The Forcing of the Pacific Decadal Oscillation

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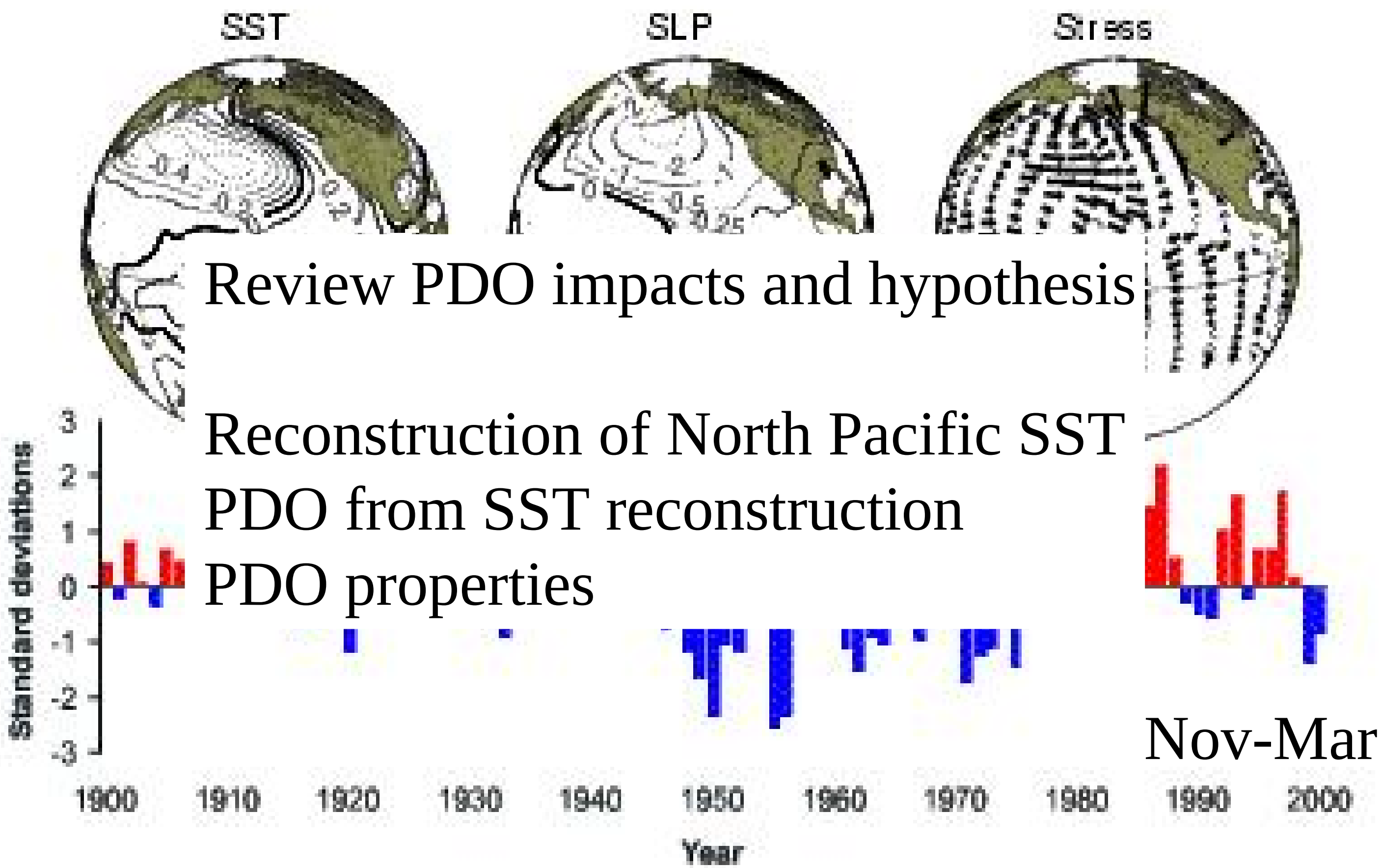


Review PDO impacts and hypothesis

Reconstruction of North Pacific SST

PDO from SST reconstruction

PDO properties

Mantua and Hare, JO, 2002

Impact on ocean ecosystem

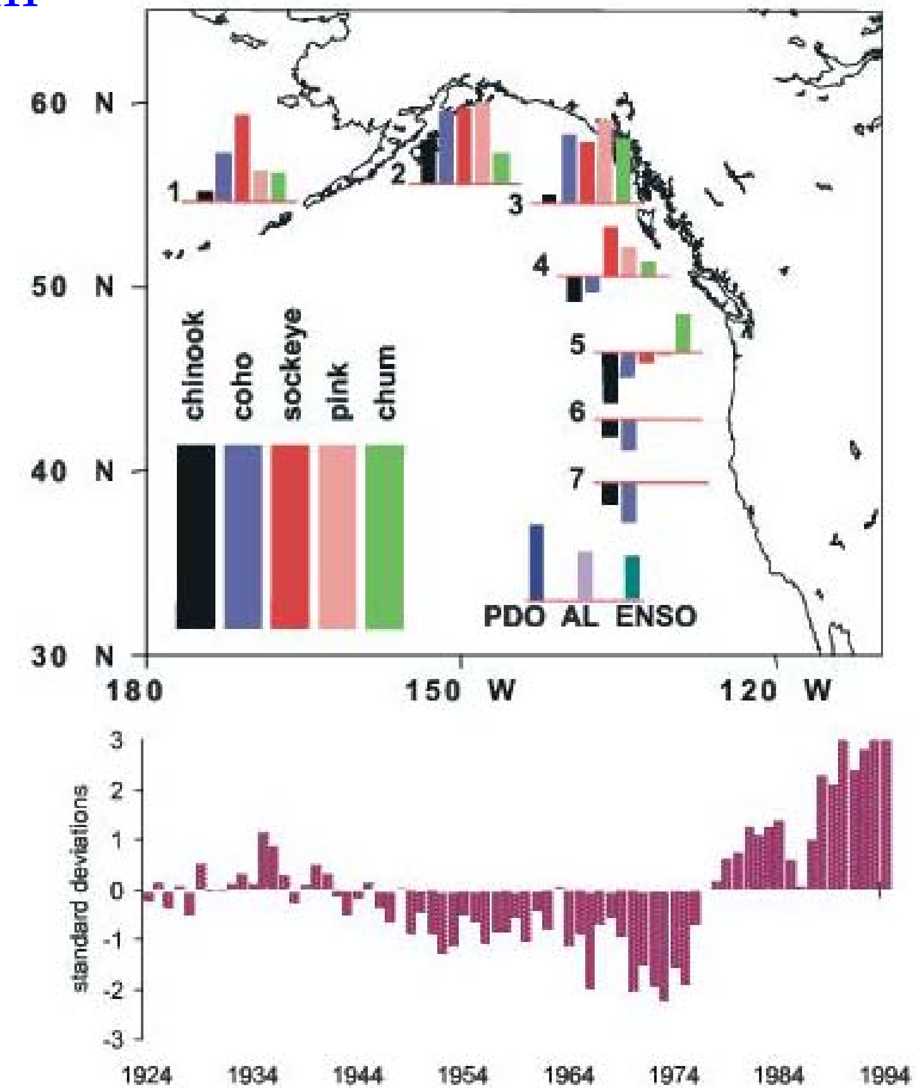
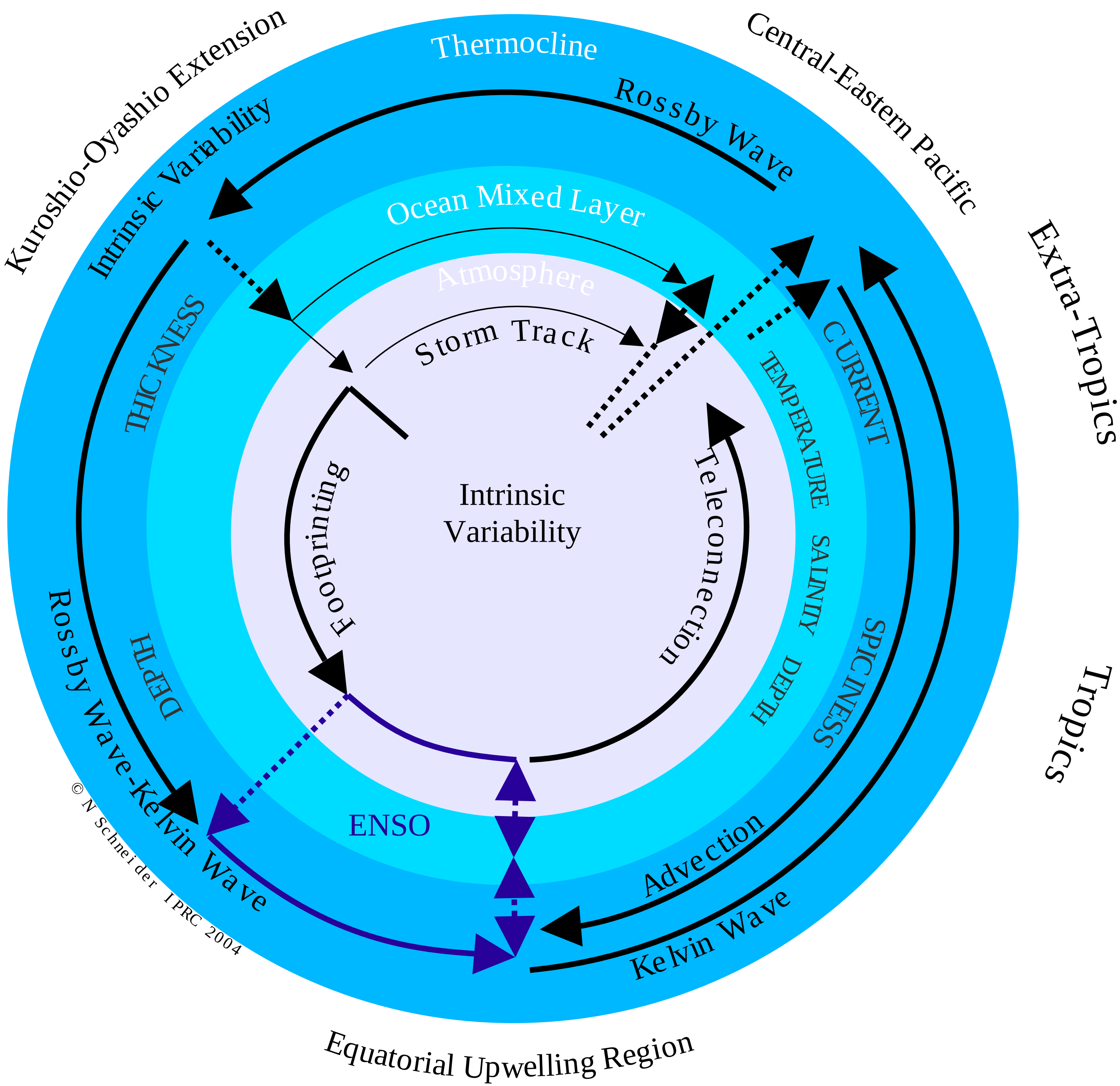


Figure 4. A graphical depiction of the "Inverse Production Regimes" of Hare et al. (1999). The bars represent loadings from a principal component analysis (PCA) of 30 salmon time series for the period 1925-1997. Regional definitions are as follows: 1 – Western Alaska, 2 – Central Alaska, 3 – Southeast Alaska, 4 – British Columbia, 5 – Washington, 6 – Oregon, 7 – California. Three climate indices were included in the PCA: Pacific Decadal Oscillation (PDO), Aleutian Low Pressure Index (AL) and the El Niño-Southern Oscillation (ENSO). The longest bar, Central Alaska pink salmon, represents a correlation coefficient with a value of 0.855, and represents the correlation between that time series and the illustrated temporal component (score) from the PCA.

Mantua and Hare, JO, 2002

Hypotheses for Pacific decadal variability


Kuroshio-Oyashio Extension
Central-Eastern Pacific
Extra-Tropics
Tropics
Equatorial Upwelling Region
Thermocline
Rossby Wave
Intrinsic Variability
Ocean Mixed Layer
Atmosphere
Storm Track
THICKNESS
CURRENT
TEMPERATURE
SALINITY
DEPTH
SPICINESS
Intrinsic
Variability
Footprinting
Teleconnection
DEPTH
Rossby Wave-Kelvin Wave
ENSO
Advection
Kelvin Wave
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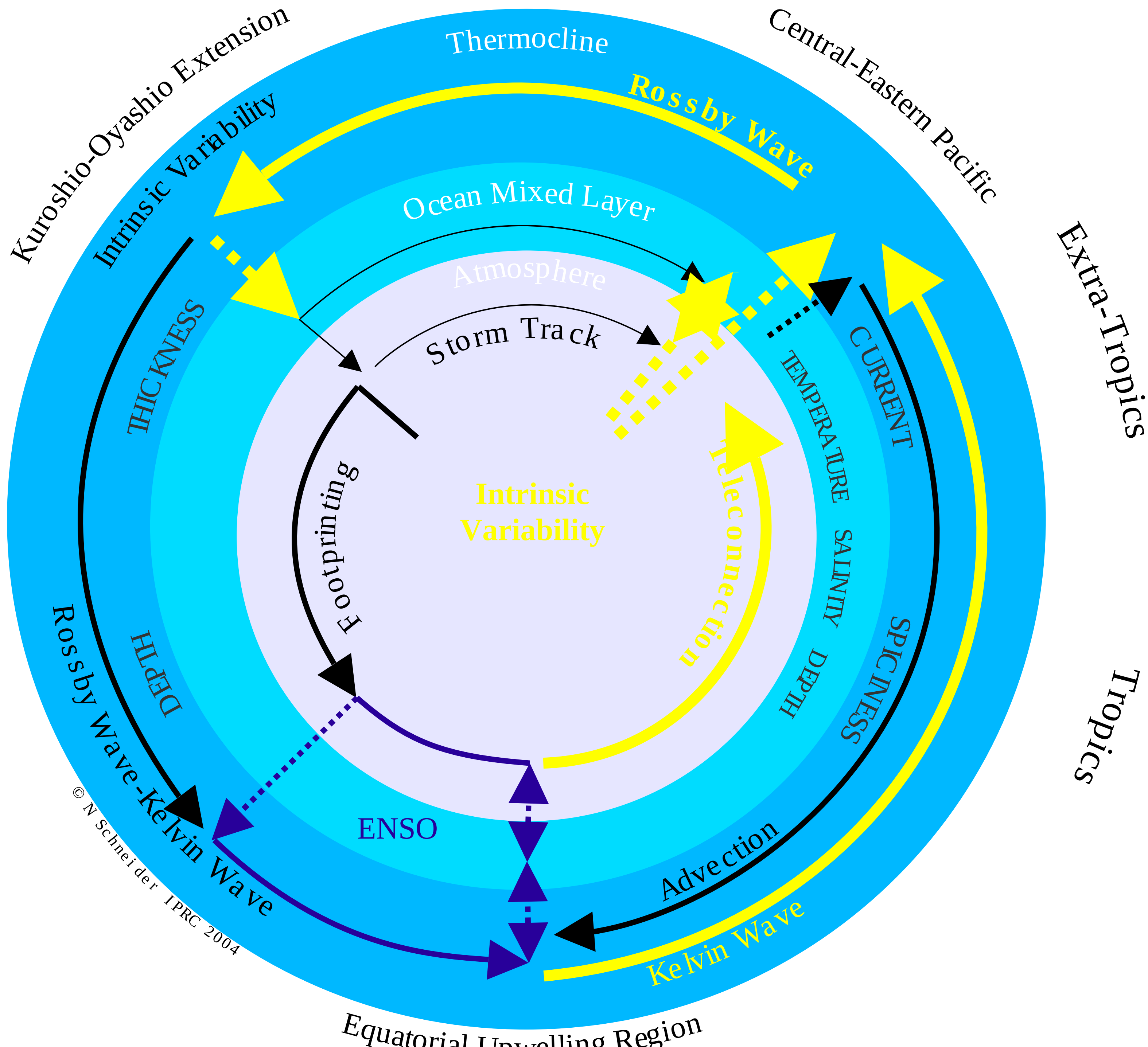
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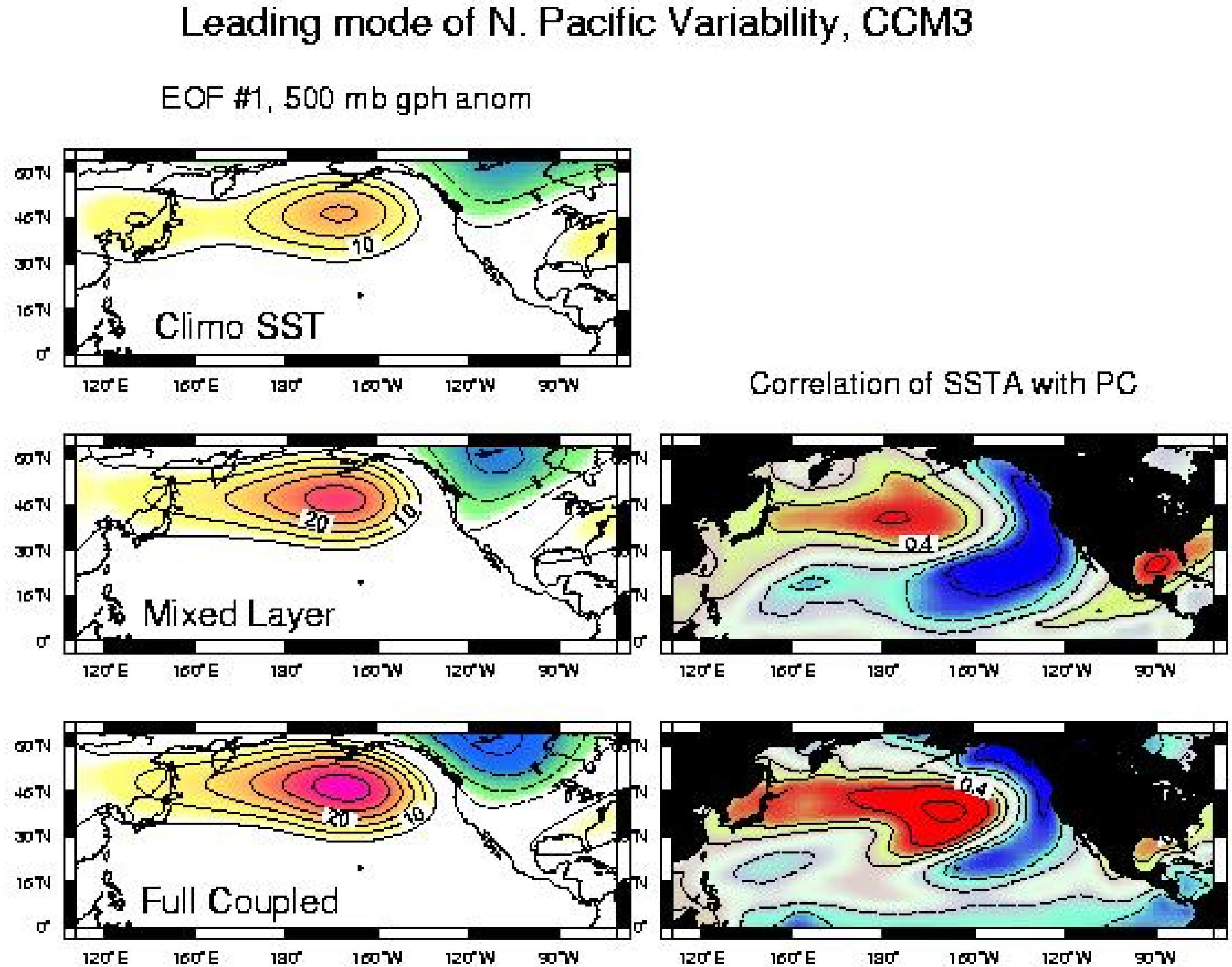
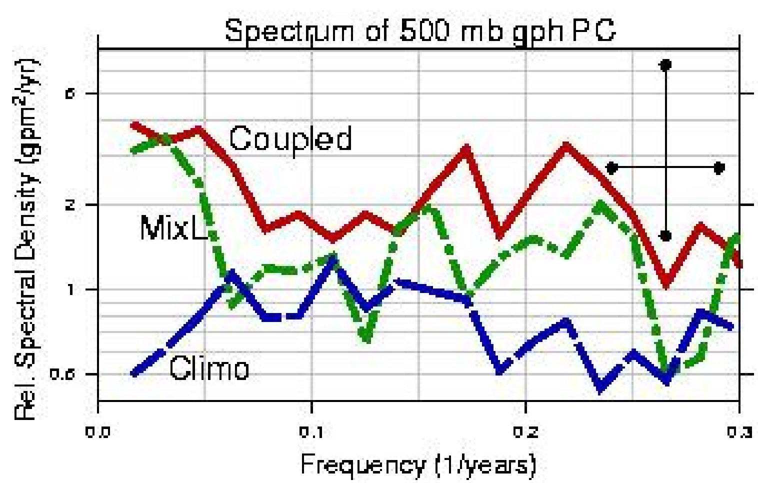
Atmosphere only

Atmosphere +
Mixed Layer

Atmosphere +
Ocean GCMs





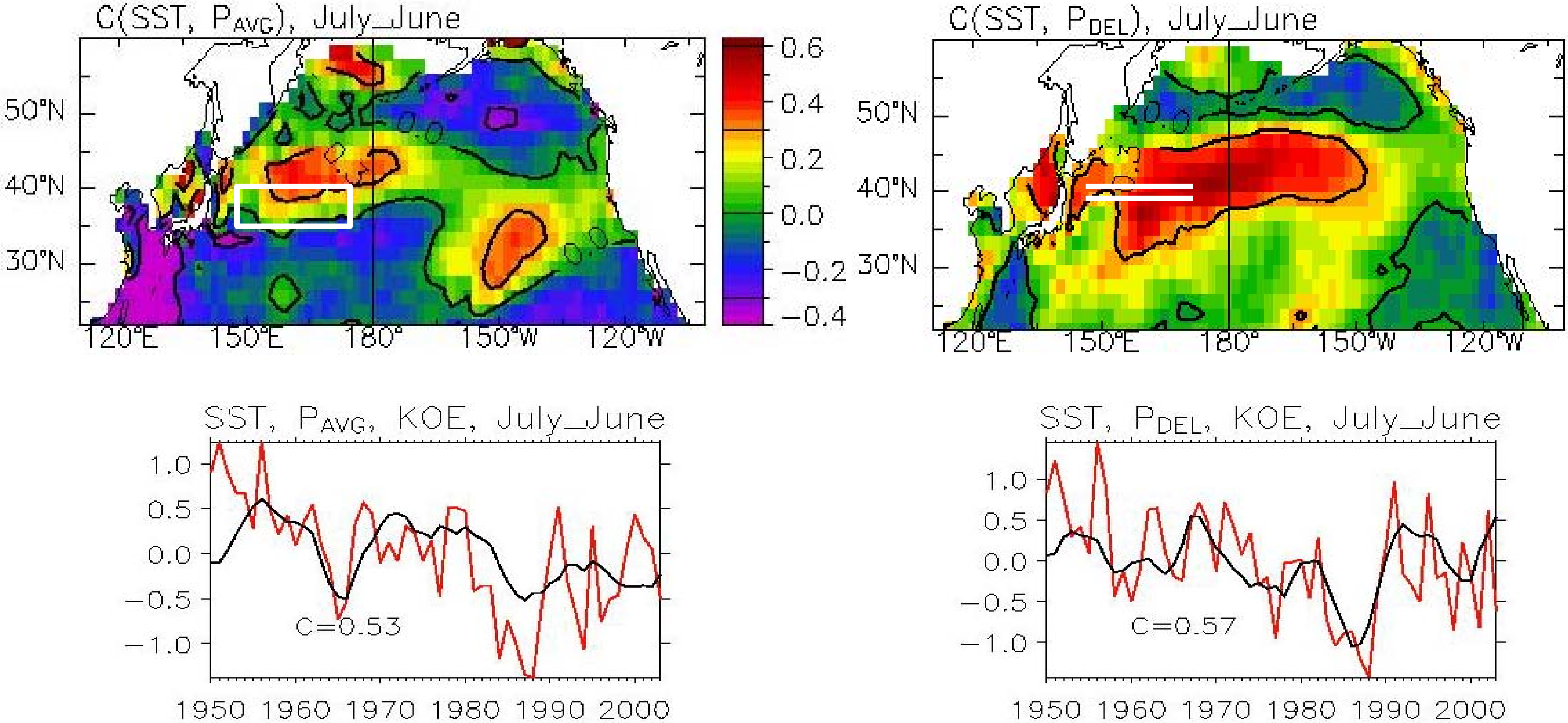
Pierce 2001

Rossby Waves in the Kuroshio Extension

$$\partial_t P + c\partial_x P = F_{EK}(x,t)$$

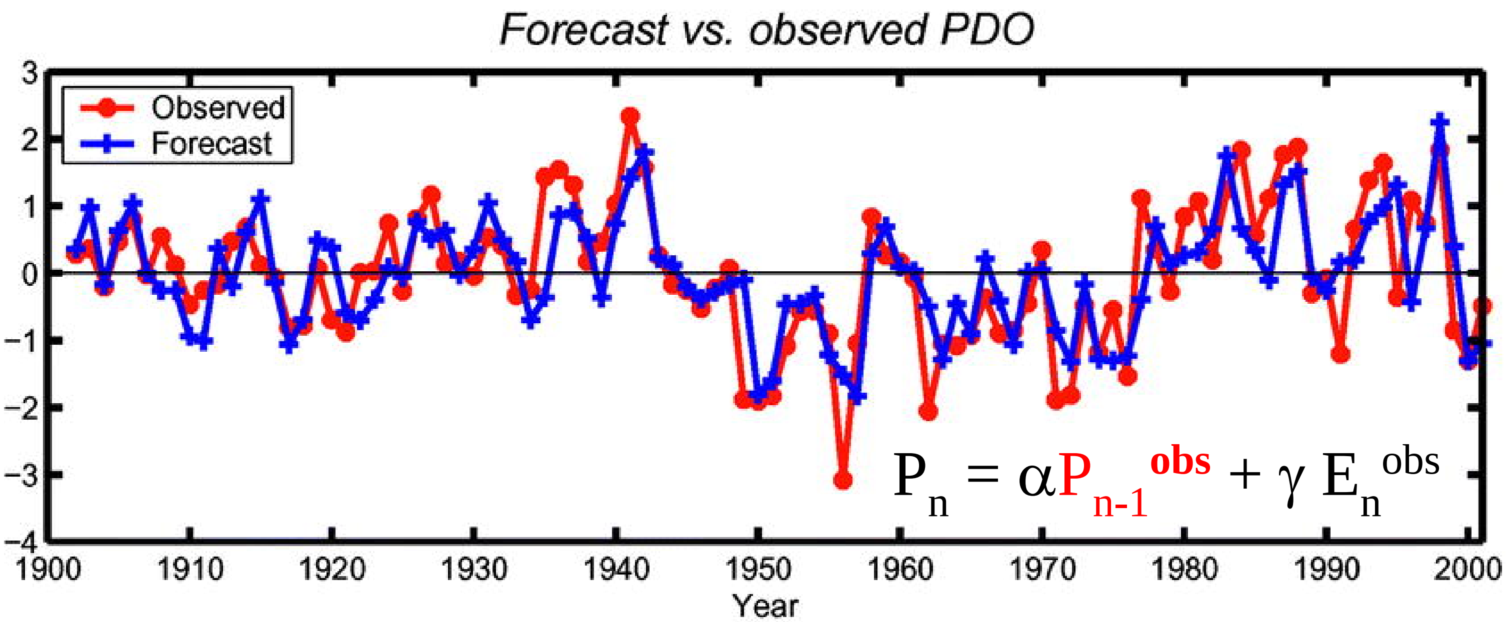
$SST \sim P$

$SST \sim \partial_y P$ Qiu (2003)



Telconnections from the Tropics

July-June averages



$$P_n = \alpha P_{n-1}^{\mathbf{obs}} + \gamma E_n^{obs}$$

Correlation: 0.53 0.57

0.74

Newman et al. 2003

To understand the Pacific Decadal Oscillation

we need to understand the processes affecting the leading empirical orthogonal function of SST in the Pacific north of 20N

Approach

Reconstruct SST in the North Pacific from indices of

- intrinsic variability of the Aleutian Low
- El Nino
- adjustment of the ocean circulation in the Kuroshio/Oyashio

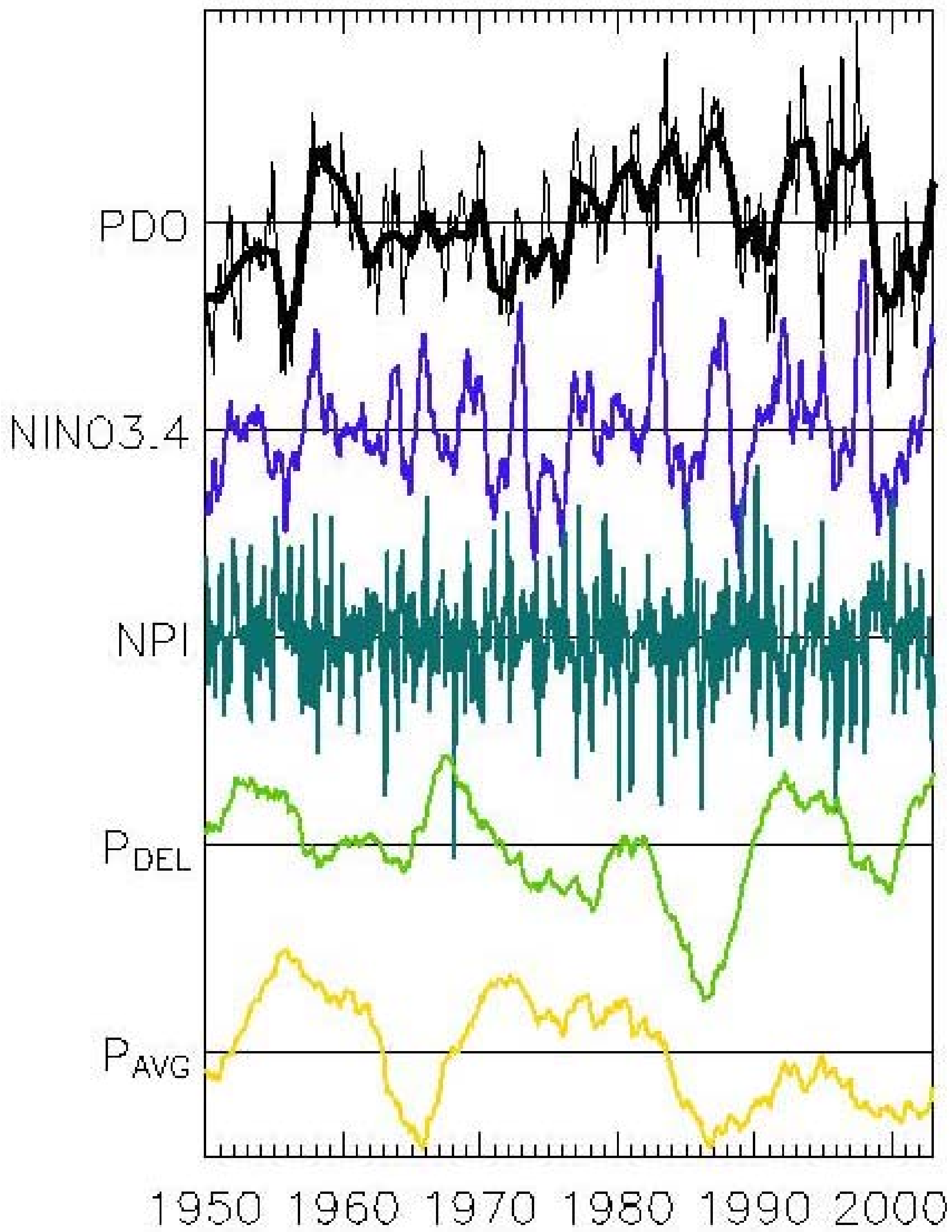
compare leading empirical orthogonal functions of SST reconstruction and observations

Data

NCEP/NCAR reanalysis sea surface temperature, sea level pressure and wind stress

focus on July to June averages

The Hypothesis



SST and PDO reconstruction

Reconstruct SST from AR-1 process and forcing indices, evaluate leading EOF of reconstruction of SST, compare with observations.

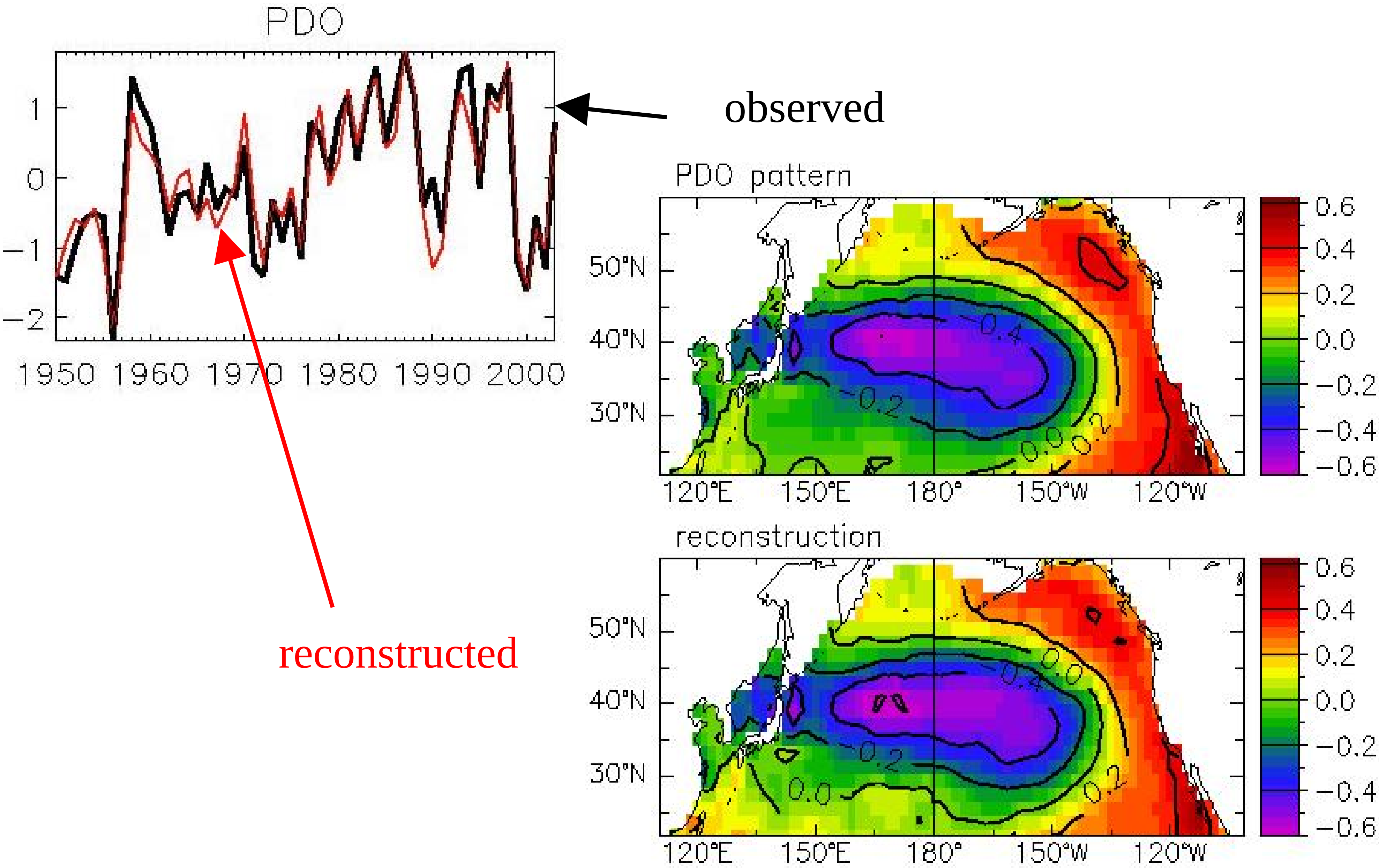
$$\partial_t T(\mathbf{x},t) = -\tilde{\alpha}(\mathbf{x})T(\mathbf{x},t) \;+\; \gamma_i(\mathbf{x})\tilde{F}_i(t)$$

Integrate over one year, and form July to June averages

$$\begin{aligned}
\overline{T(\mathbf{x},t)} &= \gamma_i(\mathbf{x})\overline{\int_{t-\delta}^{t} dt'\; \tilde{F}_i(t')e^{-\tilde{\alpha}(\mathbf{x})\,(t-t')}} + e^{-\tilde{\alpha}(\mathbf{x})\delta}\;\overline{T(\mathbf{x},t-\delta)} \\
&=: \gamma_i(\mathbf{x}) \qquad\qquad F_i(\mathbf{x},t) \qquad\qquad\quad + \;\alpha(\mathbf{x}) \quad \overline{T(\mathbf{x},t-\delta)}
\end{aligned}$$

Orthogonalize forcing time series

PDO from observations and SST hindcast

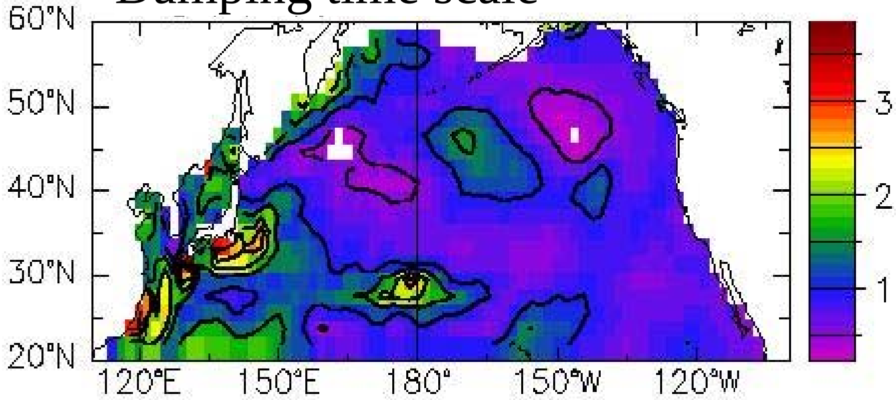


Reconstruction of SST from NPI, NINO3.4, KOE indices

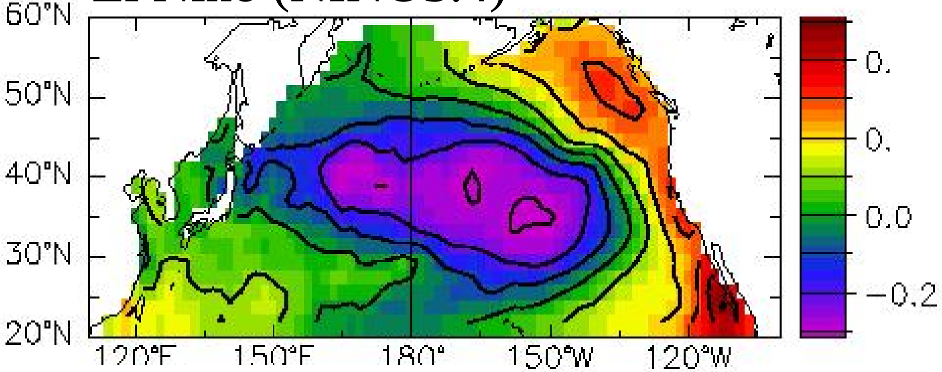
$$T_n = \alpha T_{n-1} + \gamma_i F_{i,n}$$

July to June averages

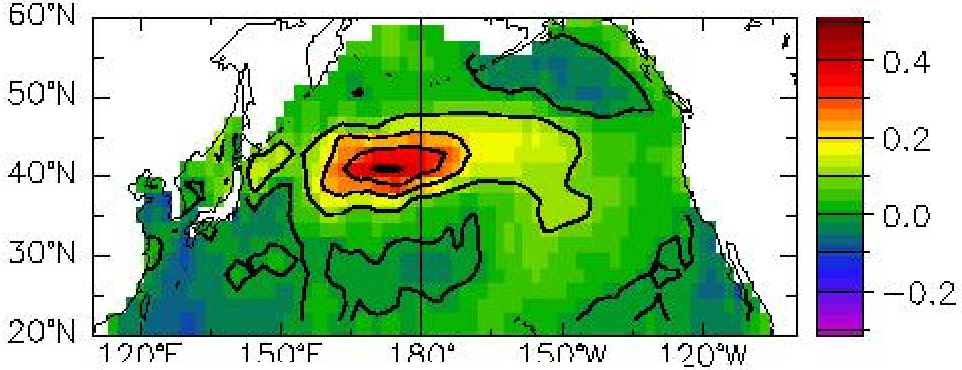
Damping time scale



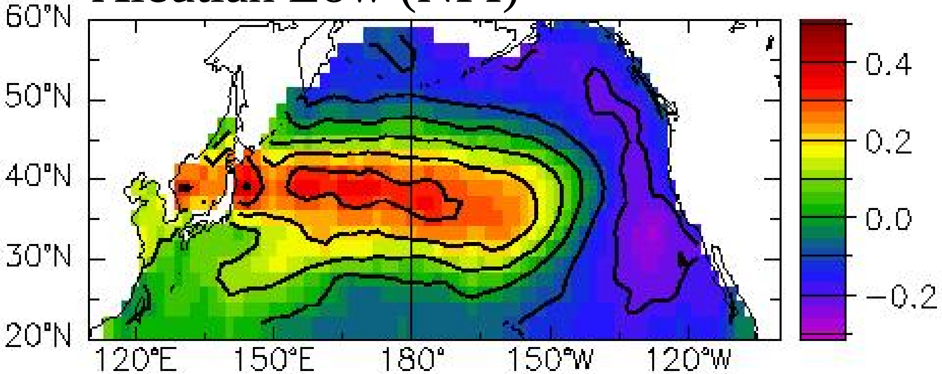
El Nino (NINO3.4)



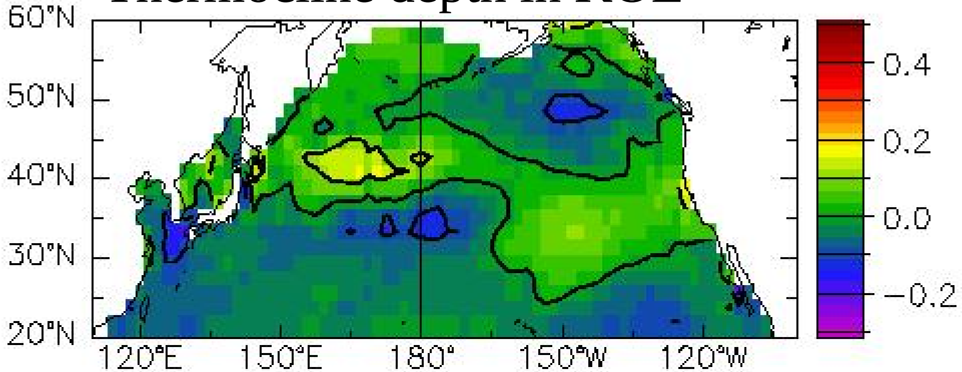
Zonal advection in KOE



Aleutian Low (NPI)



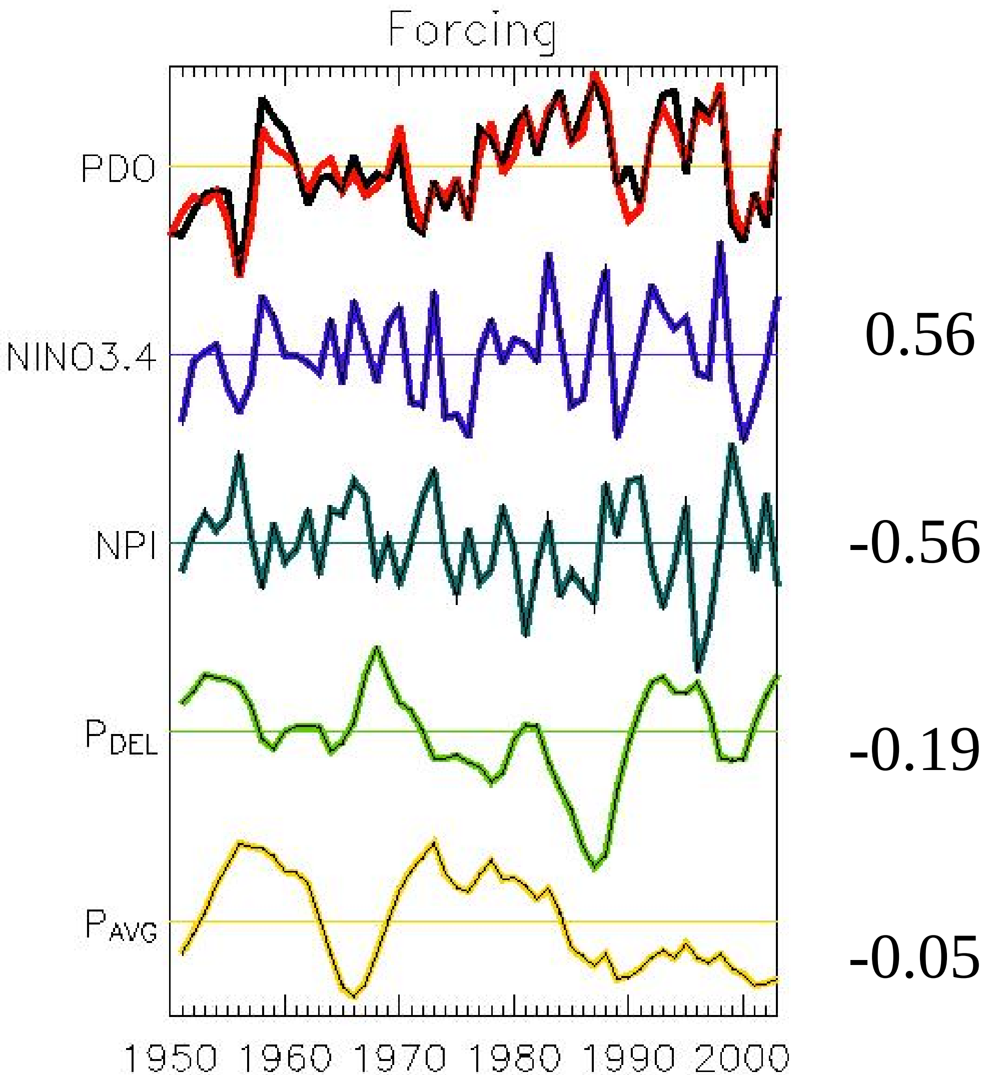
Thermocline depth in KOE



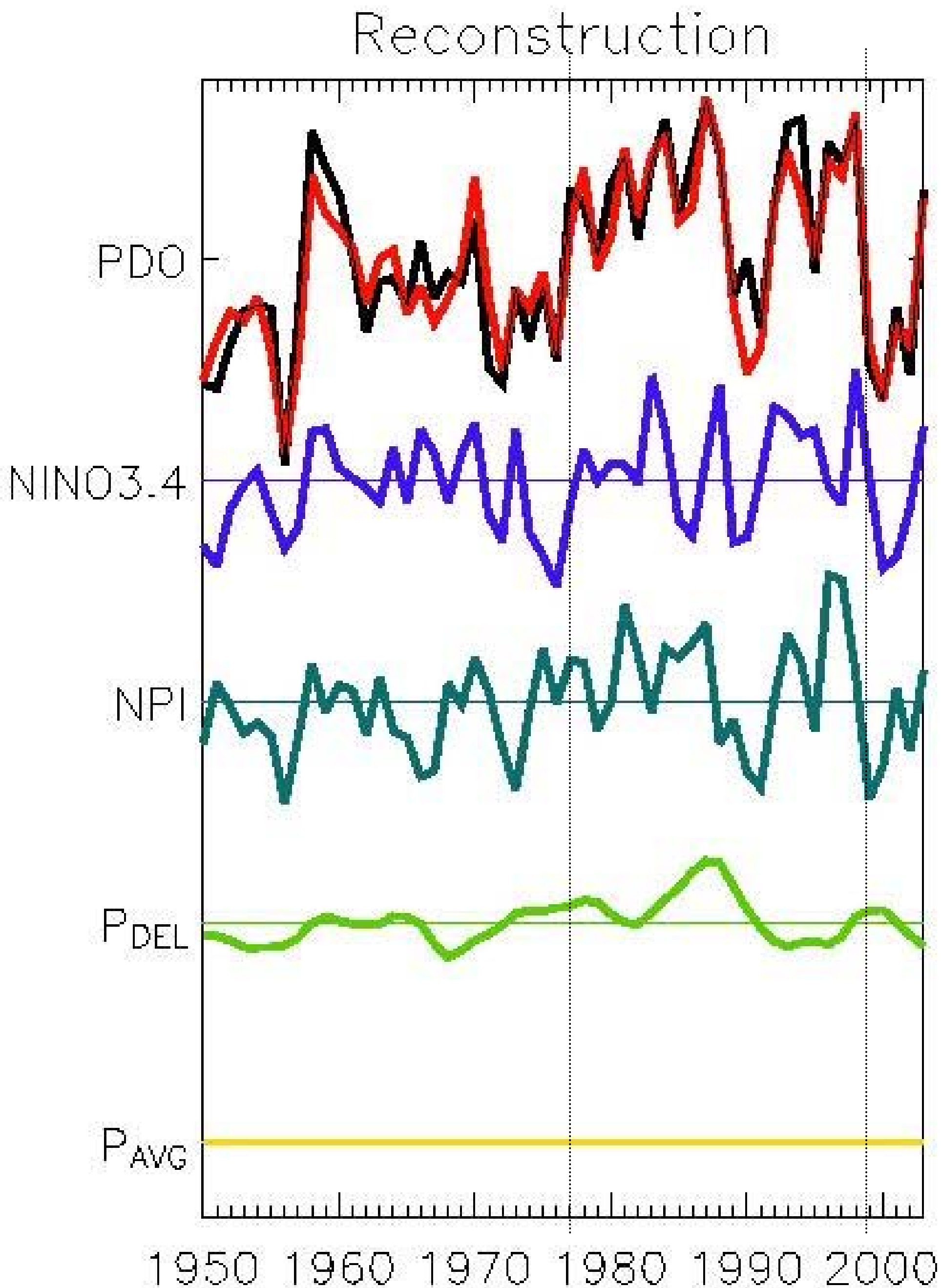
PDO dynamics

$$a_0(t) \ = < \alpha\Phi_k\Phi_0 > a_k(t-1) \ + \ < \gamma_i\Phi_0 F_i(\mathbf{x},t) >$$

	$< \alpha\Phi_k\Phi_0 >$			
	k= 0	1	2	$\cdots$
SST	0.26	-0.004	-0.03	<O(0.03)

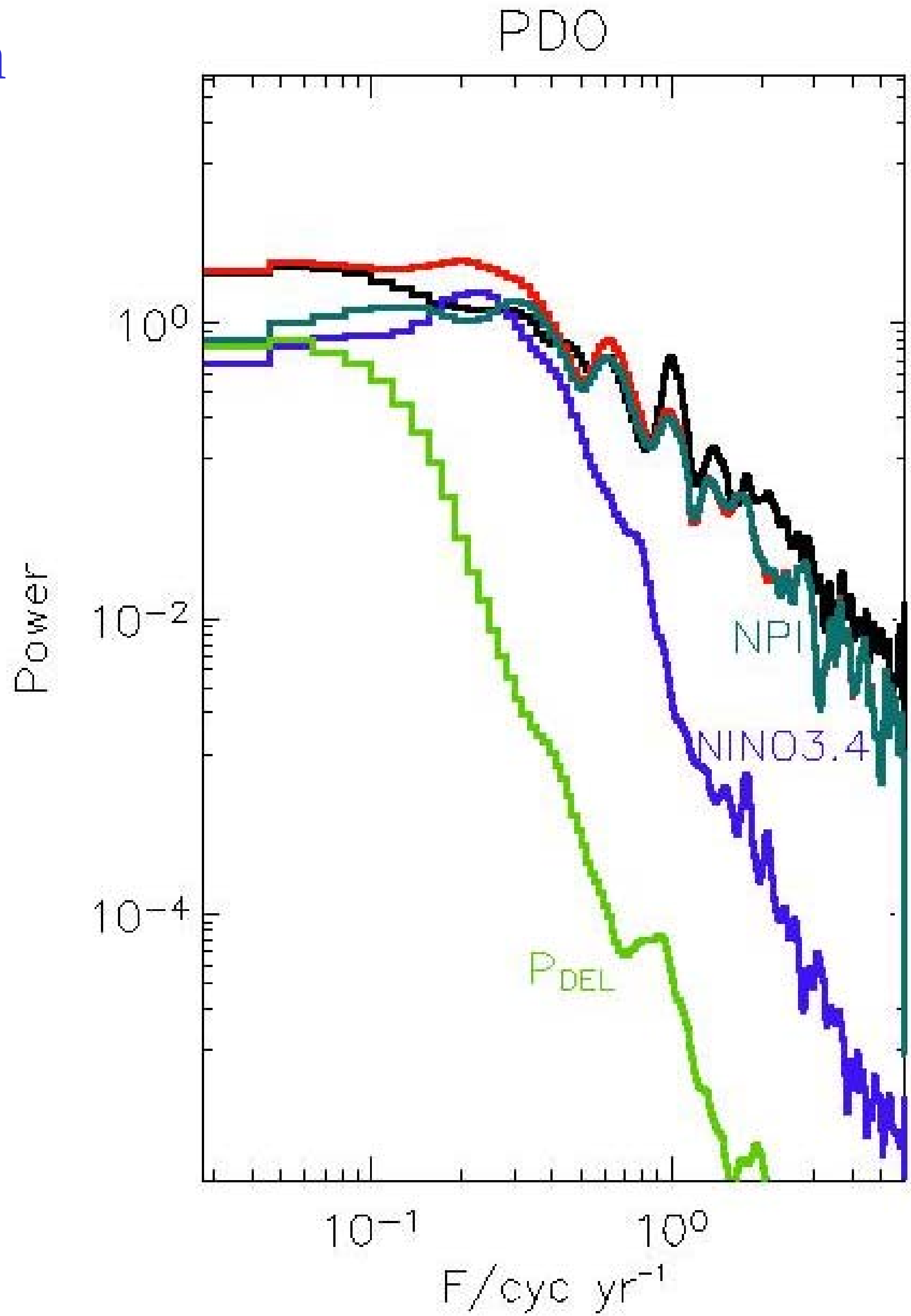


The PDO reconstruction



	>8years
85%	75%
41%	20%
38%	31%
7%	24%
0%	

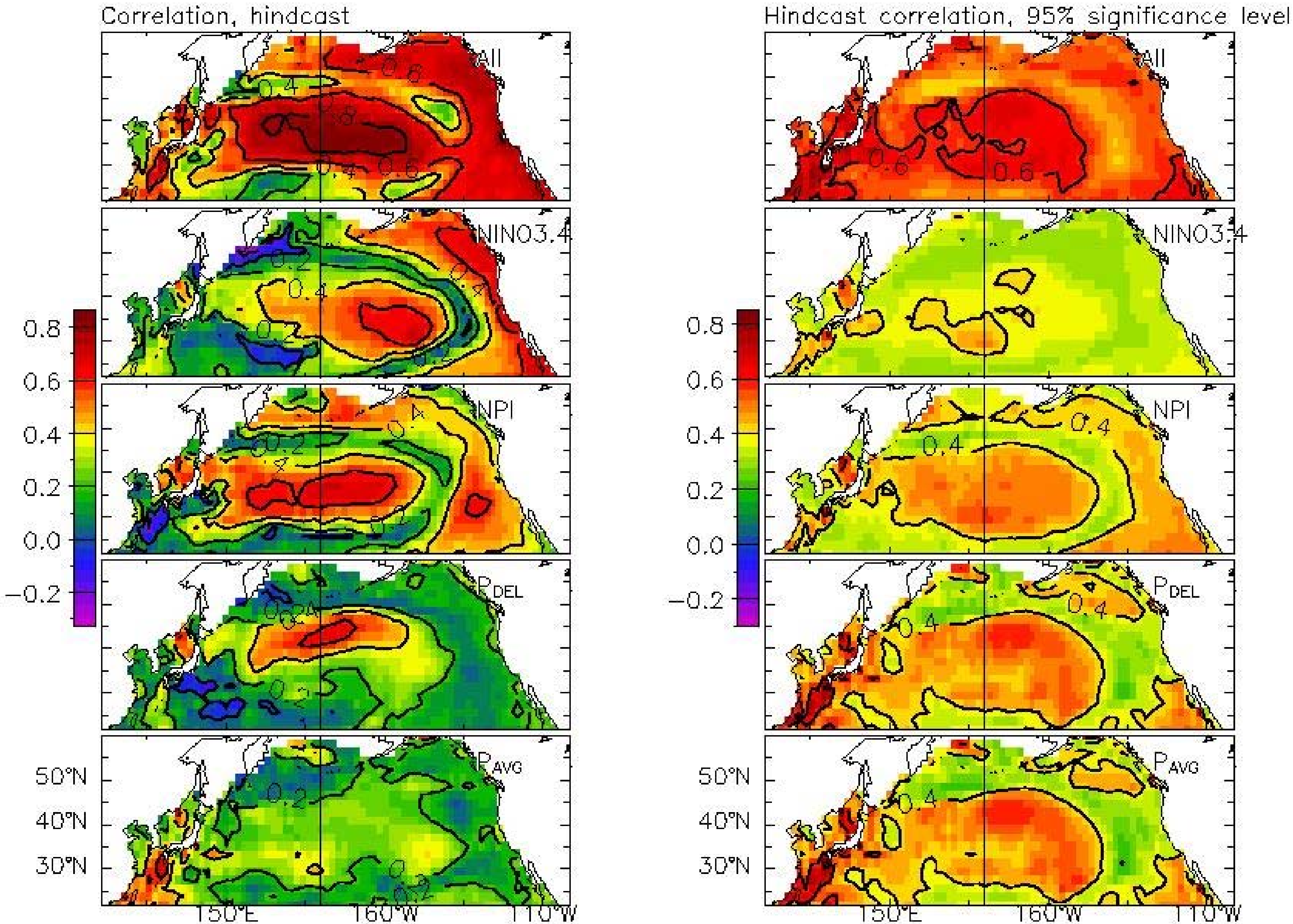
The PDO spectrum



Conclusion

- The PDO results from a superposition of forcing by ENSO, NPI (interpreted as intrinsic mid-latitude variability), and zonal advection anomalies in the Kuroshio Extension P_{DEL}.
- The forcing footprints are non-orthogonal and determine the PDO.
- The contributions of the forcing are frequency dependent. At yearly time scales, NPI dominates, at interannual time scales anomalies NPI and ENSO are on par, at decadal time scale, NPI, ENSO and P_{DEL} are of equal importance.
- The `impact’ of the PDO is a reflection of shared forcing.

Reconstruction skill



Reconstruction of the PDO