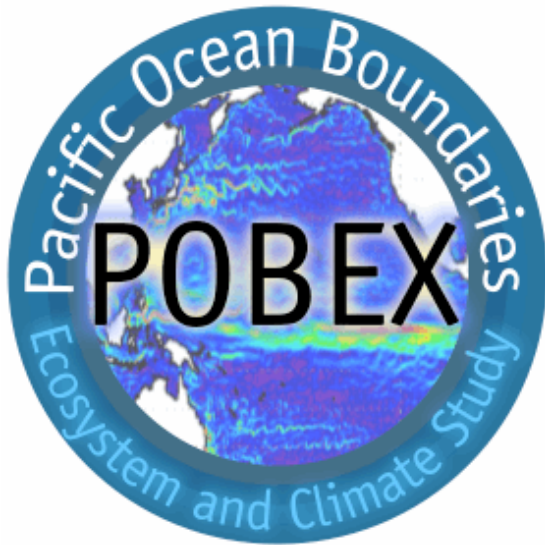
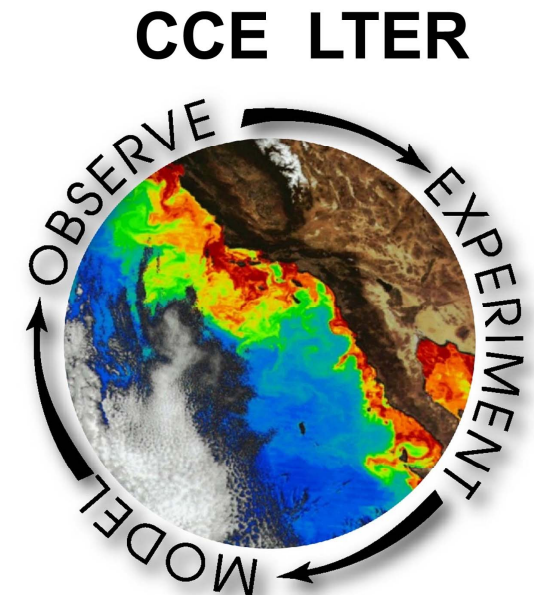


A *null hypothesis* to explain
climate driven “*regime-like*”
transitions in ecosystem species

E. Di Lorenzo and M. D. Ohman

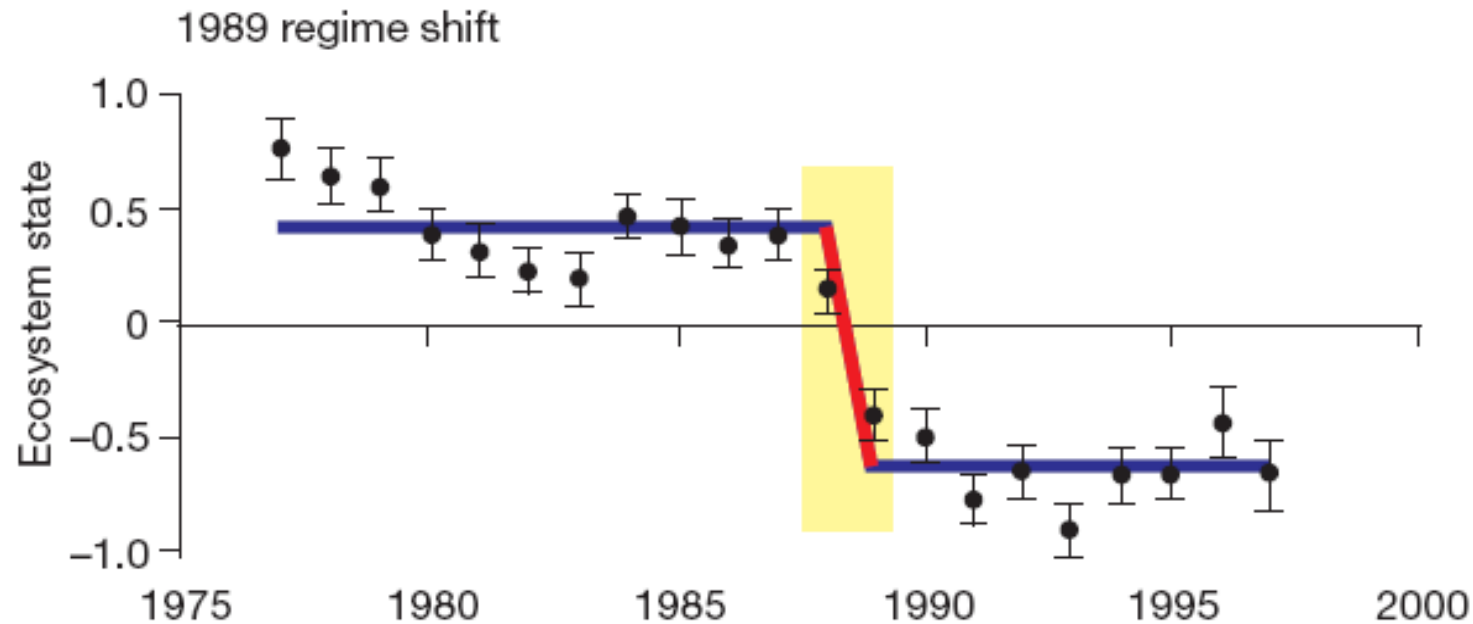
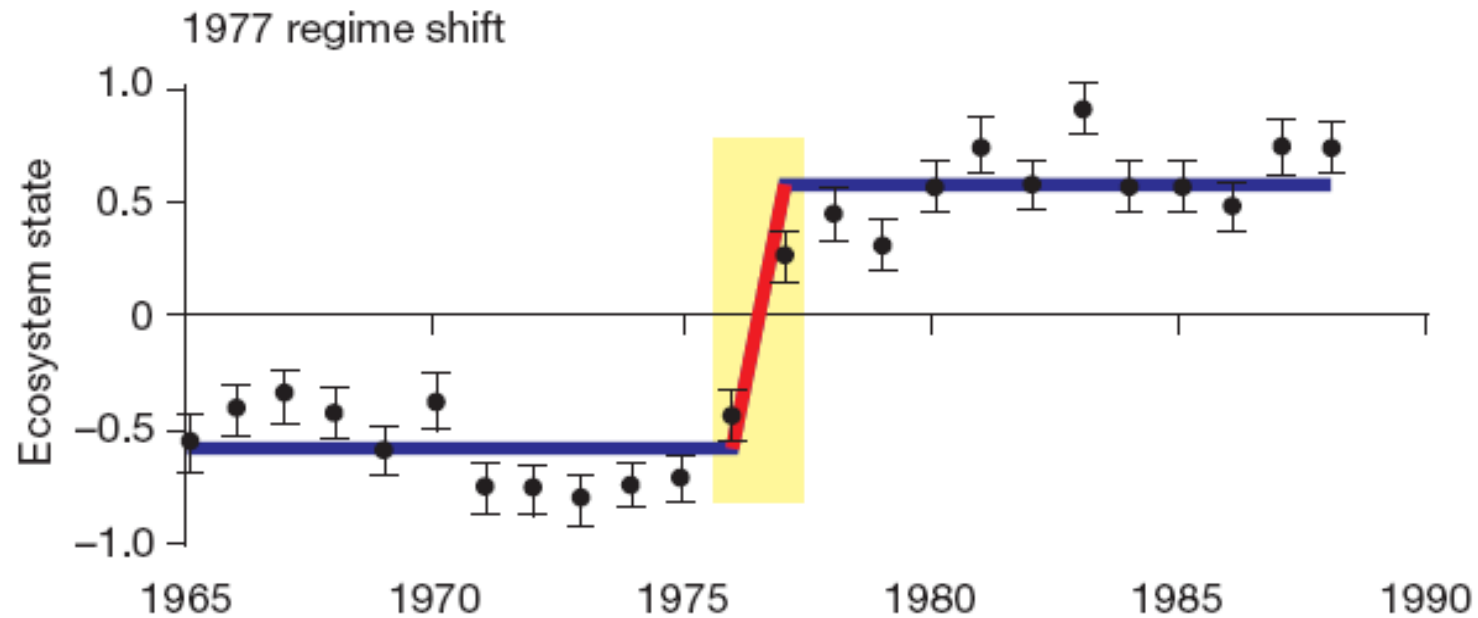


Georgia Institute
of Technology



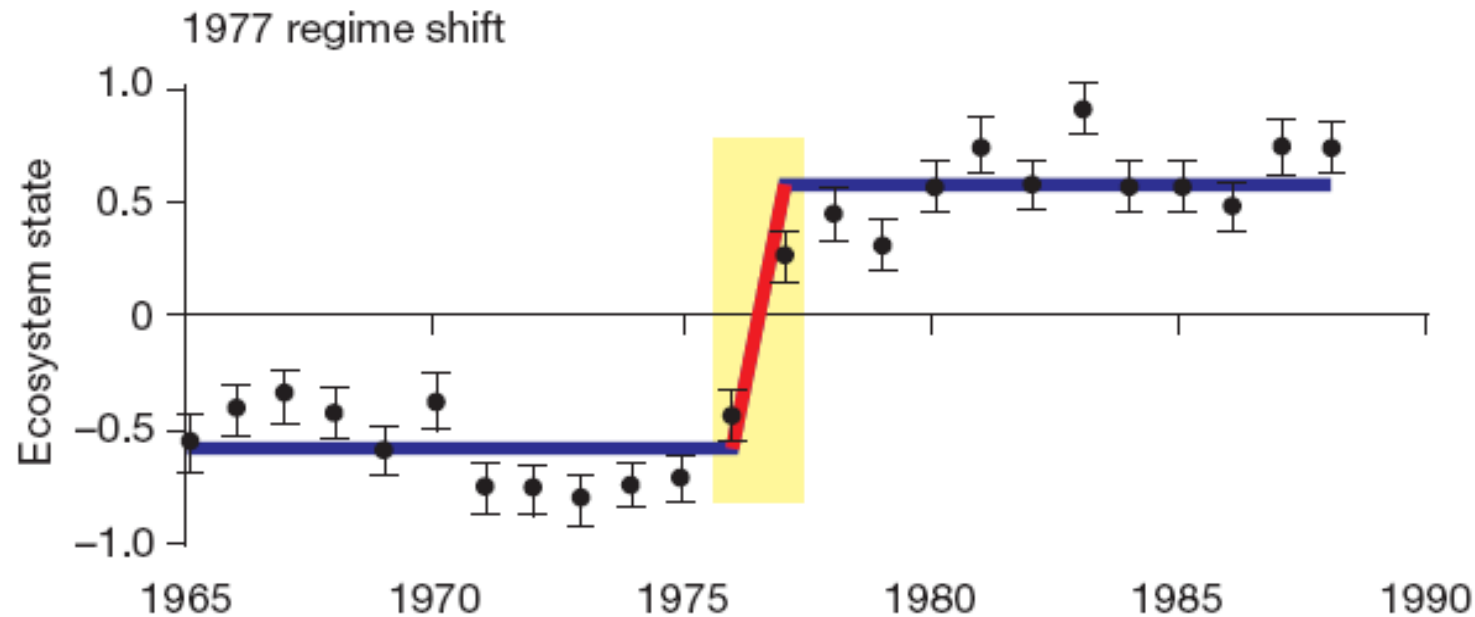
Khabarovsk, October 20, 2011

Ecosystem exhibit “regime-like” behavior



(from Hare and Mantua 2000, modified by Sheffer et al. 2009)

Ecosystem exhibit “regime-like” behavior



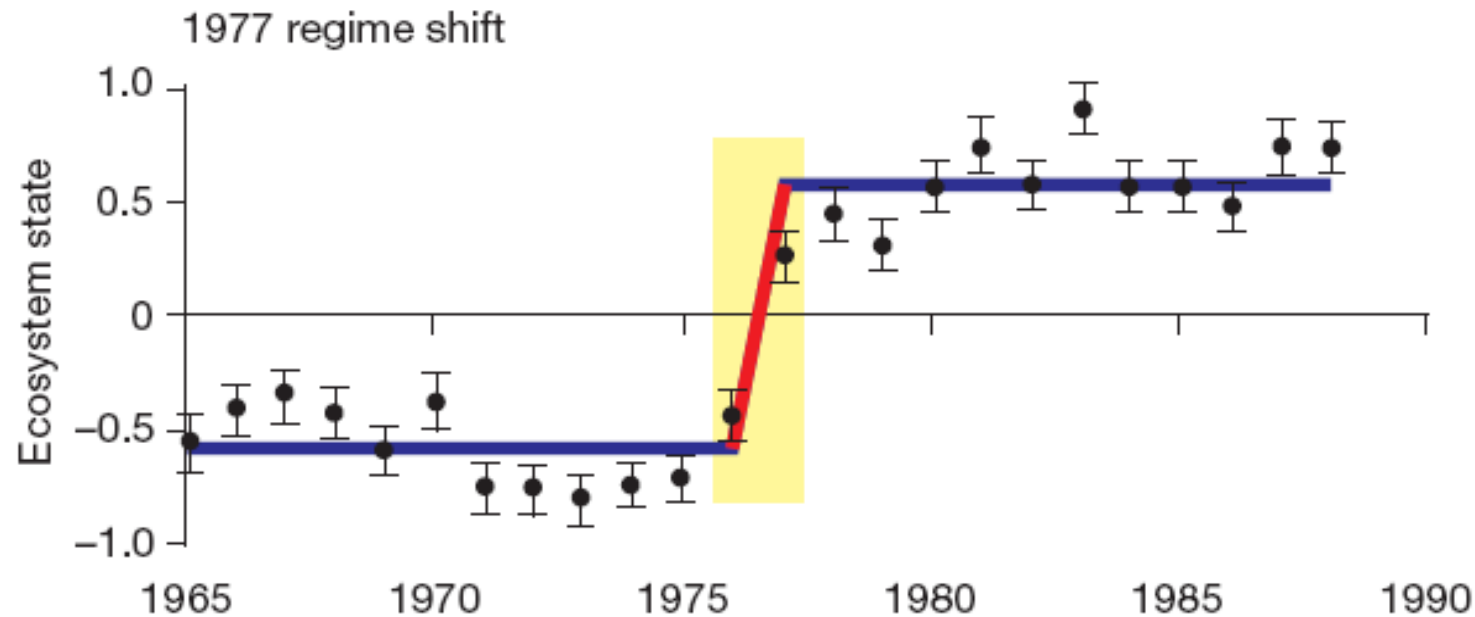
QUESTION:

Are these real regime shifts?

1975 1980 1985 1990 1995 2000

(from Hare and Mantua 2000, modified by Sheffer et al. 2009)

Ecosystem exhibit “regime-like” behavior

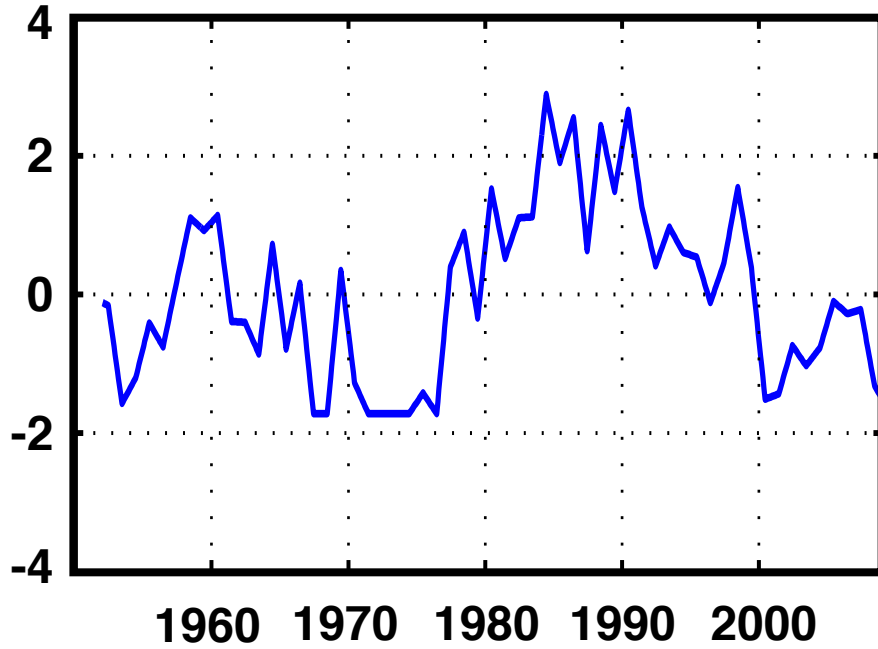


QUESTION:

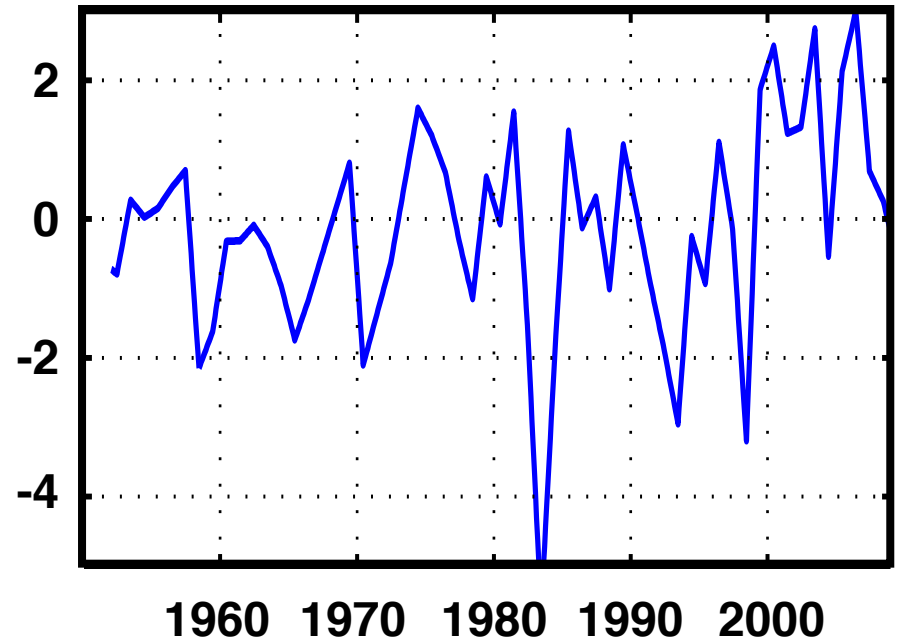
What do these regime-like changes tell us about the dynamics of ecosystem variability?

1975 1980 1985 1990 1995 2000

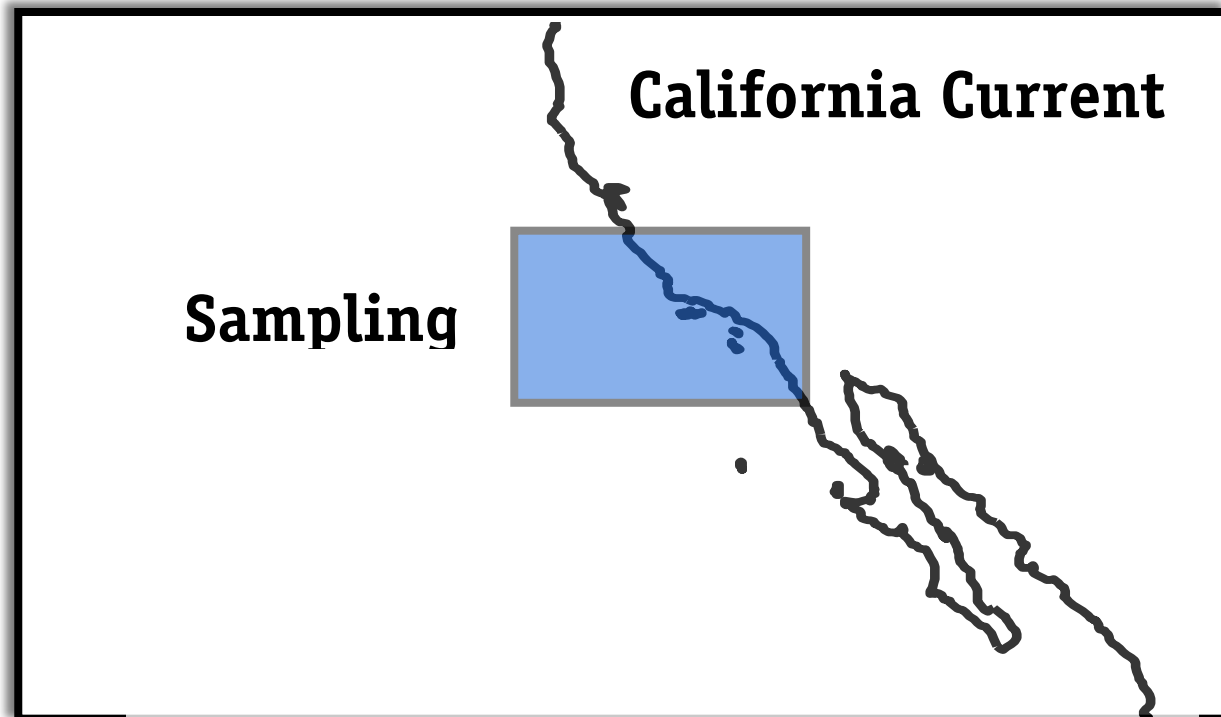
Nyctiphanes simplex



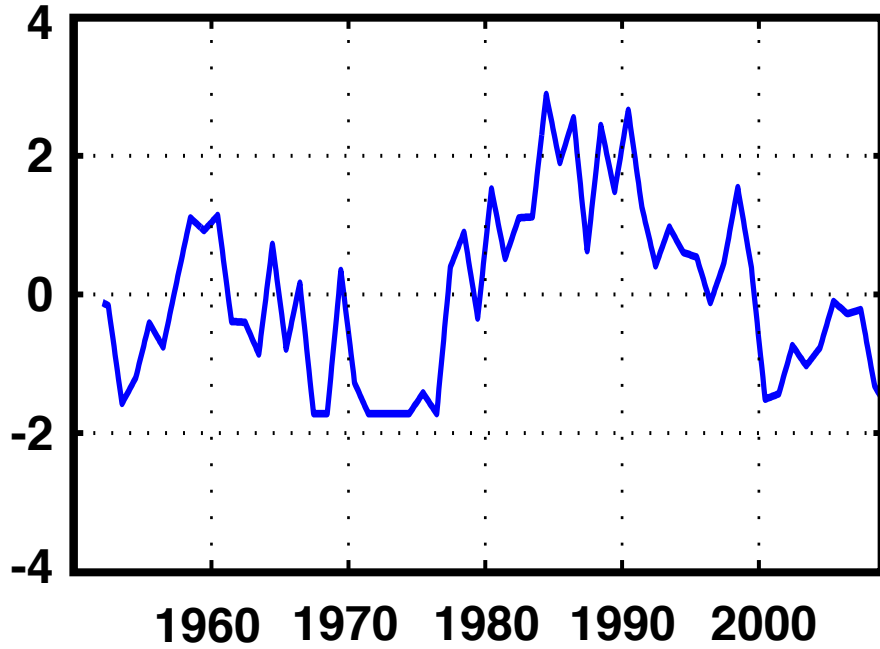
Euphausia pacifica



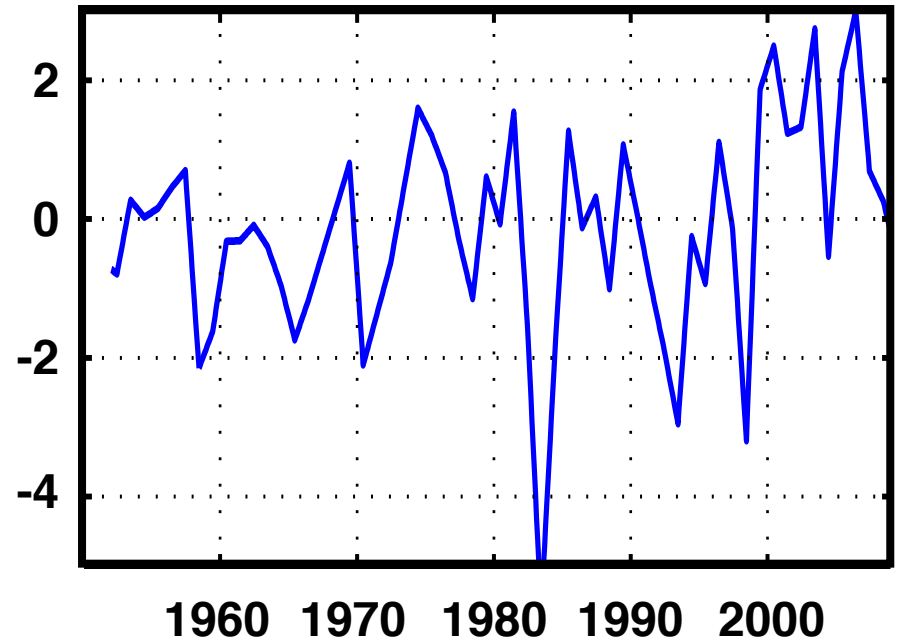
Zooplankton observations in the California Current



Nyctiphanes simplex



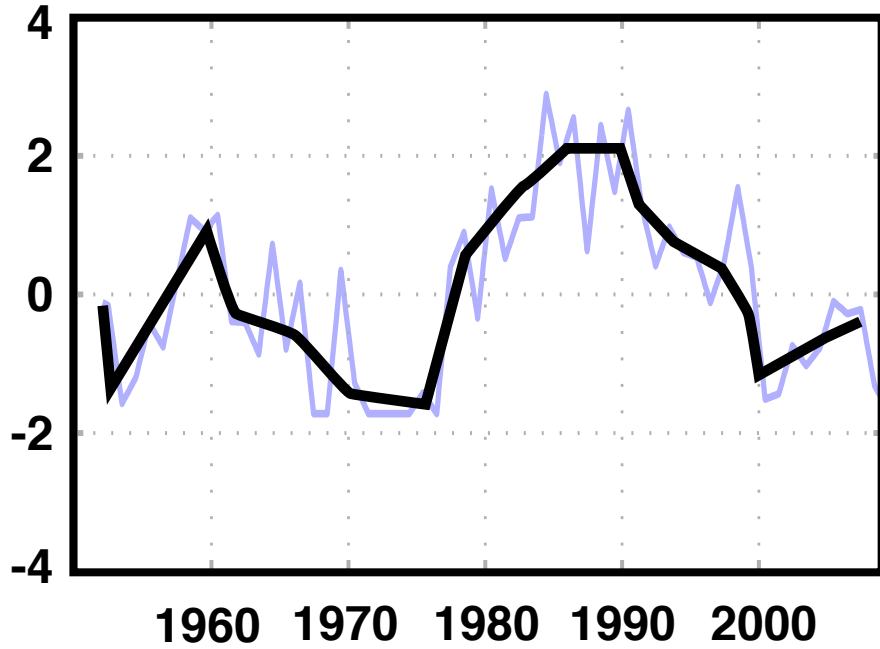
Euphausia pacifica



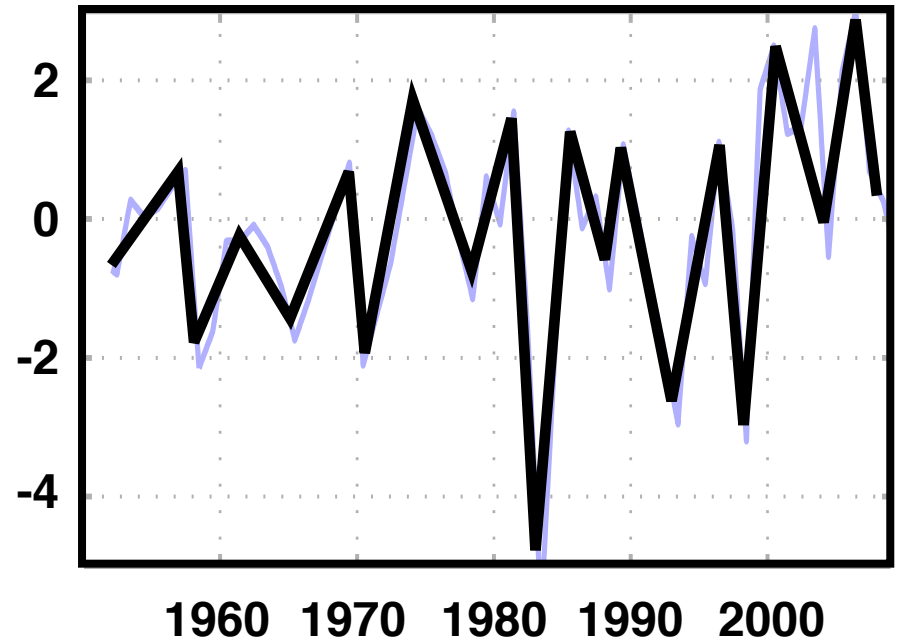
Zooplankton

*observations in the
California Current*

Nyctiphanes simplex



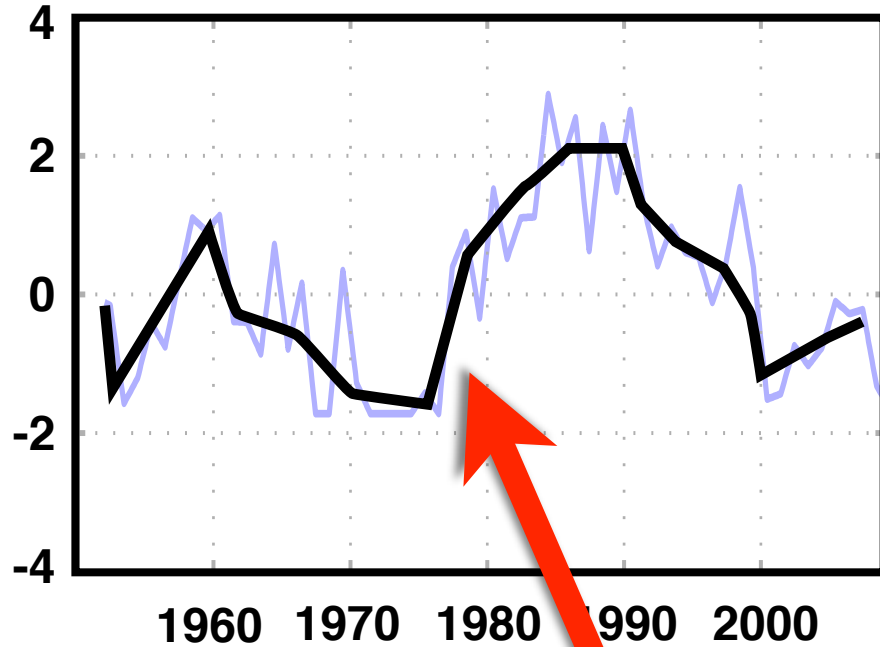
Euphausia pacifica



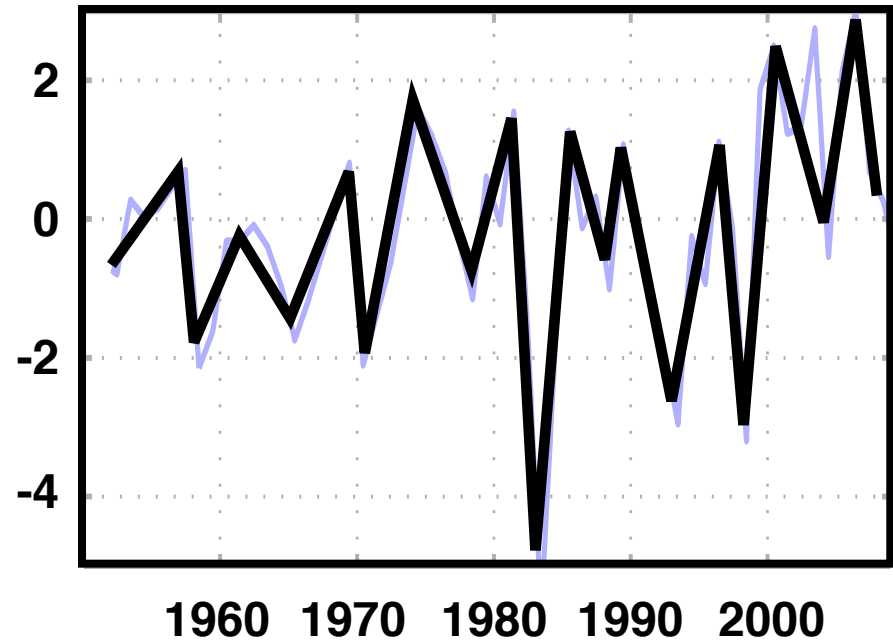
Zooplankton

*observations in the
California Current*

Nyctiphanes simplex



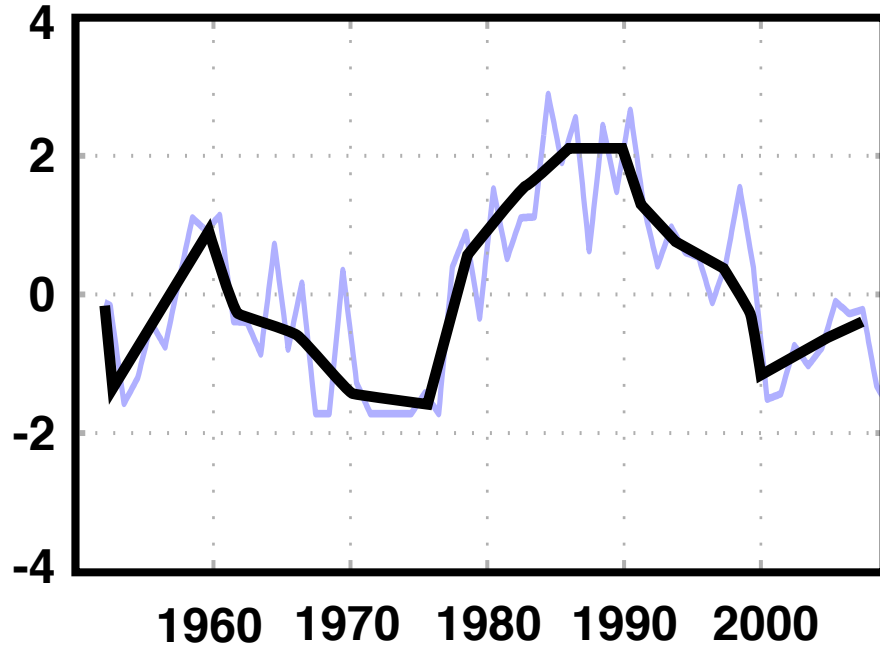
Euphausia pacifica



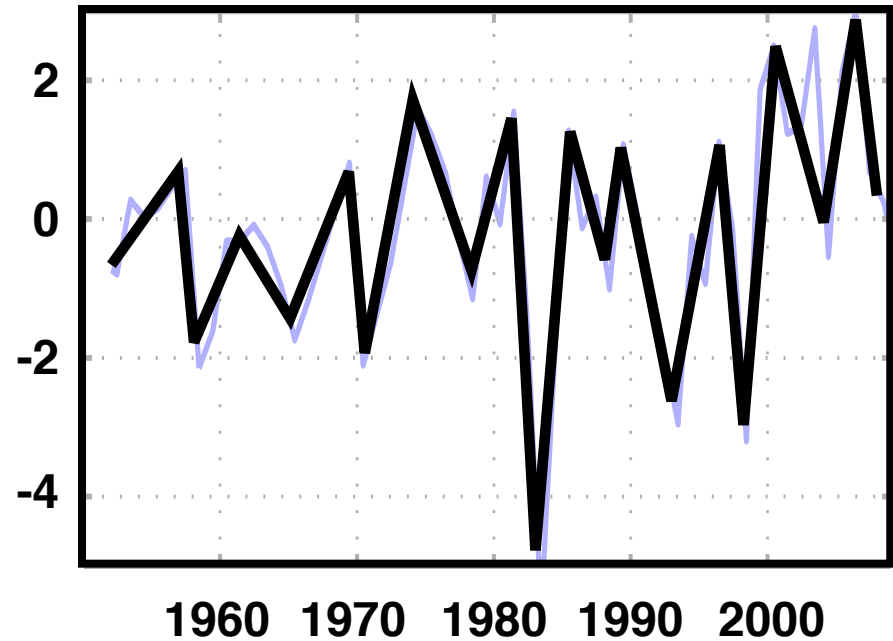
QUESTION:

Why do some zooplankton time series exhibit sudden and prolonged transitions on decadal scales?

Nyctiphanes simplex

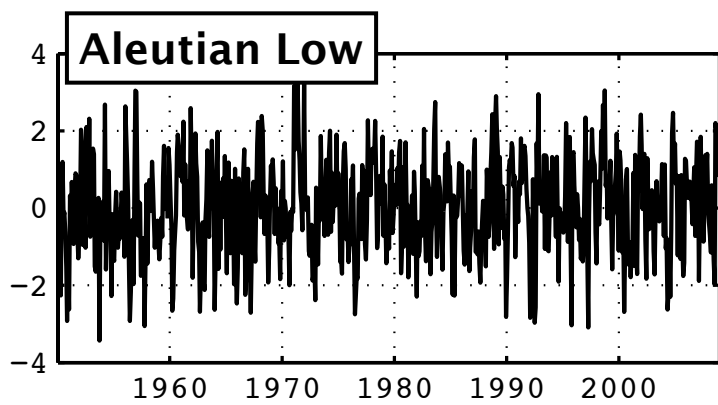


Euphausia pacifica



GOAL:

Develop a null hypothesis or conceptual model of ecosystem variability driven by climate forcing.

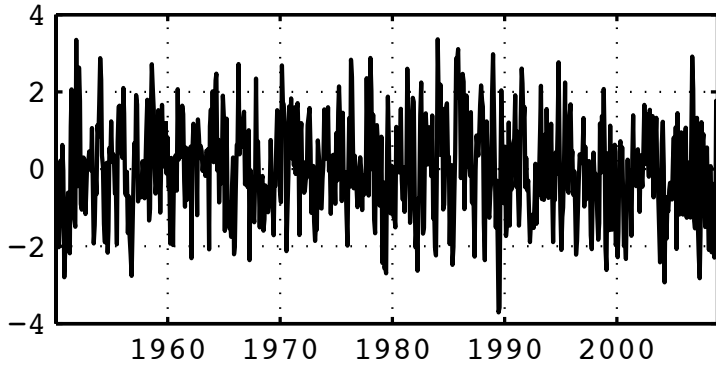
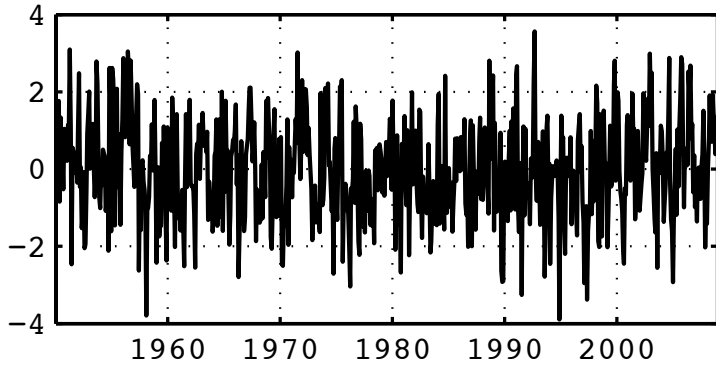
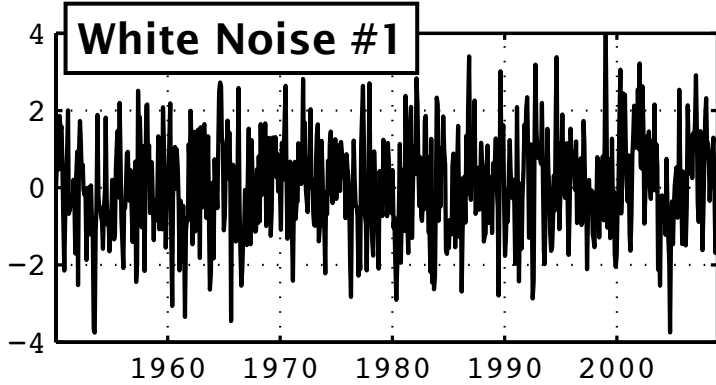
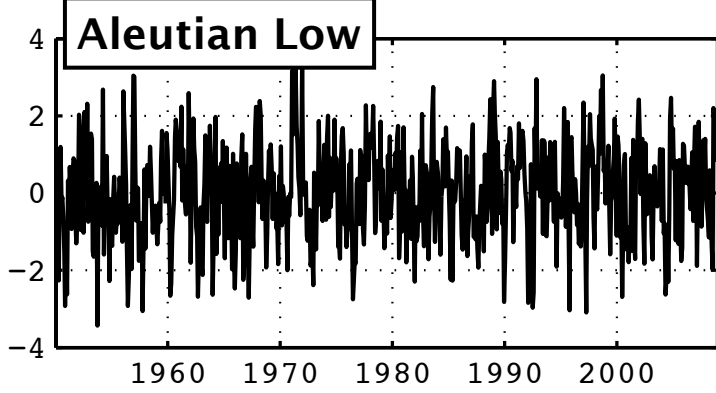


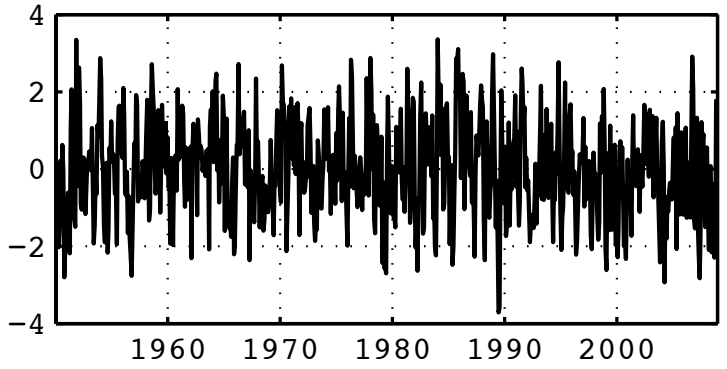
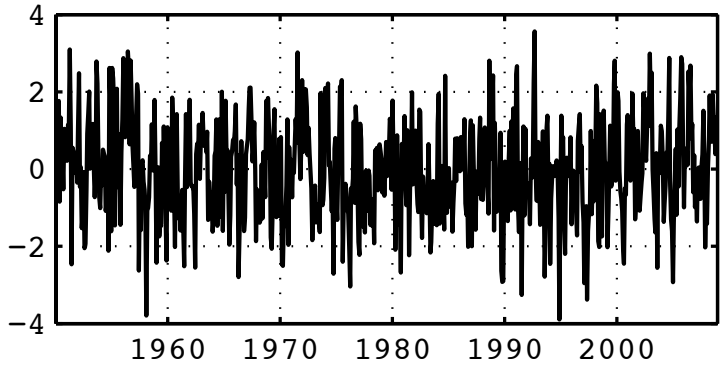
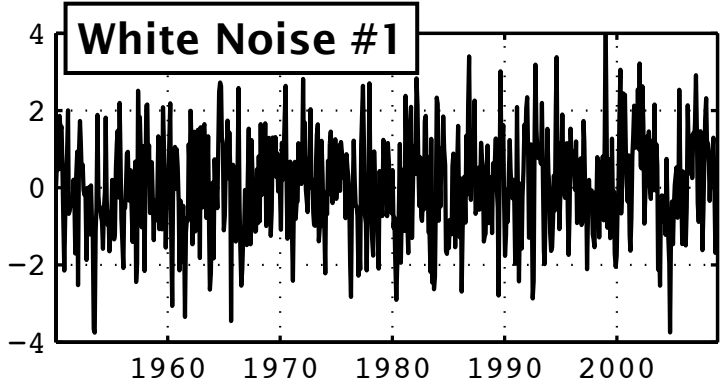
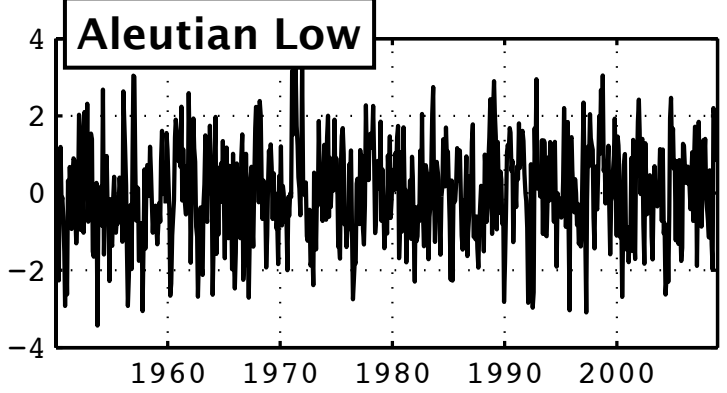
Atmosphere

GOAL:

Develop a null hypothesis or conceptual model of ecosystem variability driven by climate forcing.

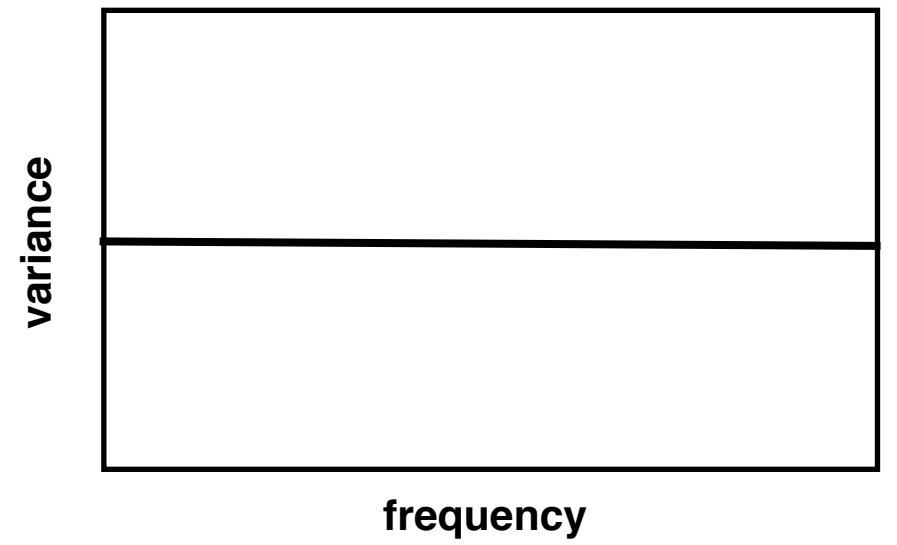
Atmosphere

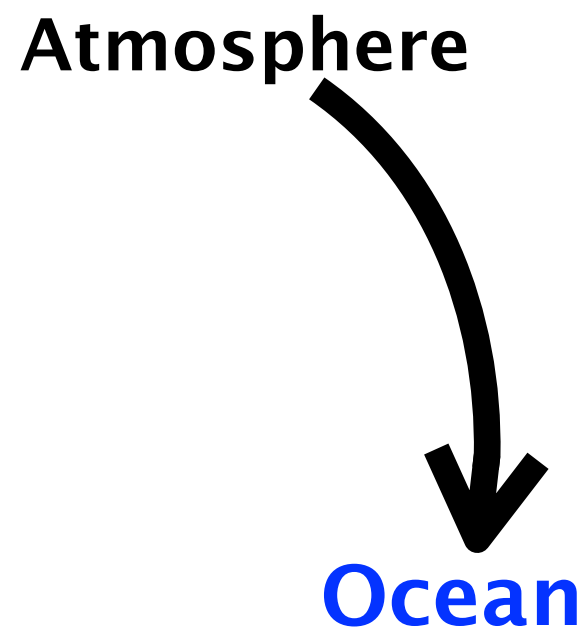
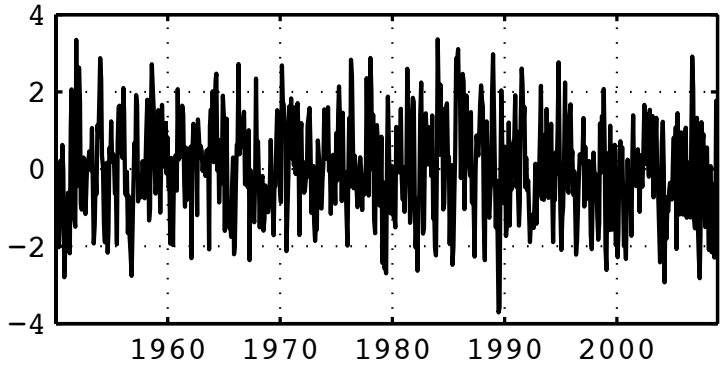
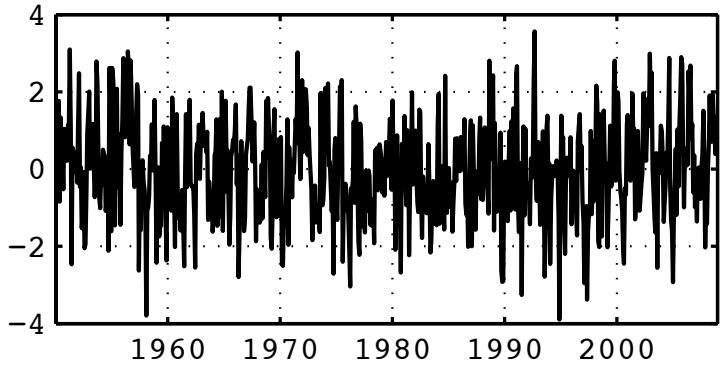
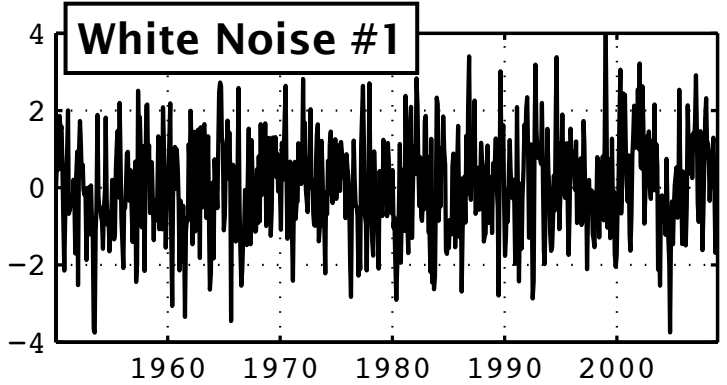
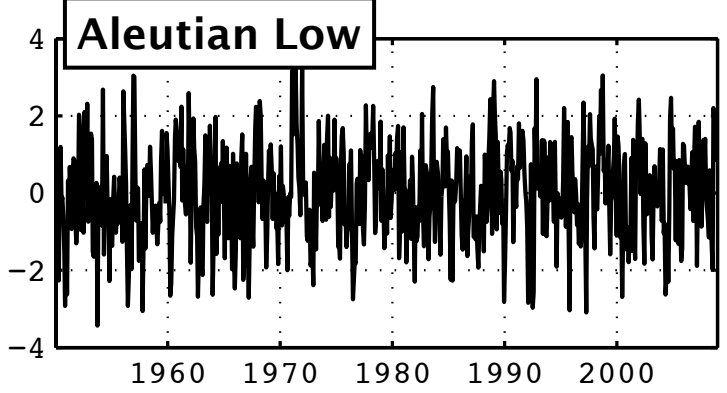


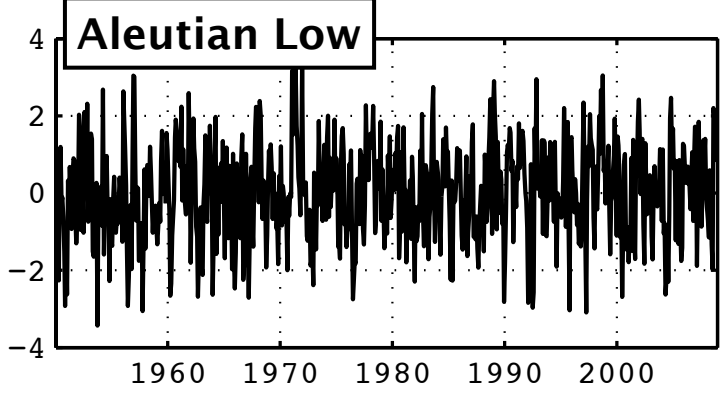


Atmosphere

White Noise (Spectrum)



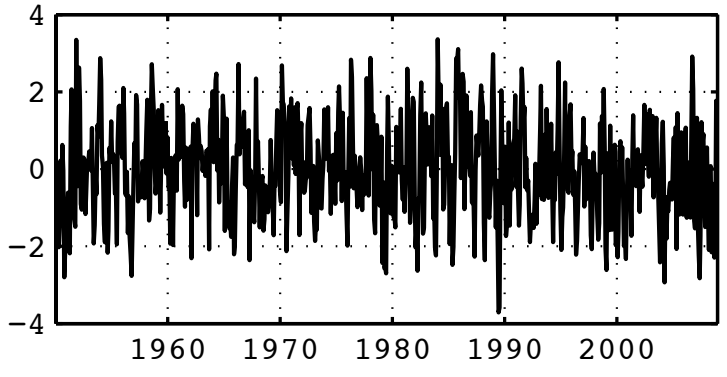
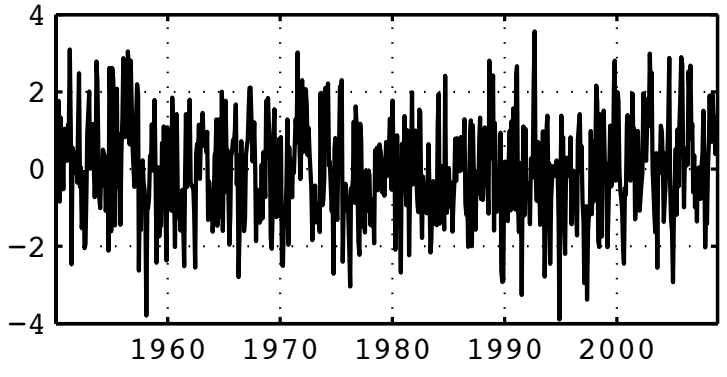
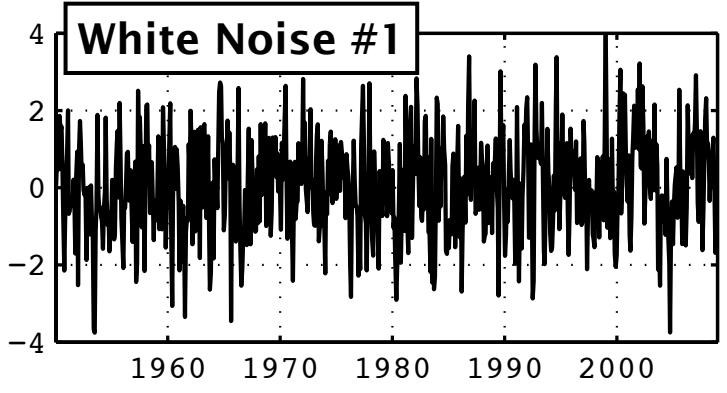
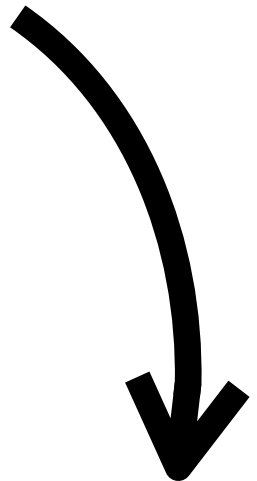


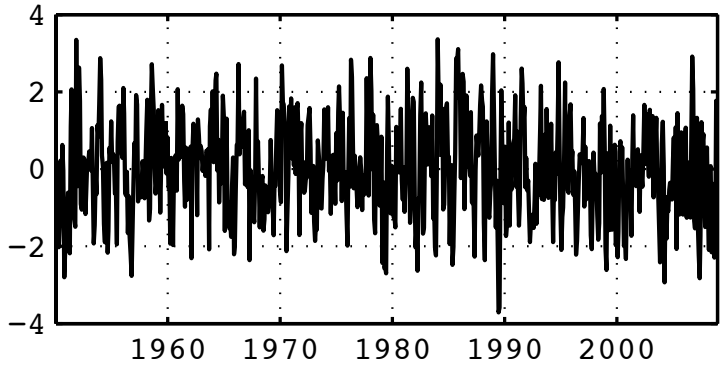
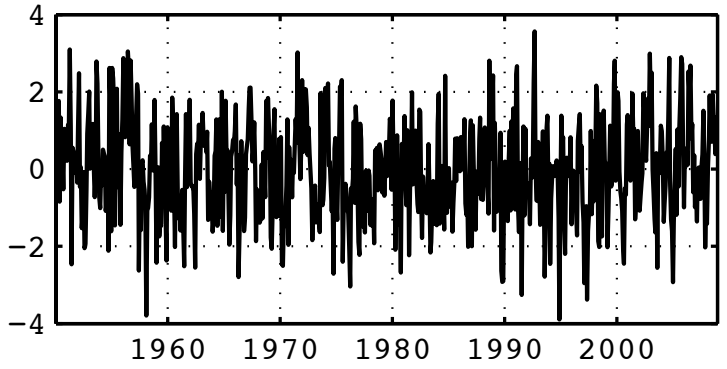
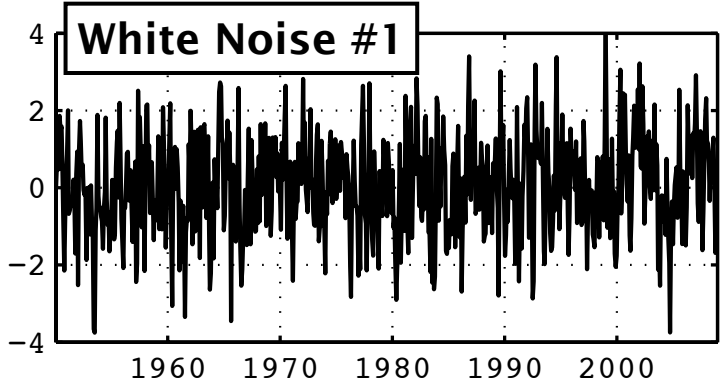
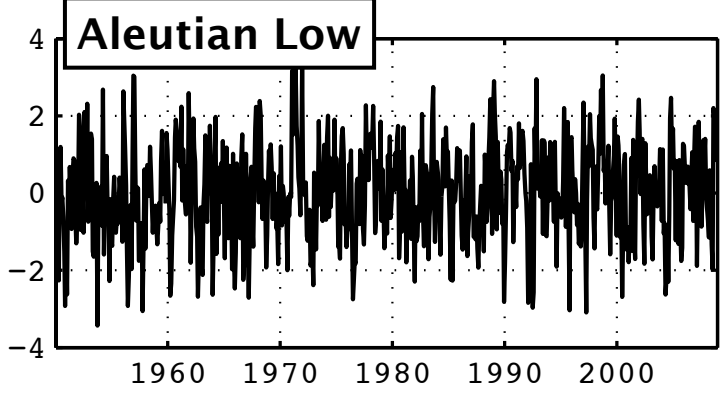


$f(t)$

Atmosphere

Ocean

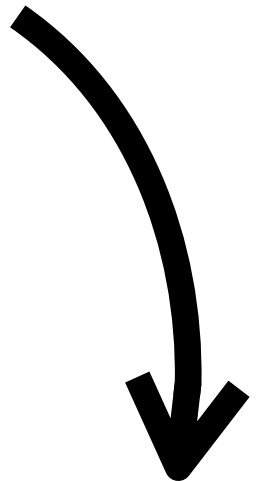




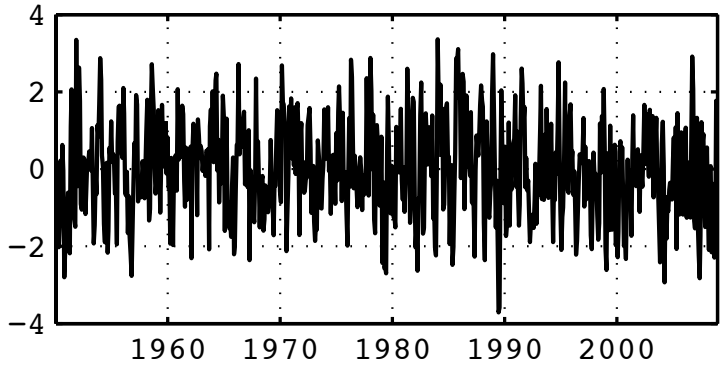
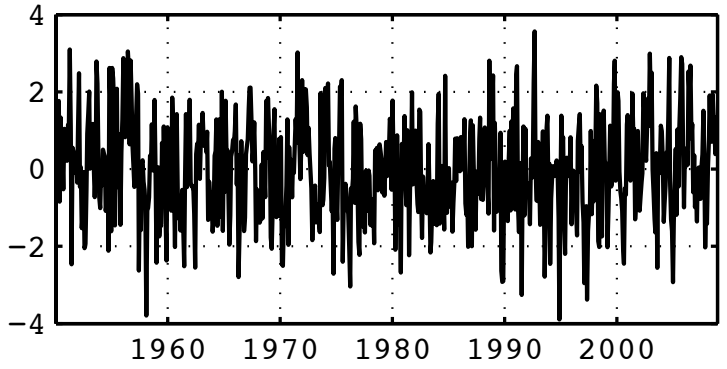
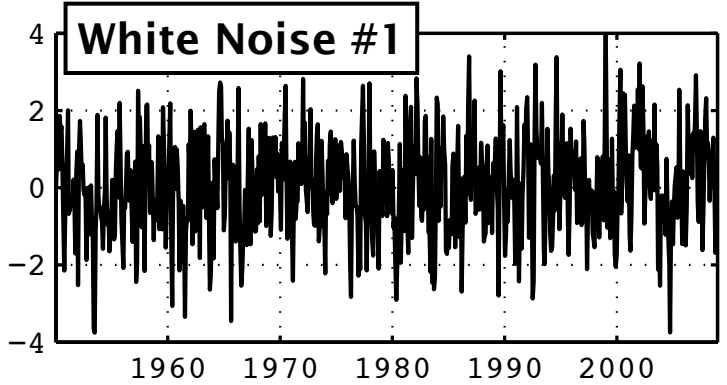
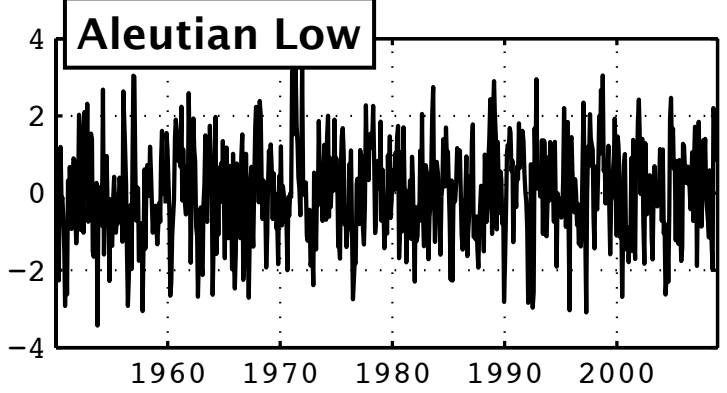
$$f(t)$$

$$\frac{d\varphi(t)}{dt} = f(t)$$

Atmosphere

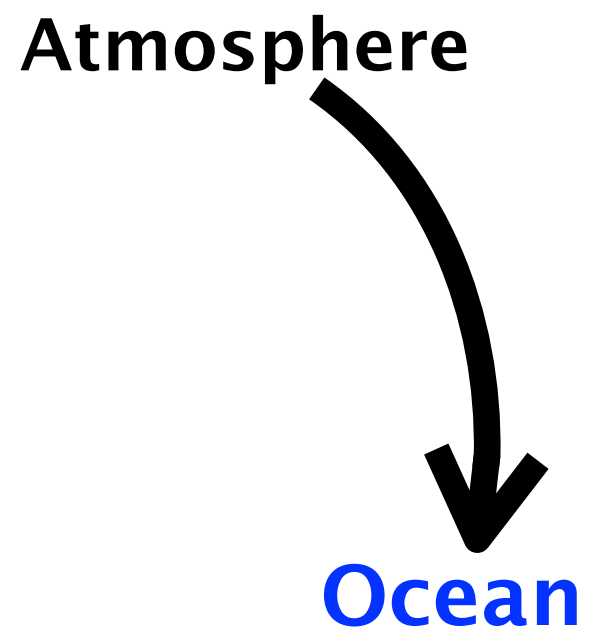


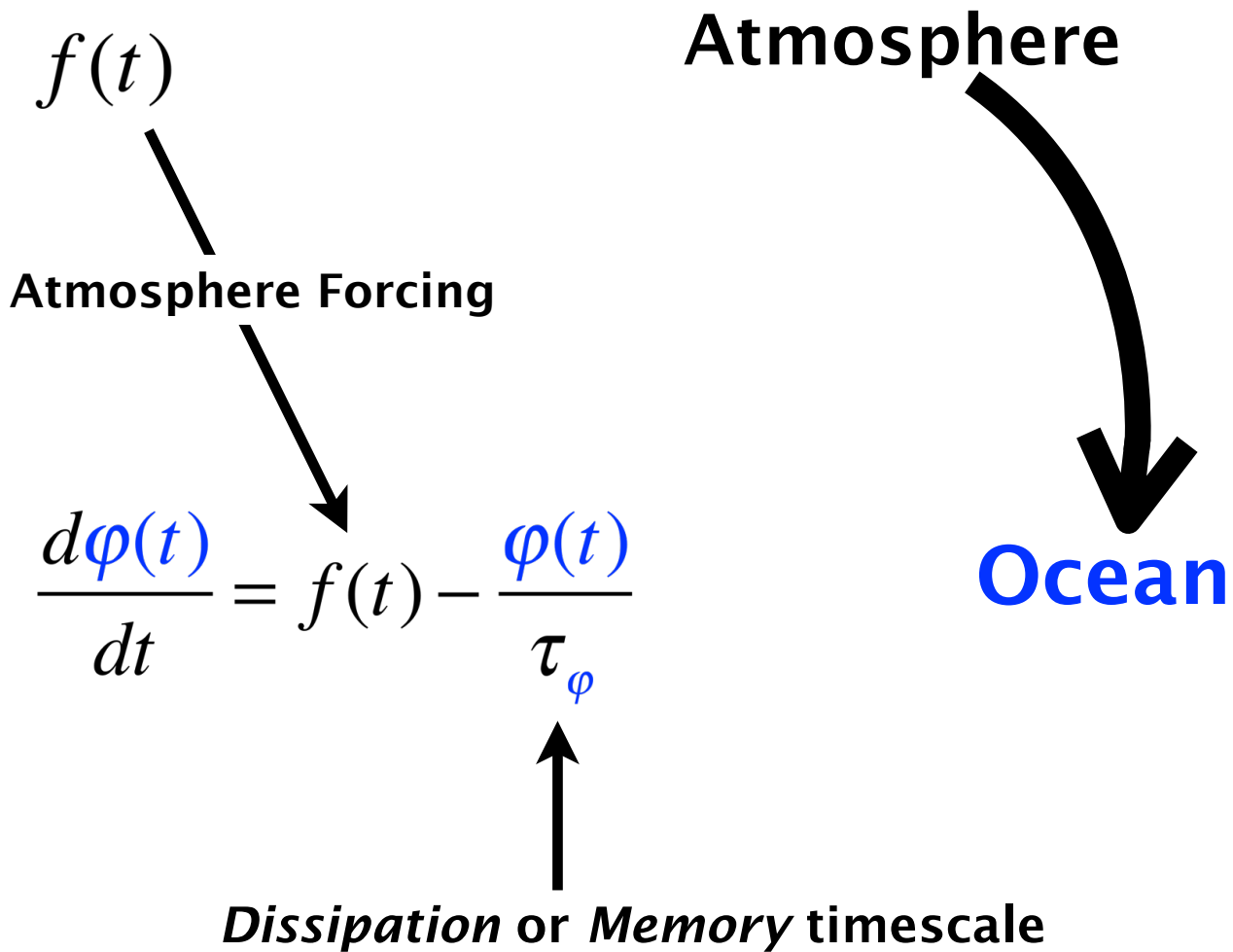
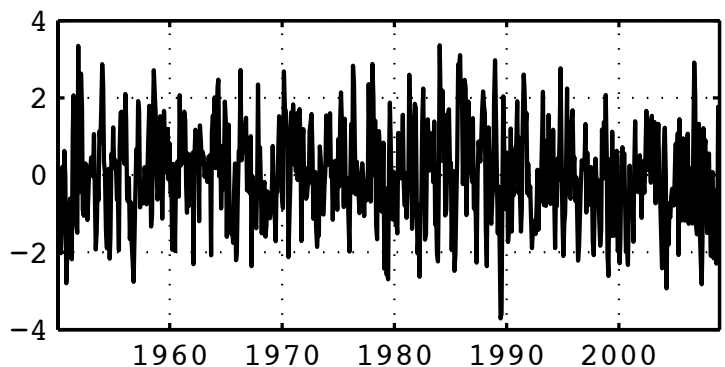
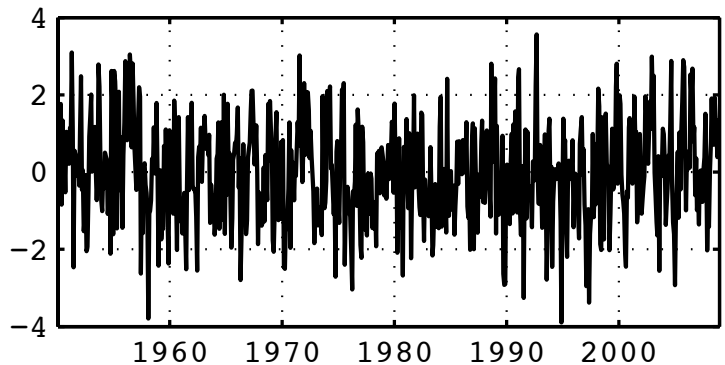
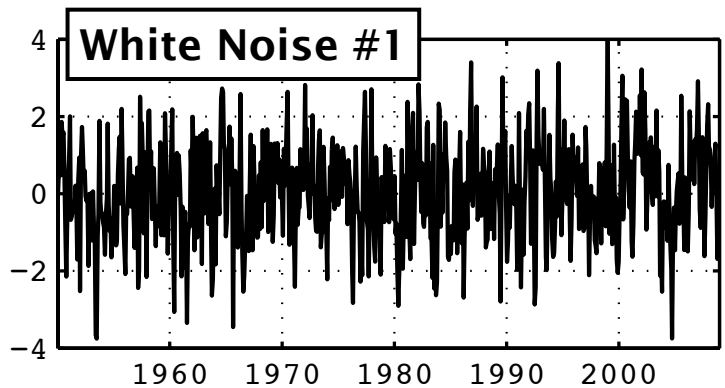
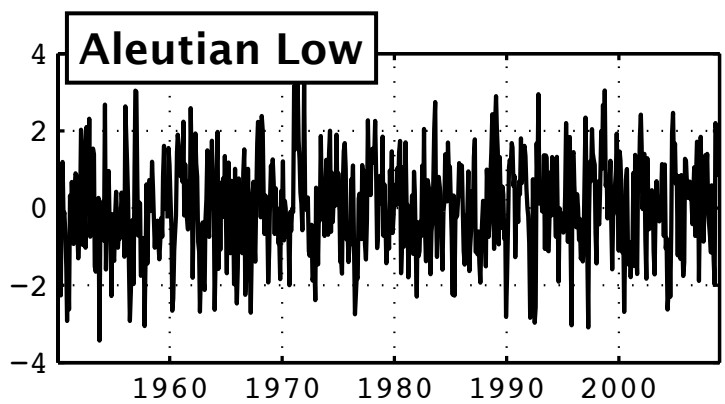
Ocean

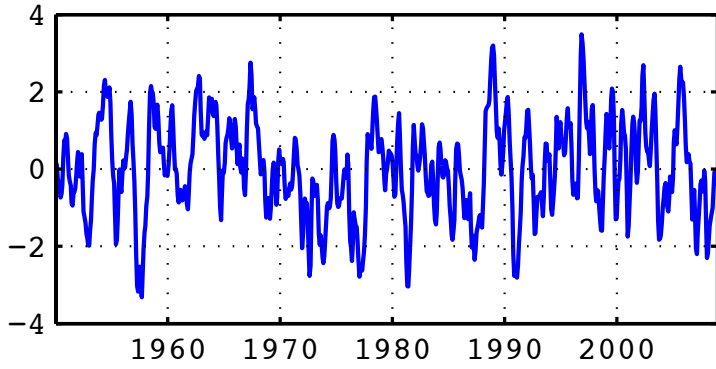
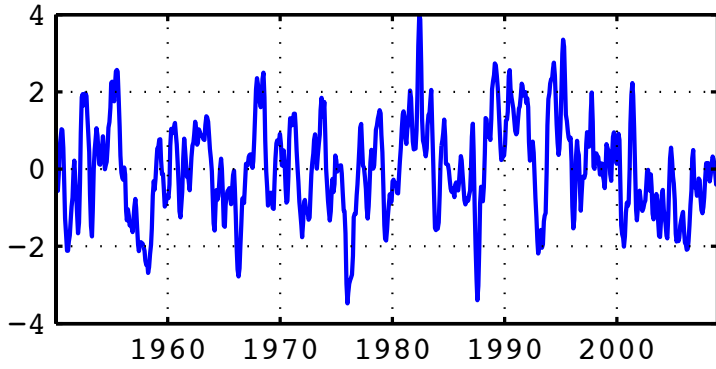
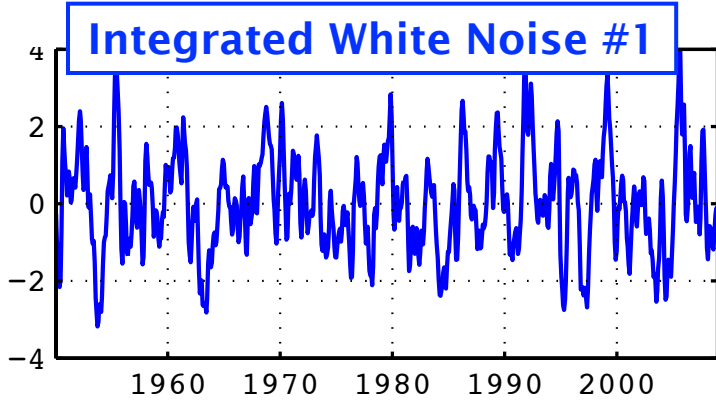
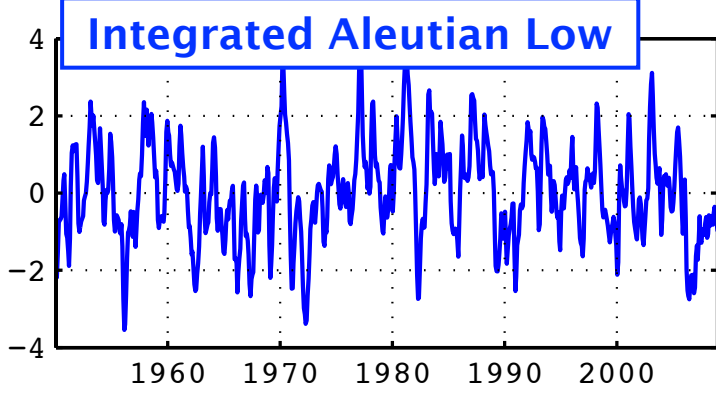


$f(t)$
Atmosphere Forcing

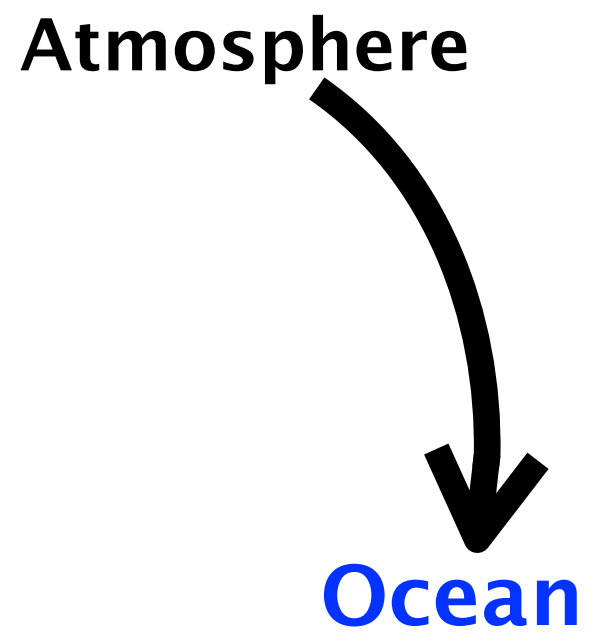
$$\frac{d\varphi(t)}{dt} = f(t)$$

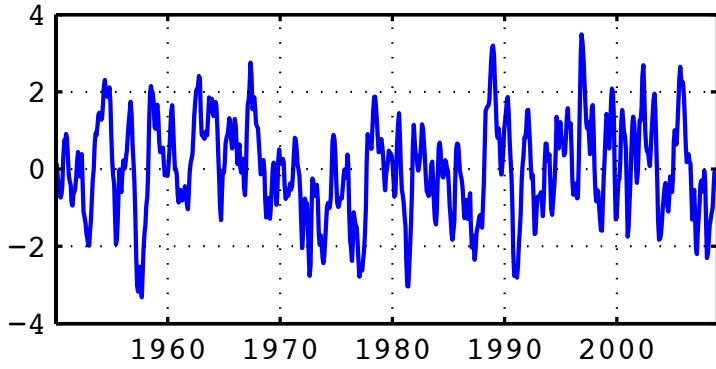
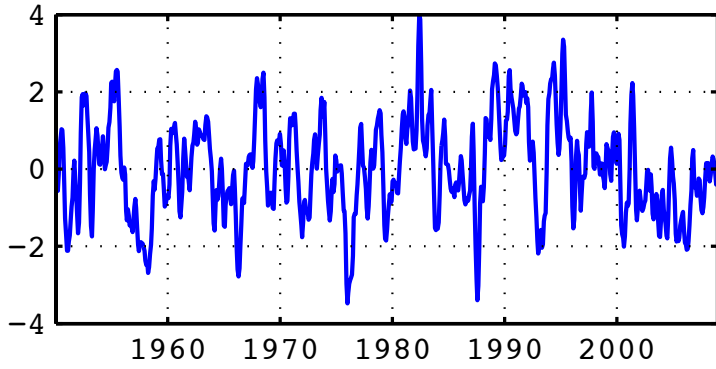
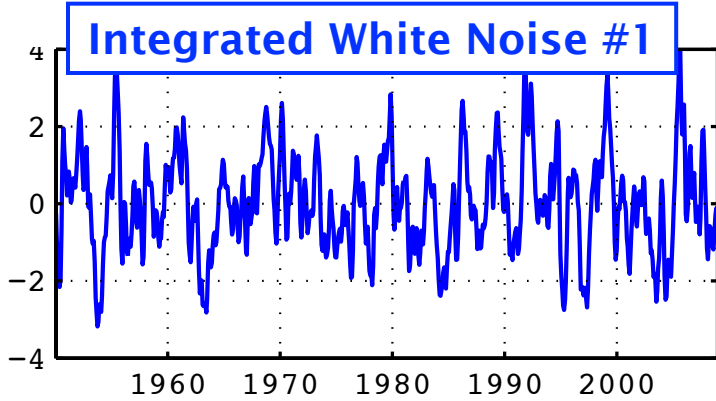
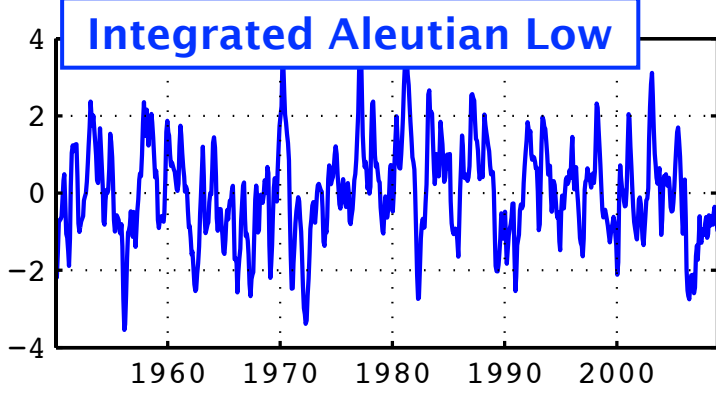




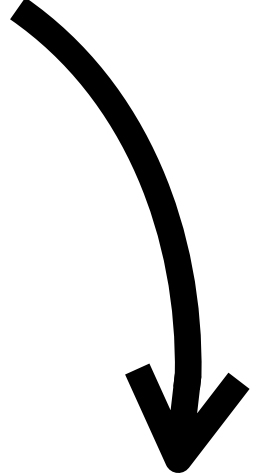


$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$





Atmosphere



Ocean

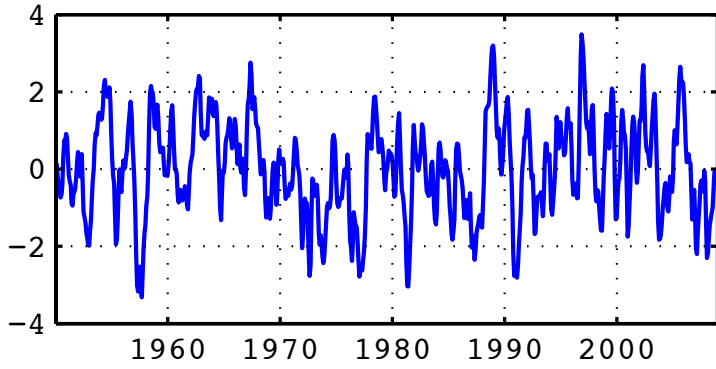
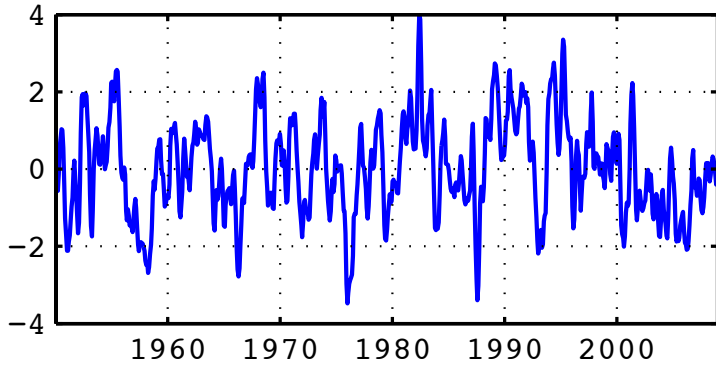
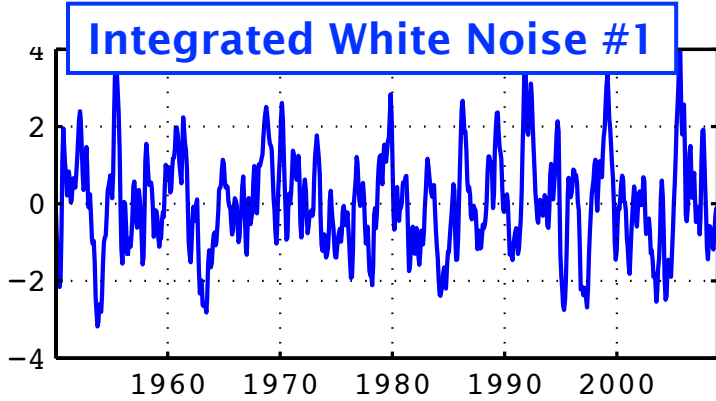
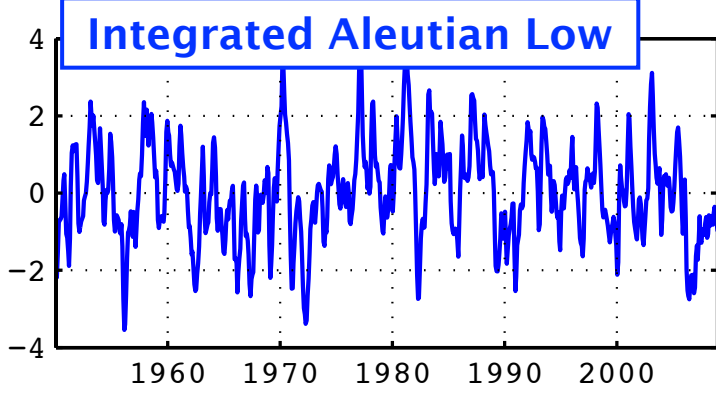
$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

AR-1 Model

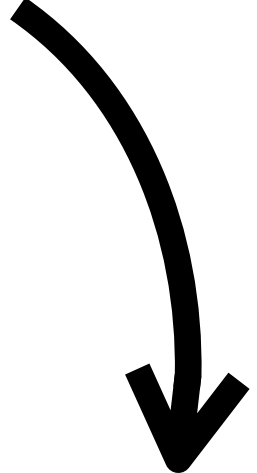
(Autoregressive Model of Order 1)



integration of white noise



Atmosphere

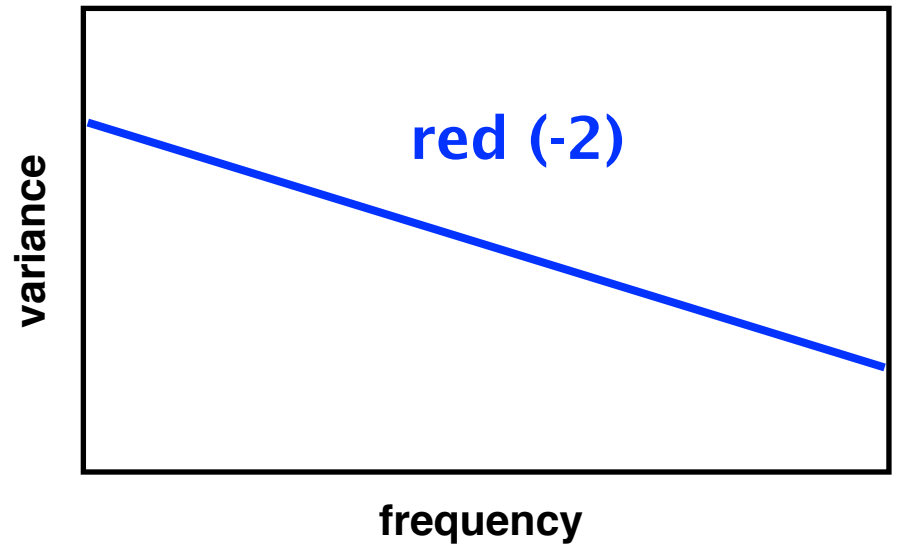


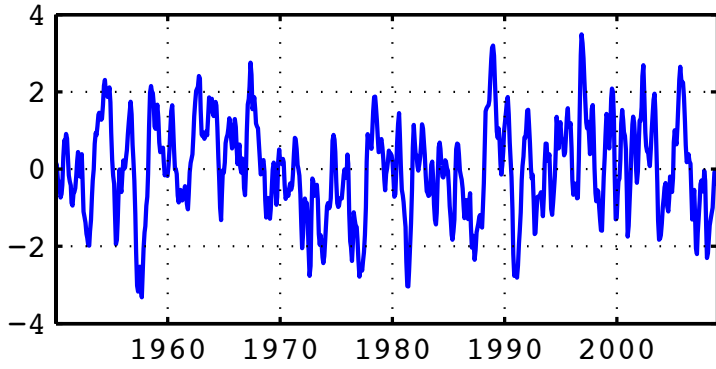
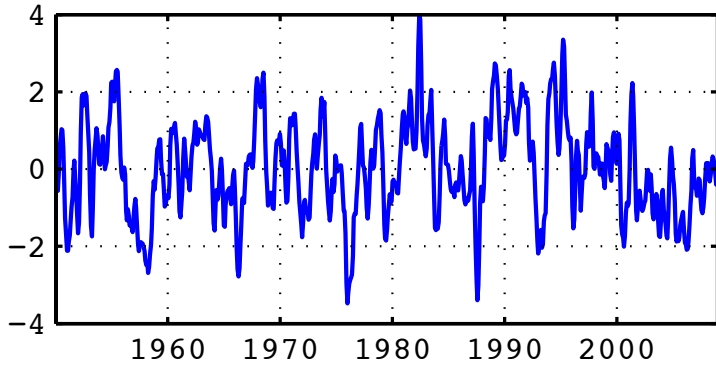
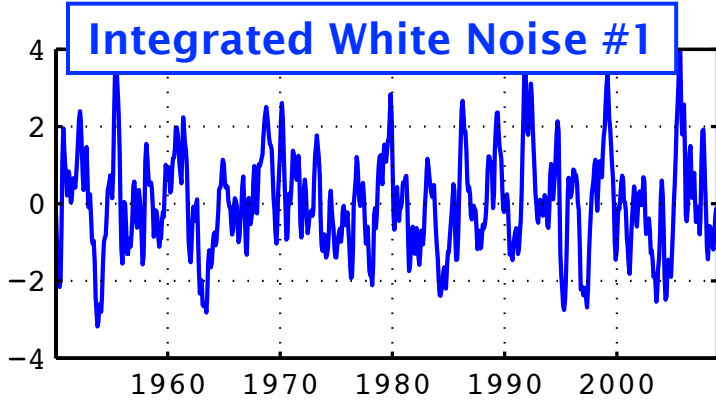
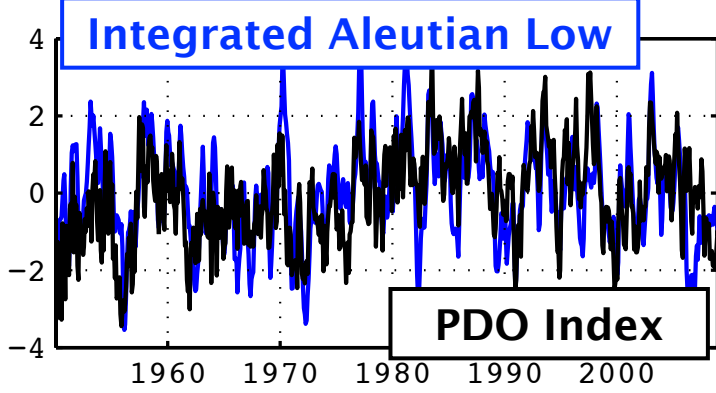
Ocean

$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

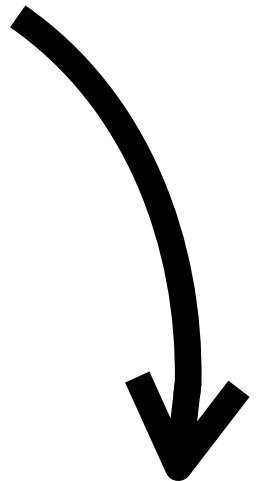
AR-1 Model

Red Noise (Spectrum)



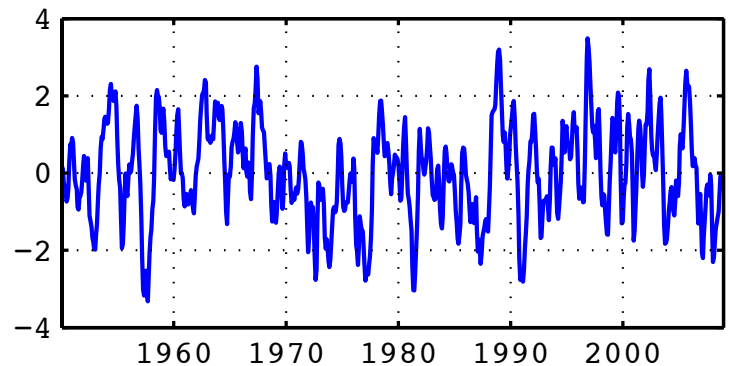
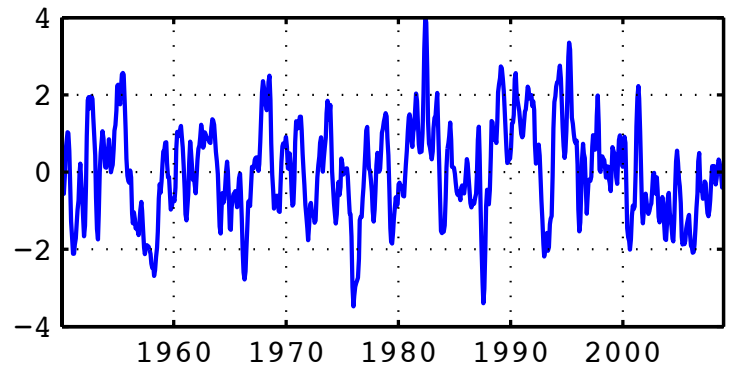
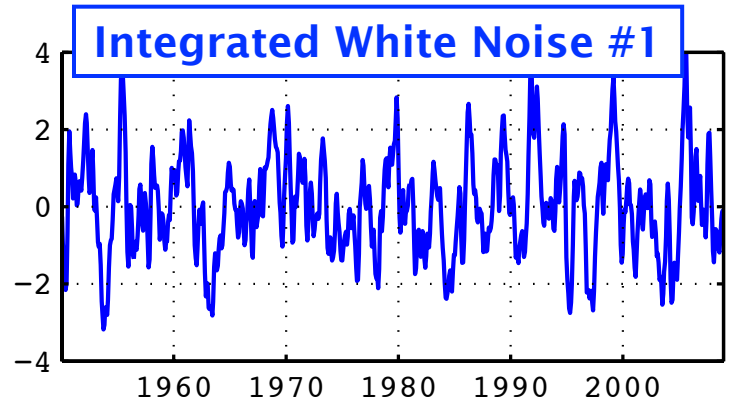
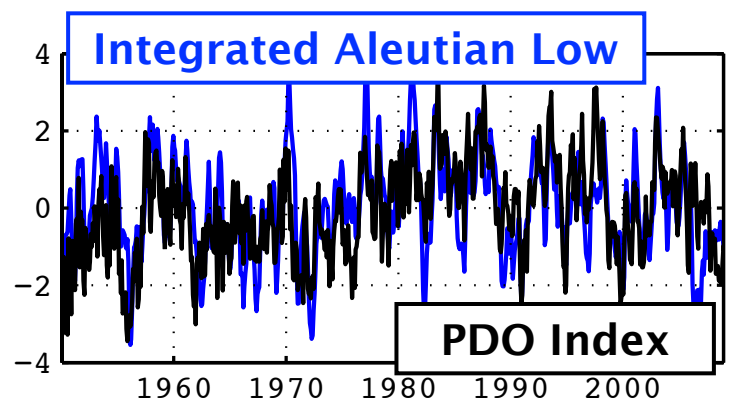


Atmosphere



Ocean

$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$



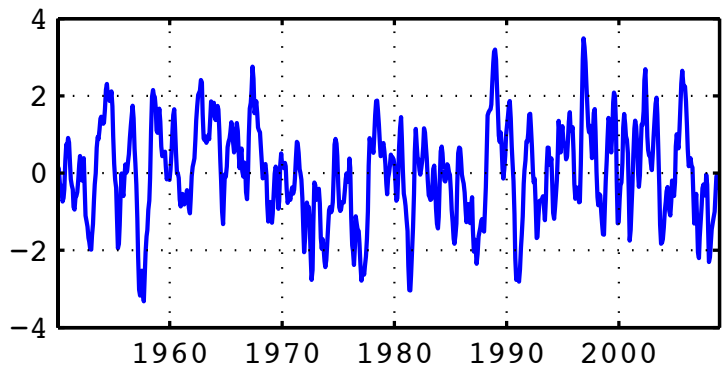
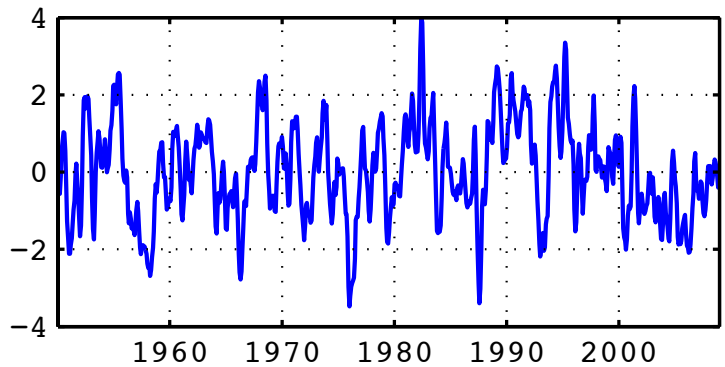
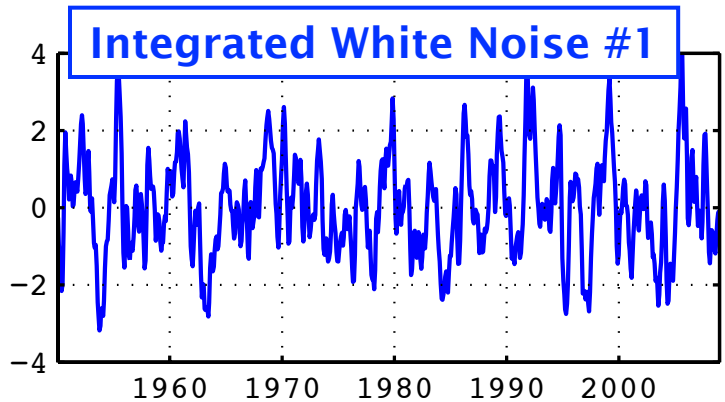
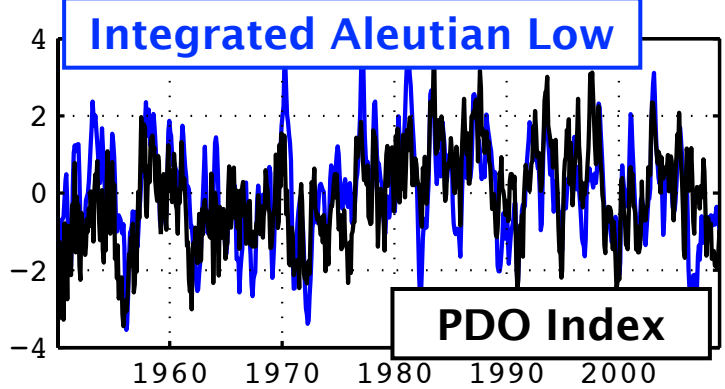
$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

Atmosphere

Ocean

Biology





$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

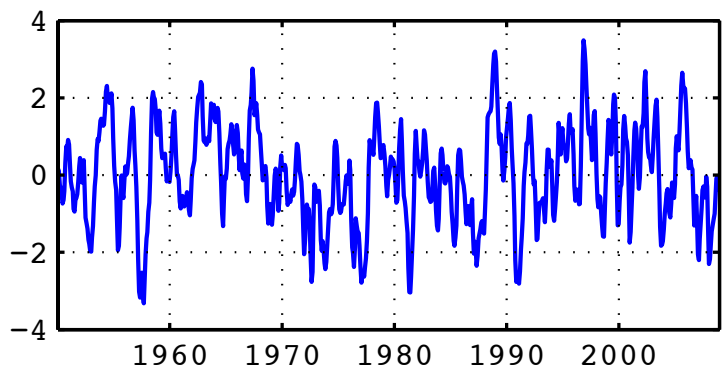
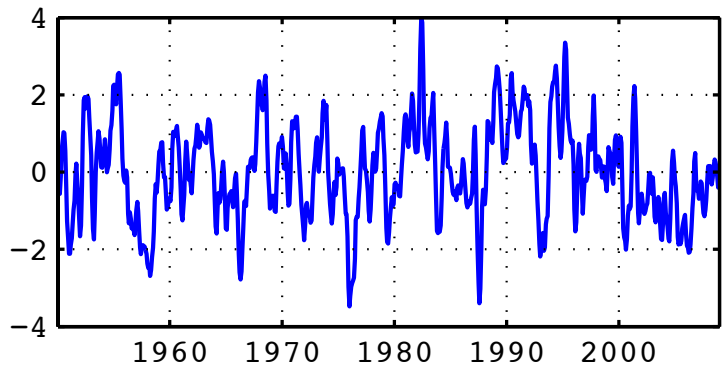
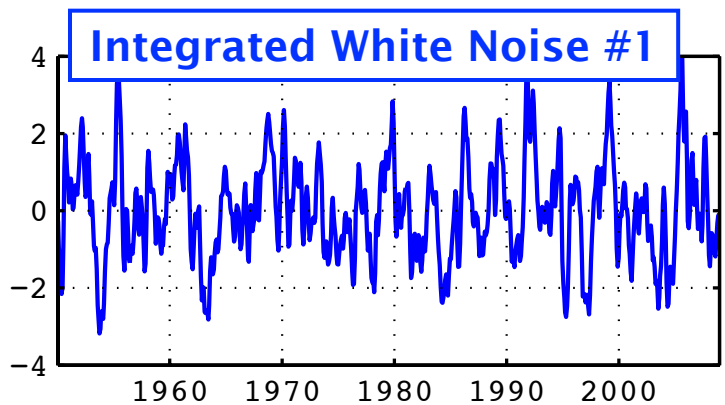
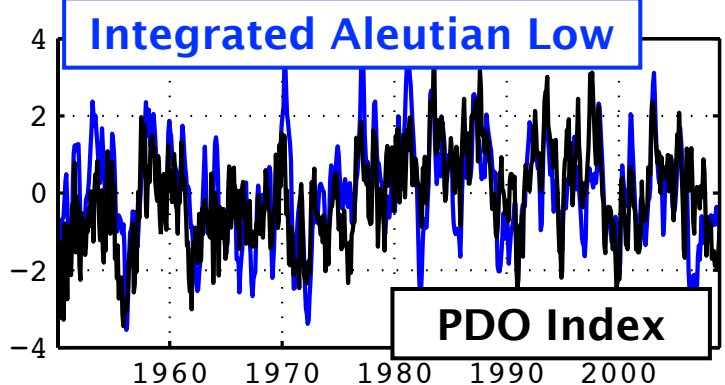
$$\frac{d\varepsilon(t)}{dt} = \varphi(t)$$

Atmosphere

Ocean

Biology





$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

Ocean Forcing

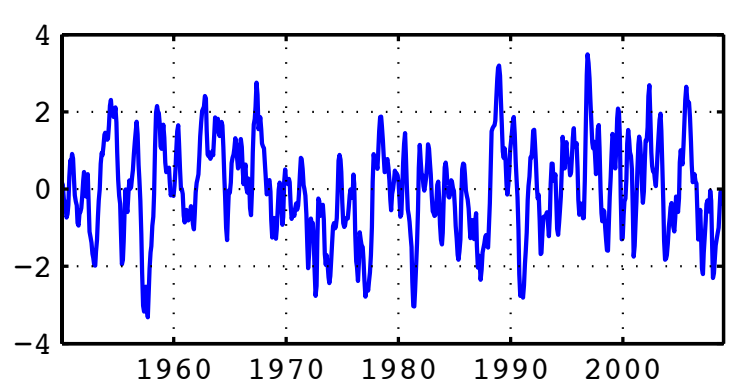
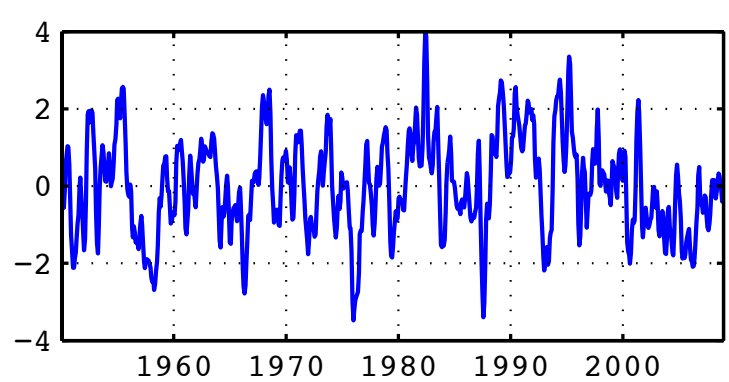
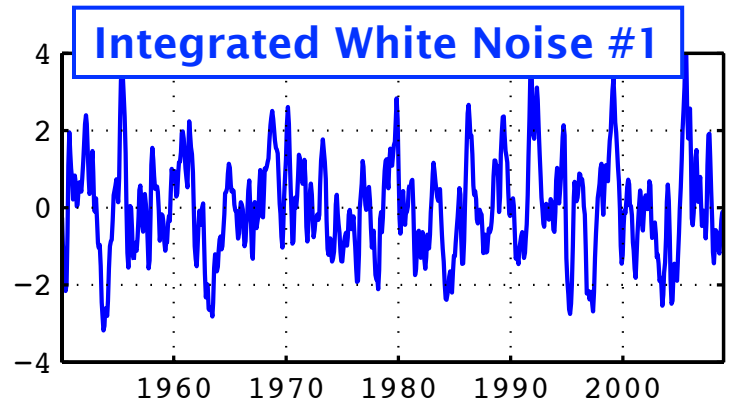
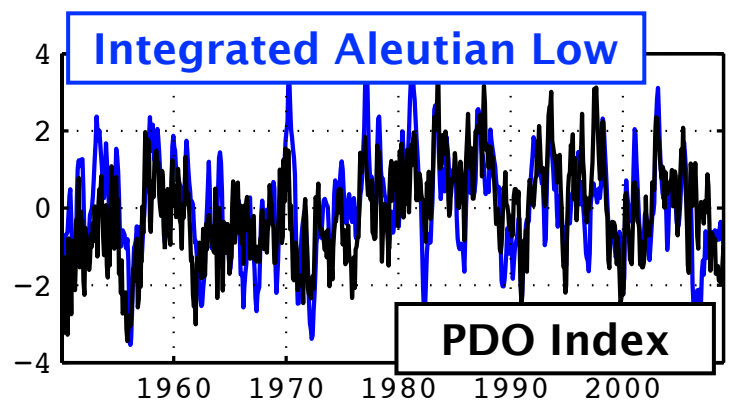
$$\frac{d\mathcal{E}(t)}{dt} = \varphi(t)$$

Atmosphere

Ocean

Biology





$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

Ocean Forcing

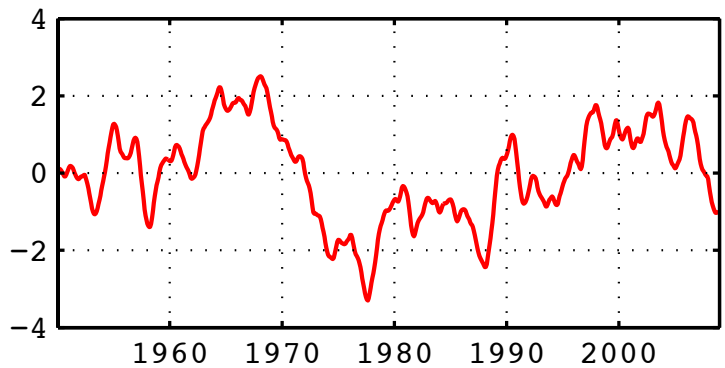
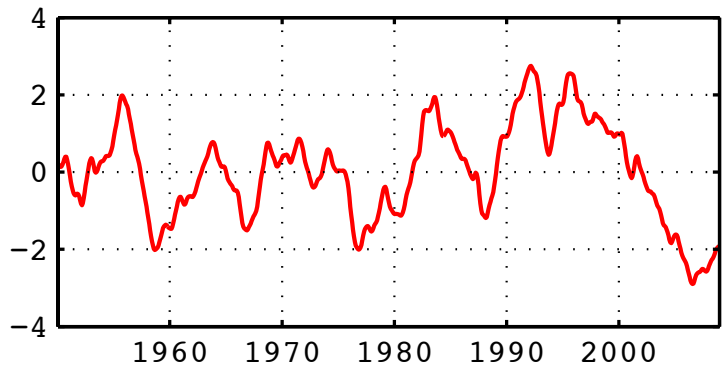
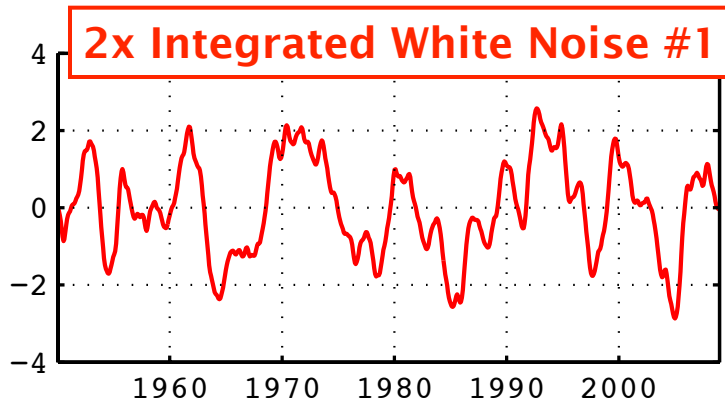
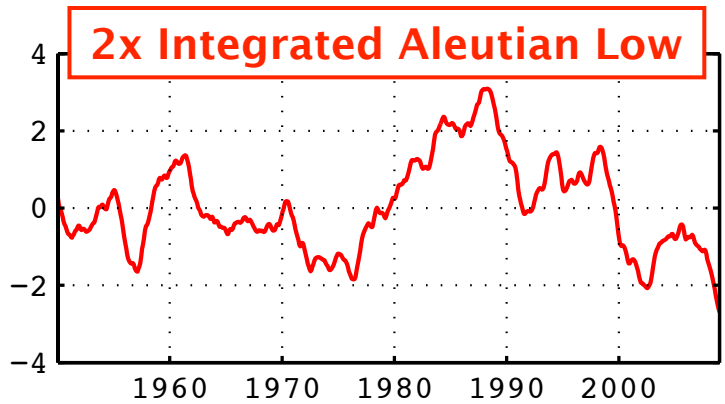
$$\frac{d\varepsilon(t)}{dt} = \varphi(t) - \frac{\varepsilon(t)}{\tau_\varepsilon}$$

Dissipation or Memory timescale

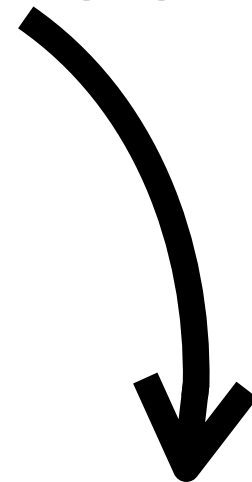
Atmosphere

Ocean

Biology



Atmosphere



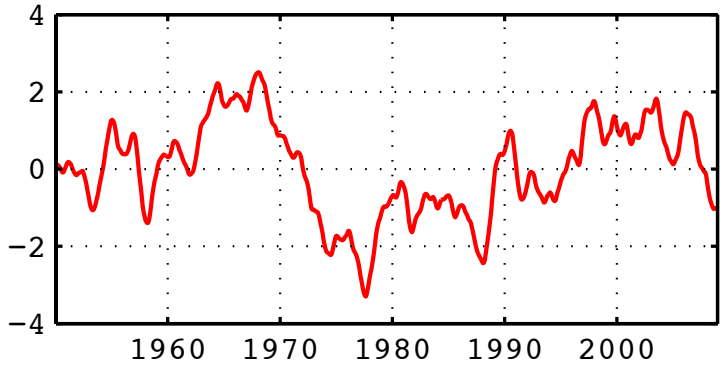
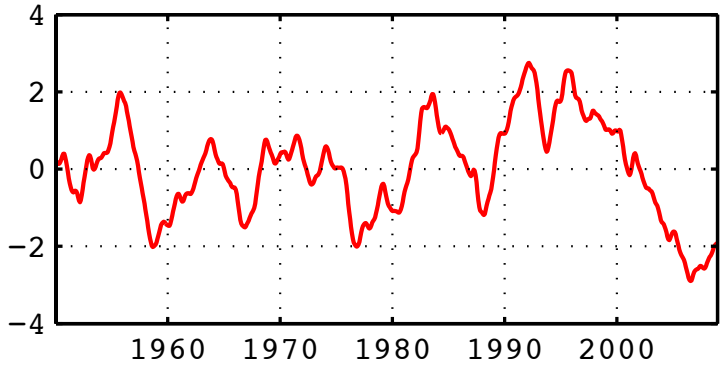
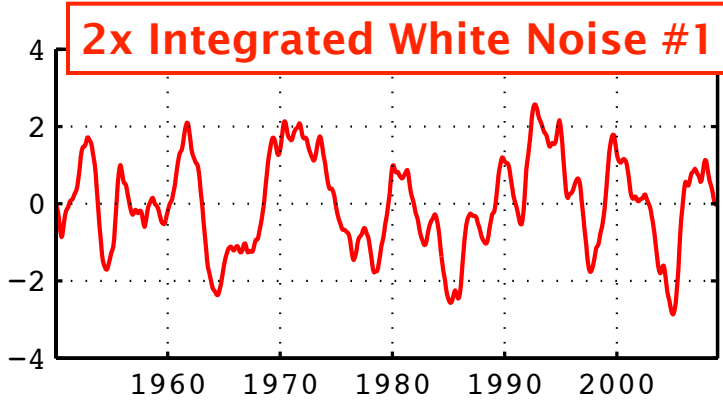
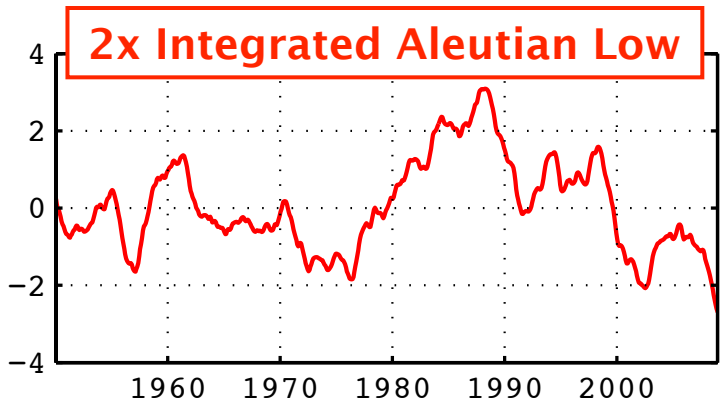
Ocean



Biology

Biology

$$\frac{d\varepsilon(t)}{dt} = \varphi(t) - \frac{\varepsilon(t)}{\tau_\varepsilon}$$



1 x integration

2 x integration

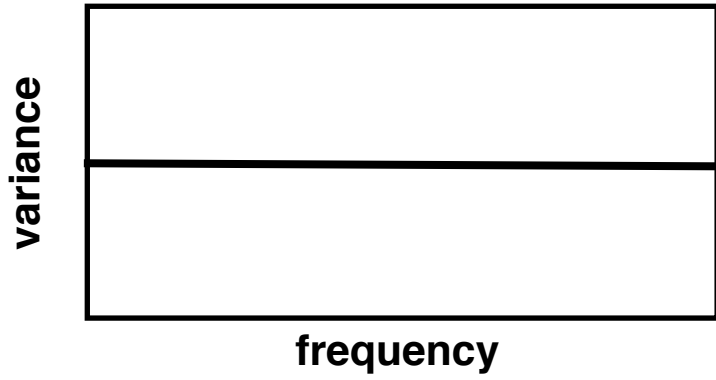
Atmosphere

Ocean

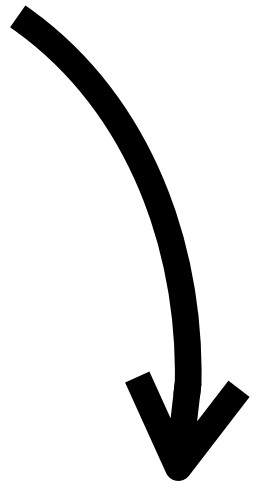
Biology



White Noise (Spectrum)

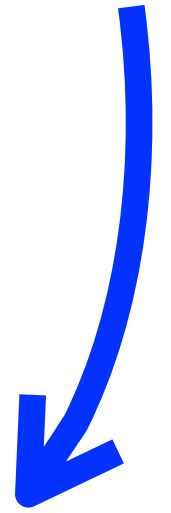


Atmosphere



1 x integration

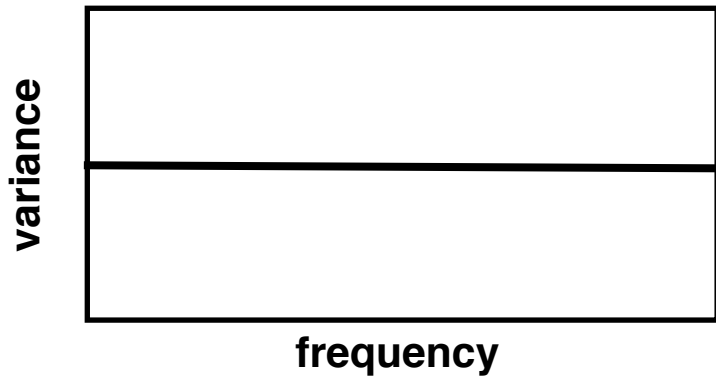
Ocean



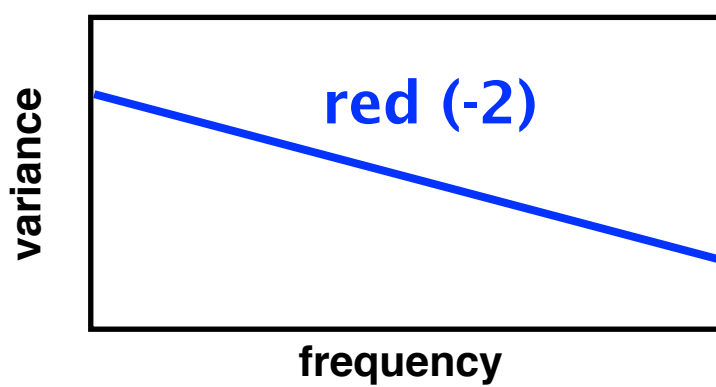
2 x integration

Biology

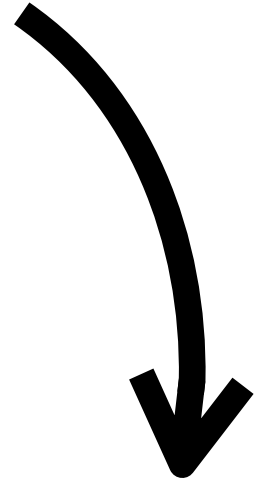
White Noise (Spectrum)



Red Noise (Spectrum)



Atmosphere

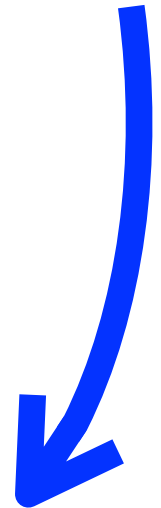


1 x integration

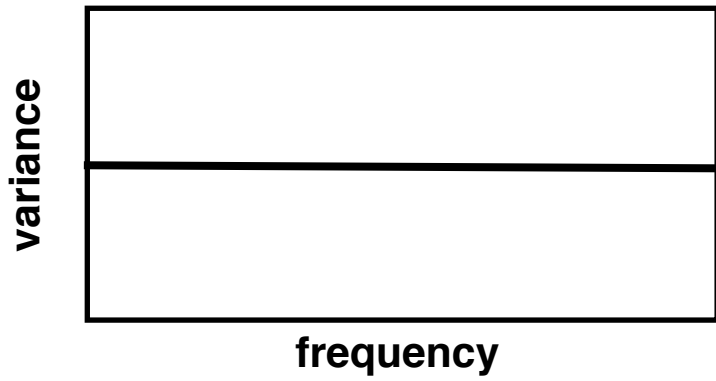
Ocean

2 x integration

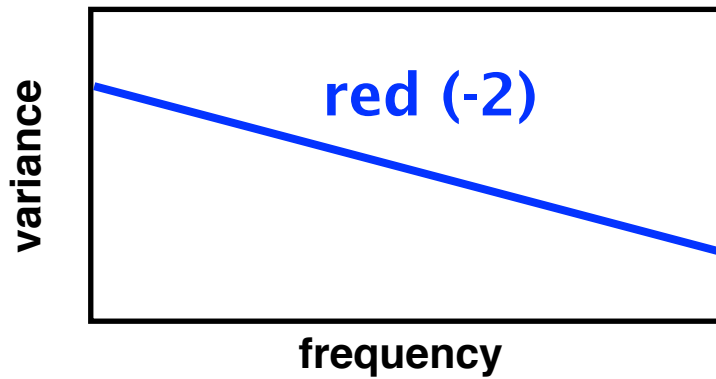
Biology



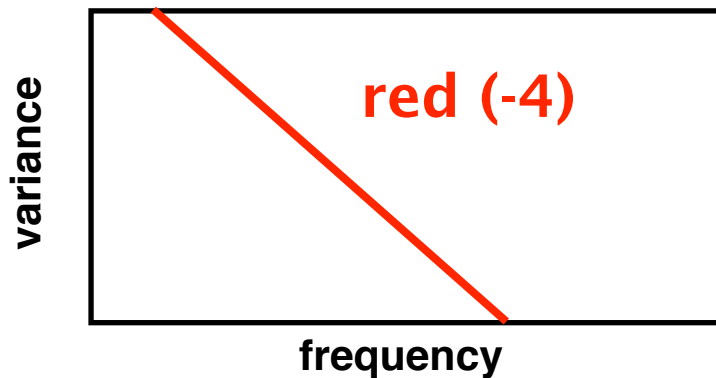
White Noise (Spectrum)



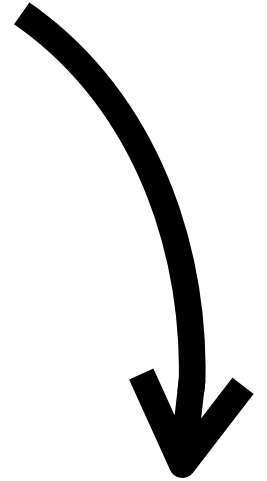
Red Noise (Spectrum)



VERY Red Noise (Spectrum)

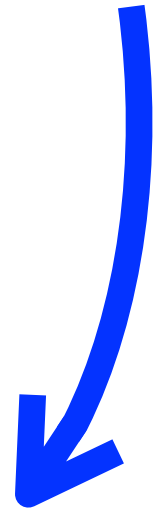


Atmosphere



1 x integration

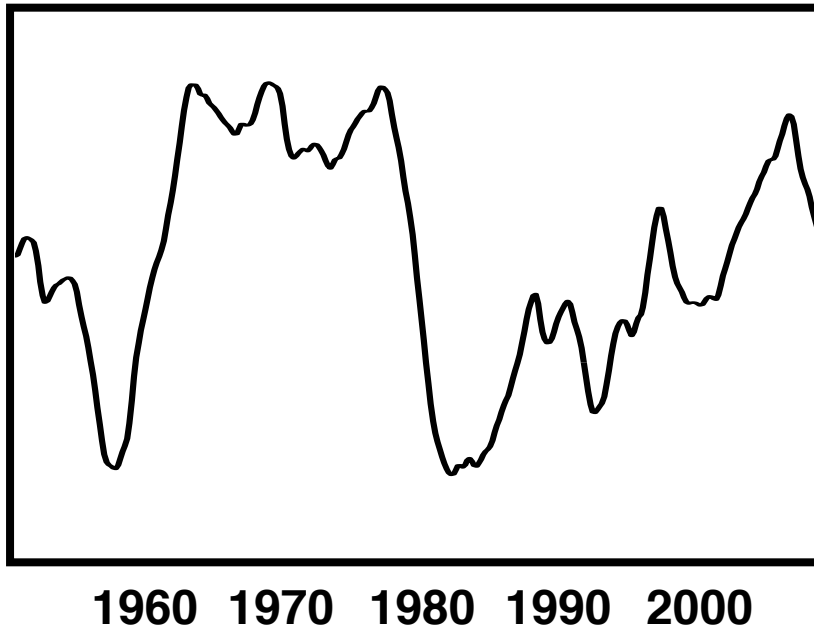
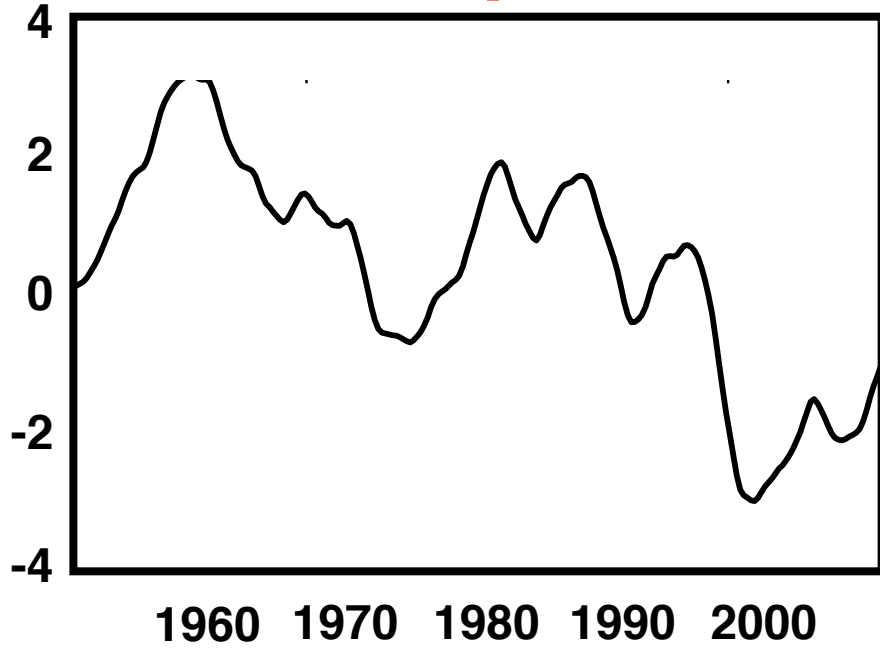
Ocean



2 x integration

Biology

Examples



2 x integration

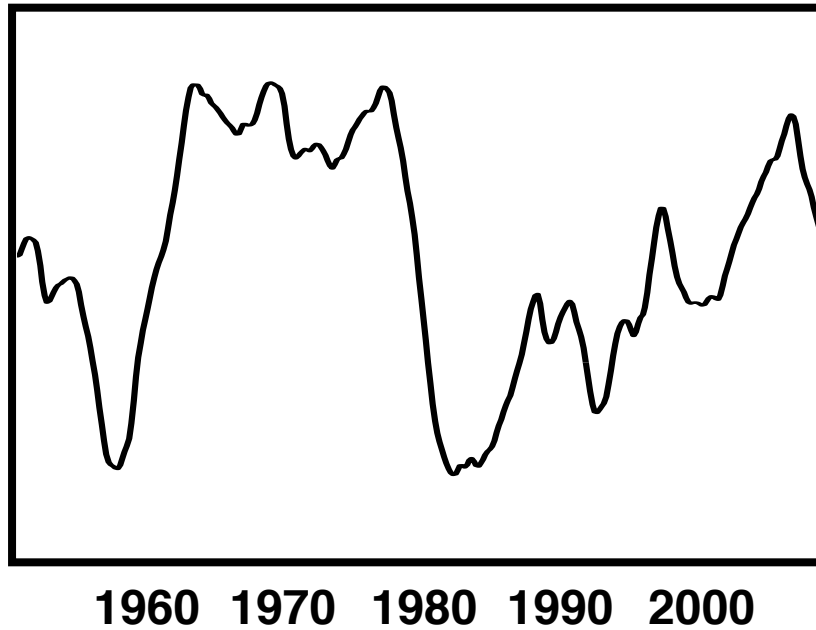
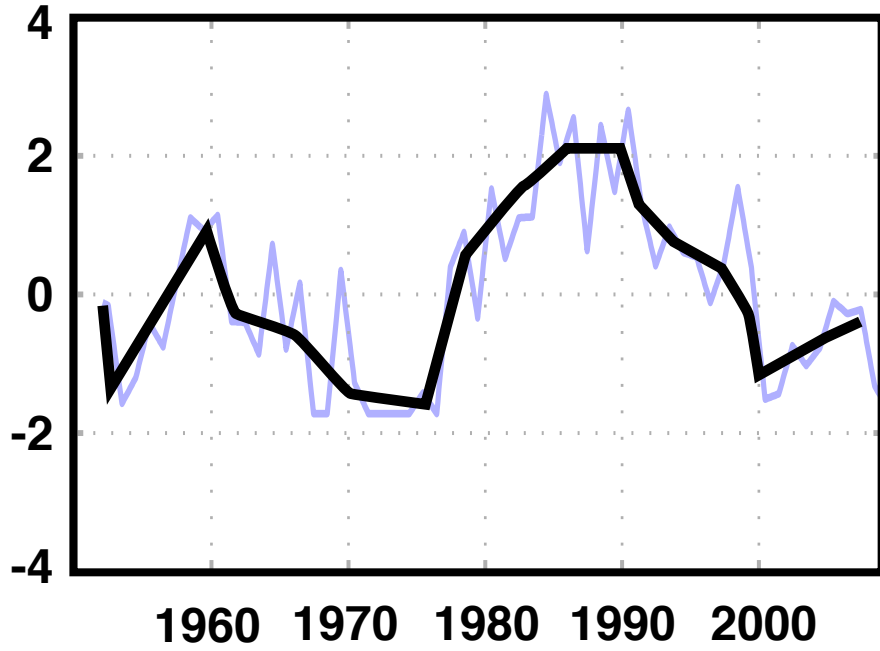
Atmosphere

Ocean

Biology



Nyctiphanes simplex



2 x integration

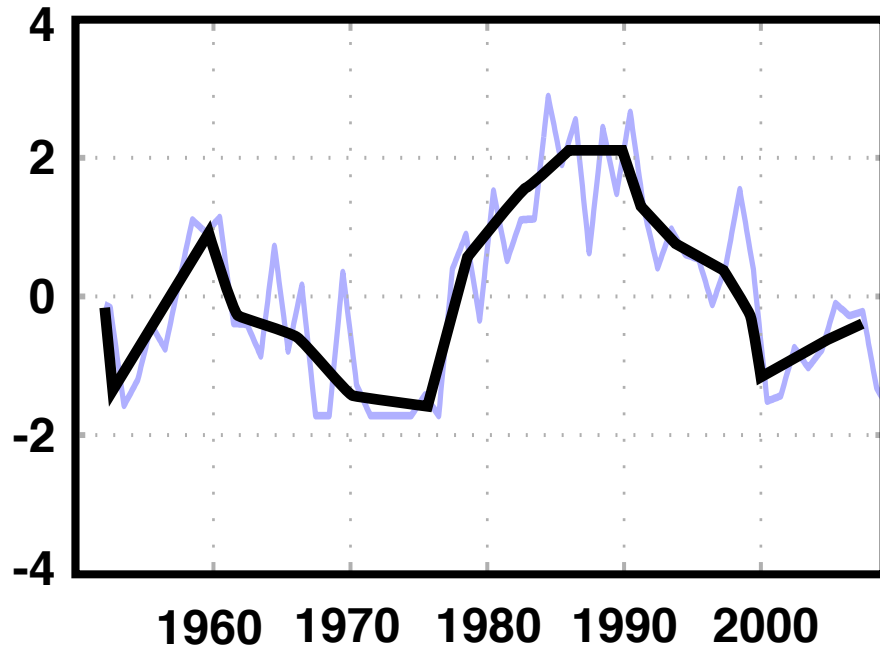
Atmosphere

Ocean

Biology



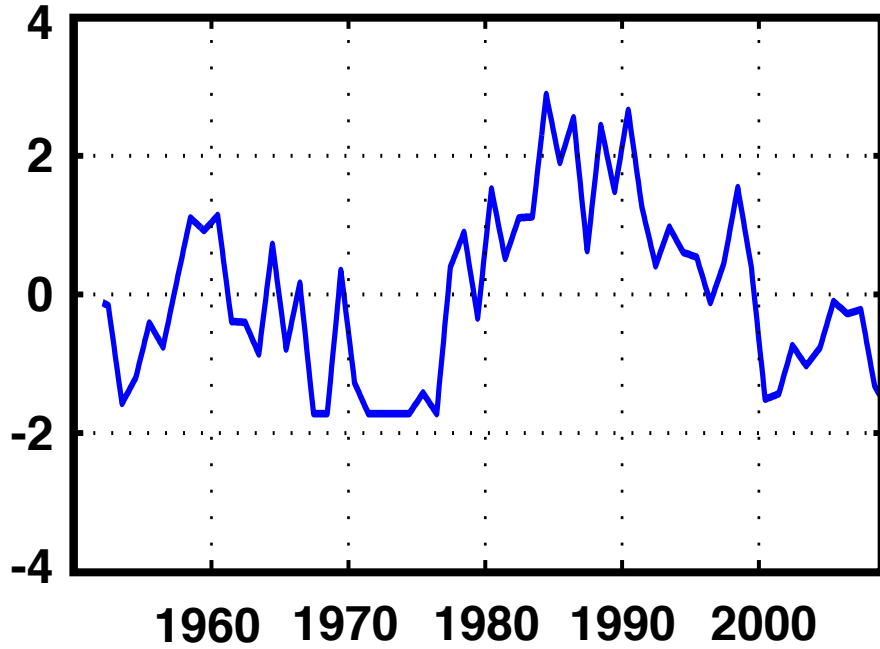
Nyctiphanes simplex



QUESTION:

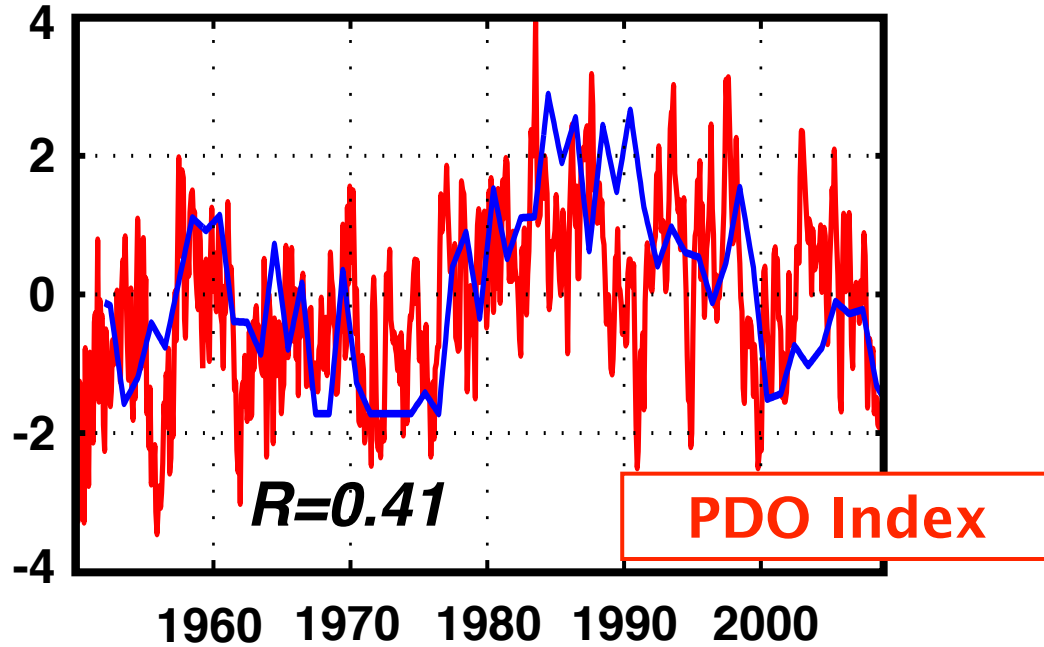
Is the Zooplankton timeseries in the California Current an example of multiple integrations of the climate forcing?

Nyctiphanes simplex



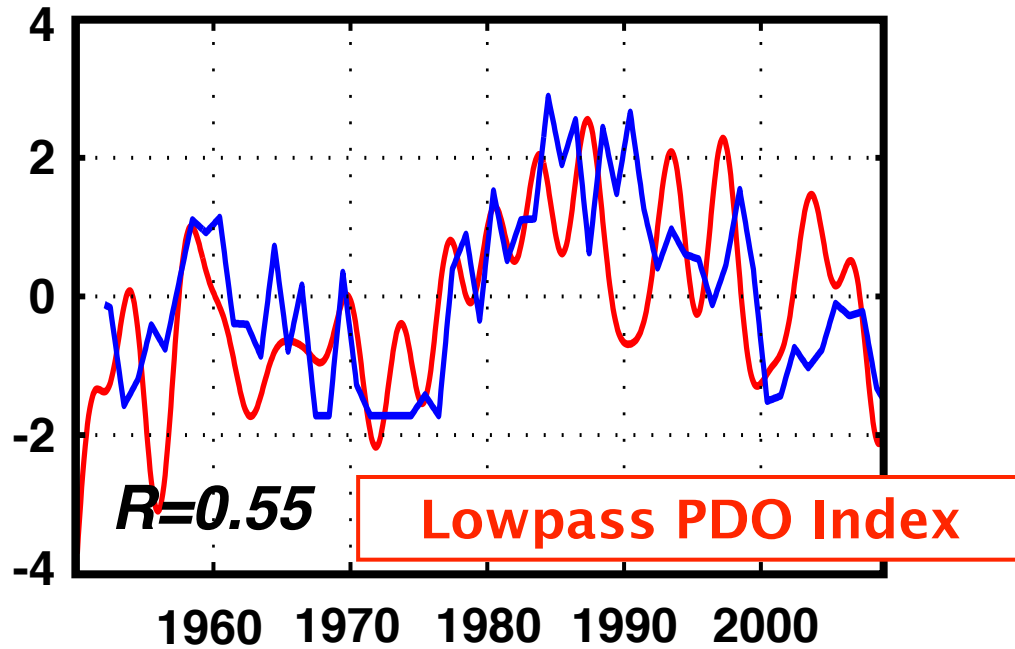
This krill species is connected to the Pacific Decadal Oscillation (PDO)

Nyctiphanes simplex



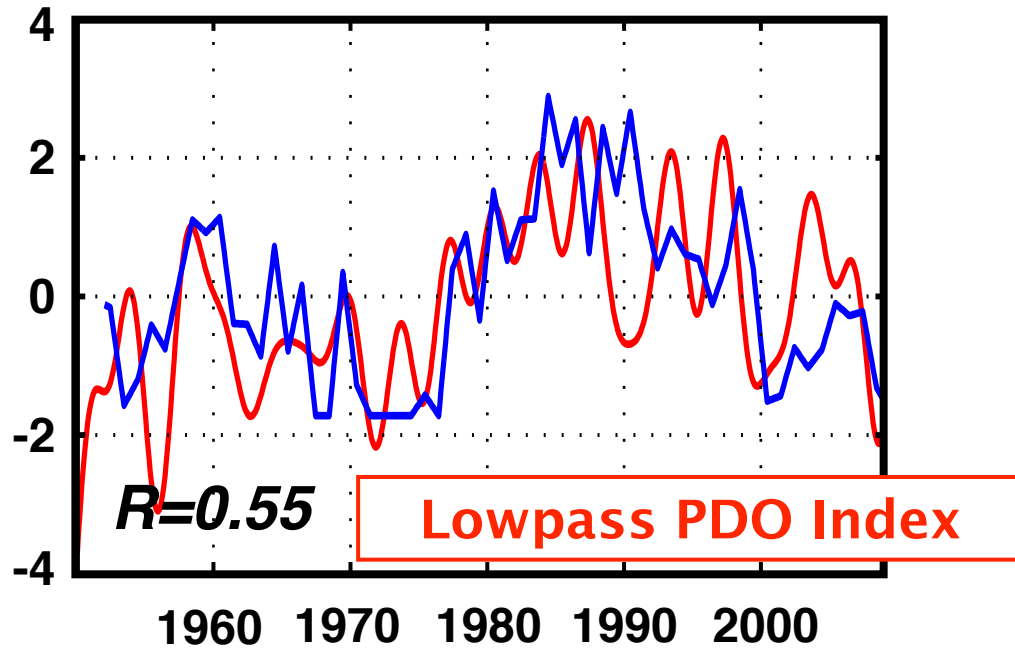
**This krill species is connected to the
Pacific Decadal Oscillation (PDO)**

Nyctiphanes simplex



This krill species is connected to the Pacific Decadal Oscillation (PDO)

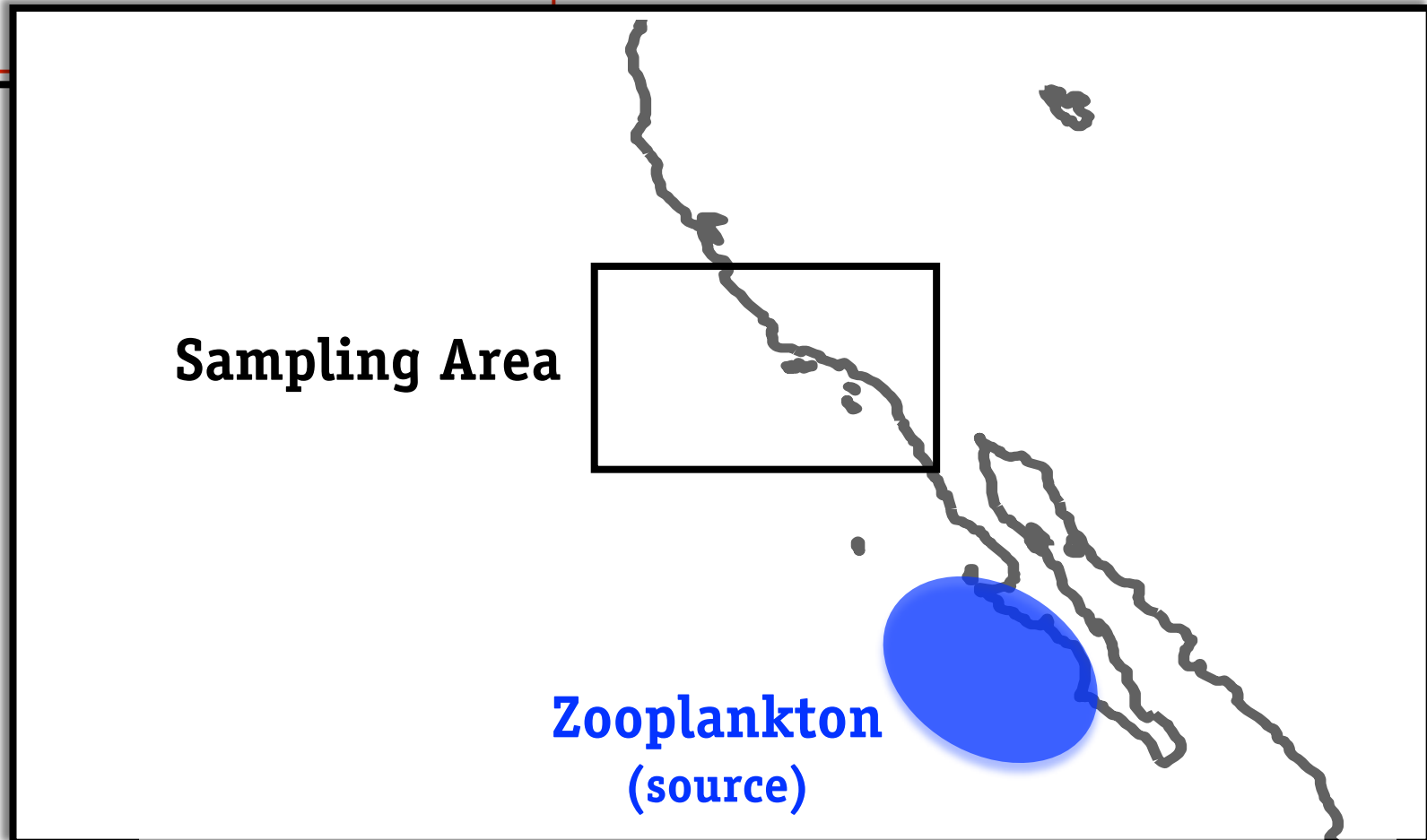
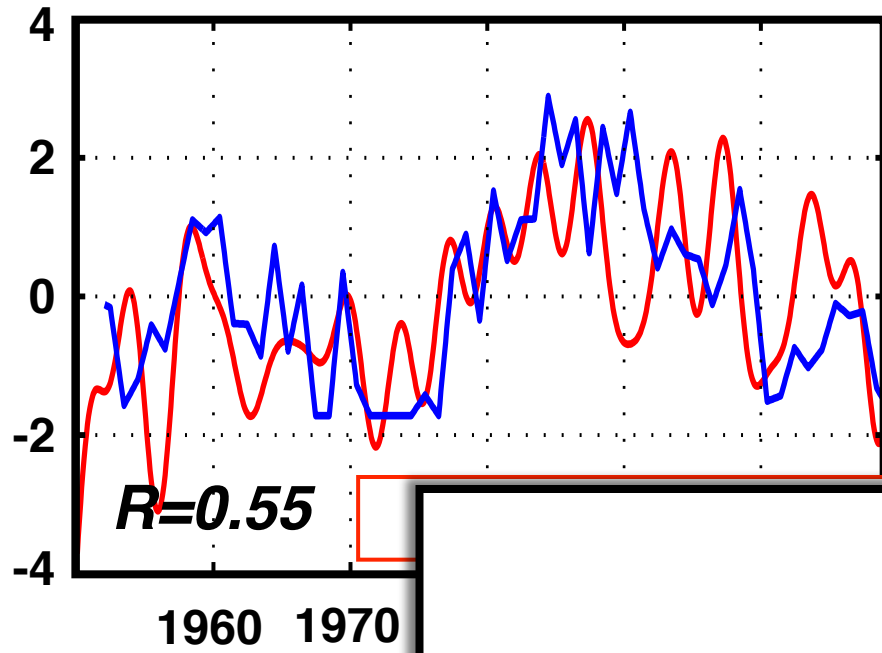
Nyctiphanes simplex



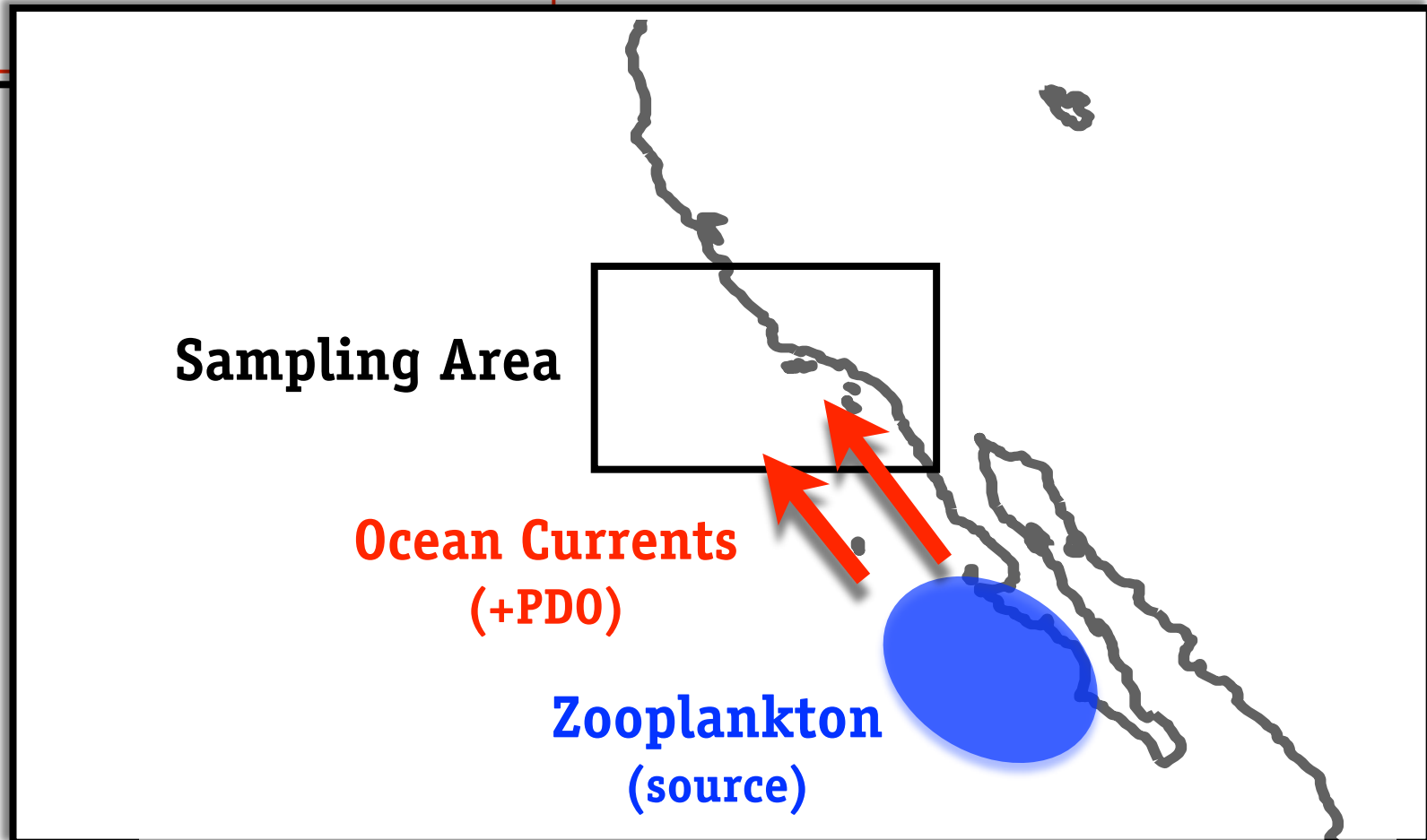
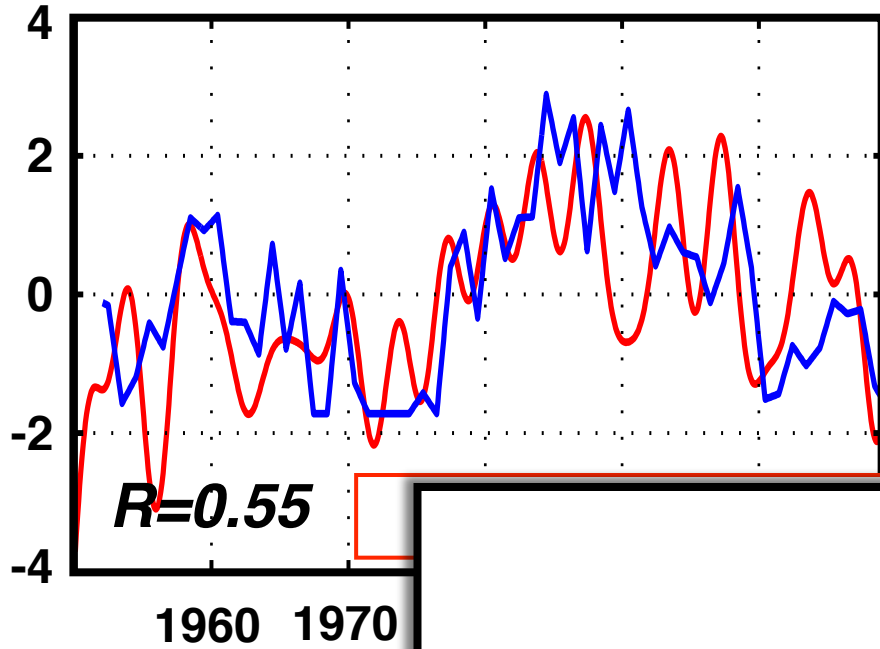
QUESTION:

Can we do better than this?

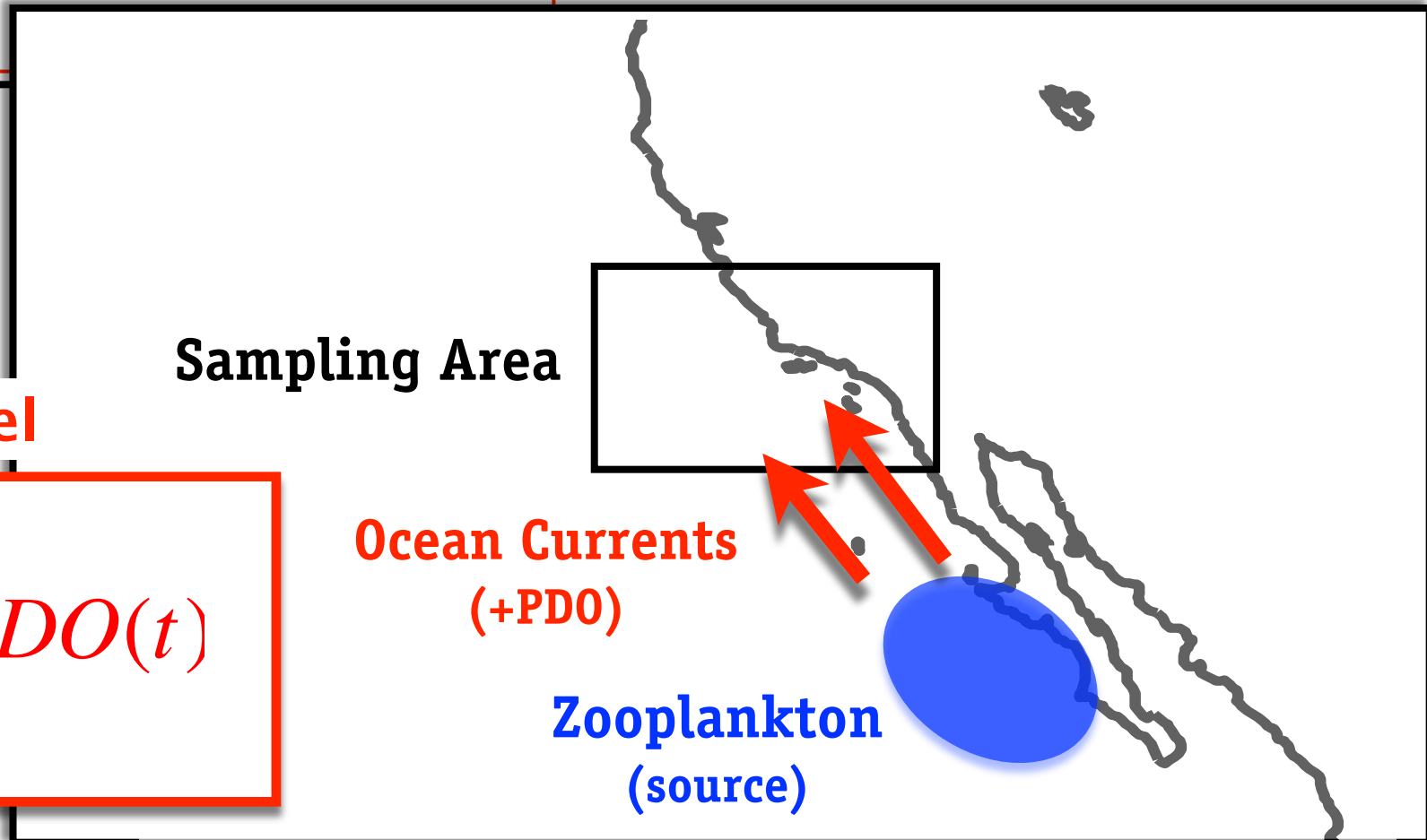
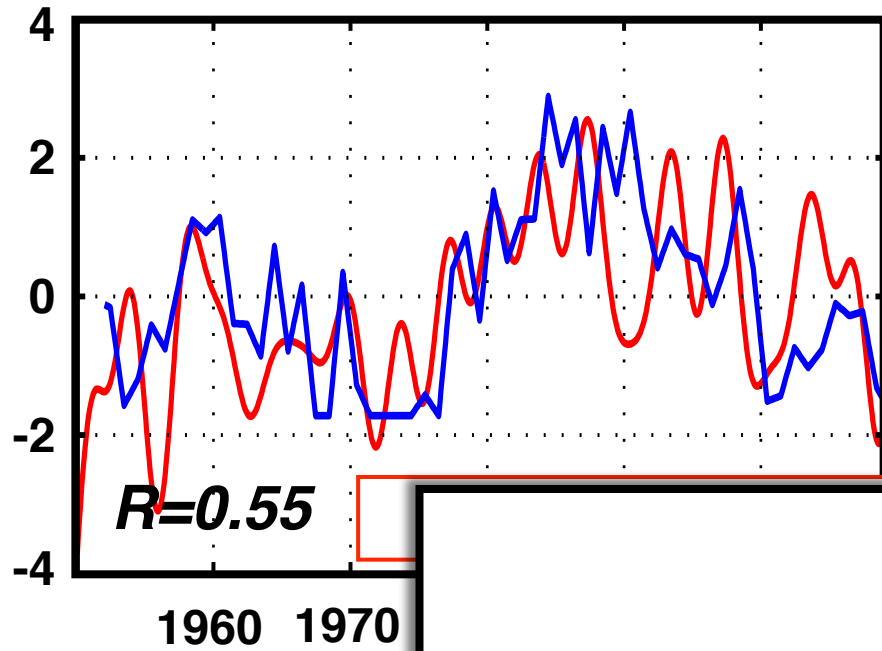
Nyctiphanes simplex



Nyctiphanes simplex



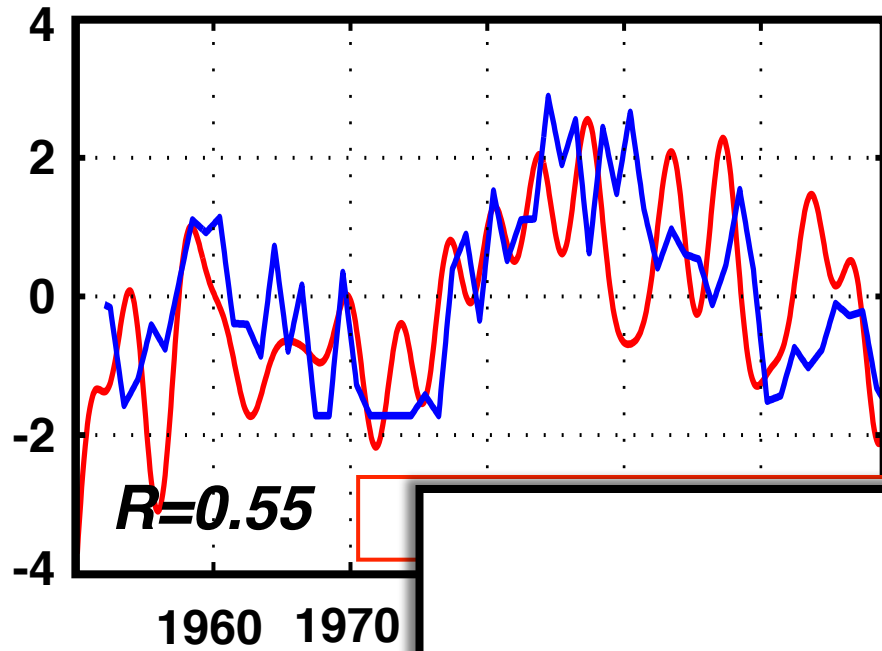
Nyctiphanes simplex



Process Model

$$\frac{dZ(t)}{dt} = PDO(t)$$

Nyctiphanes simplex



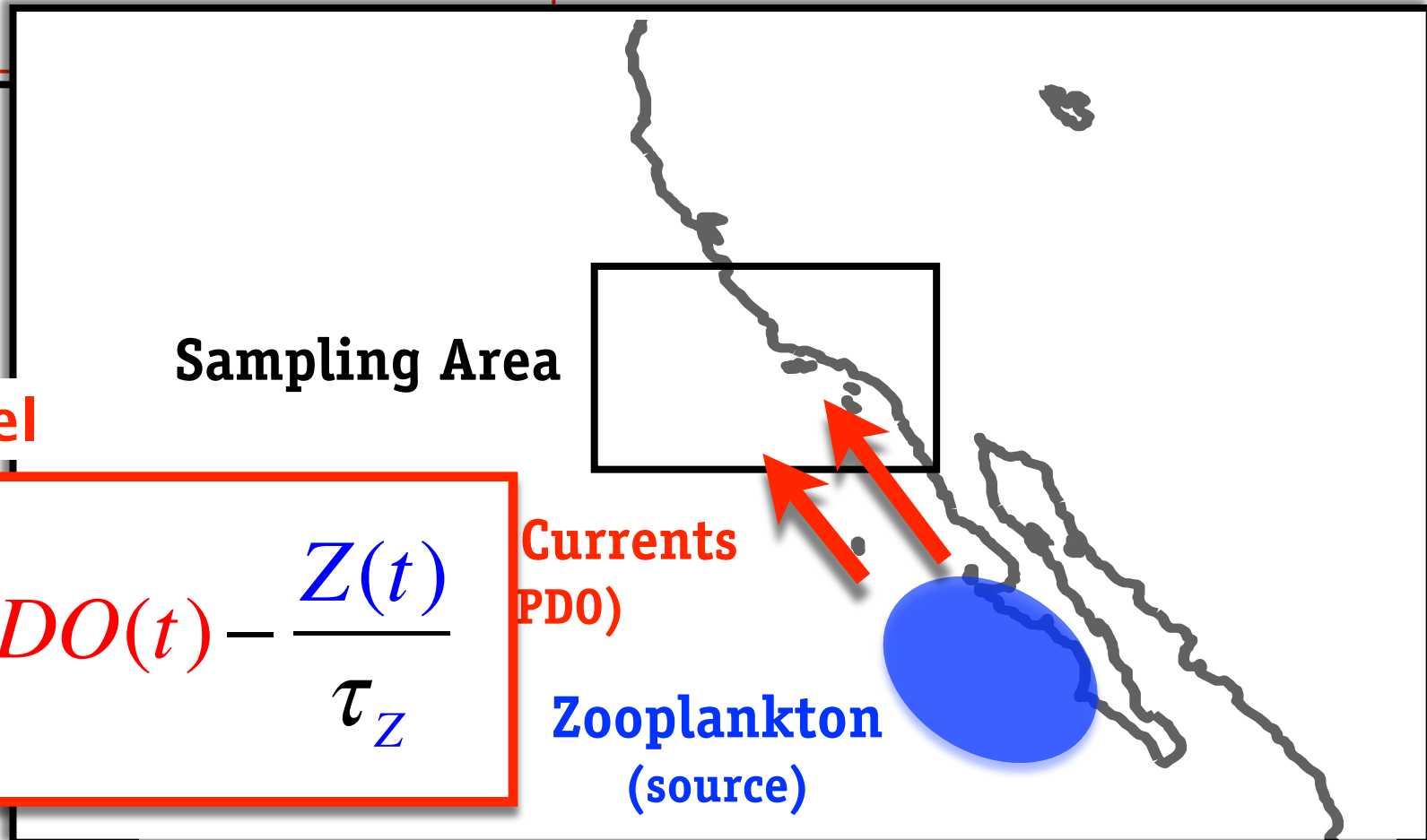
Sampling Area

Process Model

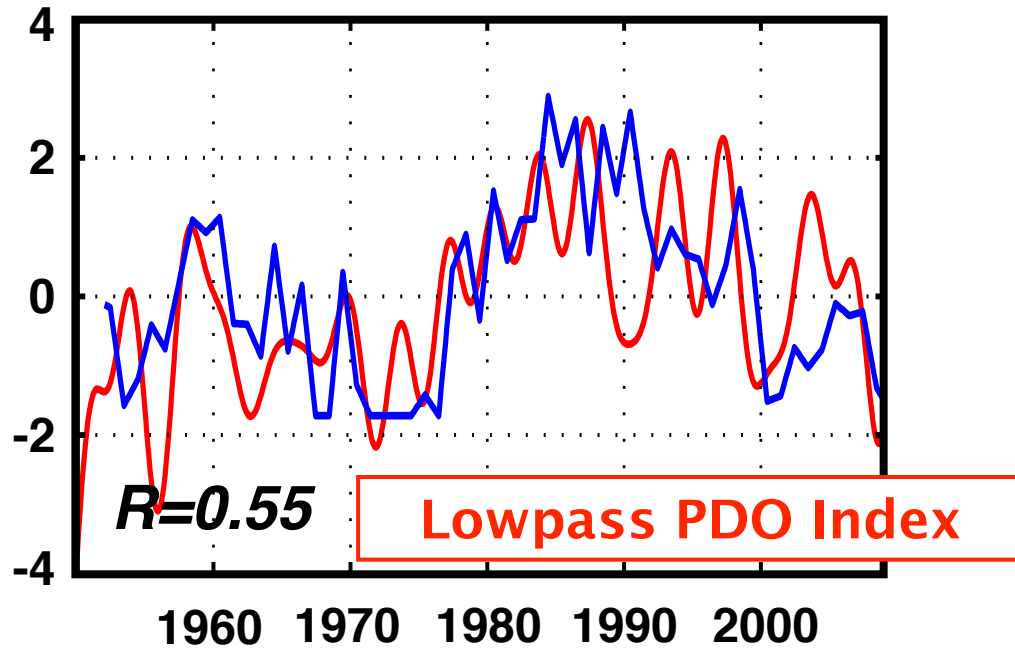
$$\frac{dZ(t)}{dt} = PDO(t) - \frac{Z(t)}{\tau_Z}$$

Currents
(PDO)

Zooplankton
(source)



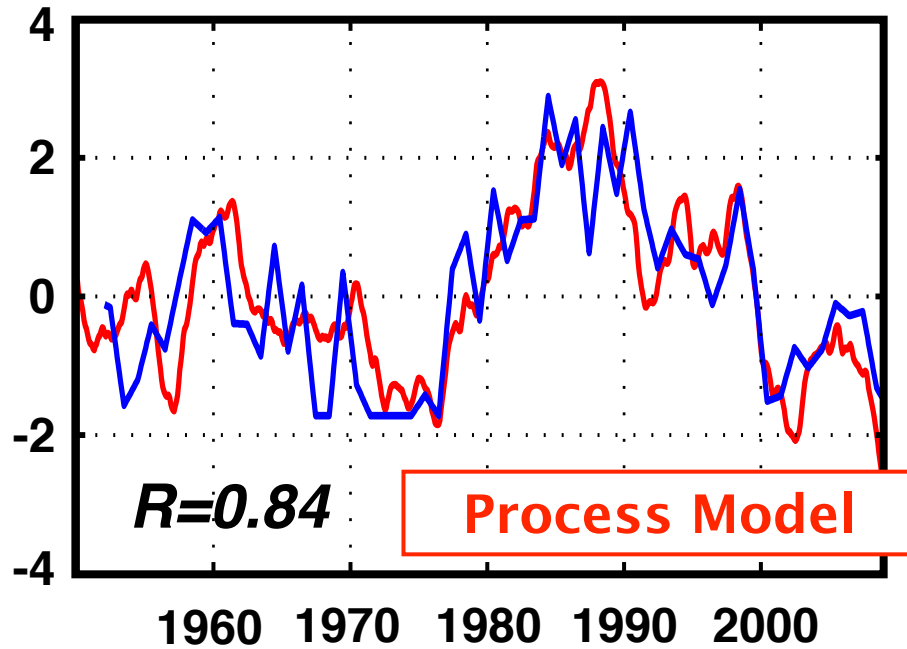
Nyctiphanes simplex



Process Model (AR1 Model)

$$\frac{dZ(t)}{dt} = PDO(t) - \frac{Z(t)}{\tau_Z}$$

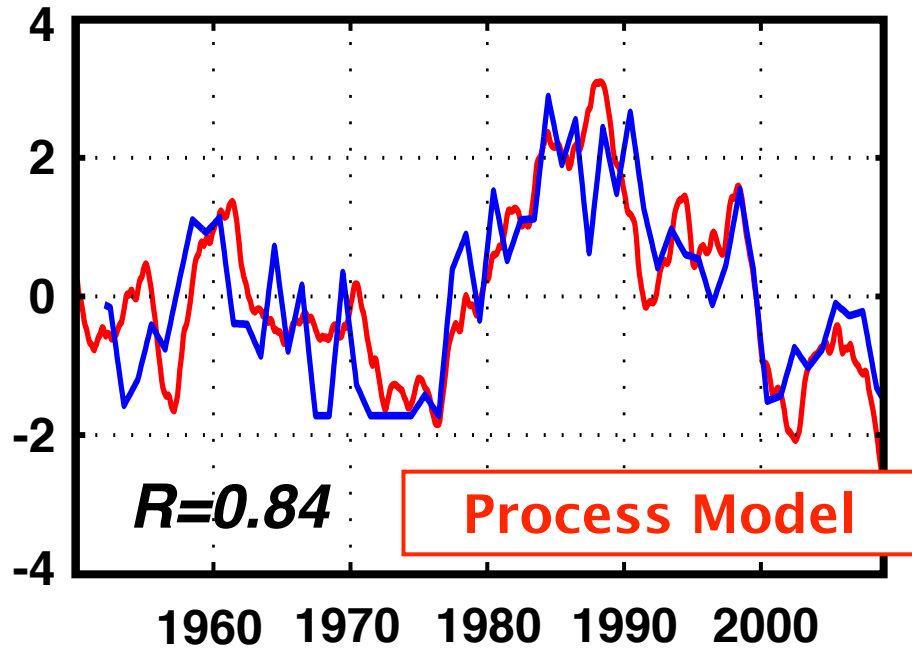
Nyctiphanes simplex



Process Model (AR1 Model)

$$\frac{dZ(t)}{dt} = PDO(t) - \frac{Z(t)}{\tau_Z}$$

Nyctiphanes simplex

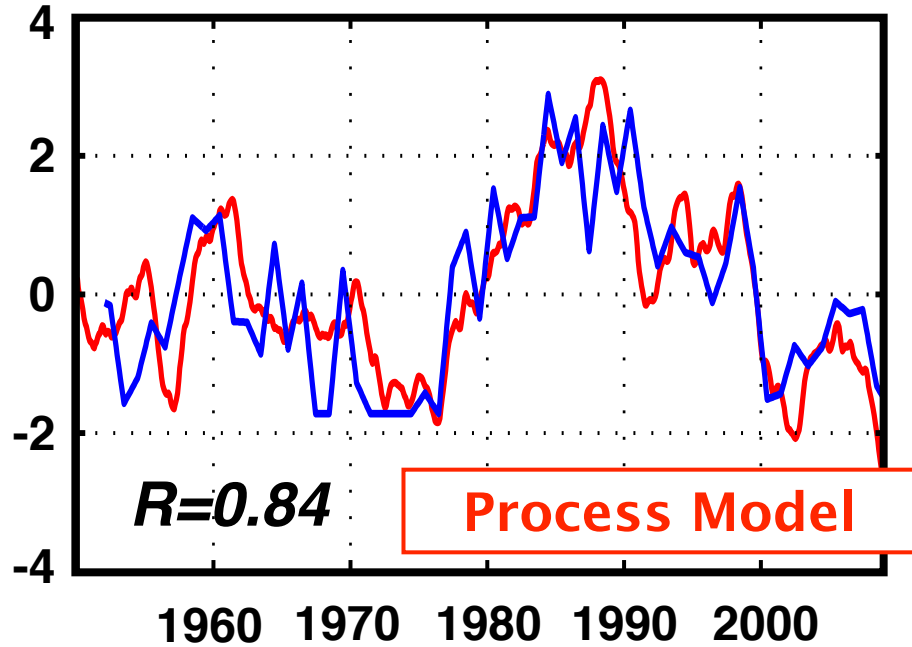


Atmospheric
Forcing
Aleutian Low

Process Model (AR1 Model)

$$\frac{dZ(t)}{dt} = PDO(t) - \frac{Z(t)}{\tau_Z}$$

Nyctiphanes simplex



Atmospheric
Forcing
Aleutian Low

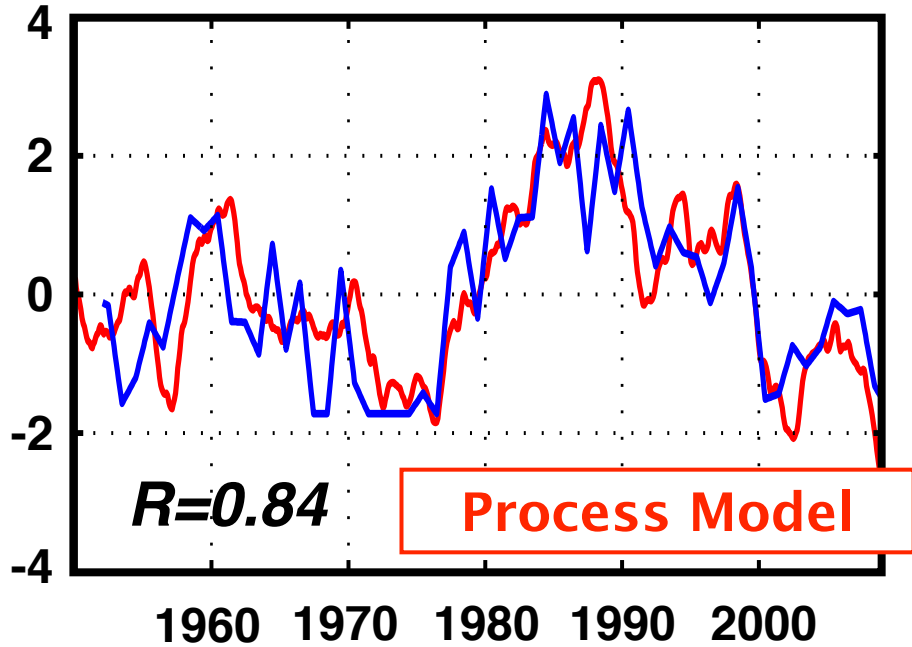
**1 x
integration**

Ocean Transport
Pacific Decadal Oscillation

Process Model (AR1 Model)

$$\frac{dZ(t)}{dt} = PDO(t) - \frac{Z(t)}{\tau_Z}$$

Nyctiphanes simplex



Process Model (AR1 Model)

$$\frac{dZ(t)}{dt} = PDO(t) - \frac{Z(t)}{\tau_Z}$$

Atmospheric Forcing
Aleutian Low

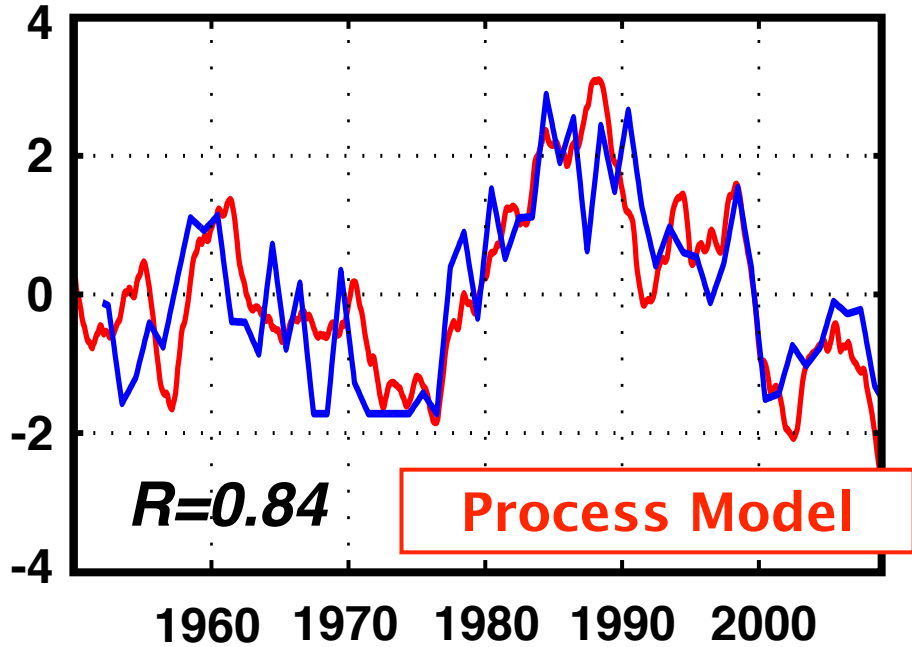
1 x integration

Ocean Transport
Pacific Decadal Oscillation

2 x integration

Zooplankton

Nyctiphanes simplex



Process Model (AR1 Model)

**null hypothesis for
ecosystem low-frequency
variability**

**Atmospheric
Forcing**
Aleutian Low

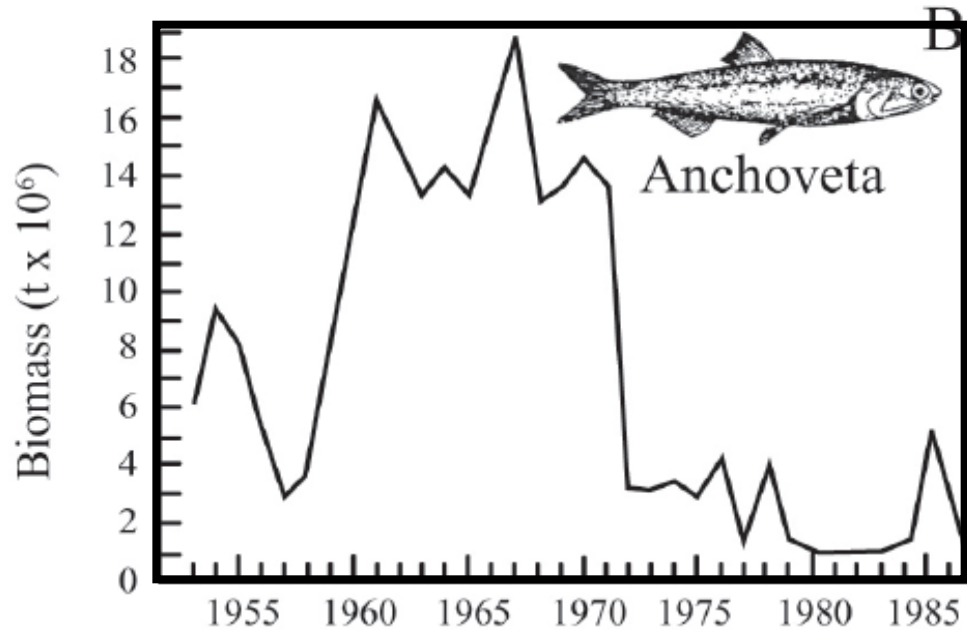
**1 x
integration**

Ocean Transport
Pacific Decadal Oscillation

**2 x
integration**

Zooplankton

Anchoveta



Process Model (AR1 Model)

null hypothesis for
ecosystem low-frequency
variability

Atmospheric
Forcing
Aleutian Low

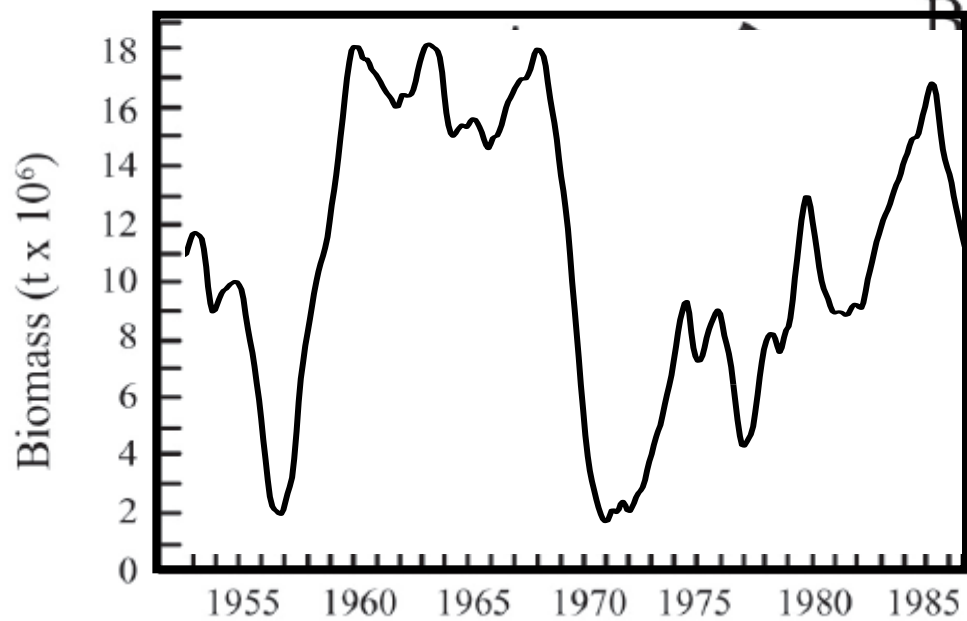
1 x
integration

Ocean Transport
Pacific Decadal Oscillation

2 x
integration

FISH ?

synthetic fish from 2 x integration



Process Model (AR1 Model)

**null hypothesis for
ecosystem low-frequency
variability**

**Atmospheric
Forcing**
Aleutian Low

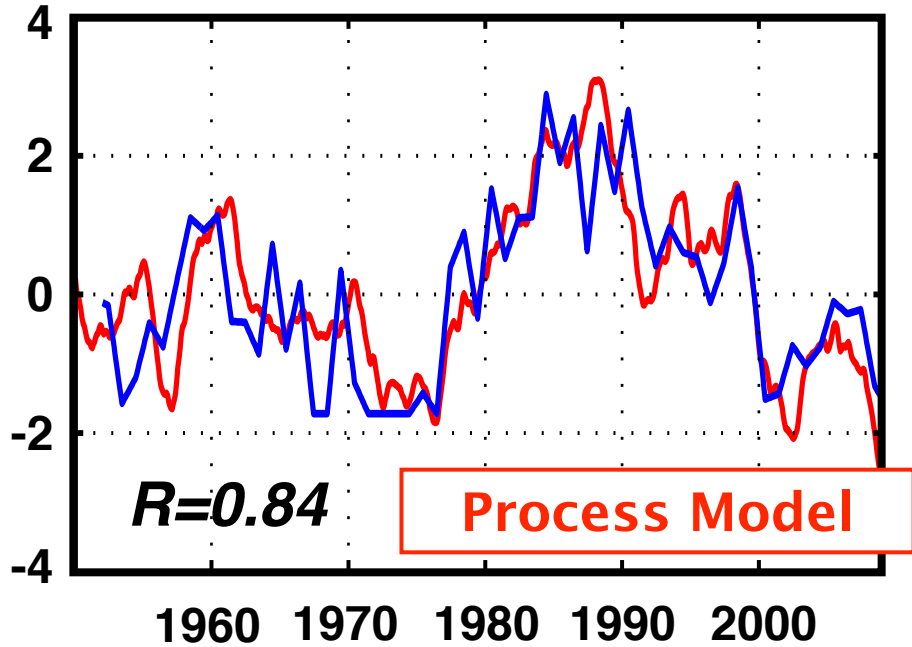
**1 x
integration**

Ocean Transport
Pacific Decadal Oscillation

**2 x
integration**

FISH ?

Nyctiphanes simplex



Process Model (AR1 Model)

**null hypothesis for
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**Atmospheric
Forcing**
Aleutian Low

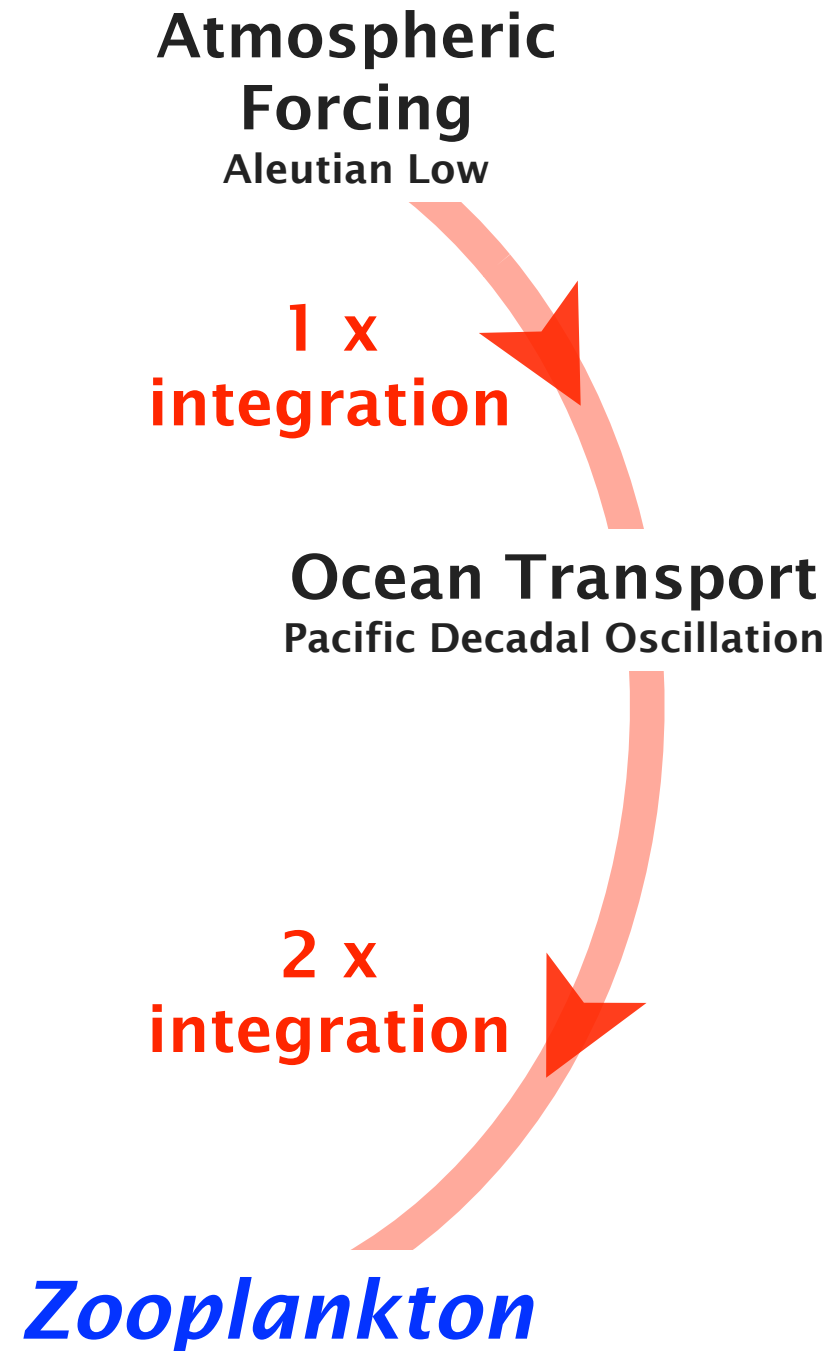
**1 x
integration**

Ocean Transport
Pacific Decadal Oscillation

**2 x
integration**

Zooplankton

null hypothesis
for ecosystem species
response to climate forcing



null hypothesis
for ecosystem species
response to climate forcing



decadal-scale smooth ecosystem
transitions & variability can emerge
from *cumulative integrations* of
random climate forcing

Atmospheric
Forcing
Aleutian Low

1 x
integration

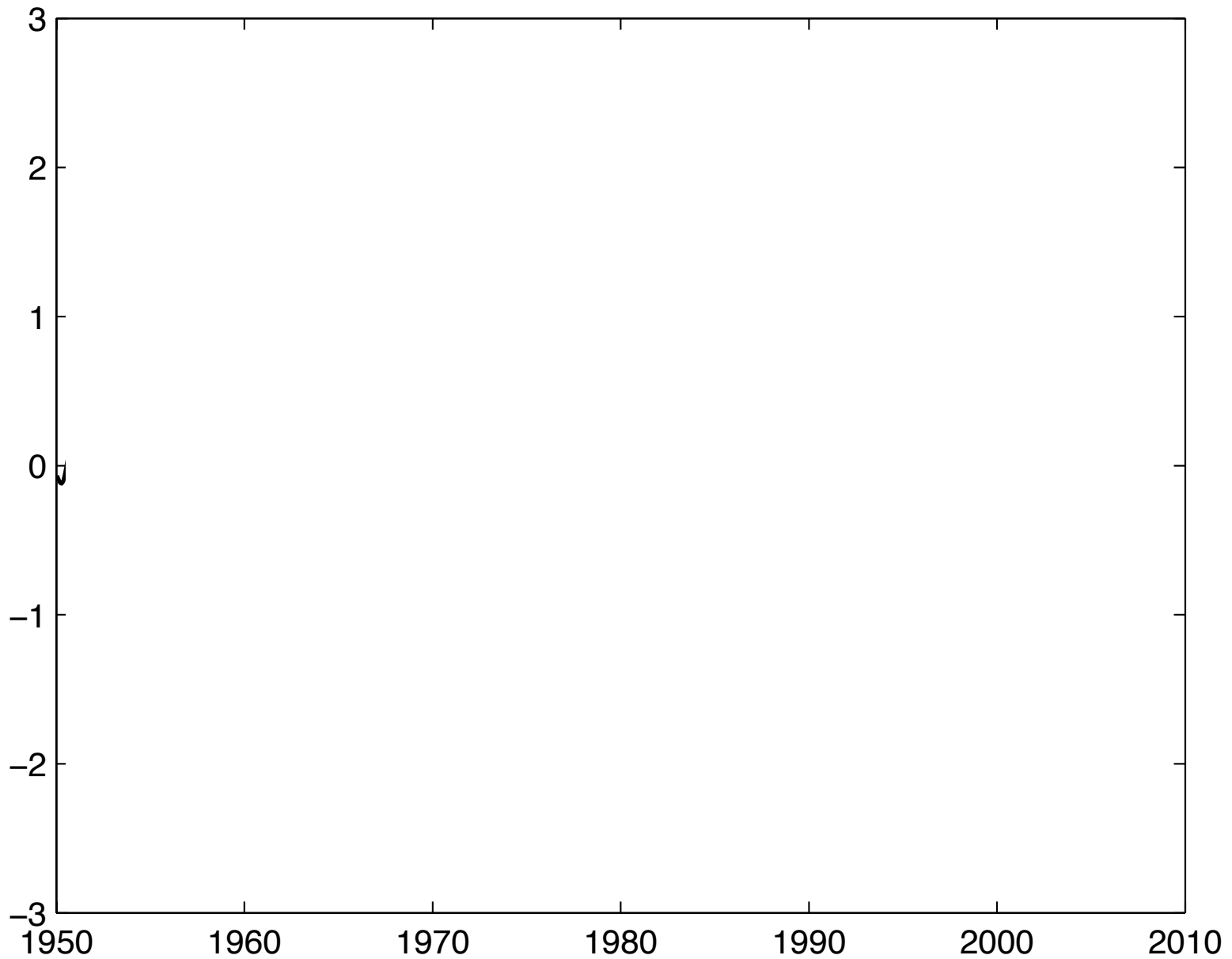
Ocean Transport
Pacific Decadal Oscillation

2 x
integration

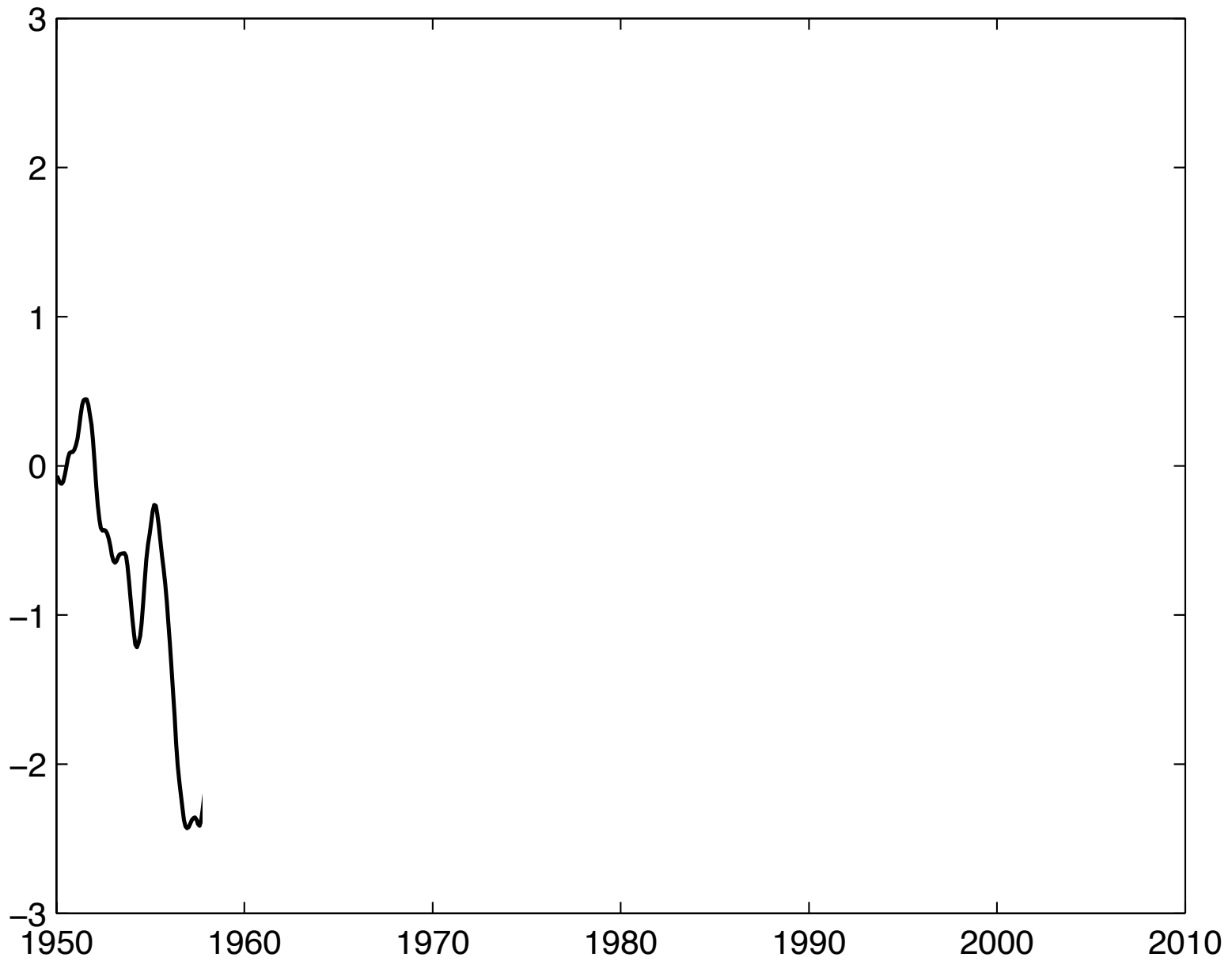
Zooplankton



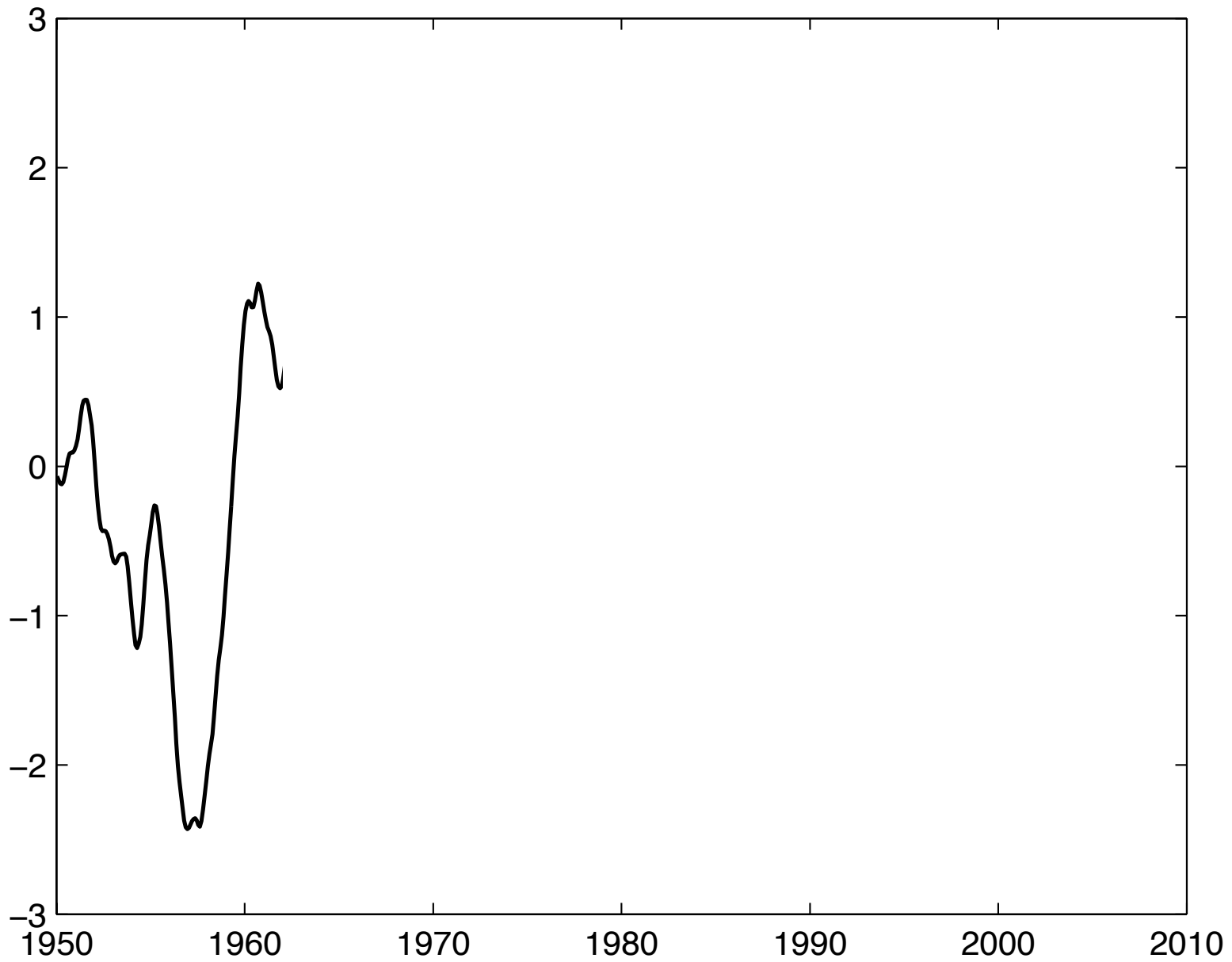
Idealized Ecosystem Species



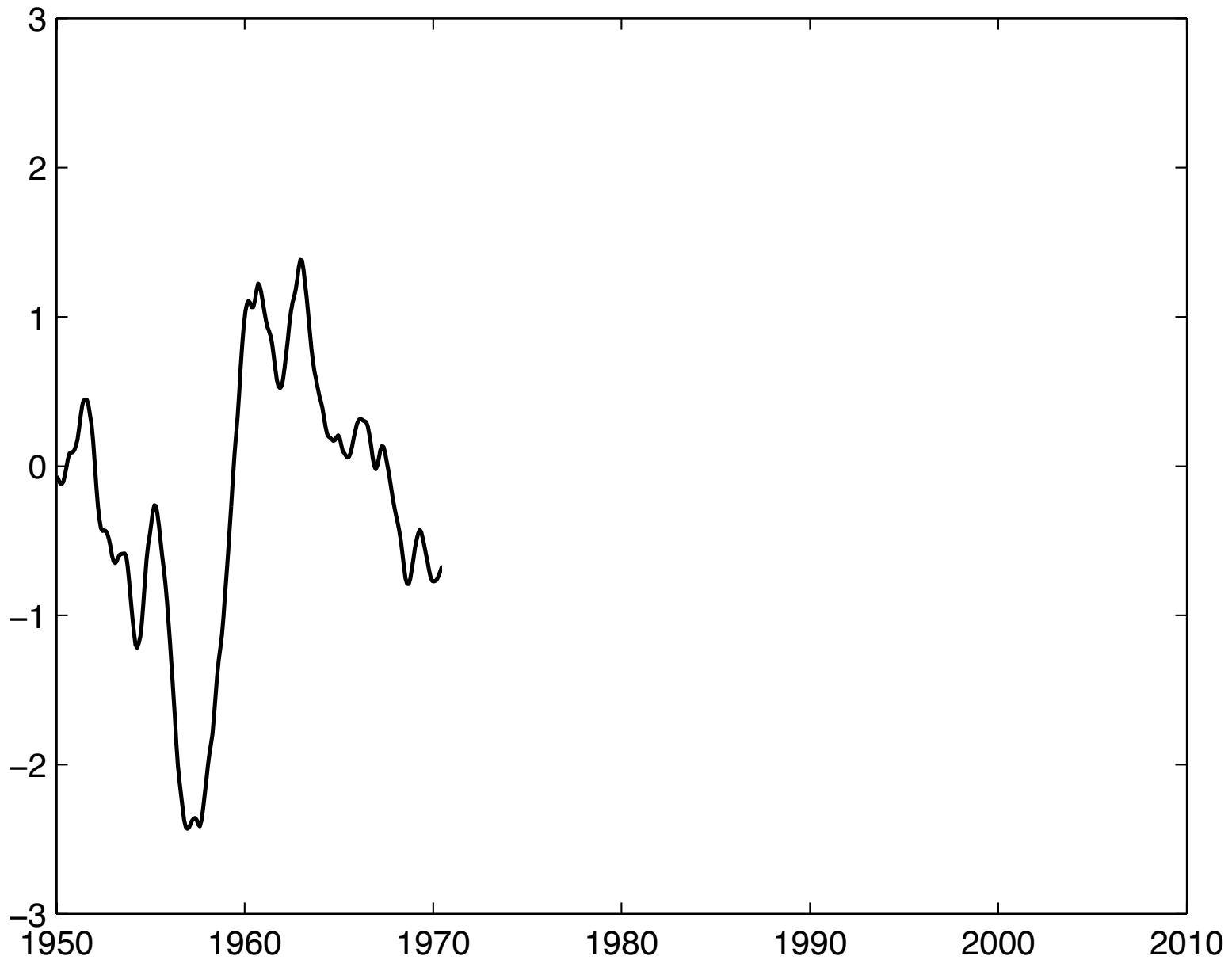
Idealized Ecosystem Species



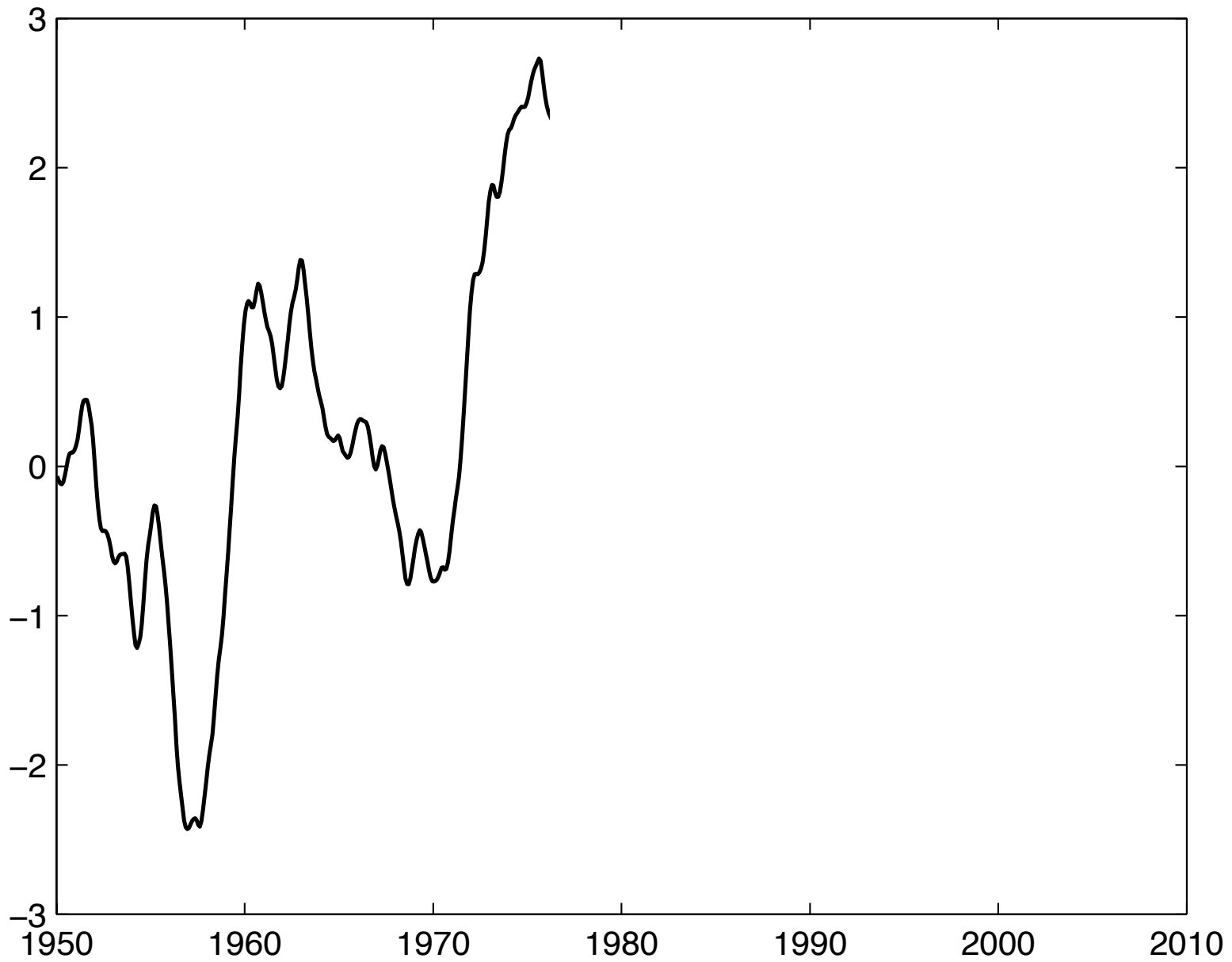
Idealized Ecosystem Species



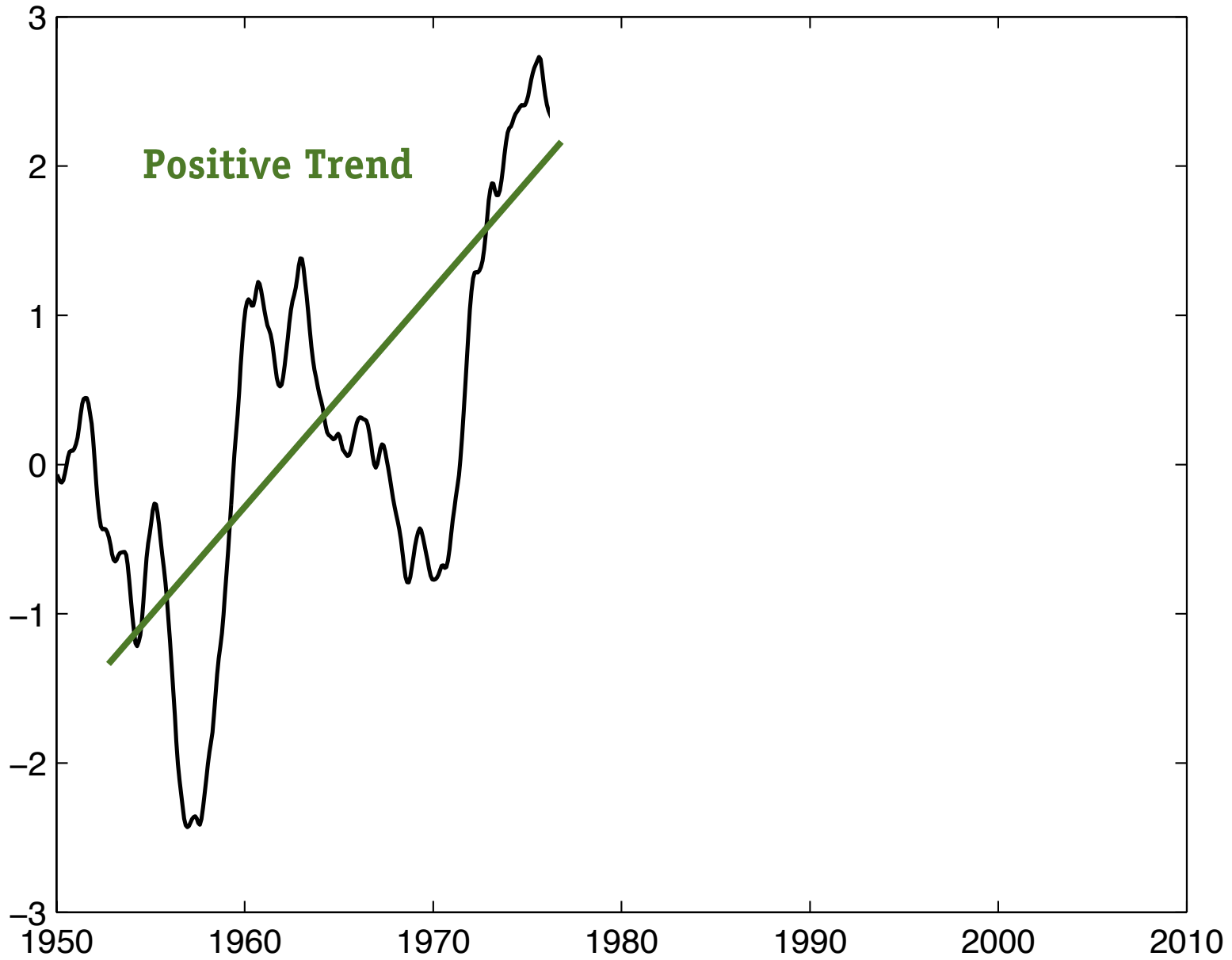
Idealized Ecosystem Species



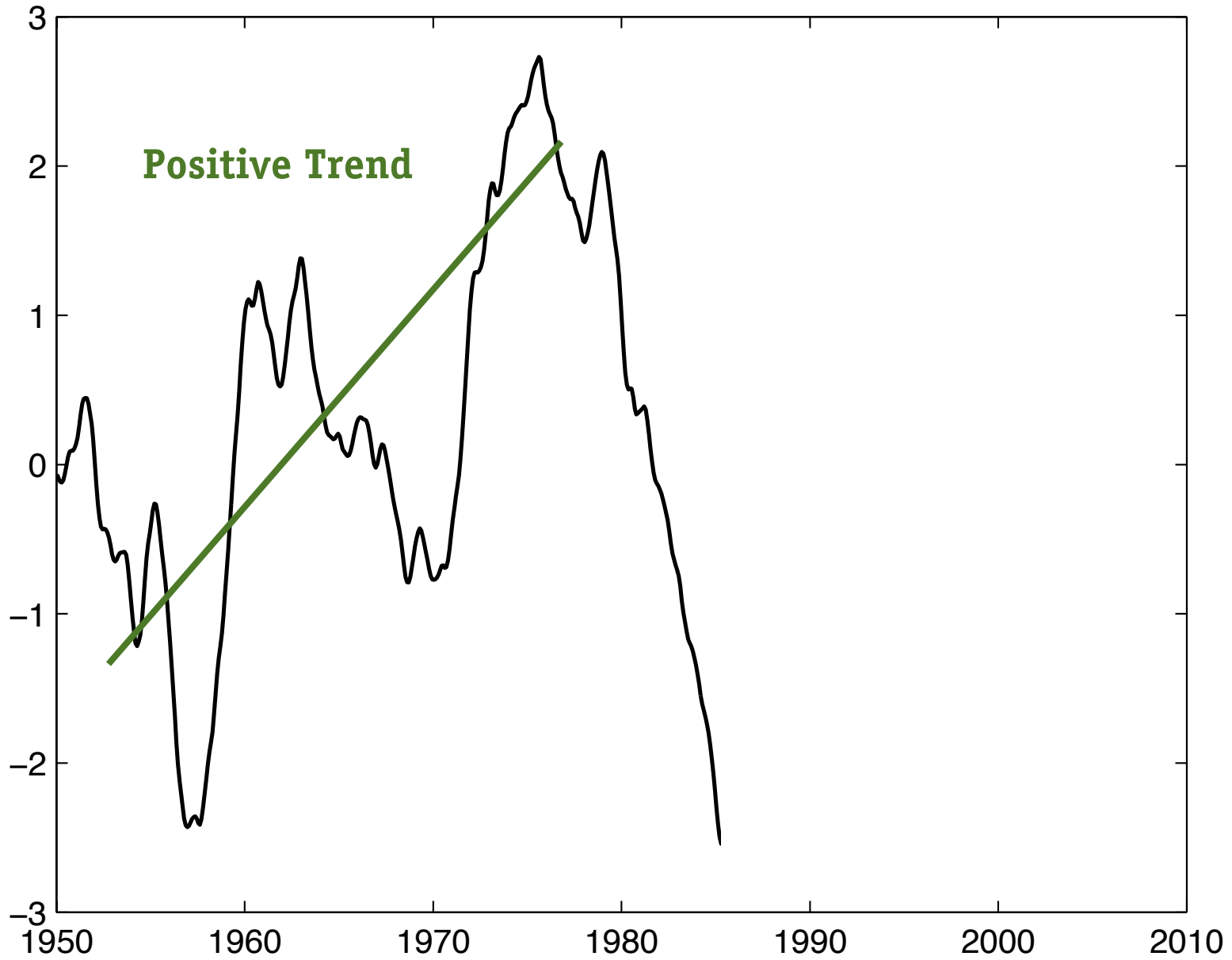
Idealized Ecosystem Species



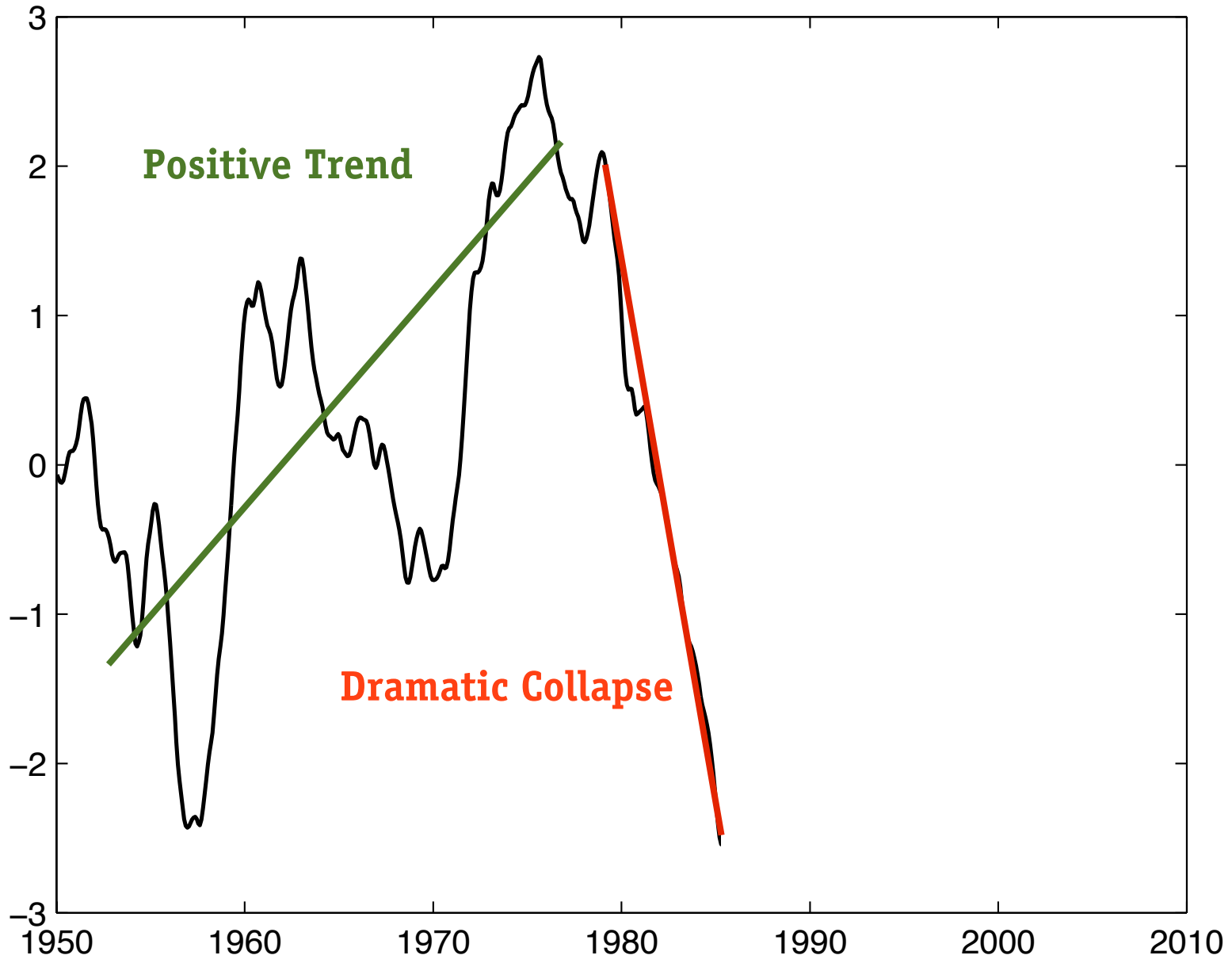
Idealized Ecosystem Species



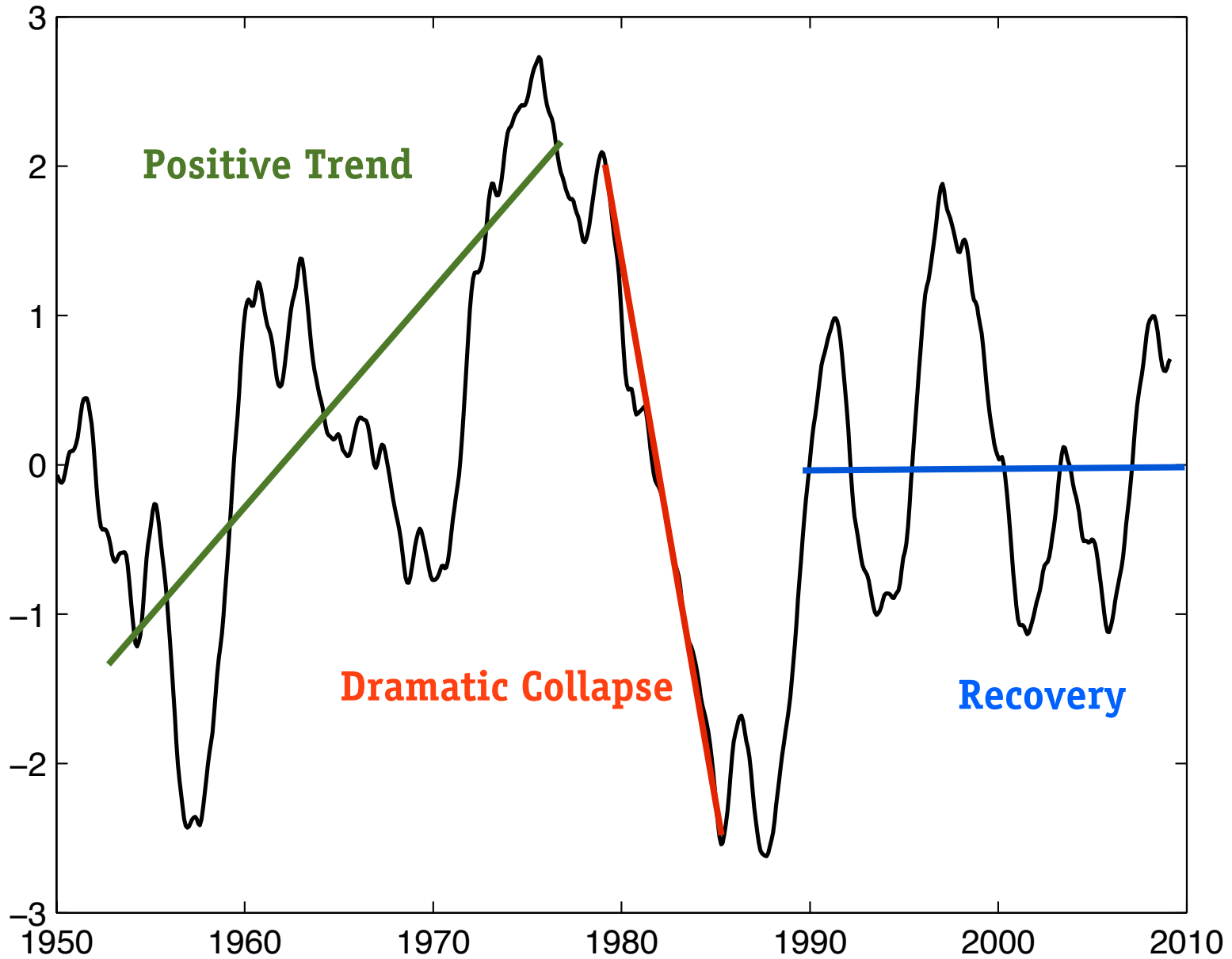
Idealized Ecosystem Species



Idealized Ecosystem Species



Idealized Ecosystem Species



null hypothesis
for ecosystem species
response to climate forcing



decadal-scale smooth ecosystem
transitions & variability can emerge
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Atmospheric
Forcing
Aleutian Low

1 x
integration

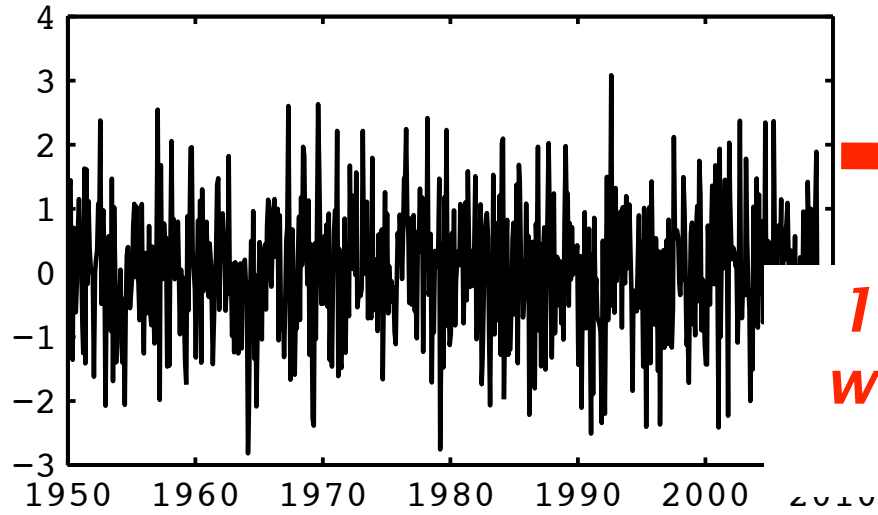
Ocean Transport
Pacific Decadal Oscillation

2 x
integration

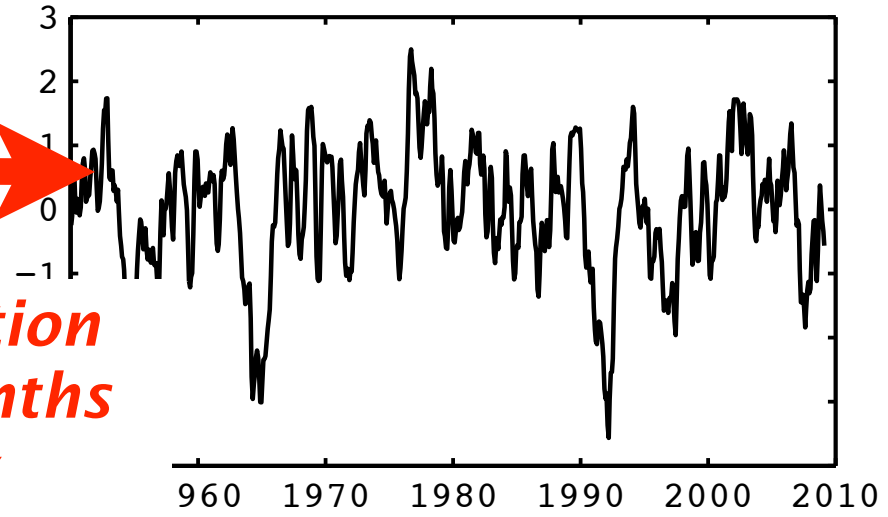
Zooplankton



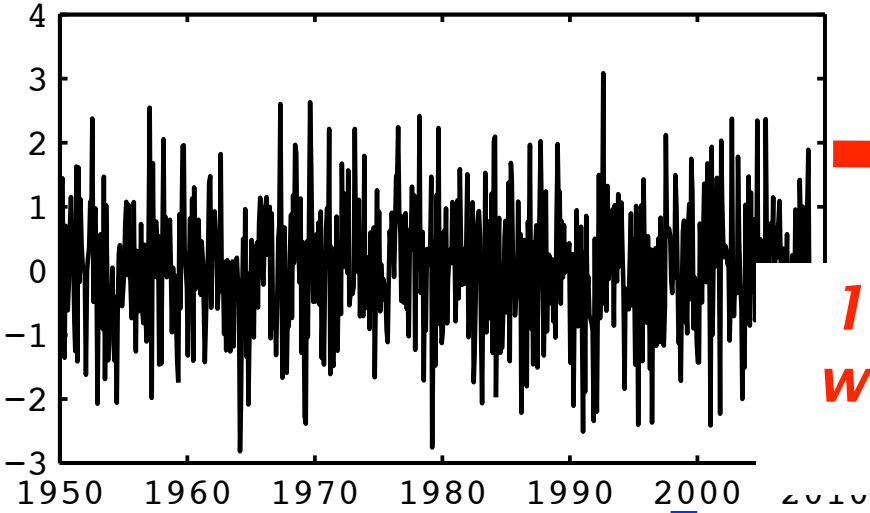
White Noise



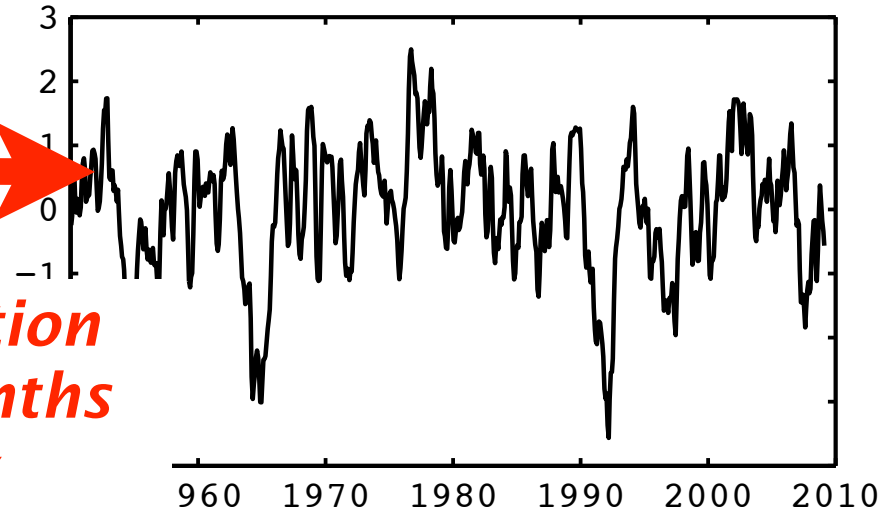
*1 x integration
with 12 months
memory*



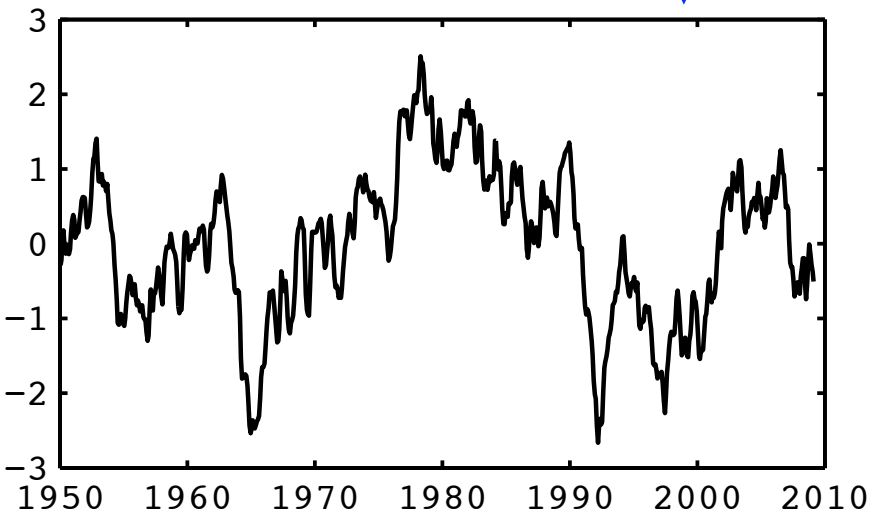
White Noise



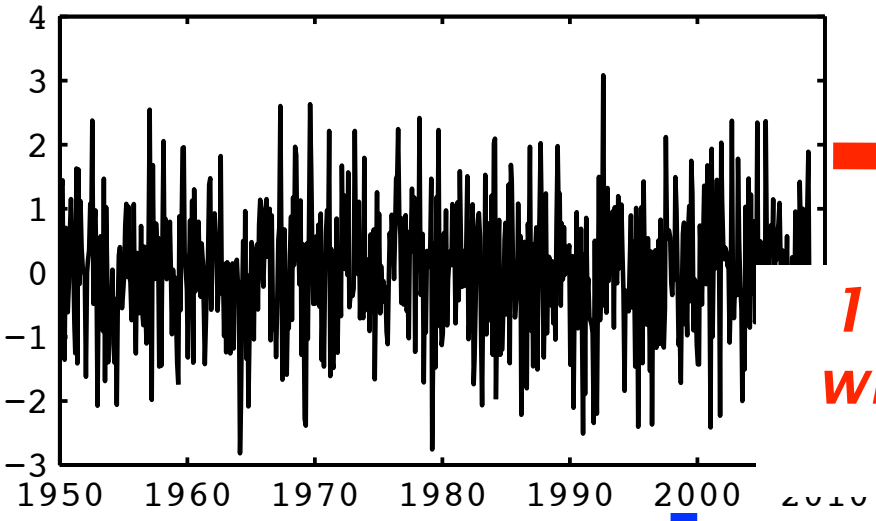
*1 x integration
with 12 months
memory*



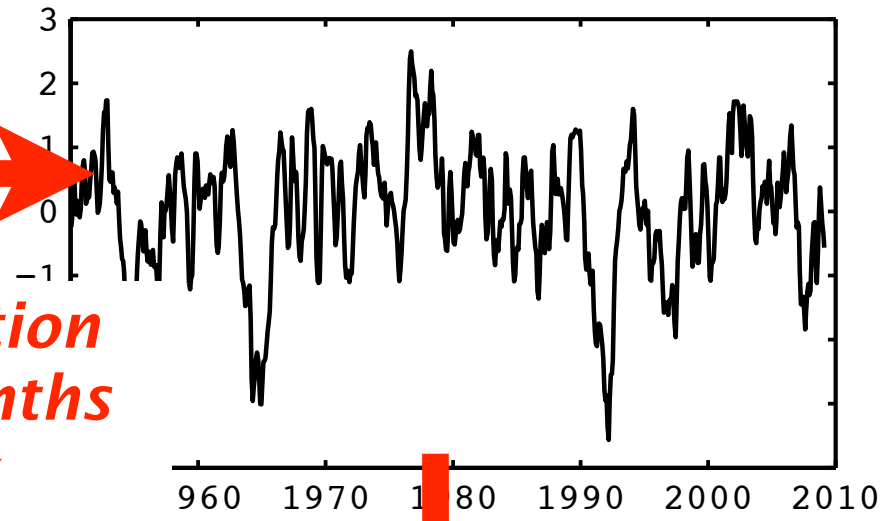
*1 x integration
with infinite
memory*



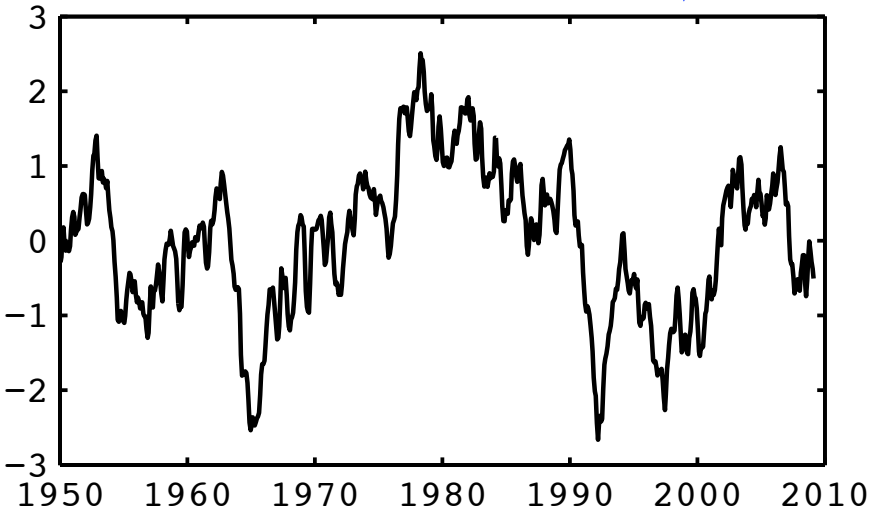
White Noise



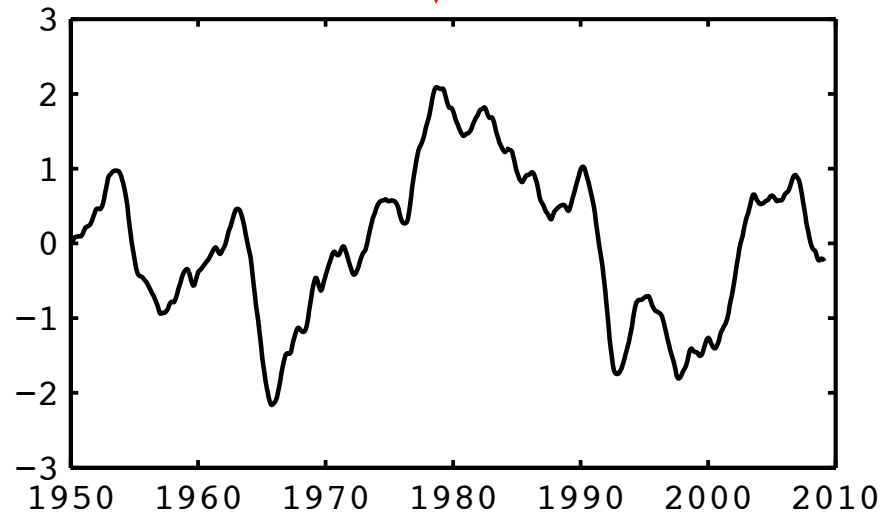
*1 x integration
with 12 months
memory*



*1 x integration
with infinite
memory*

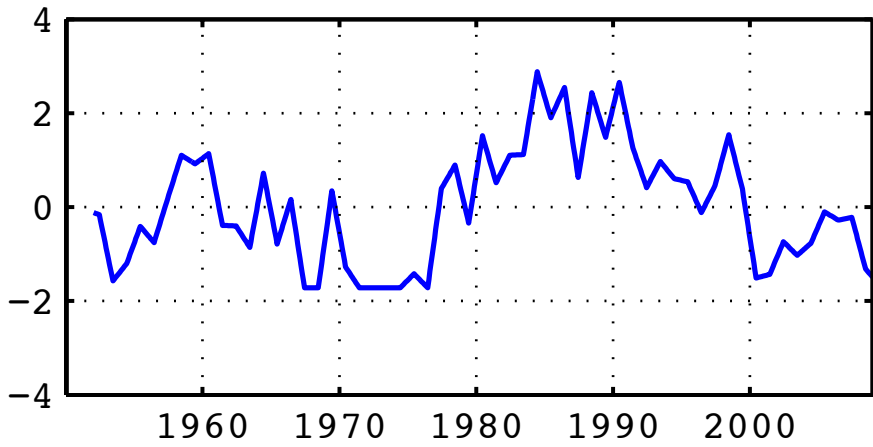


2 x integration

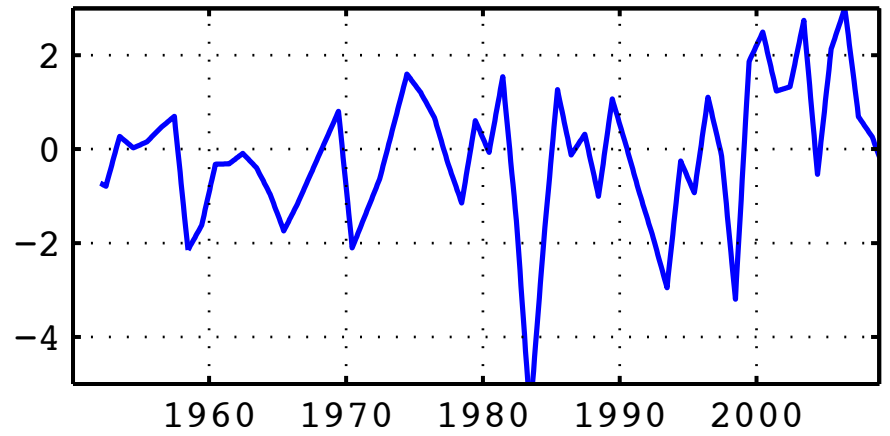


Comparison of Zooplankton

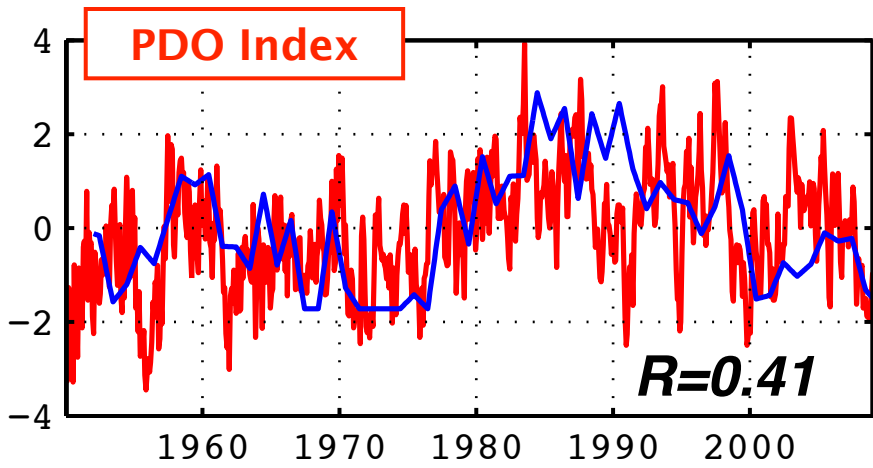
Nyctiphanes simplex



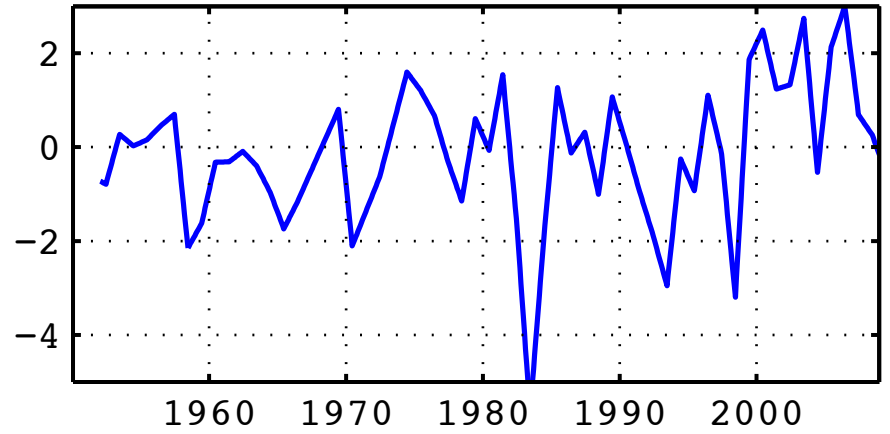
Euphausia pacifica



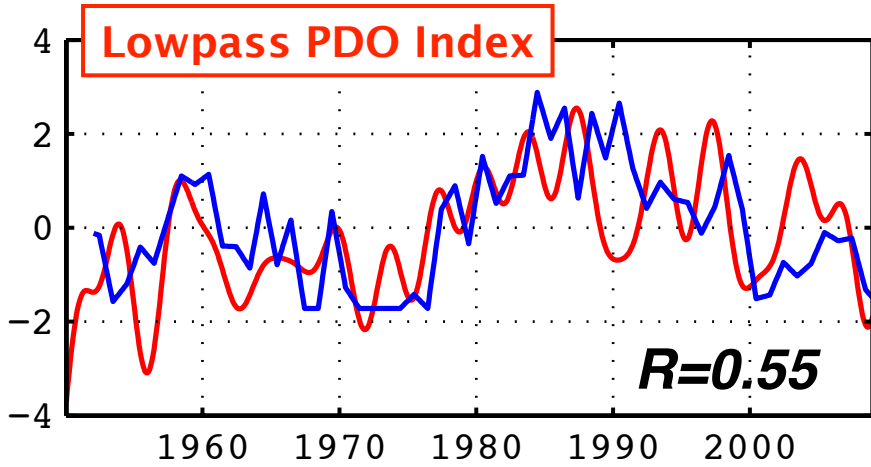
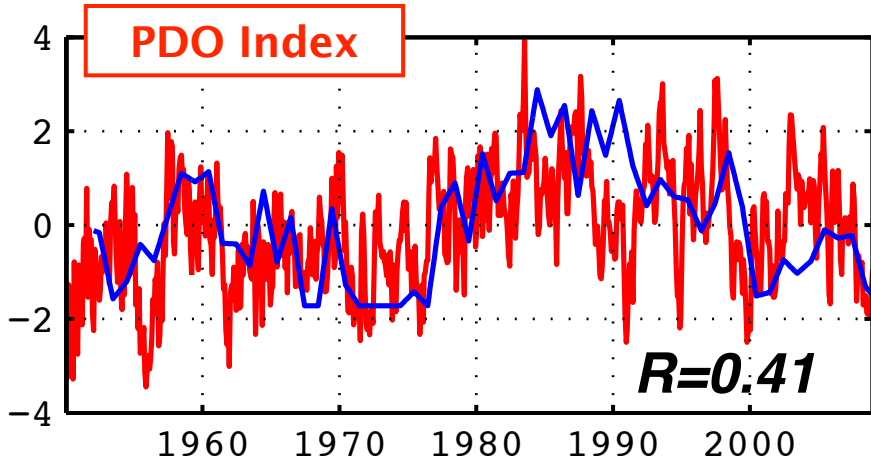
Nyctiphanes simplex



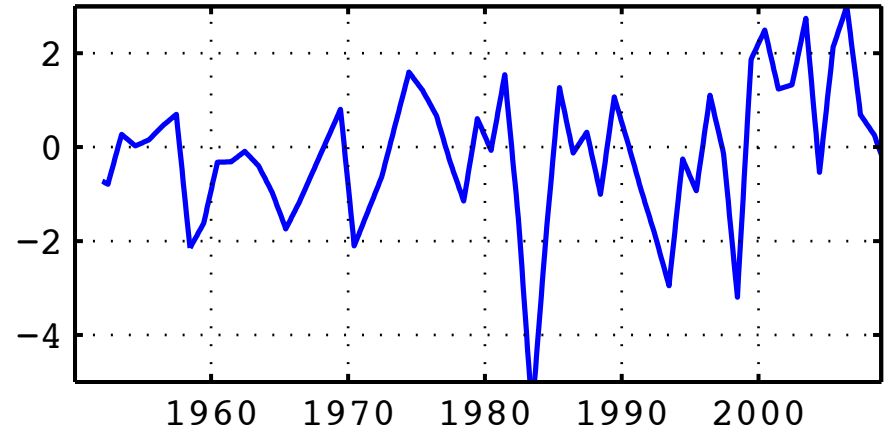
Euphausia pacifica



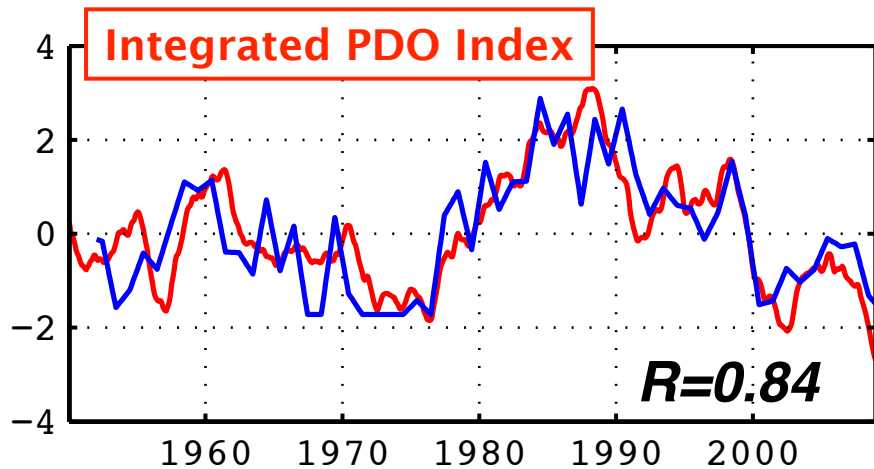
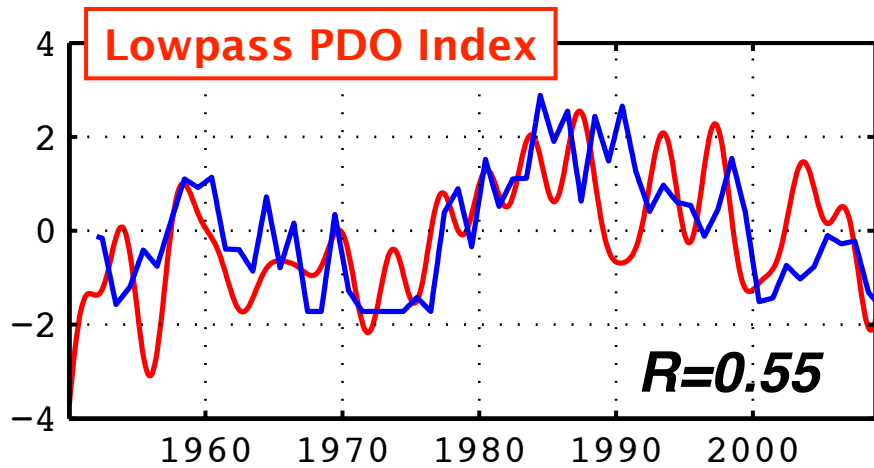
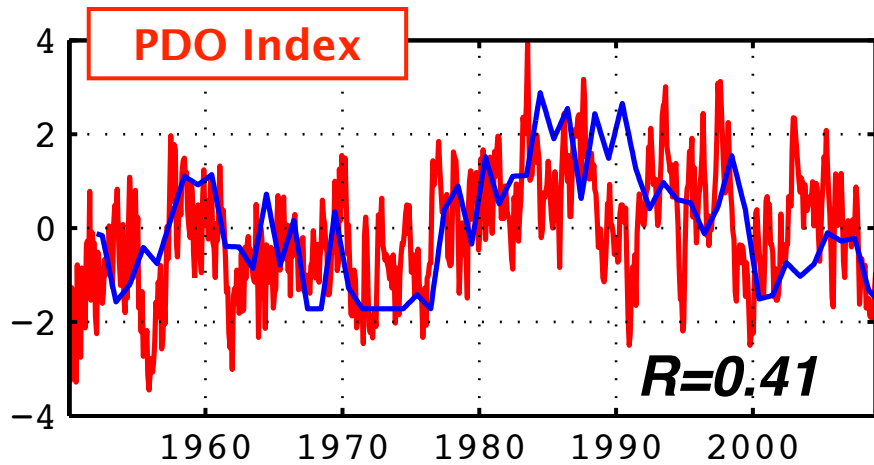
Nyctiphanes simplex



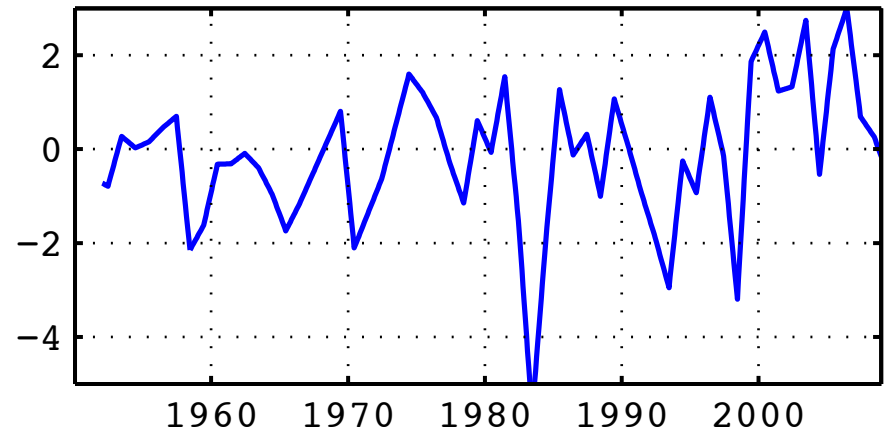
Euphausia pacifica



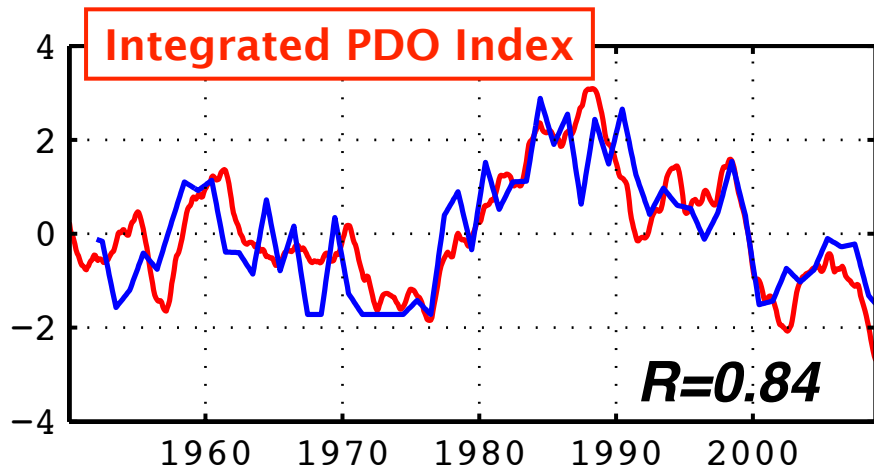
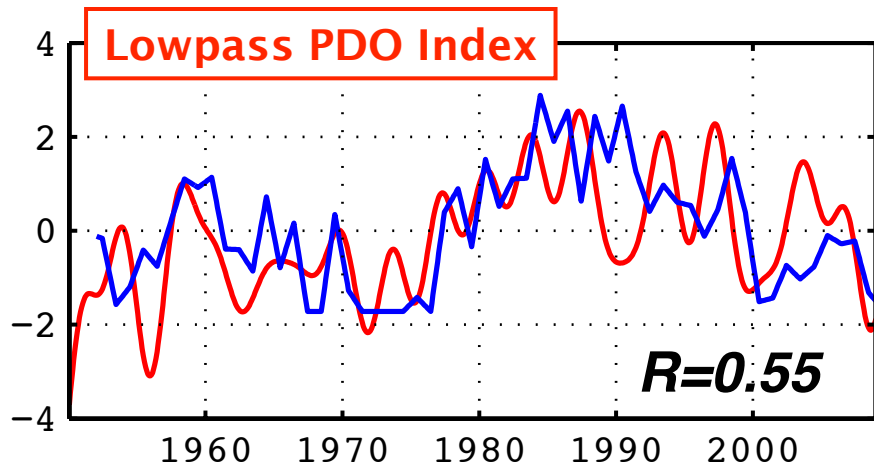
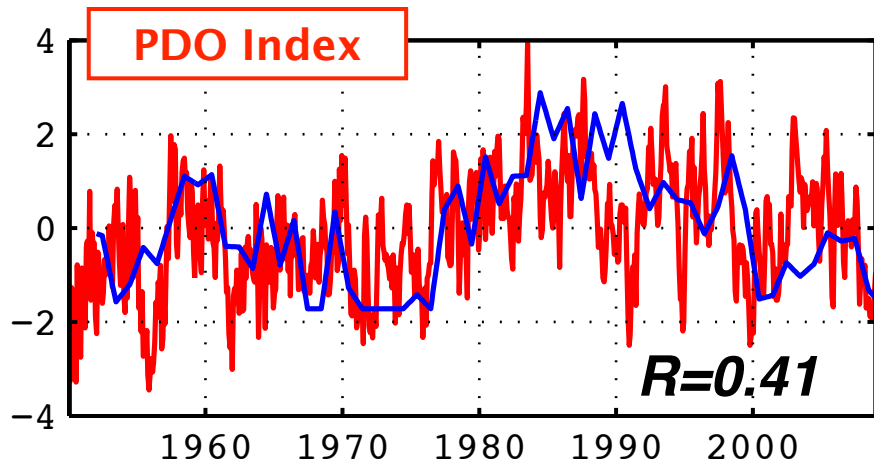
Nyctiphanes simplex



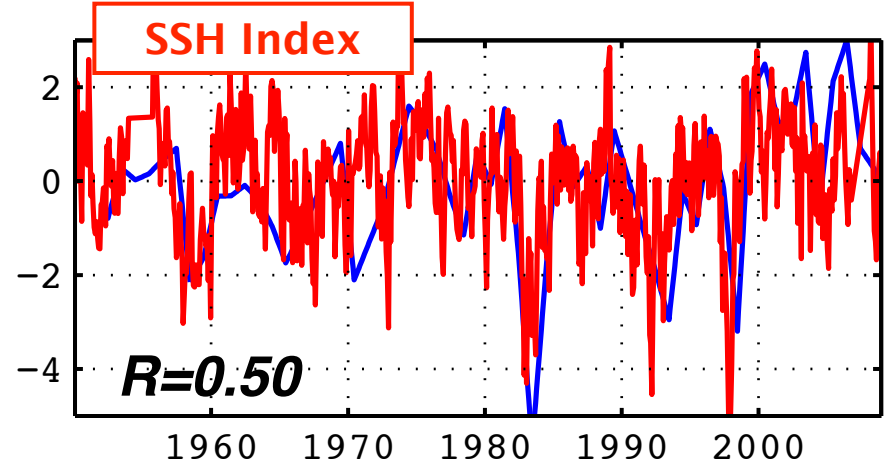
Euphausia pacifica



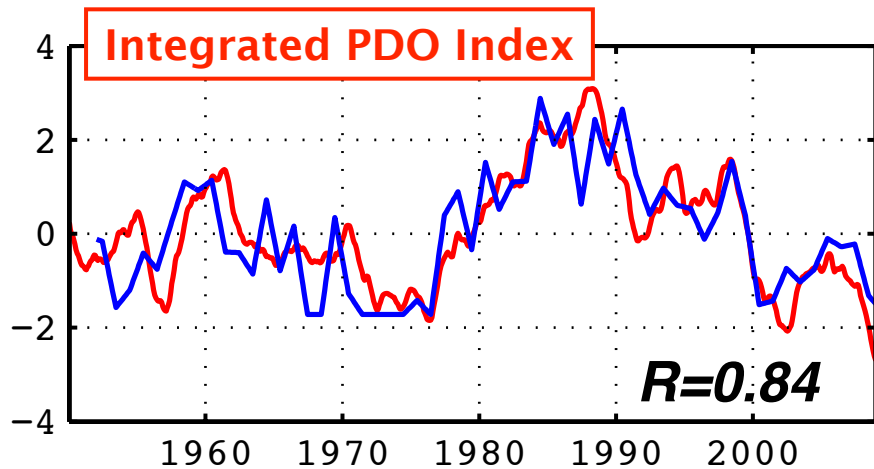
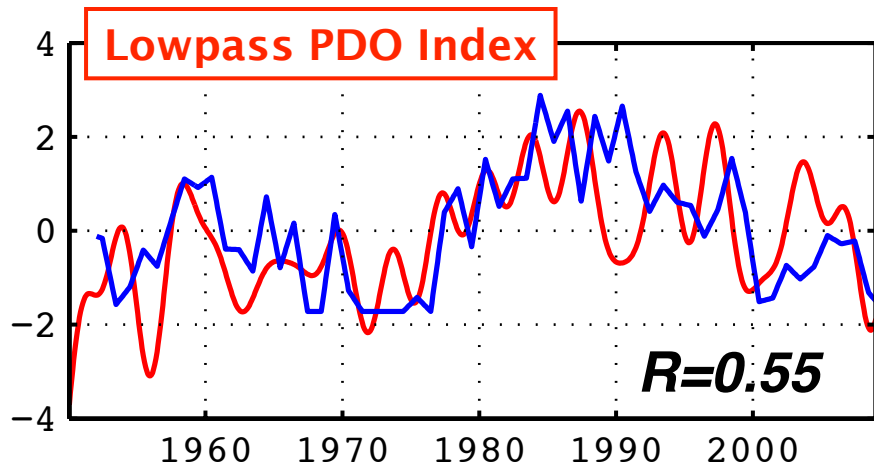
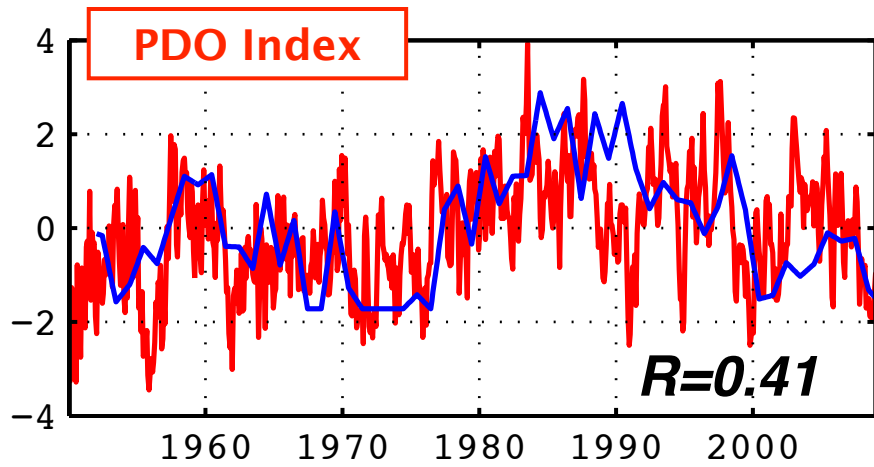
Nyctiphanes simplex



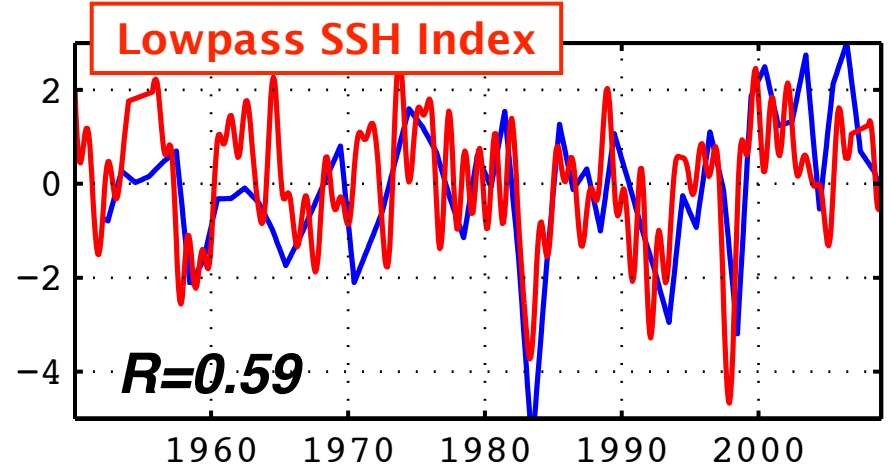
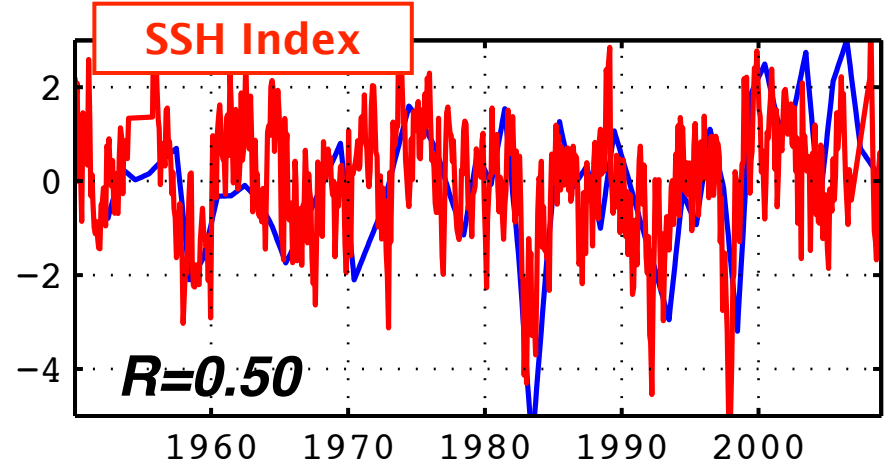
Euphausia pacifica



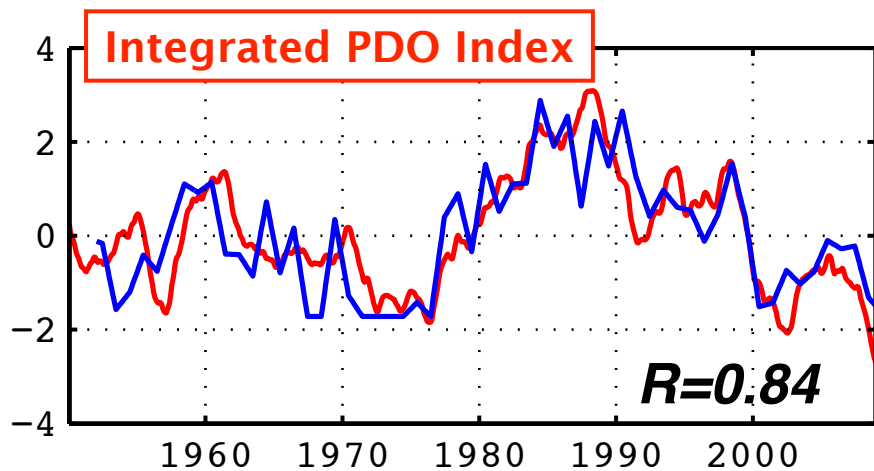
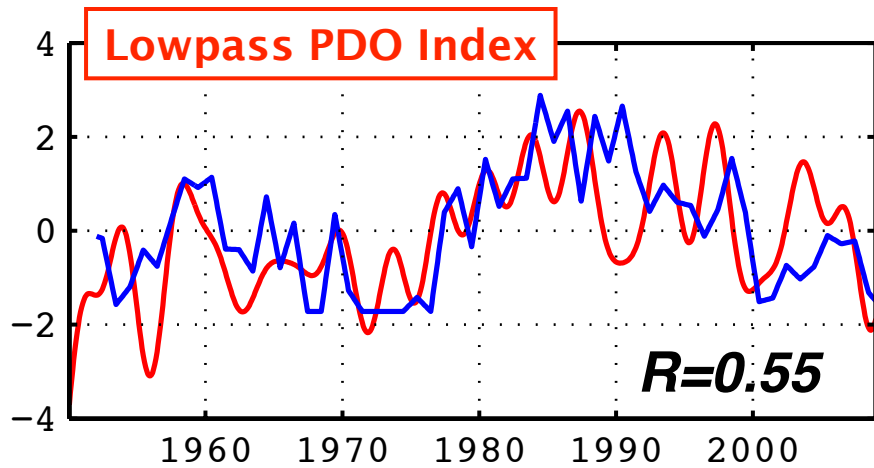
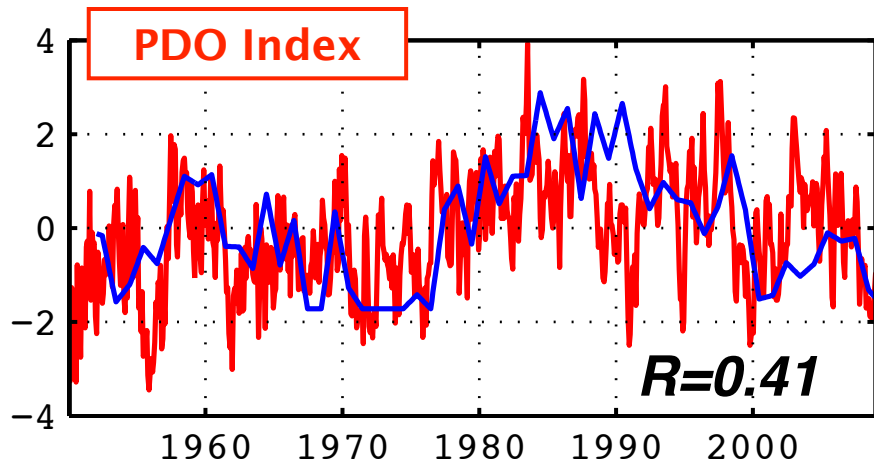
Nyctiphanes simplex



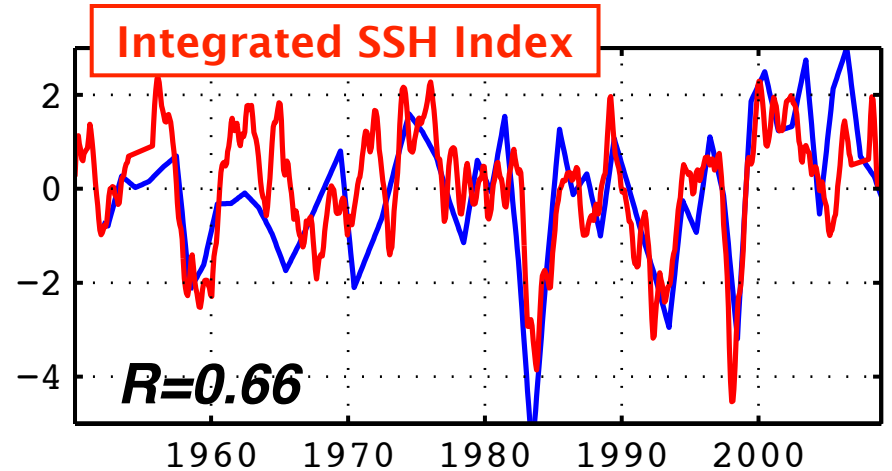
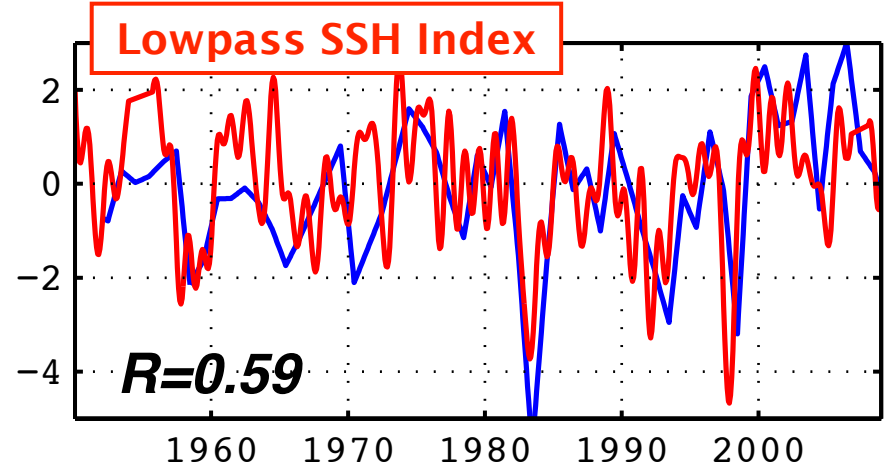
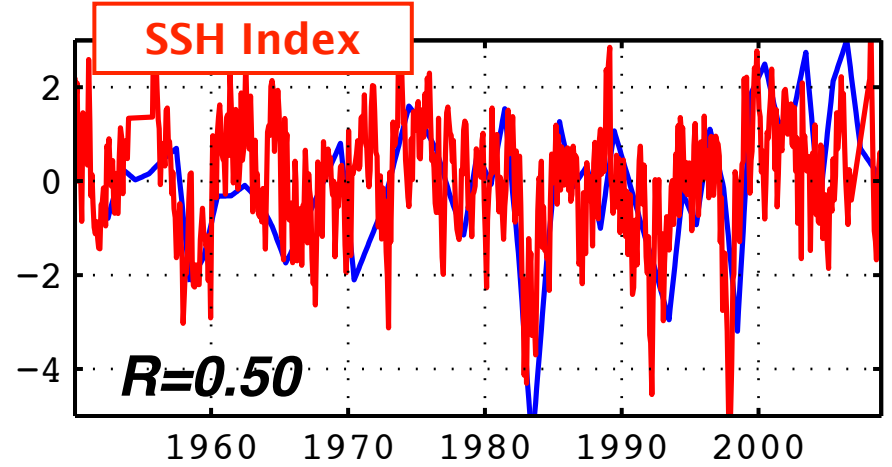
Euphausia pacifica



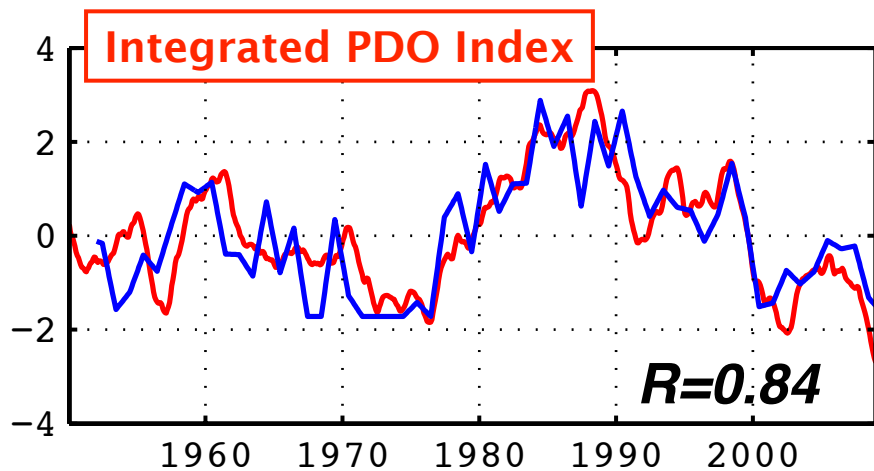
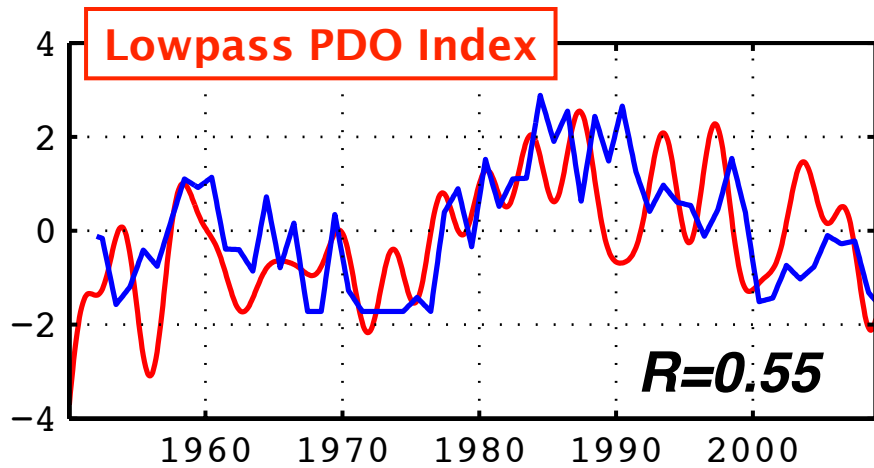
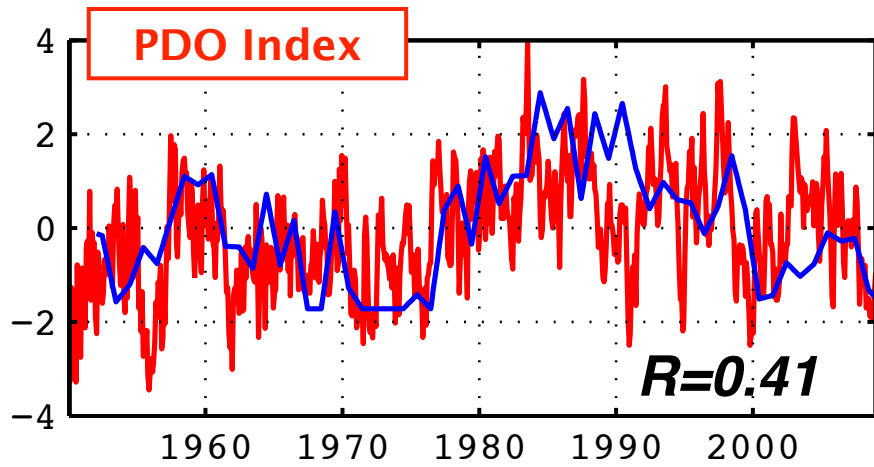
Nyctiphanes simplex



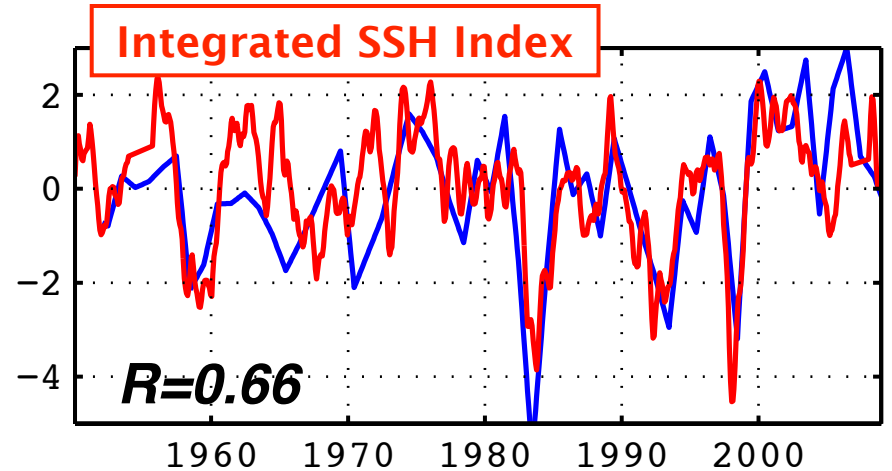
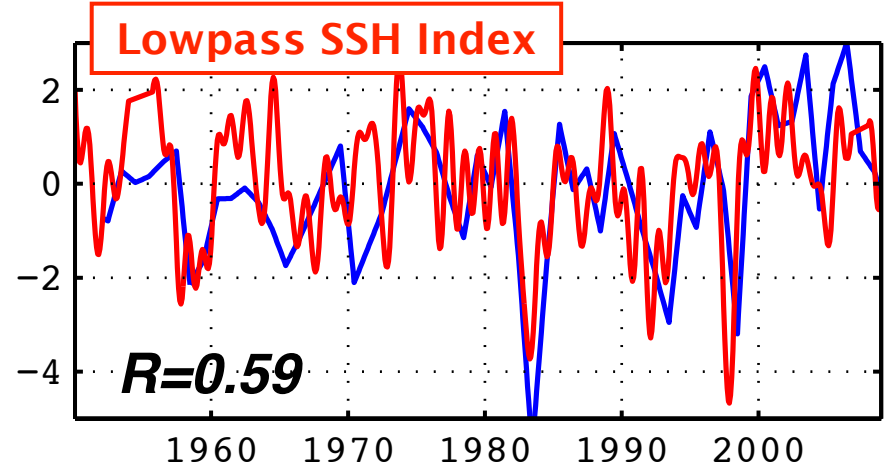
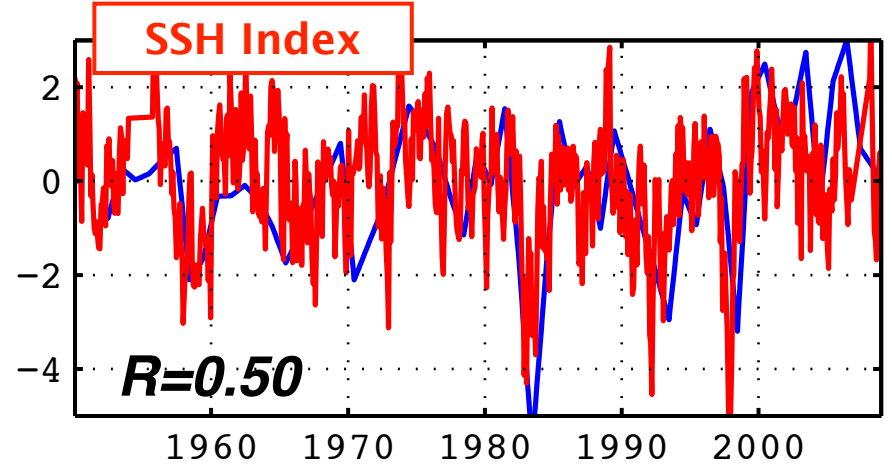
Euphausia pacifica



Nyctiphanes simplex

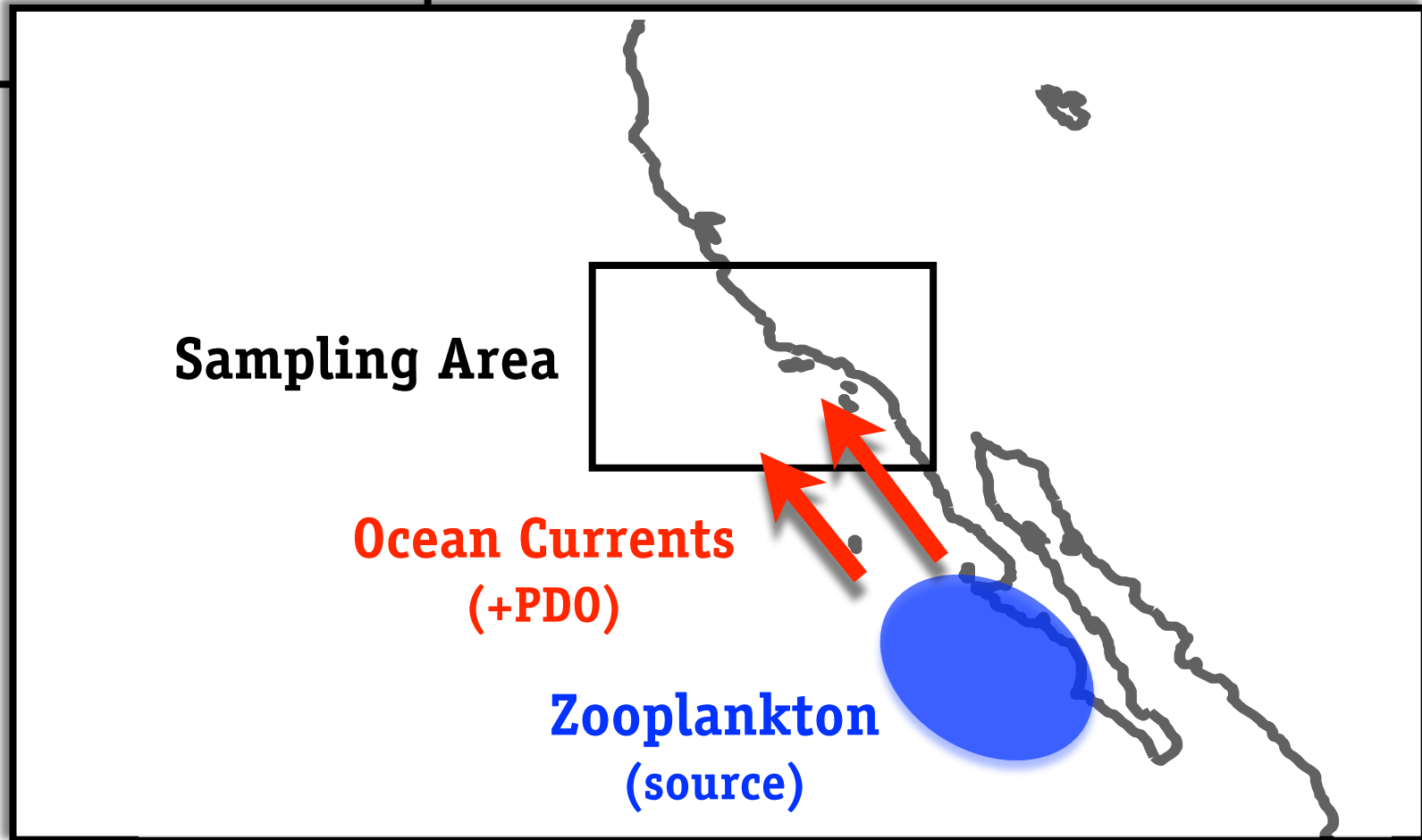
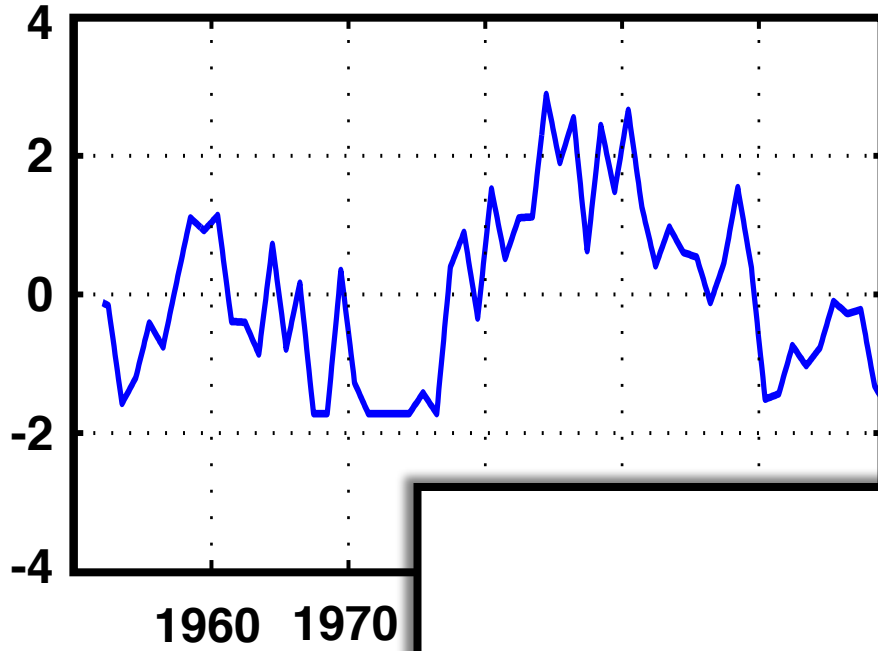


Euphausia pacifica



END

Nyctiphanes simplex



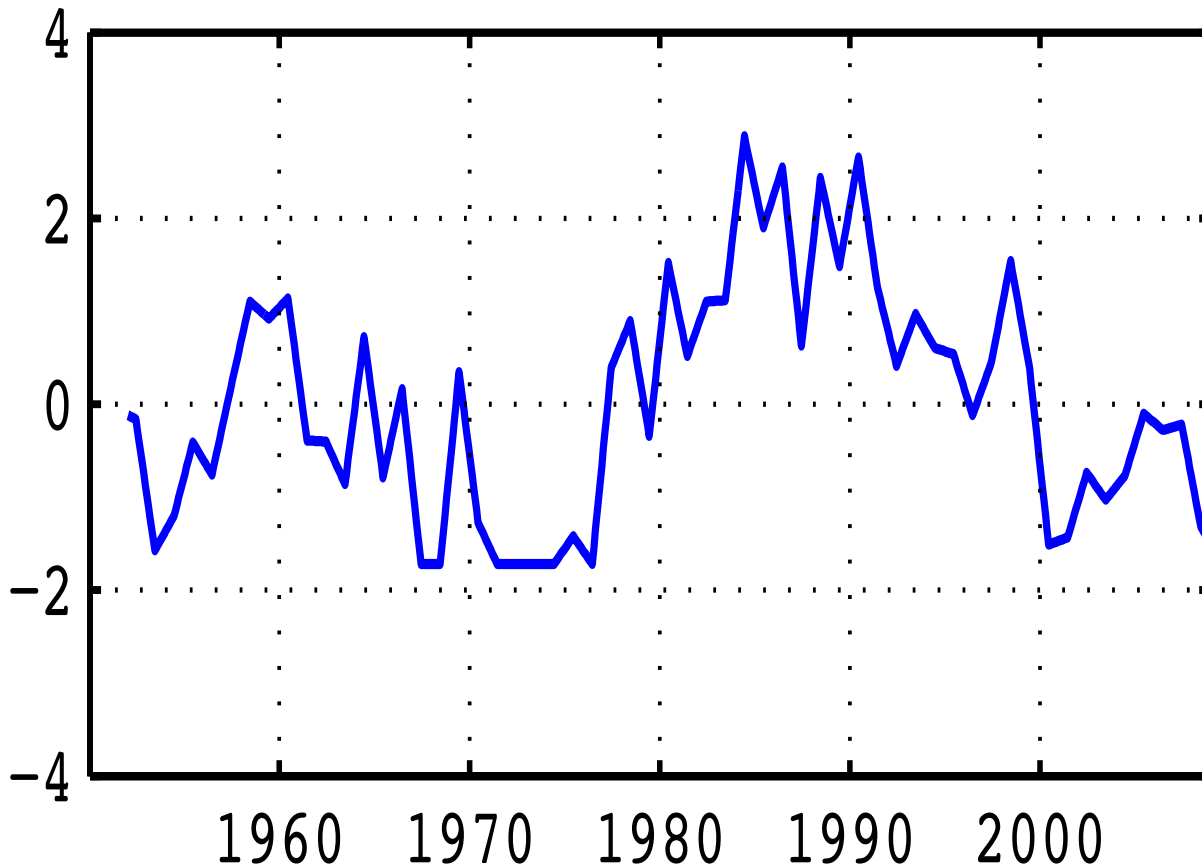
Effects of cumulative forcing on Zooplankton in the California Current

AN EXAMPLE

AL
Aleutian Low
Trenberth and Hurrell 1995
atmosphere
(winter)

PDO
Pacific Decadal Oscillation
Mantua et al. 1997
ocean
(winter)

Zooplankton (*Nyctiphanes simplex*)



2 changes in horizontal transport

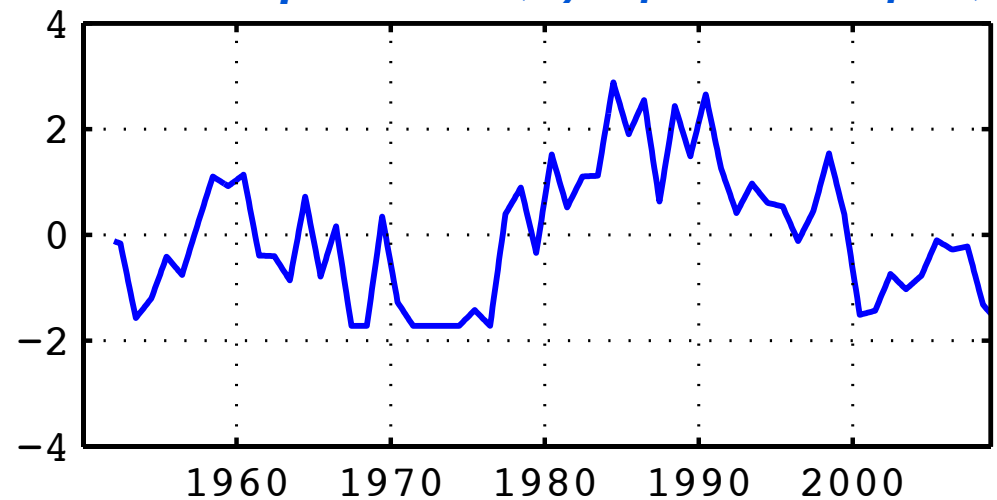
Effects of cumulative forcing on Zooplankton in the California Current

AN EXAMPLE

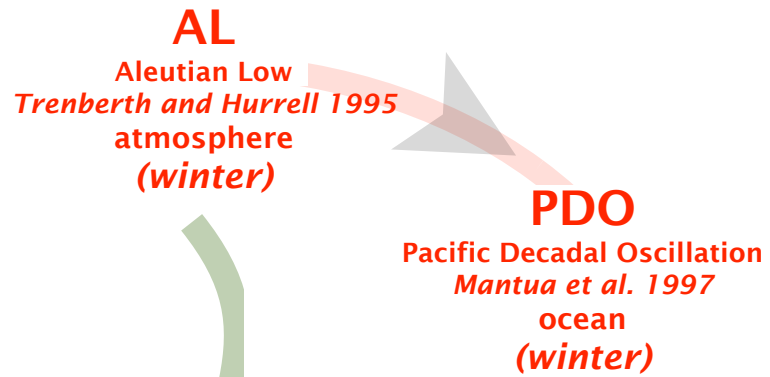


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Zooplankton (*Nyctiphanes simplex*)

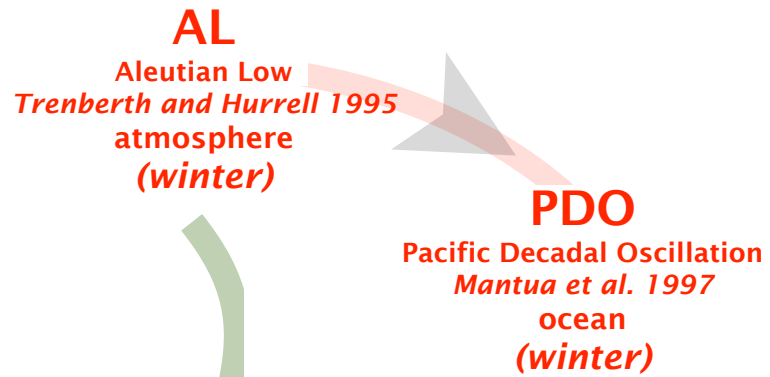


Types of impacts of climate modes on Ecosystem



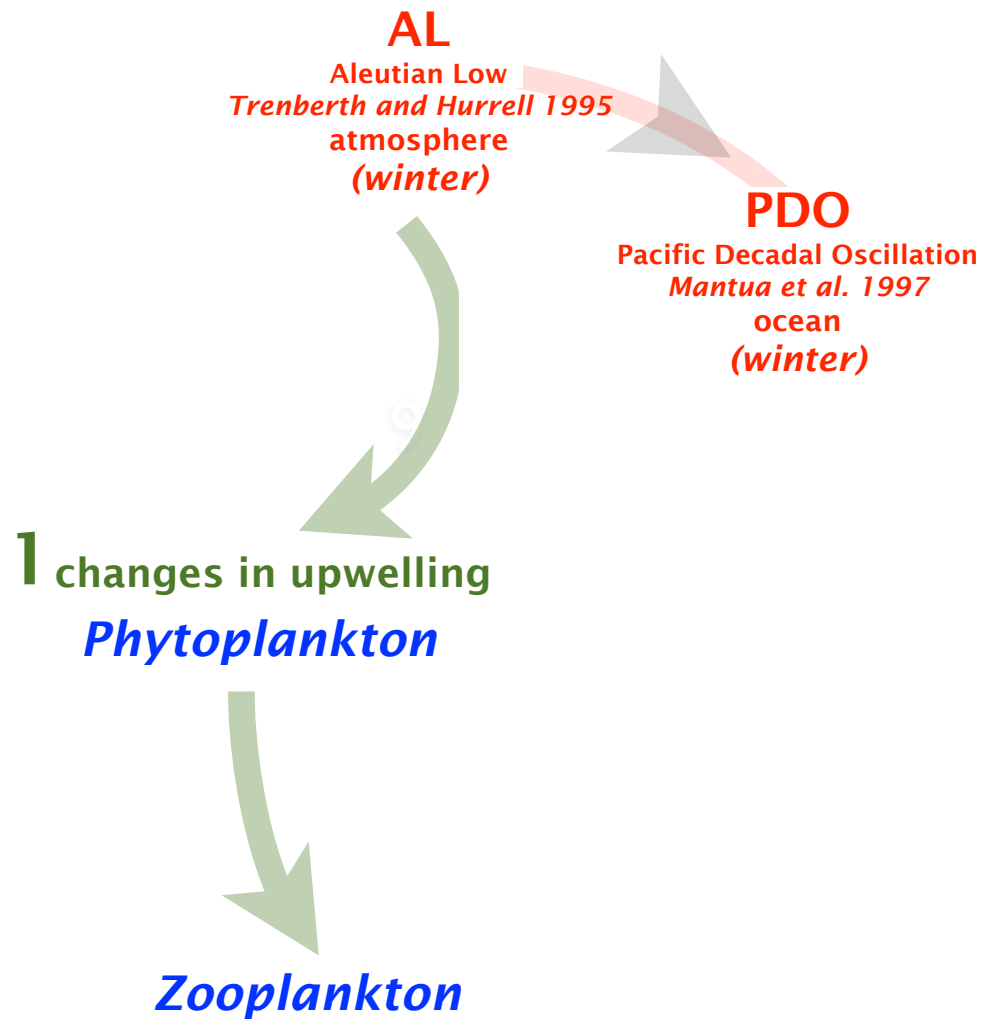
↑ changes in upwelling

Types of impacts of climate modes on Ecosystem

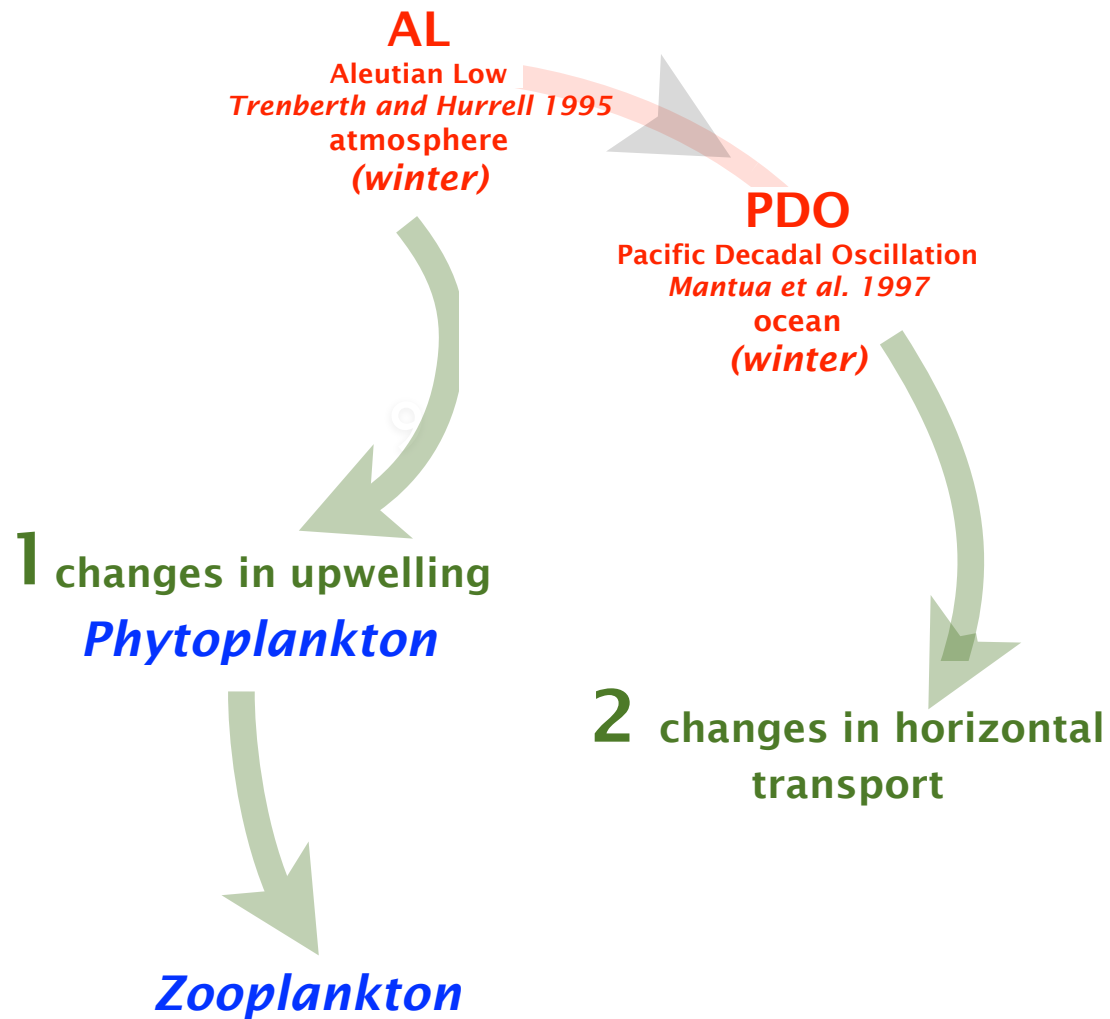


↑ changes in upwelling
Phytoplankton

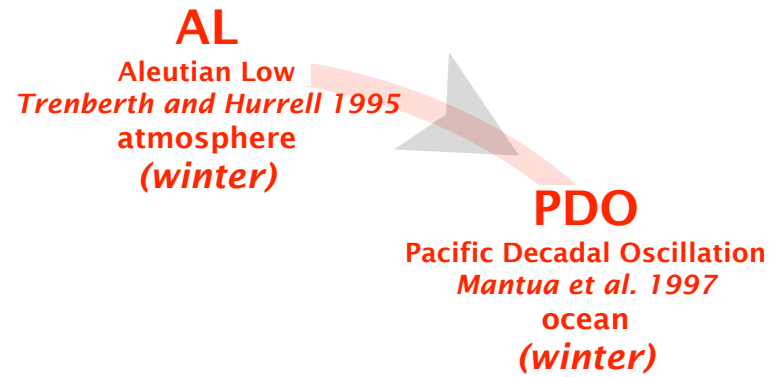
Types of impacts of climate modes on Ecosystem



Types of impacts of climate modes on Ecosystem



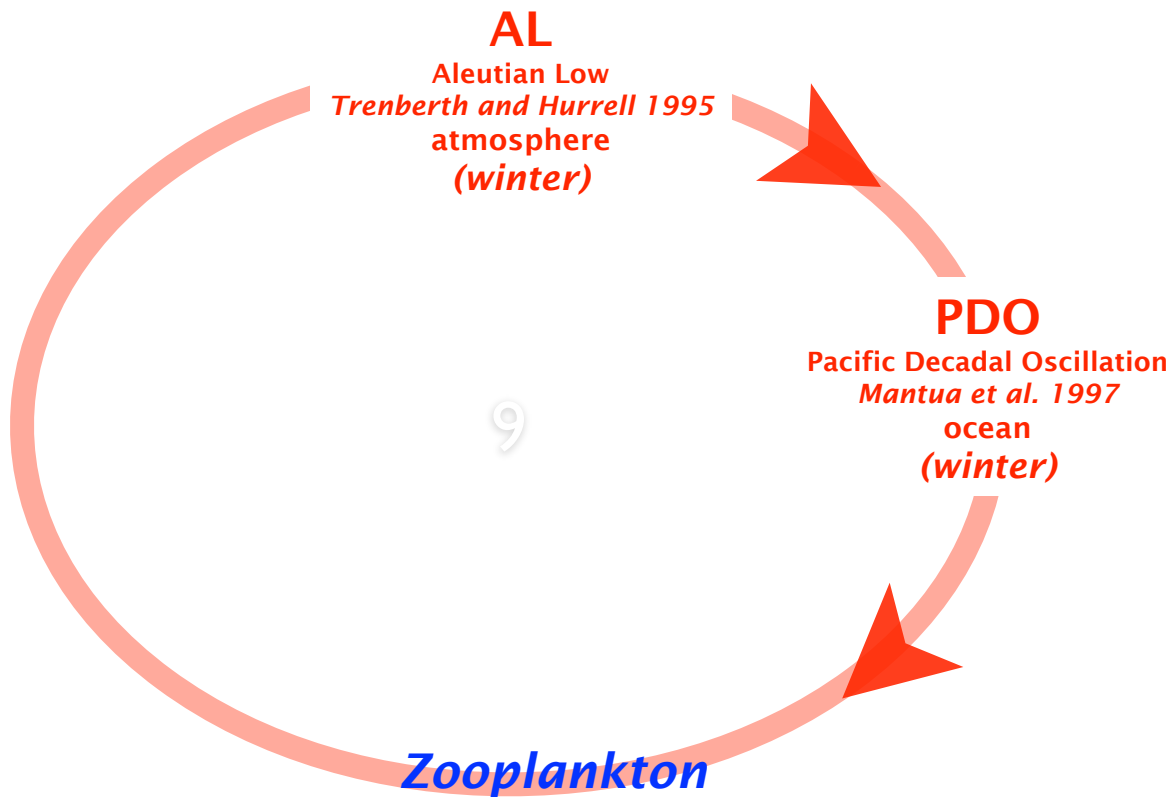
Types of impacts of climate modes on Ecosystem



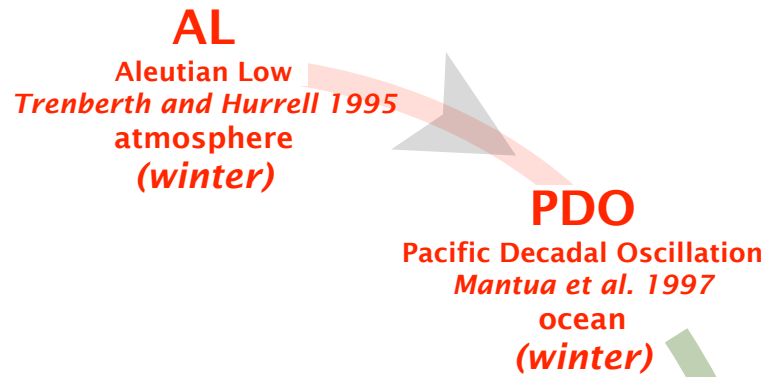
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2 changes in horizontal
transport

Zooplankton

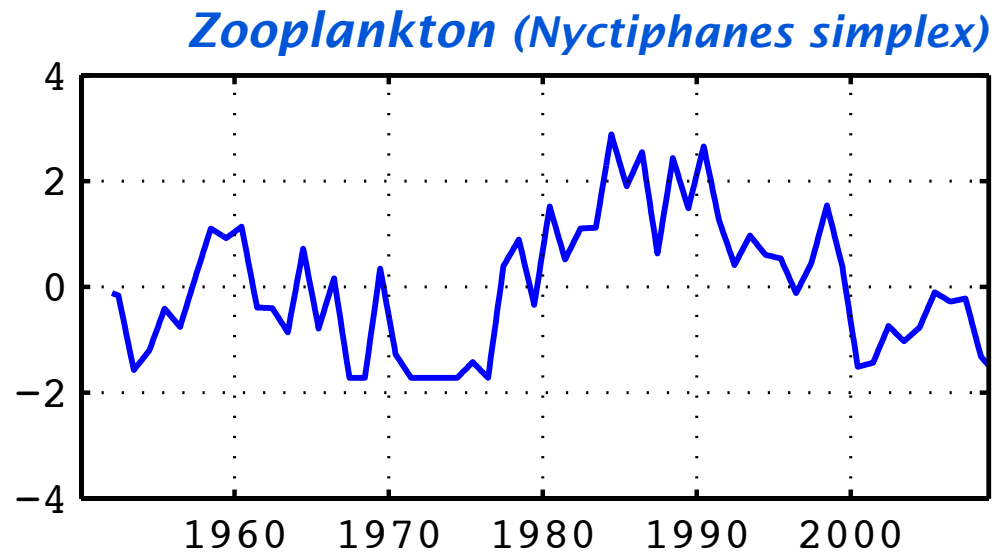


Types of impacts of climate modes on Ecosystem

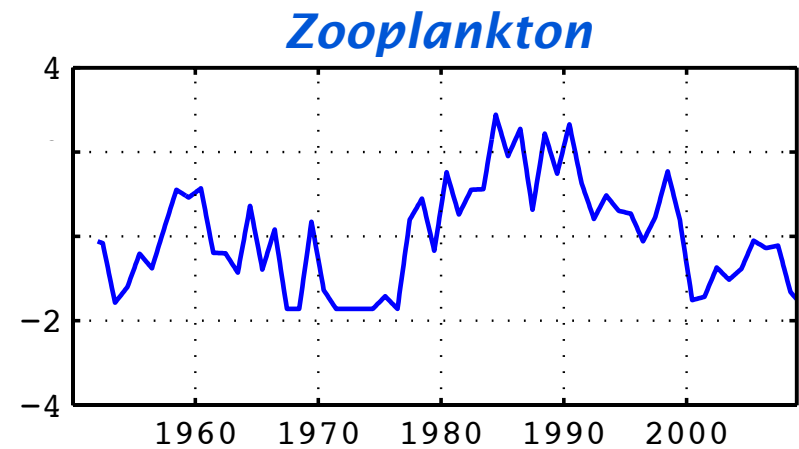
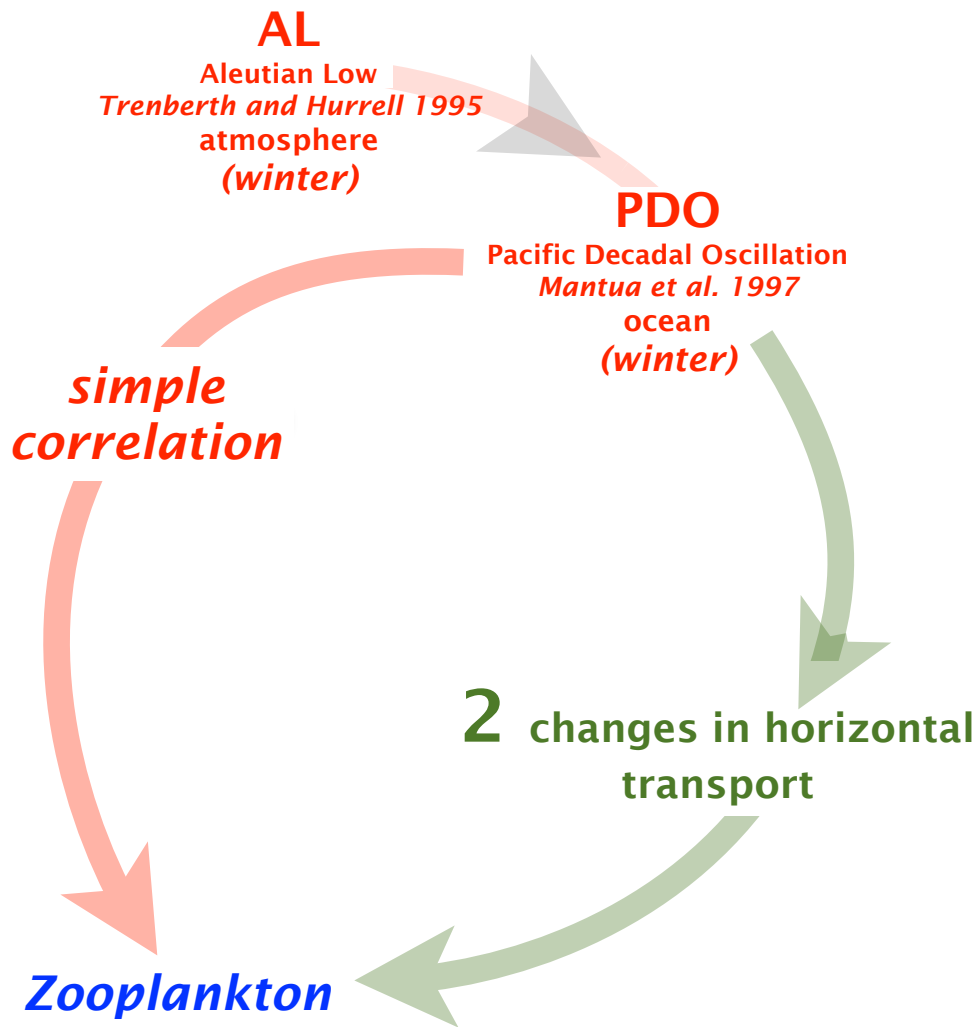


2 changes in horizontal transport

Zooplankton

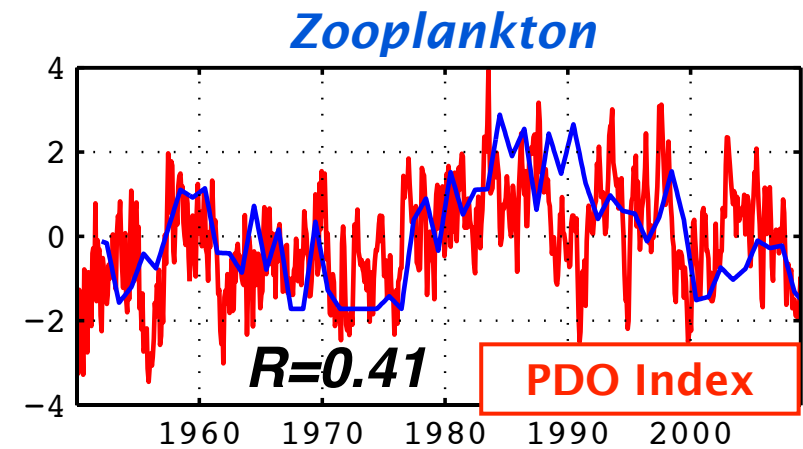
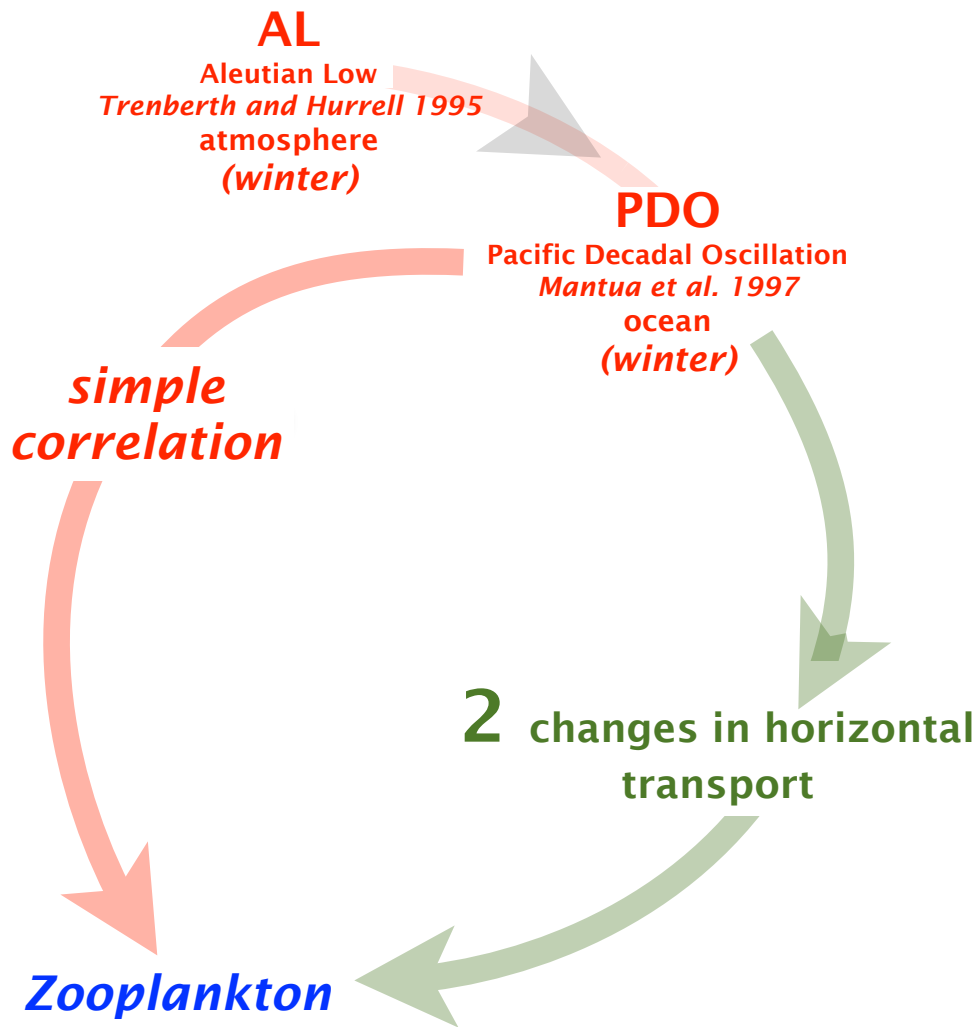


Types of impacts of climate modes on Ecosystem



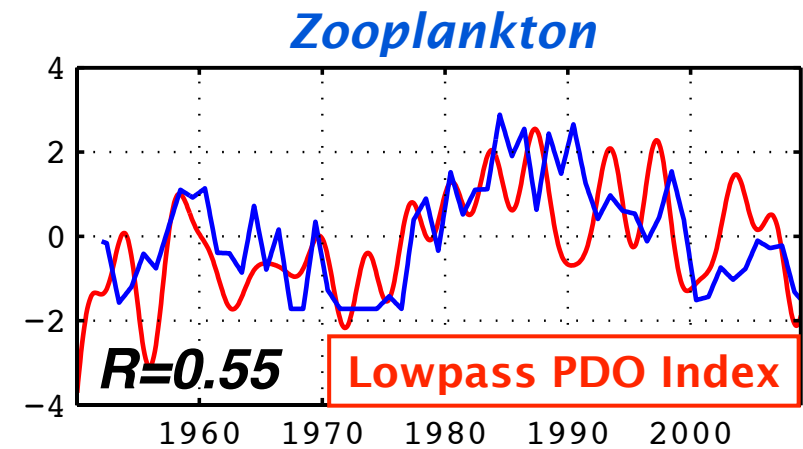
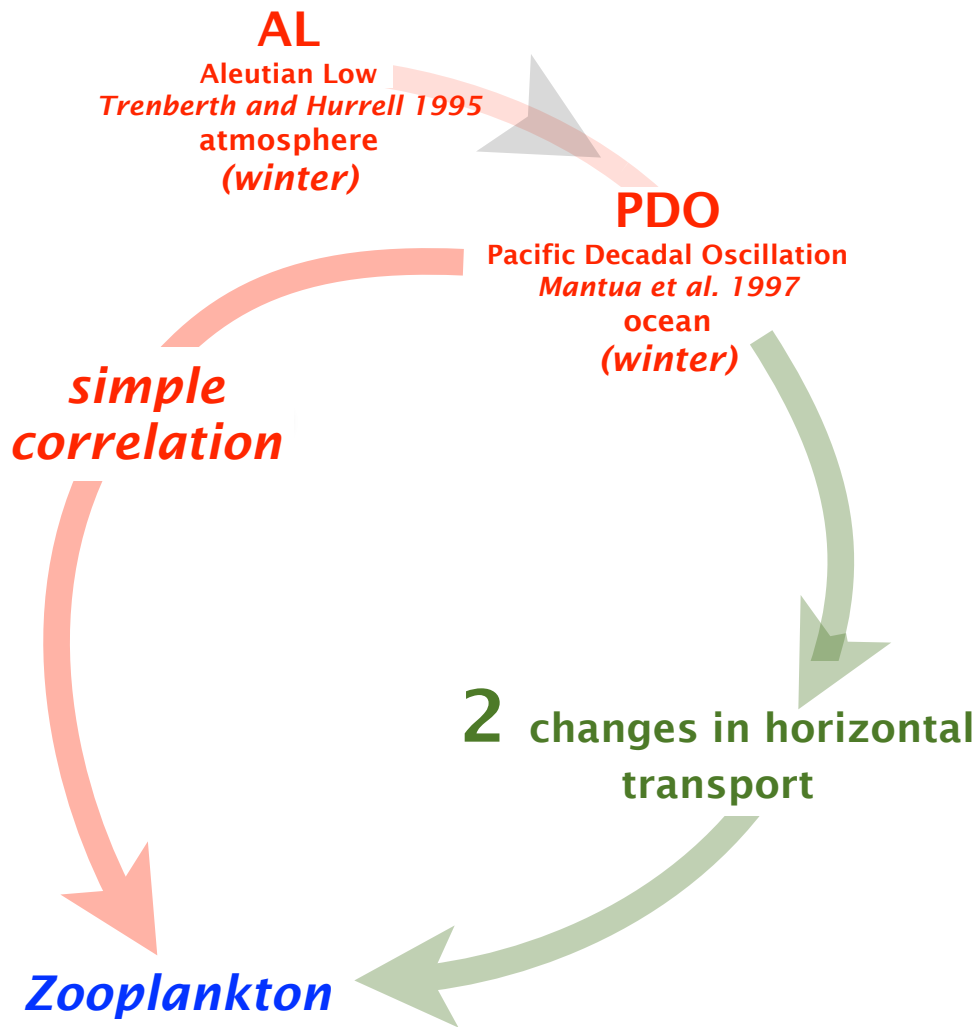
data from M. Ohman

Types of impacts of climate modes on Ecosystem



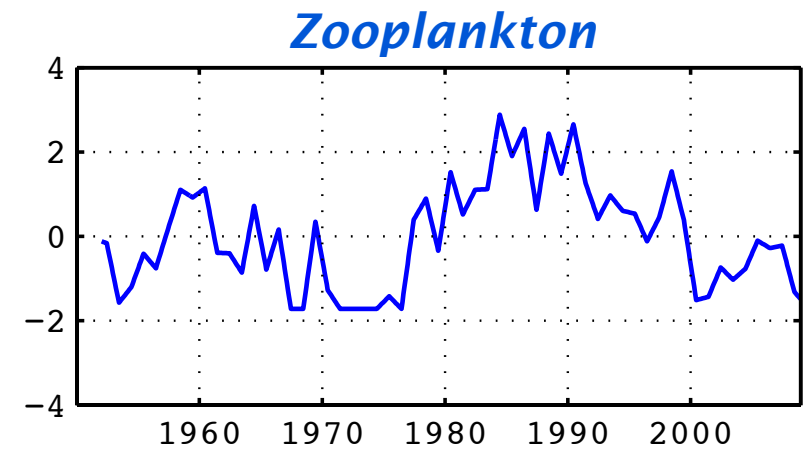
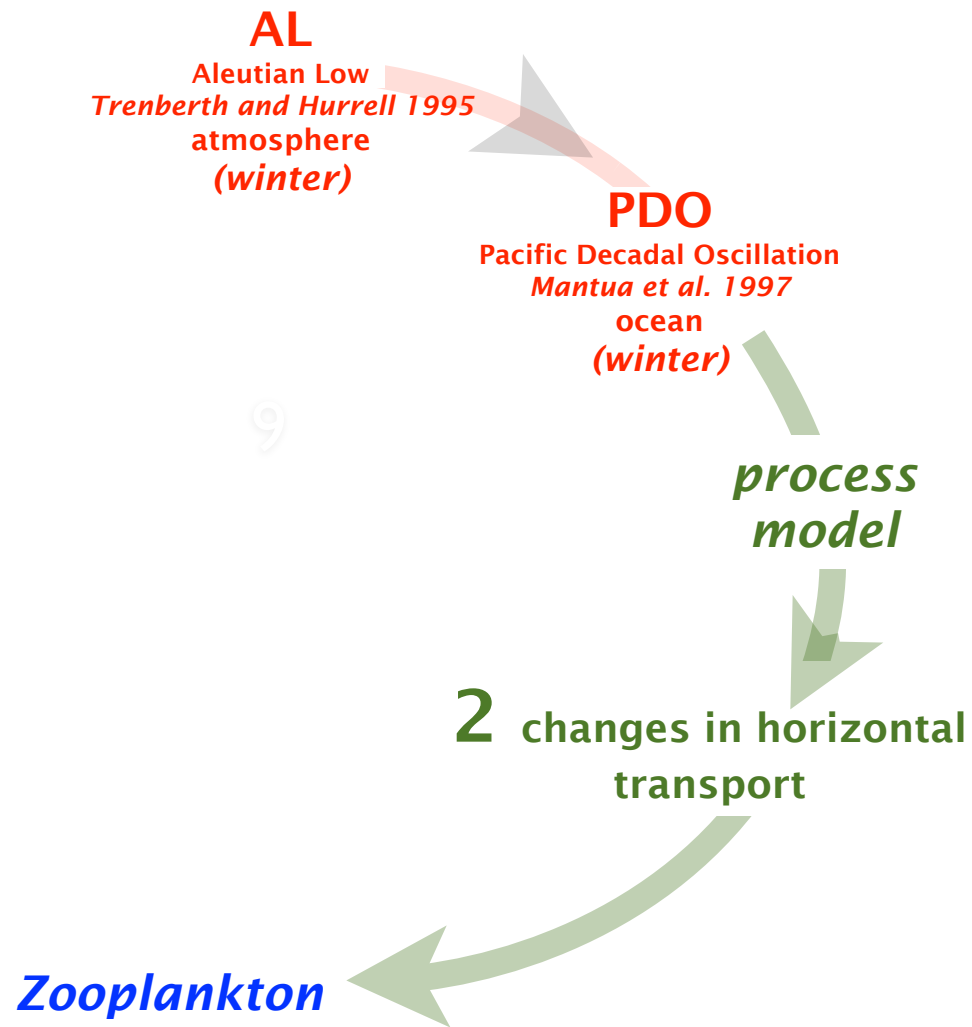
data from M. Ohman

Types of impacts of climate modes on Ecosystem



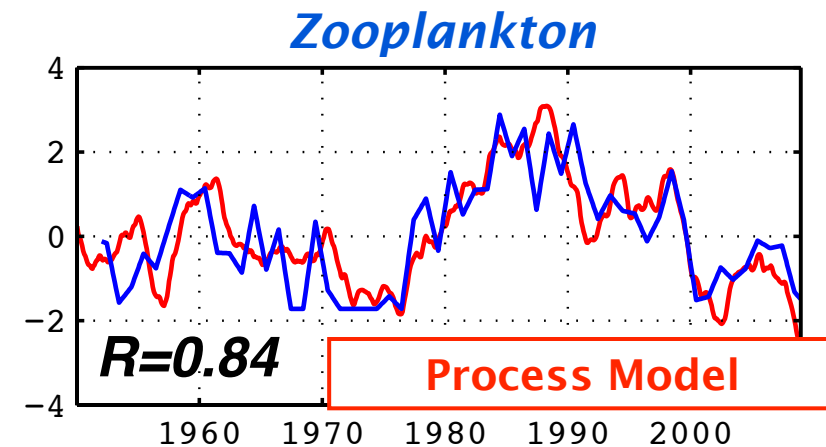
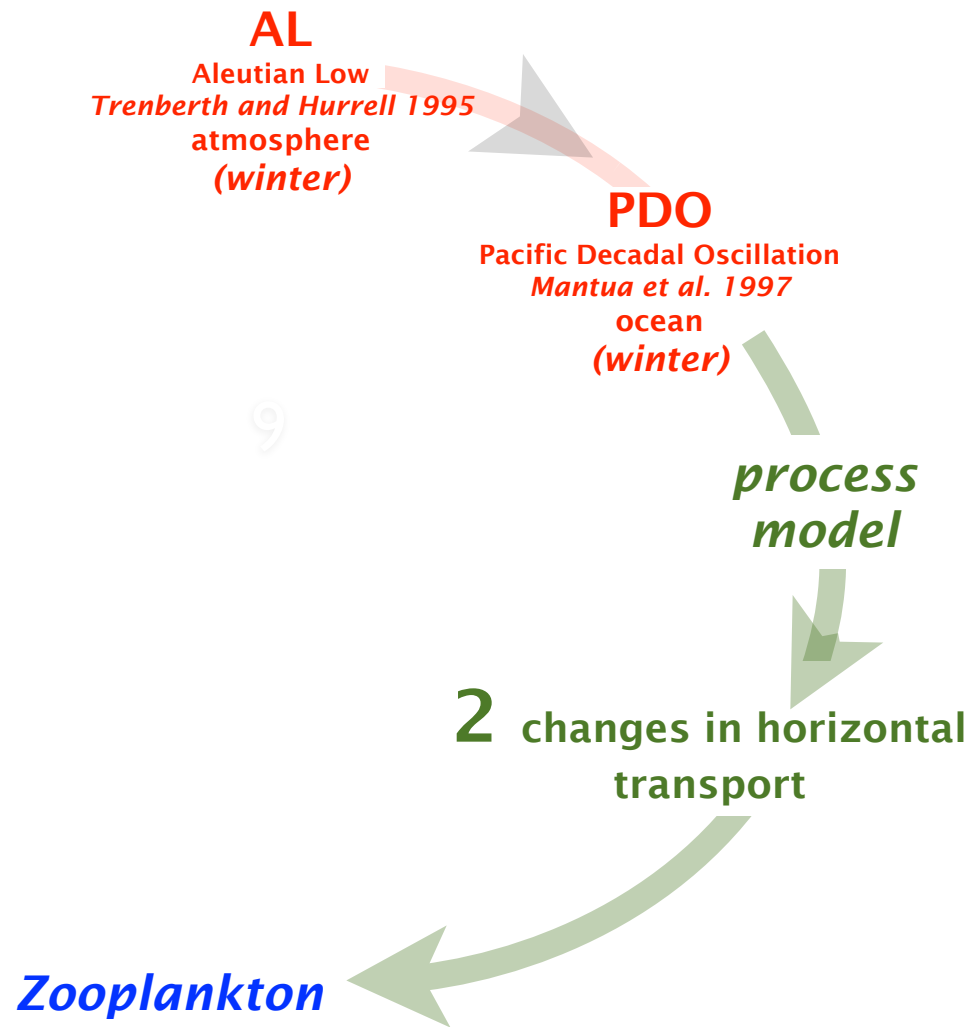
data from M. Ohman

Types of impacts of climate modes on Ecosystem



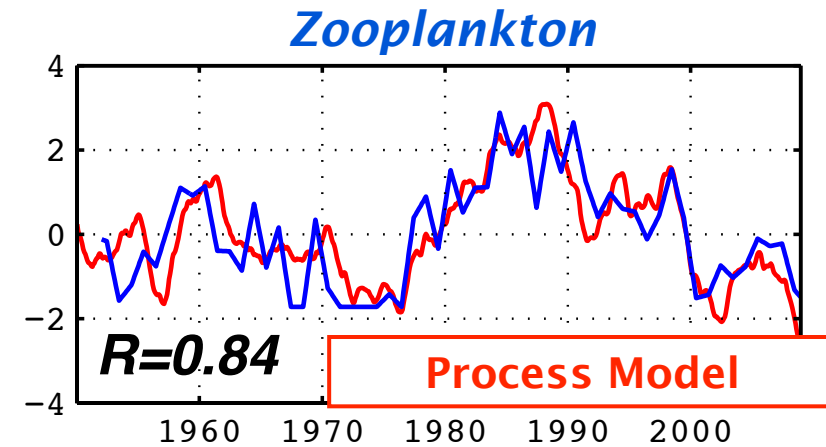
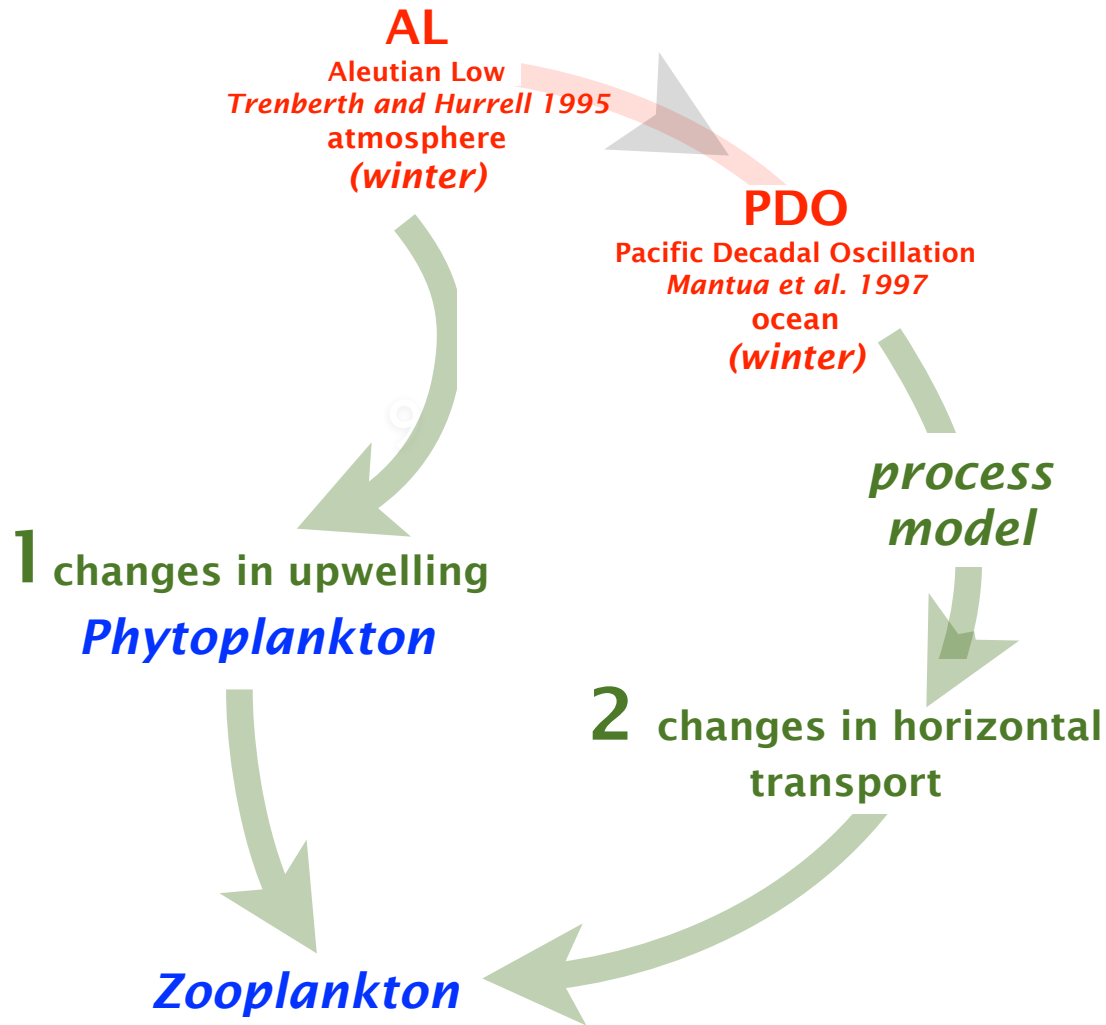
data from M. Ohman

Types of impacts of climate modes on Ecosystem



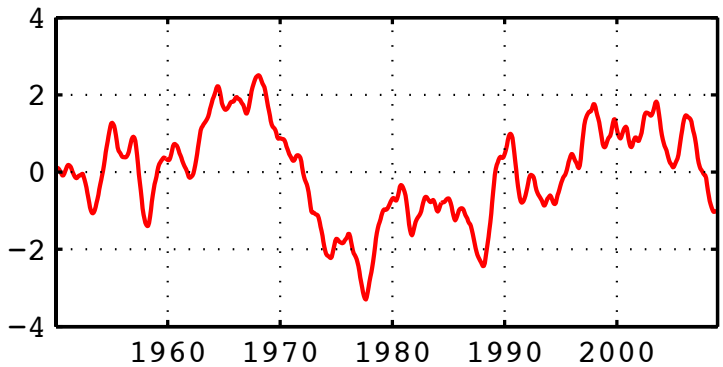
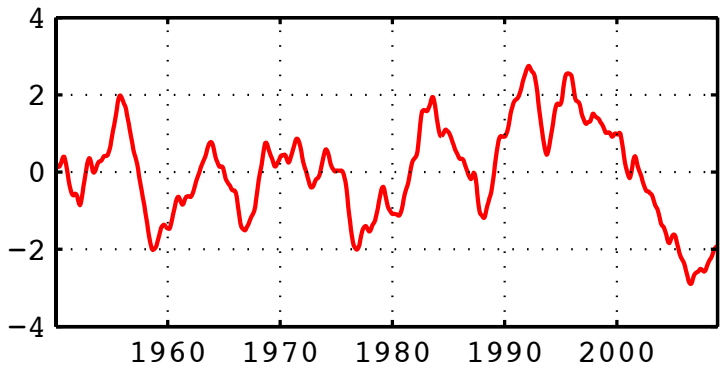
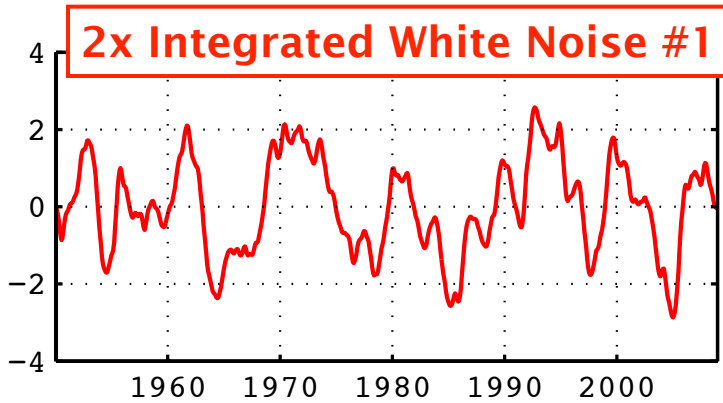
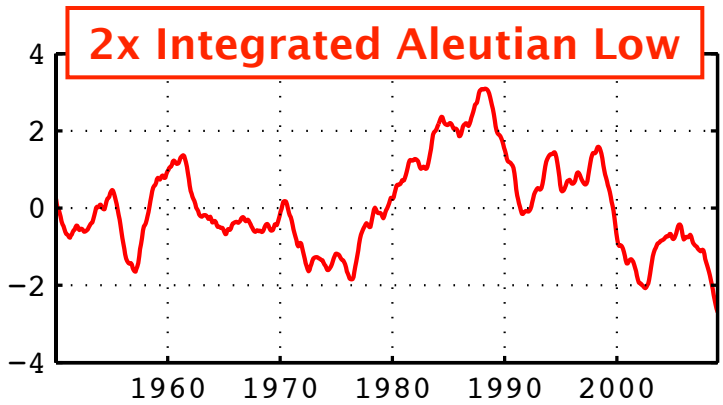
data from M. Ohman

Types of impacts of climate modes on Ecosystem



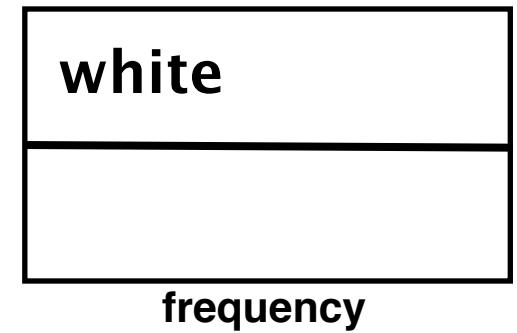
data from M. Ohman

JUNK



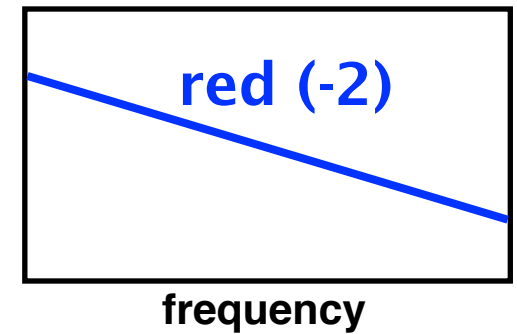
Atmosphere

$$f(t)$$



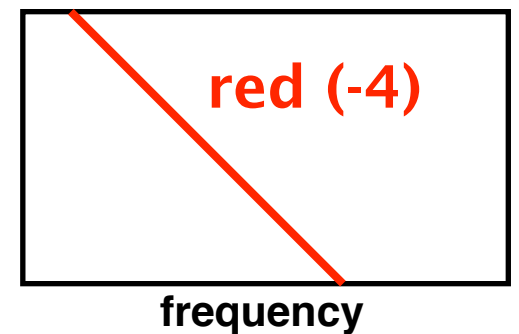
Ocean

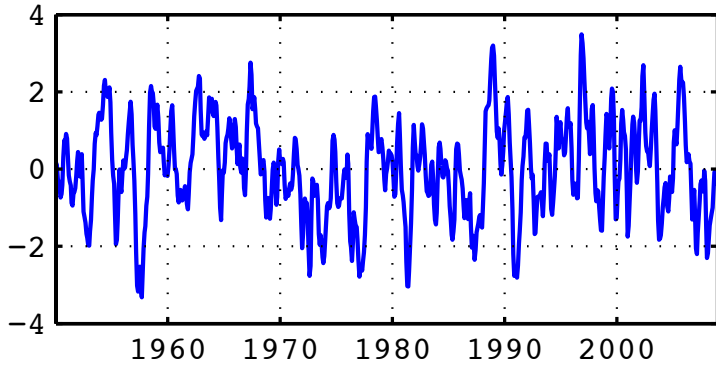
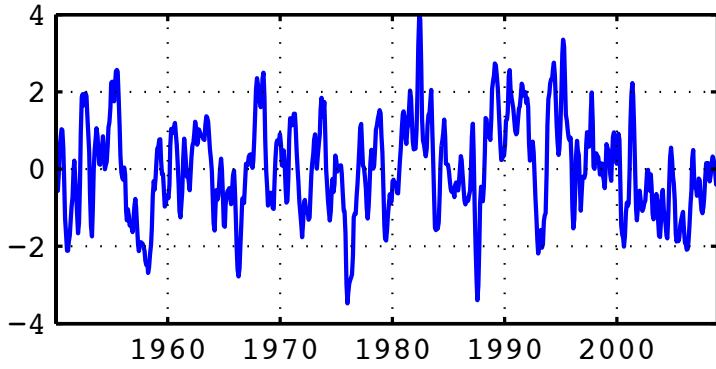
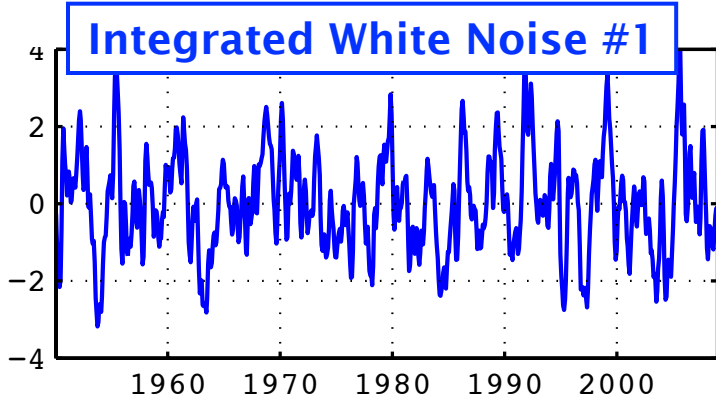
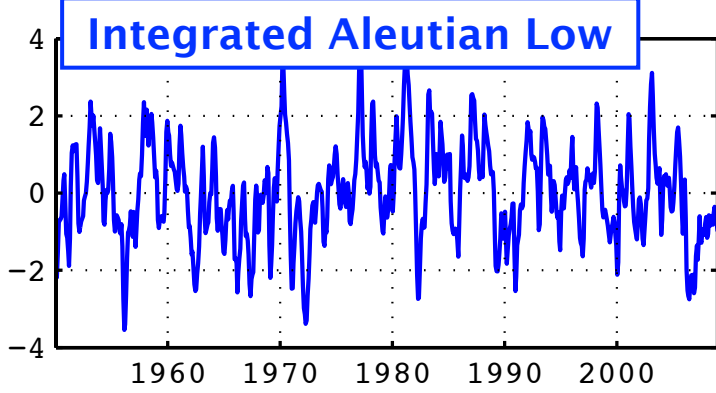
$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$



Biology

$$\frac{d\varepsilon(t)}{dt} = \varphi(t) - \frac{\varepsilon(t)}{\tau_\varepsilon}$$

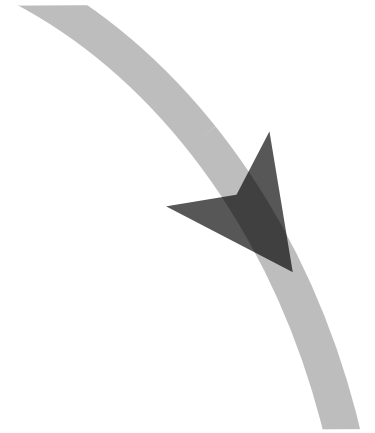




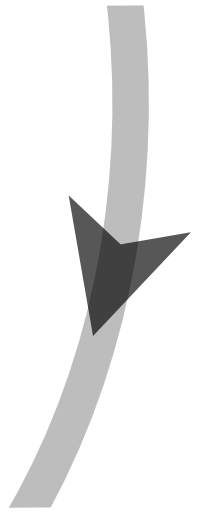
Atmosphere Forcing

$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

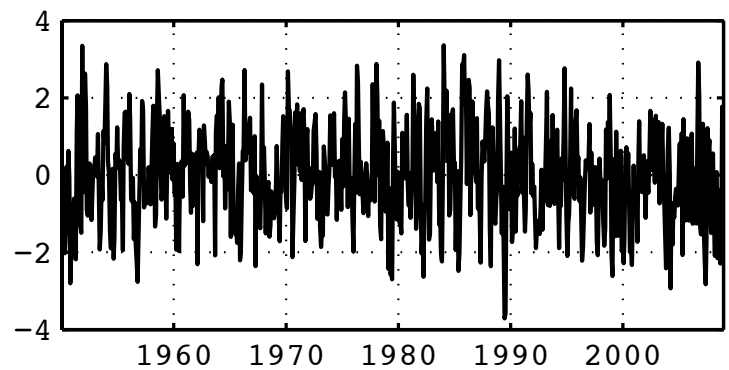
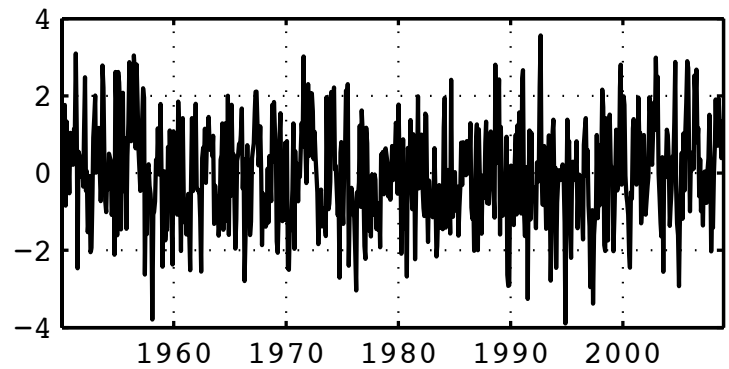
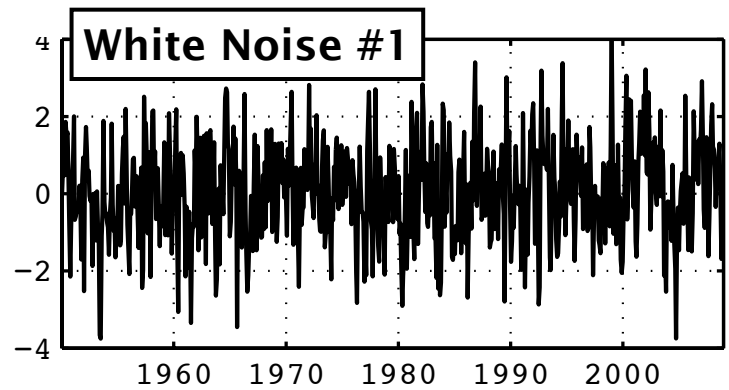
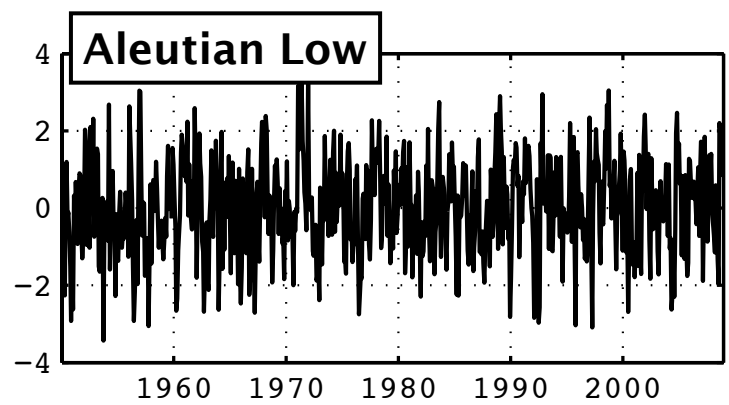
Atmosphere



Ocean



Biology



$f(t)$
Atmosphere Forcing

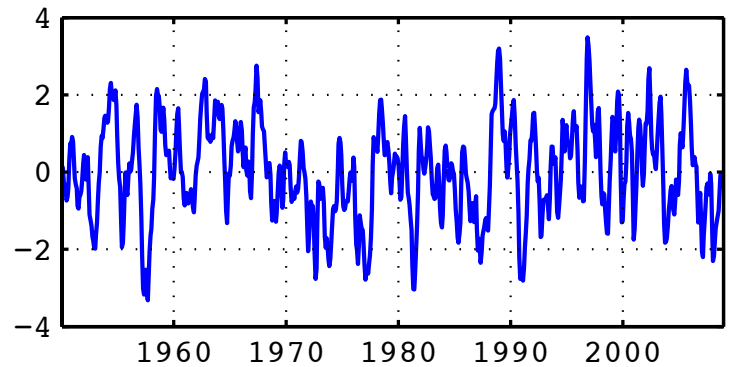
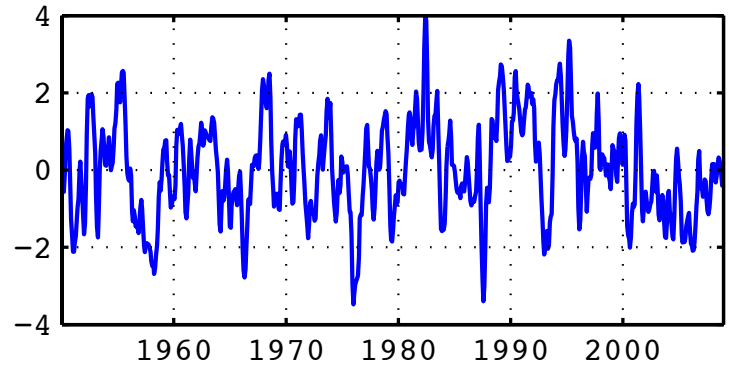
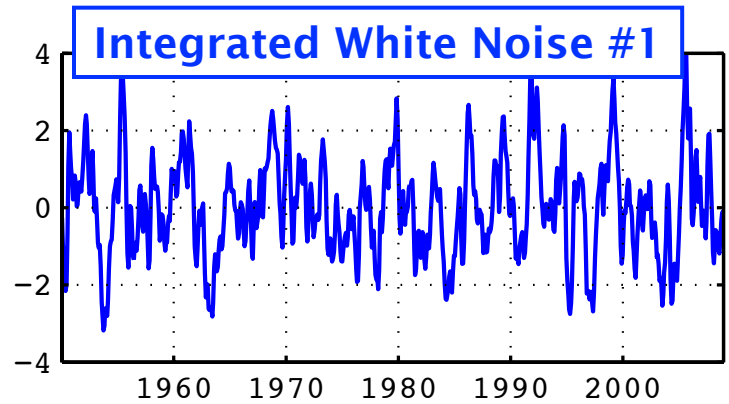
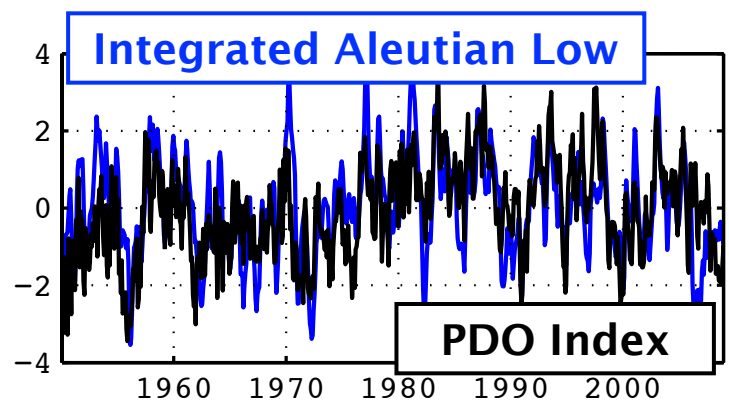
$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

Atmosphere

Ocean

Biology





$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

Ocean Forcing

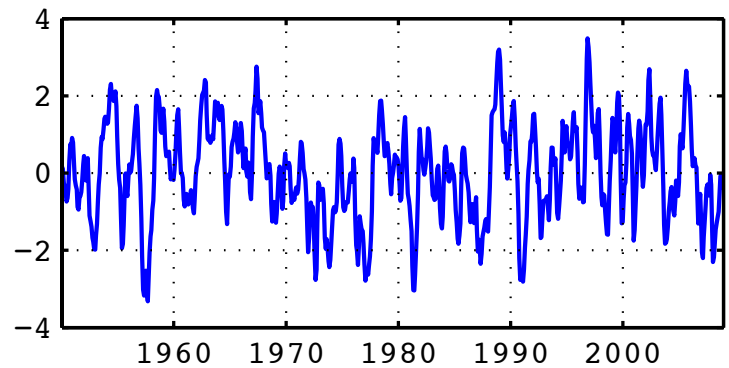
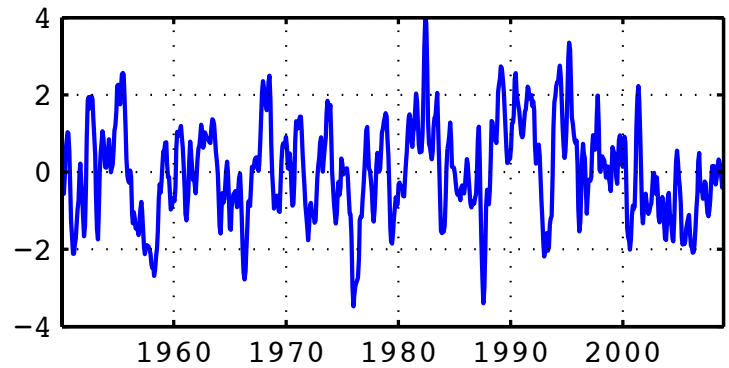
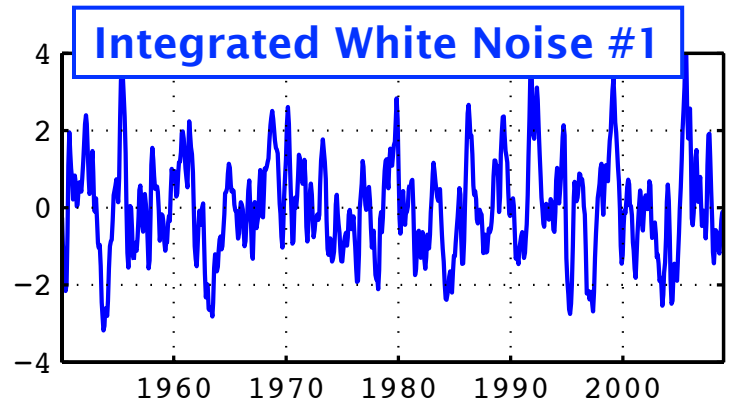
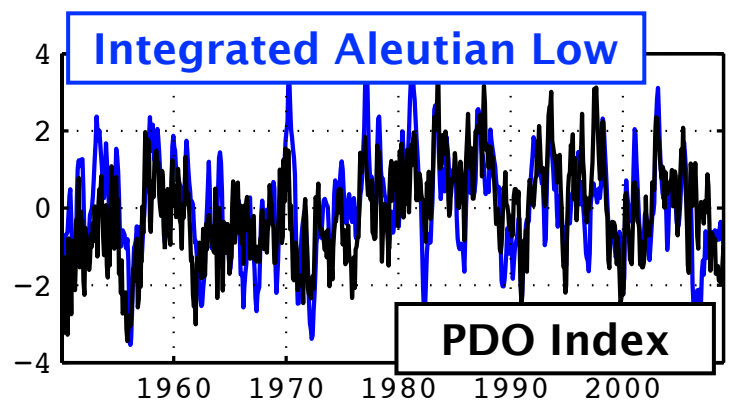
$$\frac{d\varepsilon(t)}{dt} = \varphi(t) - \frac{\varepsilon(t)}{\tau_\varepsilon}$$

Atmosphere

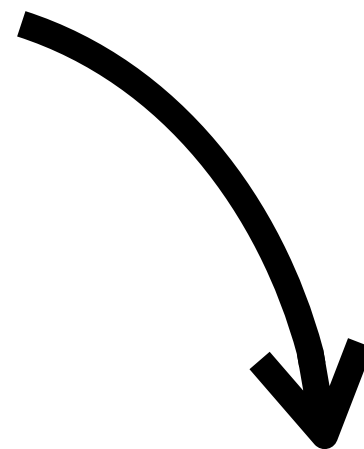
Ocean

Biology





Atmosphere



Ocean

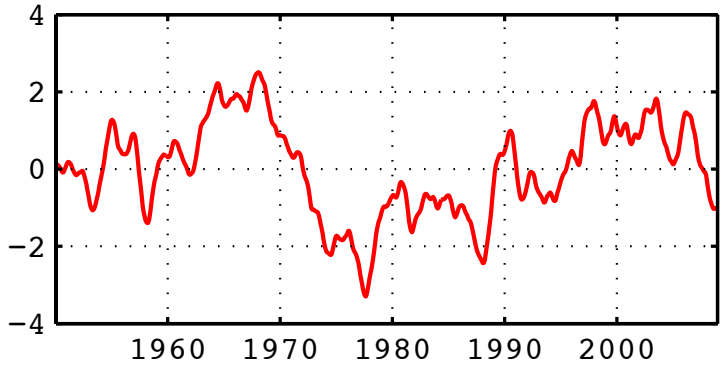
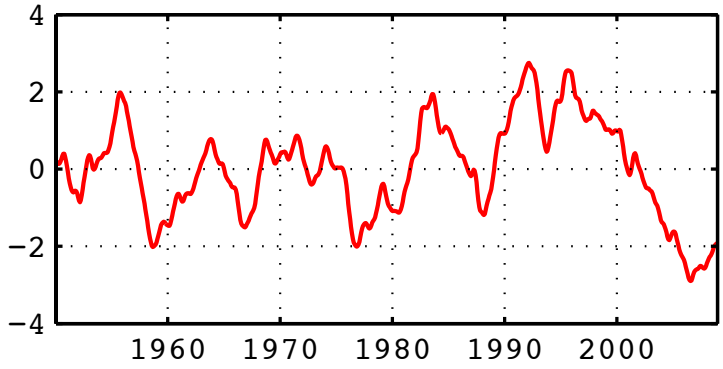
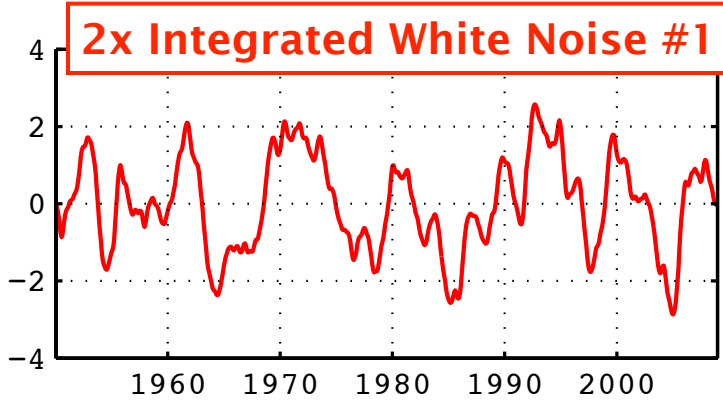
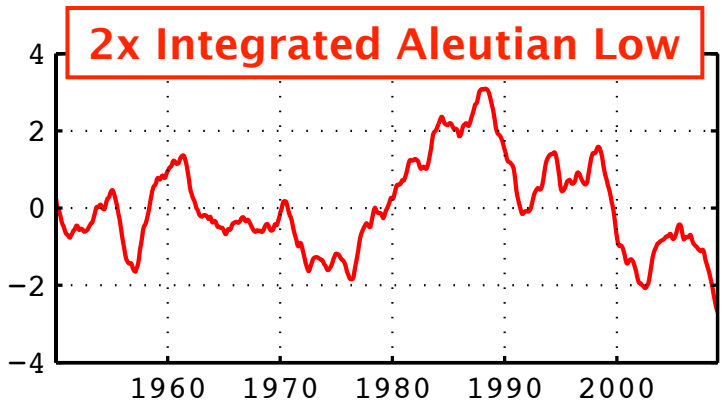


Biology

$$\frac{d\varphi(t)}{dt} = f(t) - \frac{\varphi(t)}{\tau_\varphi}$$

Ocean Forcing

$$\frac{d\varepsilon(t)}{dt} = \varphi(t) - \frac{\varepsilon(t)}{\tau_\varepsilon}$$



Biology

$$\frac{d\varepsilon(t)}{dt} = \varphi(t) - \frac{\varepsilon(t)}{\tau_\varepsilon}$$

Ocean Forcing

Atmosphere



Ocean

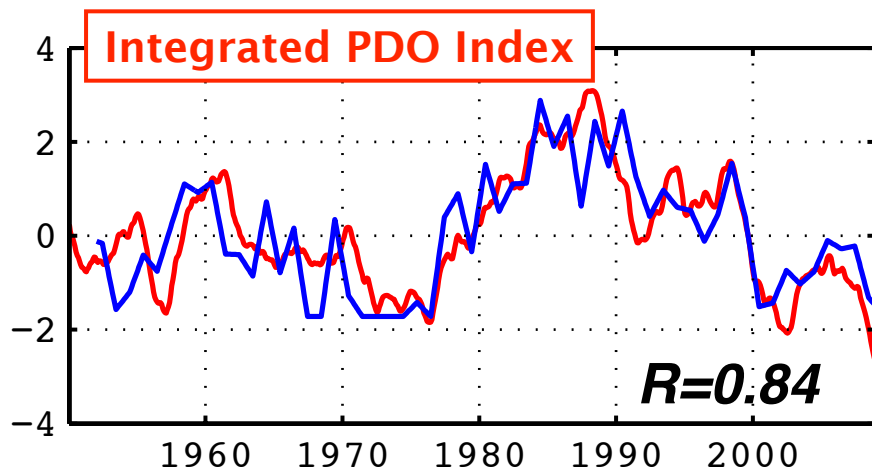
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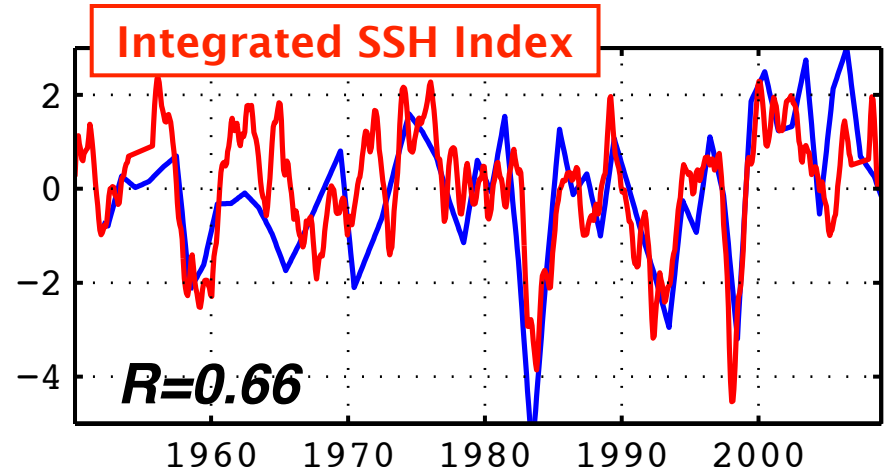
Biology

Summary

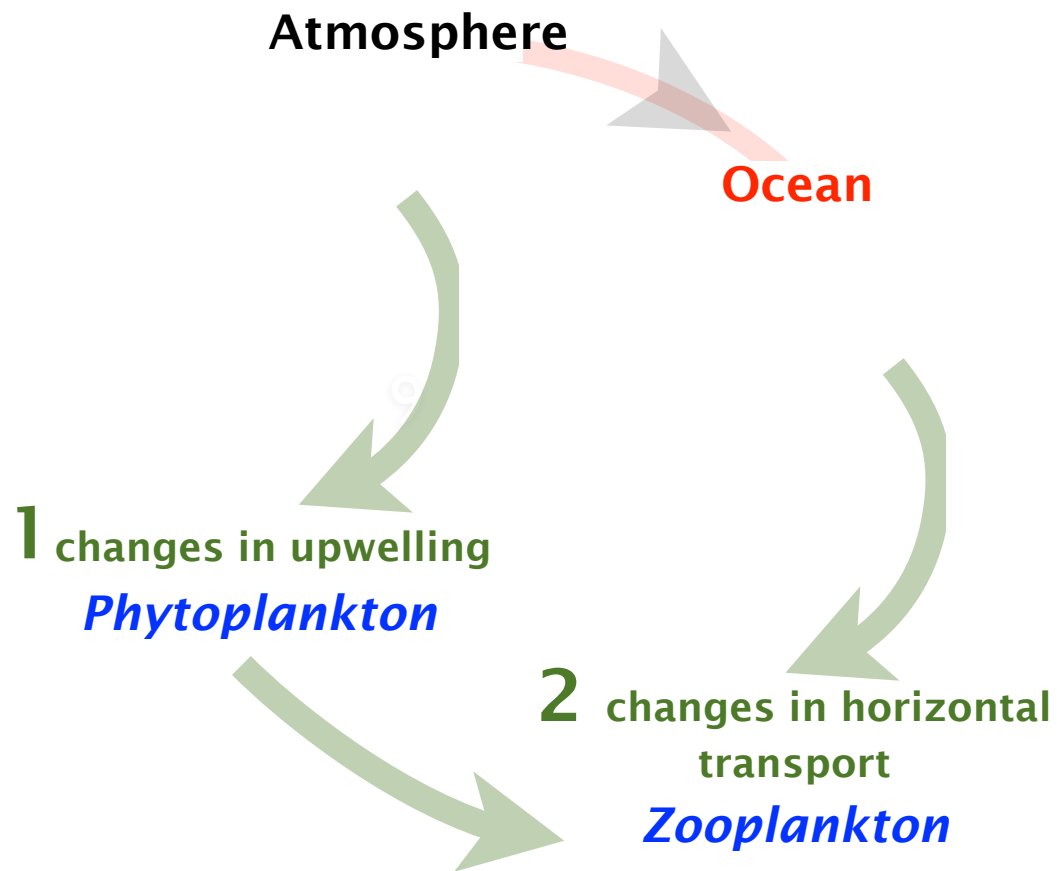
Nyctiphanes simplex



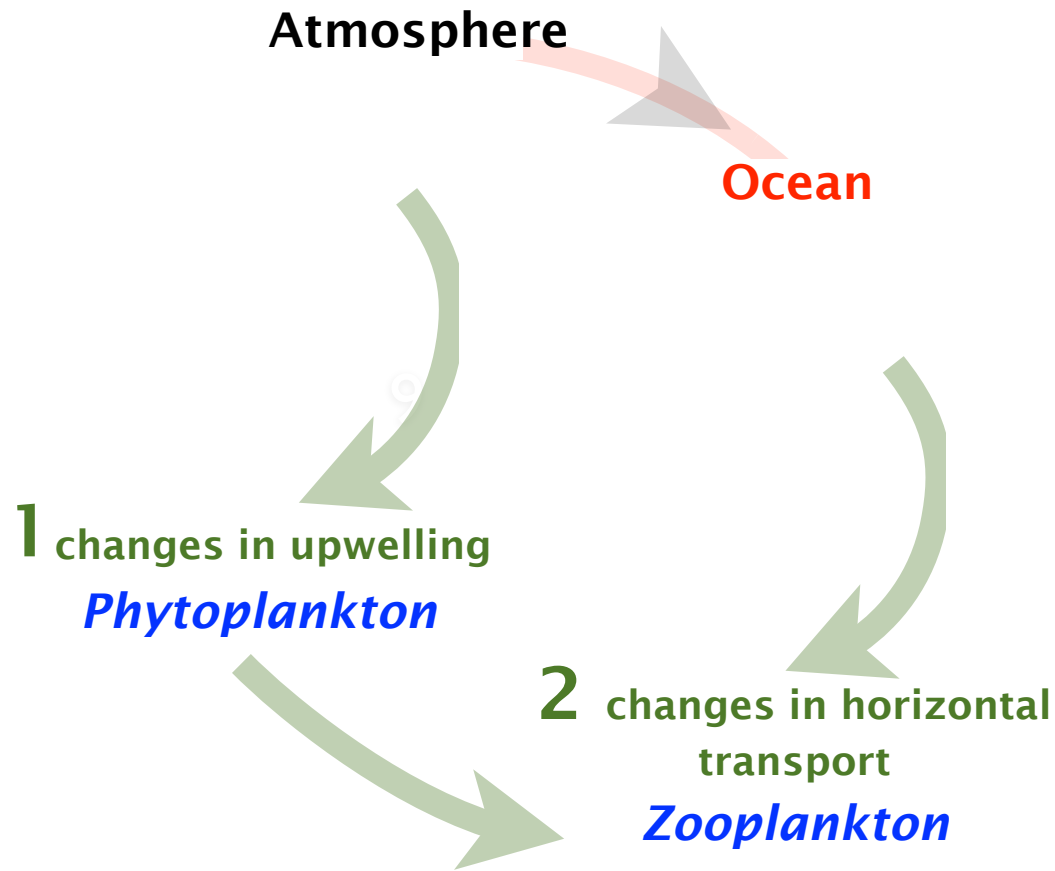
Euphausia pacifica



Types of impacts of climate variability on Ecosystem Species

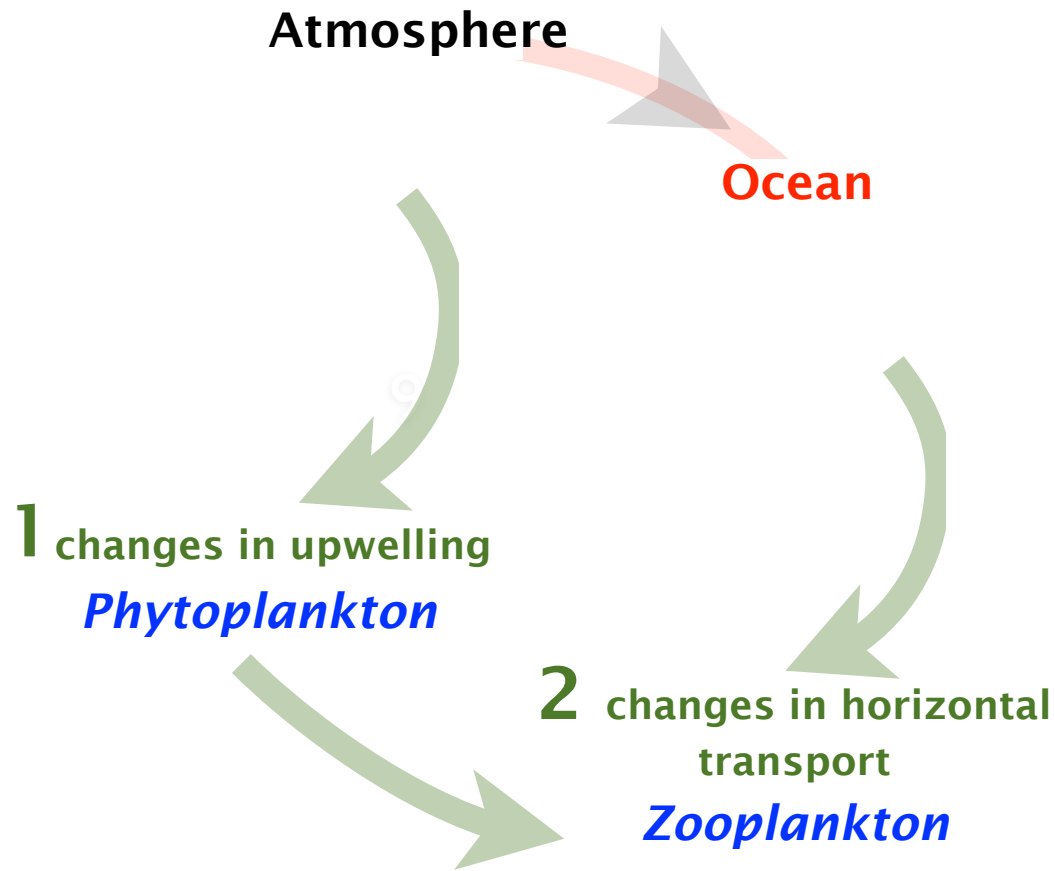


Types of impacts of climate variability on Ecosystem Species



1 *Biology integrates the effects of atmospheric forcing*

Types of impacts of climate variability on Ecosystem Species



1 *Biology integrates the effects of atmospheric forcing*

2 *Biology integrates the effects of oceanic forcing*

Framework for Pacific Climate Variability & Ecosystem

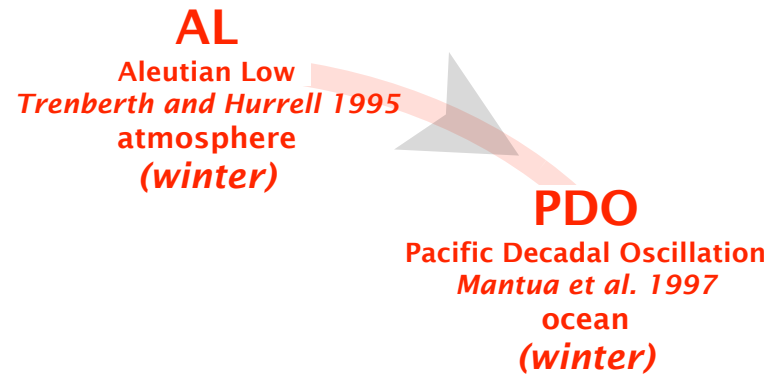
Framework for Pacific Climate Variability & Ecosystem



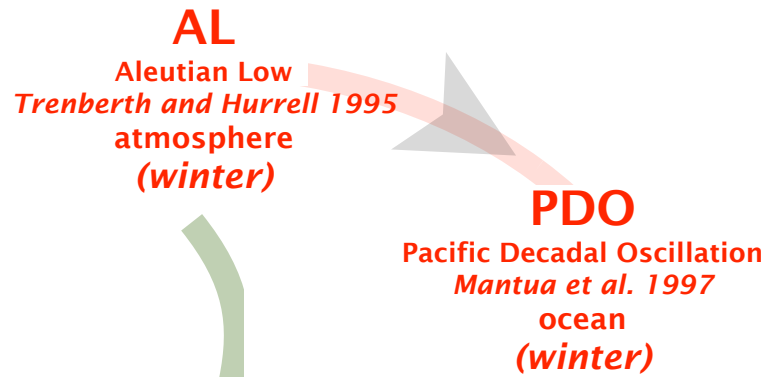
9

How is this framework useful to understand, quantify and predict ecosystem variability?

Types of impacts of climate modes on Ecosystem

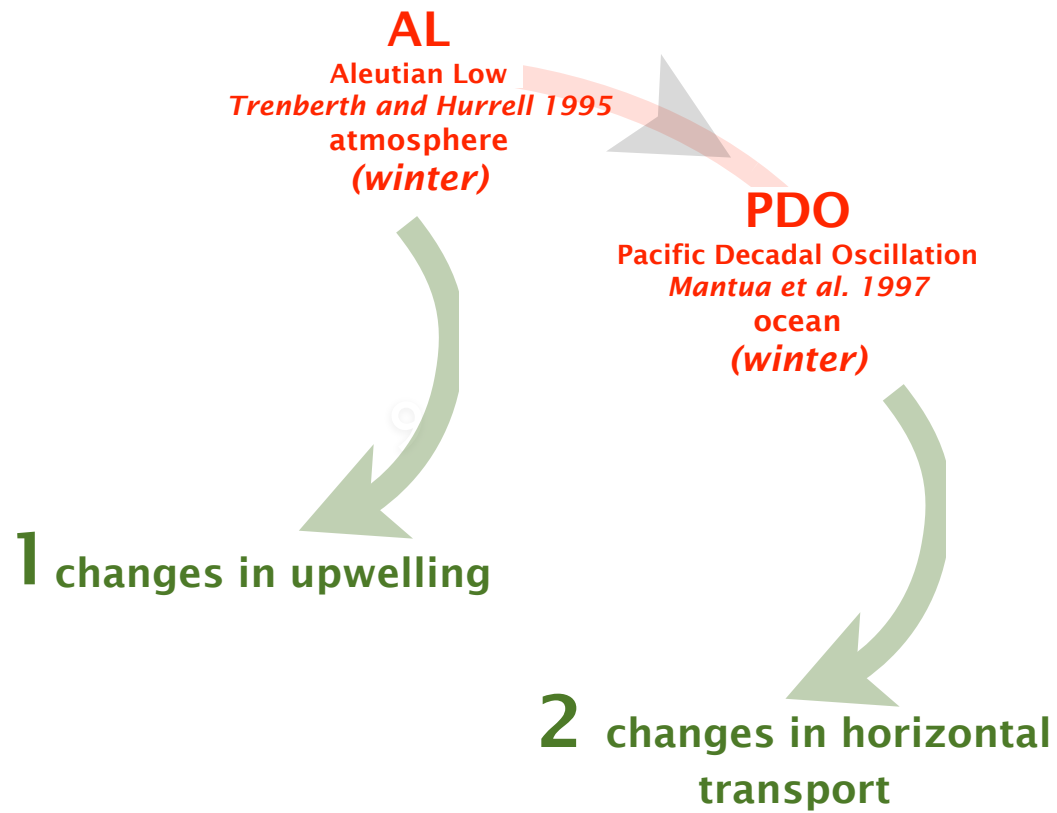


Types of impacts of climate modes on Ecosystem

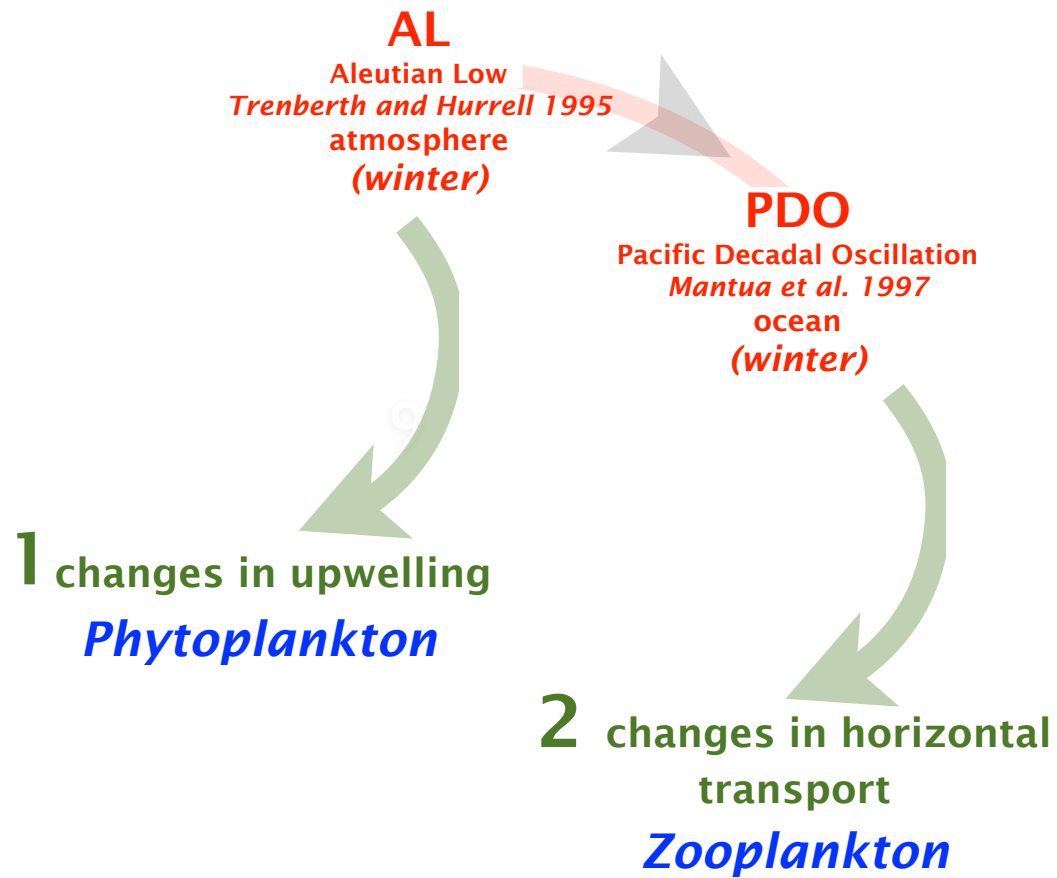


↑ changes in upwelling

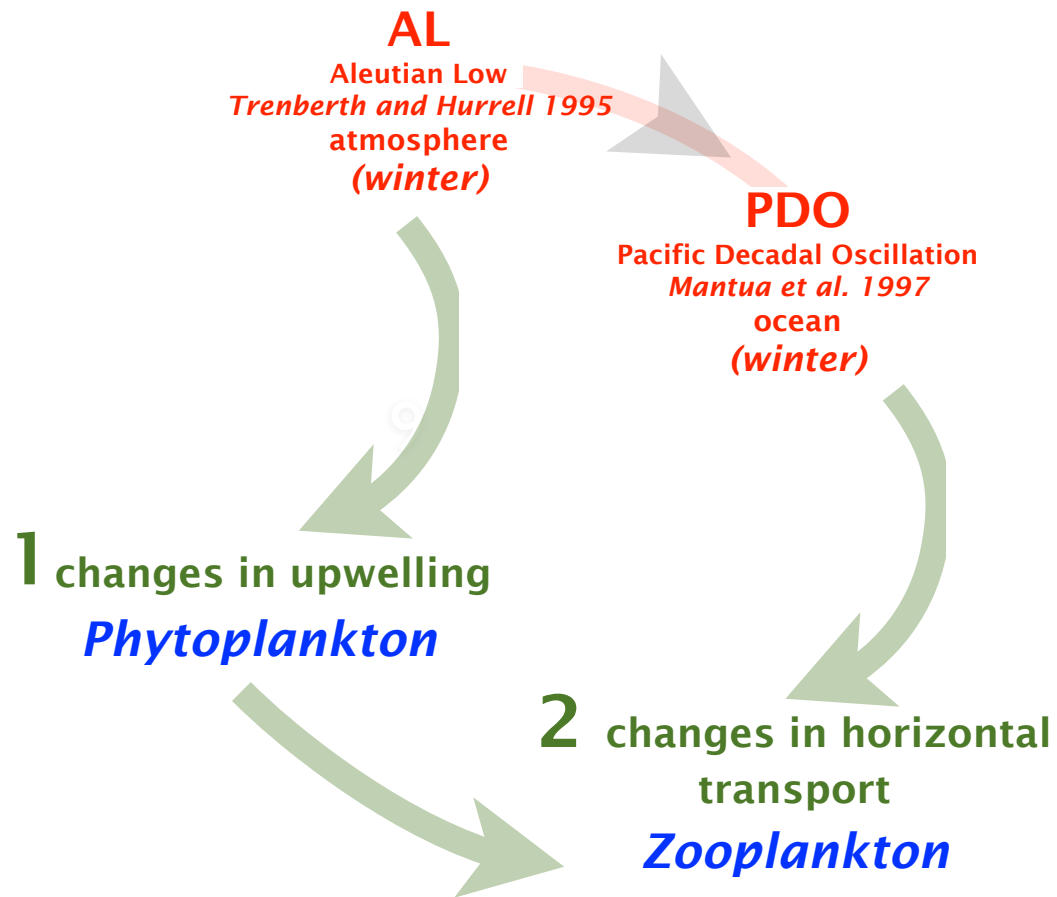
Types of impacts of climate modes on Ecosystem



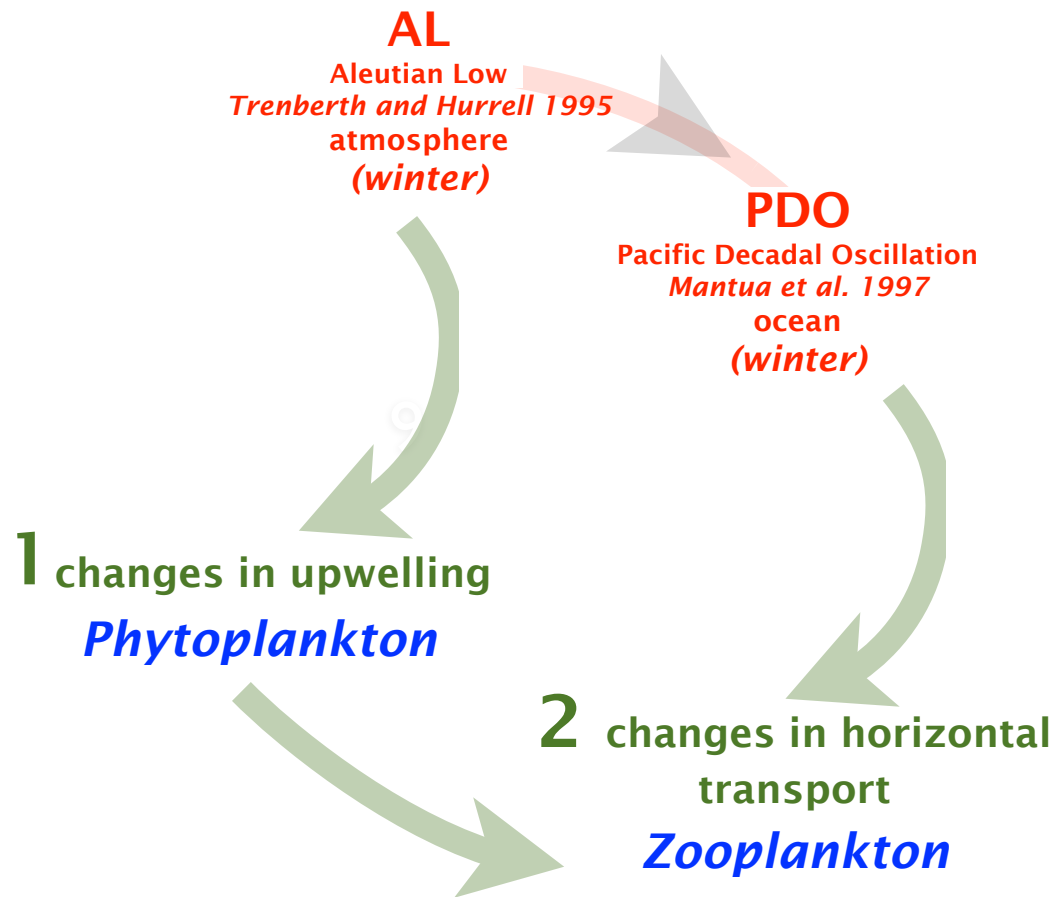
Types of impacts of climate modes on Ecosystem



Types of impacts of climate modes on Ecosystem

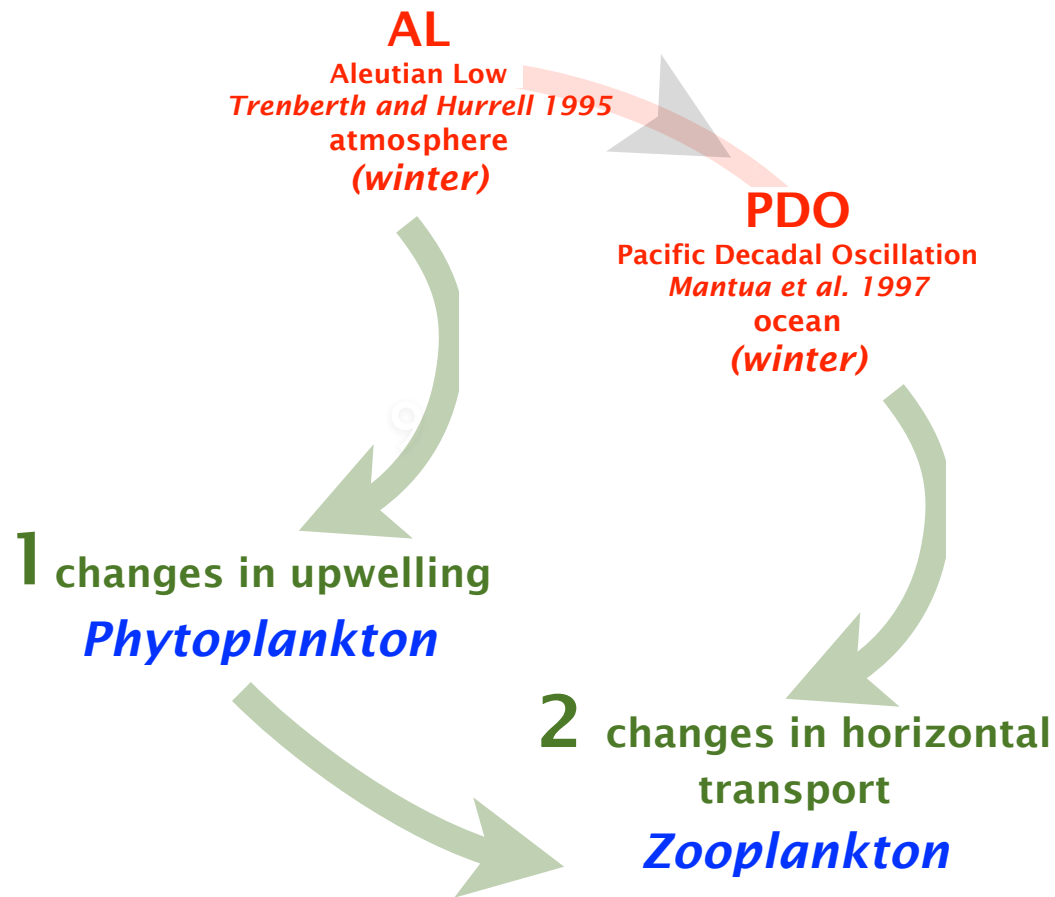


Types of impacts of climate modes on Ecosystem



1 *Biology integrates the effects of atmospheric forcing*

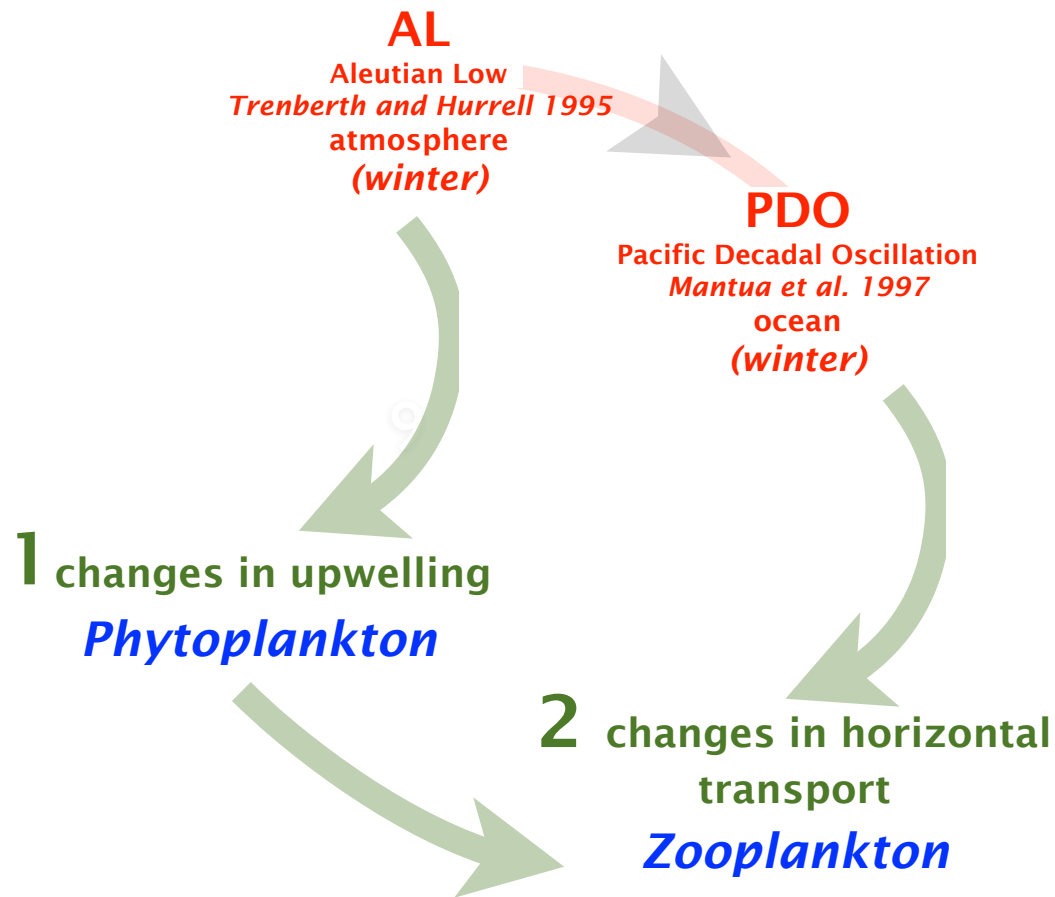
Types of impacts of climate modes on Ecosystem



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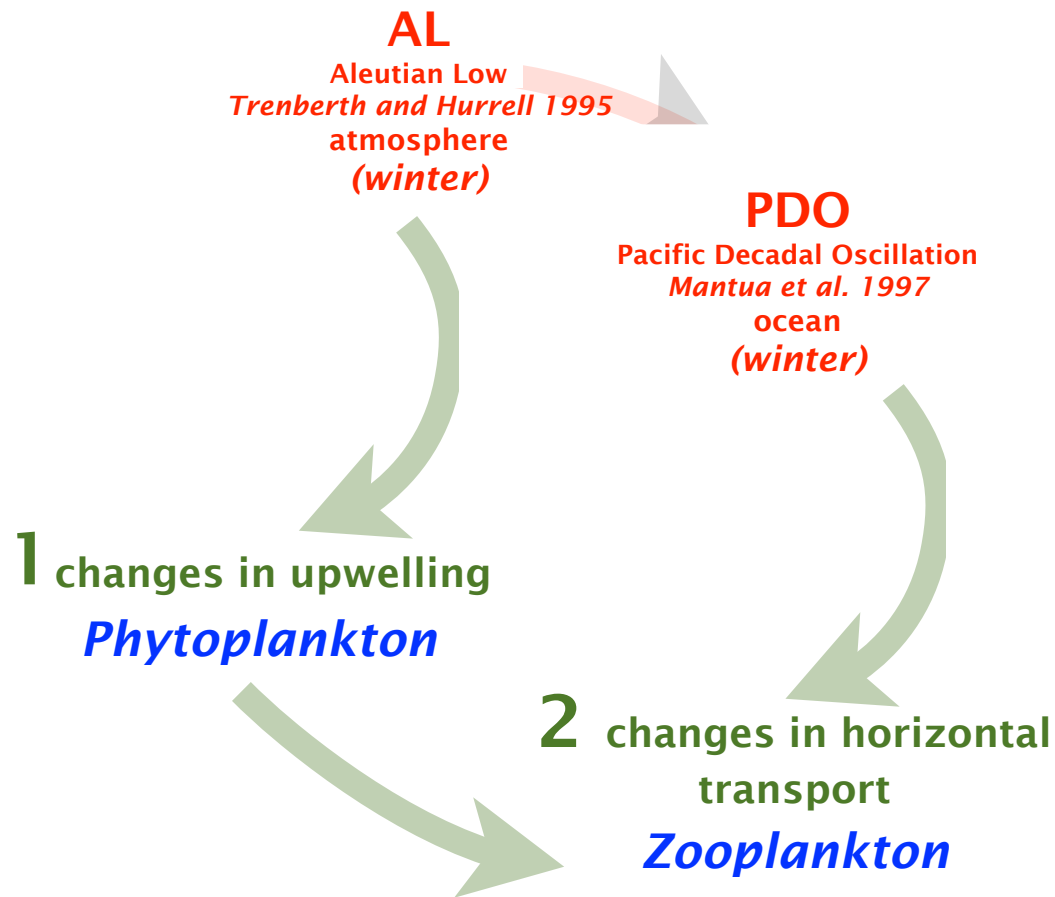
Types of impacts of climate modes on Ecosystem



1 *Biology integrates the effects of atmospheric forcing*

2 *Biology integrates the effects of atmospheric forcing 2X*

Types of impacts of climate modes on Ecosystem



A simple process model

Biology

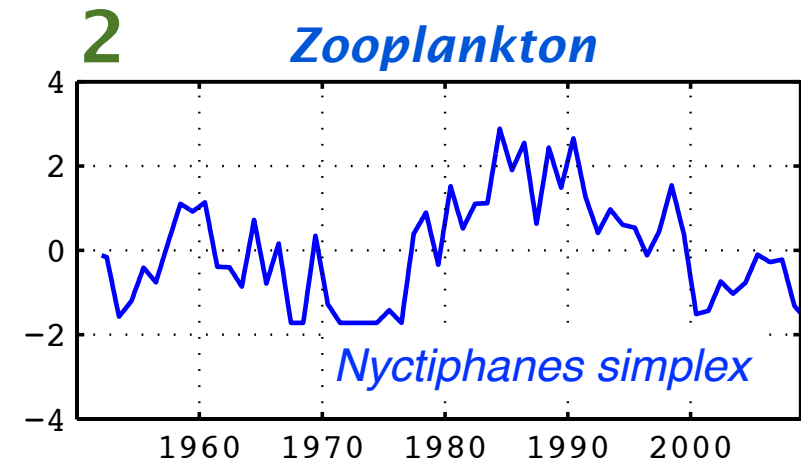
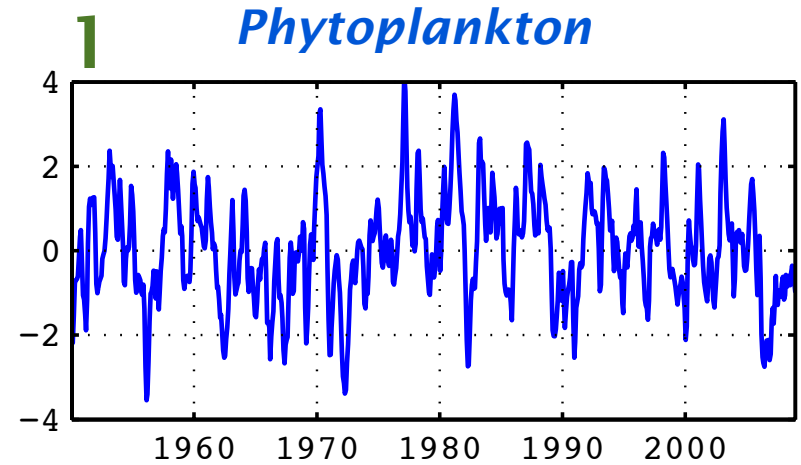
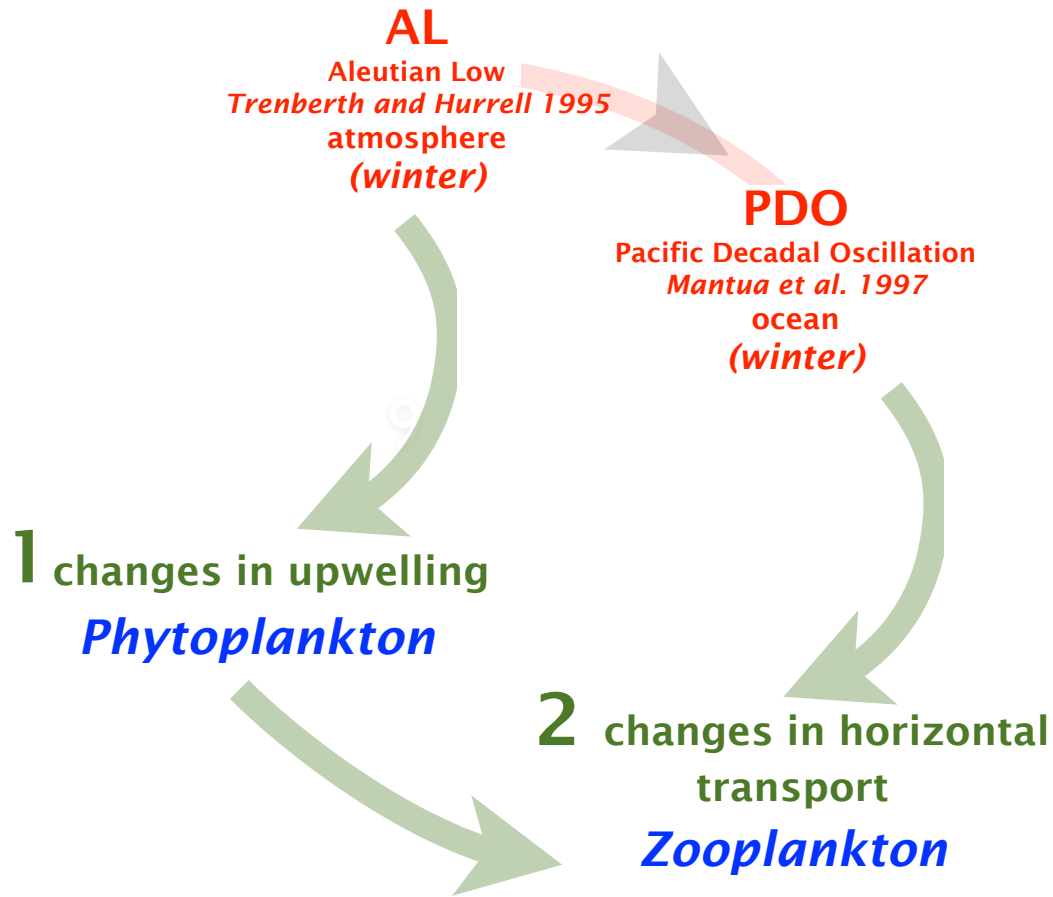
Climate Forcing or Indices

$$\beta(t+1) = a\beta(t) + b\phi(t) + \varepsilon(t)$$

↑
memory

noise

Types of impacts of climate modes on Ecosystem



A simple process model

Biology

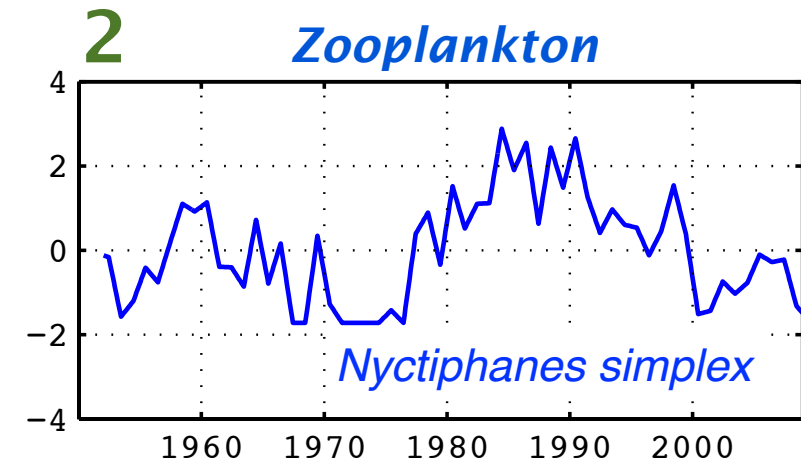
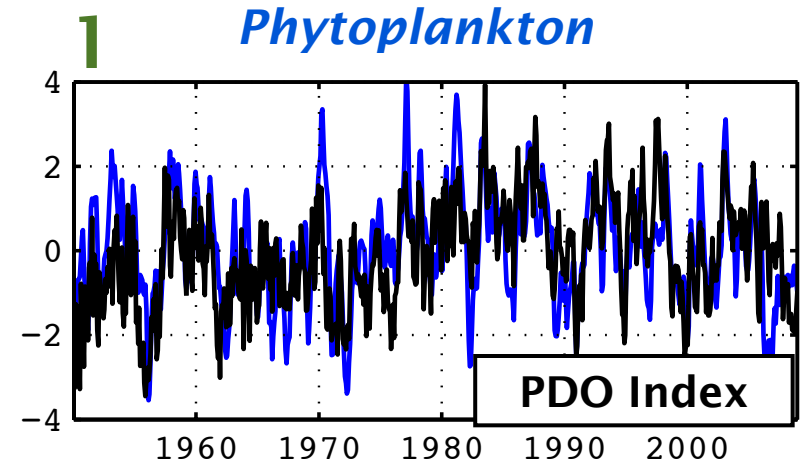
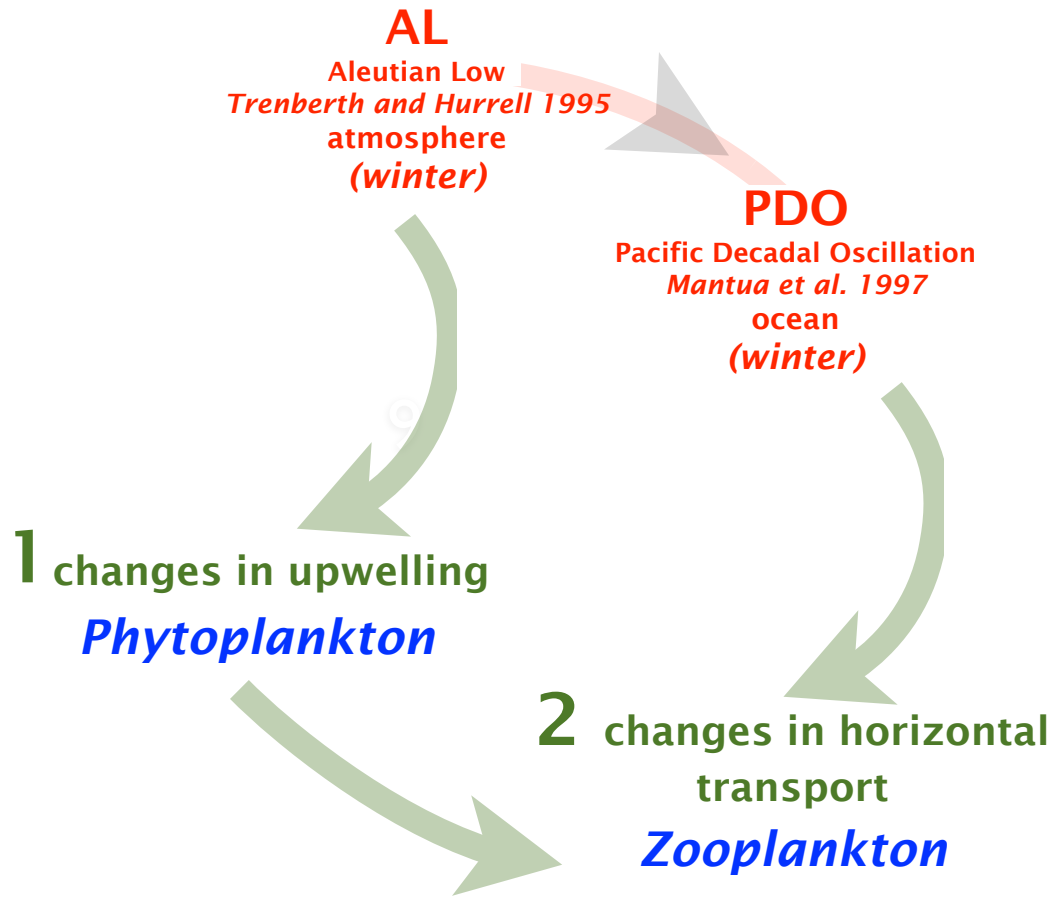
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Types of impacts of climate modes on Ecosystem



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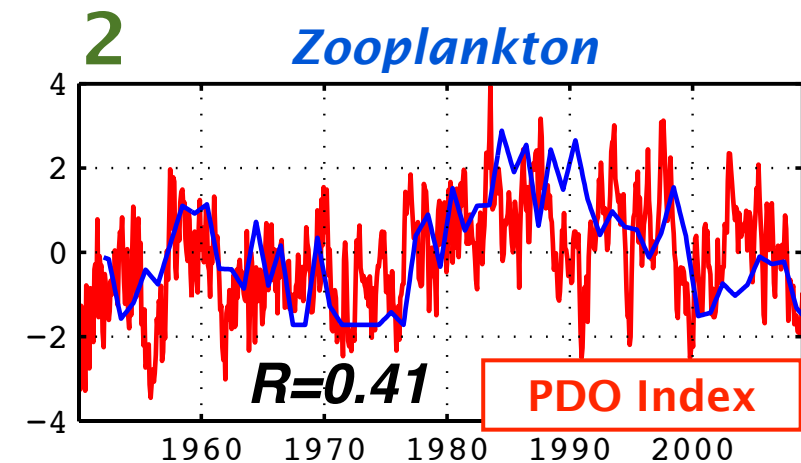
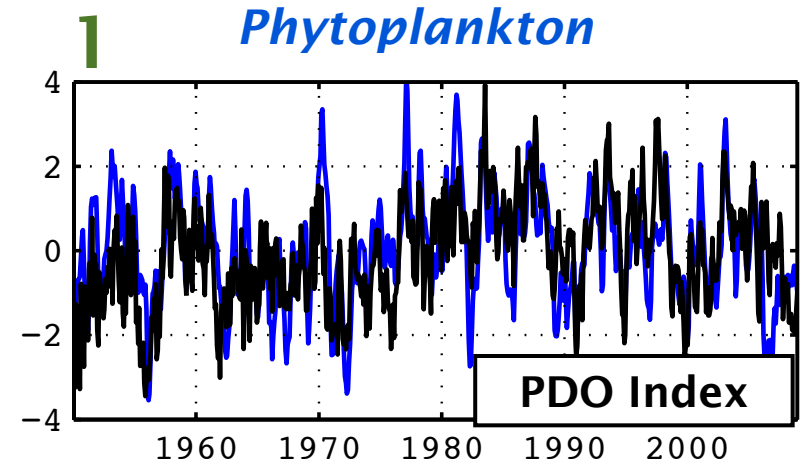
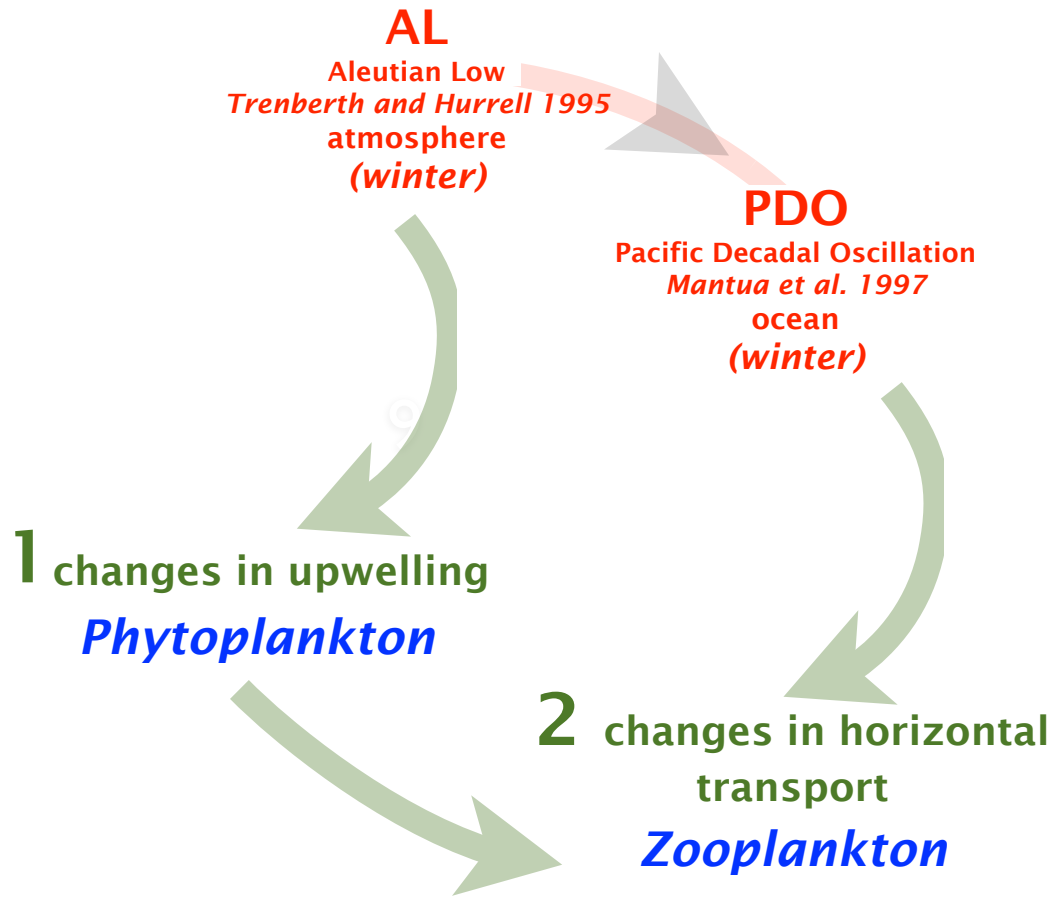
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Types of impacts of climate modes on Ecosystem



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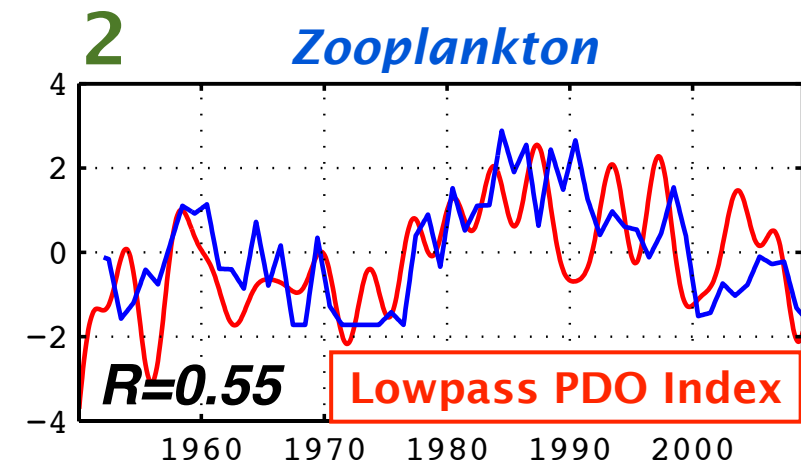
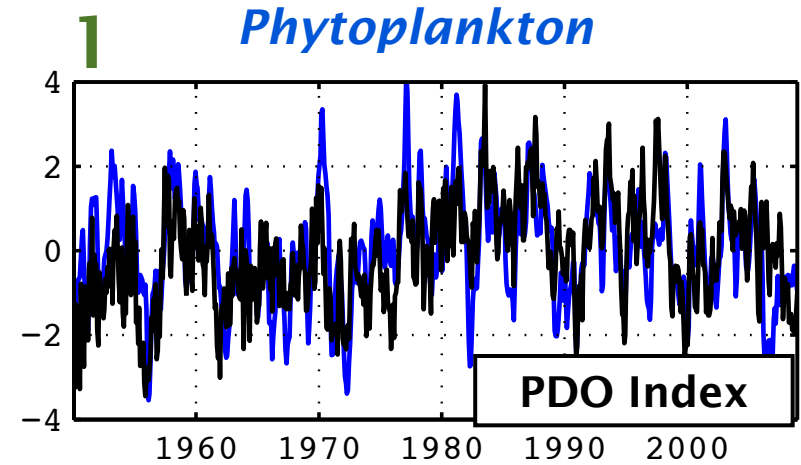
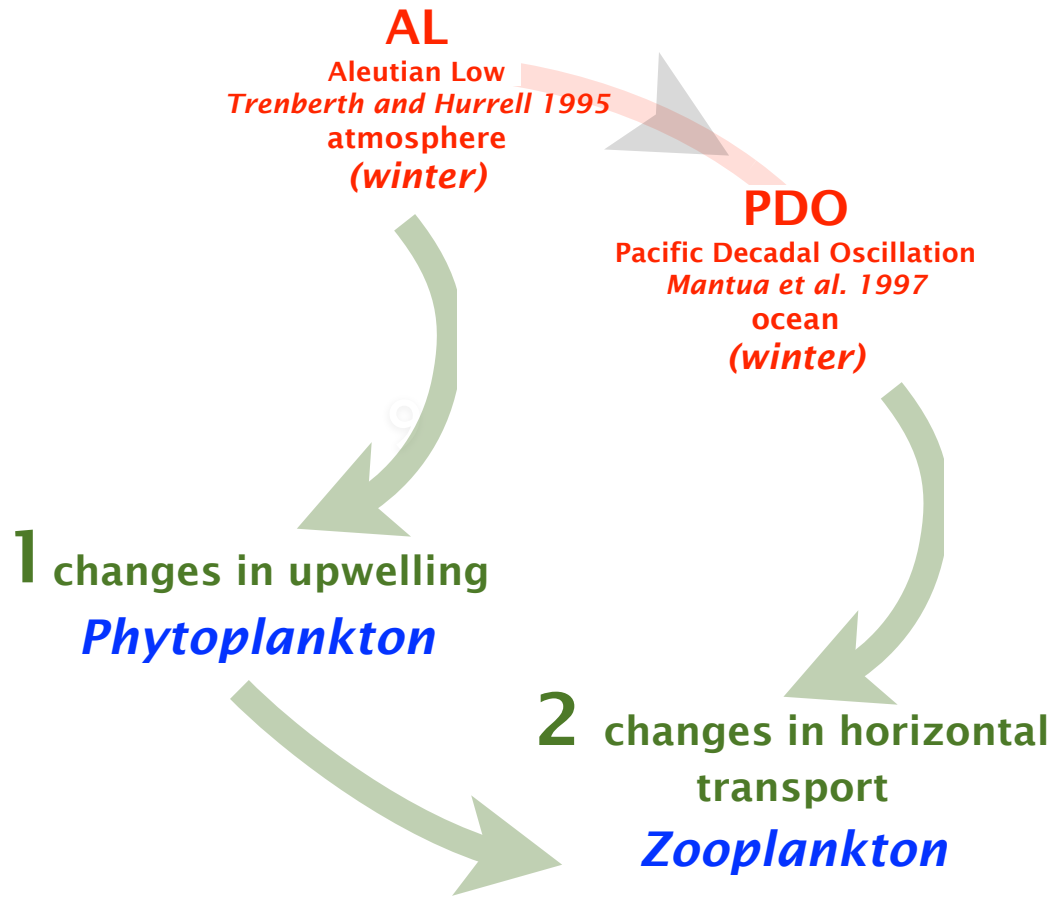
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Types of impacts of climate modes on Ecosystem



A simple process model

Biology

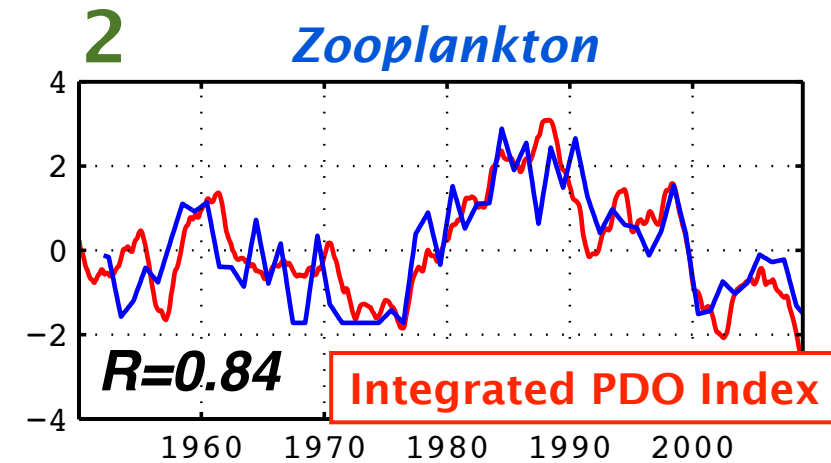
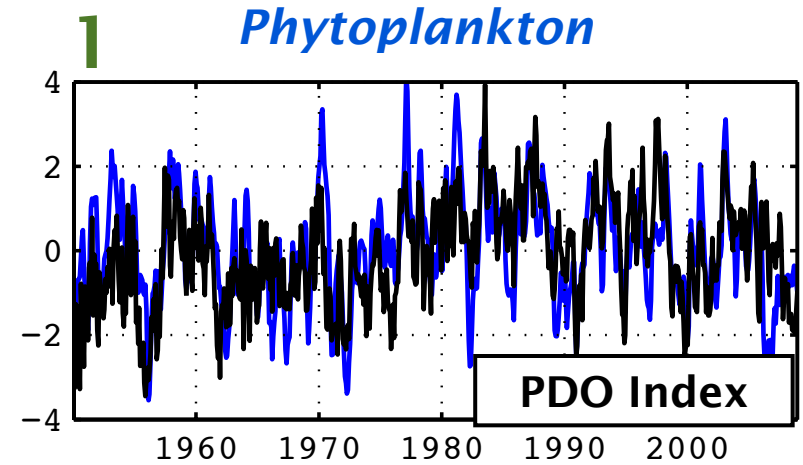
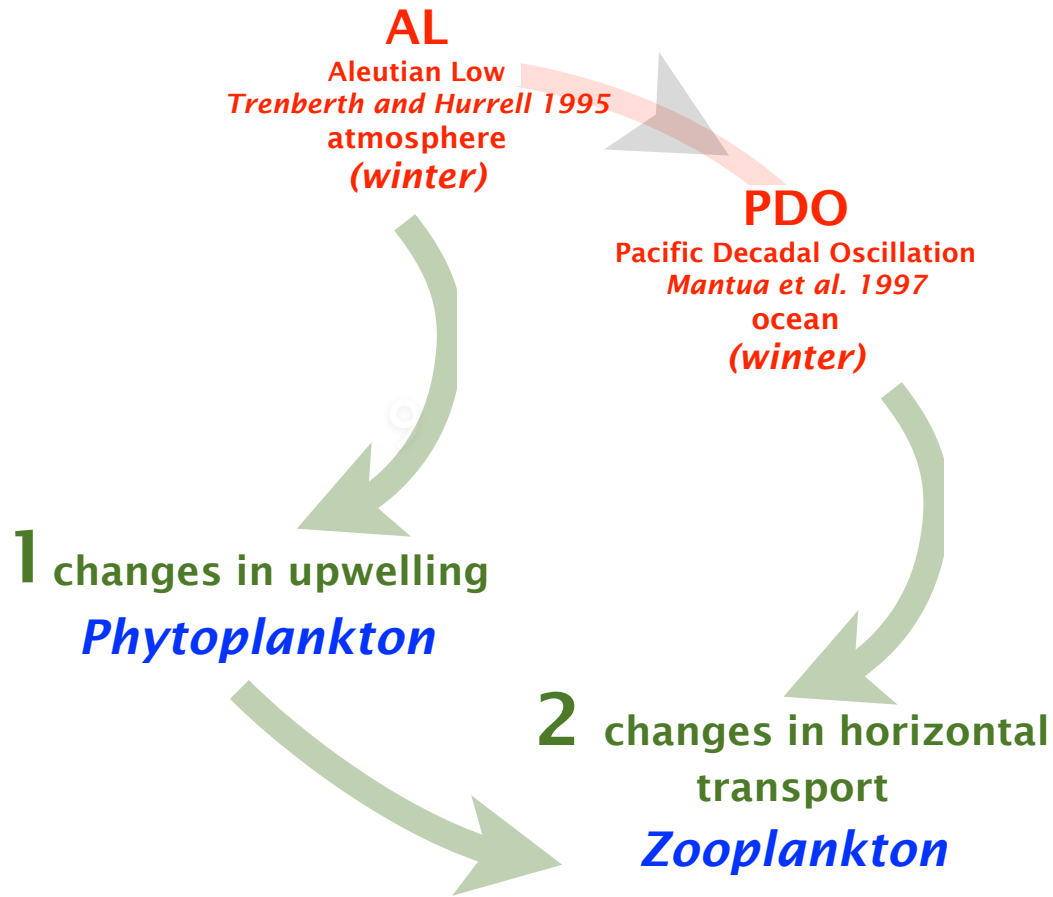
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memory

noise

Types of impacts of climate modes on Ecosystem



A simple process model

Biology

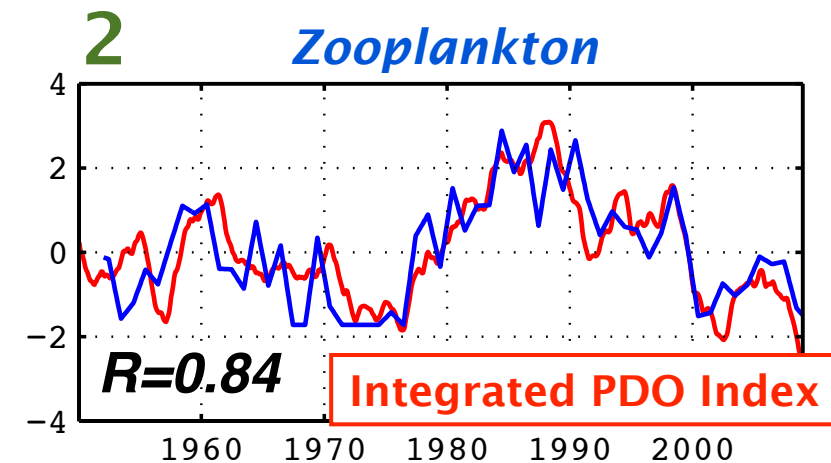
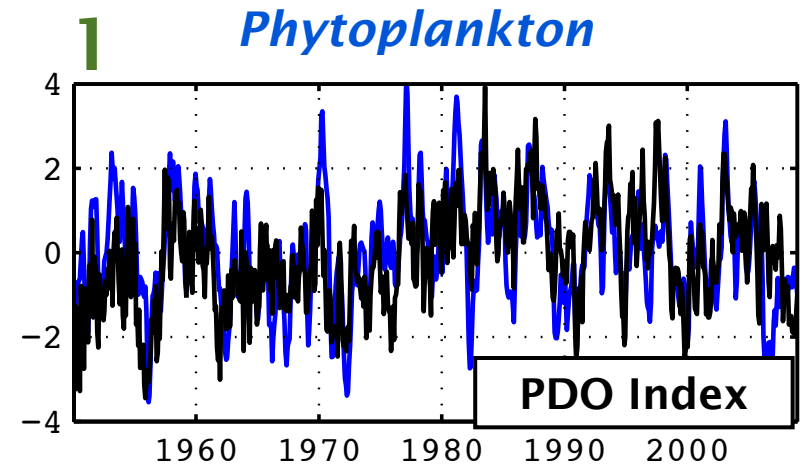
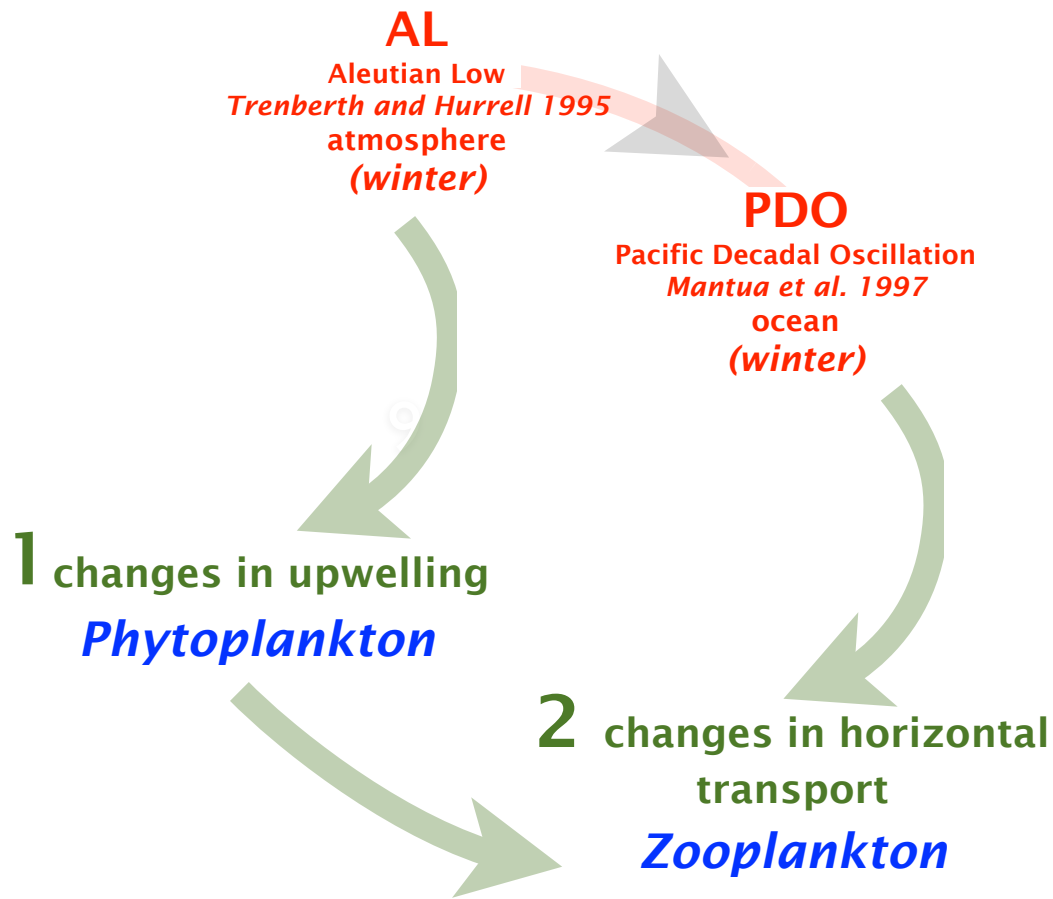
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Types of impacts of climate modes on Ecosystem



A simple process model

Biology

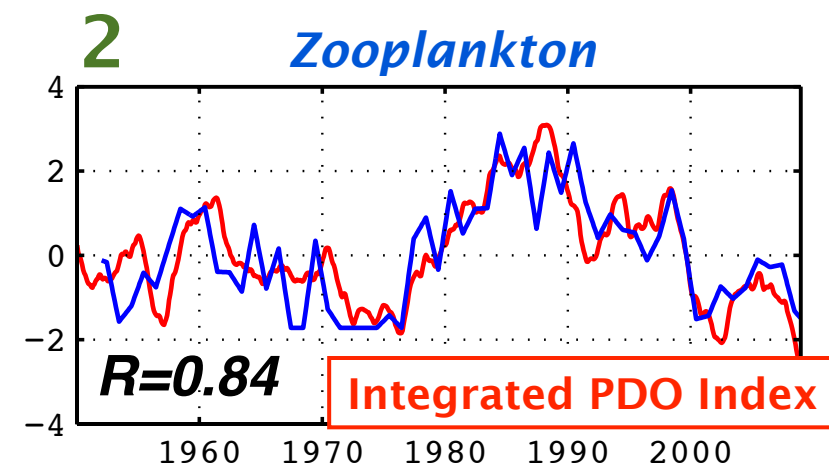
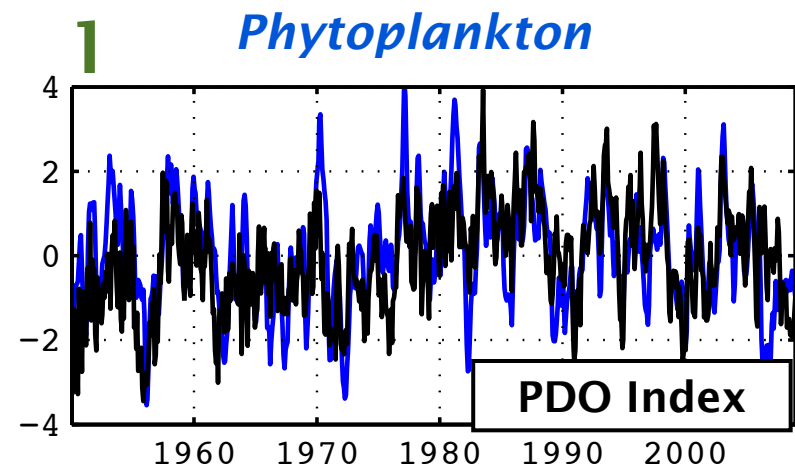
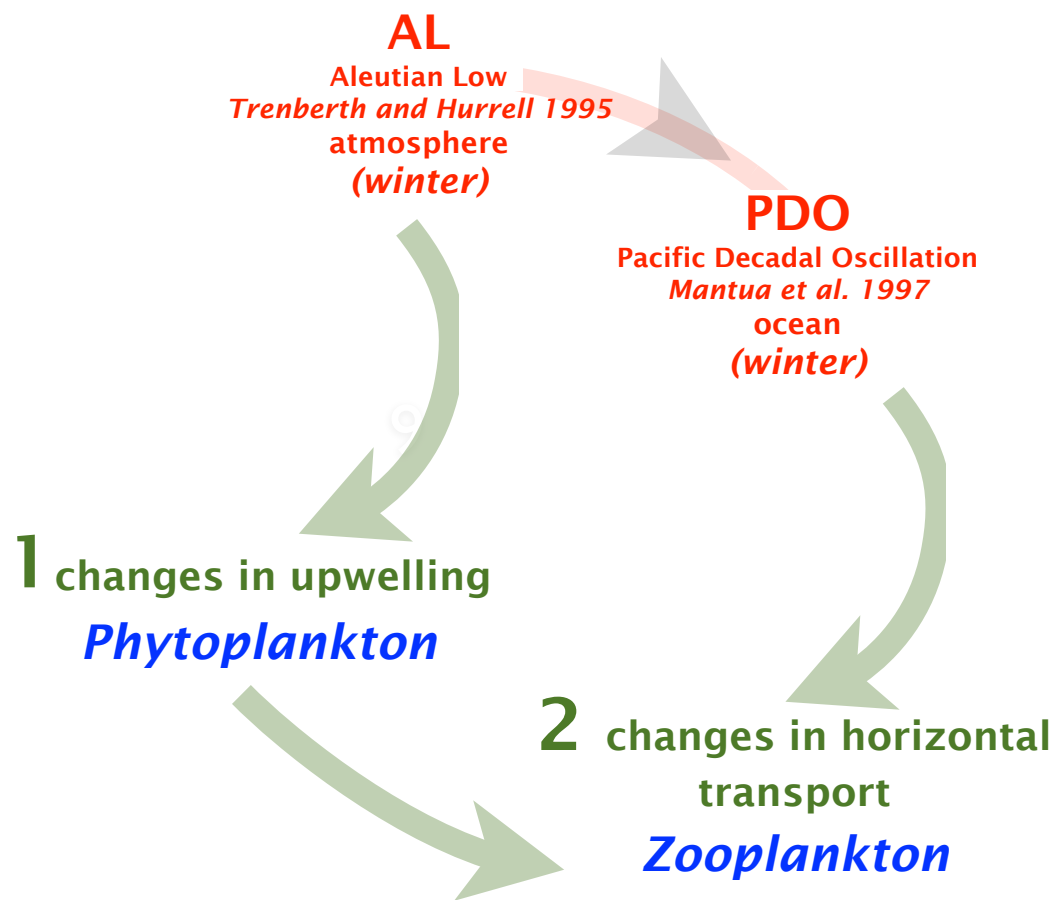
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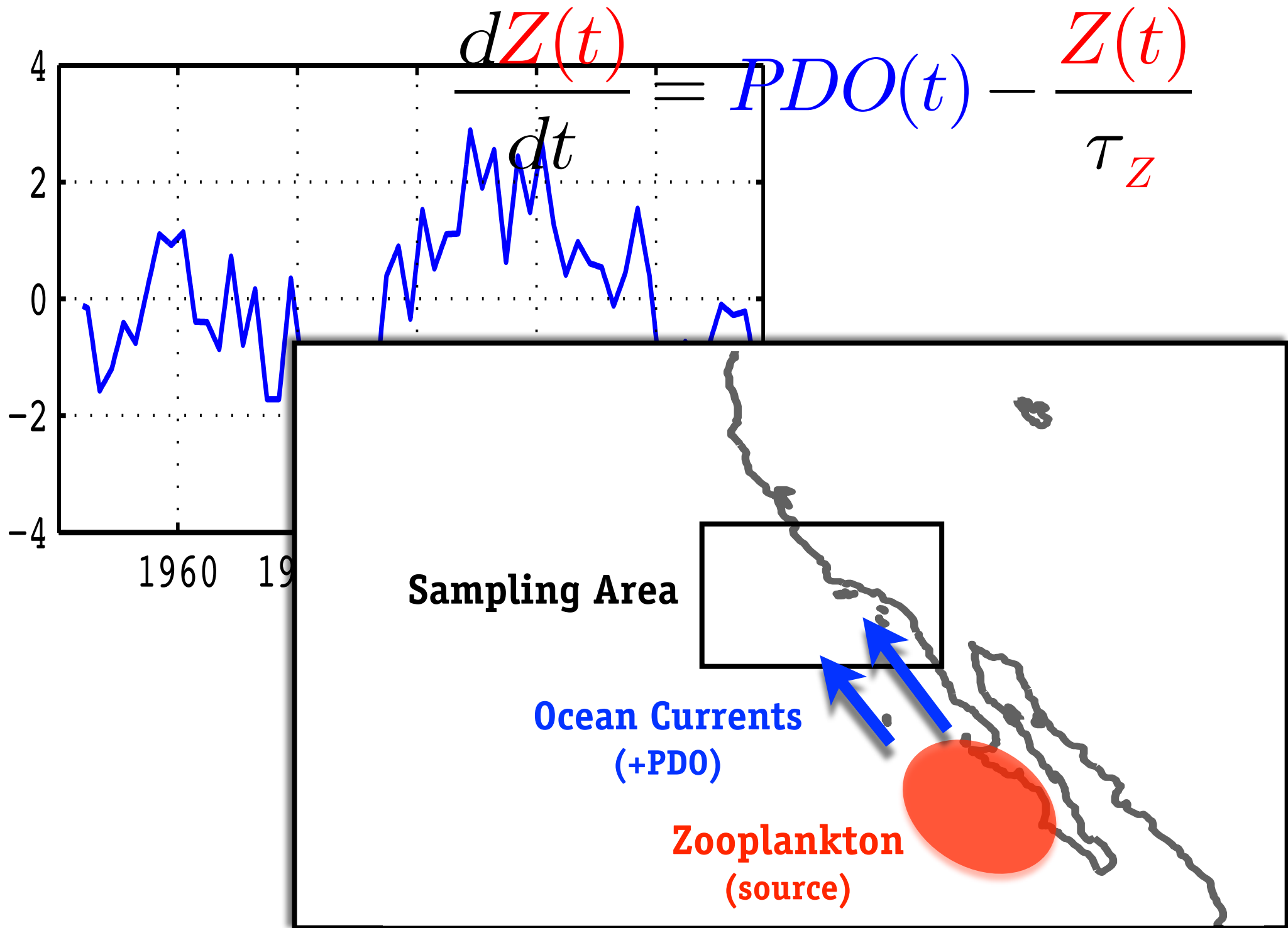
noise

Types of impacts of climate modes on Ecosystem

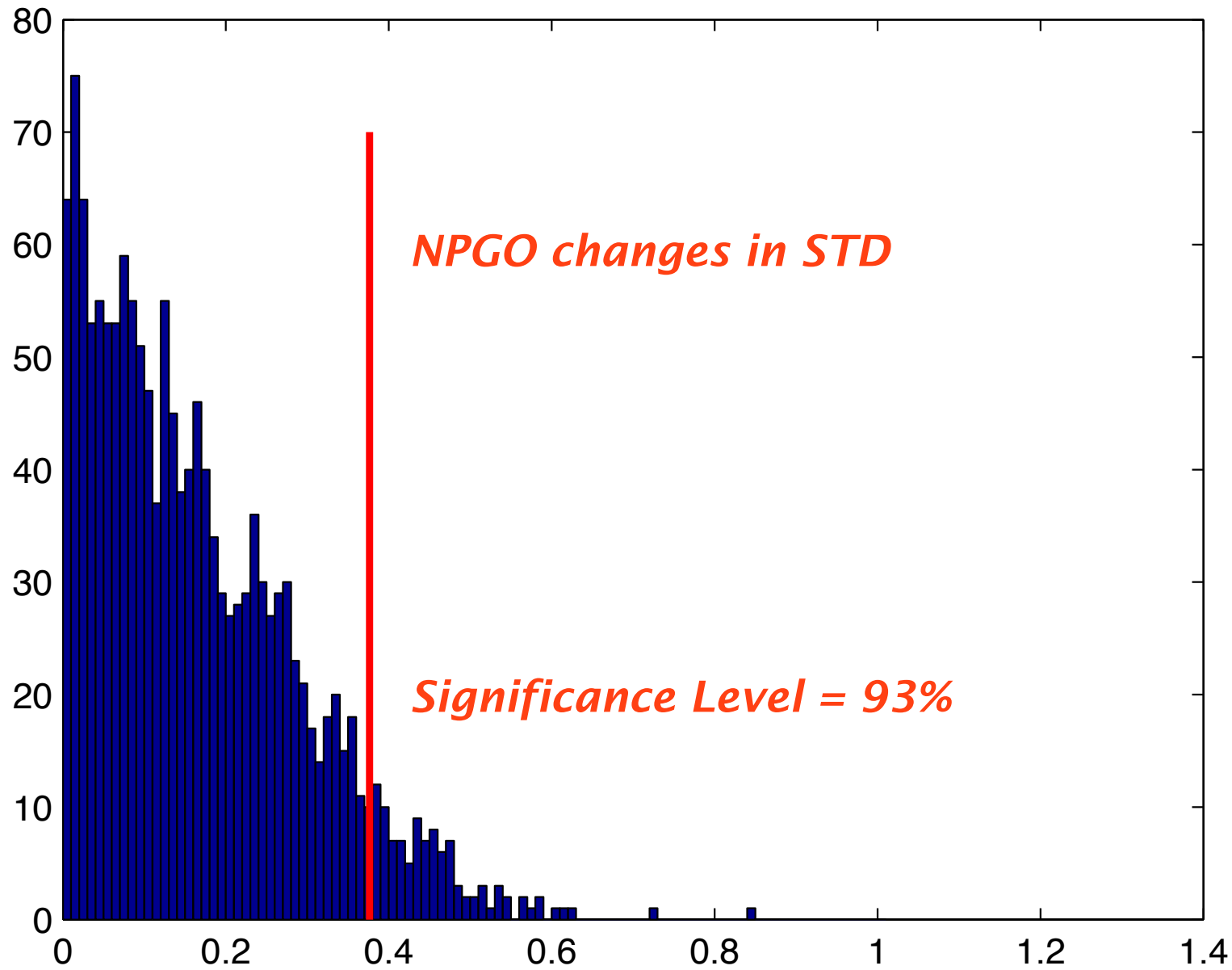


1 *Biology integrates the effects of atmospheric forcing*

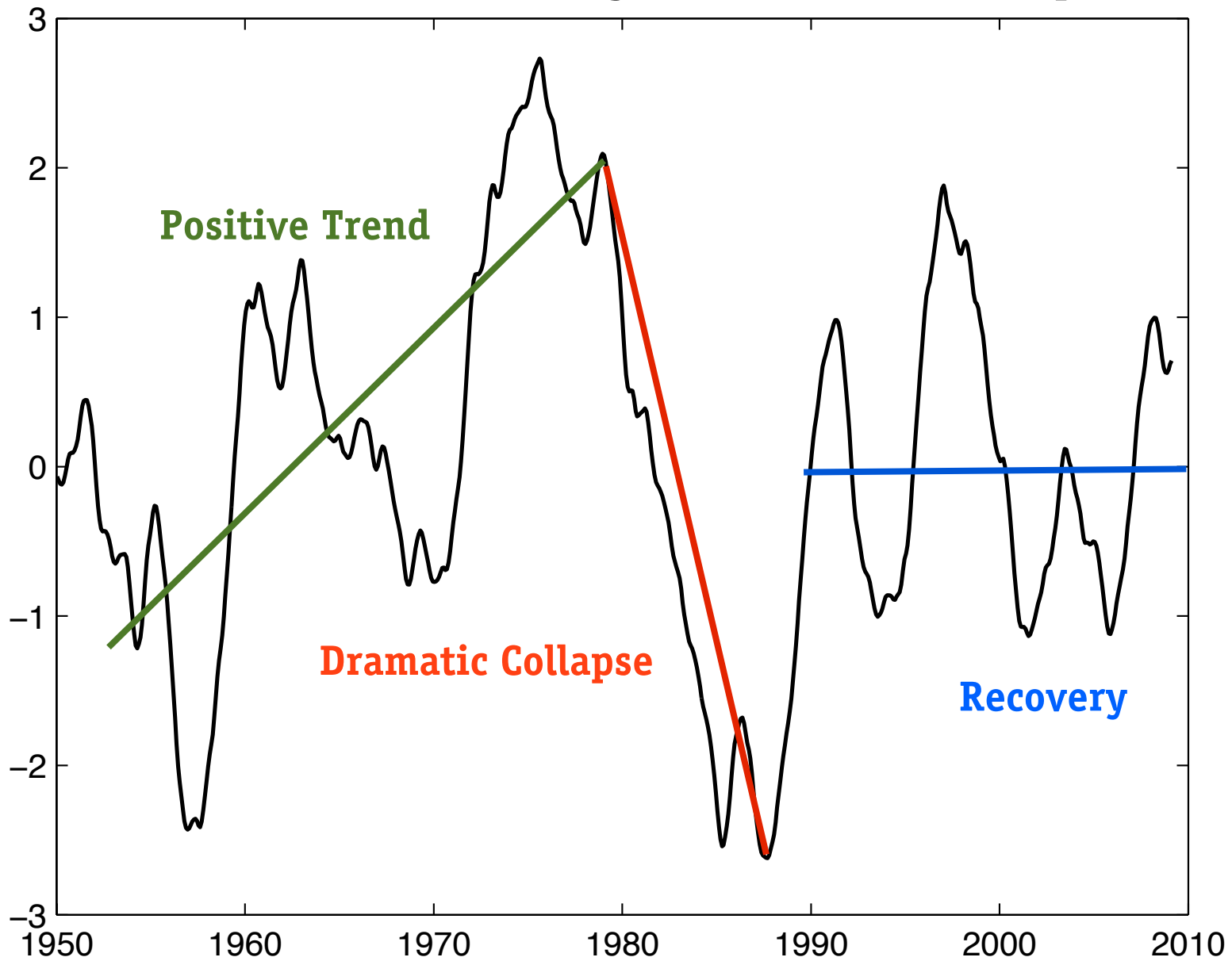
2 *Biology integrates the effects of atmospheric forcing 2X*



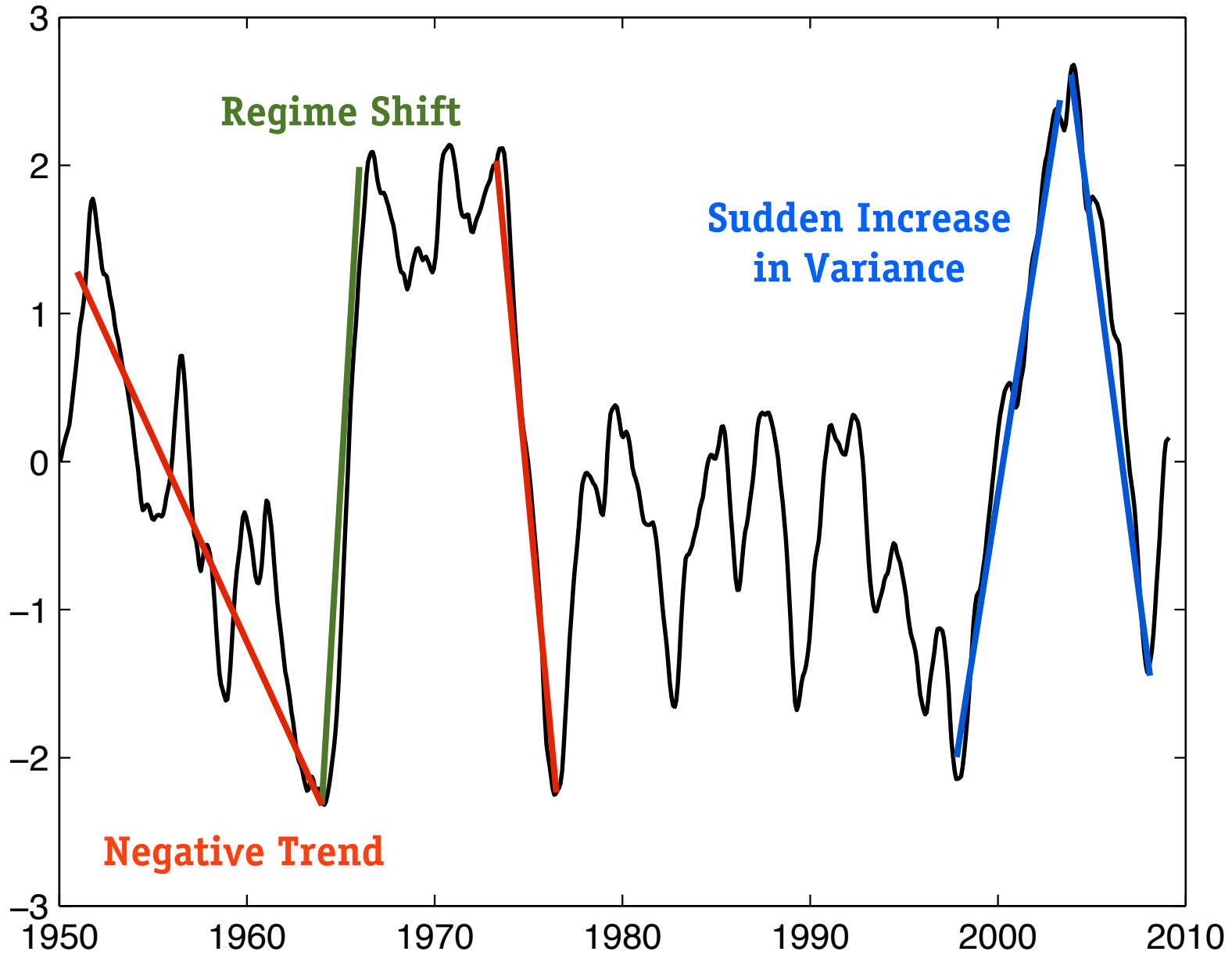
Probability Distribution of changes in STD



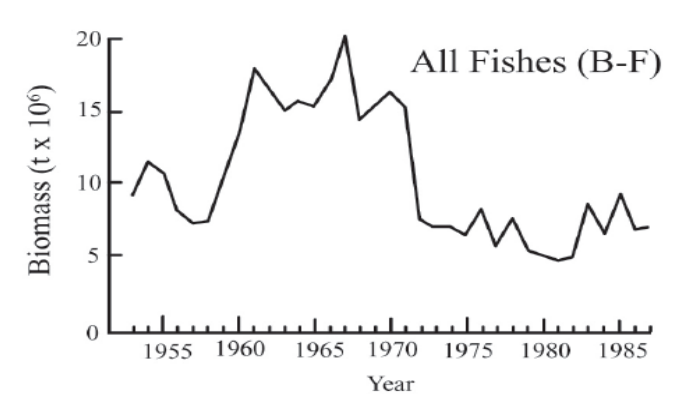
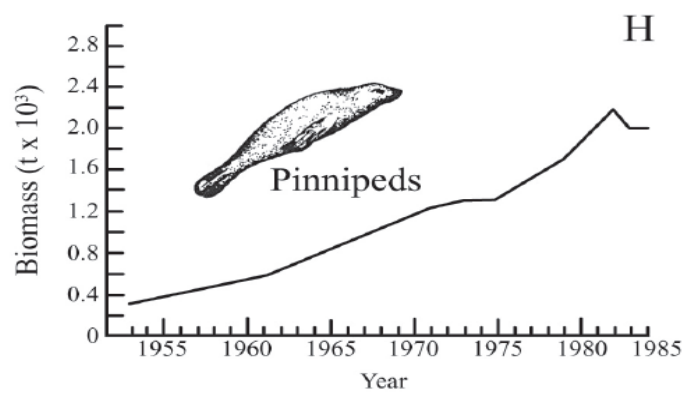
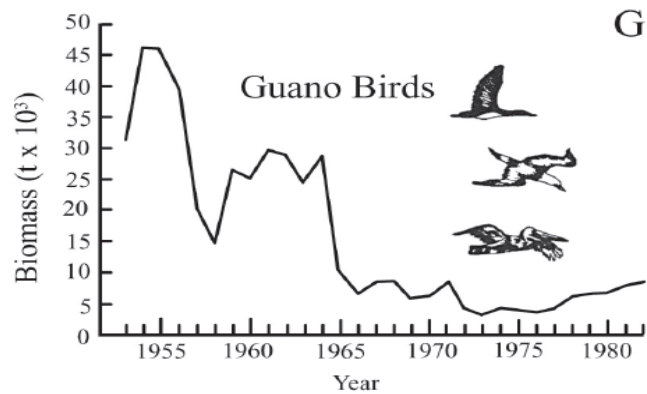
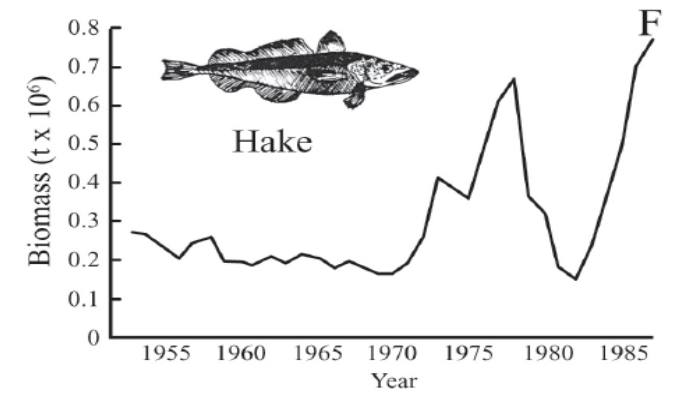
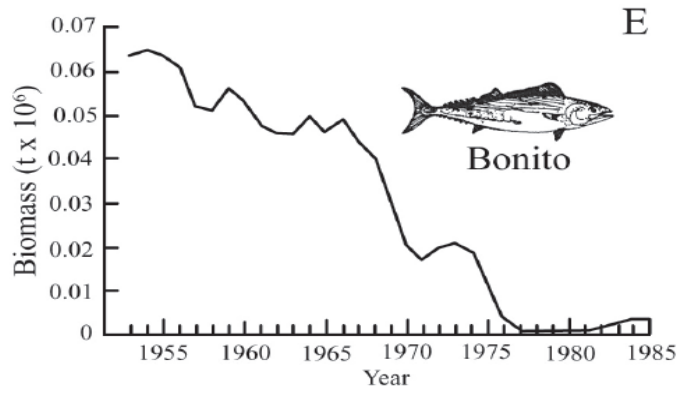
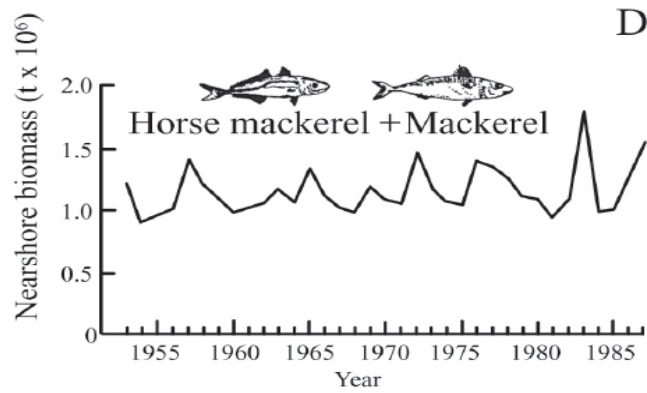
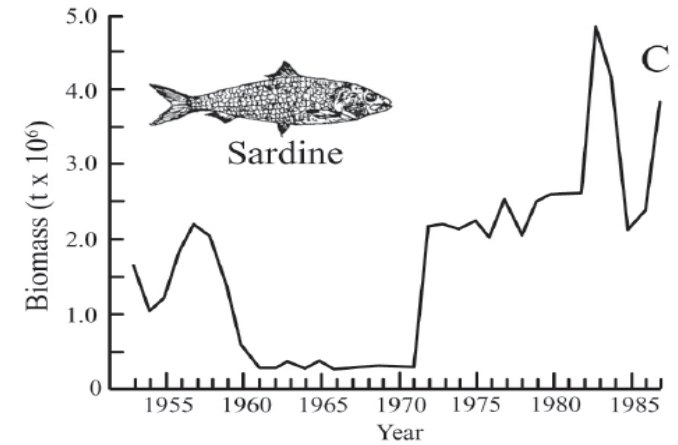
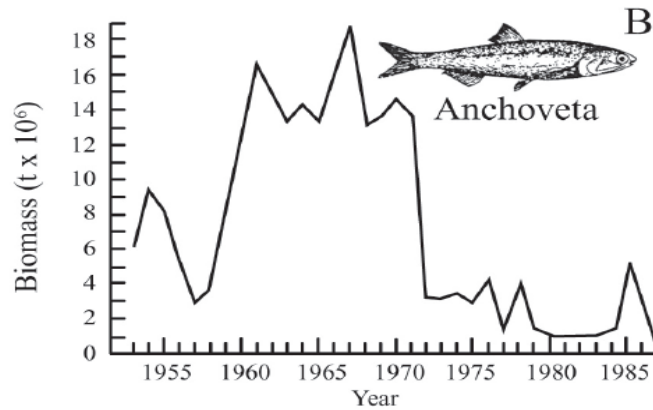
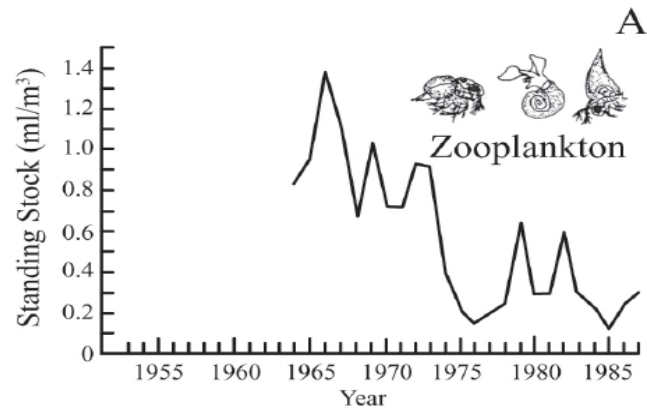
Effects of Cumulative Forcing on an Idealized Fish Species



Idealized Fish Species

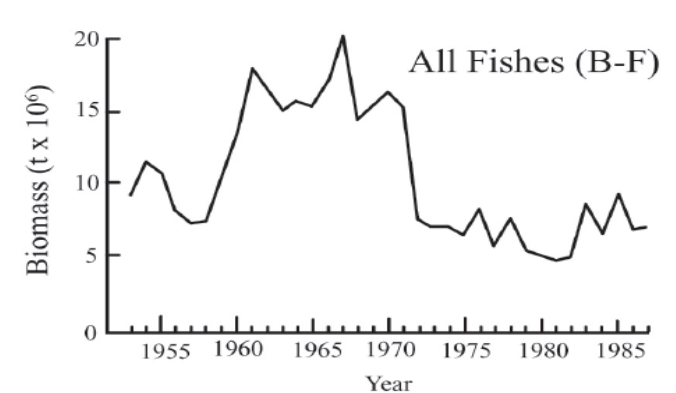
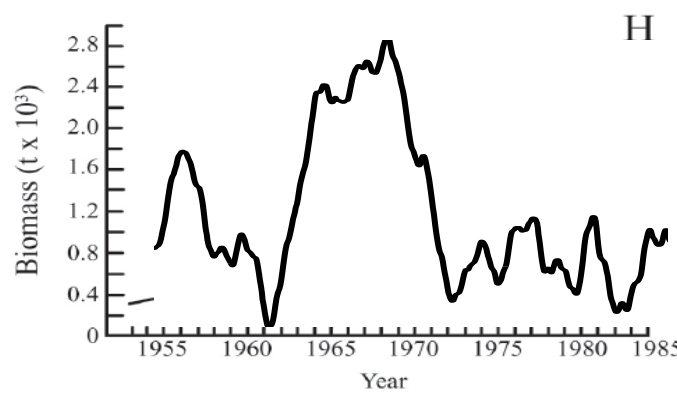
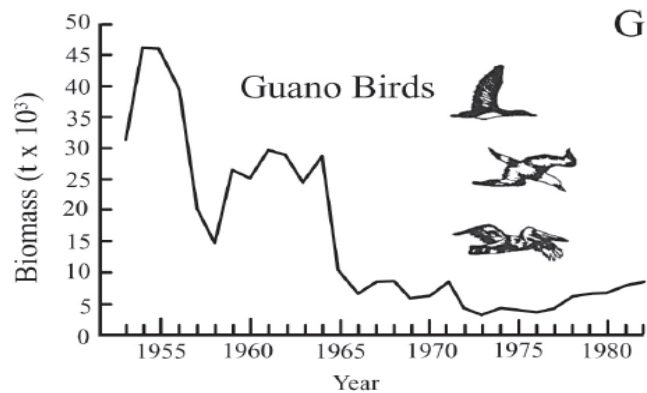
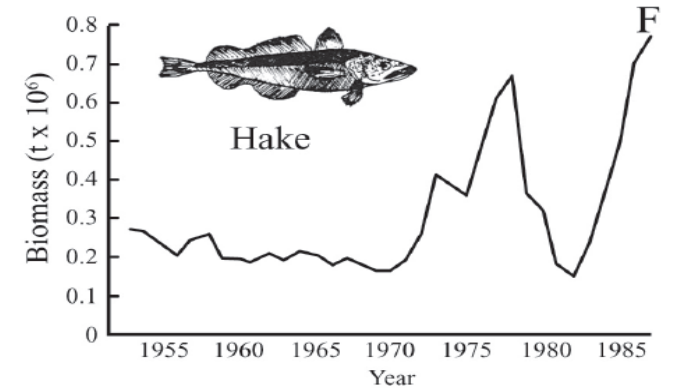
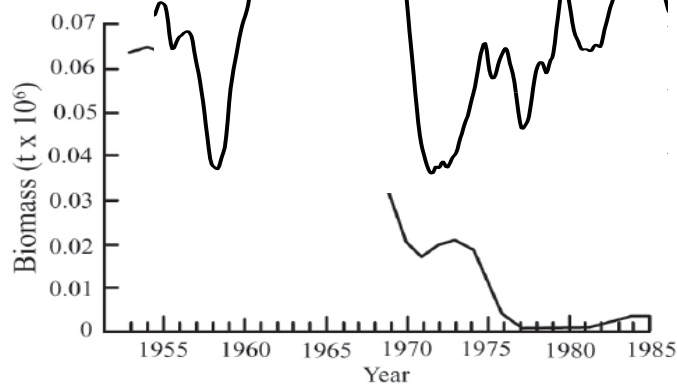
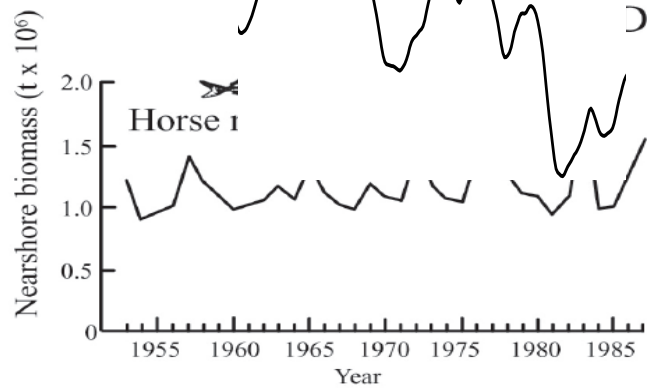
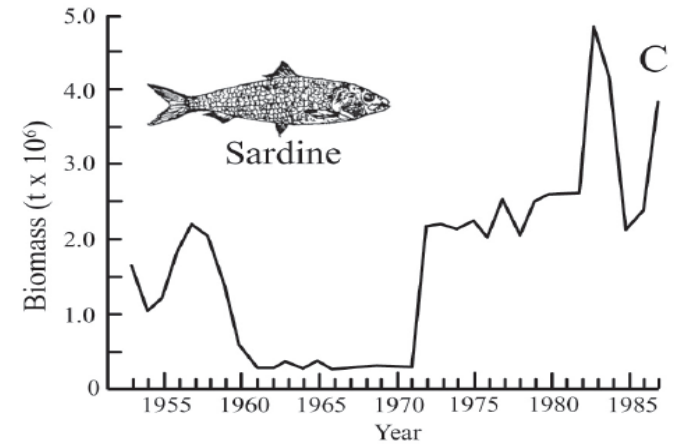
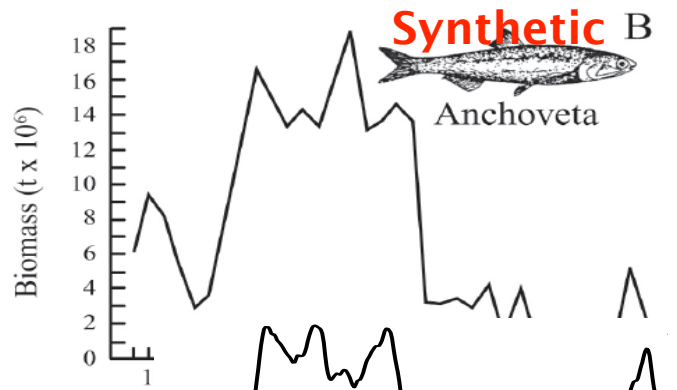
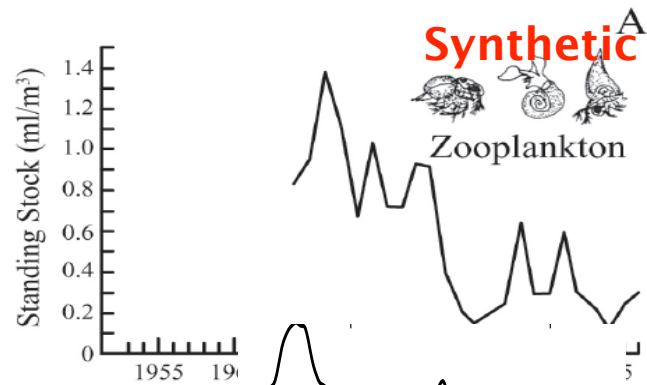


Timeseries of Fish



(from Polovina 2005, modified from Muck 1989)

Timeseries of Fish



(from Polovina 2005, modified from Muck 1989)

12

