Decadal aspects of variability in the California Current: Dynamics and ecosystem implications

Emanuele Di Lorenzo

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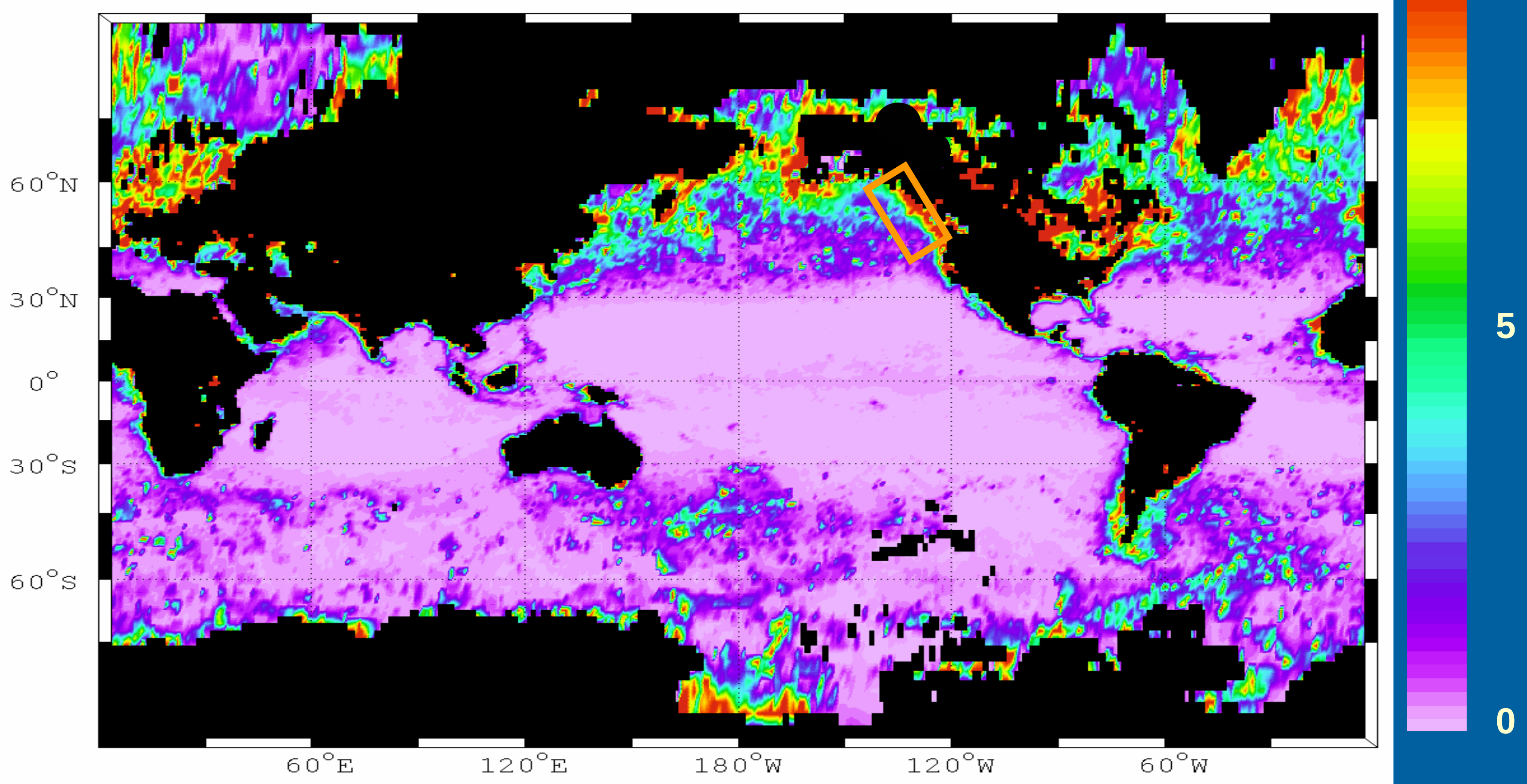
Scripps Institution of Oceanography, UCSD
Trieste, ICTP, April 30th 2004

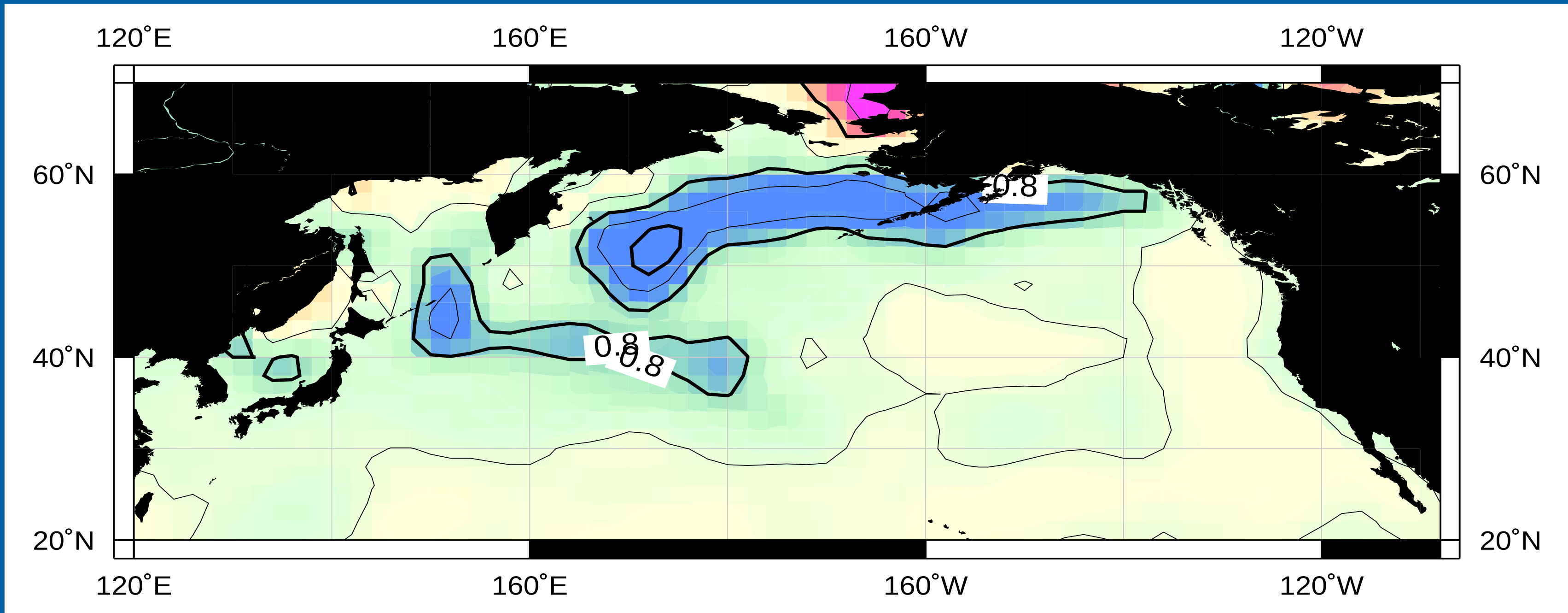
Satellite Maximum Chlorophyll-a

Units mg chla/m^3



source: Coastal Zone Color Scanner

Effects of anthropogenic forcing on biological activity



Biological Model Phytoplankton [mmol C/m³]

Ratio, Year 2100 / Year 2000

Pierce, Climate Change, 2003, submitted

Observational Dataset

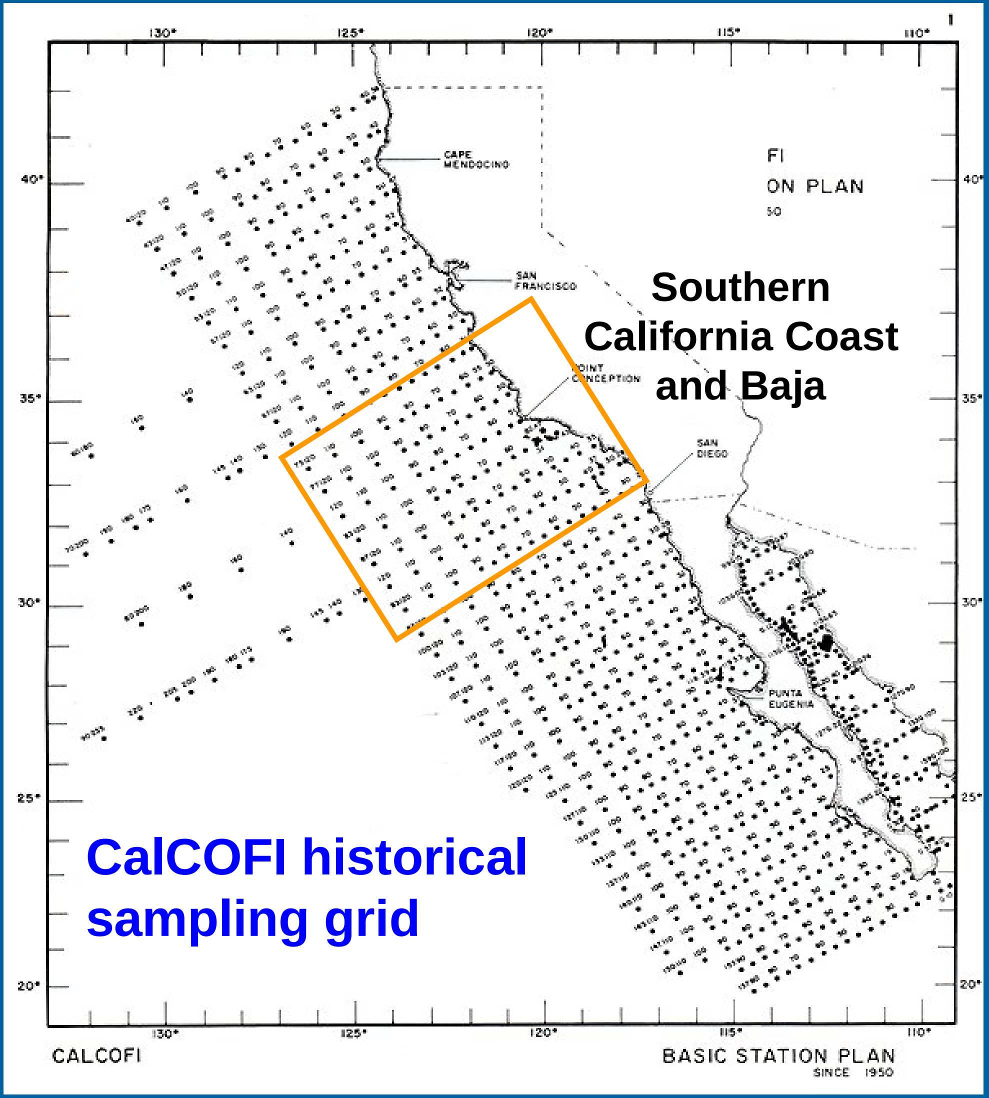
California Cooperative Oceanic Fisheries Investigation Hydrography

Temperature, Salinity and Zooplankton

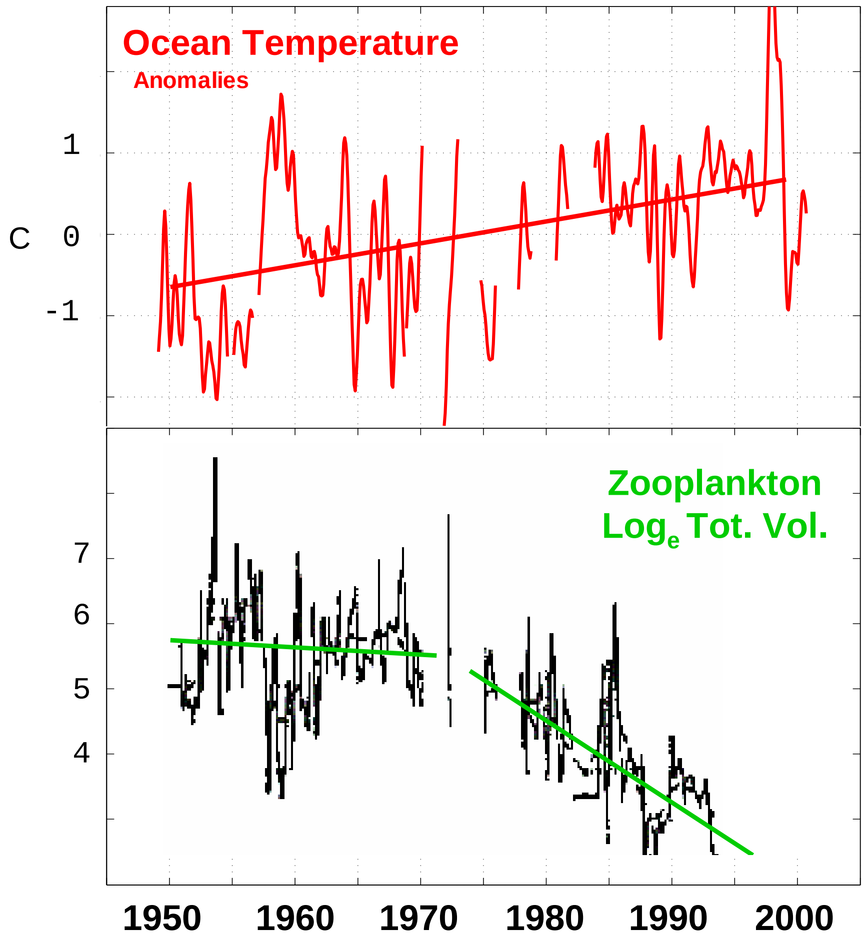
1949 – 2003 seasonal data

20 m vertical resolution, from 0– 500 m

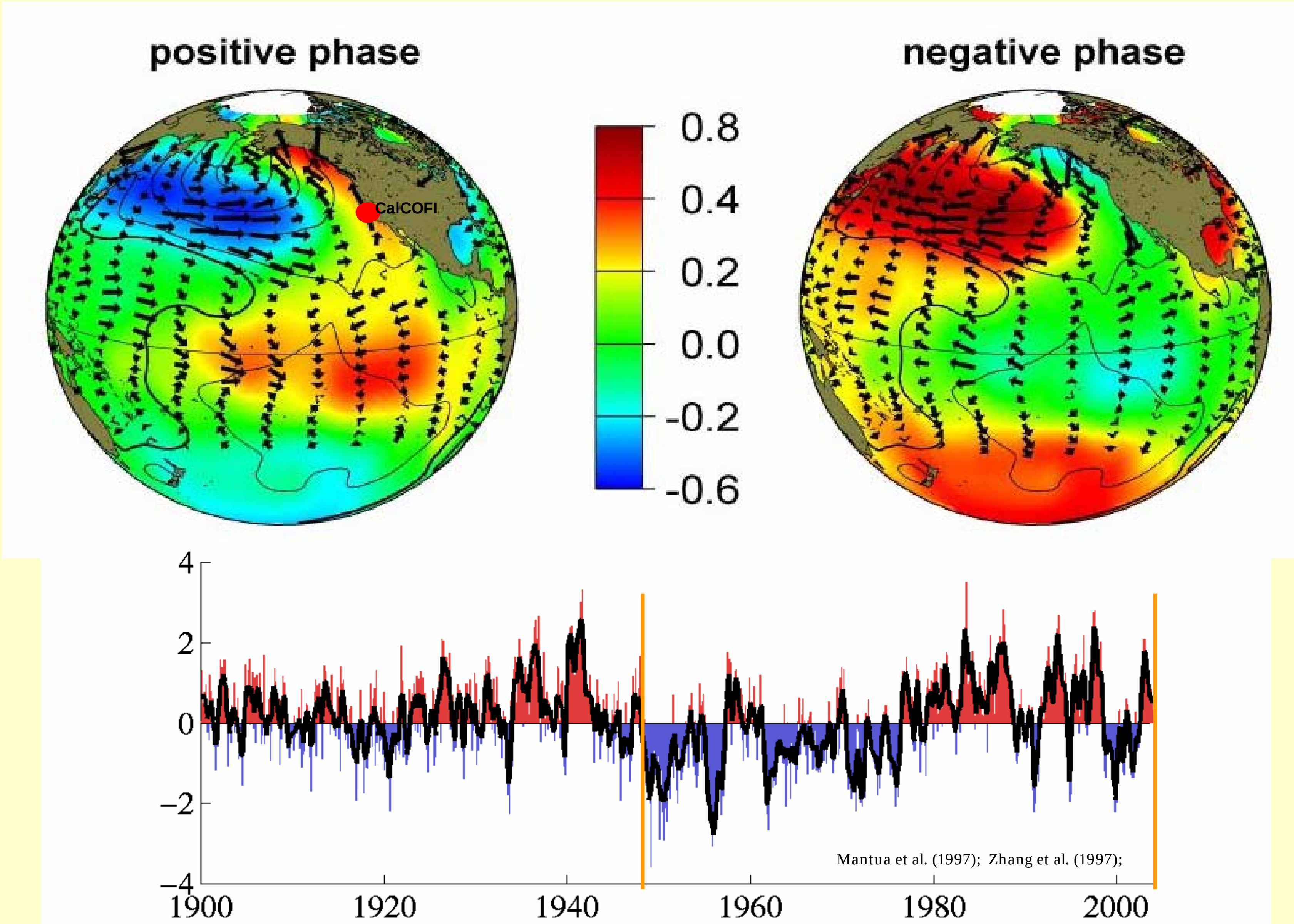
70 - 80 km horizontal grid



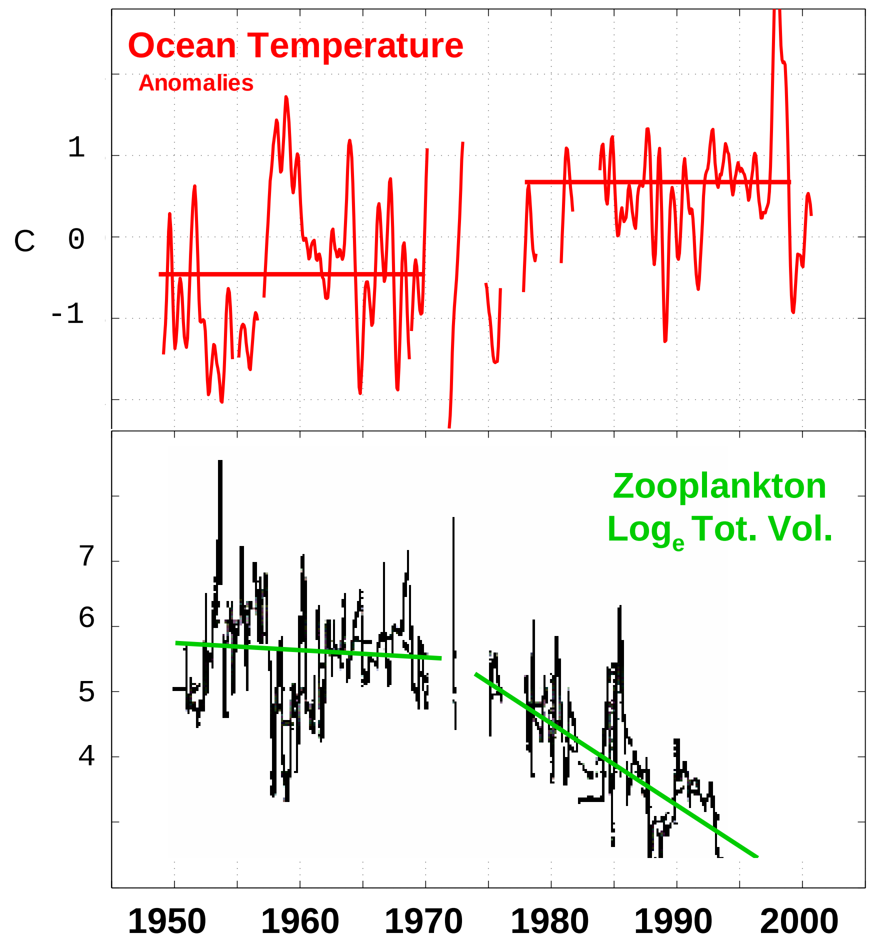
Observations along the Southern California Coast



Large scale Pacific Decadal mode of Variability (also known as PDO, NPO, PDV, ...)

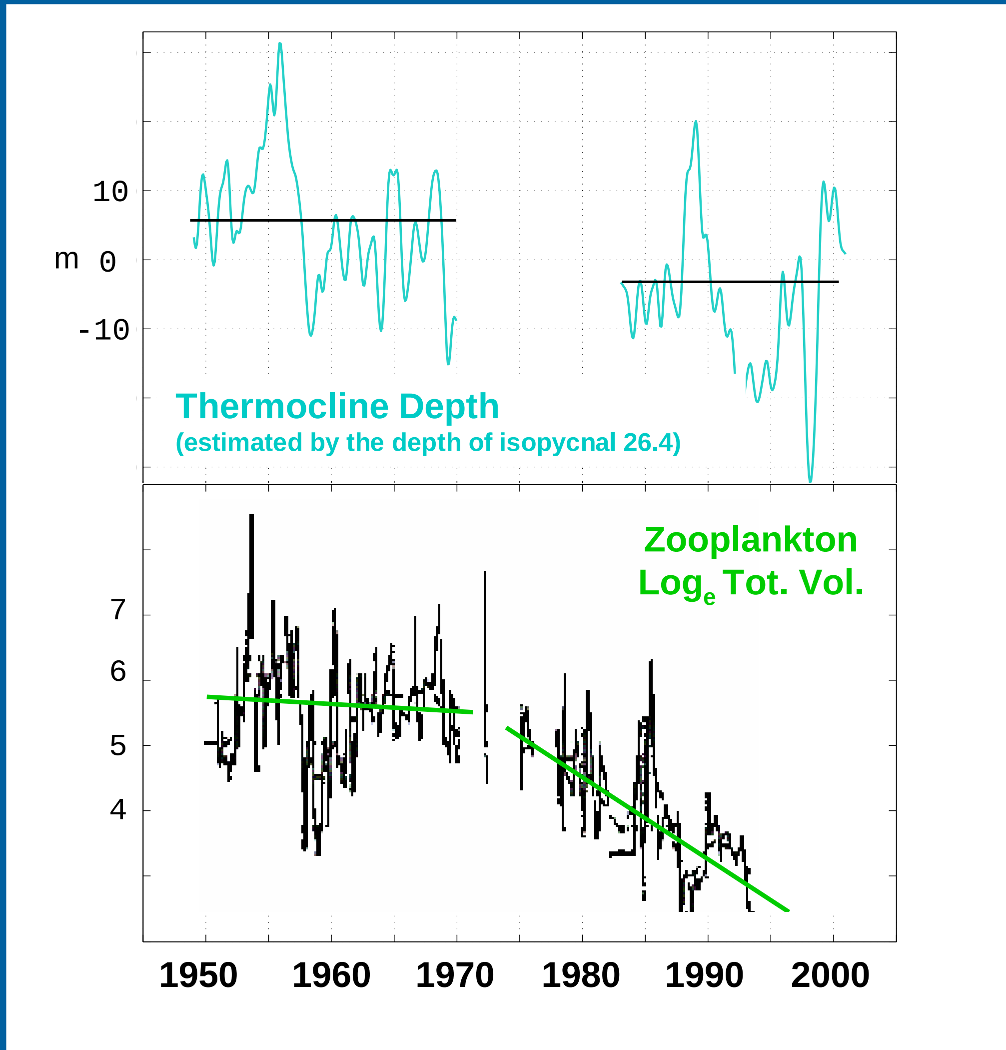


Impacts on the Ecosystem



1 C warming
over the last
from 1950 -1998

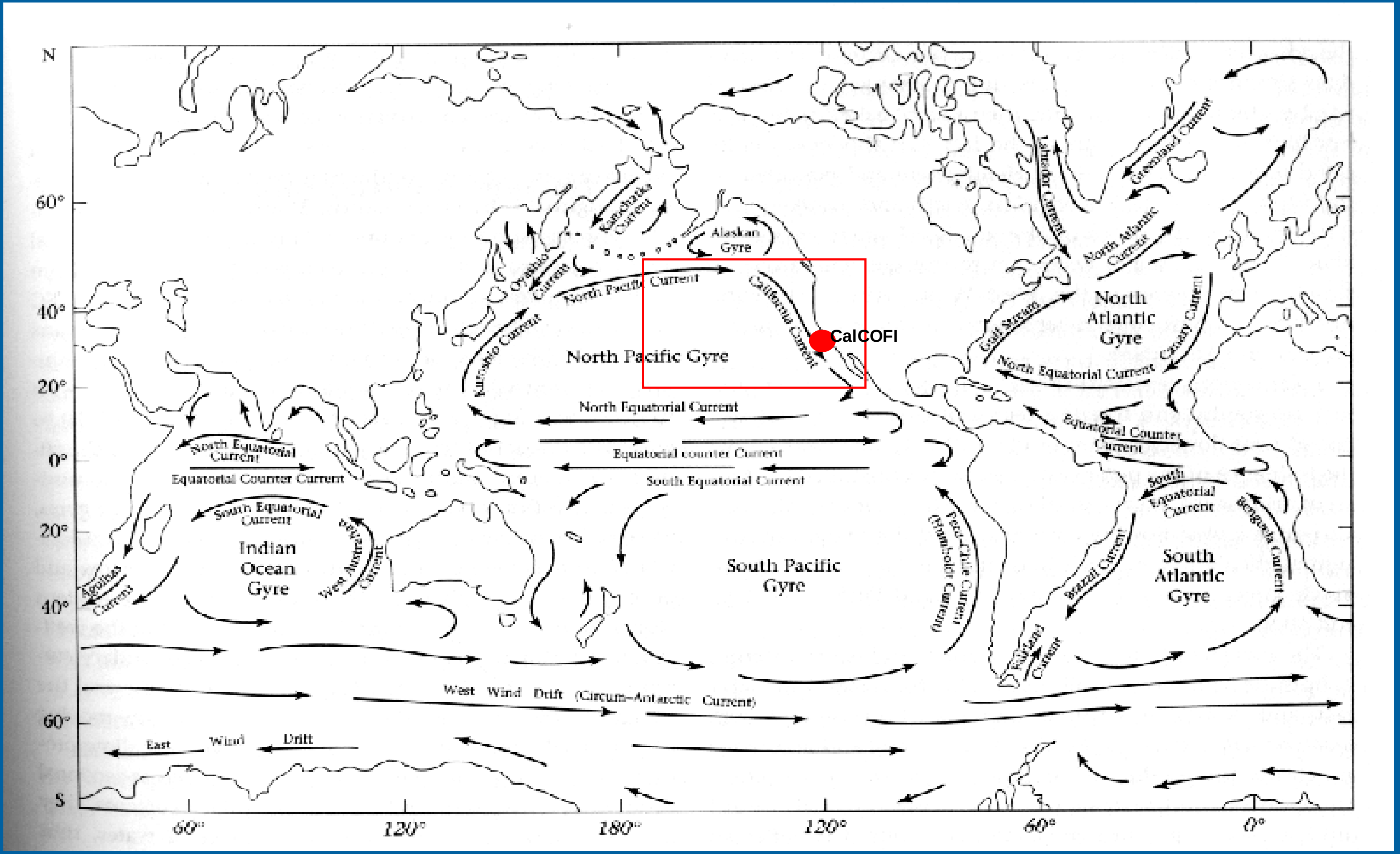
Impacts on the Ecosystem

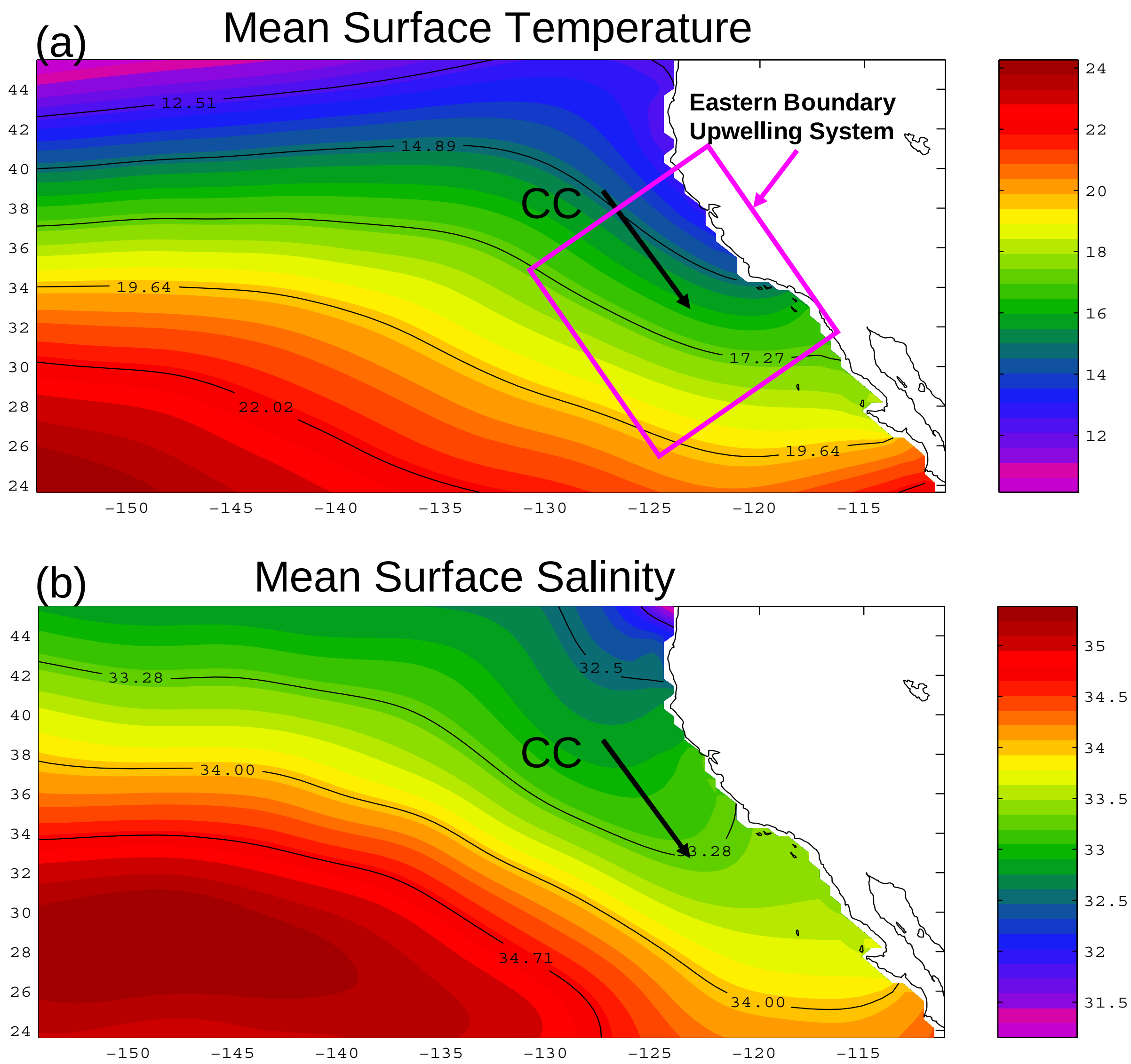


20 m deepening of the isopycnals

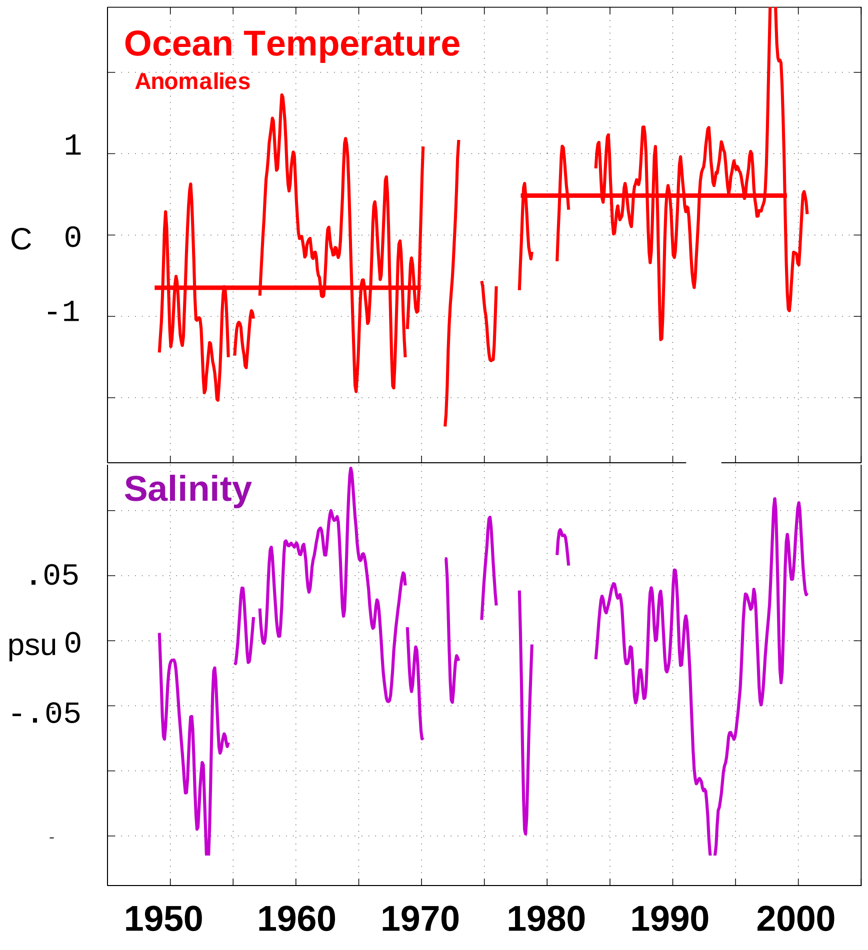
over the last from 1950 -1998

Diagram of Mean Current

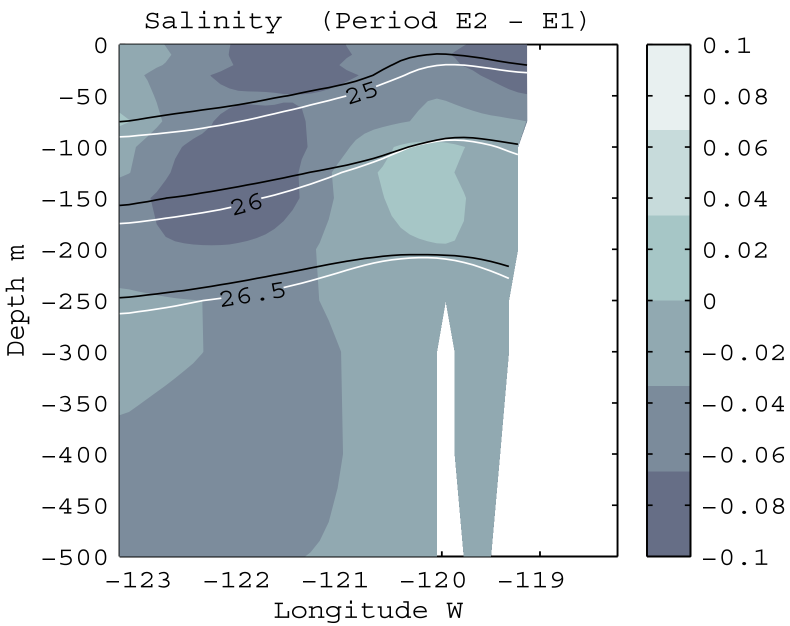



(a)
Mean Surface Temperature
Eastern Boundary
Upwelling System
CC
12.51
14.89
19.64
17.27
22.02
19.64
(b)
Mean Surface Salinity
CC
33.28
32.5
34.00
33.28
34.71
34.00

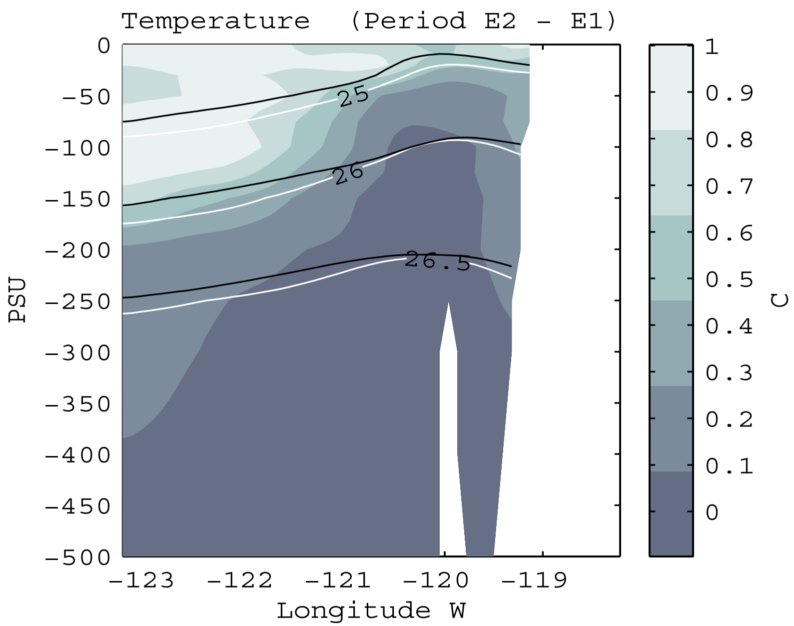
Temperature and Salinity
are NOT correlated on decadal timescales



Salinity



Temperature



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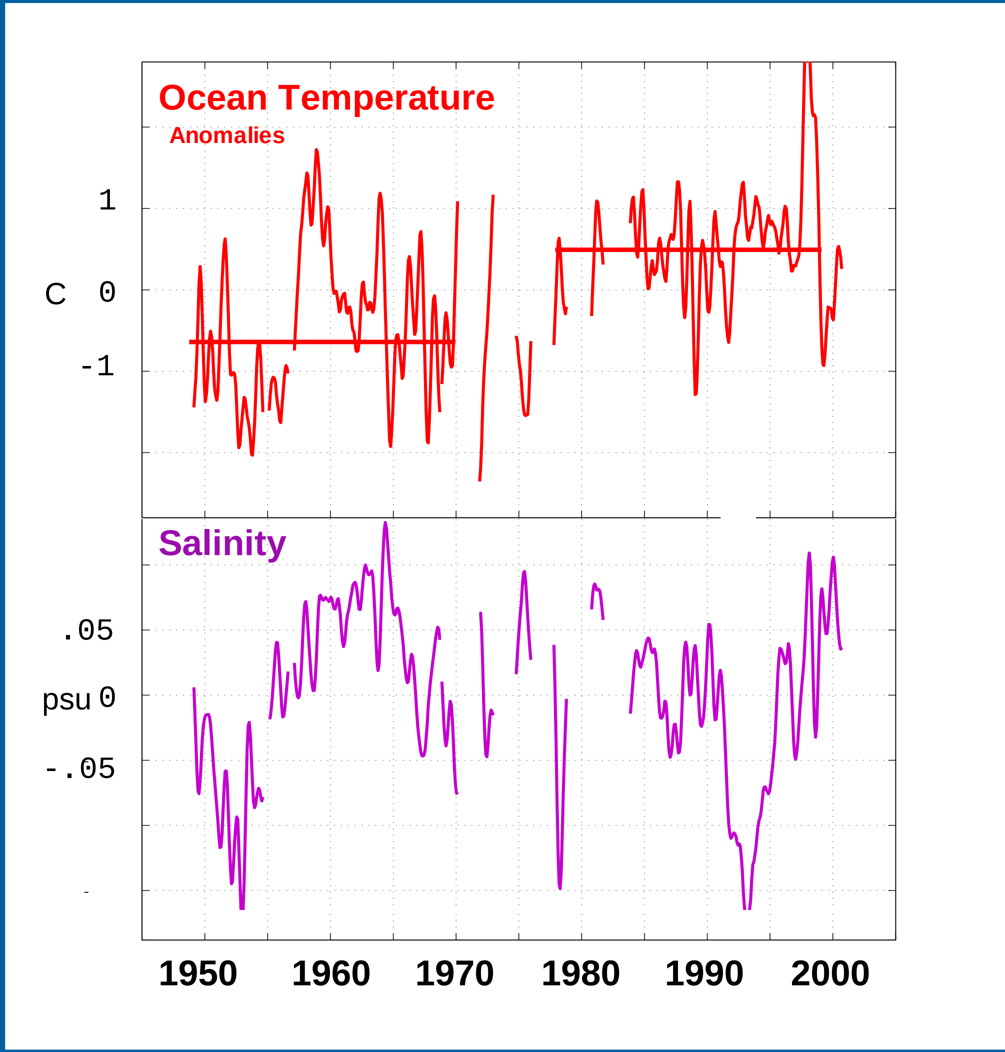
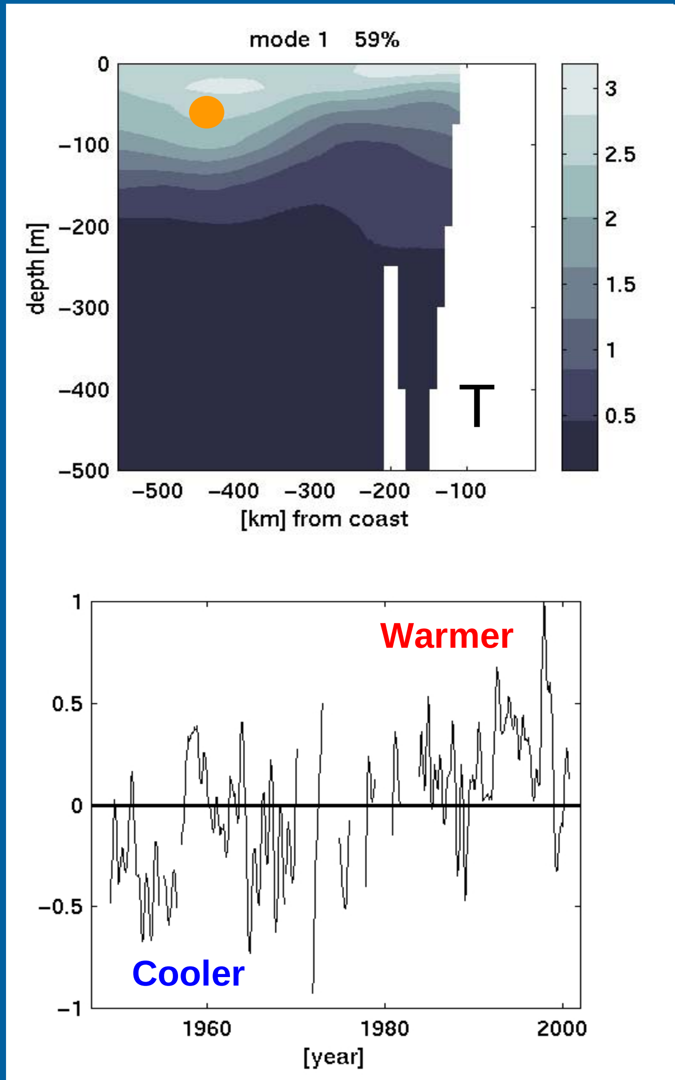
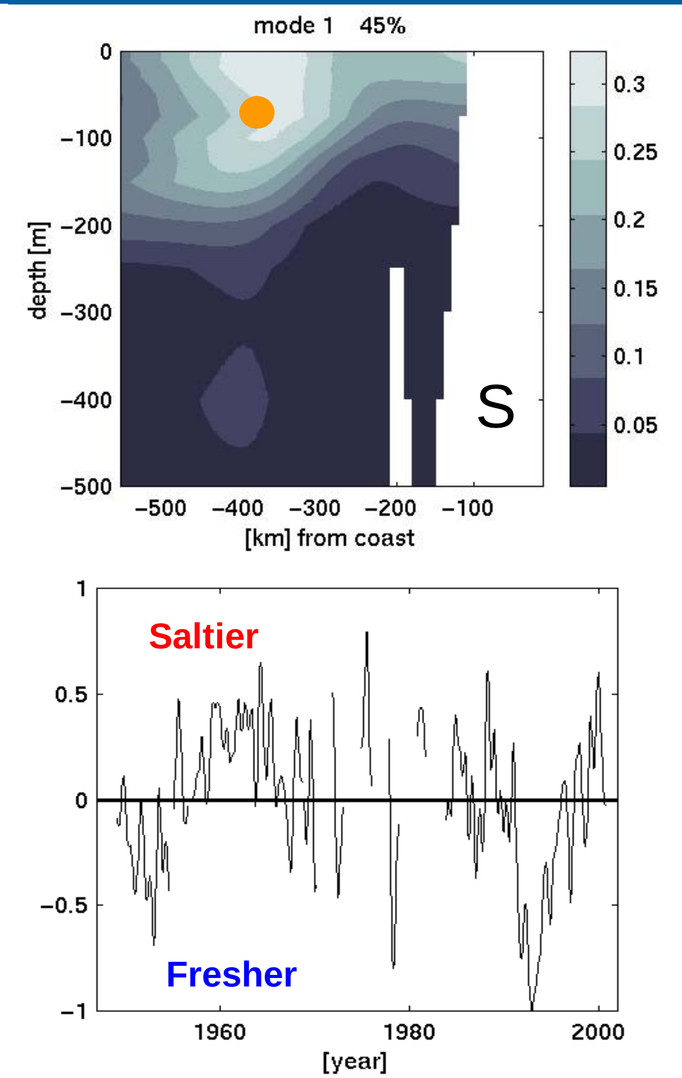


Temperature



Salinity



Fundamental questions

Basic observations 1950-2000:

1 – observed warming trend of 1.0 degree C
2 – decline in zooplankton
3 – enhanced low frequency salinity variations

What are the physics that control the observed temperature and salinity changes?

Are these temperature changes linked to global warming?

Can we identify mechanisms by which these physical changes impact the ecosystem?

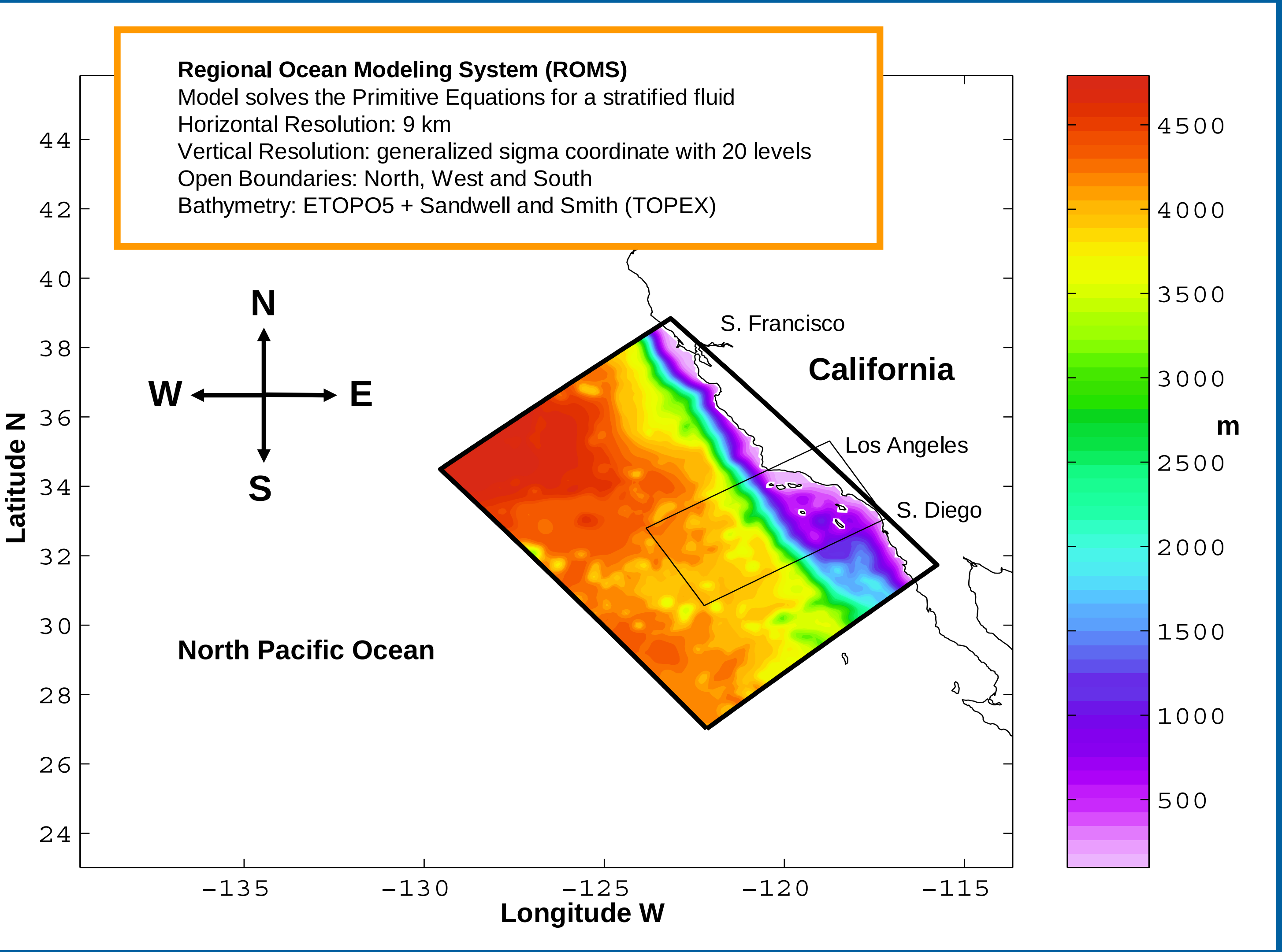
Strategy of Investigation

Interpret the **coastal observation** with the aid of:

1) Simple **dynamical considerations** based on analysis of the hydrographic dataset.

2) a **numerical ocean model**, which can resolve the relevant physical processes of this coastal environment.

The Ocean Model

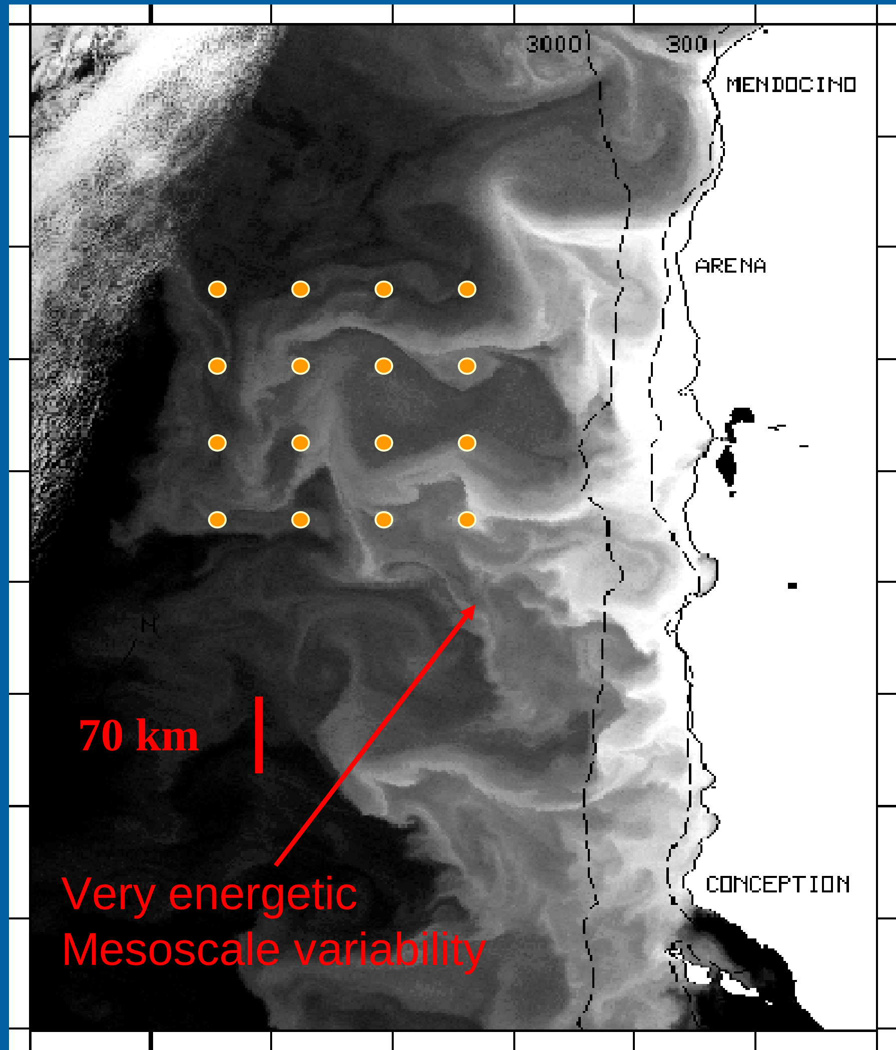


Di Lorenzo (2003)

Limitations of the Observational Dataset

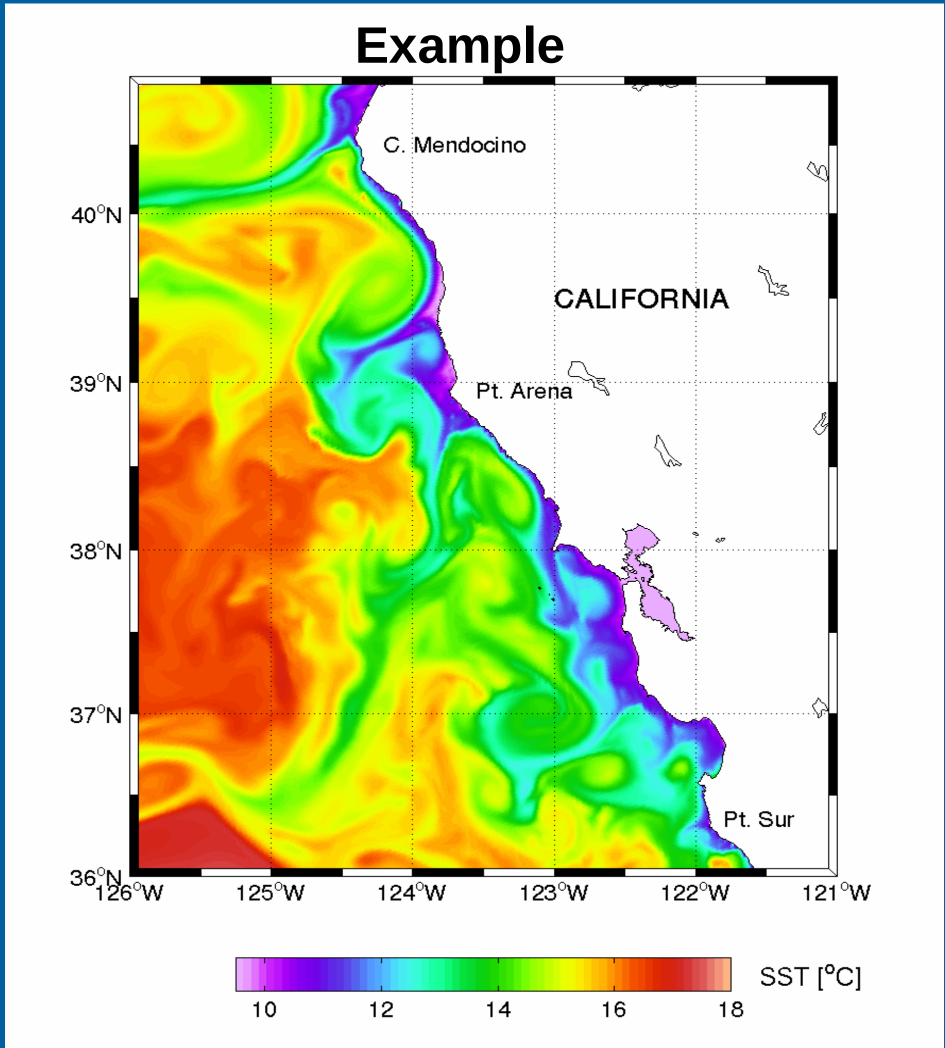
Spatial and Temporal sampling aliasing

Satellite SST

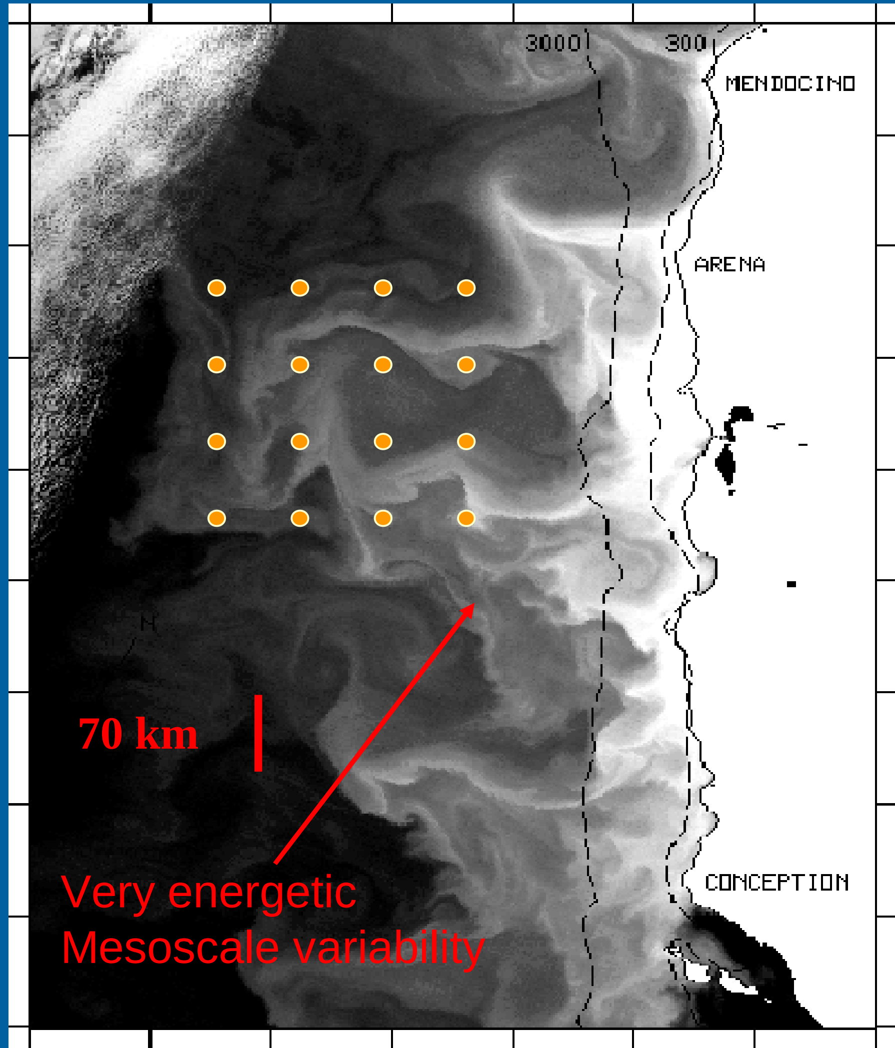


The Ocean Model

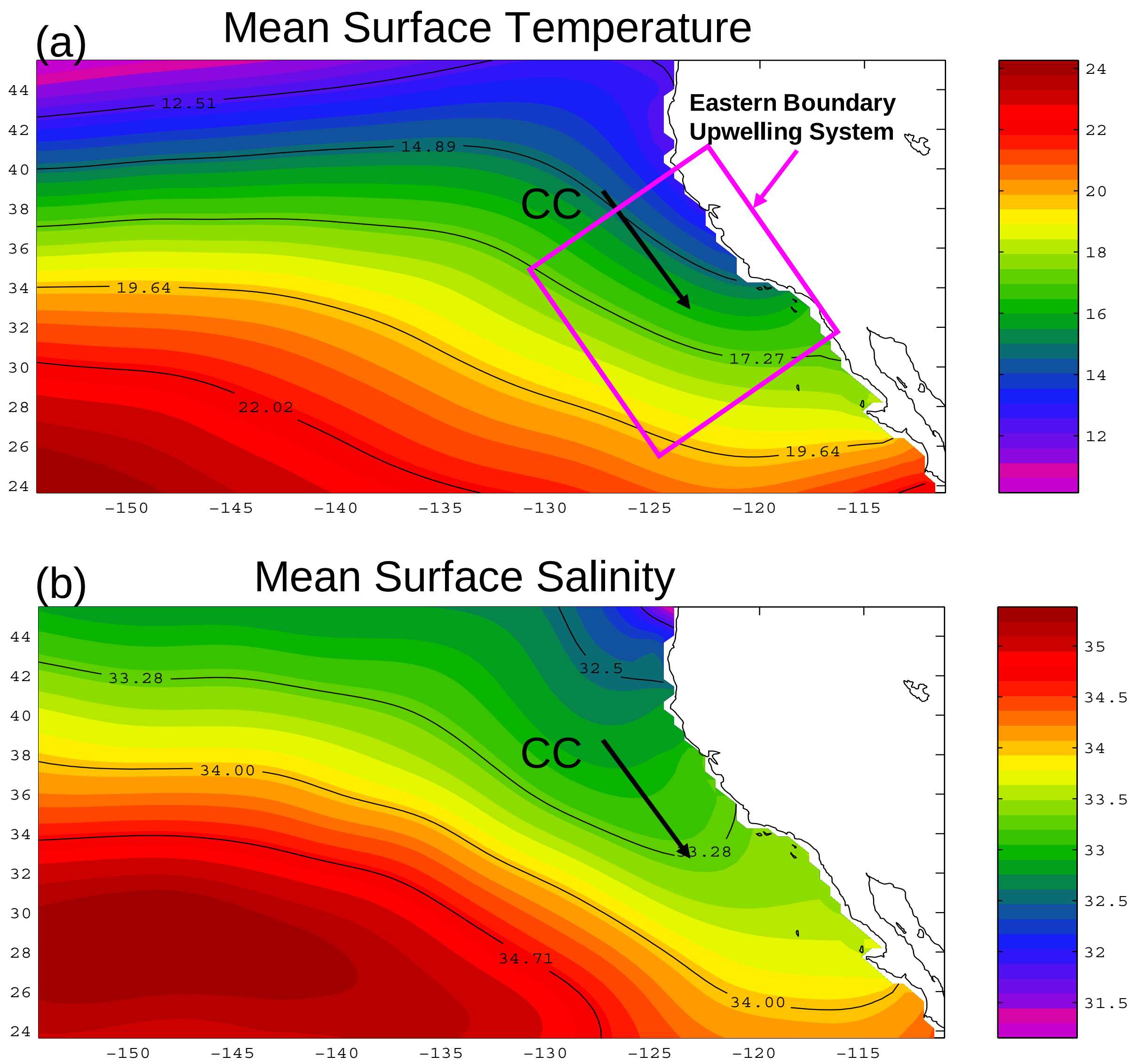
Ocean Model SST



Satellite SST



Processes that control Temperature changes


(a)
Mean Surface Temperature
Eastern Boundary Upwelling System
CC
12.51
14.89
19.64
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22.02
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(b)
Mean Surface Salinity
CC
33.28
32.5
34.00
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34.71
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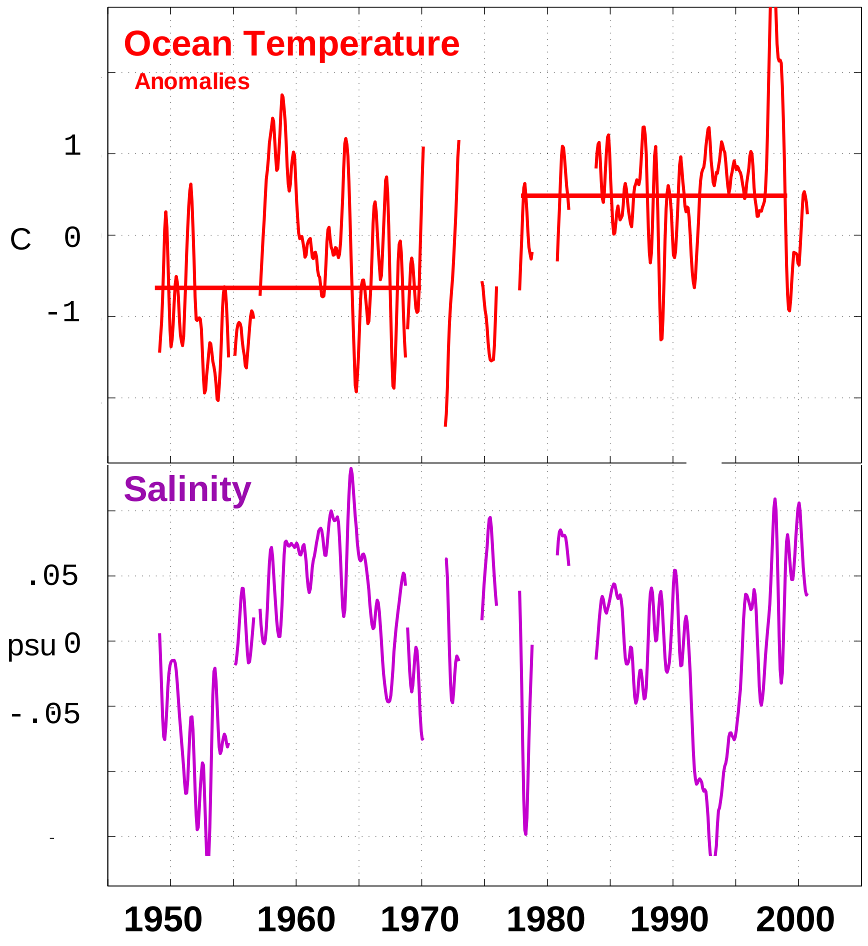
Processes that control Temperature changes

$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Anomalous Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

Temperature and Salinity are NOT correlated on decadal timescales

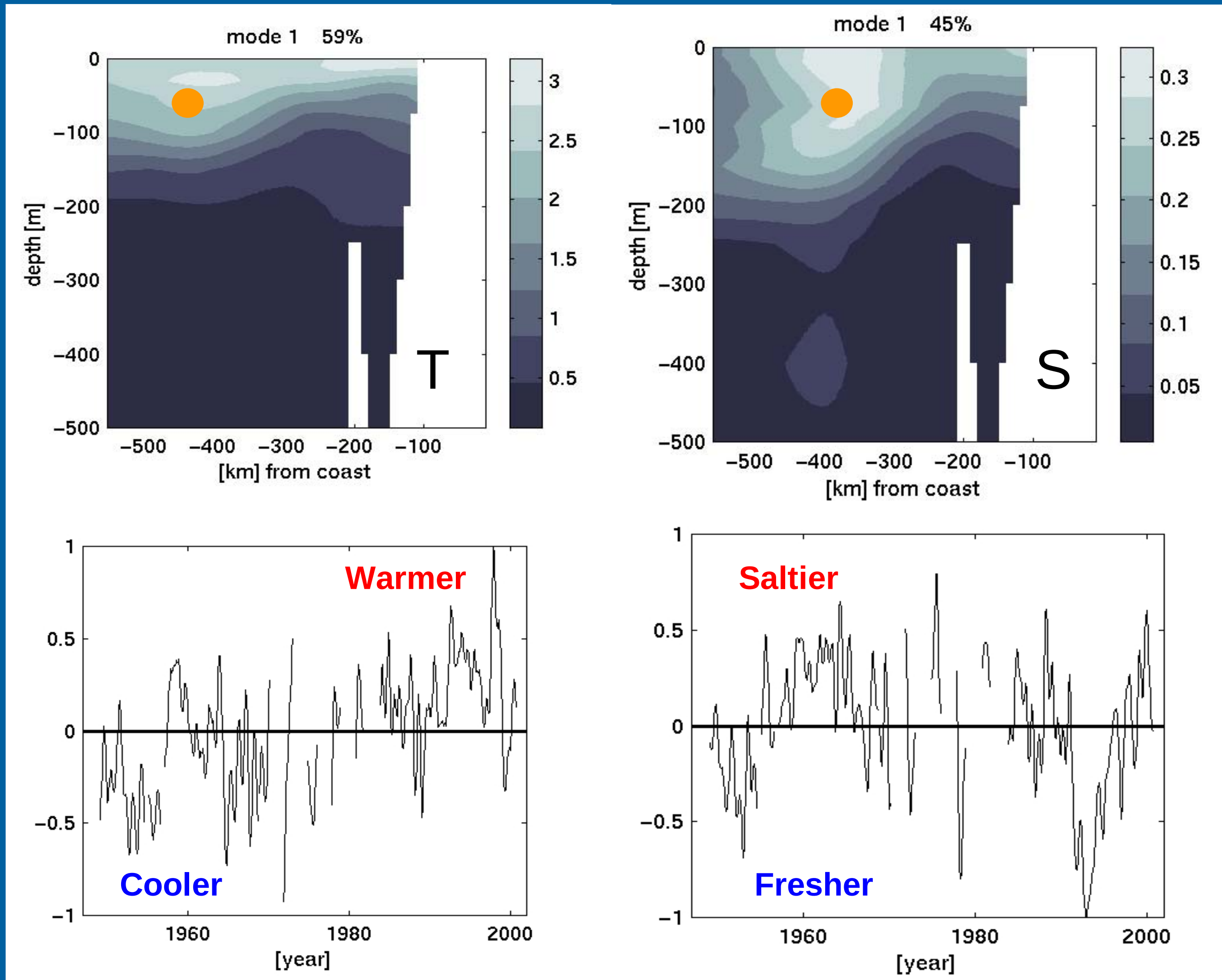


Differences in the dynamics between Temperature and Salinity

$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Anomalous Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

$$\frac{\partial S}{\partial t} = \text{Mean Advection} + \text{Anomalous Advection} + \text{E-P Fluxes} + \text{Upwelling}$$

Temperature **Salinity**



Differences in the dynamics between Temperature and Salinity

$$\frac{\partial T'}{\partial t} = \text{Mean Advection} + \text{Anomalous Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

$$\frac{\partial S'}{\partial t} = \text{Mean Advection} + \text{Anomalous Advection} + \text{E-P Fluxes} + \text{Upwelling}$$

$$\frac{\partial S'}{\partial t} \approx -\underset{\rightarrow}{u}'_H \cdot \nabla_H \bar{S} + \kappa S'$$

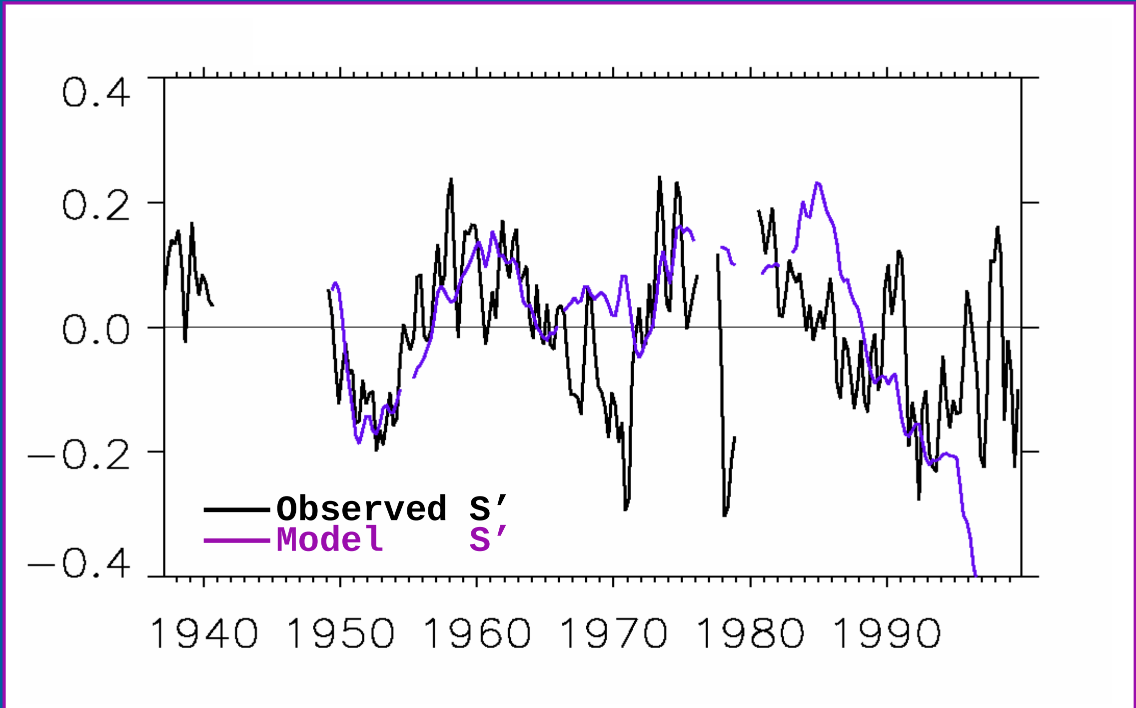
Model to explain Salinity decadal changes

If $$\frac{\partial S'}{\partial t} \approx -\underset{\rightarrow}{u}'_H \cdot \nabla_H \bar{S} + \kappa S'$$

then $$\hat{S}(\omega)^2 \approx \frac{\hat{u}(\omega)^2}{\omega^2 + \kappa^2}$$

Anomalous Advection Model for Salinity

psu



Schneider, N., E. Di Lorenzo, and P. Niiler, 2004,
Salinity variations in the California Current, J. Phys. Oceanogr.,
in revision.

Processes that control Temperature changes

$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Anomalous Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

Processes that control Temperature changes

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Processes that control Temperature changes

$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

Ocean Model Experiments

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X

EXP 1

Upwelling

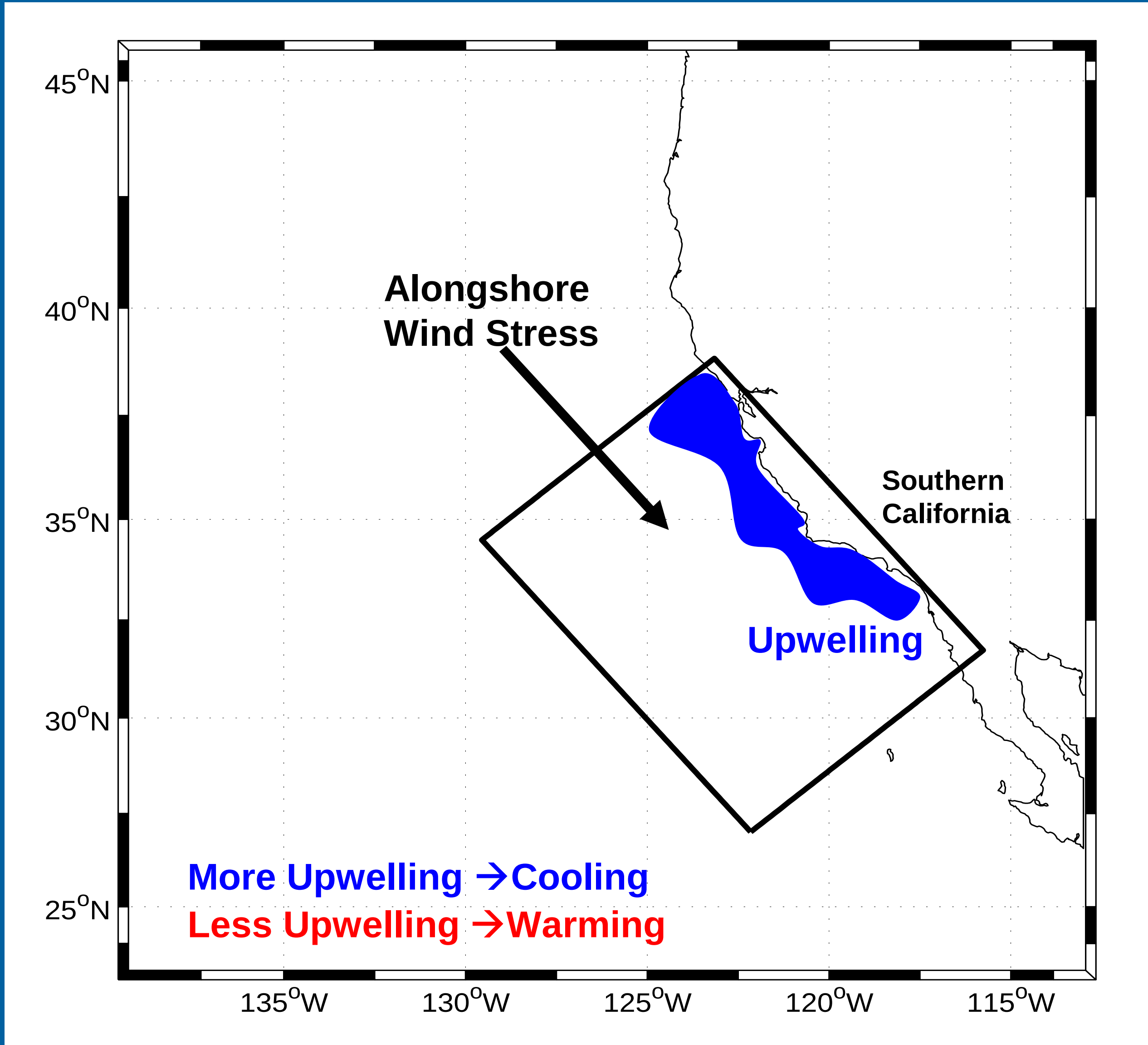
$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

Ocean Model Experiments

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			**X**
Exp 2		X	X
Exp 3	X	X	X

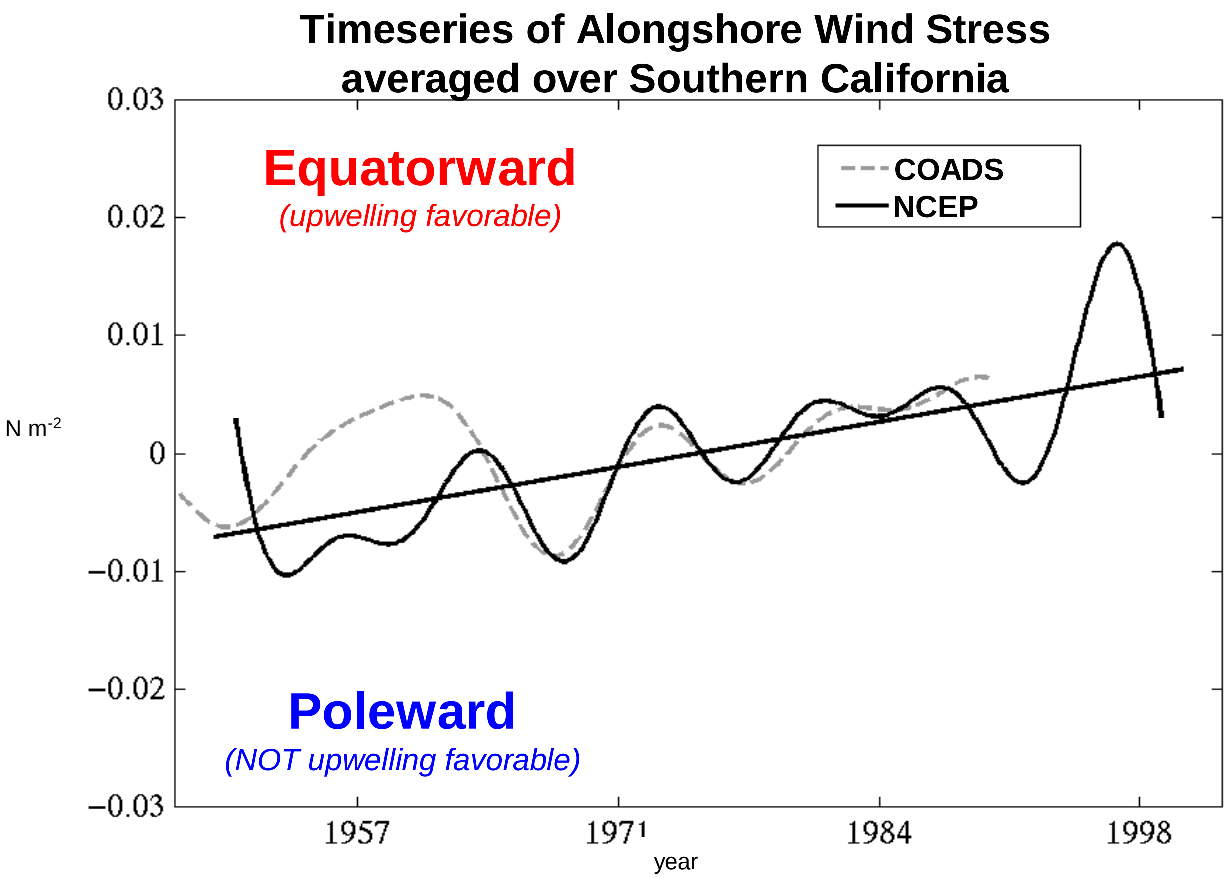
Upwelling

EXP 1

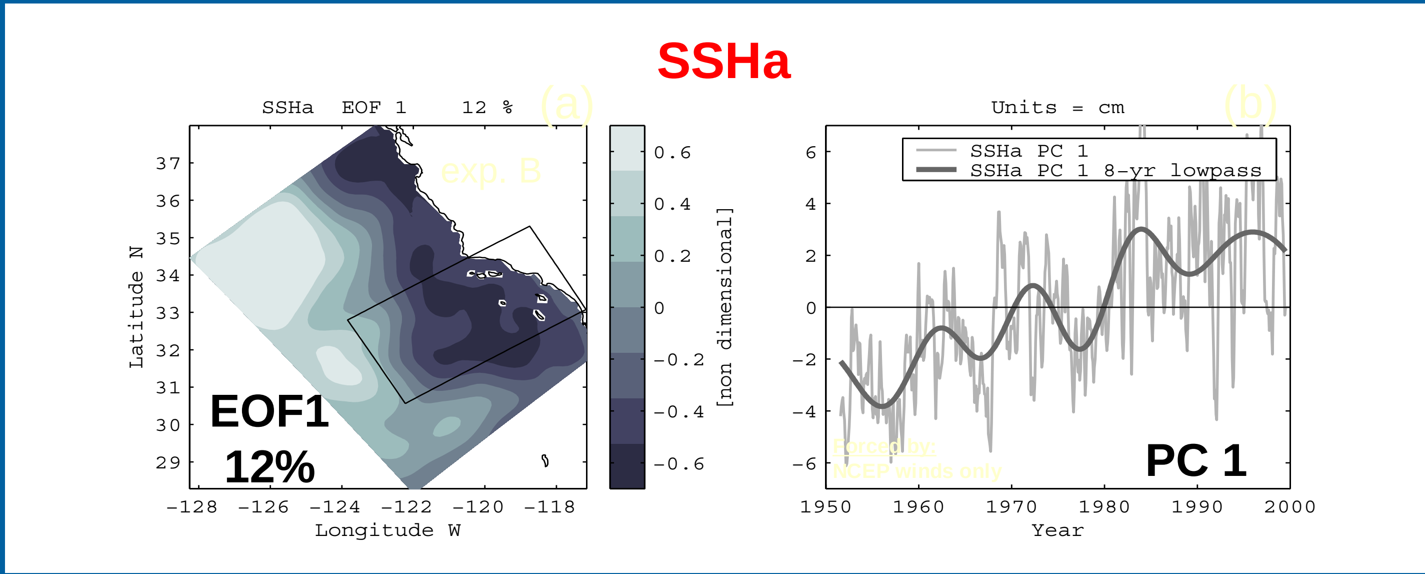


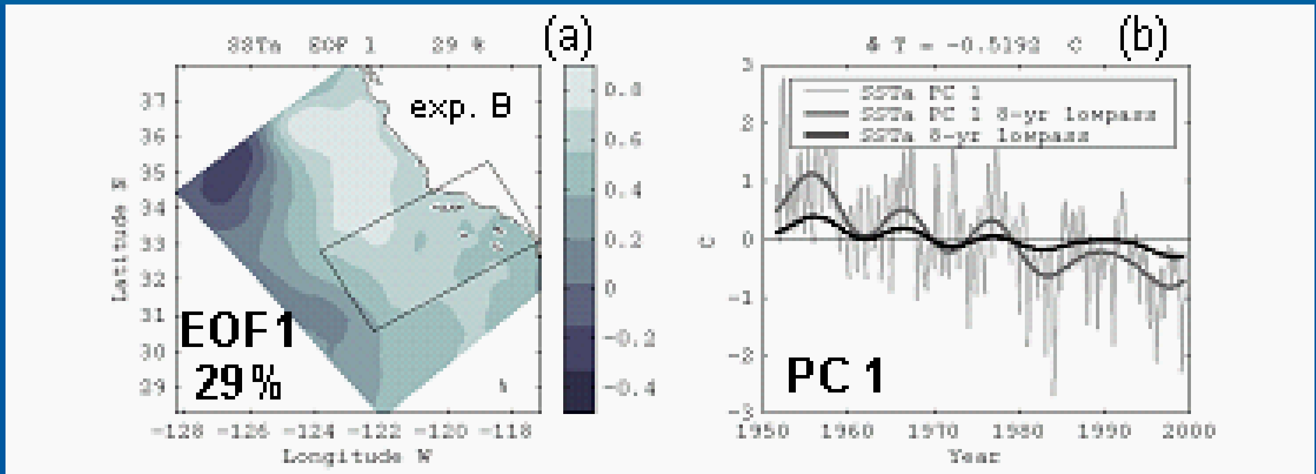
Alongshore Winds

EXP 1



Model dynamical response to the winds





Model SSTa

Forced by:
NCEP winds only

EXP 2

Local Heat Fluxes

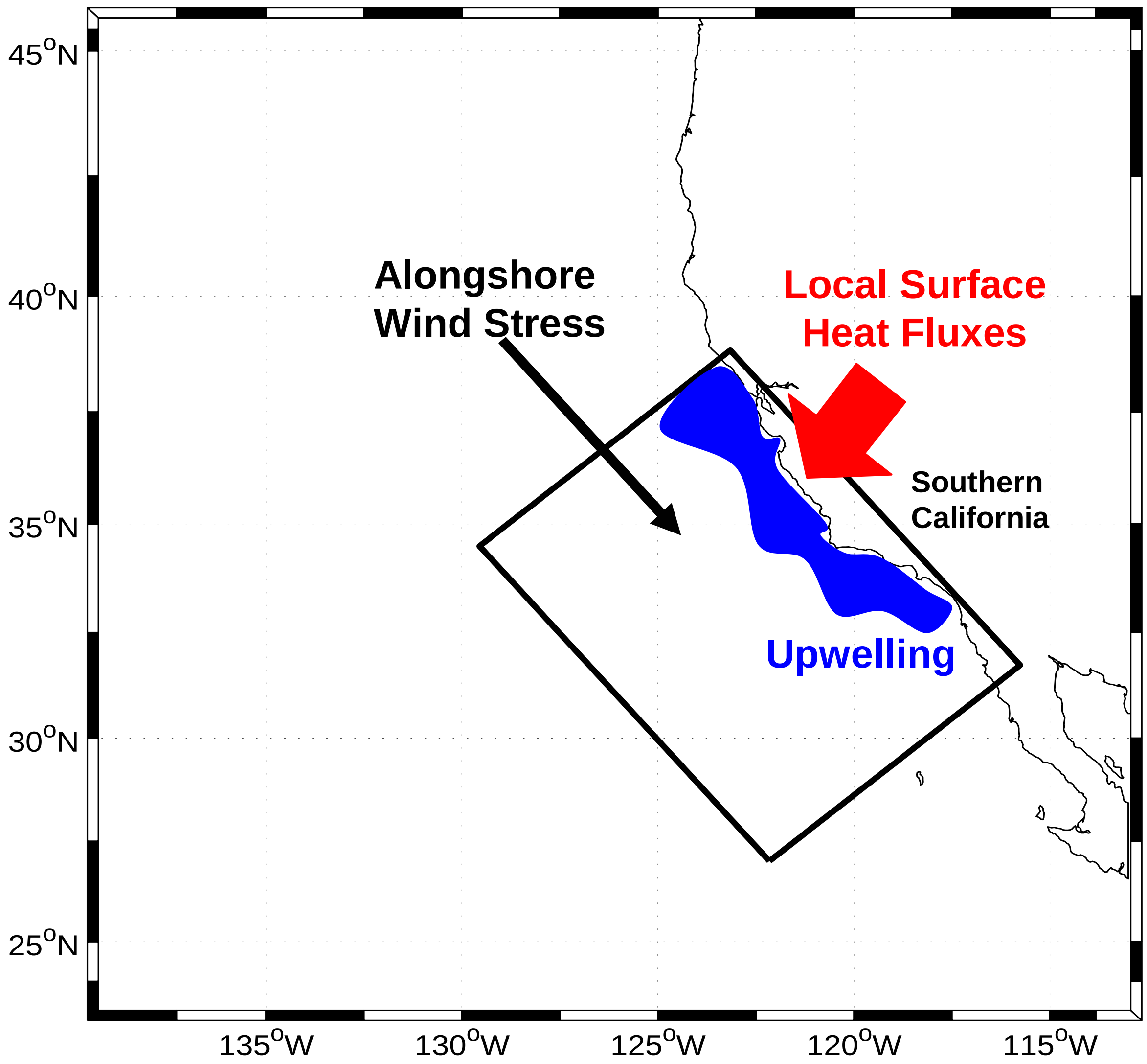
$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

Ocean Model Experiments

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		**X**	**X**
Exp 3	X	X	X

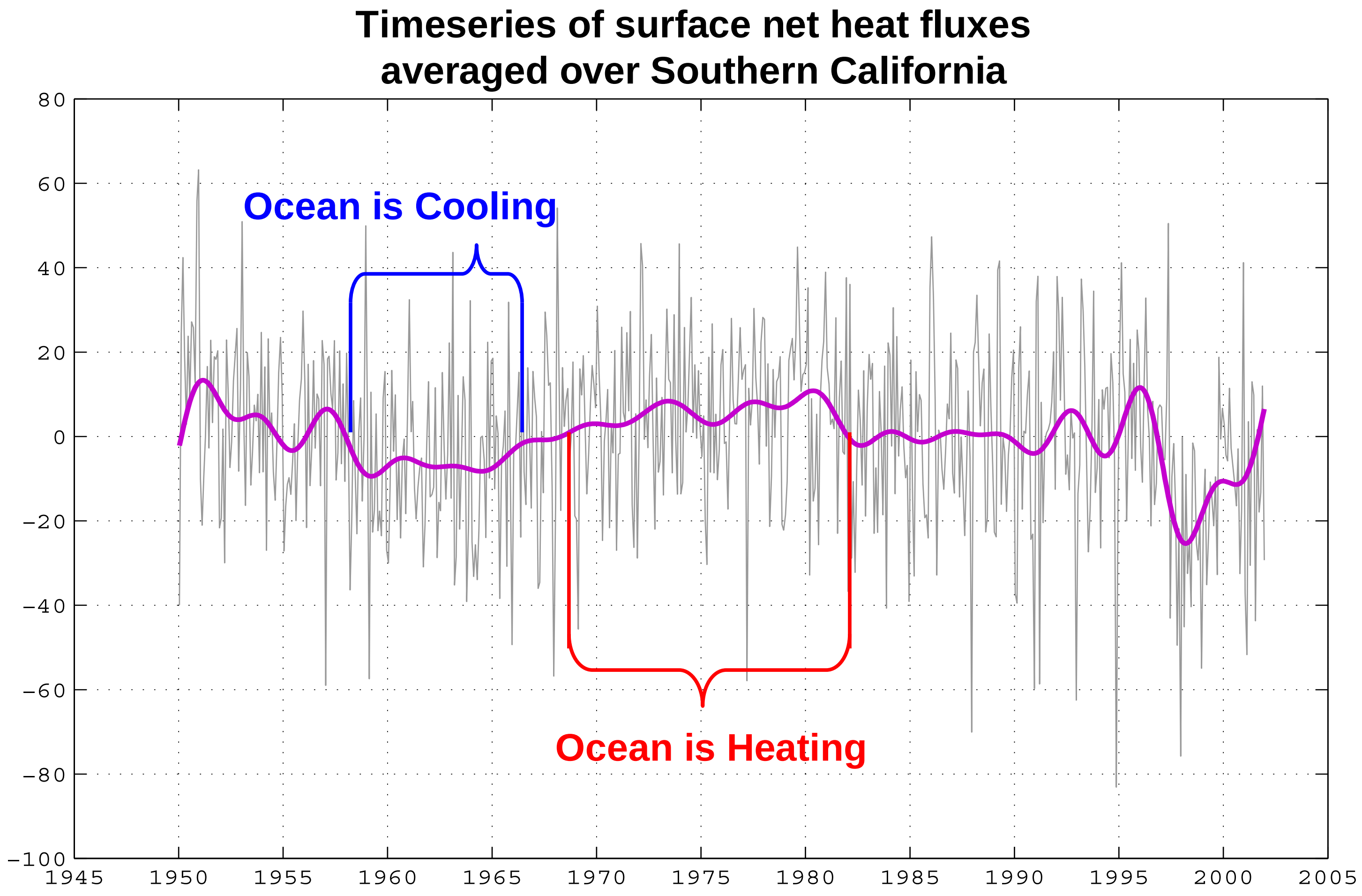
Upwelling and Local Surface Heat Fluxes

EXP 2



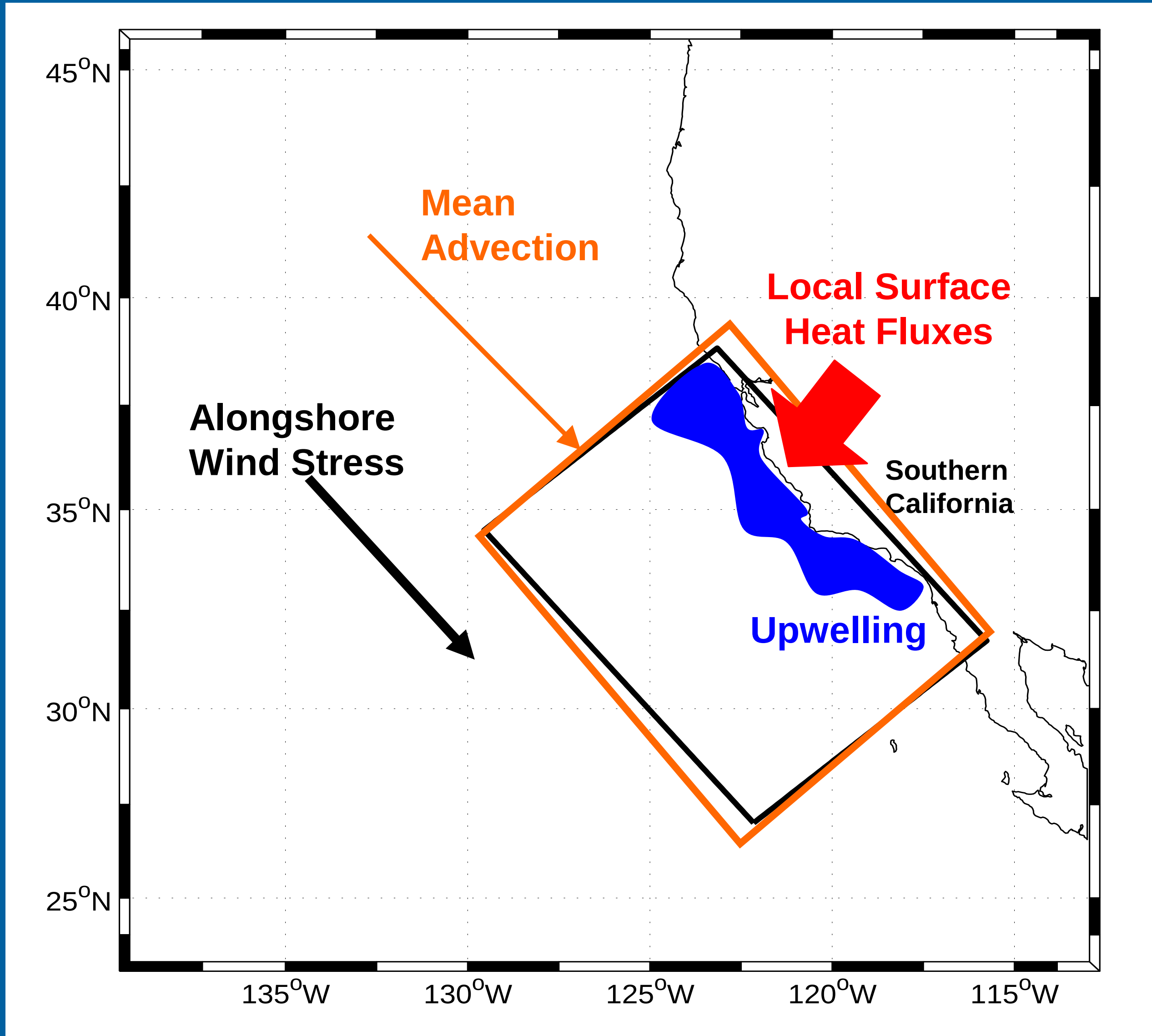
Surface Net Heat Fluxes

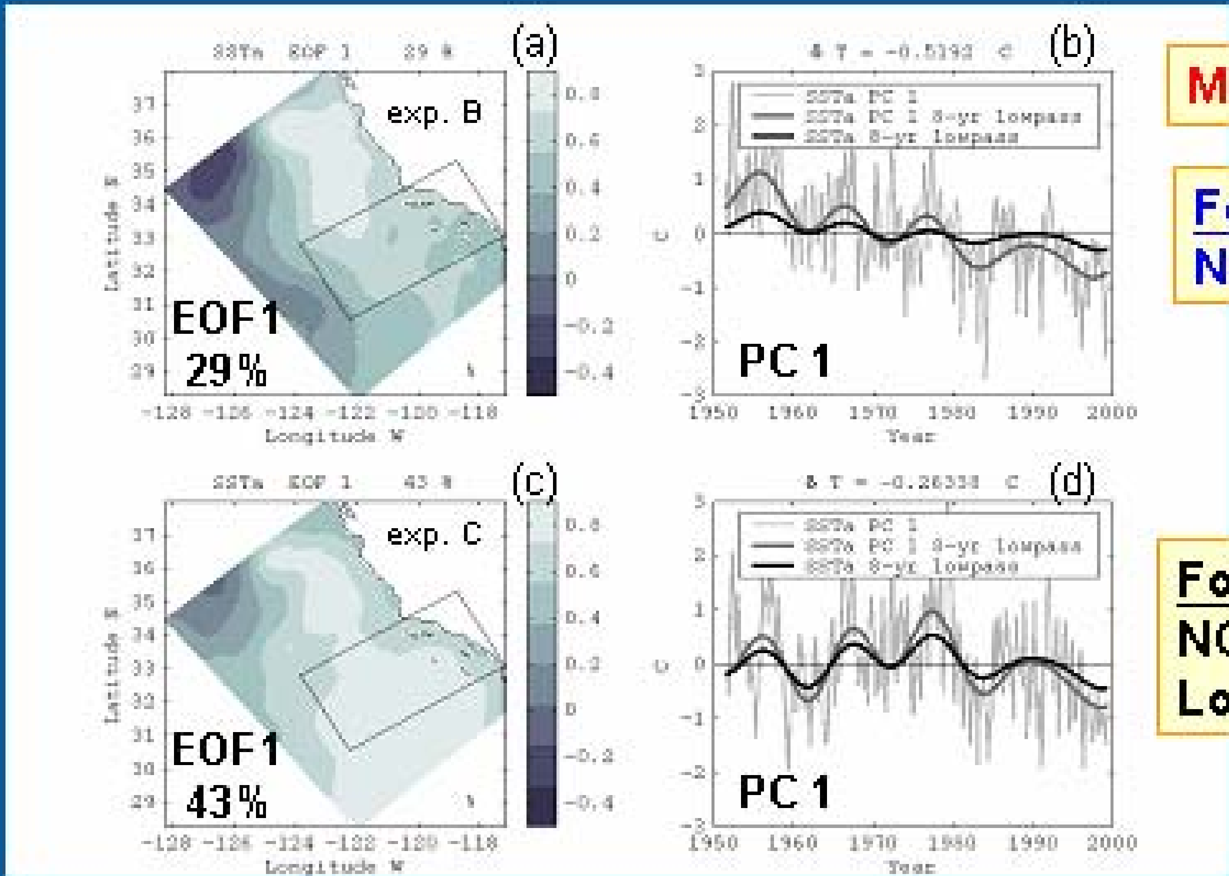
EXP 2



Upwelling and Local Surface Heat Fluxes and Mean Advection

EXP 3





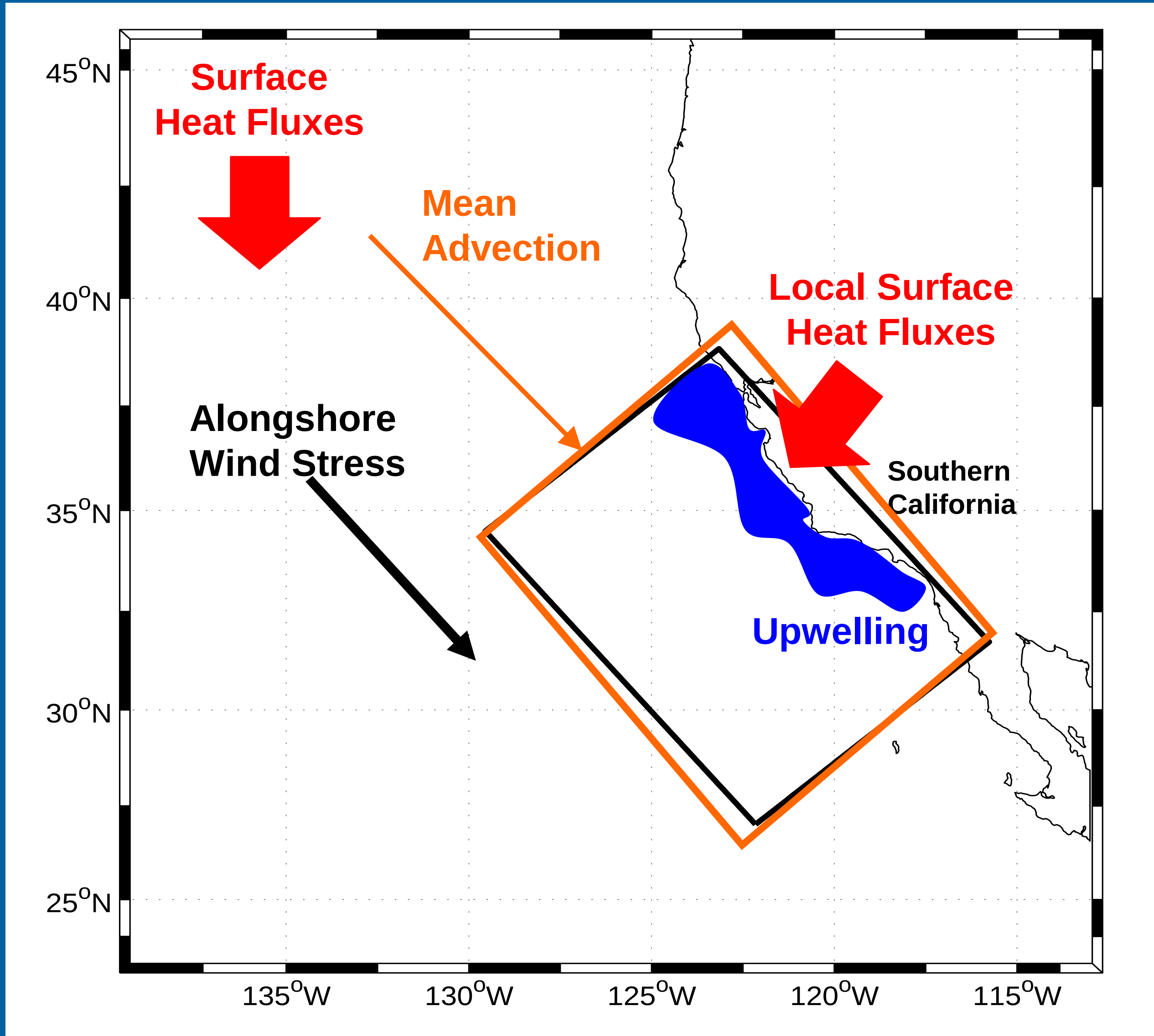
Model SSTa

Forced by:
NCEP winds only

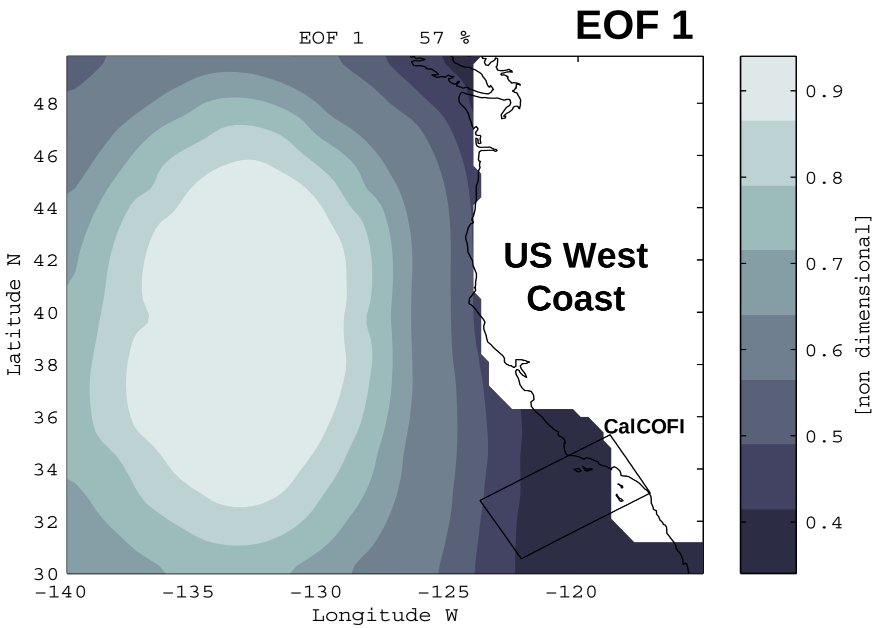
Forced by:
NCEP winds
Local Surface Heat Flux

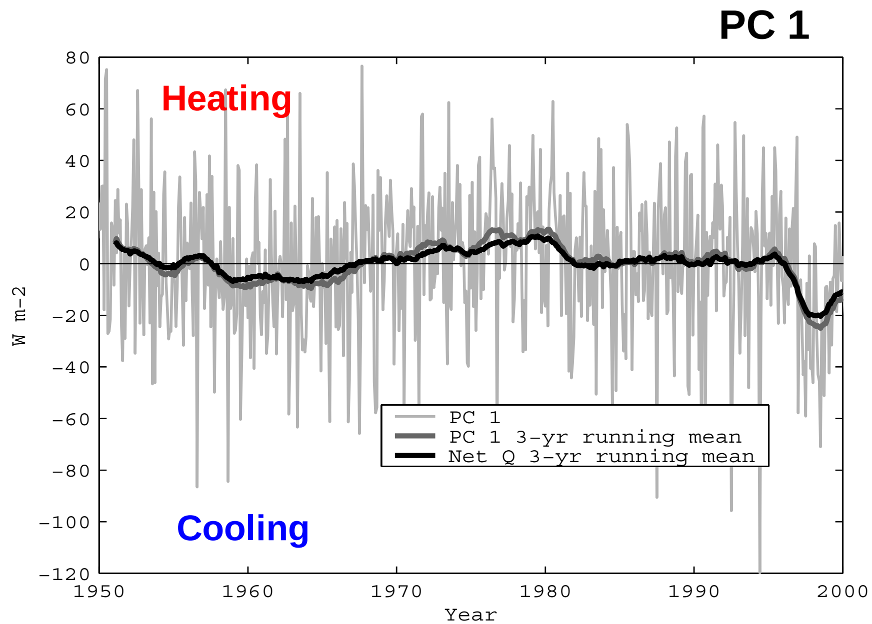
Upwelling and Local Surface Heat Fluxes and Mean Advection

EXP 3



Surface Heat Fluxes EOF



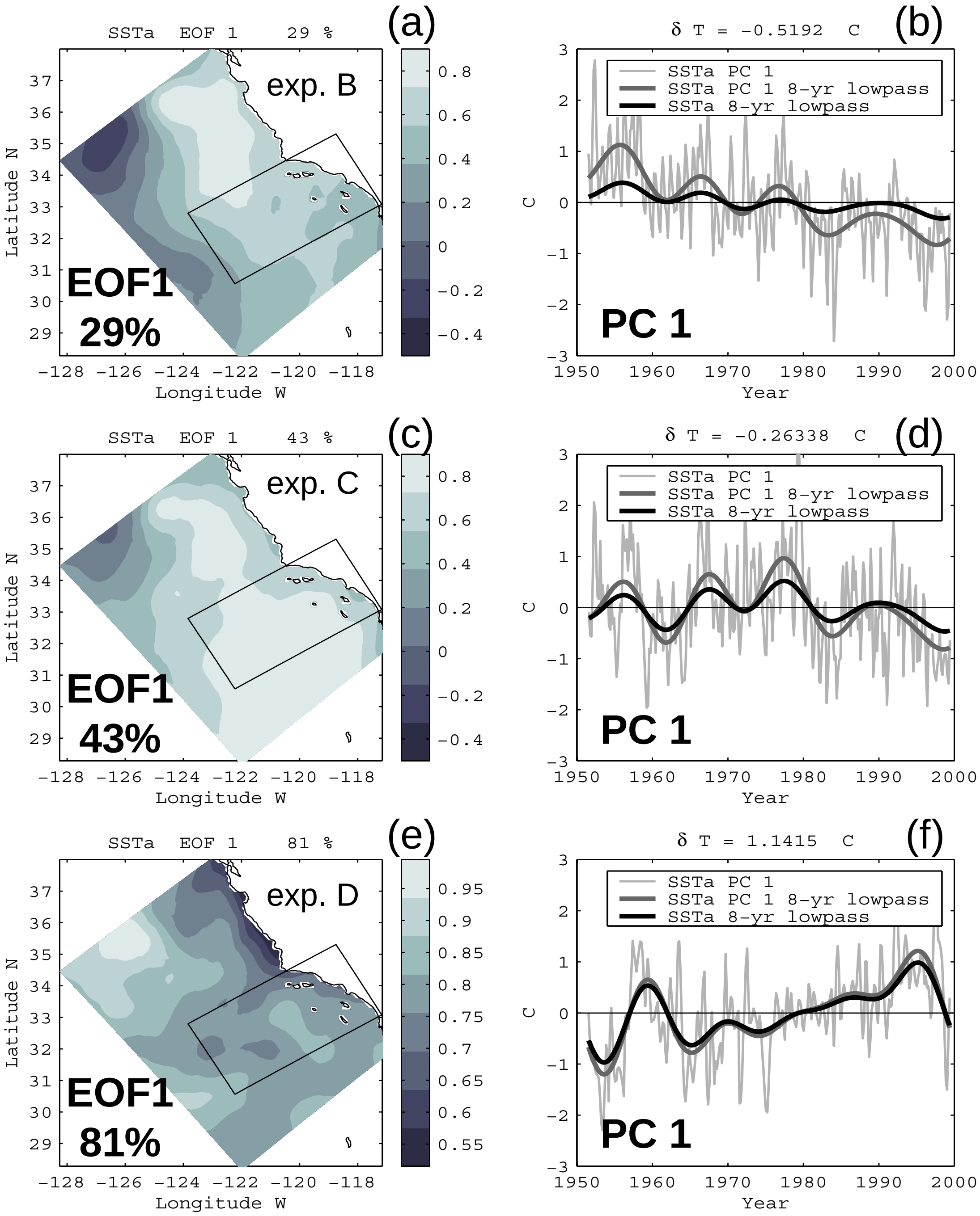


Local and Remote Heat Fluxes

$$\frac{\partial T}{\partial t} = \text{Mean Advection} + \text{Local Surface Heat Fluxes} + \text{Upwelling}$$

Ocean Model Experiments

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X



Model SSTa

Forced by:
NCEP winds only

Forced by:
NCEP winds
Local Surface Heat Flux

Forced by:
NCEP winds
Local Surface Heat Flux
Mean Advection of T'

Toy model for Temperature

Processes that control Temperature changes

(a simple dynamical framework)

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X

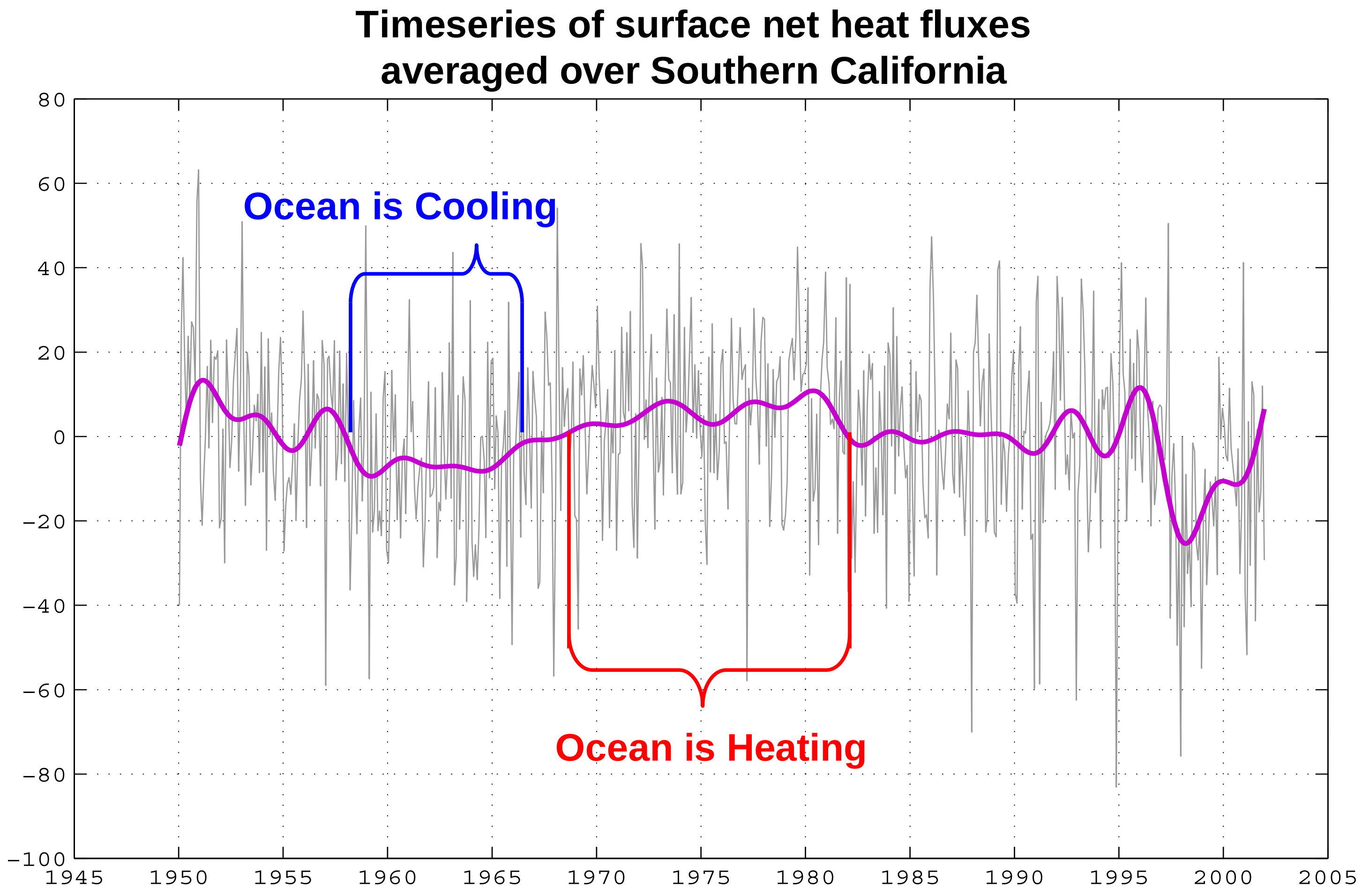
Processes that control Temperature changes

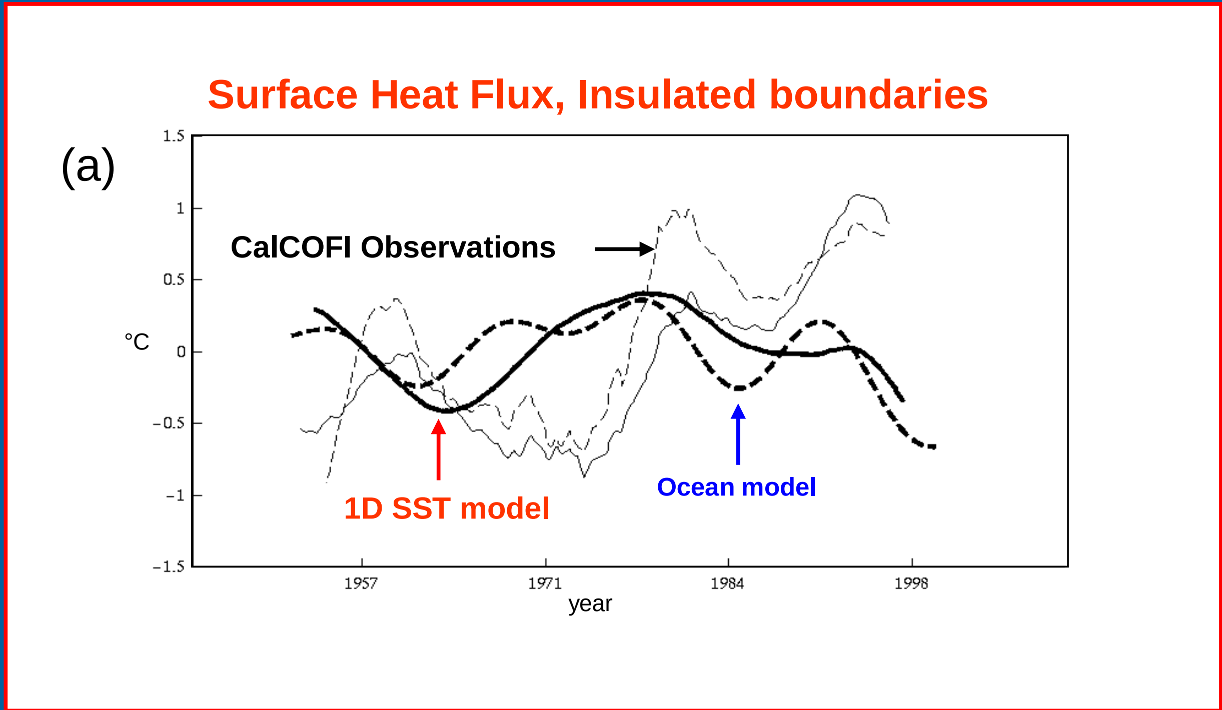
(a simple dynamical framework)

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X

$$\frac{\partial \tilde{T}}{\partial t} = \frac{\tilde{Q}}{\rho C p H} - \gamma \tilde{T}$$

Surface Net Heat Fluxes




Surface Heat Flux, Insulated boundaries
(a)
1.5
1
0.5
0
-0.5
-1
-1.5
°C
CalCOFI Observations
1D SST model
Ocean model
1957
1971
1984
1998
year

Processes that control Temperature changes

(a simple dynamical framework)

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X

$$\frac{\partial \tilde{T}}{\partial t} = \frac{\tilde{Q}}{\rho C p H} - \gamma \tilde{T}$$

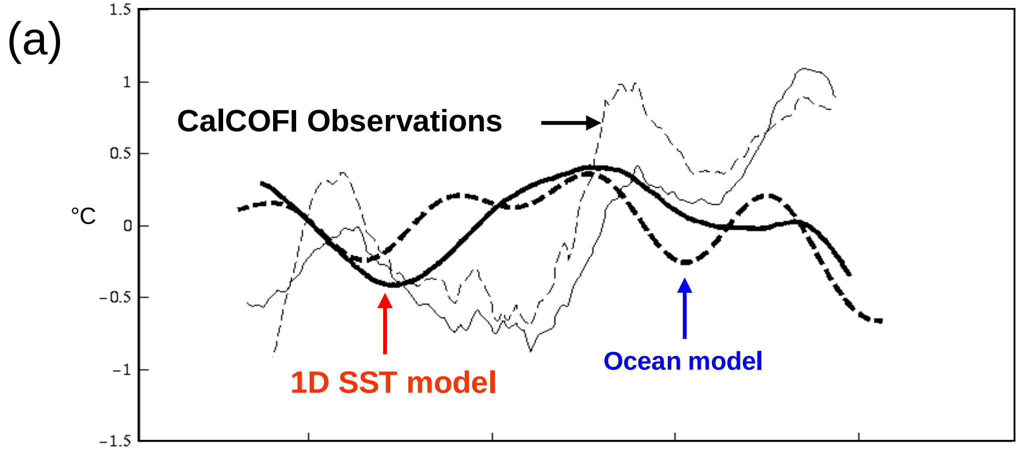
Processes that control Temperature changes

(a simple dynamical framework)

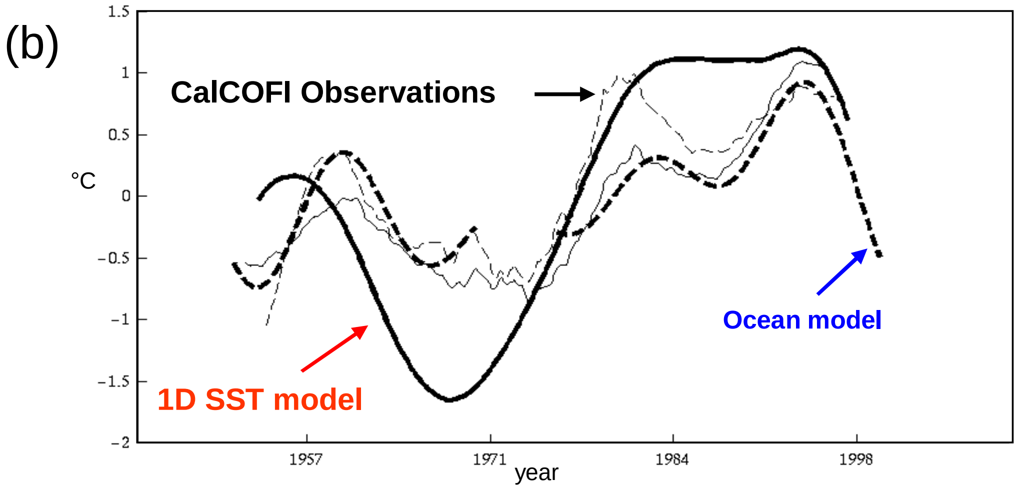
	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X

$$\frac{\partial \tilde{T}}{\partial t} = \frac{\tilde{Q}}{\rho C p H}$$

Surface Heat Flux, Insulated boundaries



Surface Heat Flux, Mean Advection of SSTa



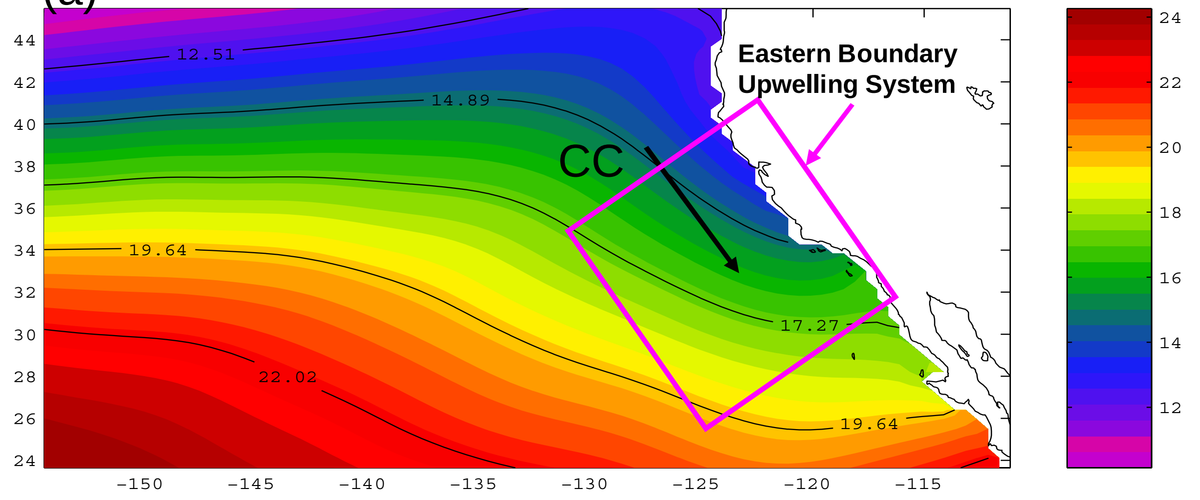
Impacts on ecosystem

Impacts on ecosystem

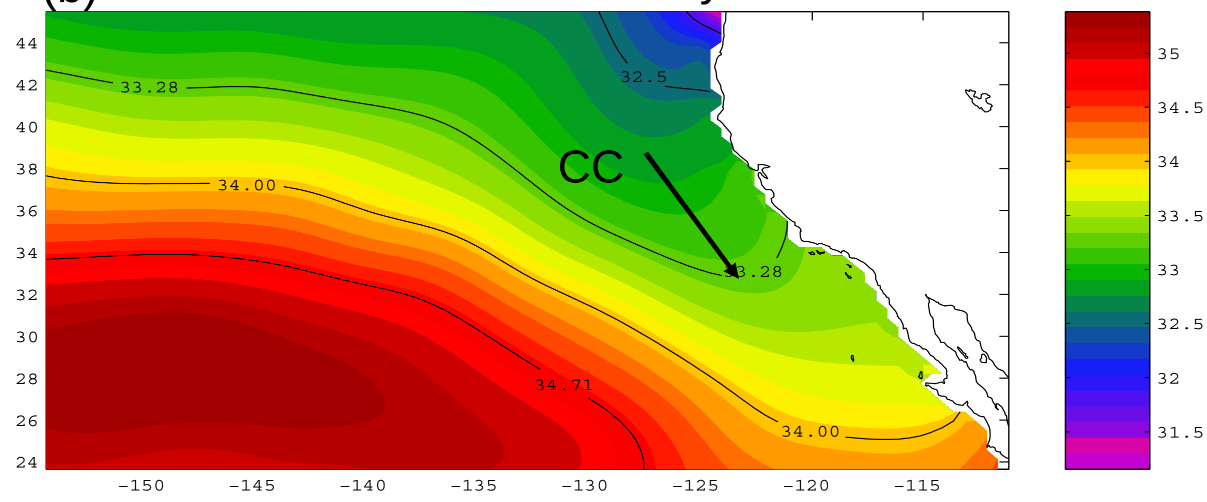
a) Changes in Upwelling

b) Changes in Mesoscale Eddy variance

(a) Mean Surface Temperature



(b) Mean Surface Salinity



Upwelling

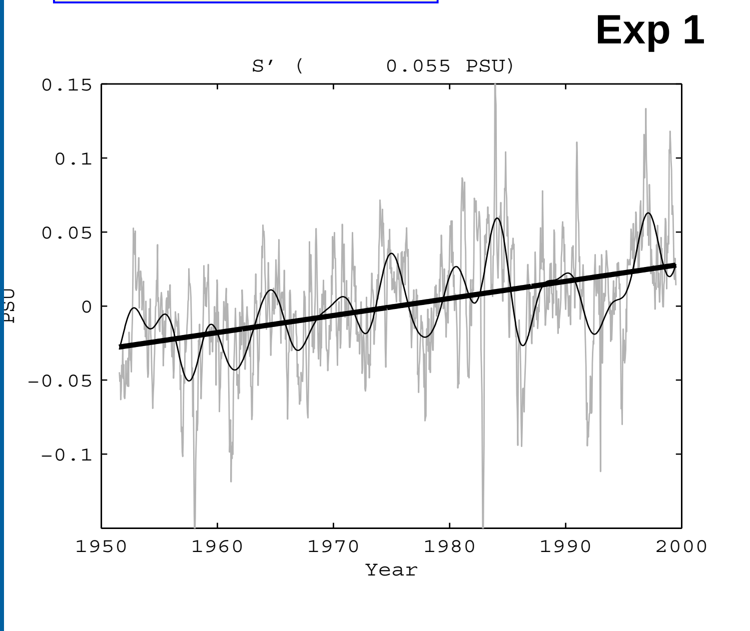
(results from the ocean model)

	Mean Advection	Local Surface Heat Fluxes	Upwelling
Exp 1			X
Exp 2		X	X
Exp 3	X	X	X

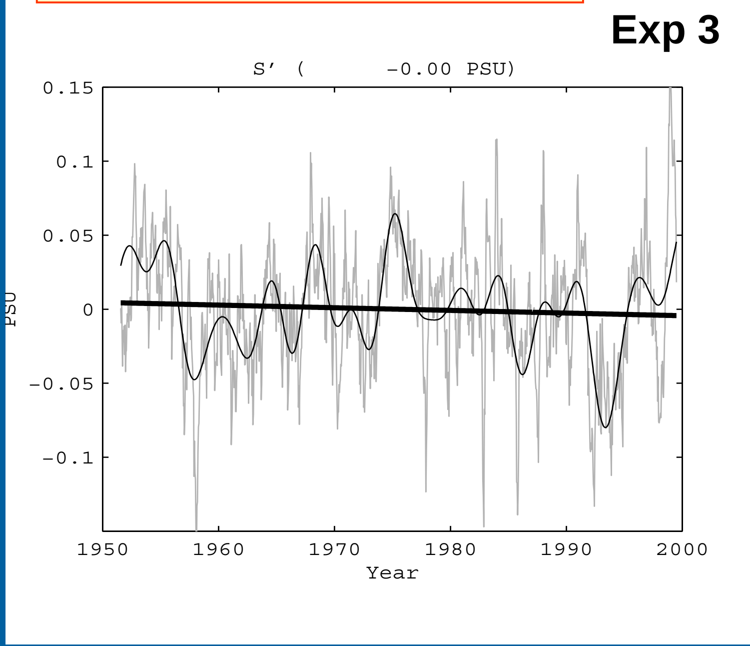
Surface Salinity

in Upwelling Boundary Layer

Model Forced by:
NCEP winds only

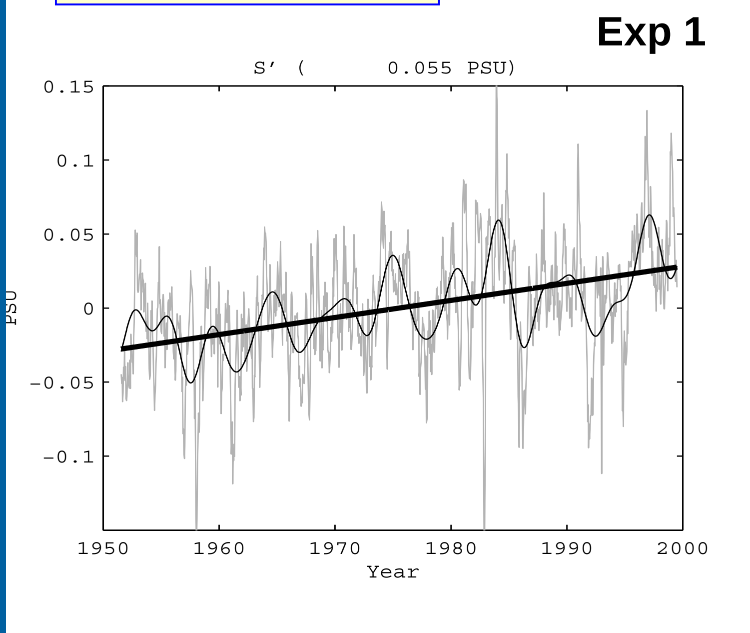


Model Forced by:
NCEP winds and warming trend



Surface Salinity
in Upwelling Boundary Layer

Model Forced by:
NCEP winds only



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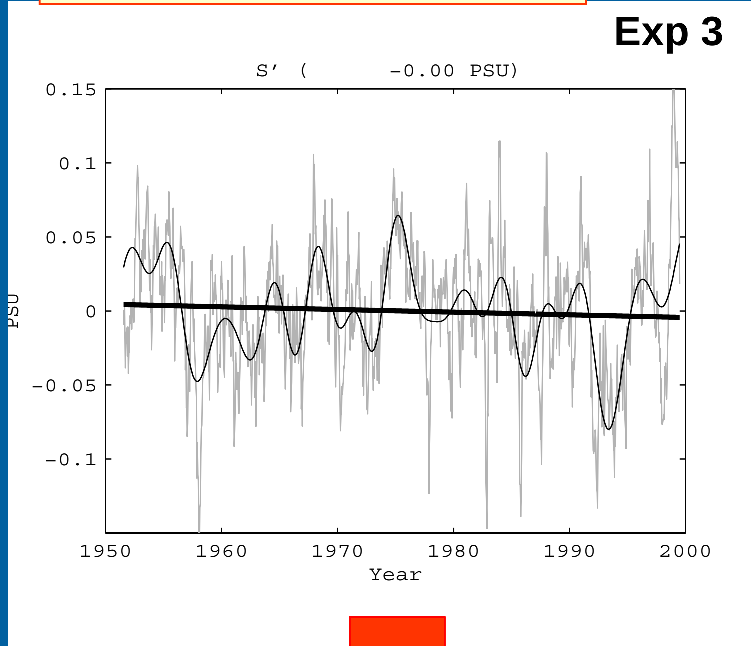
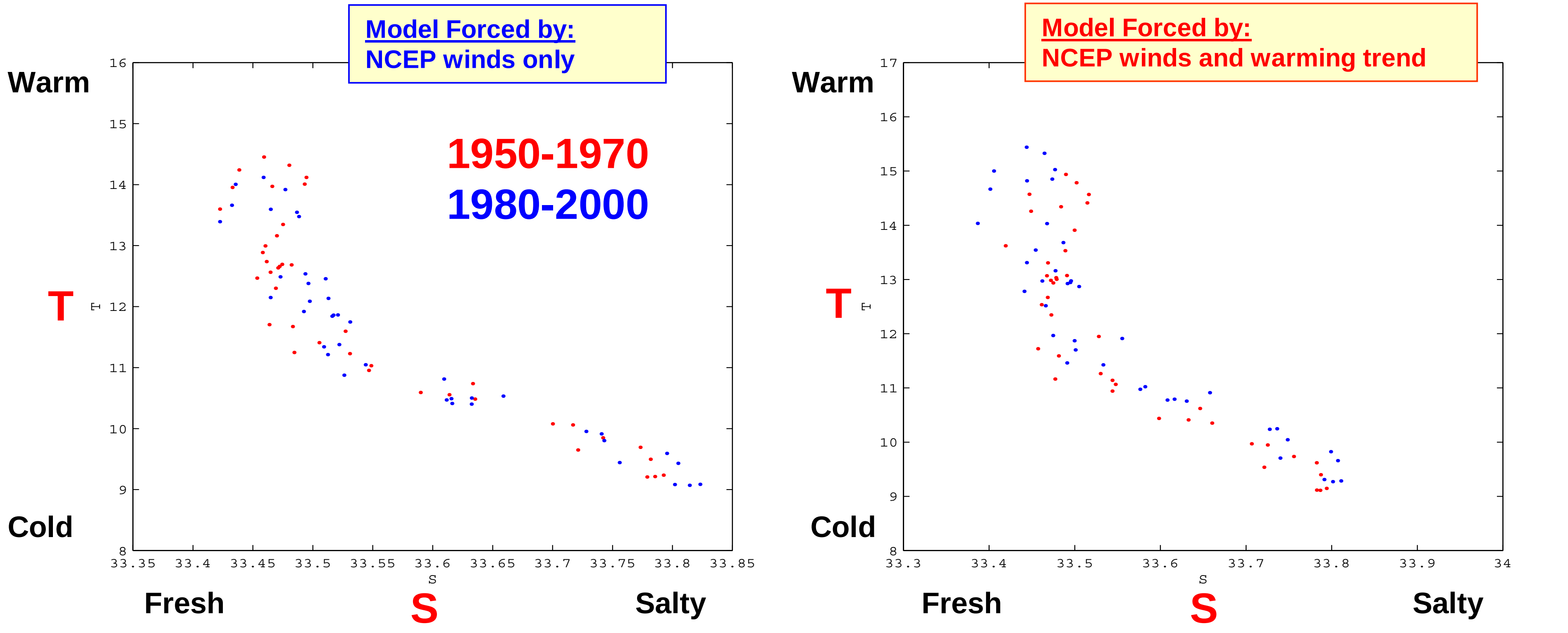


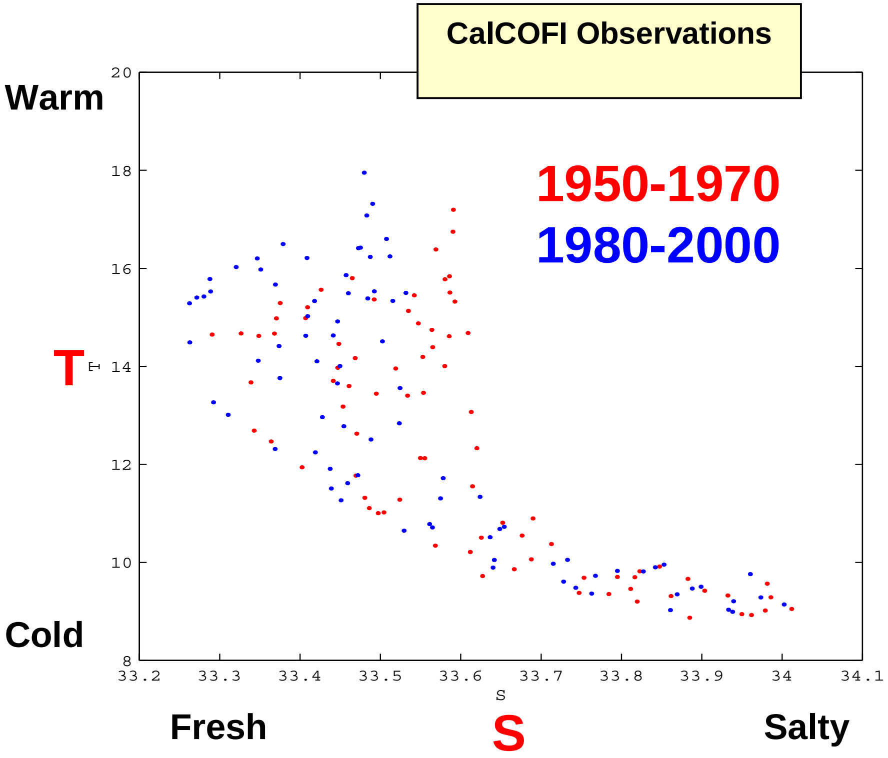
Reduced efficiency of upwelling and vertical flux of nutrient

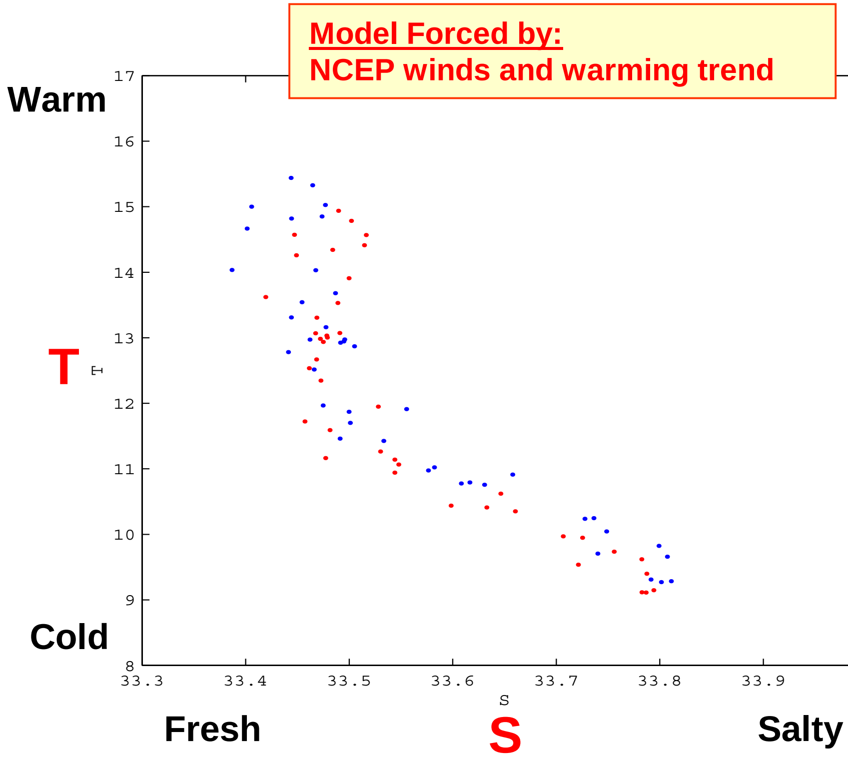
TS diagram



Model Forced by:
NCEP winds only
1950-1970
1980-2000
Warm
Cold
T
S
Fresh
Salty
Model Forced by:
NCEP winds and warming trend
Warm
Cold
T
S
Fresh
Salty

TS diagram


CalCOFI Observations
1950-1970
1980-2000
Warm
Cold
T
T
S
S
Fresh
Salty
20
18
16
14
12
10
8
33.2
33.3
33.4
33.5
33.6
33.7
33.8
33.9
34
34.1


Model Forced by:
NCEP winds and warming trend
Warm
Cold
T
T
S
S
Fresh
Salty
17
16
15
14
13
12
11
10
9
8
33.3
33.4
33.5
33.6
33.7
33.8
33.9
34

Mesoscale Eddy variance

Increase in Mesoscale Eddy variance

in the 1980s and 1990s

30 – 40 % in the core
of the California Current
(95 % significance level is 25 %)

Increase in Mesoscale Eddy variance

in the 1980s and 1990s

30 – 40 % in the core
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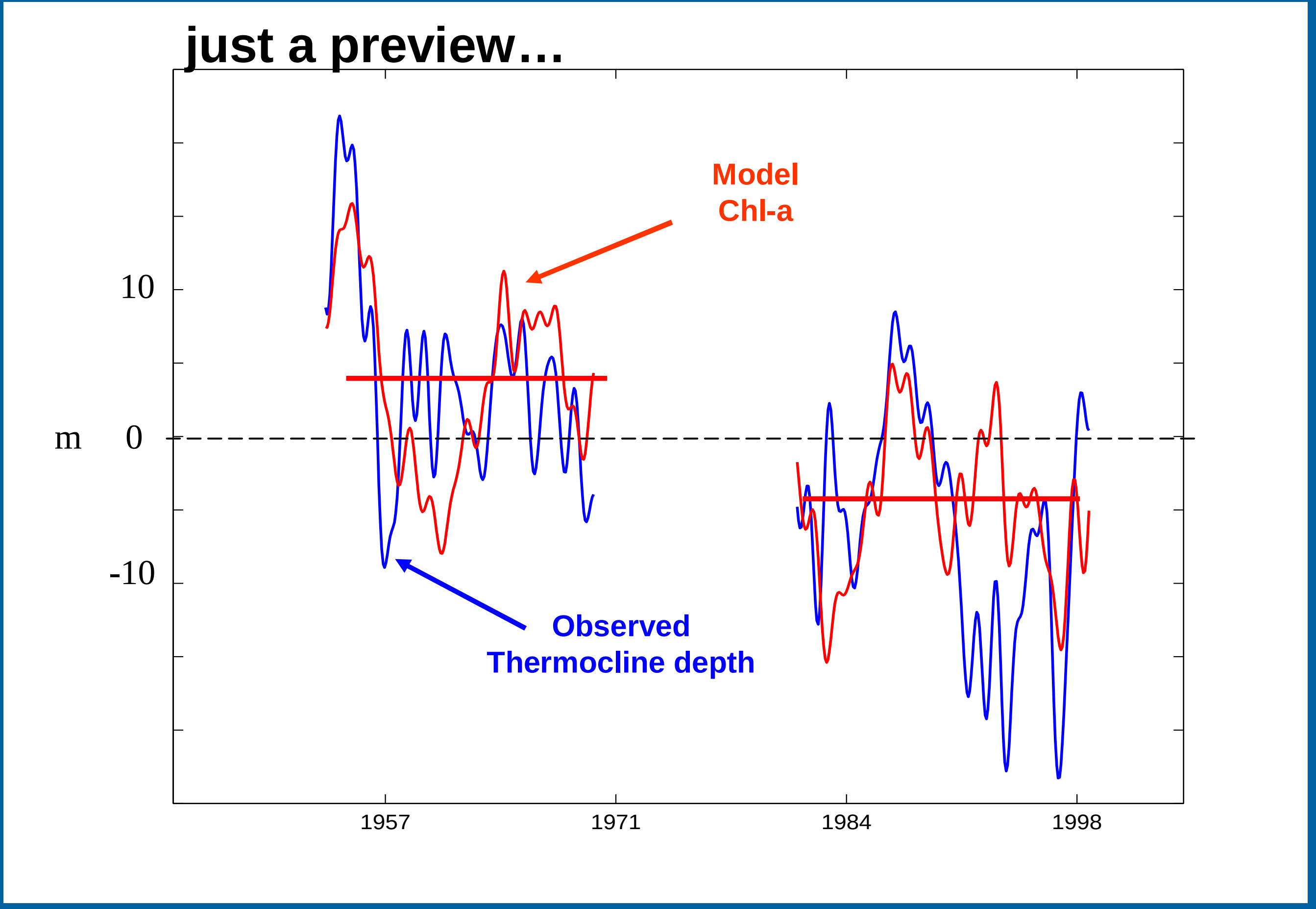
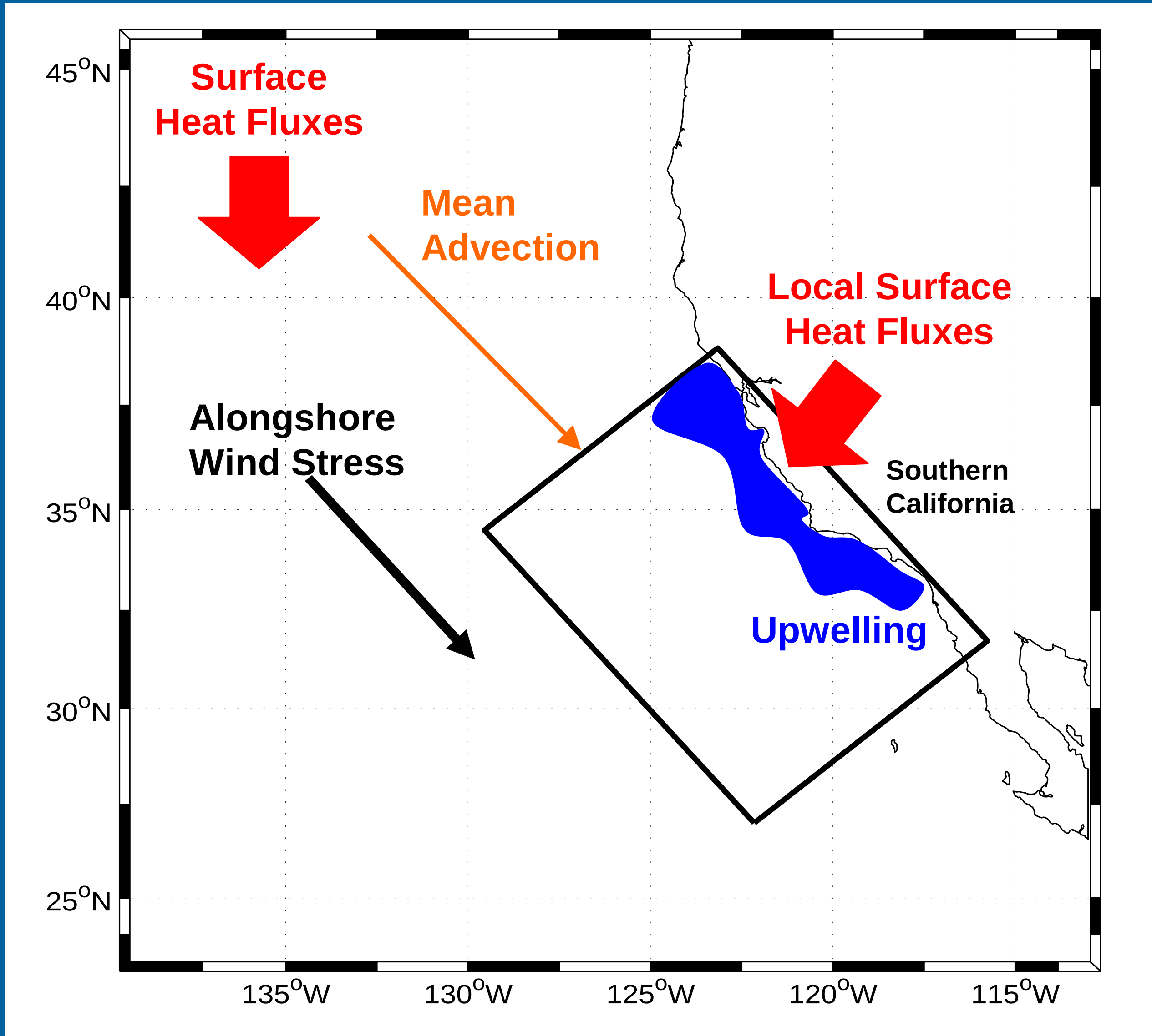
Distribution and survival of larvae

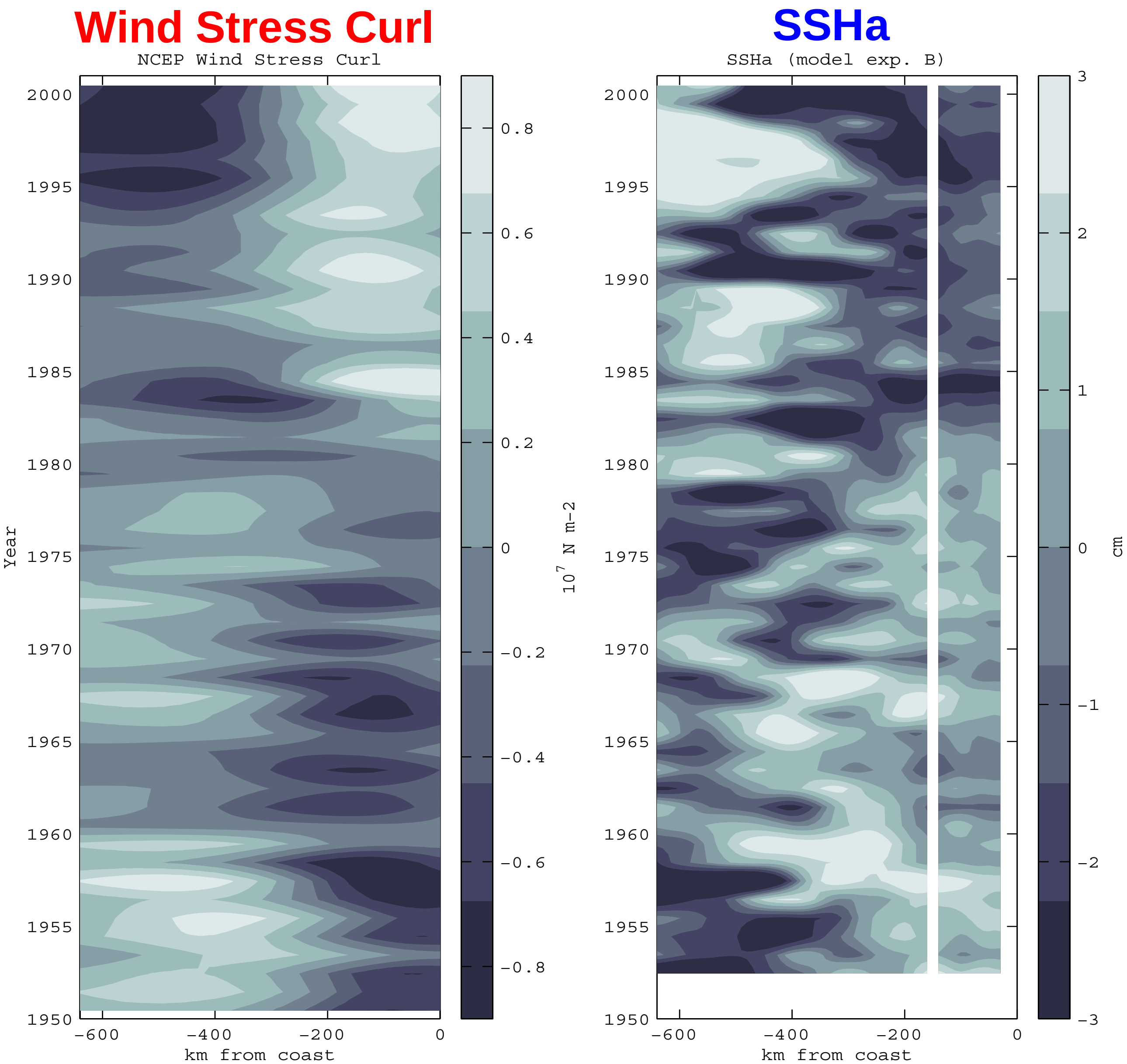
Ecosystem Model?

Ecosystem Model?



Processes controlling Temperature





Wind Stress Curl
NCEP Wind Stress Curl
Year
2000
1995
1990
1985
1980
1975
1970
1965
1960
1955
1950
-600
-400
-200
0
km from coast
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
10^7 N m-2
SSHa
SSHa (model exp. B)
3
2
1
0
-1
-2
-3
cm