Biophysical frequency response of the Bering Sea to large-scale forcing

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FOCUS

- This session theme is focused on predictability of large-scale climate
- Predictability is strongly dependent on space and time scales.
- Here, consider “predictability” of small (~100km square) regions if had perfect knowledge of some forcing variable there – look for coherence across frequency bands
- Consider physical and biological variables

BEST/BSIERP Integrated Modeling

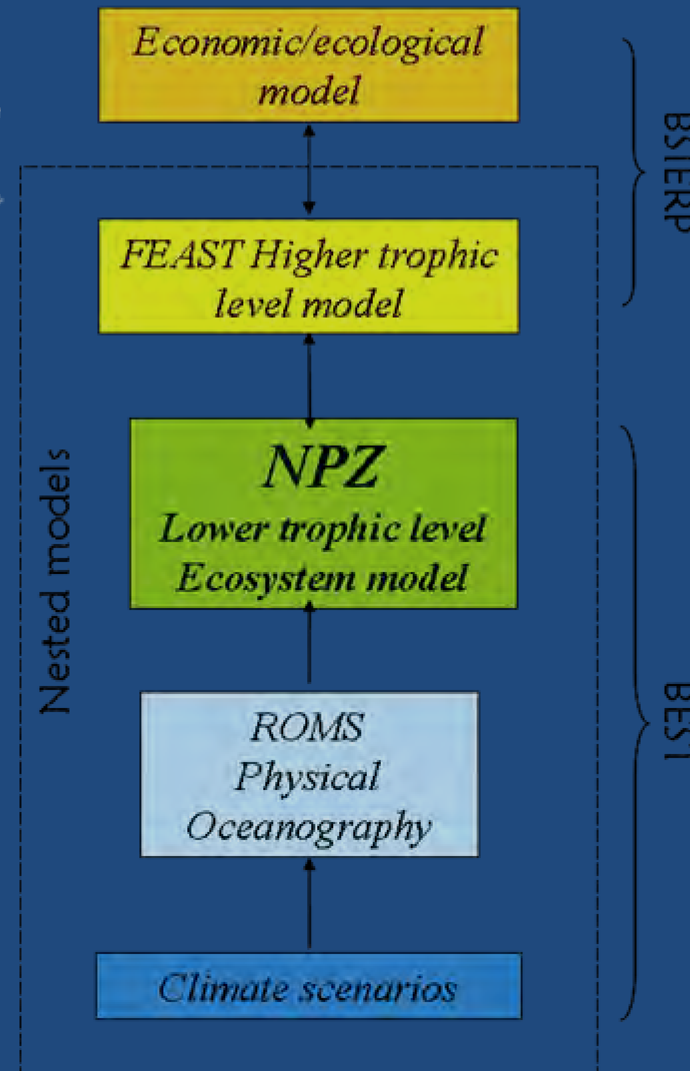
Higher trophic levels
(Pollock etc.)

Secondary Producers
(Zooplankton)

Primary Producers
(Phytoplankton)

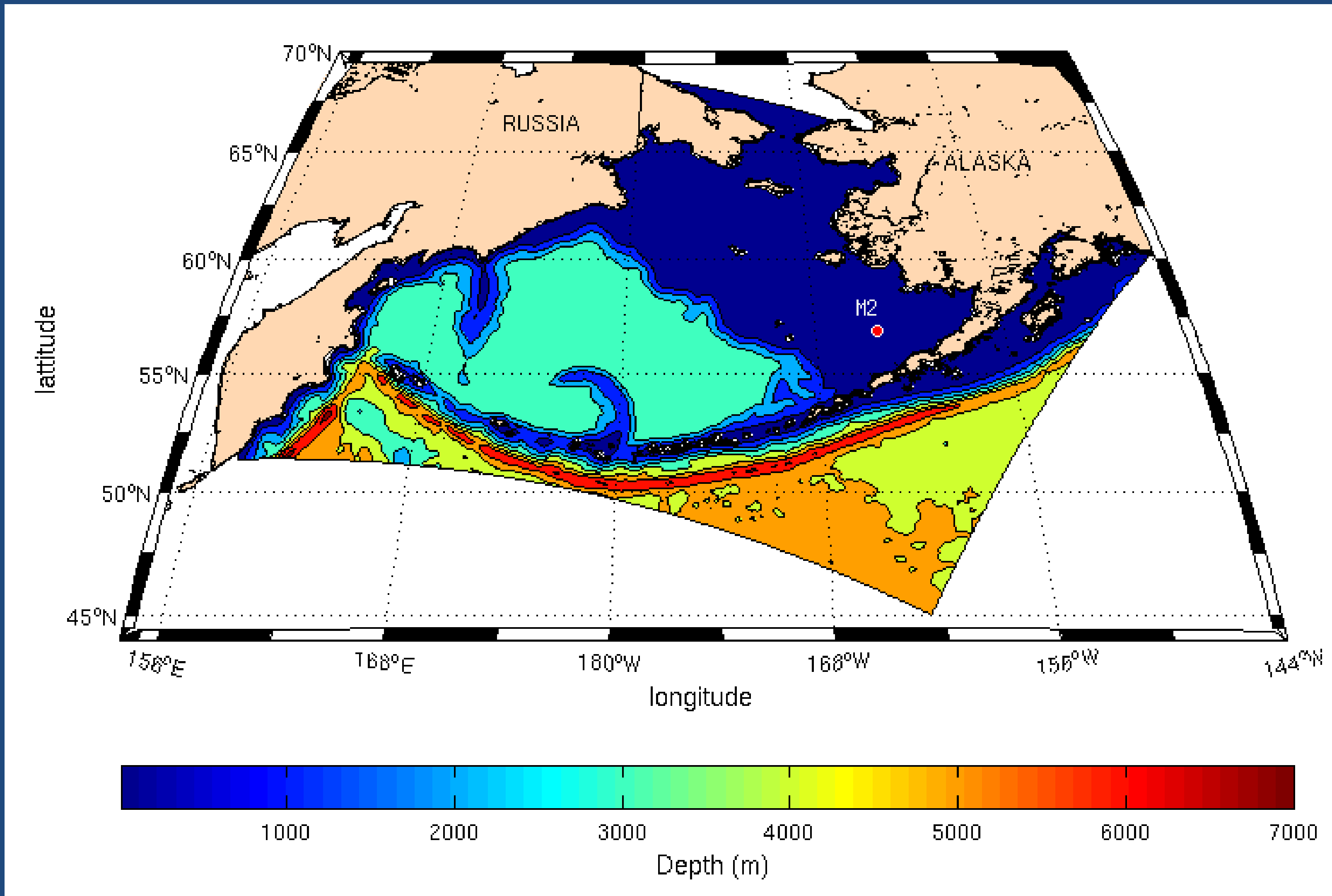
Nutrients
NO_3, NH_4…

Physical Forcing
(Wind, temp, sun)

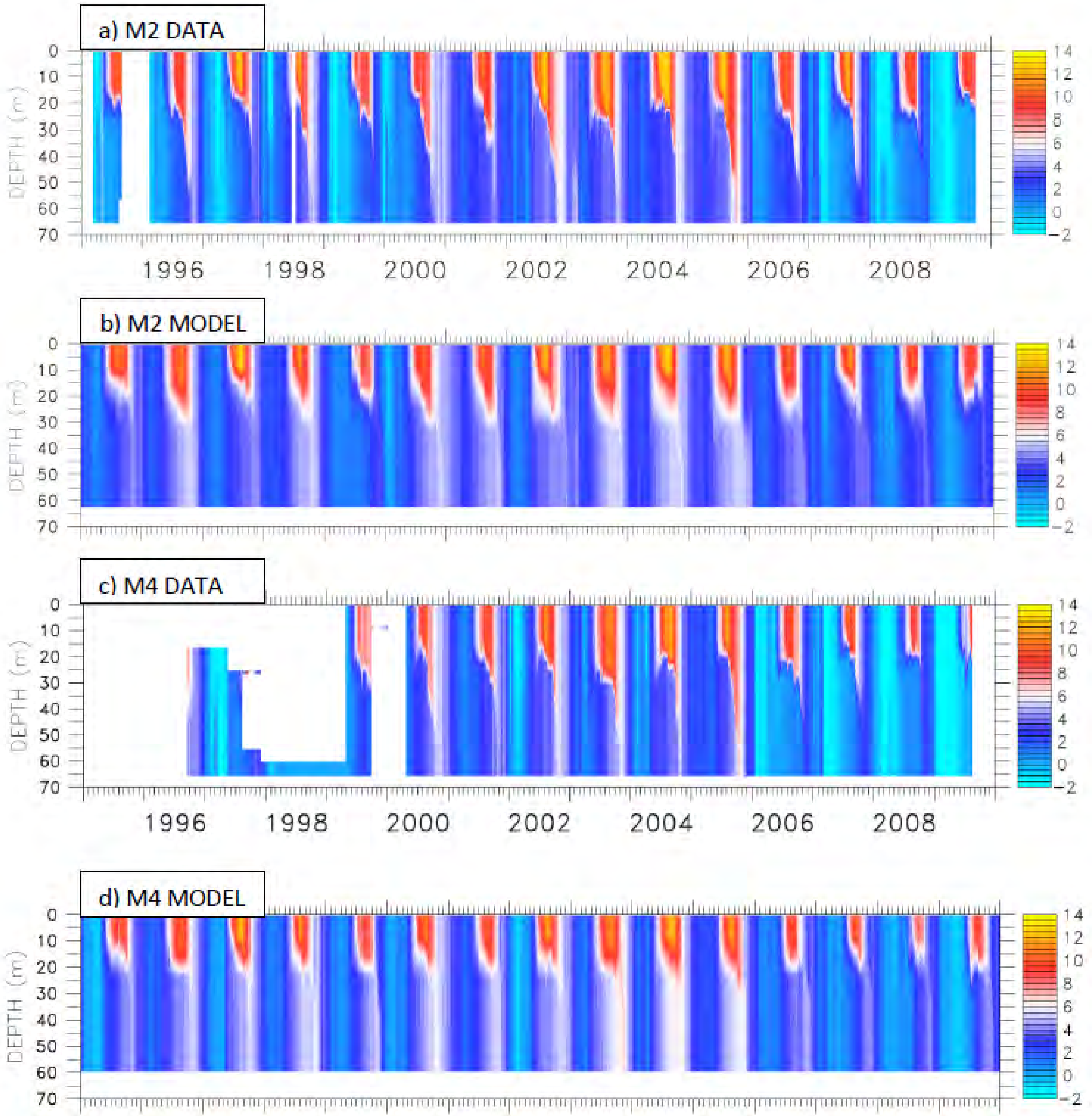


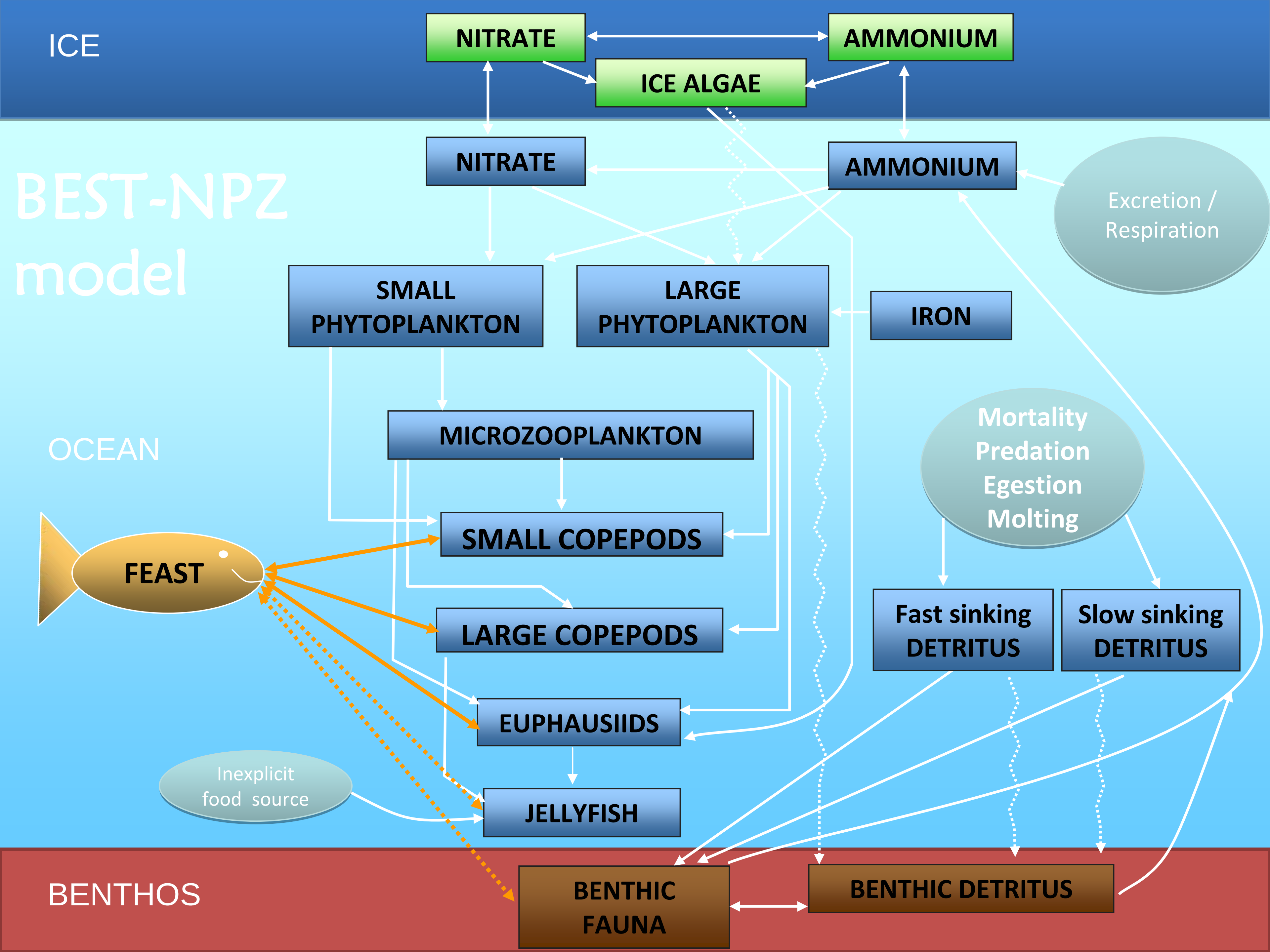
ROMS MODEL DOMAIN

10 layers, 10-km grid
Includes ice and tides
CCSM heat flux algorithms

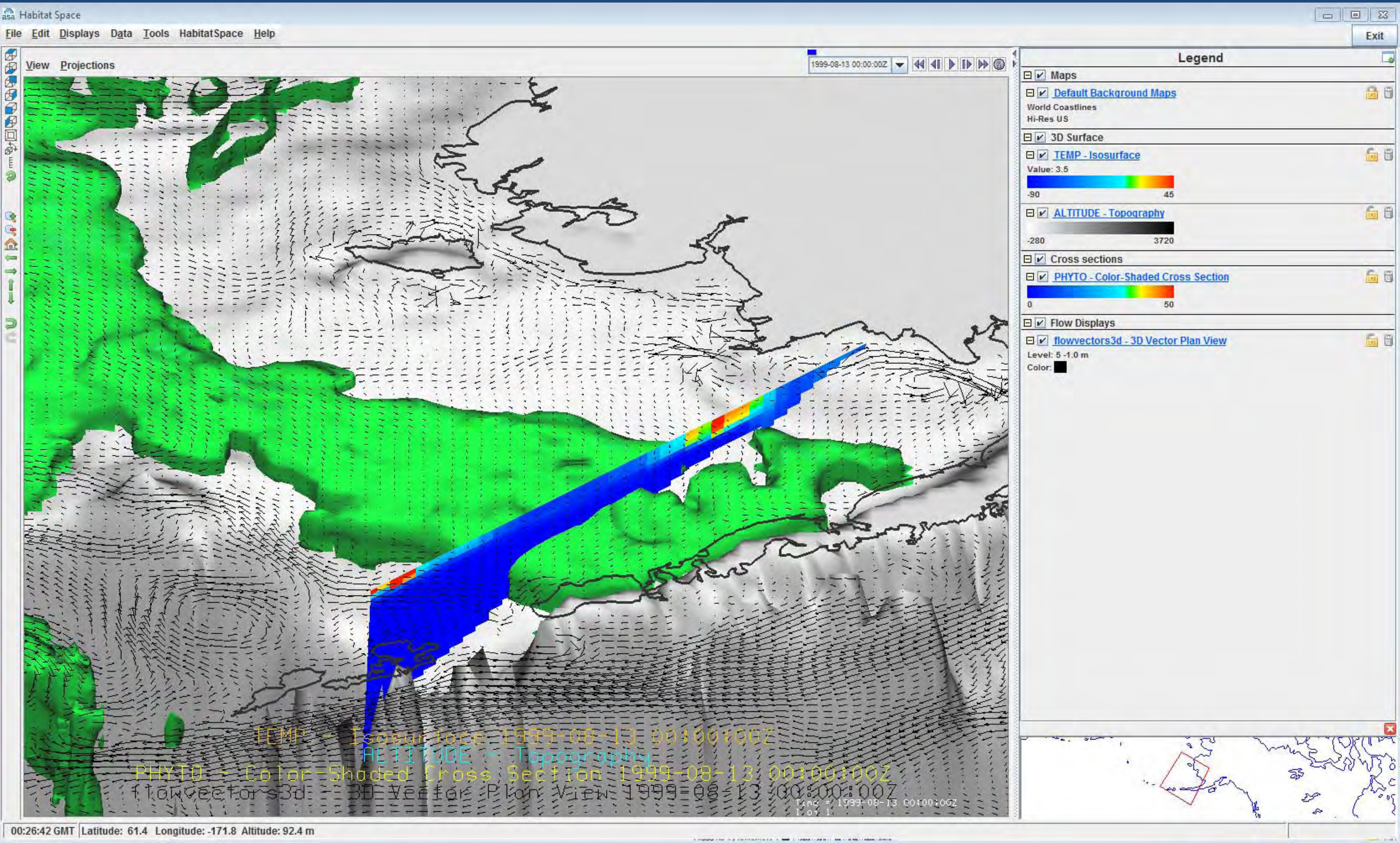


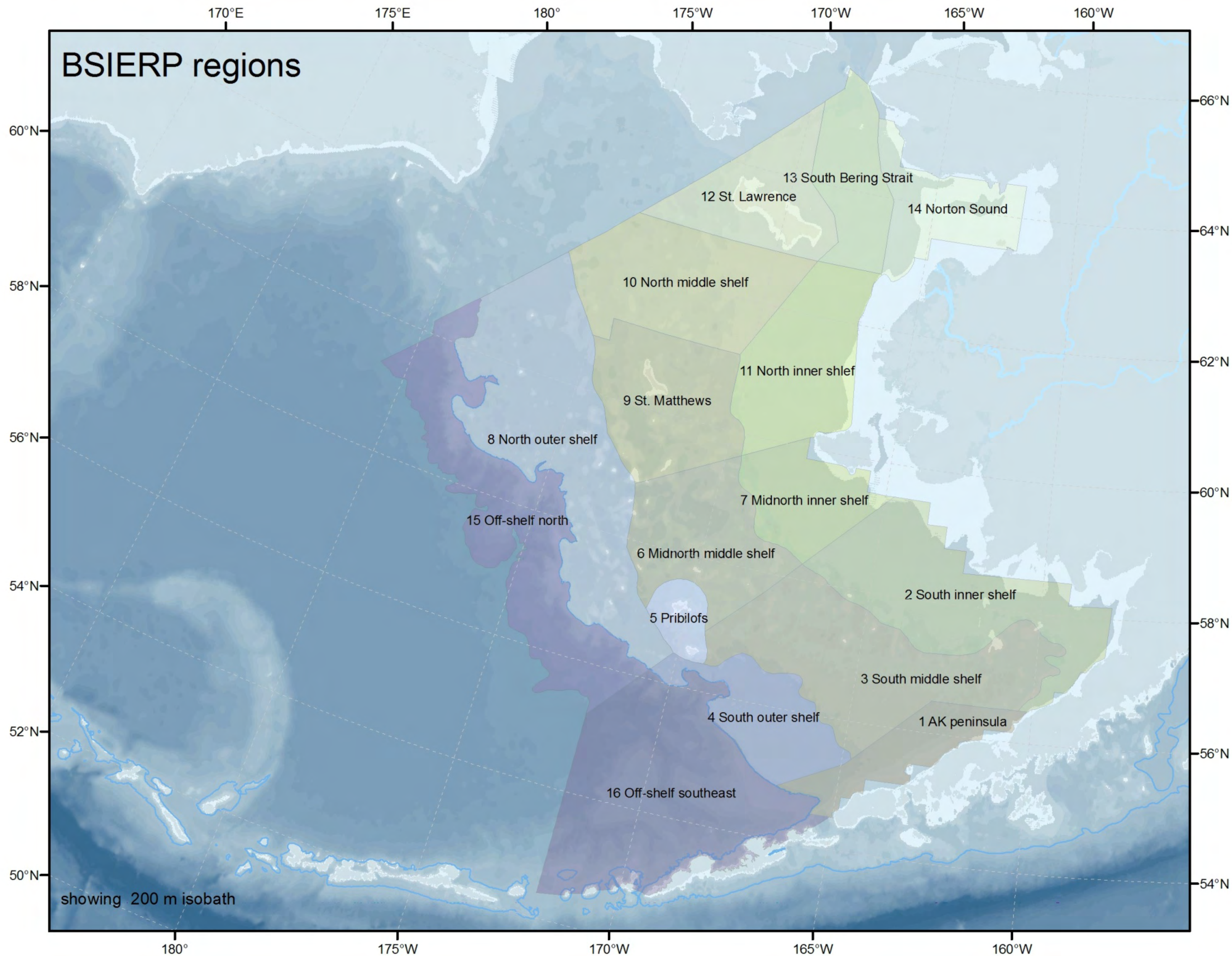
Physical model vs. data



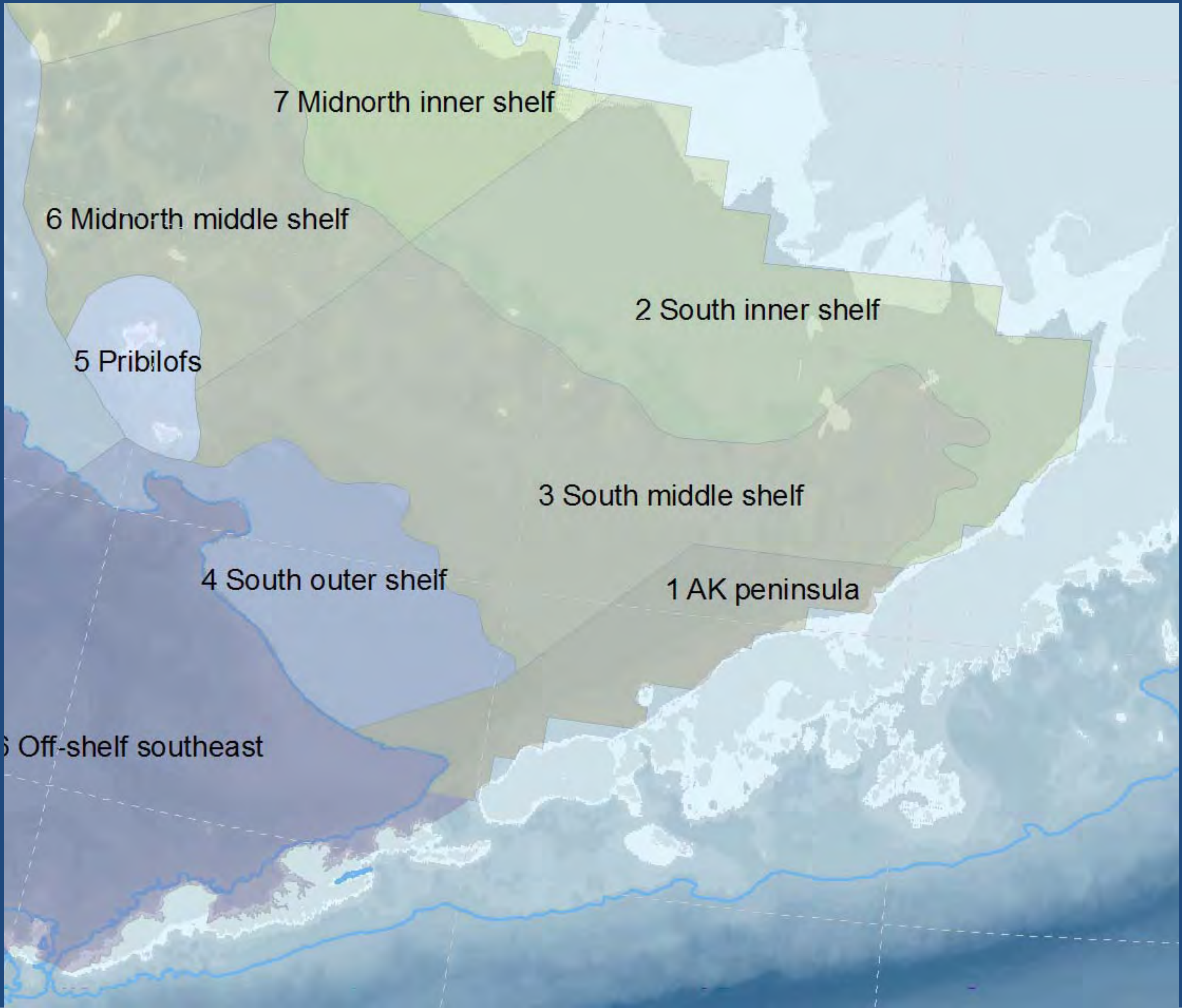

ICE
NITRATE
AMMONIUM
ICE ALGAE
NITRATE
AMMONIUM
BEST-NPZ model
Excretion / Respiration
SMALL PHYTOPLANKTON
LARGE PHYTOPLANKTON
IRON
MICROZOOPLANKTON
OCEAN
Mortality
Predation
Egestion
Molting
SMALL COPEPODS
FEAST
LARGE COPEPODS
Fast sinking DETRITUS
Slow sinking DETRITUS
EUPHAUSIIDS
Inexplicit food source
JELLYFISH
BENTHOS
BENTHIC FAUNA
BENTHIC DETRITUS

BEST/BSIERP modeling results: cold pool, phytoplankton and velocity




BSIERP regions
13 South Bering Strait
12 St. Lawrence
14 Norton Sound
10 North middle shelf
11 North inner shlef
9 St. Matthews
8 North outer shelf
7 Midnorth inner shelf
15 Off-shelf north
6 Midnorth middle shelf
2 South inner shelf
5 Pribilofs
3 South middle shelf
4 South outer shelf
1 AK peninsula
16 Off-shelf southeast
showing 200 m isobath
170°E
175°E
180°
175°W
170°W
165°W
160°W
66°N
64°N
62°N
60°N
58°N
56°N
54°N
52°N
50°N

Close-up of Southern Shelf



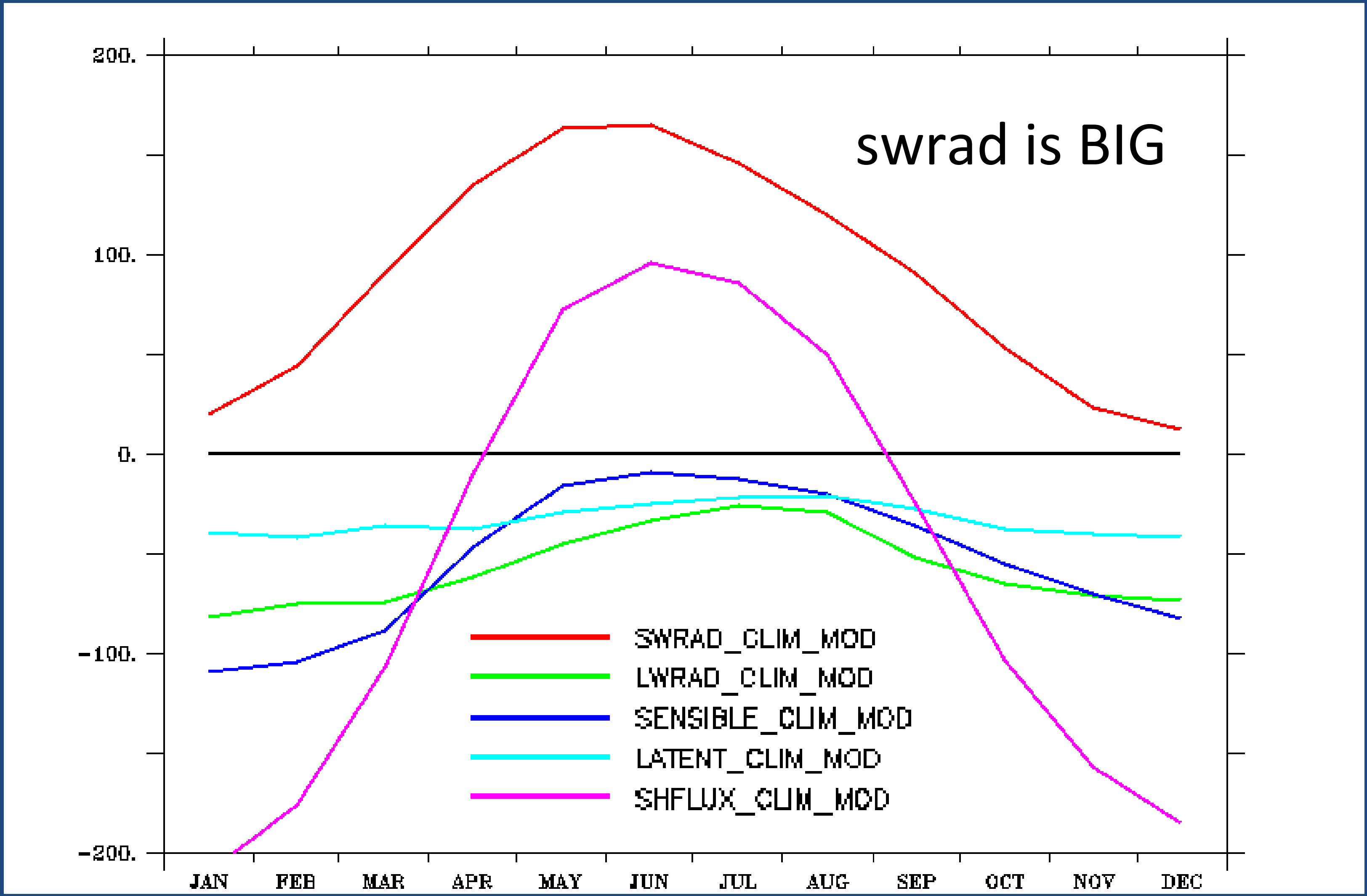
Overview of method

- For each bioregion: calculate time series of deviations from the seasonal climatology for major forcing variables and significant modeled attributes of the ocean ecosystem
- Look for pairwise coherence among these deviations
  - Physical: Tocn, Tair, swrad, lwrad, wind stress
  - Biological: euphausiid biomass
- Notes and cautions:
  - coherence analysis is similar to lagged correlations of band-passed signals
  - there is coherence among the forcing variables themselves, and among the ocean attributes themselves. Hence an established coherence may not reflect a simple forcing relationship (but still useful for prediction)
  - nonlinear relationships may confound simple linear coherence

Model Forcing Variables

- Wind Velocities
- Air Temperature
- Air Specific Humidity
- Sea Level Pressure
- Rainfall
- Runoff
- Downwelling Shortwave
- Downwelling Longwave

Major terms in the outer shelf seasonal heat budget (W m^{-2}, positive = into the ocean)



Expected frequency response 1: thermal inertia reddens the input spectrum

$dT/dt = (F - \lambda^* T) / H$

$F \sim F_o\, e^{i\omega t}$, $T \sim T_o\, e^{i\omega t}$

$T_o/F_o \sim 1/ (Hi\omega + \lambda)$

as ω->0, T_o/F_o ->1/ λ
as ω->huge, T_o/F_o ->0
white F -> red T
red F -> redder T

T = ocean temperature
H = ocean depth
F = surface heat forcing
λ = rate of heat loss at surface (e.g. sensible, longwave)
ω = frequency

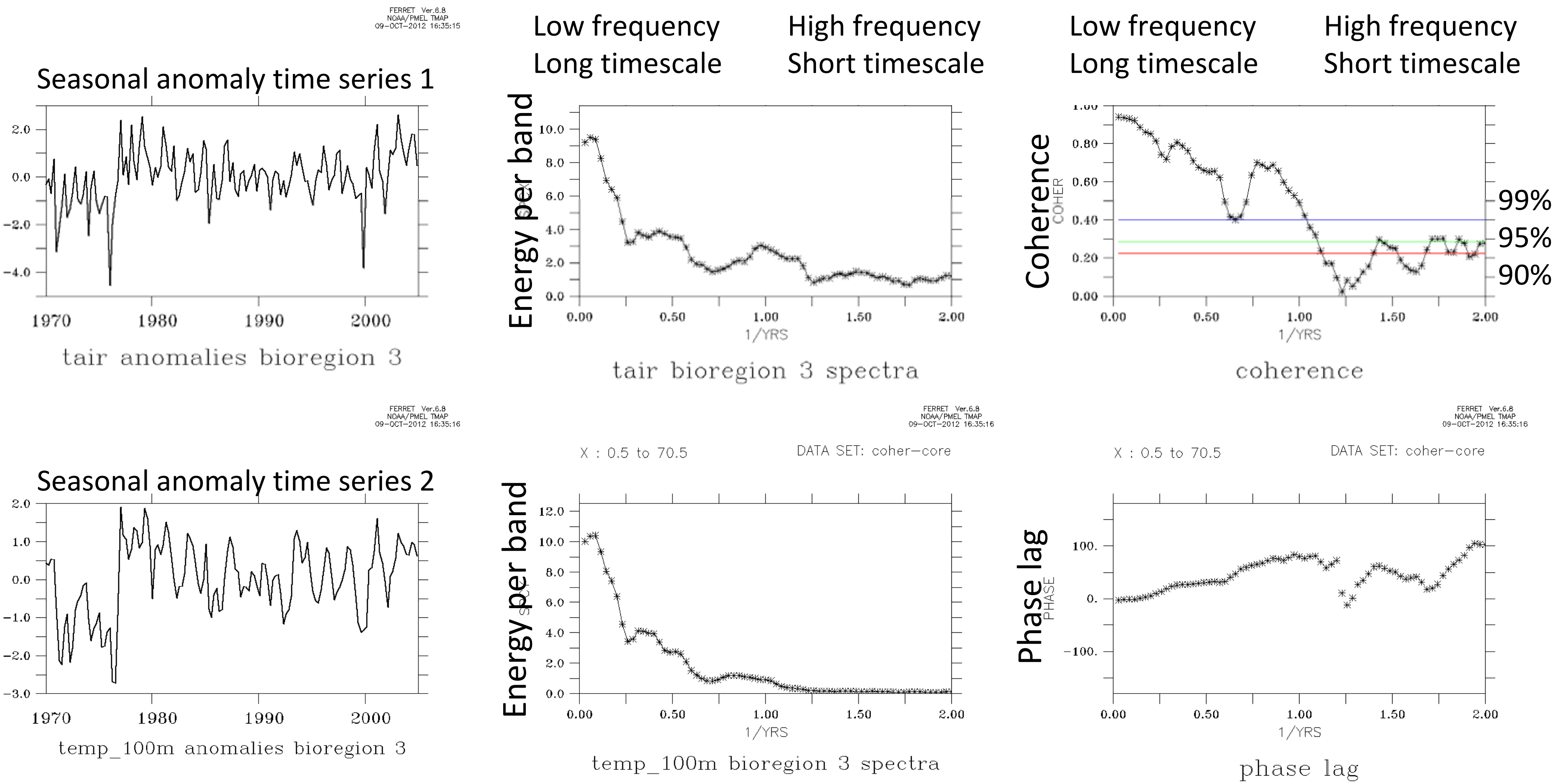
Expected frequency response 2: Biological reddening and resonance

- Some biological terms will simply redden the spectrum of the physical forcing (as with heat example, simple integration does this)
- HOWEVER, if physical forcing matches a fundamental period of the biology, can get "resonance"
  - Example: recurrence period of favorable conditions corresponds to time lag between birth and reproduction

Physical Results

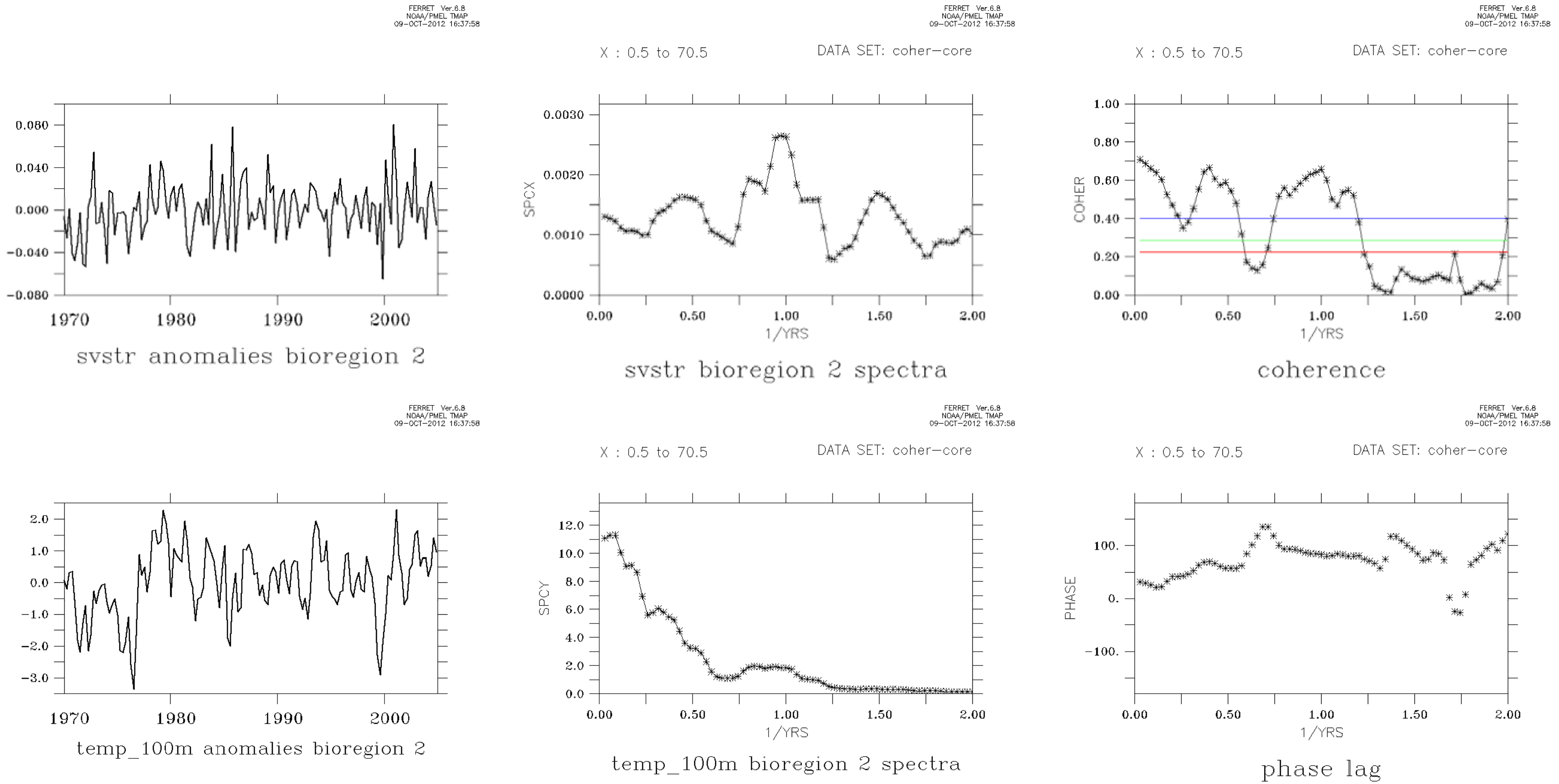
- Four forcing datasets were used:
- Hindcast
  - CORE (1970-2004)
- IPCC forecast
  - MIROC (2003-2040)
  - CCCMA (2003-2040)
  - ECHO-G (2004-2040)

CORE forcing: Mid-shelf T_{ocn} is positively coherent with T_{air} on annual to decadal scales



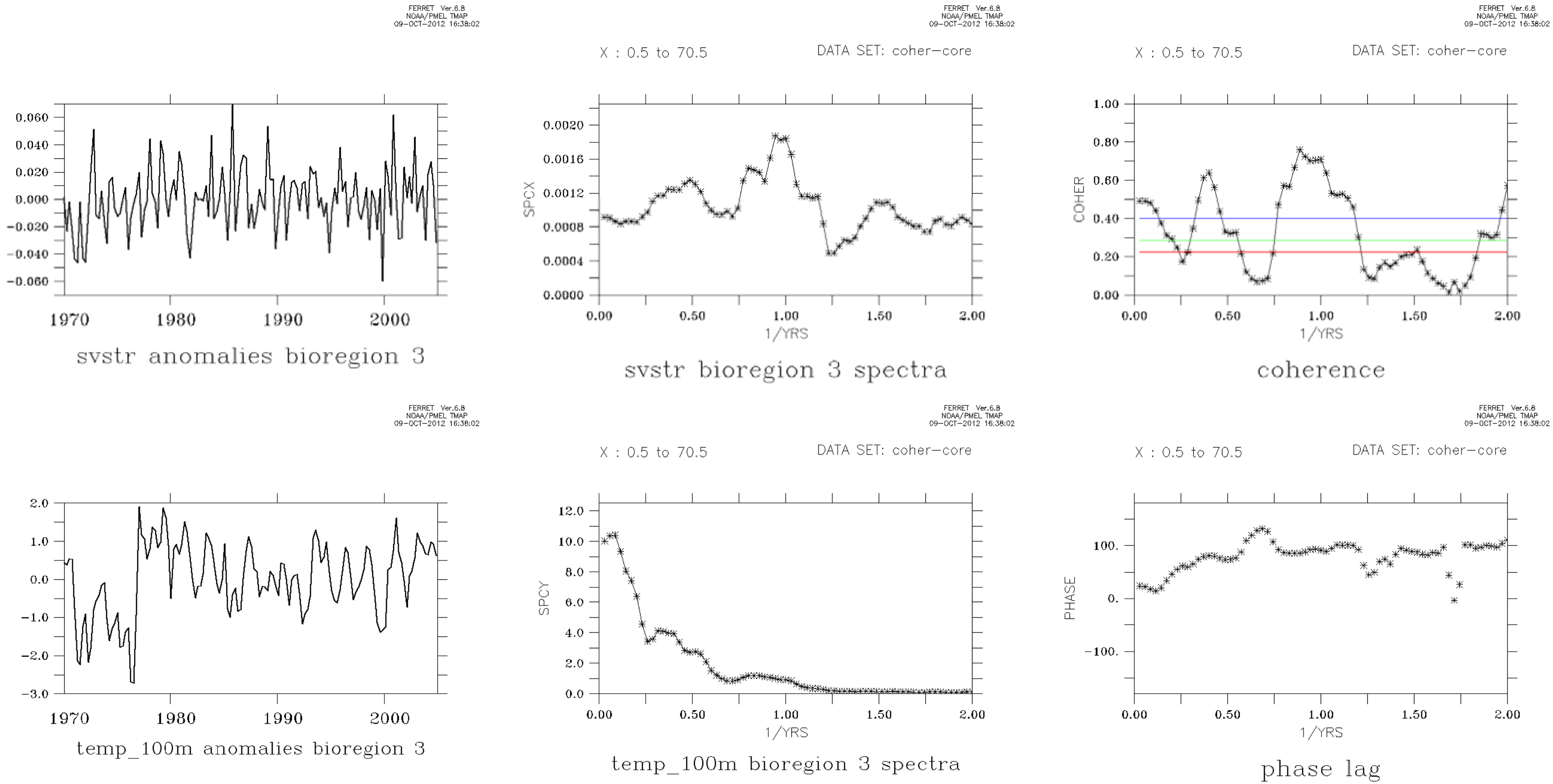
- red, green, blue lines indicate 90%,95%,99% confidence levels for coherence significantly different than zero
- positive phase means top variable leads bottom variable

CORE forcing: Inner-shelf T_{ocn} is positively coherent with along-shelf wind stress on annual to interdecadal timescales

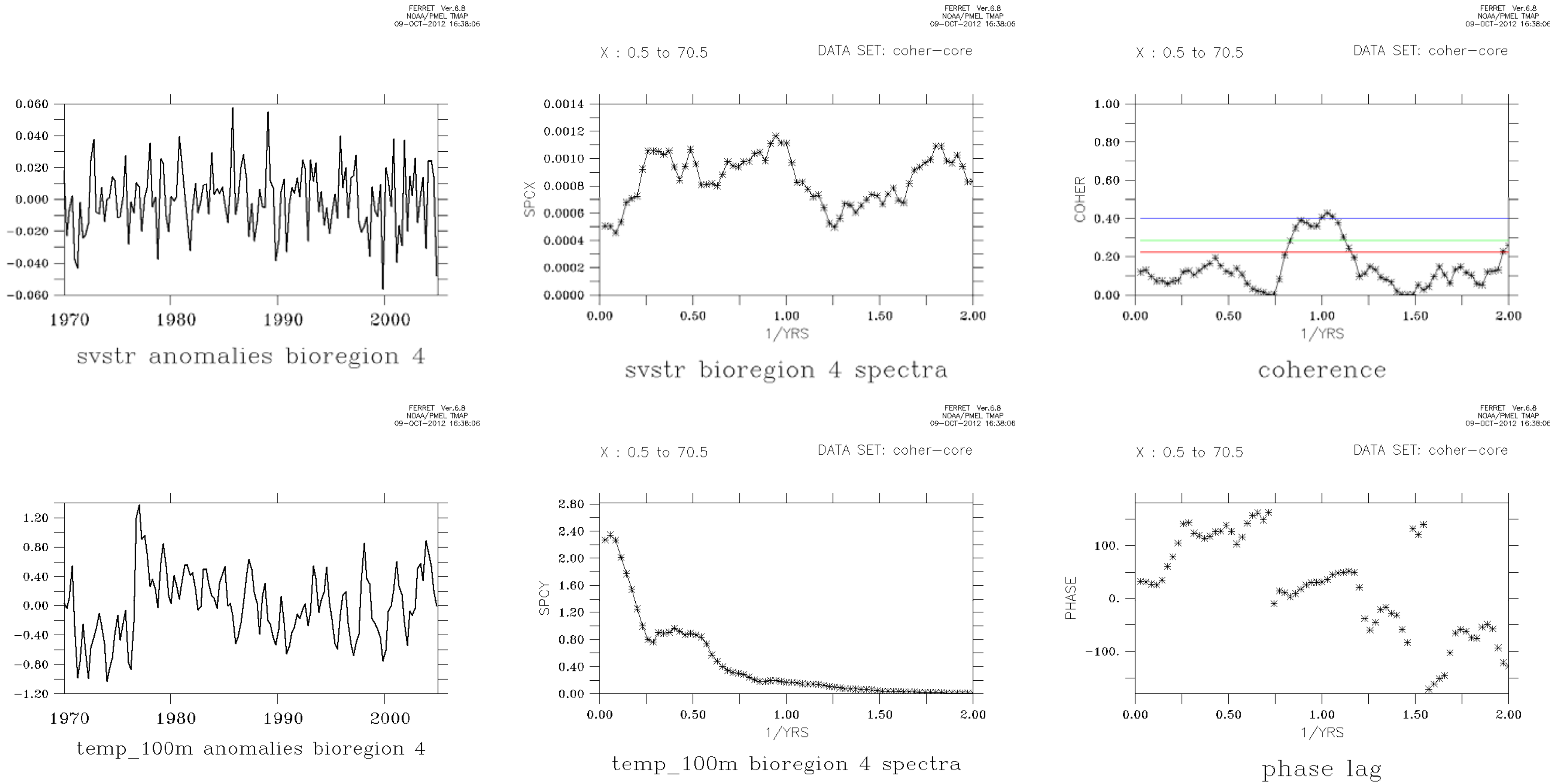


Note how windstress has *whiter spectrum* than air temperature

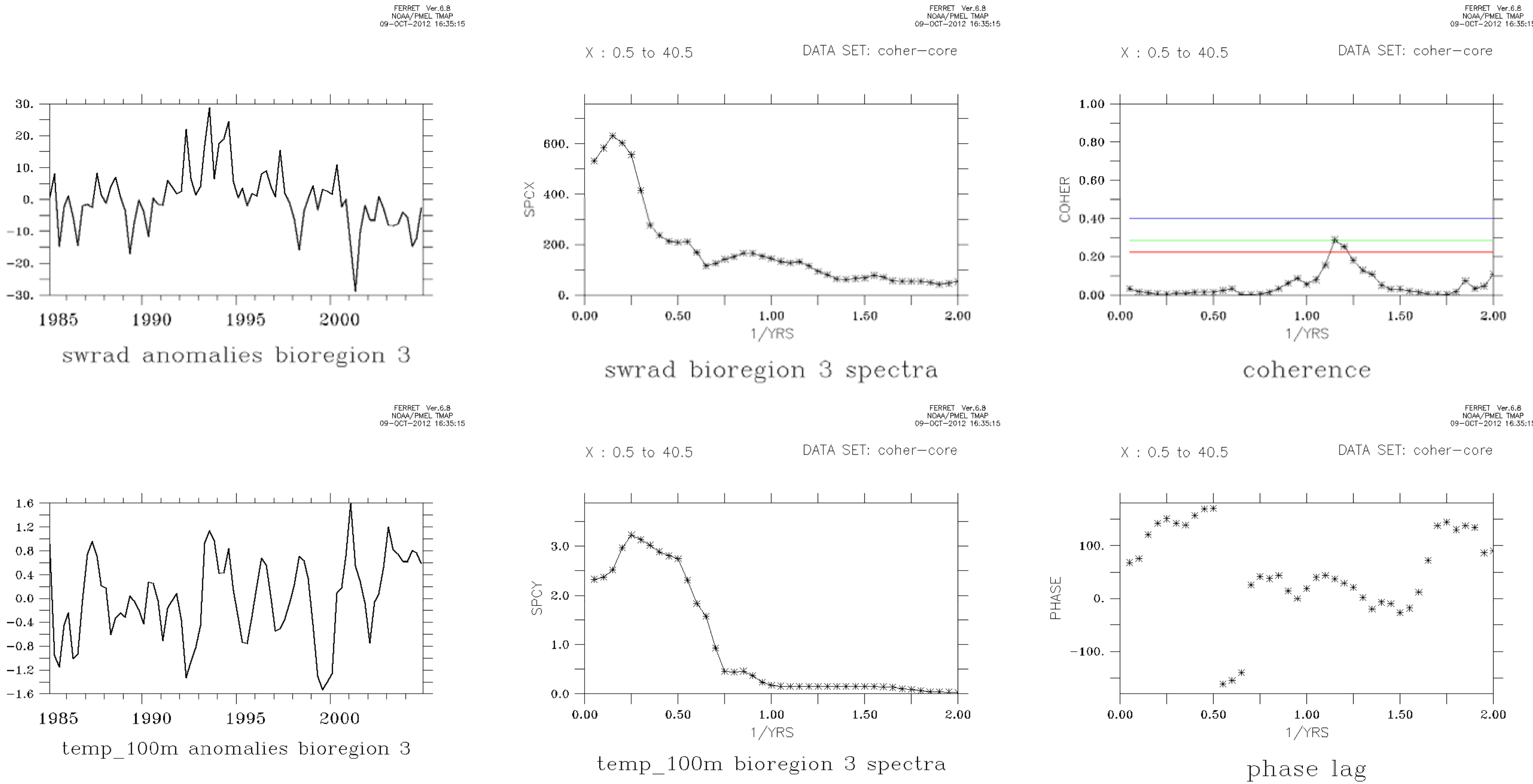
CORE forcing: Mid-shelf T_{ocn} is positively coherent with along-shelf wind stress on annual to interdecadal timescales



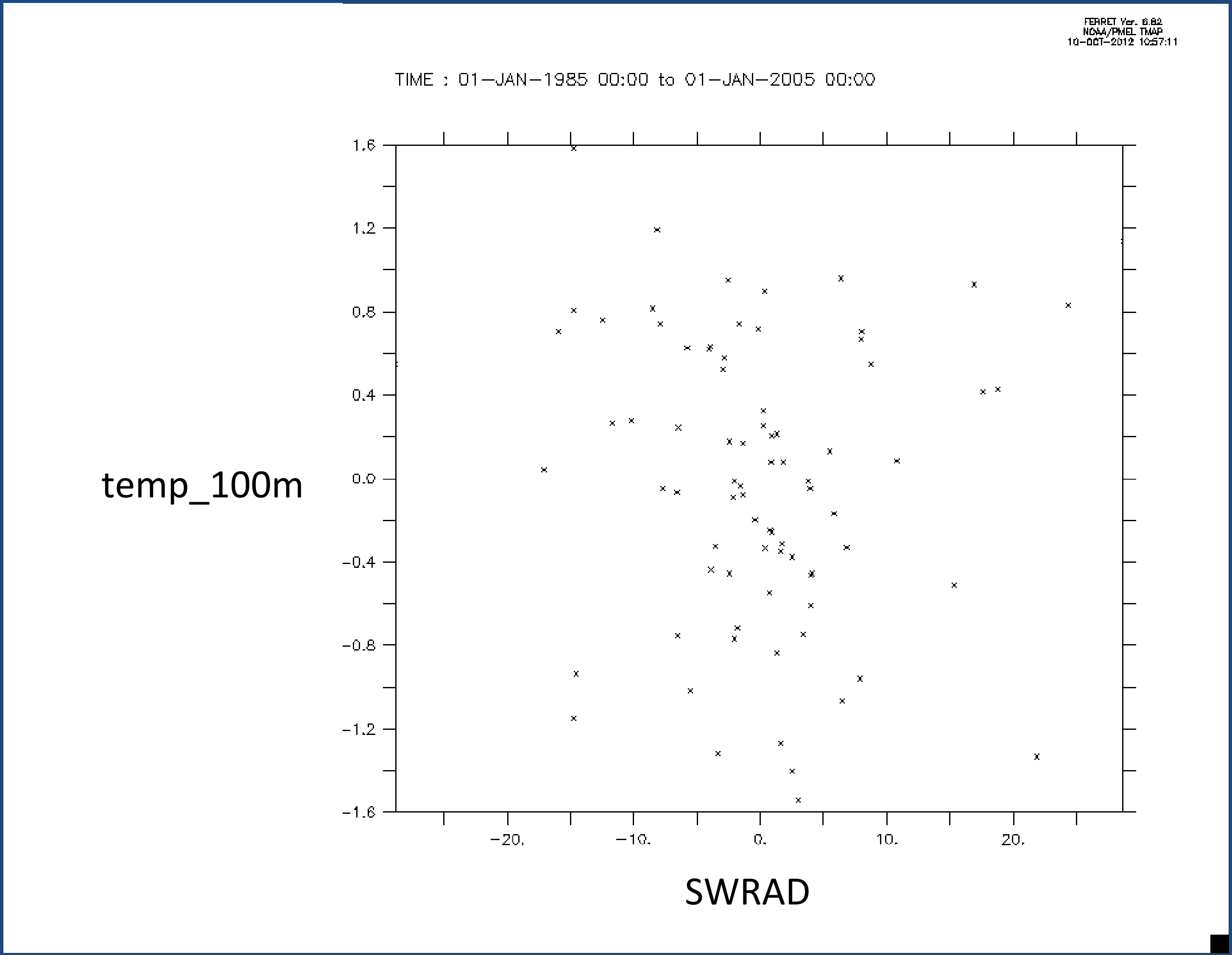
CORE forcing: Outer-shelf Tocn is NOT coherent with along-shelf wind stress on longer timescales



CORE forcing: Mid-shelf Tocn is NOT coherent with swrad



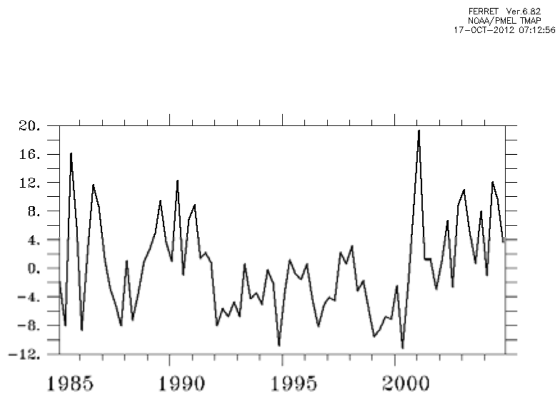
CORE forcing:
swrad (x-axis) vs T_{ocn} (y-axis)



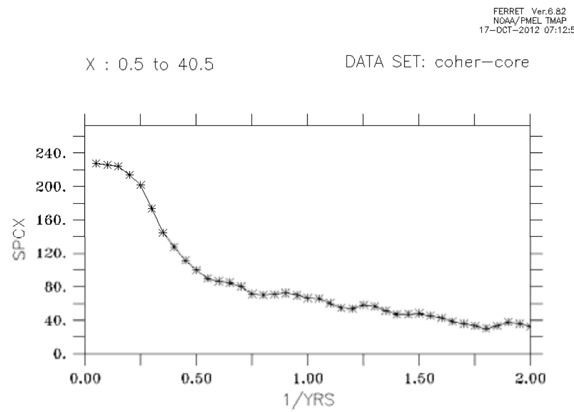
Summer Cloudiness (from Bond 2012)

Year	Cloud Fraction	
	Western Bering	Eastern Bering
2003	0.81	0.86
2004	0.85	0.86
2005	0.80	0.88
2006	0.73	0.86
2007	0.87	0.88
2008	0.76	0.85

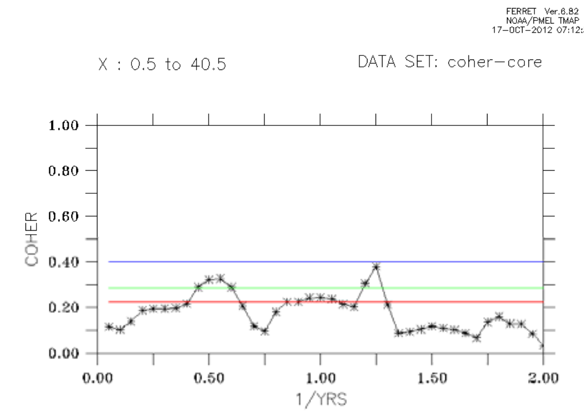
CORE forcing: Mid-shelf T_{ocn} is positively coherent with lwrad at annual to decadal scales



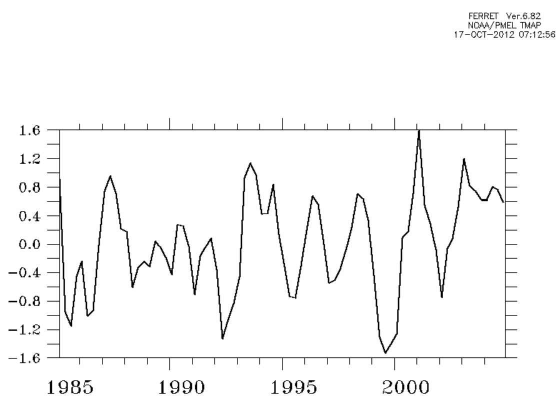
lwrad anomalies bioregion 3



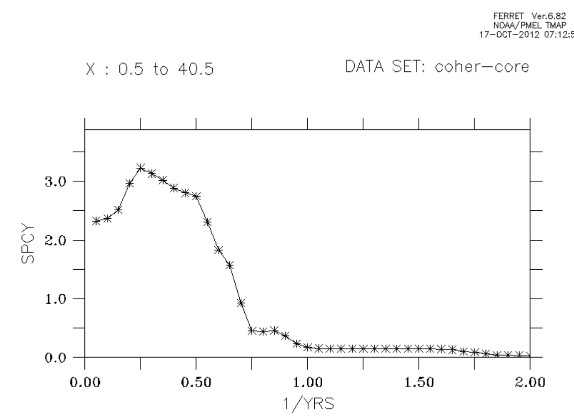
lwrad bioregion 3 spectra



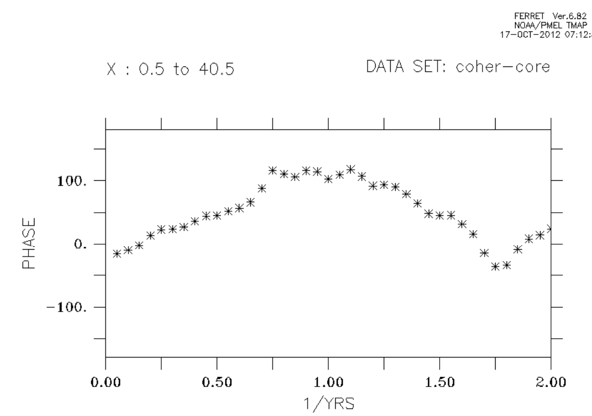
coherence



temp_100m anomalies bioregion 3



temp_100m bioregion 3 spectra

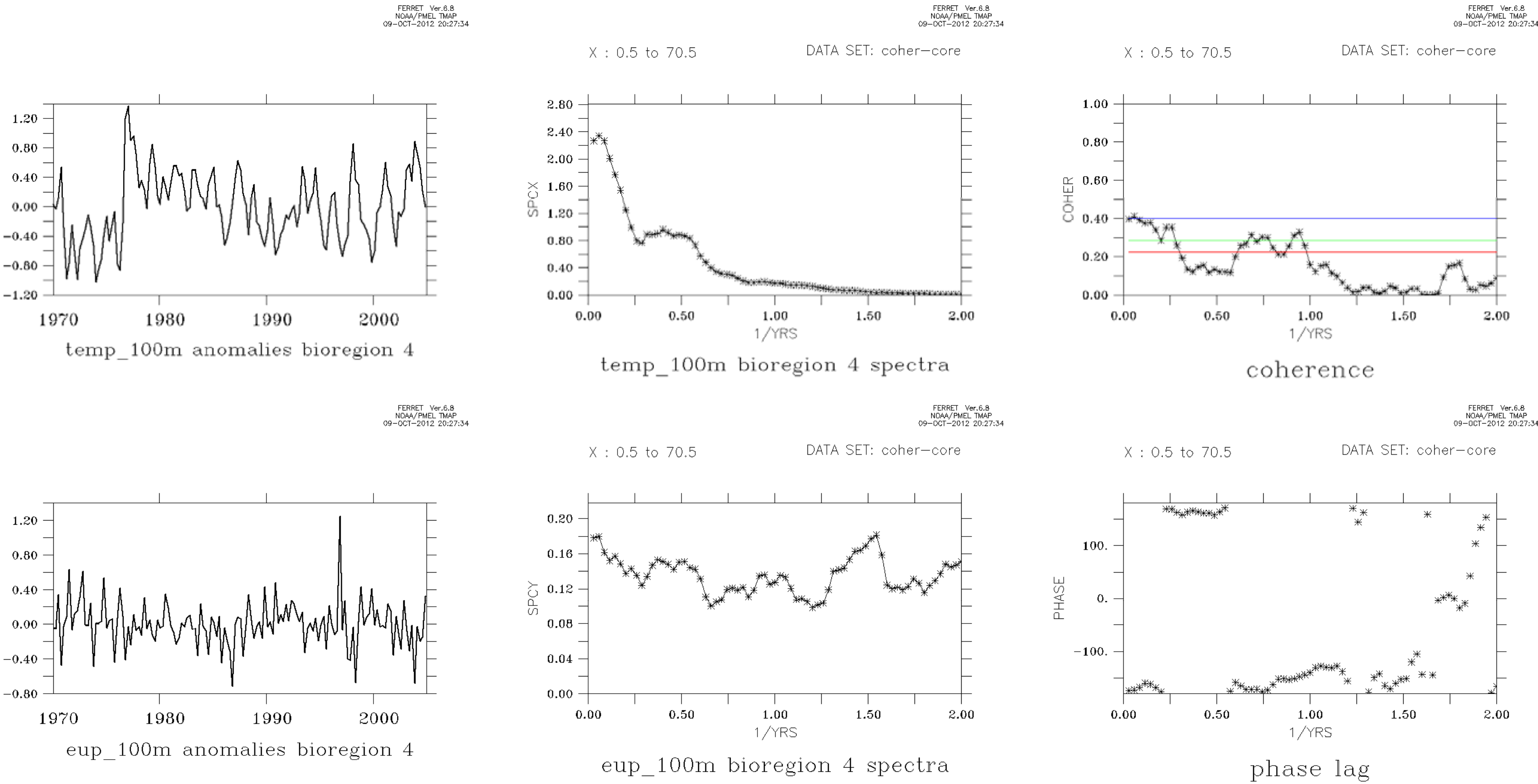


phase lag

Biological Results

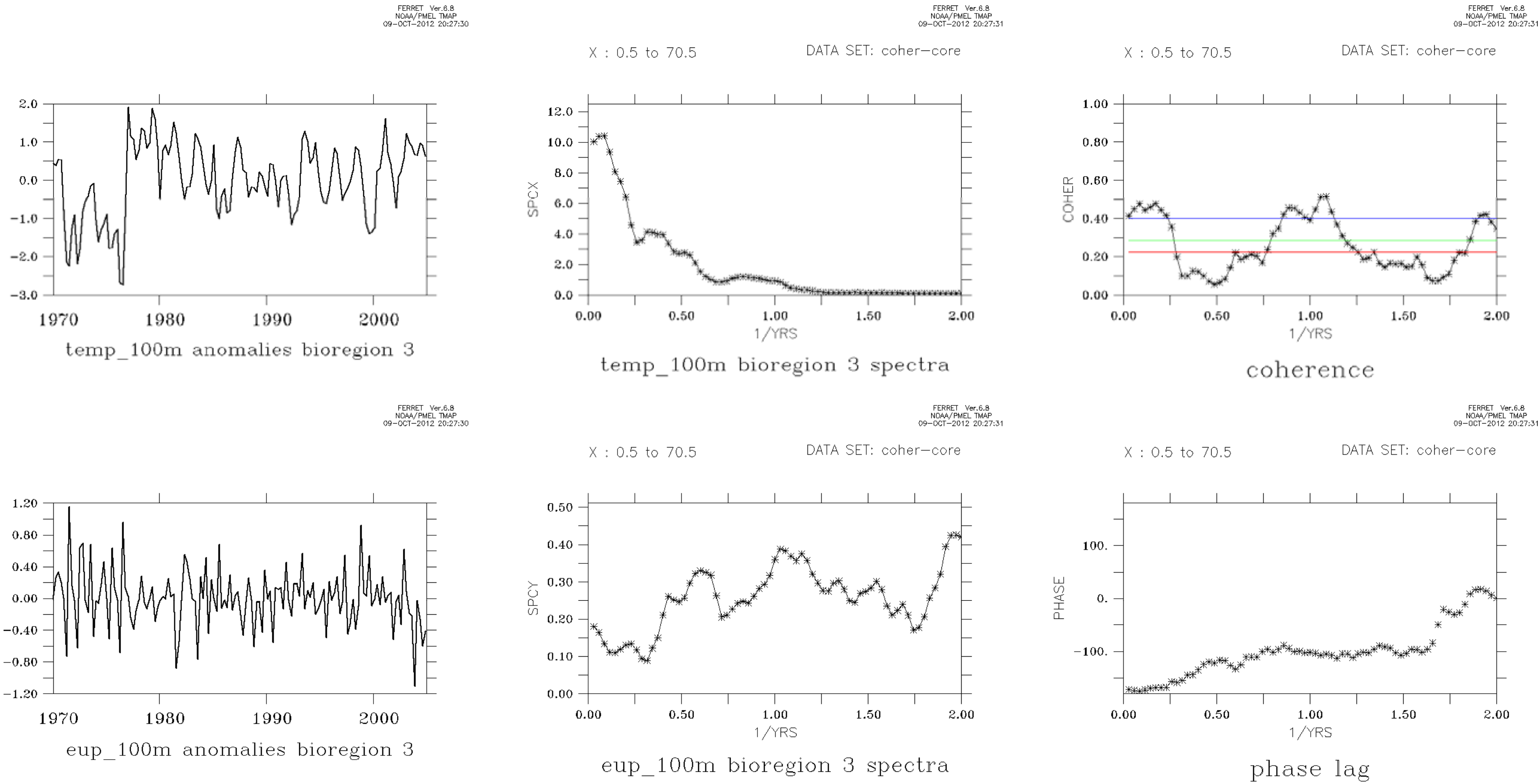
- Models and data have suggested inverse correlation between ocean temperature and large crustacean zooplankton
- Does this hold across all frequency bands?

CORE forcing: Outer-shelf euphausiids are *negatively* coherent with T_{ocn} at annual and decadal scales

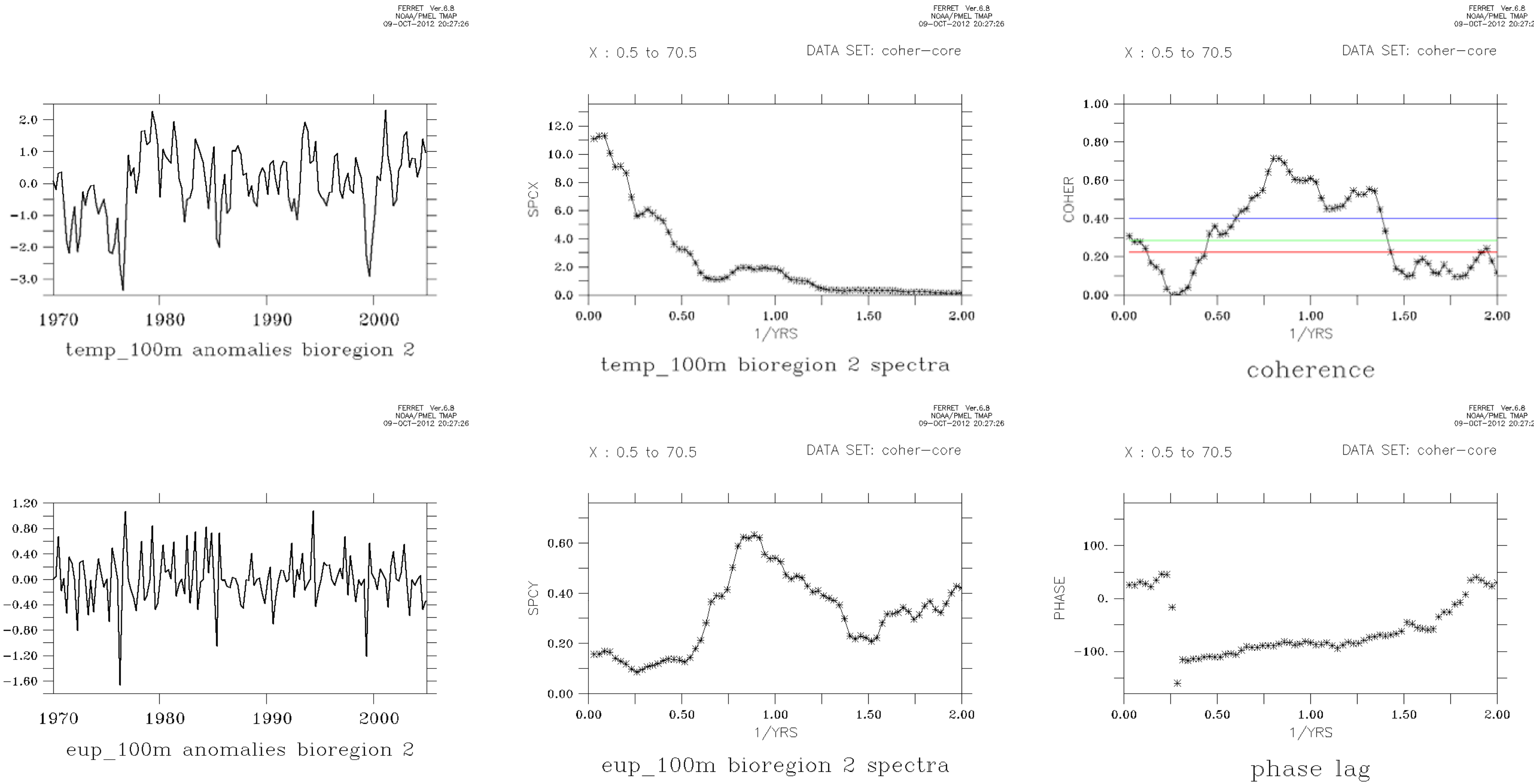


Note how euphausiids have whiter spectrum than physical ocean variables

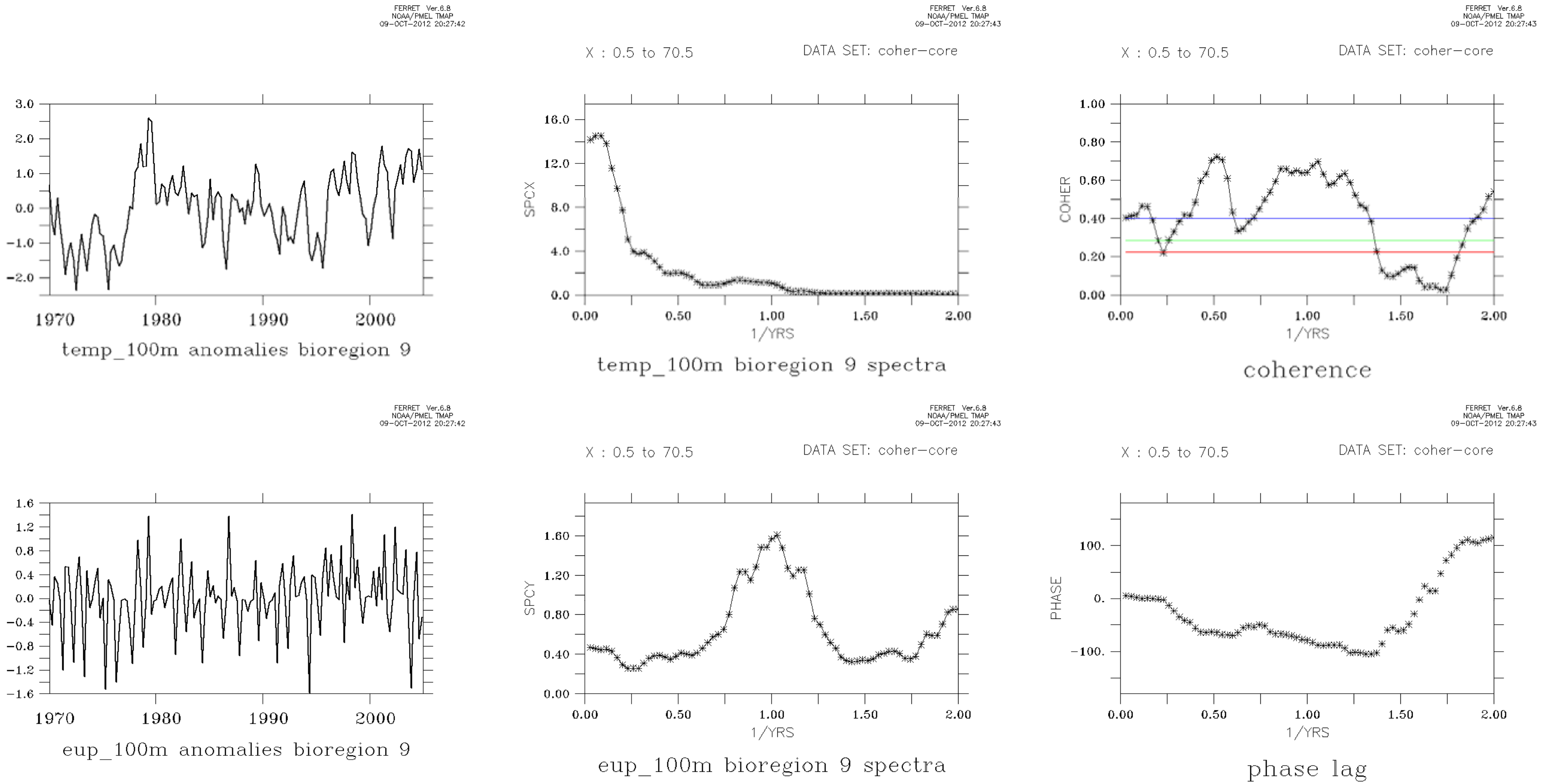
CORE forcing: Mid-shelf euphausiids are *negatively* coherent with Tocn at annual and decadal scales



CORE forcing: Inner-shelf euphausiids are coherent with Tocn at annual scales



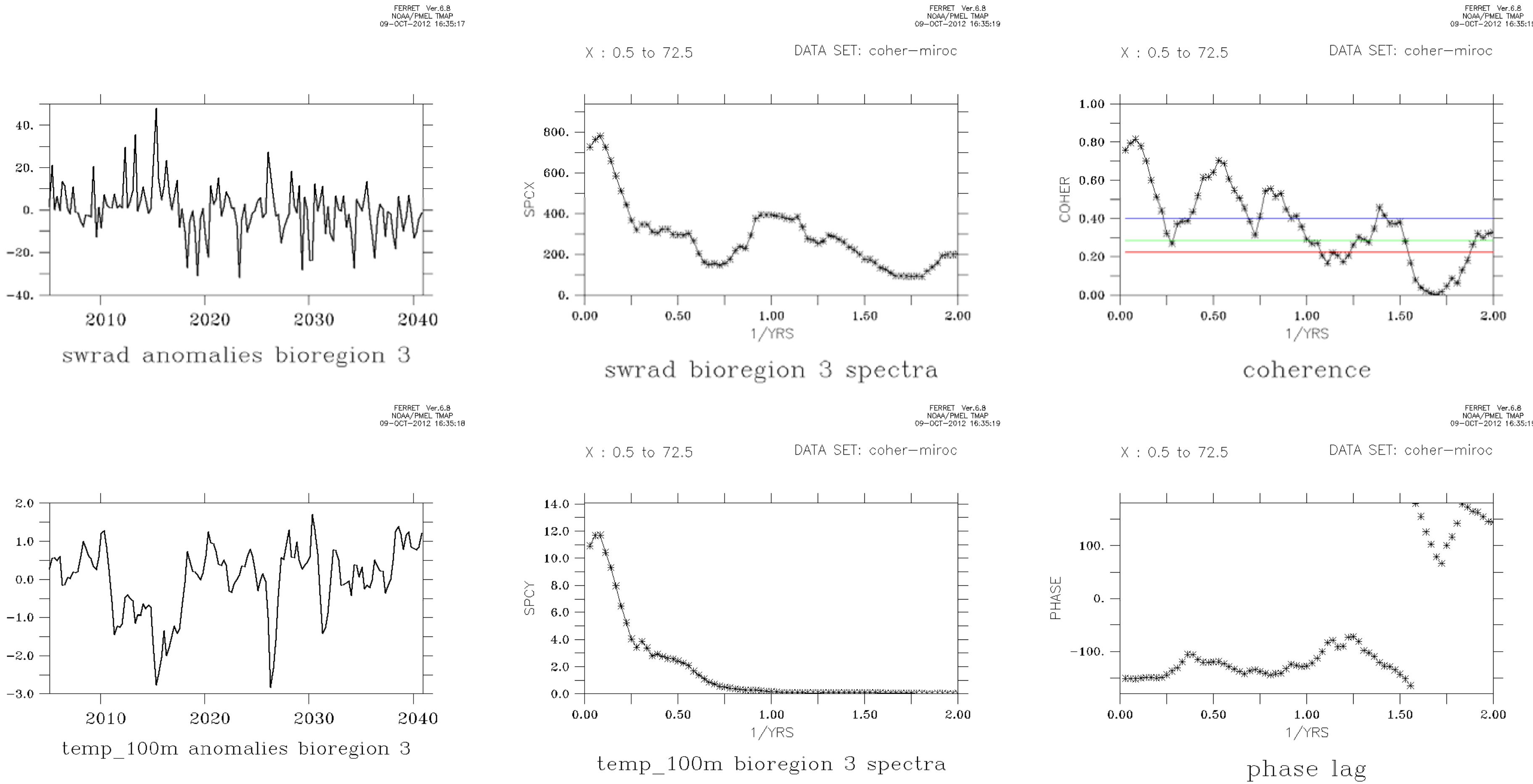
CORE forcing: Northern shelf euphausiids are *positively* coherent with Tocn across most frequencies



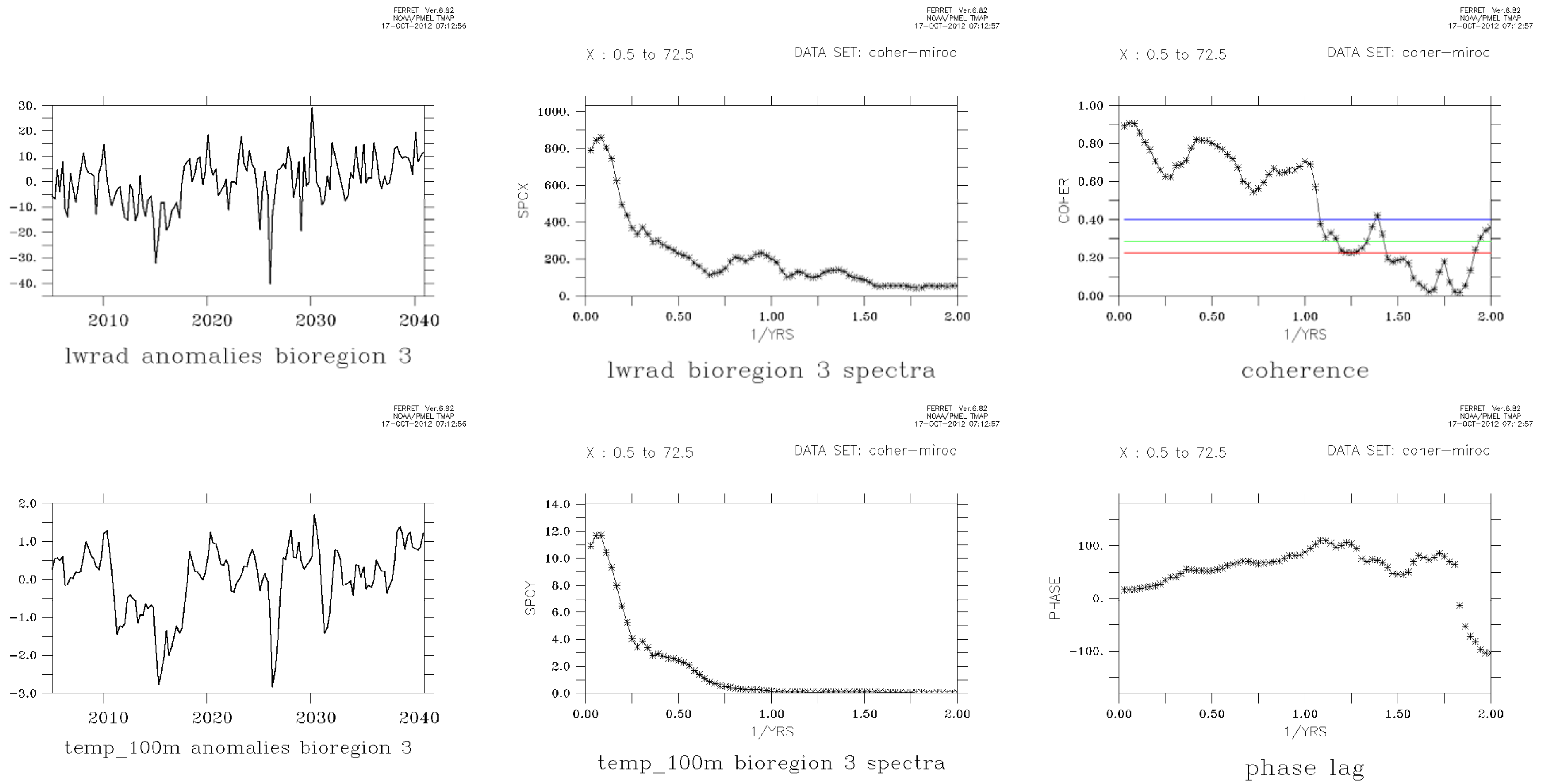
Do these relationships hold for the IPCC forcing runs?

- Generally yes, with some interesting differences….

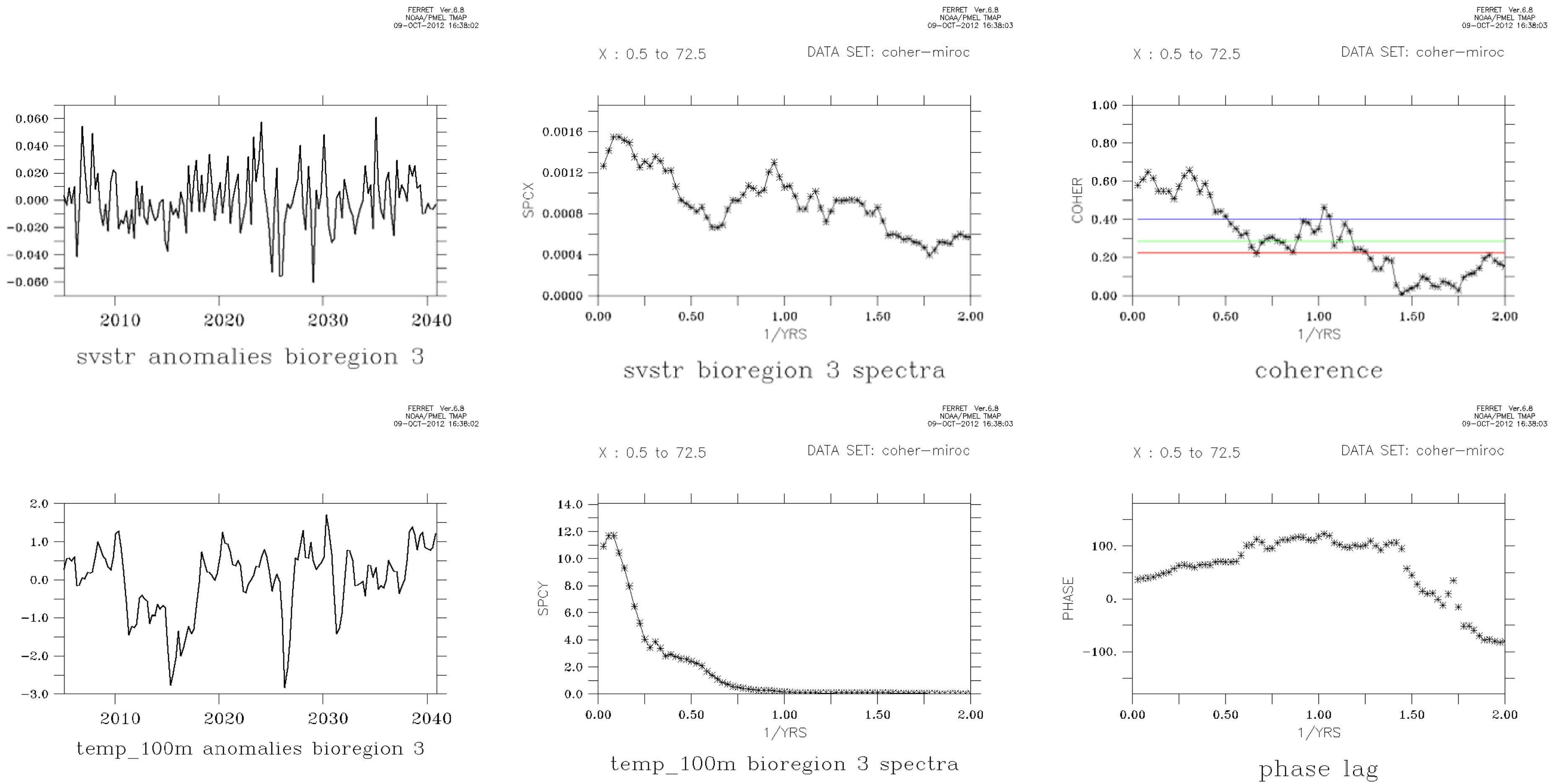
MIROC forcing: Mid-shelf T_{ocn} is *negatively* coherent with swrad at annual to decadal scales



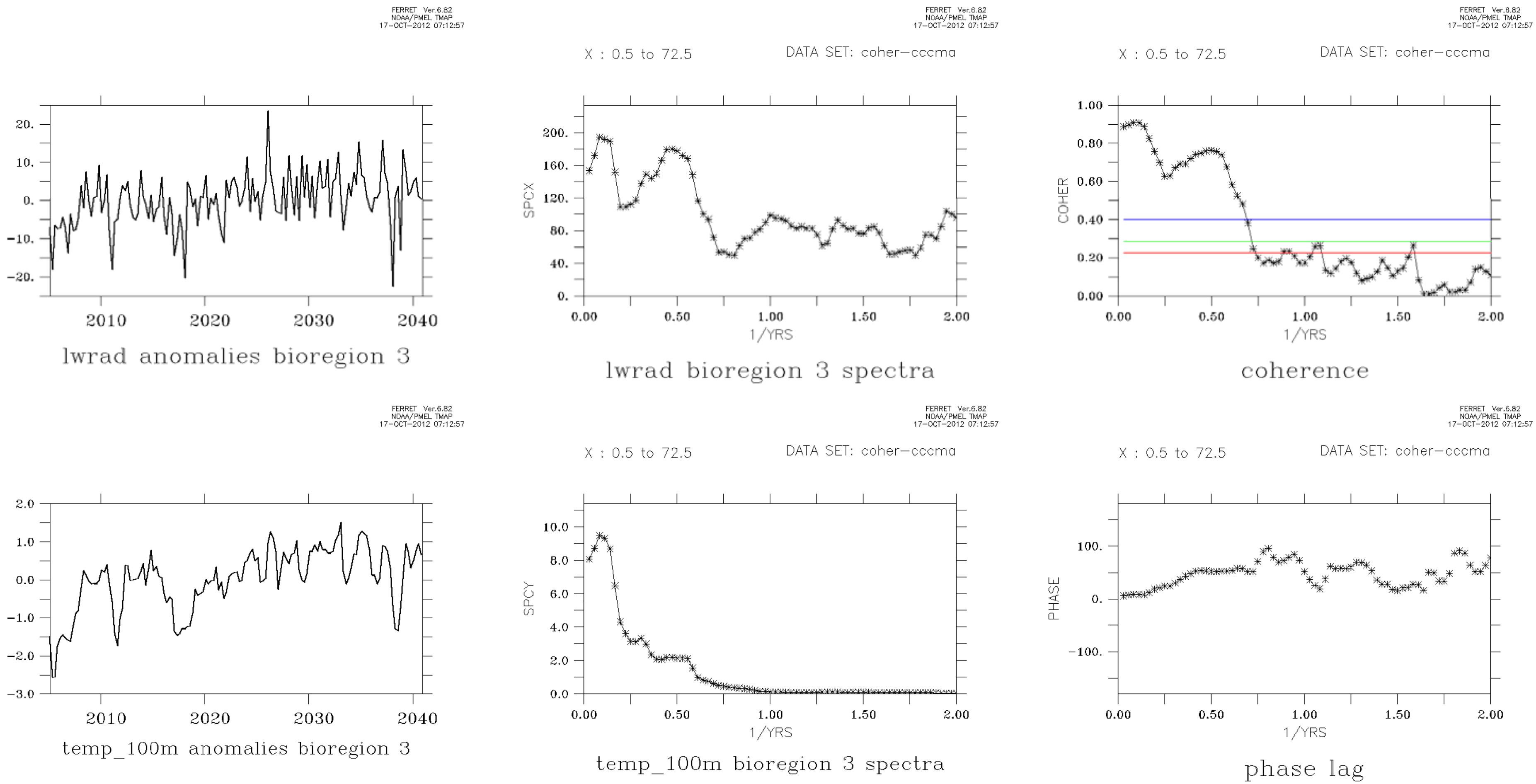
MIROC forcing: Mid-shelf Tocn is positively coherent with lwrad at annual to decadal scales



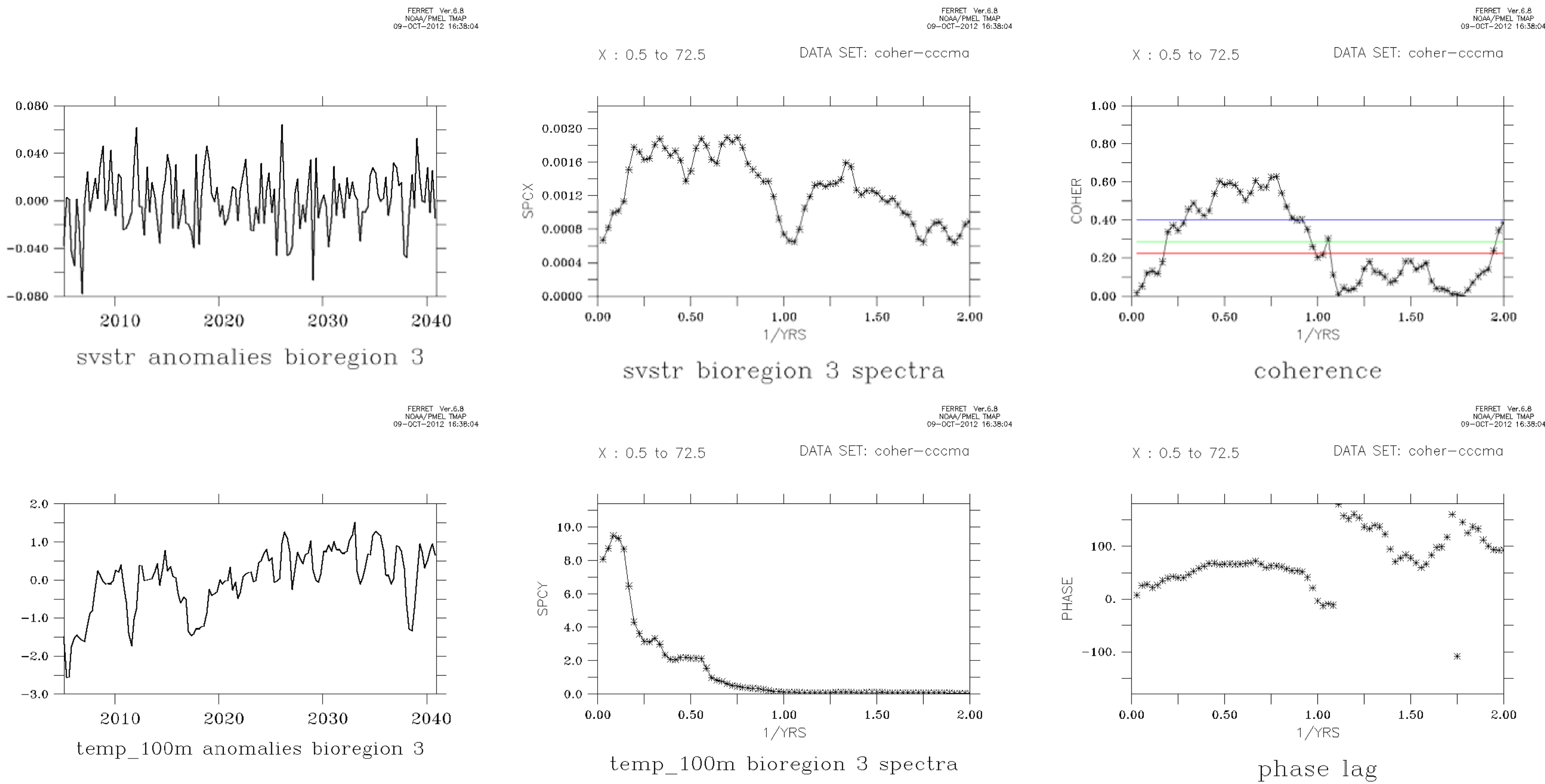
MIROC forcing: Mid-shelf T_{ocn} is positively coherent with along-shelf wind stress on interannual to interdecadal timescales



CCCMA forcing: Mid-shelf T_{ocn} is positively coherent with lwrad at interannual to decadal scales



CCCMA forcing: Mid-shelf Tocn is coherent with along-shelf wind stress on interannual timescales



Summary

- T_{ocn} *IS* coherent with T_{air}, esp on longer time scales
- T_{ocn} *IS* coherent with alongshelf wind-stress
- T_{ocn} *IS NOT* coherent with shortwave input, but *IS* coherent with longwave input
- Euphausiid biomass *IS* coherent with with T_{ocn}, esp on longer time scales. Out of phase at long time scales, in-phase on short time scales at some locations

Interpretation

- Coherence with winds, air temperature and longwave suggest these are the better predictors of heat content than shortwave!
- Coherence of euphausiids with ocean temperature may be useful for inferences regarding fish (e.g. the Oscillating Control Hypothesis of Hunt et al. 2012)