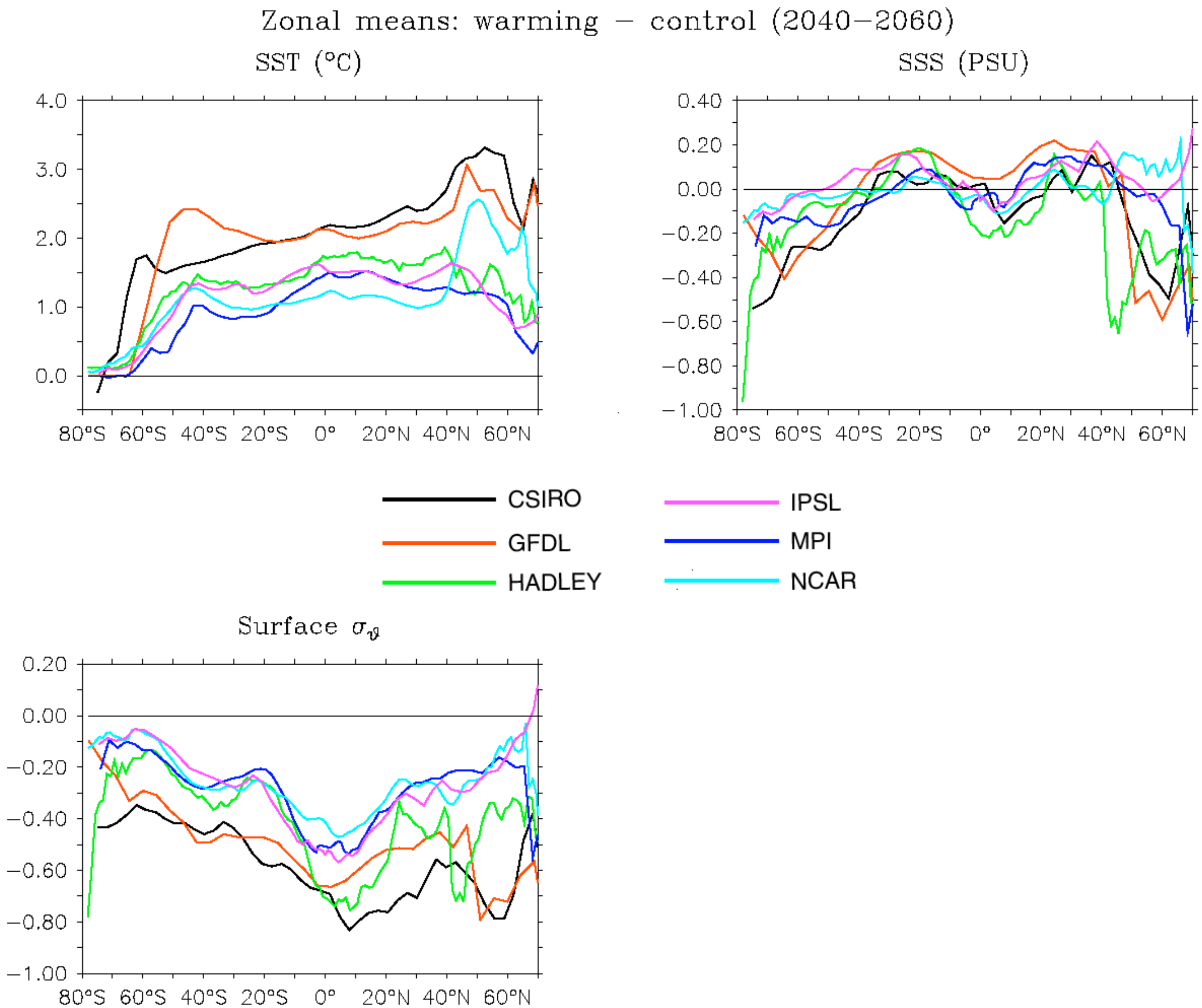
net downwelling; anticyclonic

Low Latitude Upwelling

net upwelling

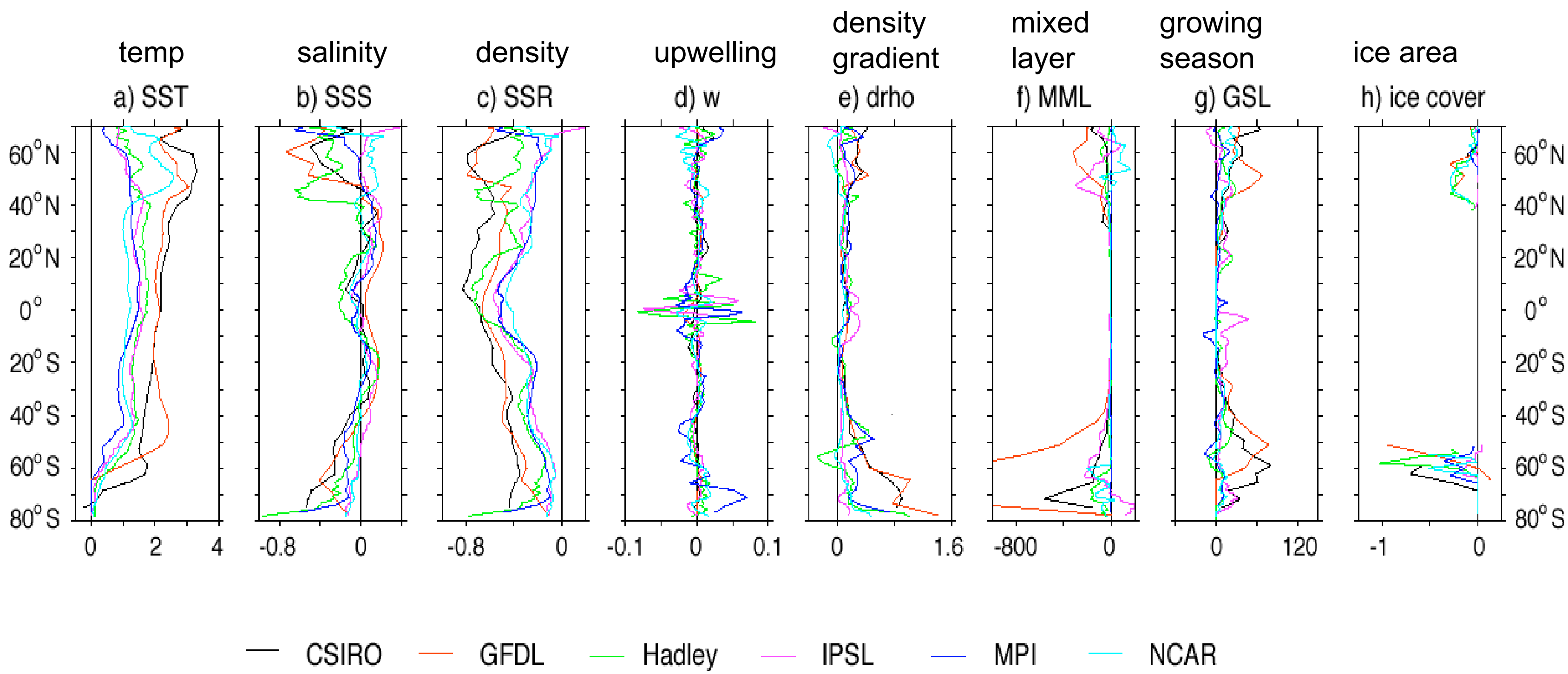
Equatorial Zone – 5°S to 5°N:

fixed boundaries; region influenced by upwelling and downwelling

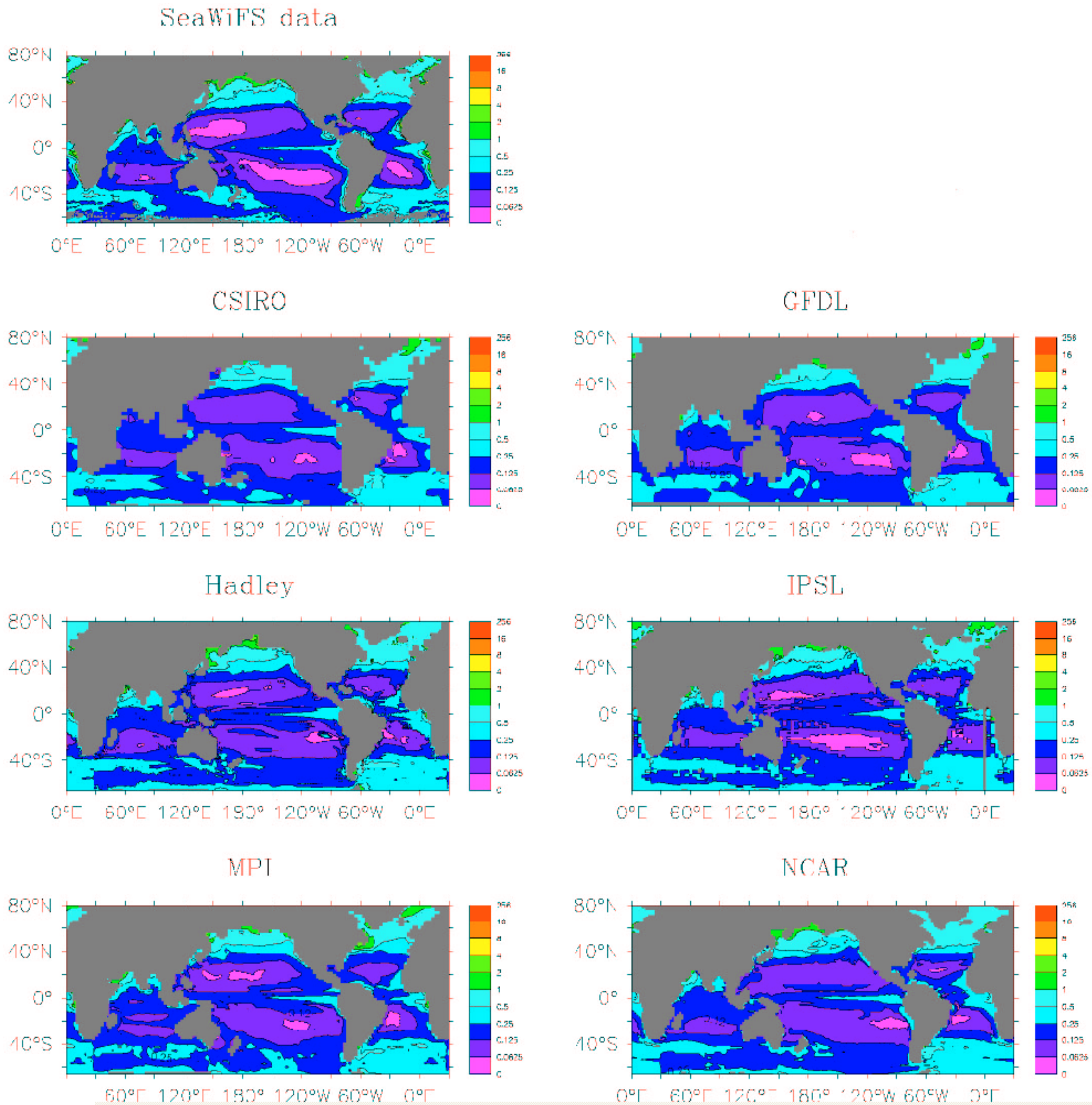


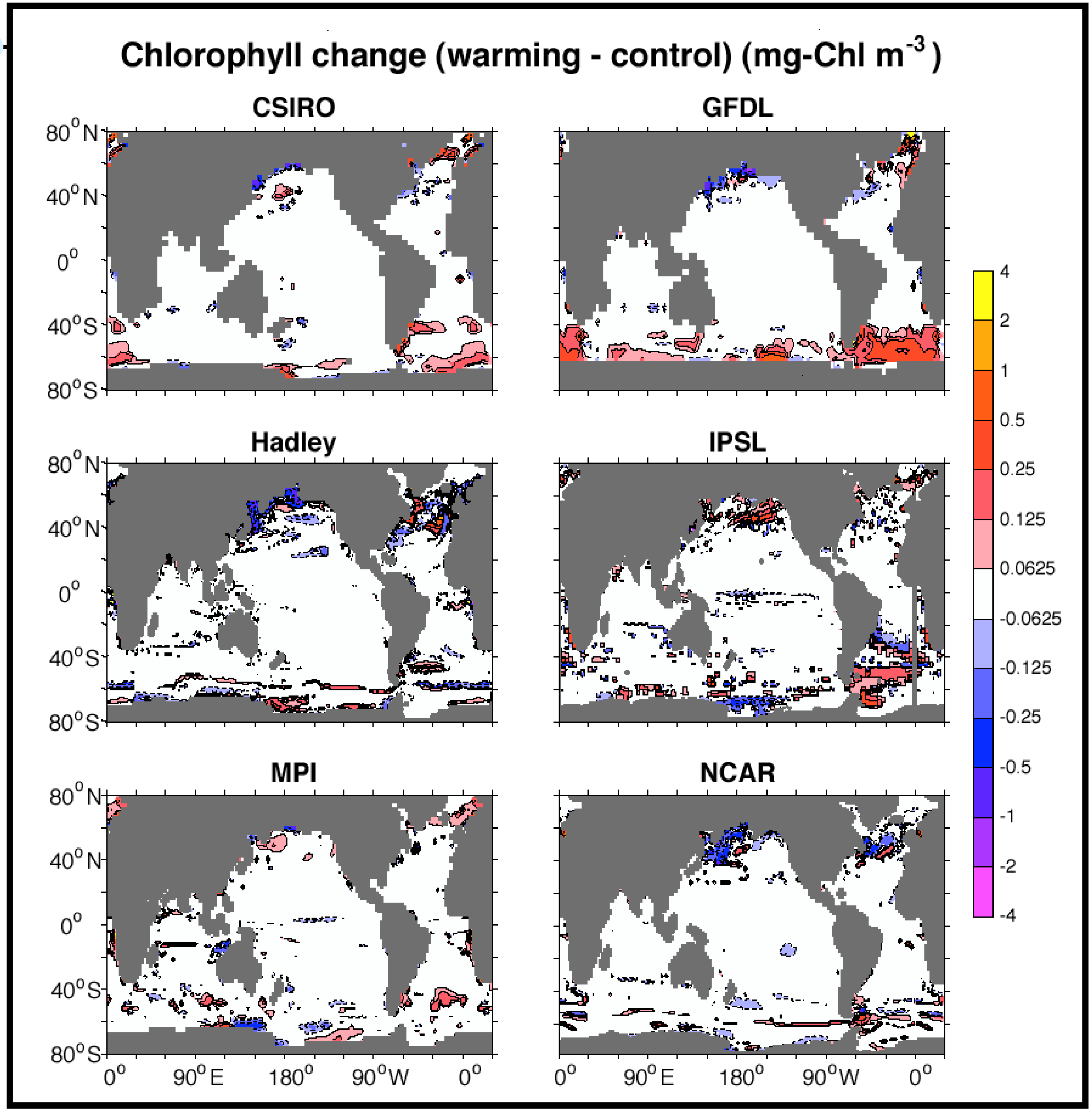
Zonal means: warming – control (2040–2060)
SST (°C)
SSS (PSU)
Surface σ_ϑ
4.0
3.0
2.0
1.0
0.0
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
80°S 60°S 40°S 20°S 0° 20°N 40°N 60°N
CSIRO
GFDL
HADLEY
IPSL
MPI
NCAR

Global zonal averages from north to south



Chlorophyll empirical fits: Split by basin, regime and hemisphere





Chlorophyll change (warming - control) (mg-Chl m-3)
CSIRO
GFDL
Hadley
IPSL
MPI
NCAR
80°N
40°N
0°
40°S
80°S
0°
90°E
180°
90°W
0°
4
2
1
0.5
0.25
0.125
0.0625
-0.0625
-0.125
-0.25
-0.5
-1
-2
-4

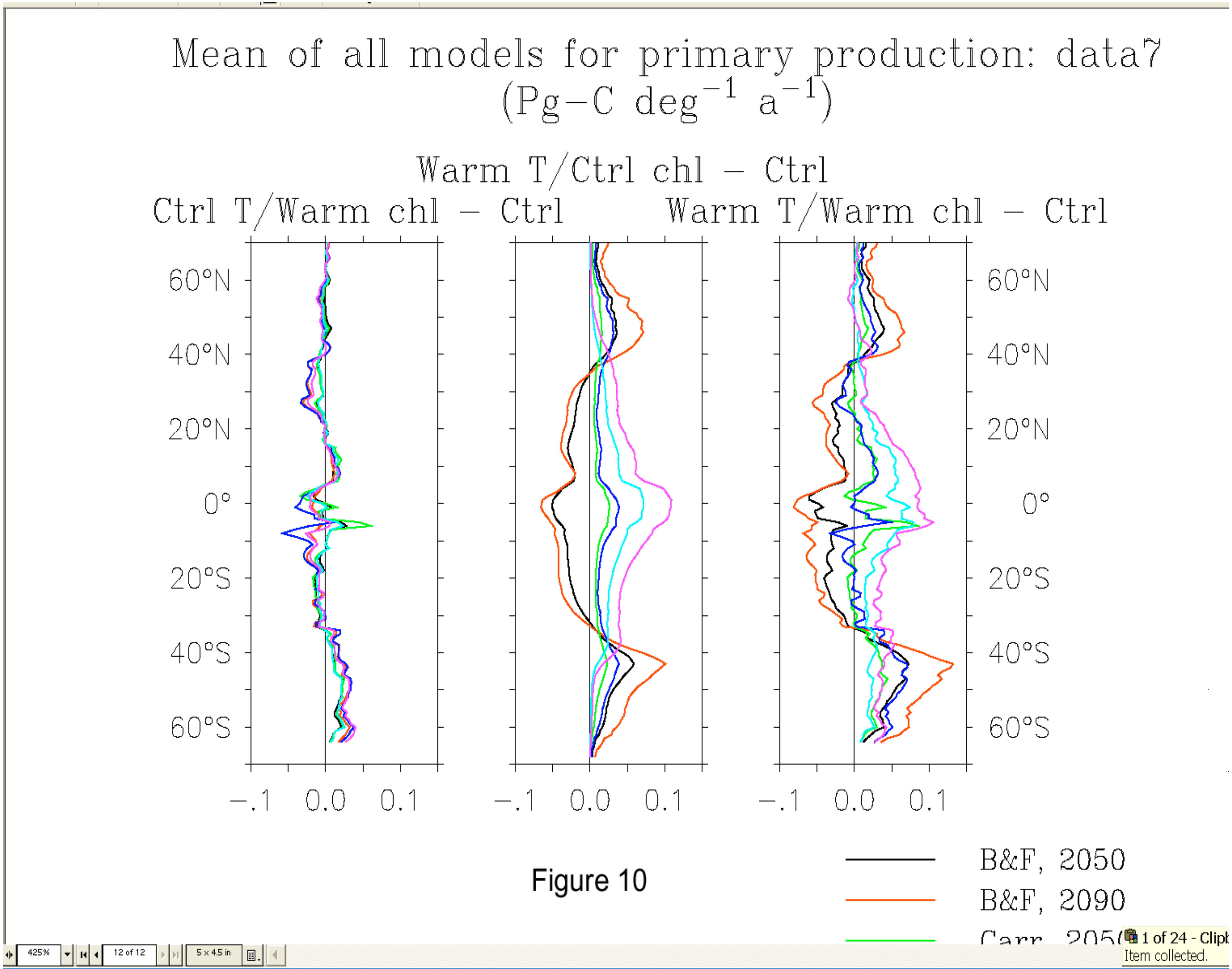

Mean of all models for primary production: data7
(Pg−C deg−1 a−1)
Warm T/Ctrl chl − Ctrl
Ctrl T/Warm chl − Ctrl
Warm T/Warm chl − Ctrl
60°N
40°N
20°N
0°
20°S
40°S
60°S
−.1
0.0
0.1
B&F, 2050
B&F, 2090
425%
12 of 12
5 x 4.5 in
1 of 24 - Clipb
Item collected.

Figure 10

Region		area % Δ (10^{12} m^2)	Chl % Δ (mg m^{-3})	PP % Δ (mg m^{-2} d^{-1})	C % Δ (Pg yr^{-1})
	Northern Hemisphere				
Marginal Sea Ice		-41.7	-1.1	13.2	-33.2
Subpolar		16.2	11.1	16.5	29.4
Subtropical Seasonal		-10.9	7	3.9	-7.4
Subtropical Permanent		4	5.5	-2.9	2.2
Low Latitude Upwelling		0.4	5	-4	-5.8
	Equatorial				
Equatorial Upwelling		3.2	-2.6	-10.5	-8.9
Equatorial Downwelling		-9.7	0.5	-5.4	-14
	Southern Hemisphere				
Low Latitude Upwelling		-2.5	5.8	-2.8	-5.4
Subtropical Permanent		9.4	0.8	-3.4	7.4
Subtropical Seasonal		10.6	3	5.7	-5.8
Subpolar		7.9	9.1	10.6	16.4
Marginal Sea Ice		-17.2	23.5	22.2	-2.7
	global mean Δ		**5.6**	**3.6**	**0.7**

< 1% change !

Ocean Ecosystems in 2050?

RESULTS

1. Relatively large (10 to 40%) changes in temperature, salinity, density and mixing.
2. Small (very small) change in upwelling.

- Biggest change was in size of domains, especially

  Marginal Sea Ice Zone at both poles.

4. 2050 Phytoplankton biomass (global mean Chlorophyll concentration in mg Chl m^{-3}) changed only 5.6%
5. 2050 Primary productivity rate (in mg C $m^{-2}d^{-1}$) changed only 3.6%
6. 2050 total global productivity (in Pg C $year^{-1}$) changed only 0.7%
7. Gains and losses in various domains in biomass and primary productivity were offsetting.

CONCLUSION

This model experiment suggests:

1. Global warming of the ocean by 2050 will cause little net change in the total global oceanic productivity.

- There will be changes in the character of oceanic domains, with shrinkage of the *Marginal Sea Ice* and *Subpolar Gyres* and expansion of the *Subtropical Gyre*.

- There will be changes in the productivity of specific oceanic domains, with increases in the *Marginal Sea Ice* and *Subpolar Gyre* and decreases in the *Subtropical Gyre* .