A Mechanistic Model of Mid-Latitude Decadal Climate Variability

(IMAGe T-O-Y Workshop IV)

Sergey Kravtsov
Department of Mathematical Sciences, UWM

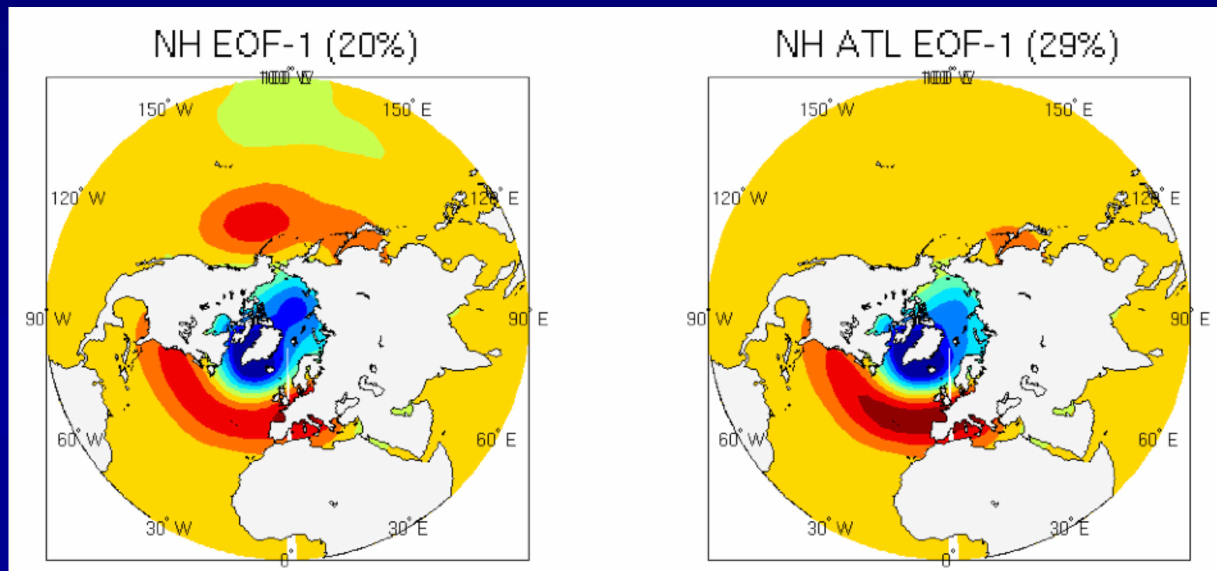
May 19, 2006

Collaborators:

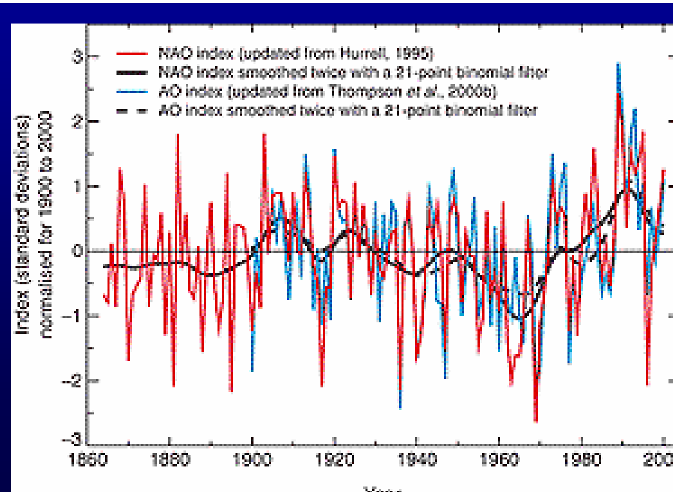
William Dewar, Pavel Berloff, Michael Ghil,
James McWilliams

North Atlantic Oscillation and Arctic Oscillation

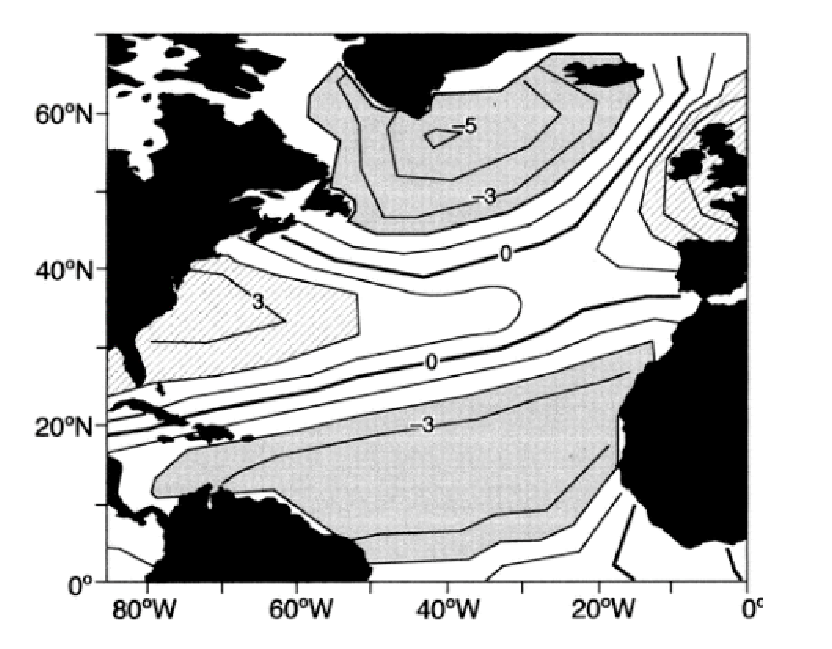
AO



NAO



SST and NAO



SST tripole pattern

(Marshall et al. 2001,

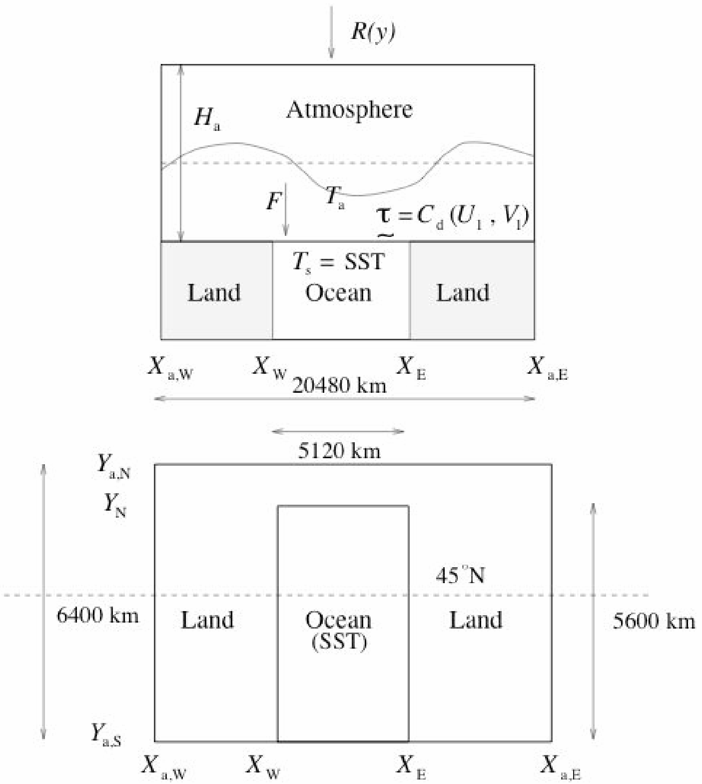
Journal of Climate: **Vol. 14, No. 7, pp. 1399–1421)**

- Decadal time scale detected in NAO/SST time series
- If real, what dynamics does this signal represent? <u>We will emphasize ocean's dynamical inertia due to eddies</u>
- AGCMs: response to (small) SSTAs is weak and model-dependent
- <u>Nonlinear</u>: small SSTAs – large response??

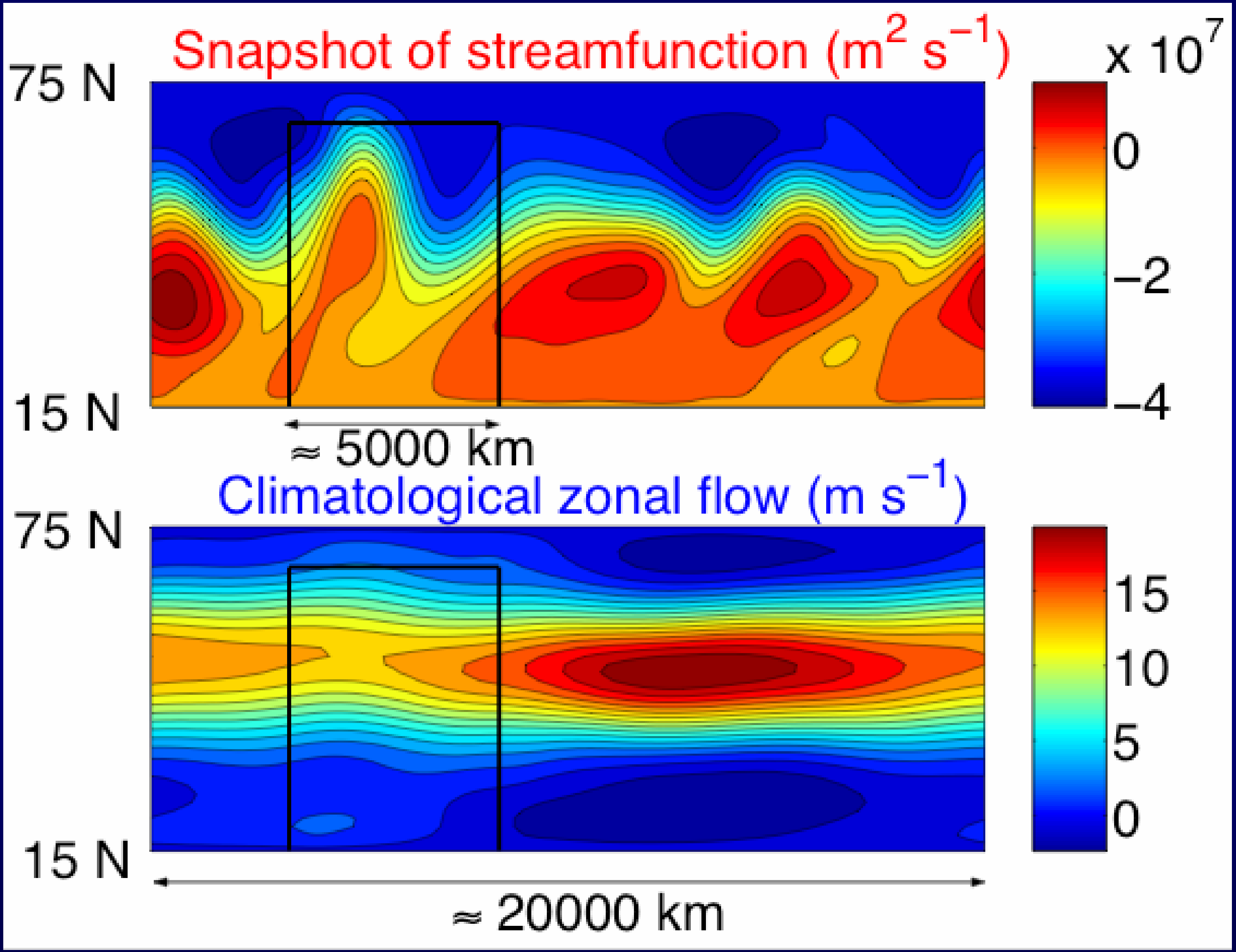
Coupled QG Model

- Eddy-resolving atmospheric and ocean components, both characterized by vigorous intrinsic variability

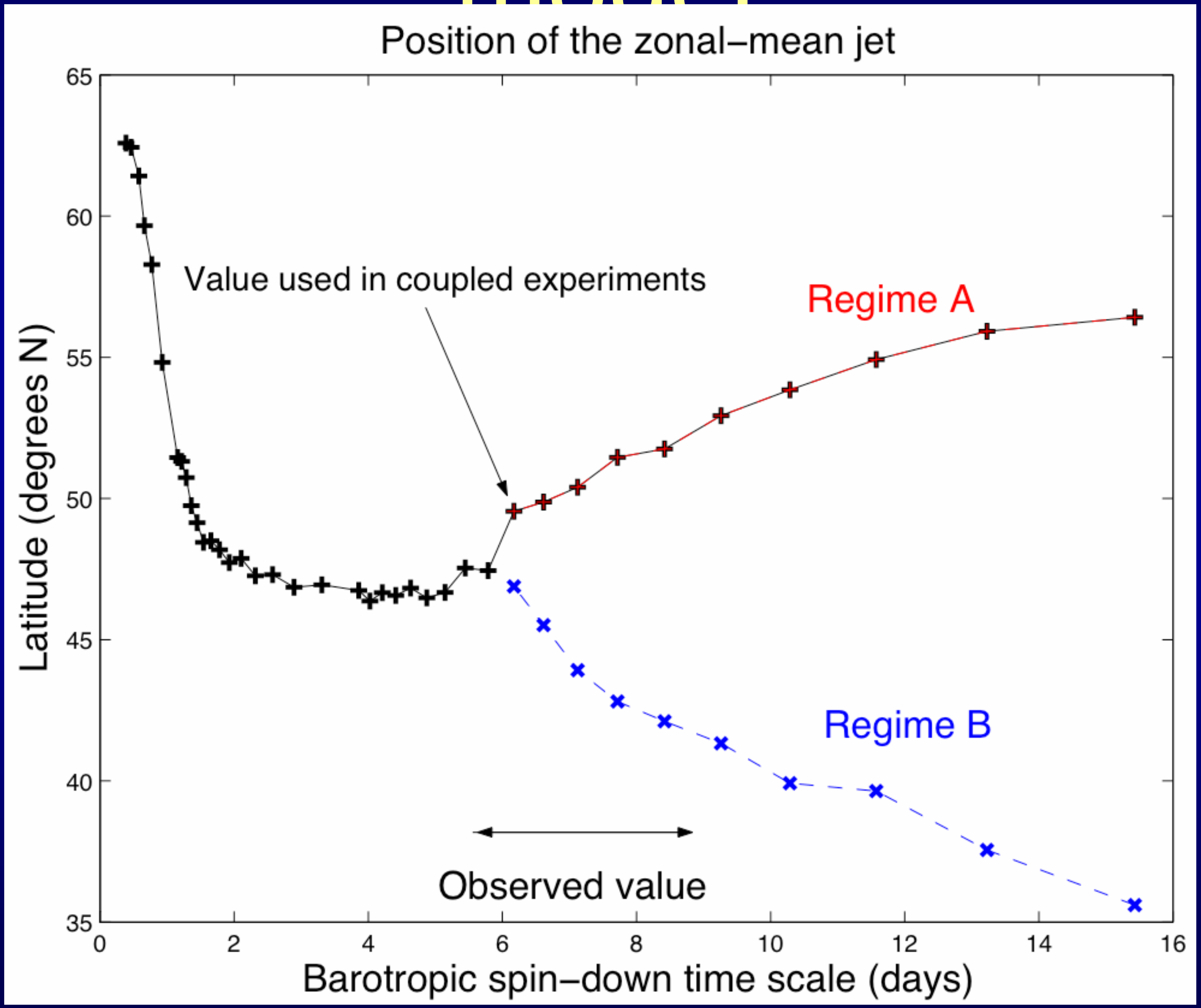
- (Thermo-) dynamic coupling via constant-depth oceanic mixed layer with entrainment



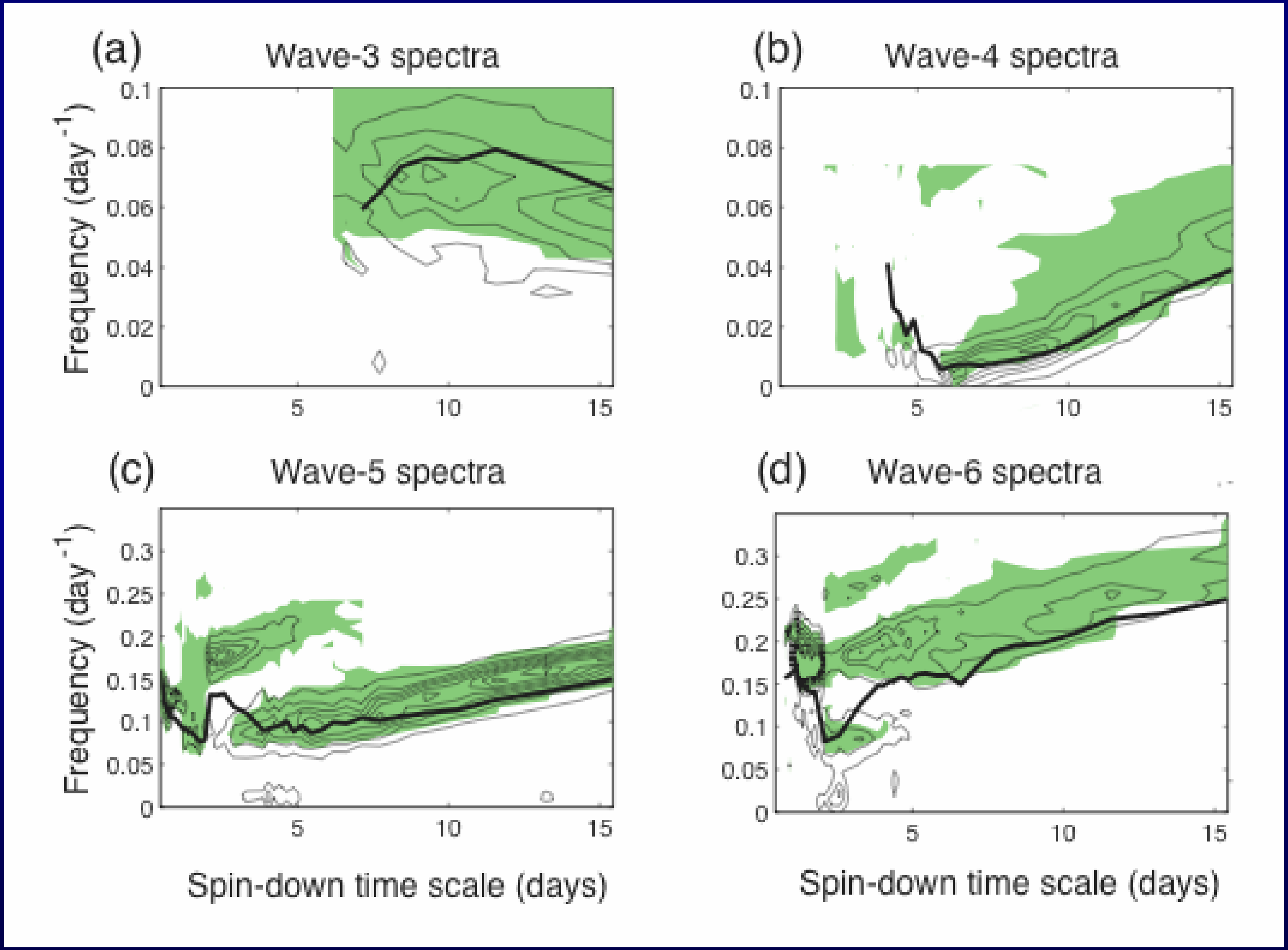
Atmospheric circulation



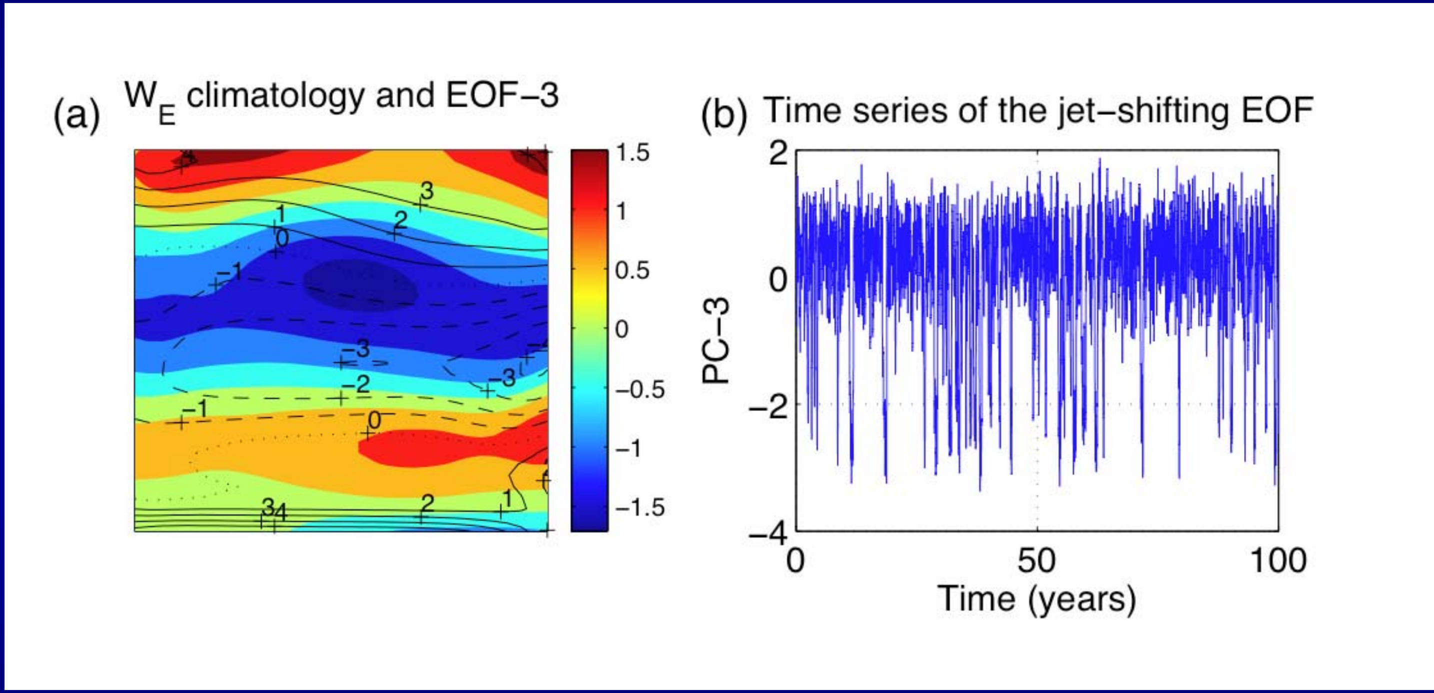
Zonal-jet bimodality in the model



Intra-seasonal oscillations in the atmospheric model

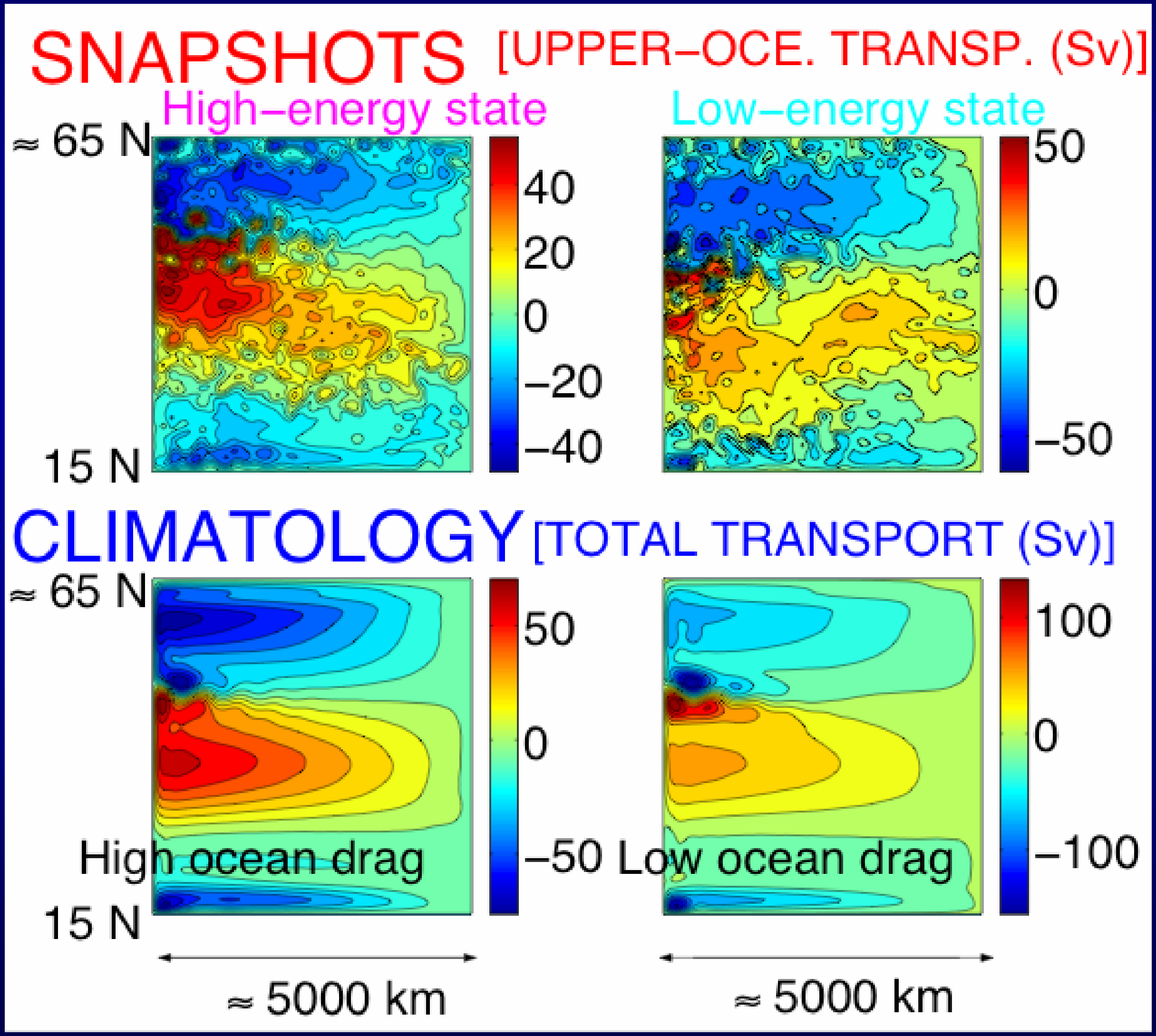


Atmospheric driving of ocean



- <u>Coupled effect</u>: Occupation frequency of atmospheric low-latitude state exhibits (inter)-decadal broad-band periodicity

Oceanic circulation



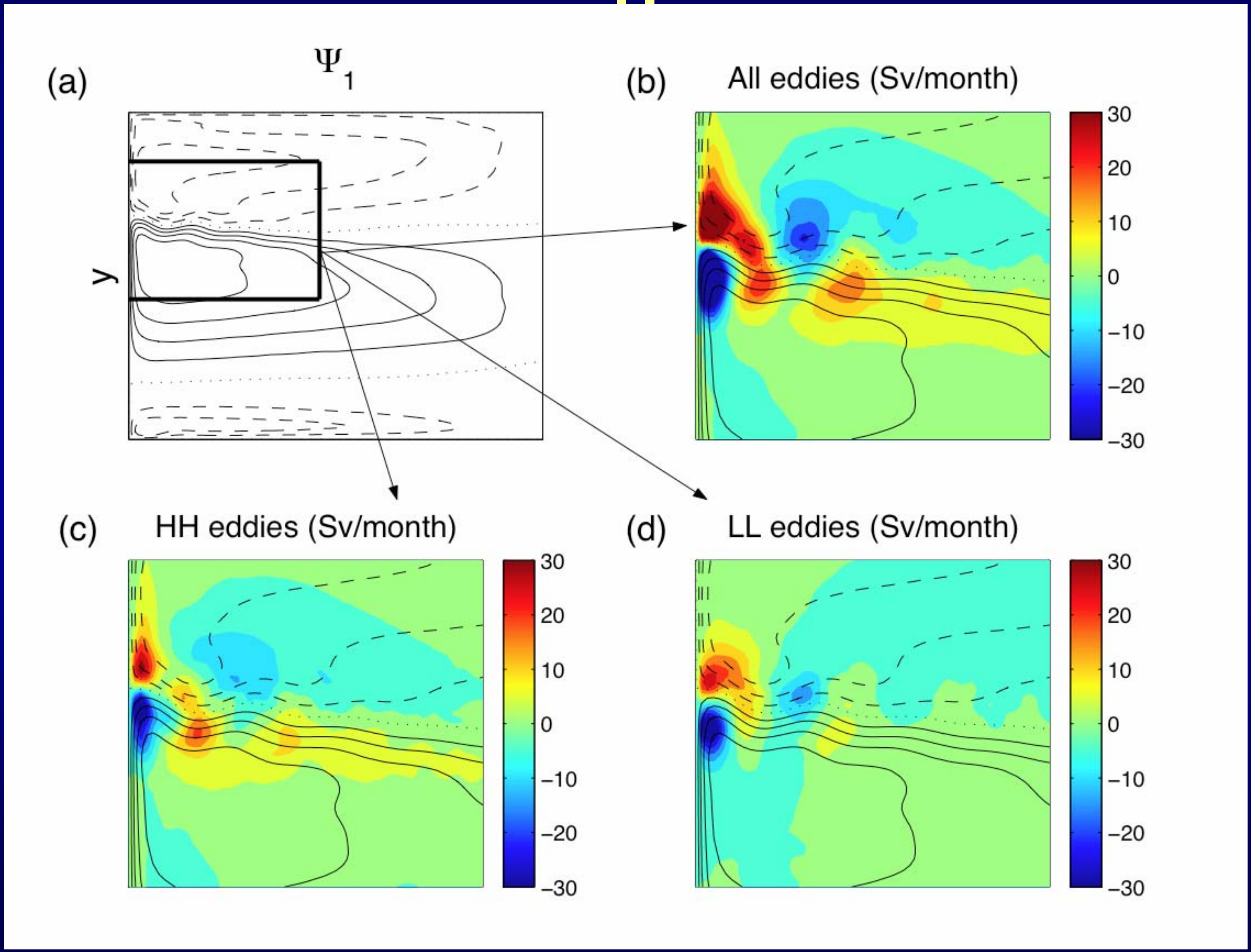
Eddy effects on O-climatology–I

$$\Psi_1 = \overline{\Psi}_1 + \Psi'_1$$
$$\Psi'_1 = \Psi'_{1,\mathsf{L}} + \Psi'_{1,\mathsf{H}}$$

$$Q_1 = \nabla^2\Psi_1 + (f_0^2/g'H)(\Psi_2 - \Psi_1)$$

$$\dot{Q} \sim -J(\Psi'_{\mathsf{H}}, Q'_{\mathsf{H}}) - J(\Psi'_{\mathsf{L}}, Q'_{\mathsf{L}})$$
$$-J(\Psi'_{\mathsf{H}}, Q'_{\mathsf{L}}) - J(\Psi'_{\mathsf{L}}, Q'_{\mathsf{H}})$$
$$+ \text{ linear terms } \ldots$$

Eddy effects on O-climatology–II



Eddy effects on O-LFV–I

(EPV-flux tendency regressed onto EOF-1 of Ψ_1)

ALL LL HH

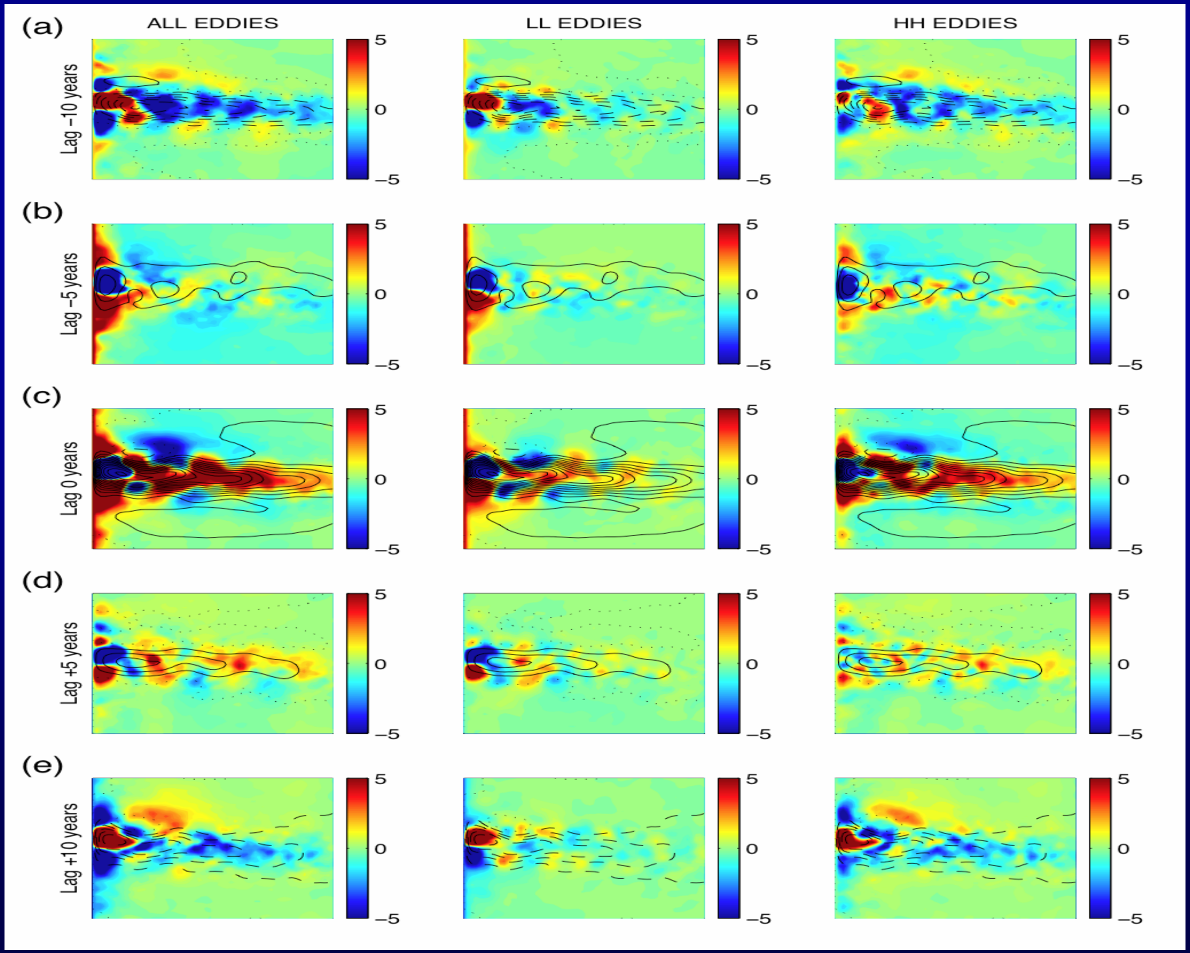
– 10 yr

– 5 yr

0 yr

+ 5 yr

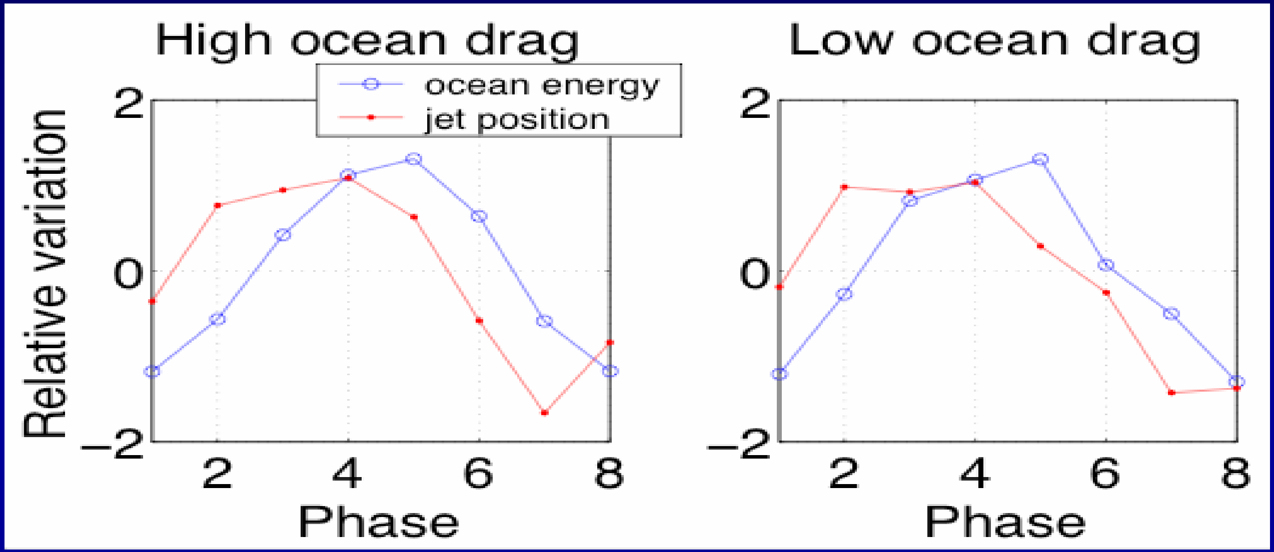
+ 10 yr

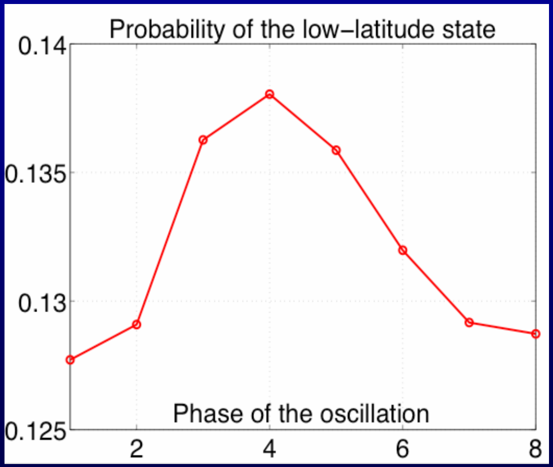


Eddy effects on O-LFV–II

- Dynamical decomposition into large-scale flow and eddy-flow components, based on parallel integration of the full and “coarse-grained” ocean models (Berloff 2005)
- “Coarse-grained” model forced by randomized spatially-coherent eddy PV fluxes exhibits realistic climatology and variability
- Main eddy effect is <u>rectification</u> of oceanic jet (eddy <u>fluctuations</u> are <u>fundamental</u>)

Dynamics of the oscillation – I



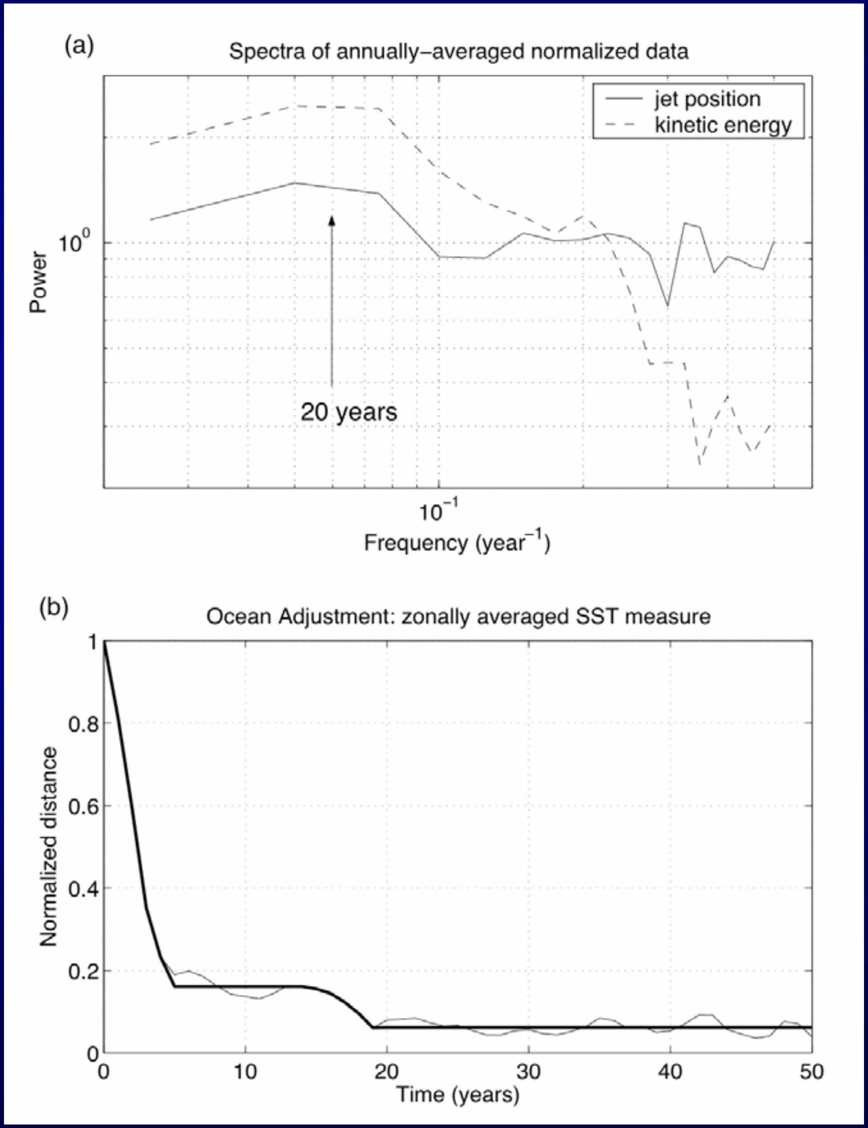


- High Ocean Energy = High-Latitude (HL) O-Jet State
- HL ocean state = A-jet's Low-Latitude (LL) state
- O-Jet stays in HL state for a few years due to O-eddies

Dynamics of the oscillation – II

- Oscillation's period is of about 20 yr in low-ocean-drag case and is of about 10 yr in high-ocean-drag case

- Period scales as eddy-driven adjustment time

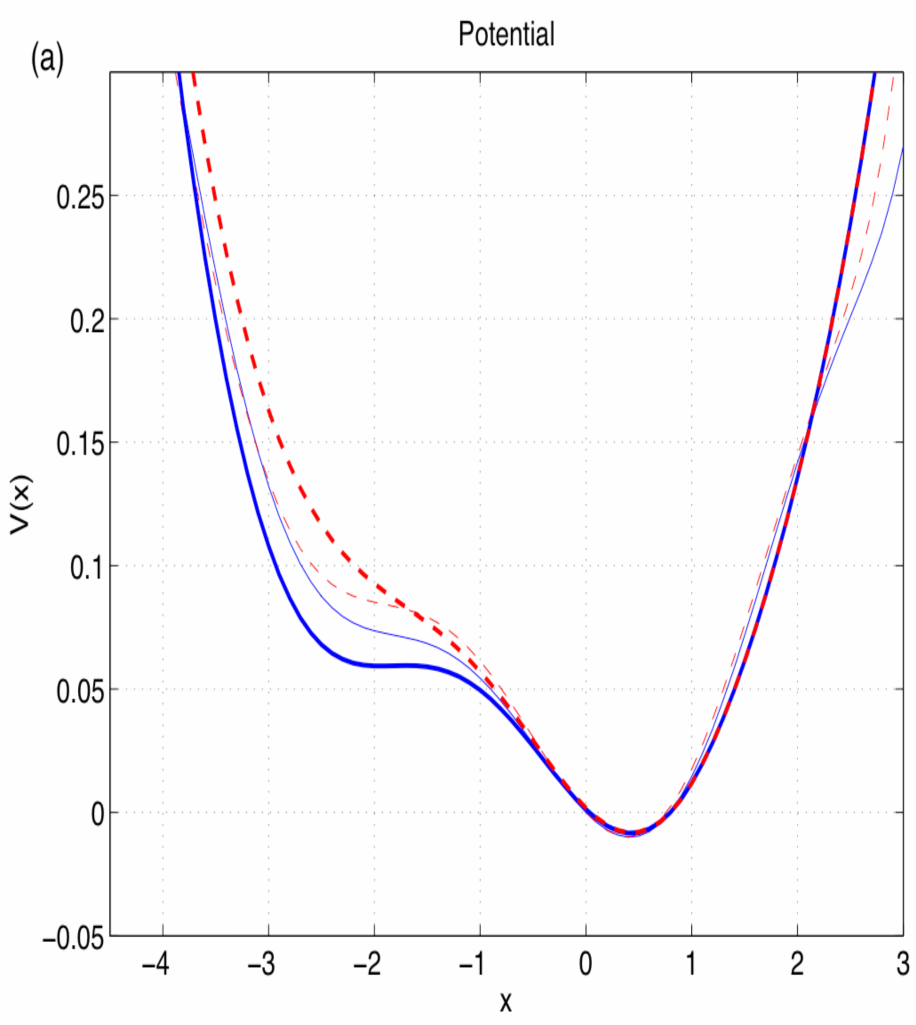


Conceptual model – I

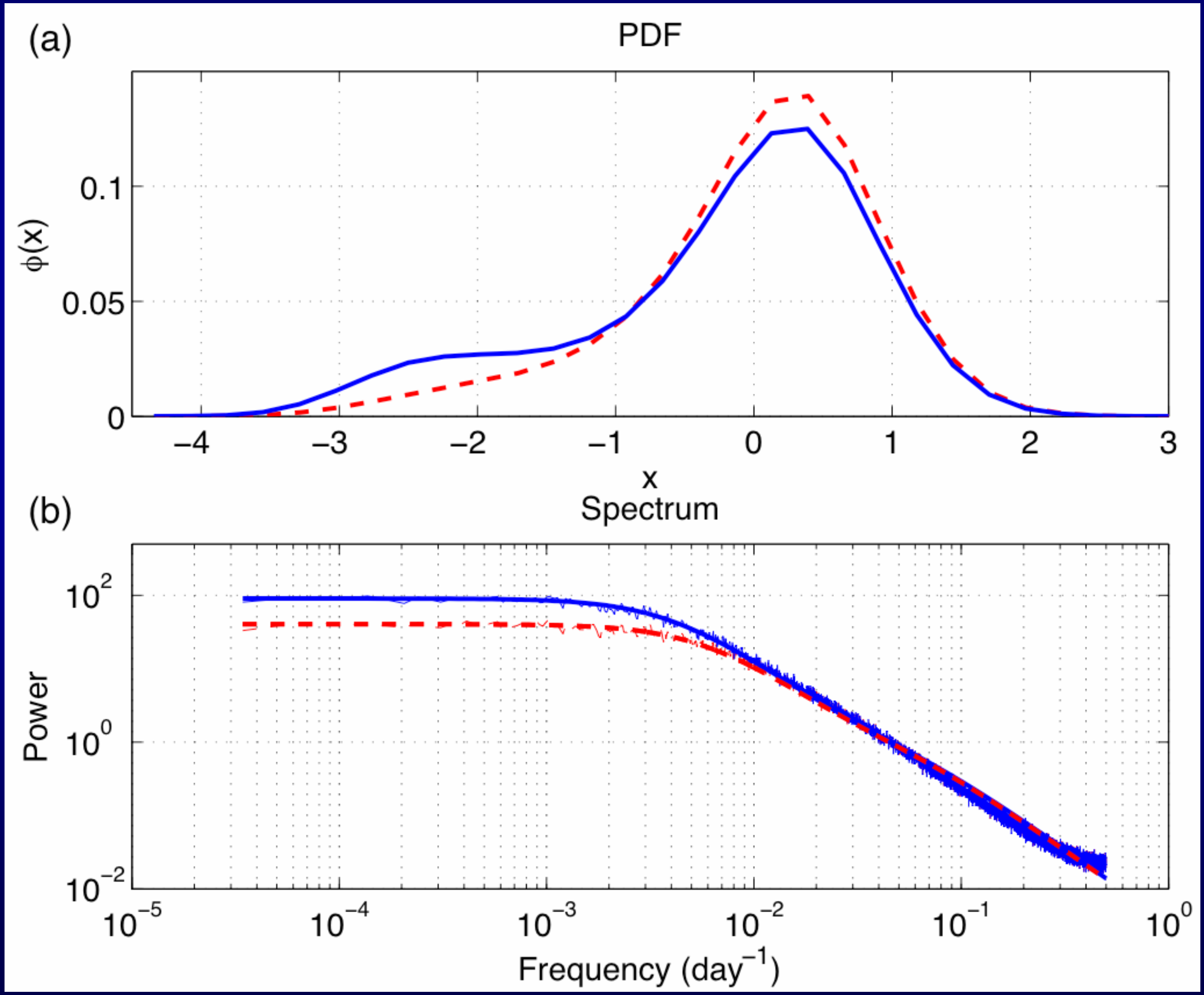
- Fit A-jet position time series from A-only simu-lations forced by O-states keyed to phases of the oscillation to a stochastic model of the form

$$dx = -V_x dt + \sigma dw$$

[$V(x)$ – polynomial in x]



Conceptual model – II



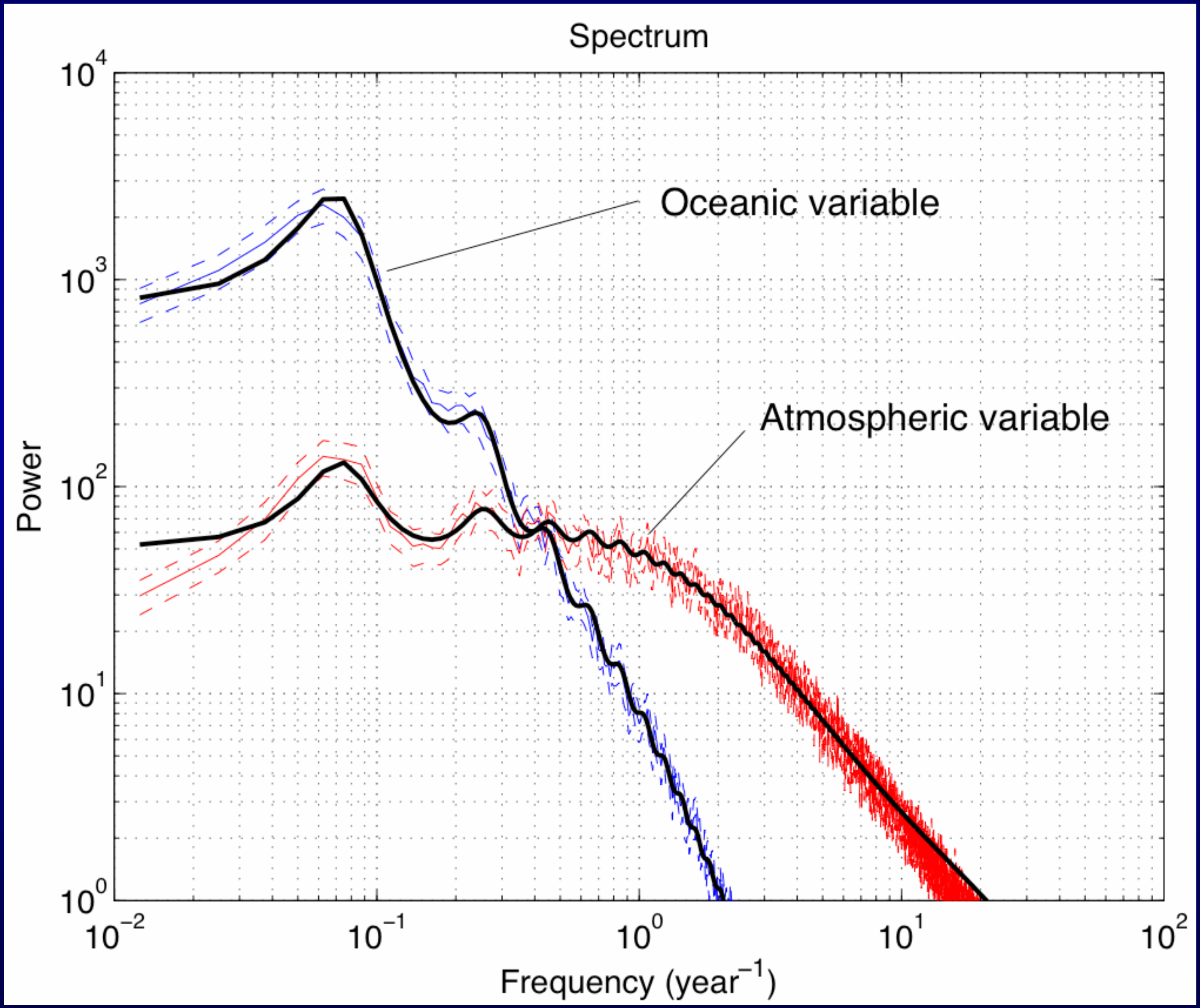
Conceptual model – III

- "Atmosphere:" $$dx = -V_x(x, y)dt + \sigma dw$$
- "Ocean:" $$\dot{y} = -\lambda y + Ax(t - T_\text{d})$$

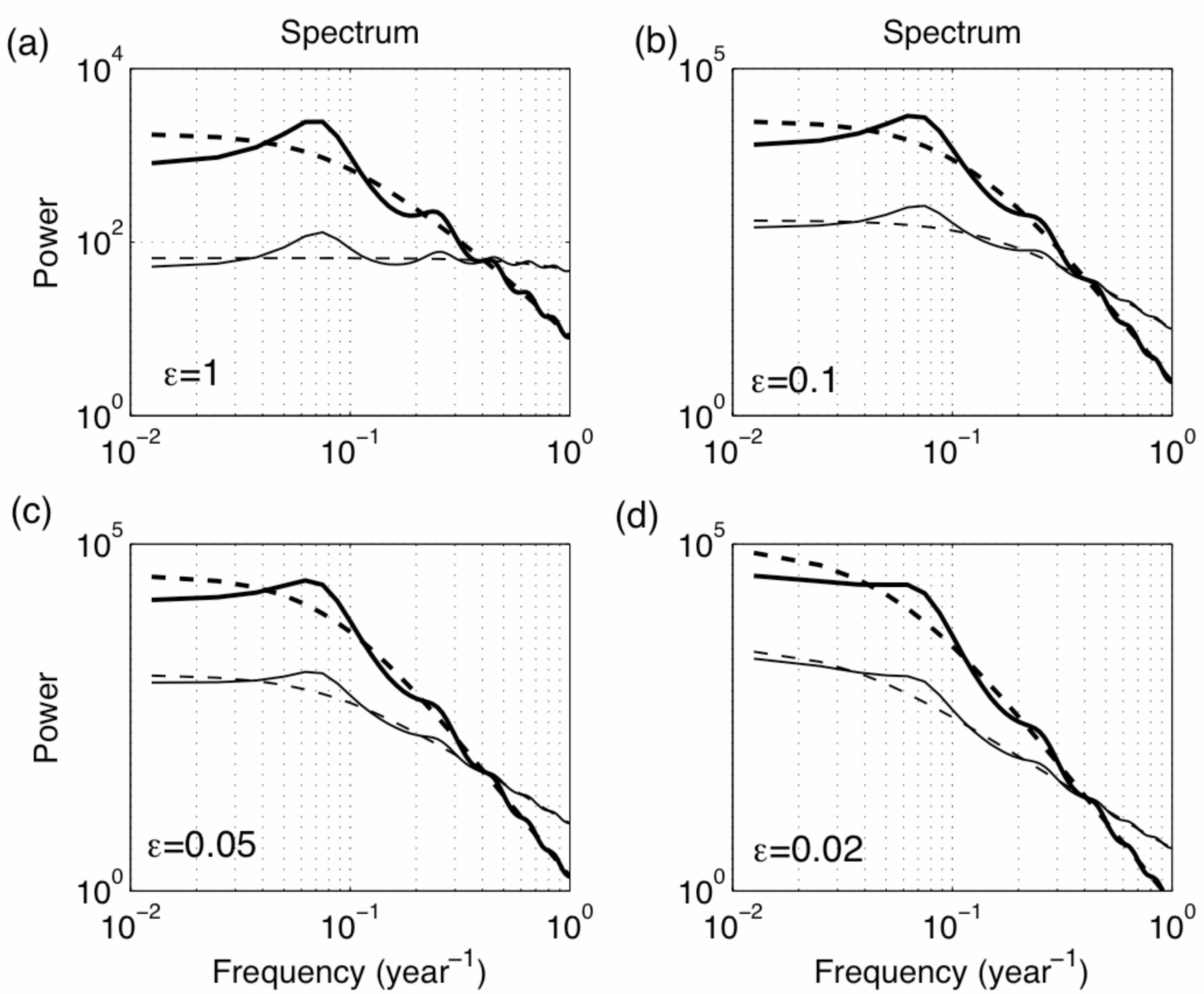
λ^{-1}=2 yr, T_d=5 yr

- Delay: ocean's jet does not "see" the loss of local atmospheric forcing because ocean eddies dominate maintenance of O-jet for as long as T_d
- Atmospheric potential function responds to oceanic changes instantaneously: O-Jet HL state favors A-Jet LL state and vice versa

Conceptual model – IV



Conceptual model – V



Summary

- Mid-latitude climate model involving turbulent oceanic and atmospheric components exhibits inter-decadal coupled oscillation
- Bimodal character of atmospheric LFV is responsible for atmospheric sensitivity to SSTAs
- Ocean responds to changes in occupation frequency of atmospheric regimes with a delay due to ocean eddy effects
- Conceptual toy model was used to illustrate how these two effects lead to the coupled oscillation