Potential early warning indicators of marine ecosystem changes in coastal British Columbia, Canada

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Drivers of change acting on the Strait of Georgia

	Drivers & Pressures	States & Impacts
Natural	Northern Oscillation Index (NOI; annual) Oceanic Niño Index (ONI; annual) Pacific Decadal Oscillation (PDO; annual) North Pacific Gyre Oscillation (NPGO; annual) Wind speed (Vancouver airport; annual) Air temperature (Vancouver airport; annual mean) Precipitation (Vancouver airport; annual sum) Sea surface temperature (SST: Entrance Is., annual) Sea surface salinity (SSS; Entrance Is., annual) Fraser River flow (volume, annual) pH (annual modal values)	Spring phytoplankton bloom start date (modelled) Sockeye salmon marine survival (Chilko Lake) Herring (number at age 3) Herring (spawning biomass) Sockeye salmon (returns to Fraser River) Pink salmon (escapement, excluding Fraser River) Chum salmon (returns to Fraser River) Harbour seals (annual number) Killer whales (residents, annual number) Seabirds – demersal feeding (Christmas Bird Count) Seabirds – pelagic feeding (Christmas Bird Count)
Human	Chinook (number of hatchery releases) Coho (number of hatchery releases) Recreational fishing effort Human population (of Regional Districts around the Strait)	Herring (commercial catch) Flatfish (commercial catch) Pacific cod (commercial catch) Lingcod (commercial catch) Pacific hake (commercial catch) Dogfish (commercial catch) Total commercial fish catch Total pelagic fish catch Total demersal fish catch Chinook salmon recreational catch Coho salmon recreational catch

15 natural and human Driver & Pressure (explanatory) variables were examined for statistical relationships with 22 State & Impact (response) variables for the Strait of Georgia, 1970-2010

Perry and Masson, 2013, Progr. In Oceanography

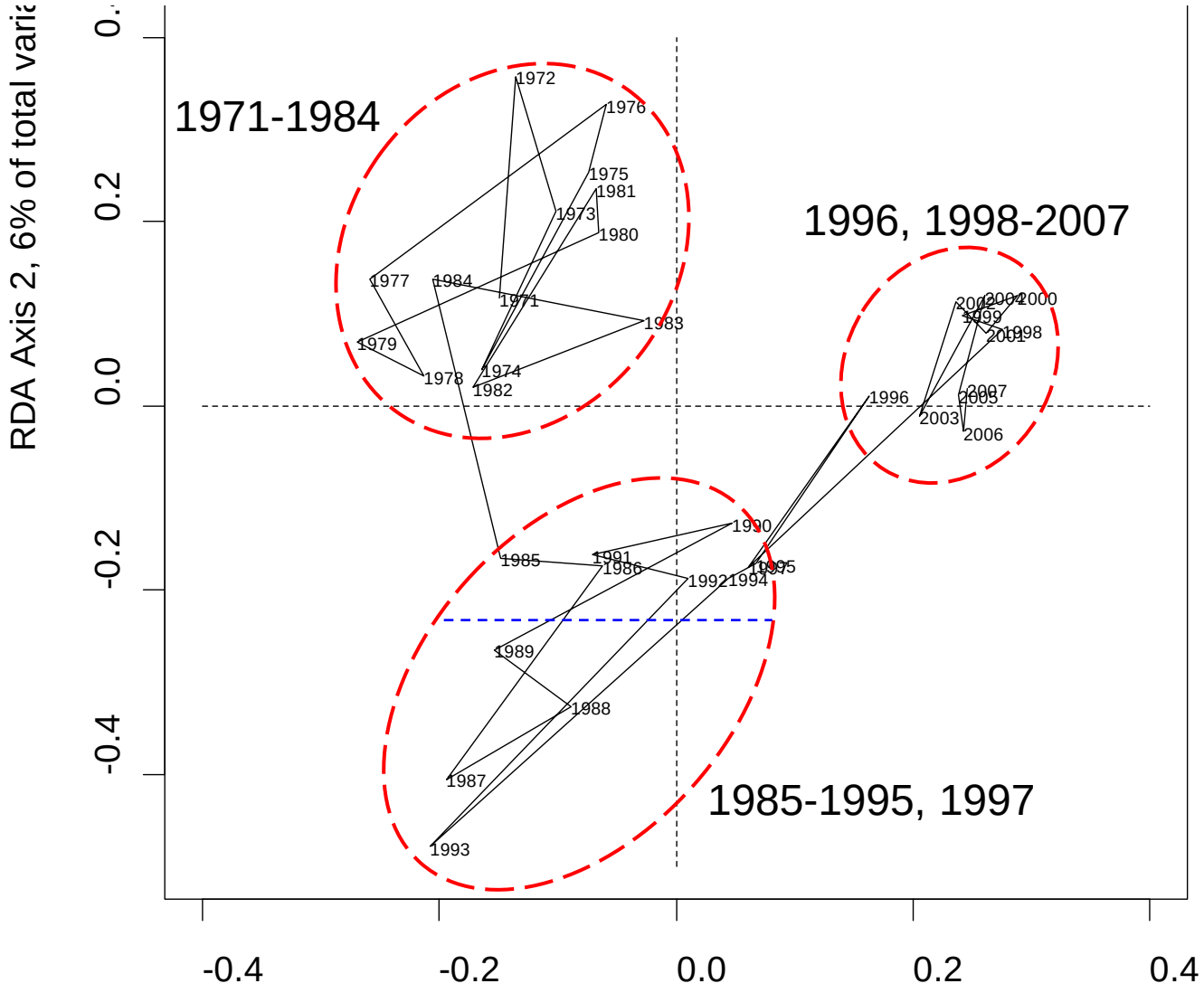
Drivers of change acting on the Strait of Georgia

Explanatory variables identified to be statistically significant (using redundancy analysis) were:

	Local scale	Large scale
Natural variables	SST	NPGO
	Wind speed (YVR)	
Human variables	Recreational fishing effort	Human population around the Strait
	Hatchery releases of Chinook	

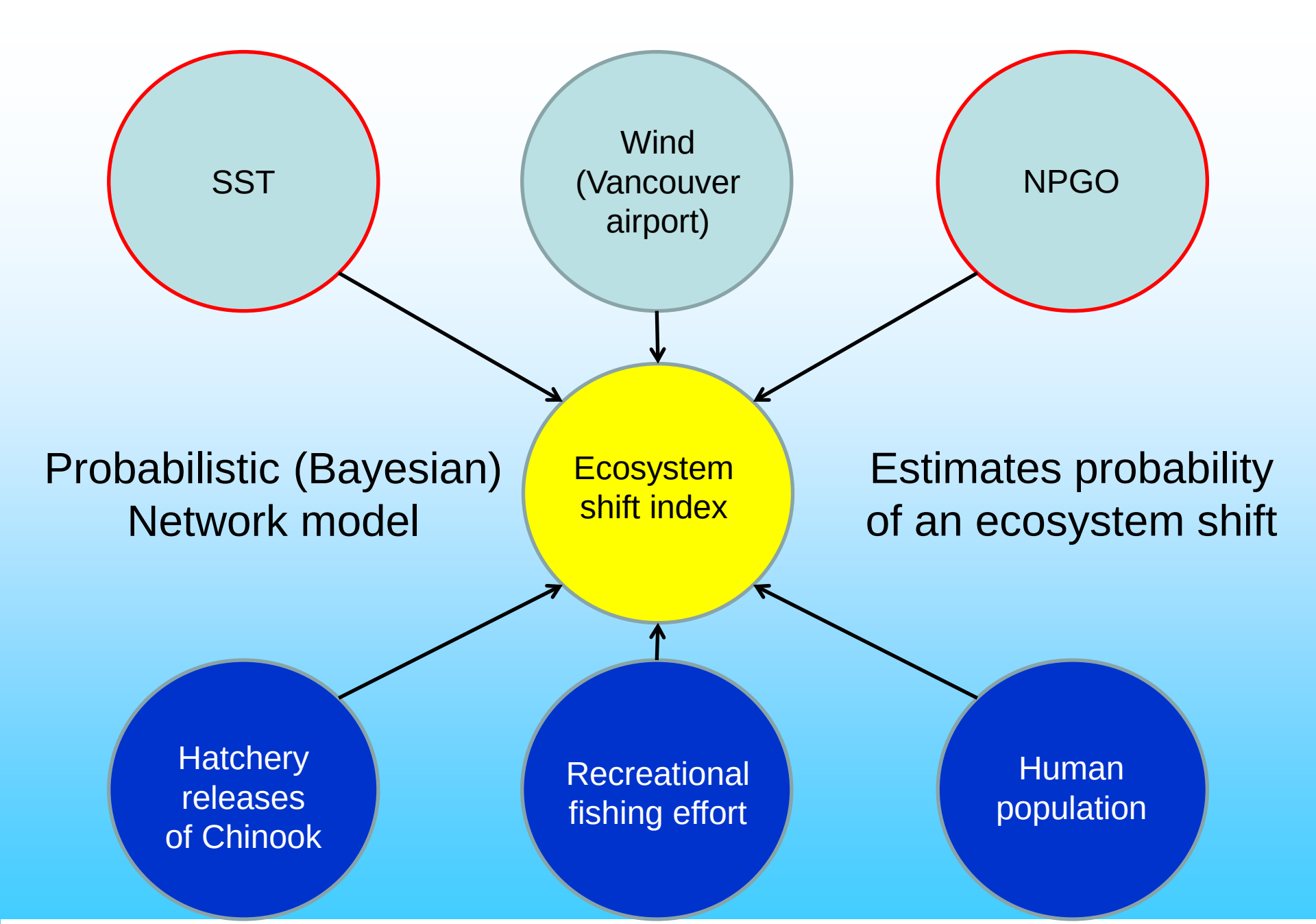
Perry and Masson, 2013, Progr. In Oceanography

These six variables describe the regime-like (Tipping Point) transitions of the Strait of Georgia since 1970

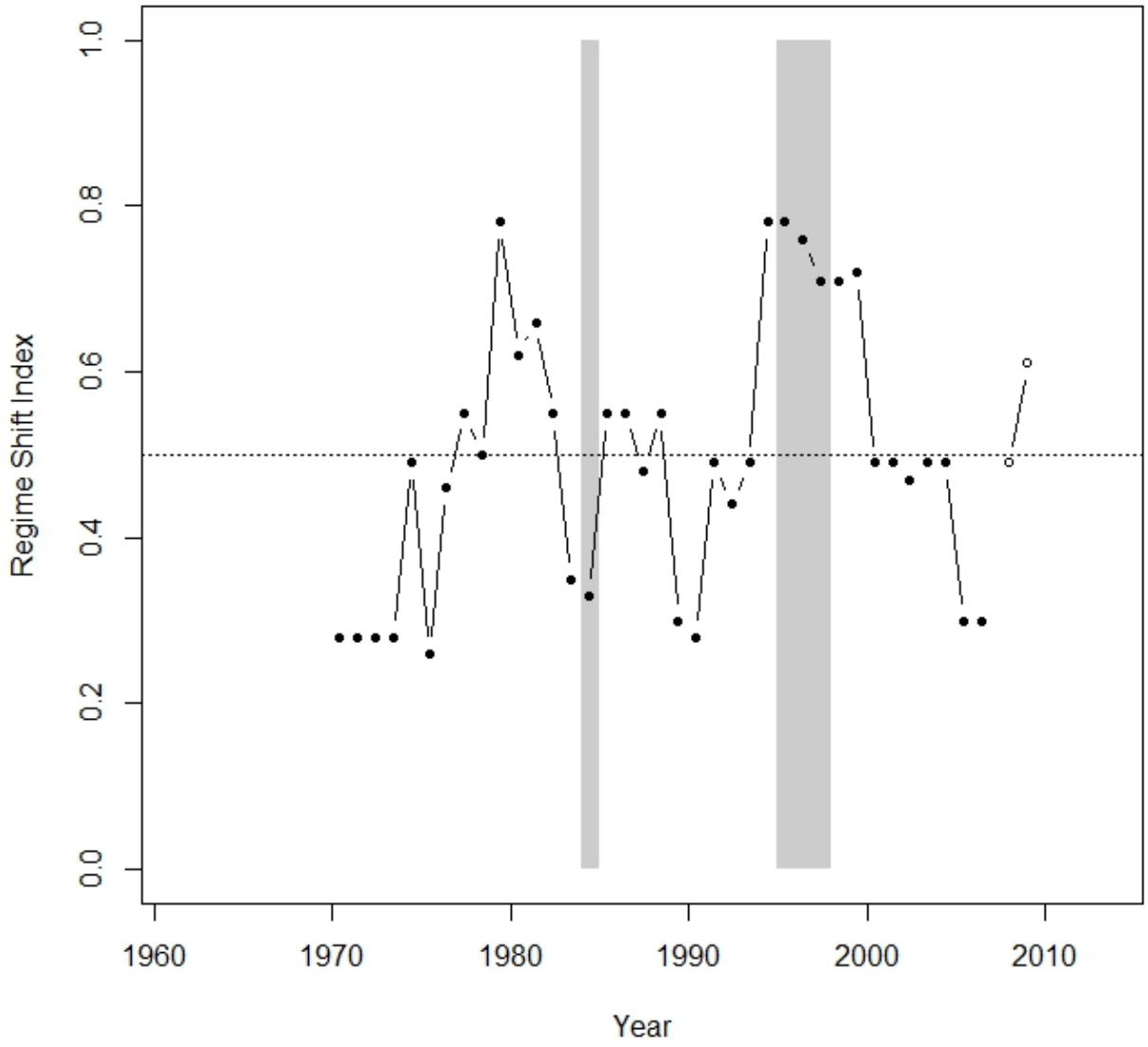


Prairie and Masson, 2013, Progr. In Oceanography

Fisheries and Canada


SST
Wind (Vancouver airport)
NPGO
Probabilistic (Bayesian) Network model
Ecosystem shift index
Estimates probability of an ecosystem shift
Hatchery releases of Chinook
Recreational fishing effort
Human population

Ecosystem (Regime) Shift Index for Strait of Georgia



Dashed line represents probability of ecosystem shift = 50%

Perry and Masson, 2013, Progr. In Oceanography

Can these six leading indicator variables be used as Early Warnings of ecosystem changes (tipping points)?

Potential predictors for significant ecosystem shifts

Table 1. Early warning signals for critical transitions.

		Phenomenon			
	Method/Indicator	**Rising memory**	**Rising variability**	**Flickering**	**Ref.**
metrics	Autocorrelation at-lag-1	x			[23]
	Autoregressive coefficient of AR(1) model	x			[19]
	Return rate (inverse of AR(1) coefficient)	x			[23]
	Detrended fluctuation analysis indicator	x			[7]
	Spectral density	x			[20]
	Spectral ratio (of low to high frequencies)	x			[25]
	Spectral exponent	x			[this paper]
	Standard deviation		x	x	[28]
	Coefficient of variation		x	x	[28]
	Skewness		x	x	[29]
	Kurtosis		x	x	[25]
	Conditional heteroskedasticity		x	x	[32]
	BDS test		x	x	[10]
models	Time-varying AR(p) models	x	x		[38]
	Nonparametric drift-diffusion-jump models	x	x	x	[16]
	Threshold AR(p) models			x	[38]
	Potential analysis (potential wells estimator)			x	[43]

Dakos V, Carpenter SR, Brock WA, Ellison AM, Guttal V, et al. (2012) Methods for Detecting Early Warnings of Critical Transitions in Time Series Illustrated Using Simulated Ecological Data. PLoS ONE 7(7)

Potential predictors for “typical” system behaviours prior to significant shifts

Variance (as standard deviation)

- Expect increasing variance approaching a Tipping Point

Autocorrelation at-lag-1

- increase in the ‘short term memory’ of a system prior to a transition.
- increasing autocorrelation at-lag-1 indicates the state of the system has become increasingly similar between consecutive observations

Conditional heteroskedasticity

- variance at one time has a positive relationship with variance at one or more previous times
- i.e., periods of high variability will follow periods of high variability and periods of low variability will follow periods of low variability

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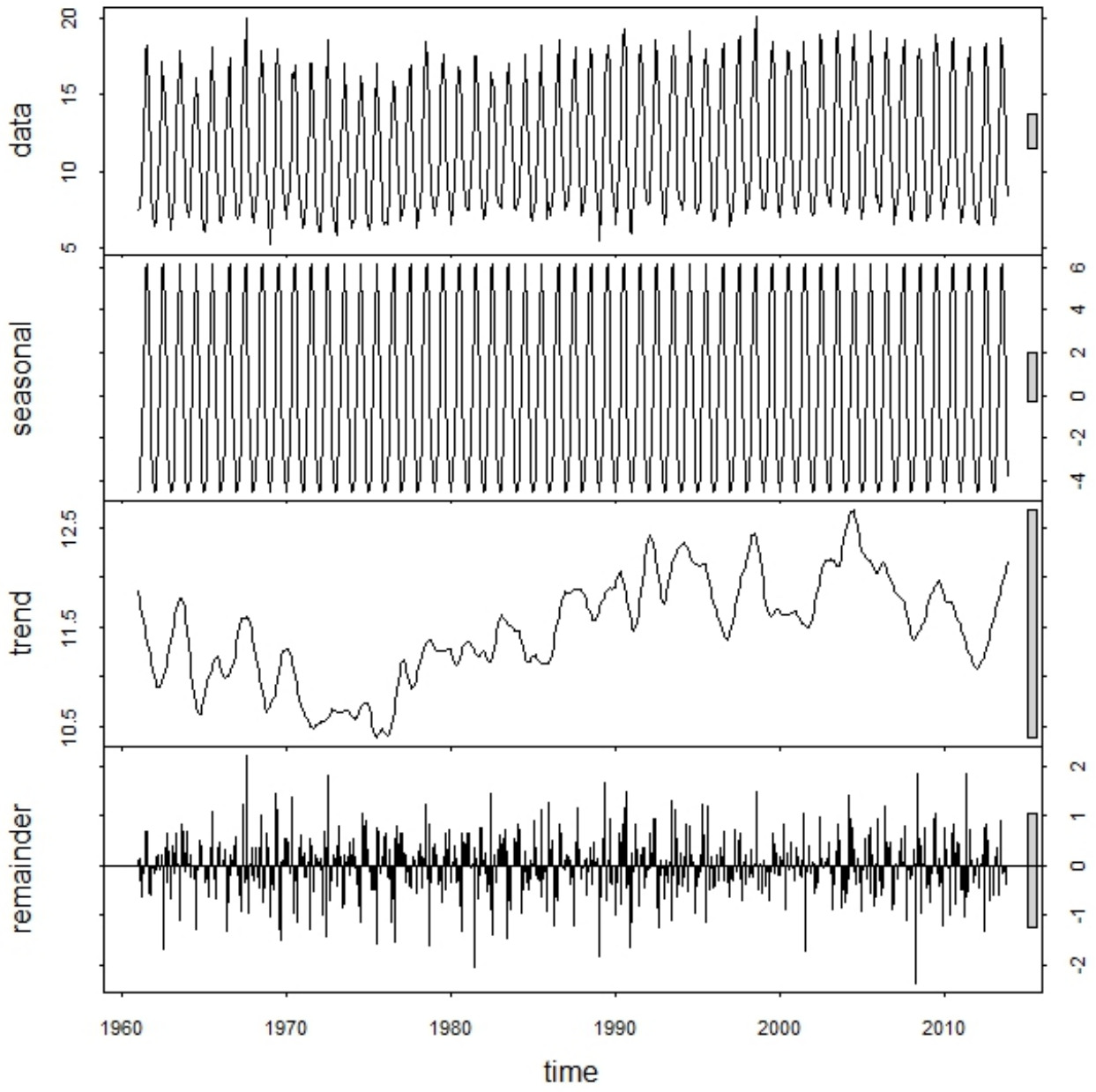
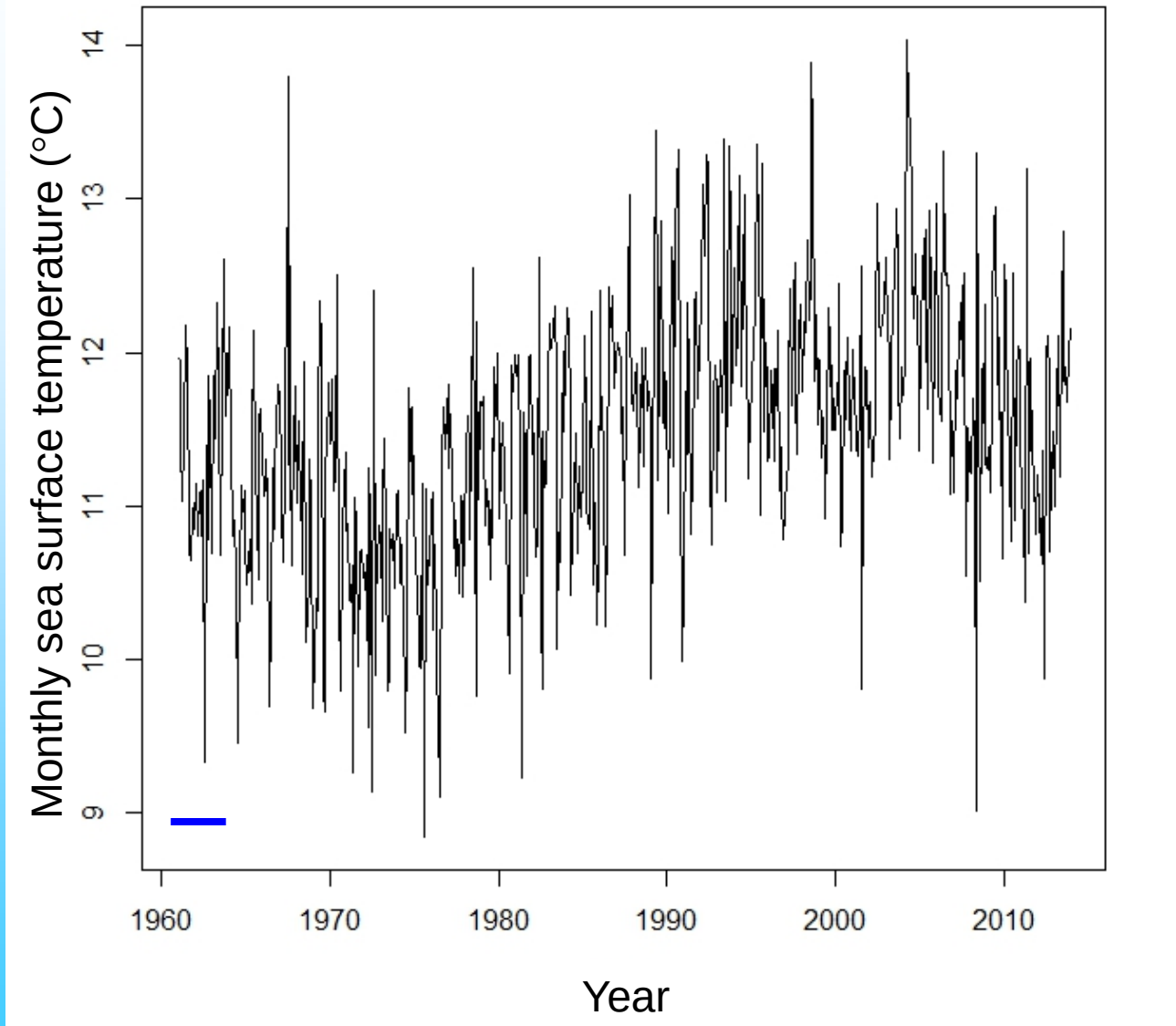
Strait of Georgia, Canada

Entrance Island



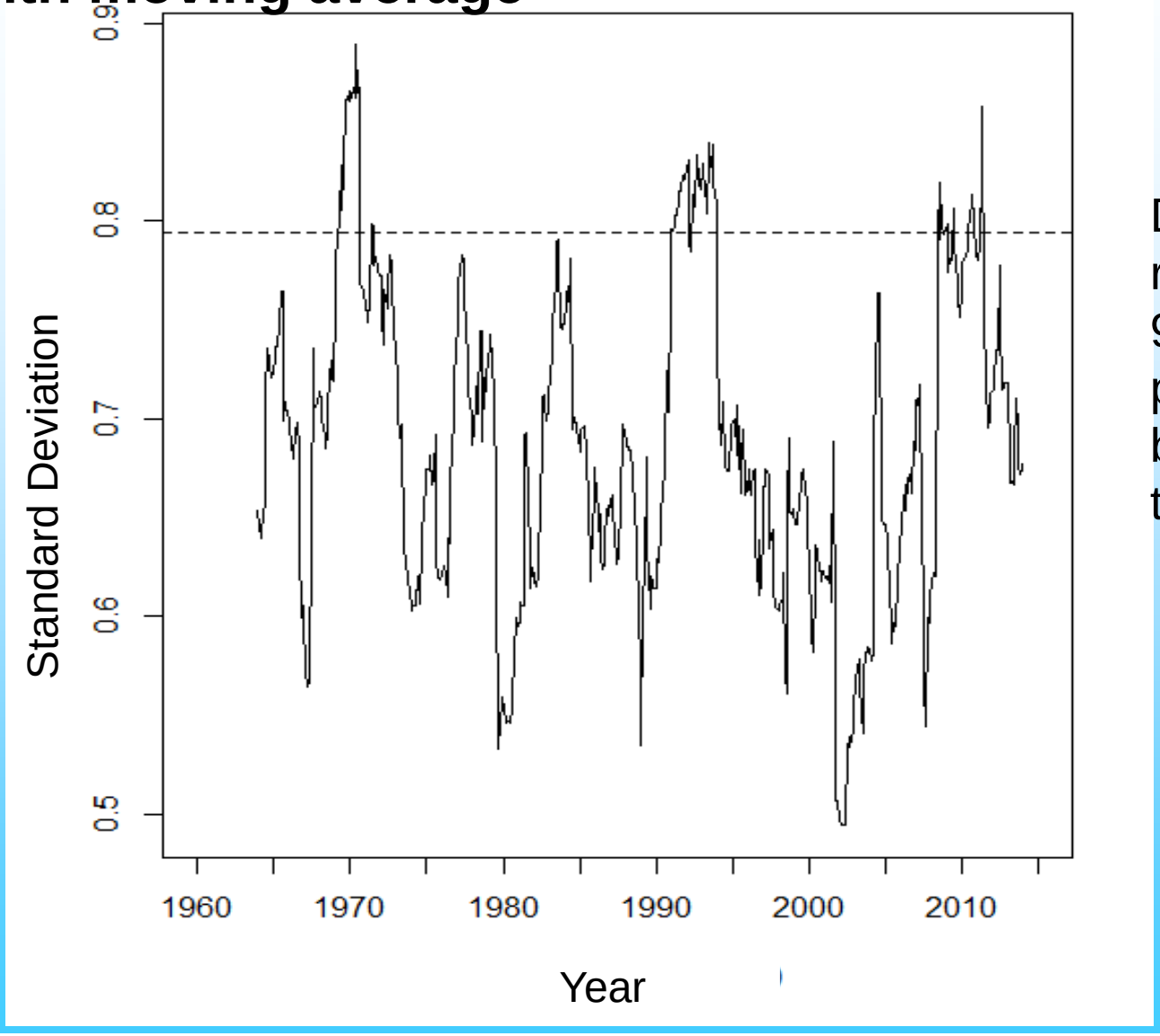
Decomposition of monthly SST time series into Seasonal, Trend, and Remainder components

Entrance Island – SST: Trend + Remainder



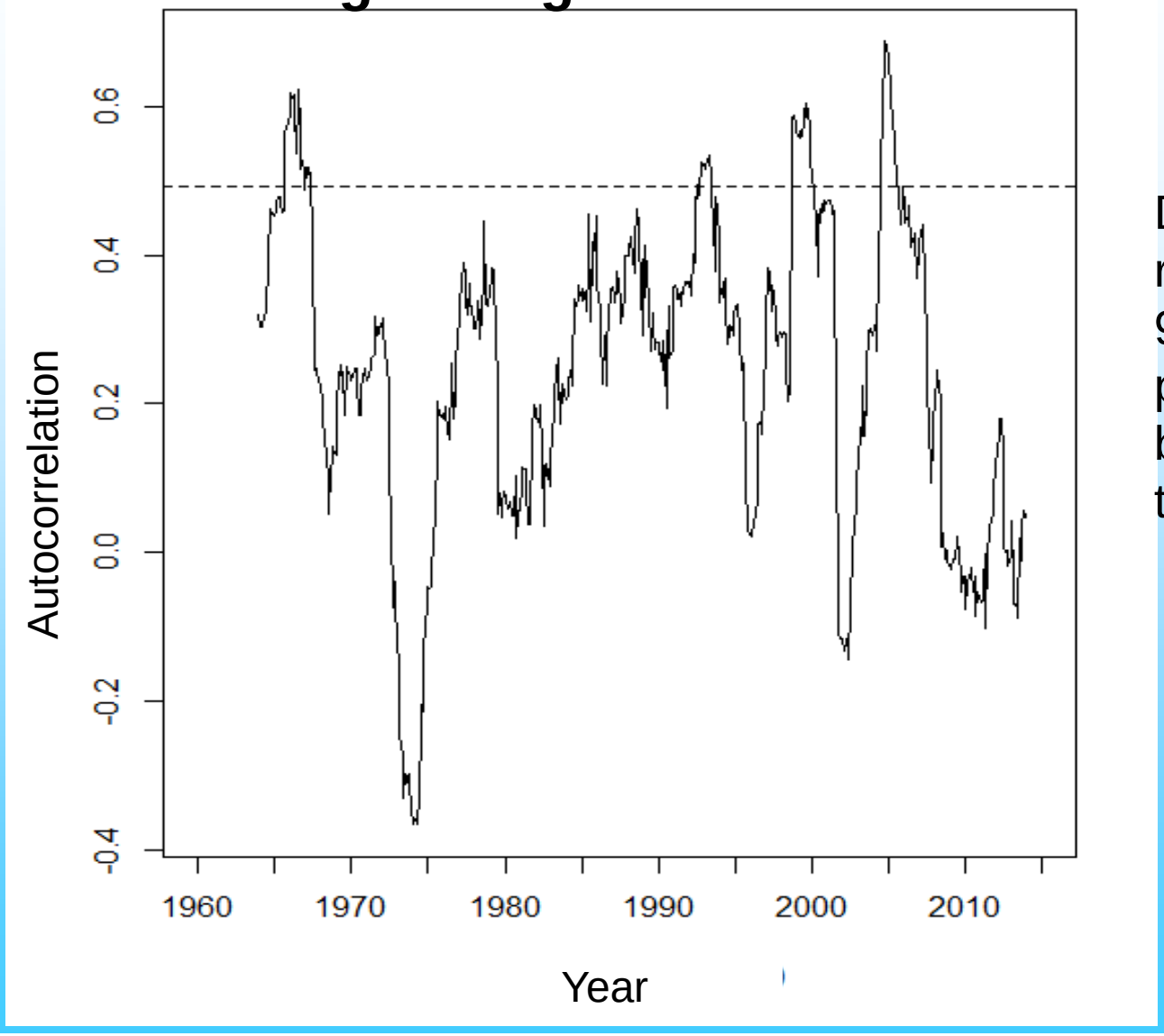
Blue line represents 37months

Entrance Island – SST: Standard Deviation within 37 month moving average



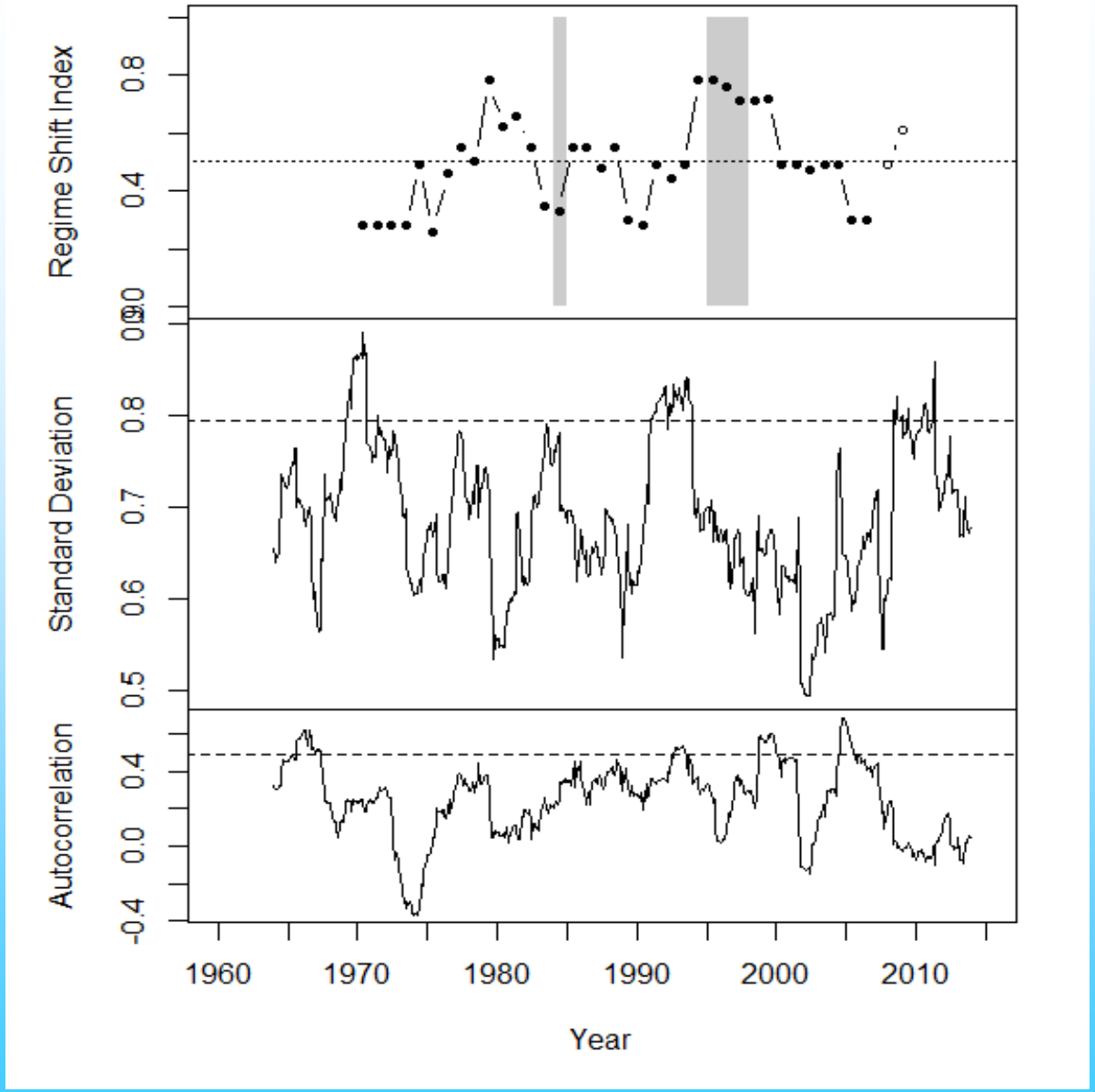
Dashed line represents 90th percentile of bootstrapped time series

Entrance Island – SST: Autocorrelation at lag 1 within 37 month moving average



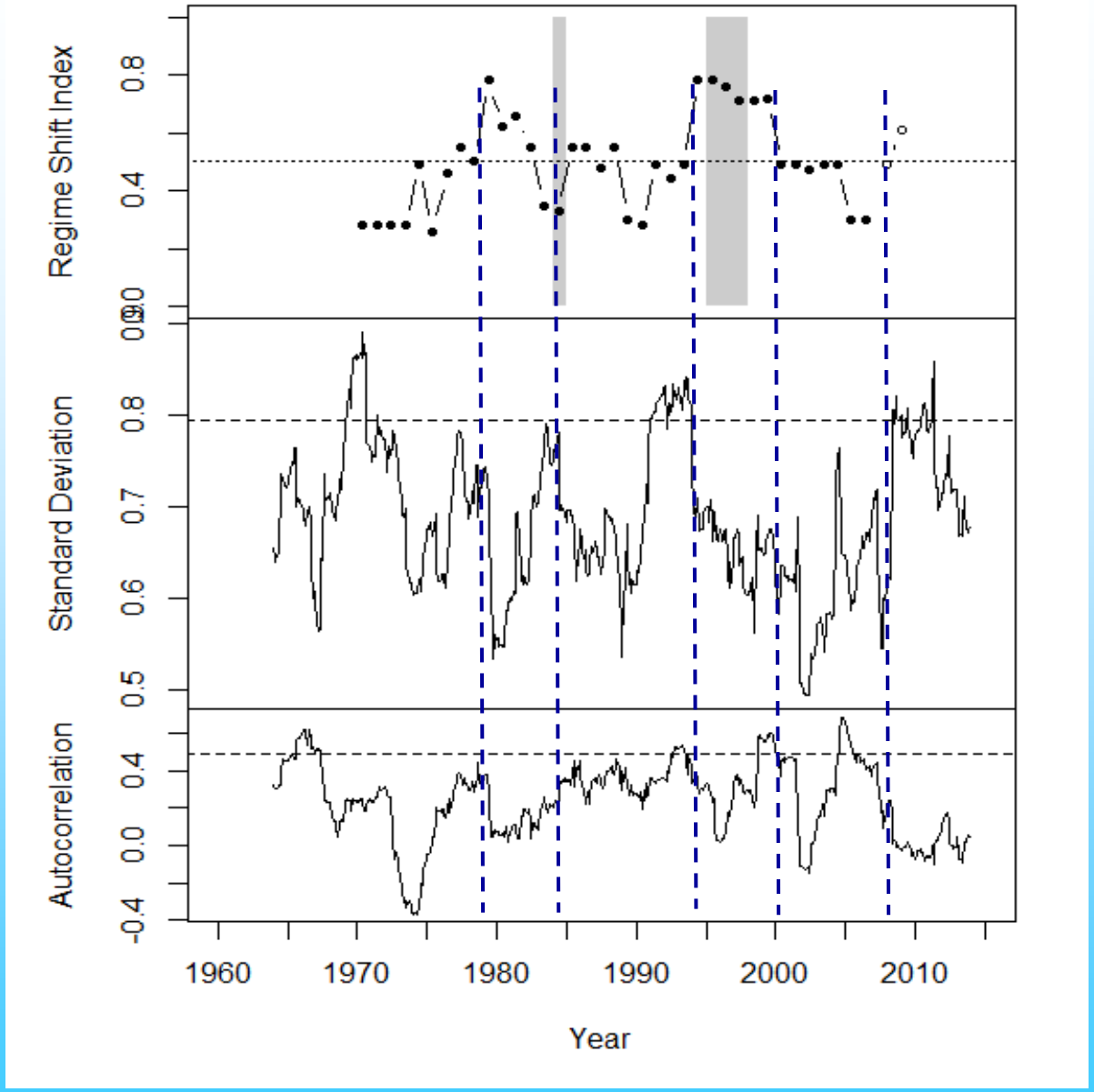
Dashed line represents 90th percentile of bootstrapped time series

Entrance Island – SST (37 month moving window)



Comparison of Standard Deviation and Auto-correlation (37 month moving window) with Regime shift Index – are they useful Early Warning Signals?

Entrance Island – SST (37 month moving window)



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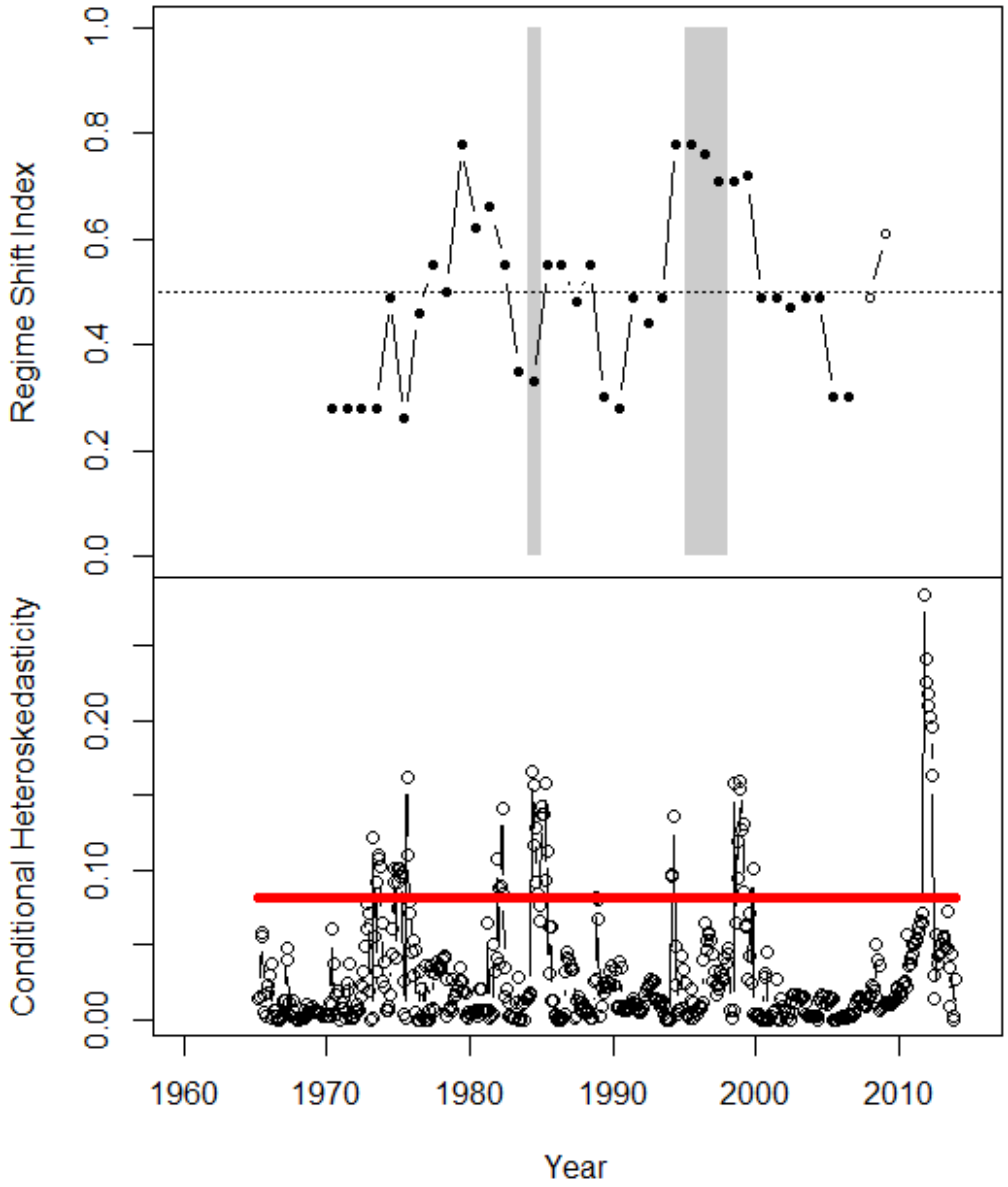
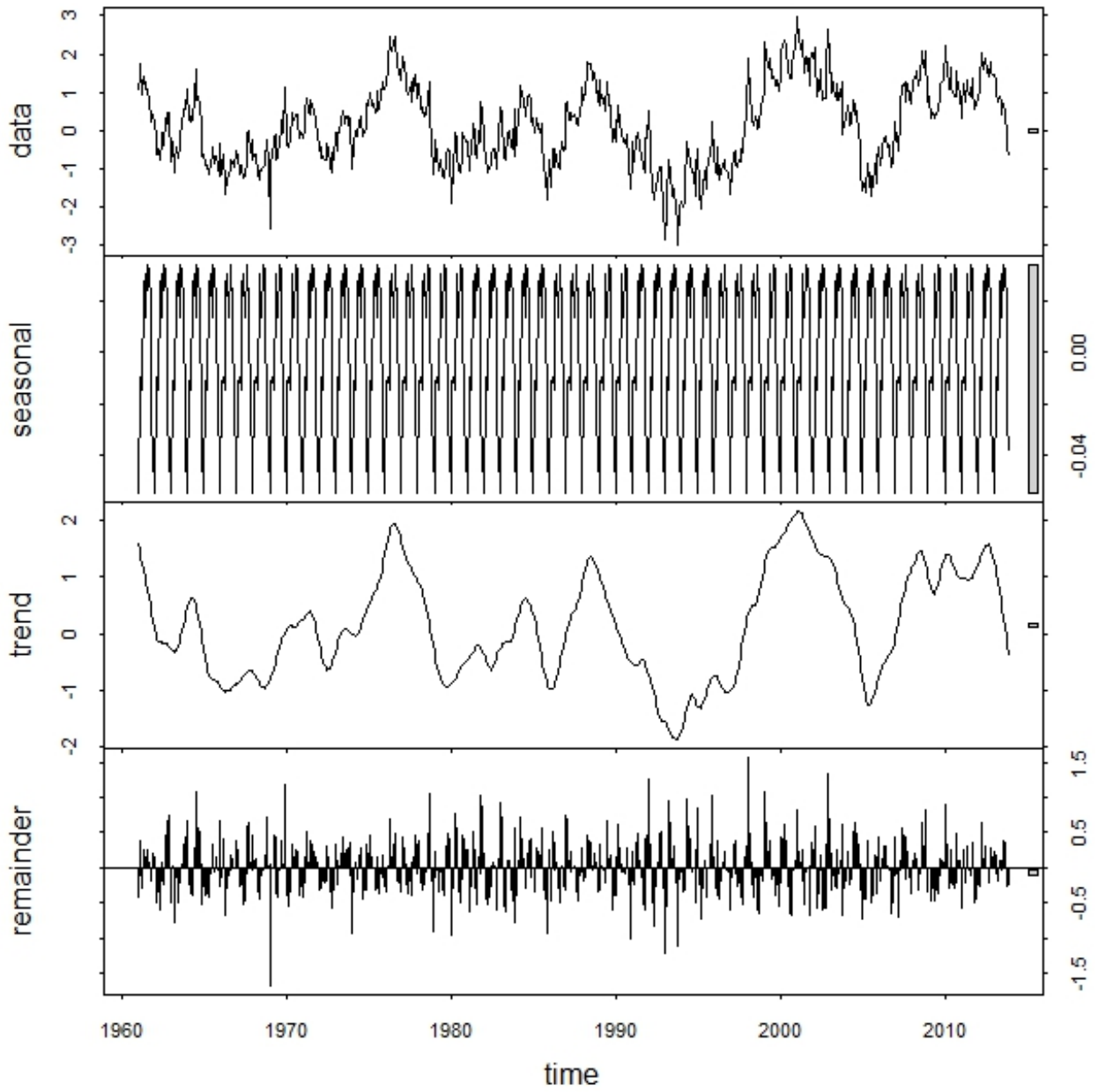
Entrance Island – SST



Regime shift index

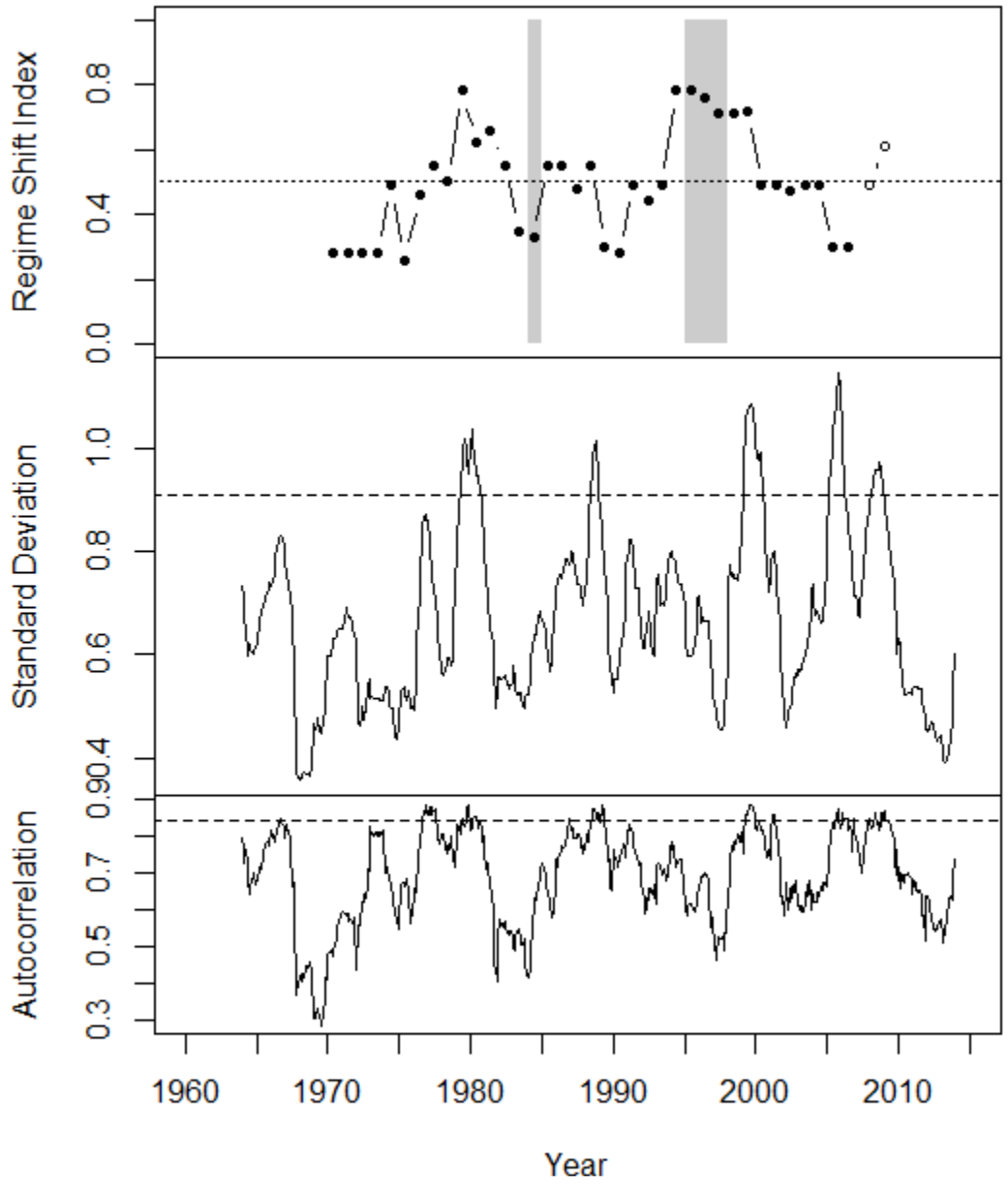
Conditional hetero-skedasticity within moving window of 37 months

North Pacific Gyre Oscillation



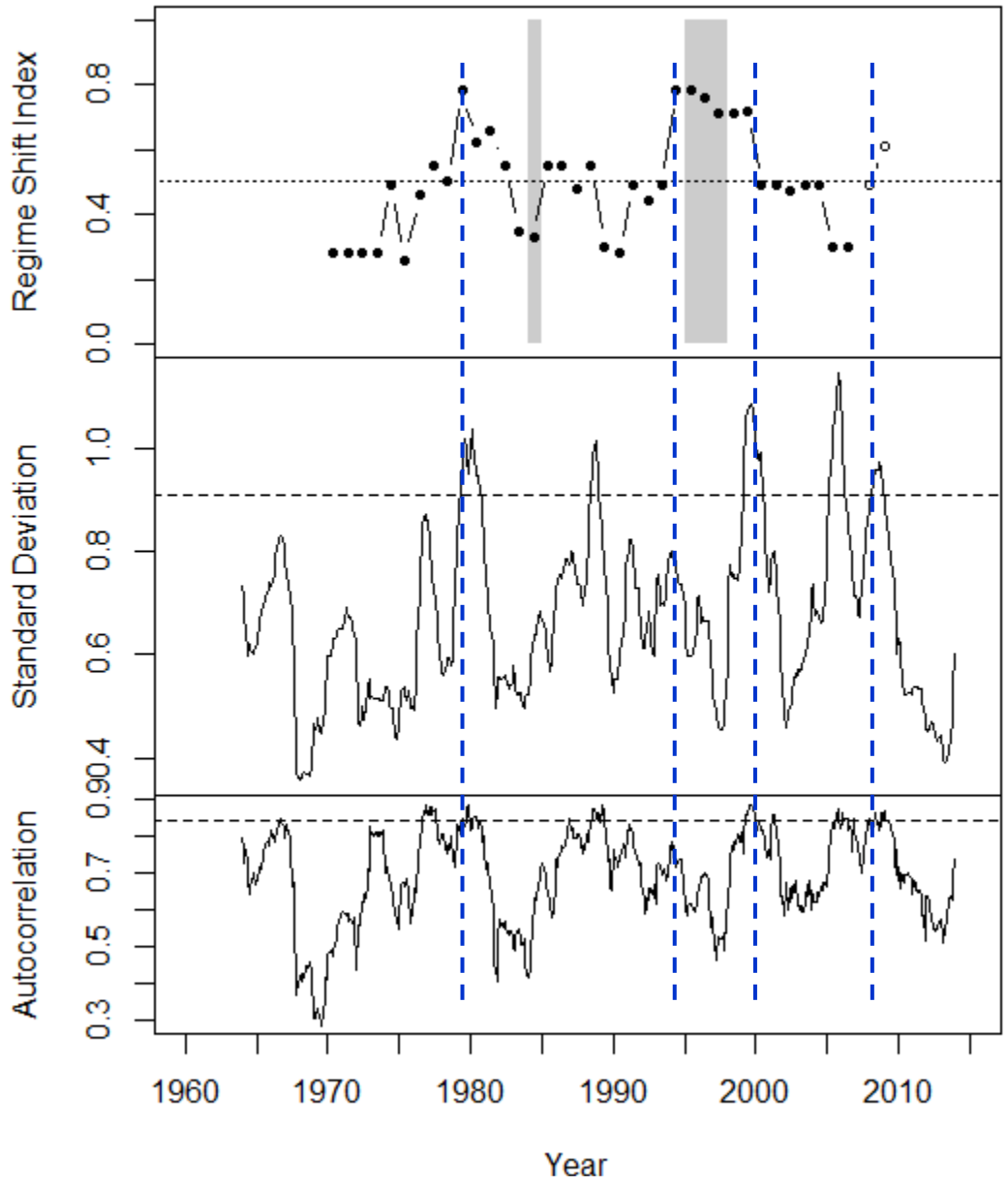
Decomposition of monthly NPGO time series into Seasonal, Trend, and Remainder components

North Pacific Gyre Oscilation



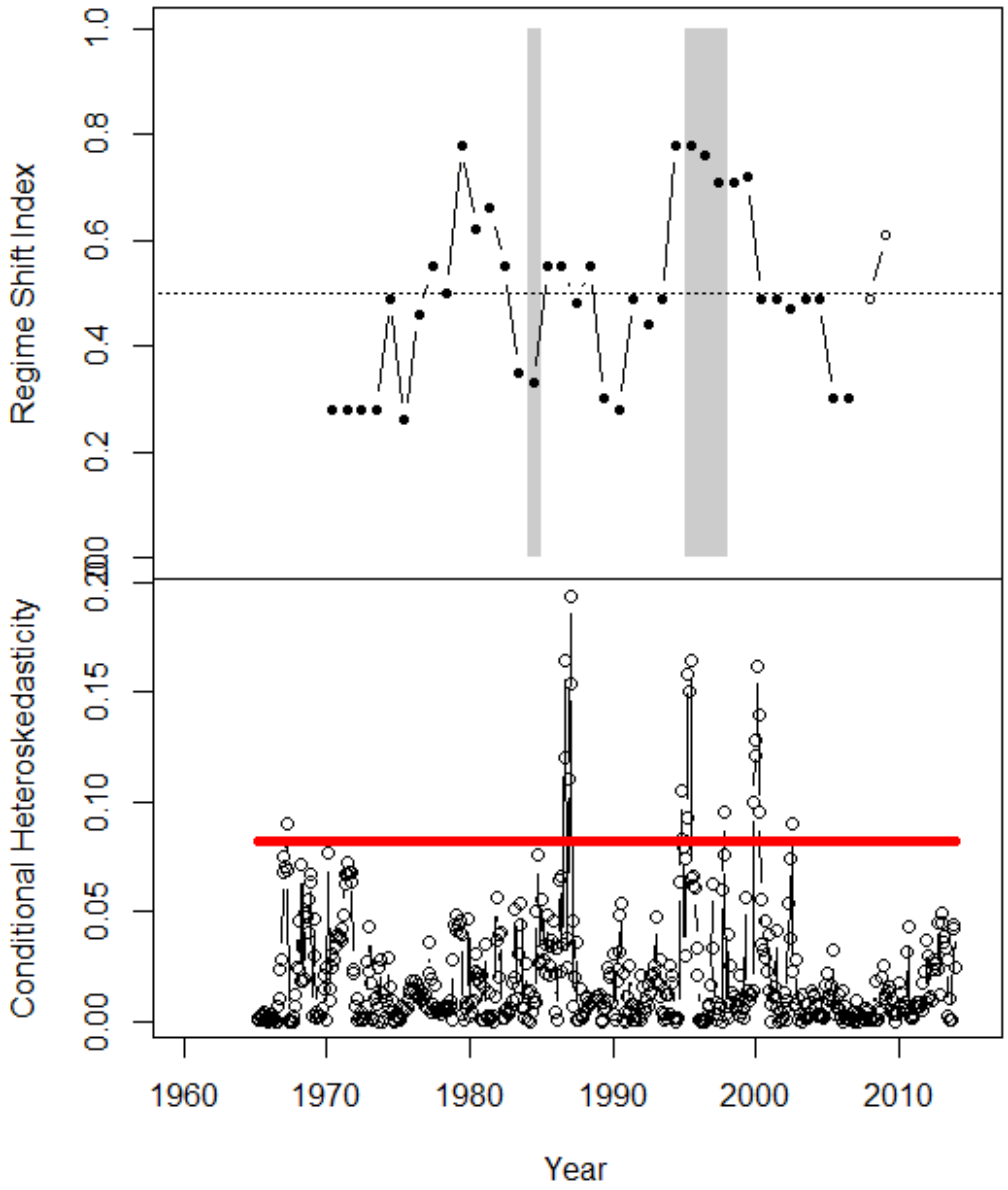
Comparison of Standard Deviation and Auto-correlation (37 month moving window) with Regime shift Index – are they useful Early Warning Signals?

North Pacific Gyre Oscilation



Comparison of Standard Deviation and Auto-correlation (37 month moving window) with Regime shift Index – are they useful Early Warning Signals?

NPGO



Regime shift index

Conditional hetero-skedasticity within moving window of 37 months

Conclusions

- Lots of potential ‘early warning’ indicators that can be run
  - – some even have conceptual basis (e.g. see Early Warnings Toolbox and related R package)
  - – some early warning indices appear promising (e.g. SD, Cond.Hetero.)
- But ‘real world’ is more messy than simulated data
  - – likely that several indices will be necessary, perhaps using several variables
  - – consider combining using a probability approach (e.g. Bayesian network)
- Important to have some idea of what/when the target “Shift” or Tipping Point is that is being ‘predicted’
- Choice of time period (e.g. for moving average calculations): need to be cautious of signal-to-noise issues
- Need to examine lower trophic level biological variables, as these should have faster response times than higher trophic levels and may integrate variability among physical conditions