Decadal Variability, Impact, and Prediction of the Kuroshio Extension System

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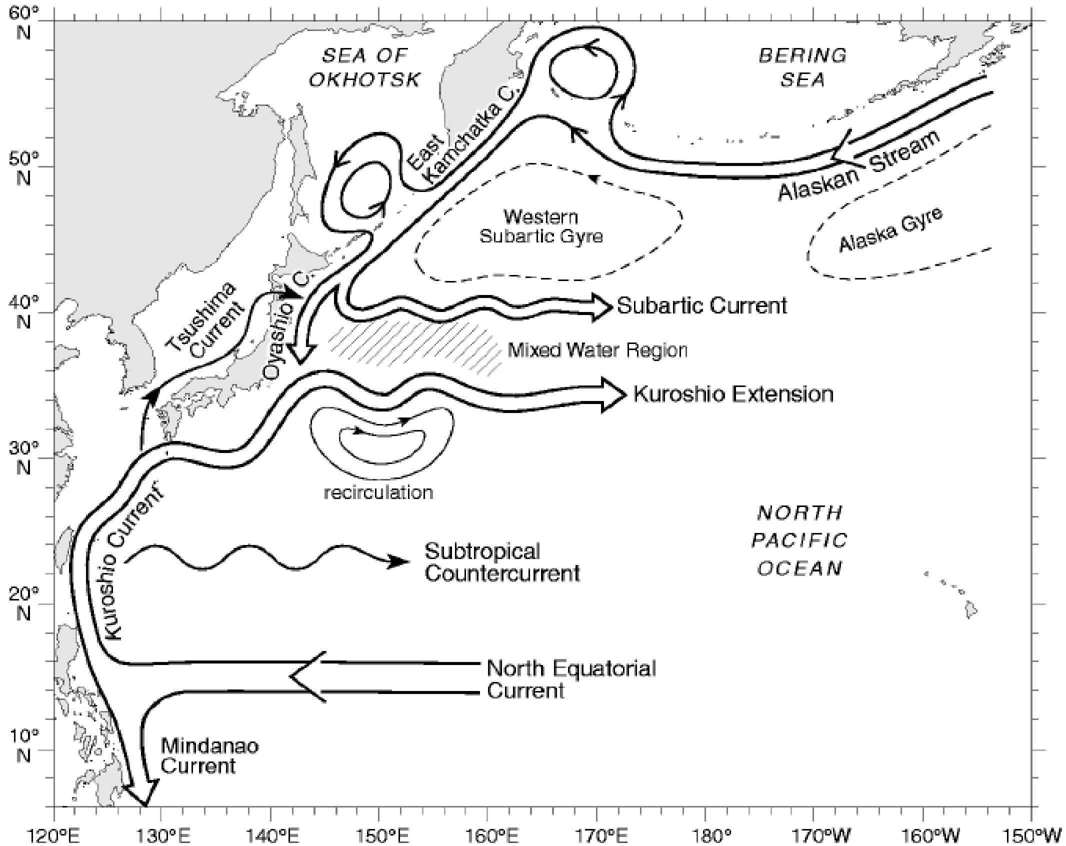
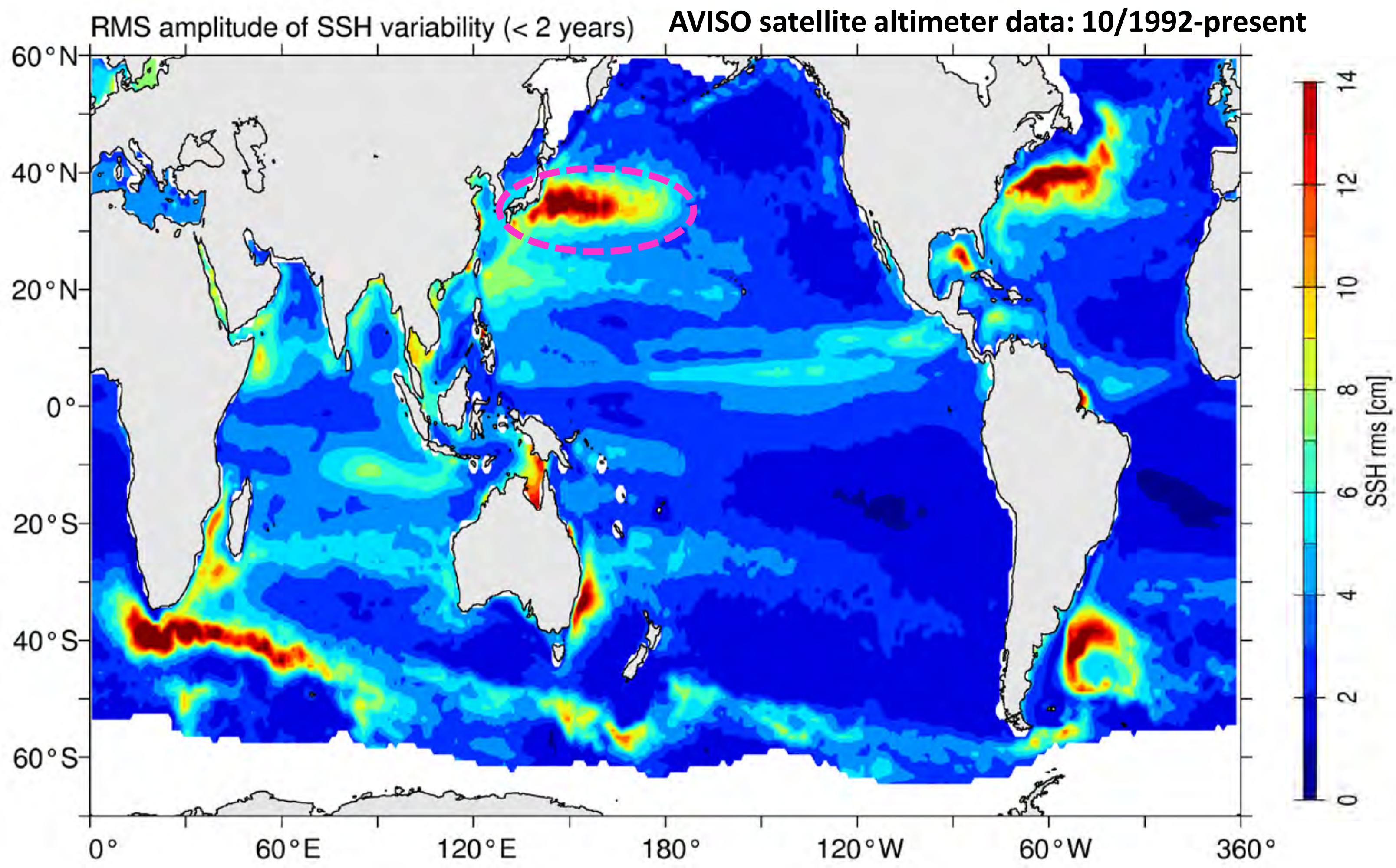
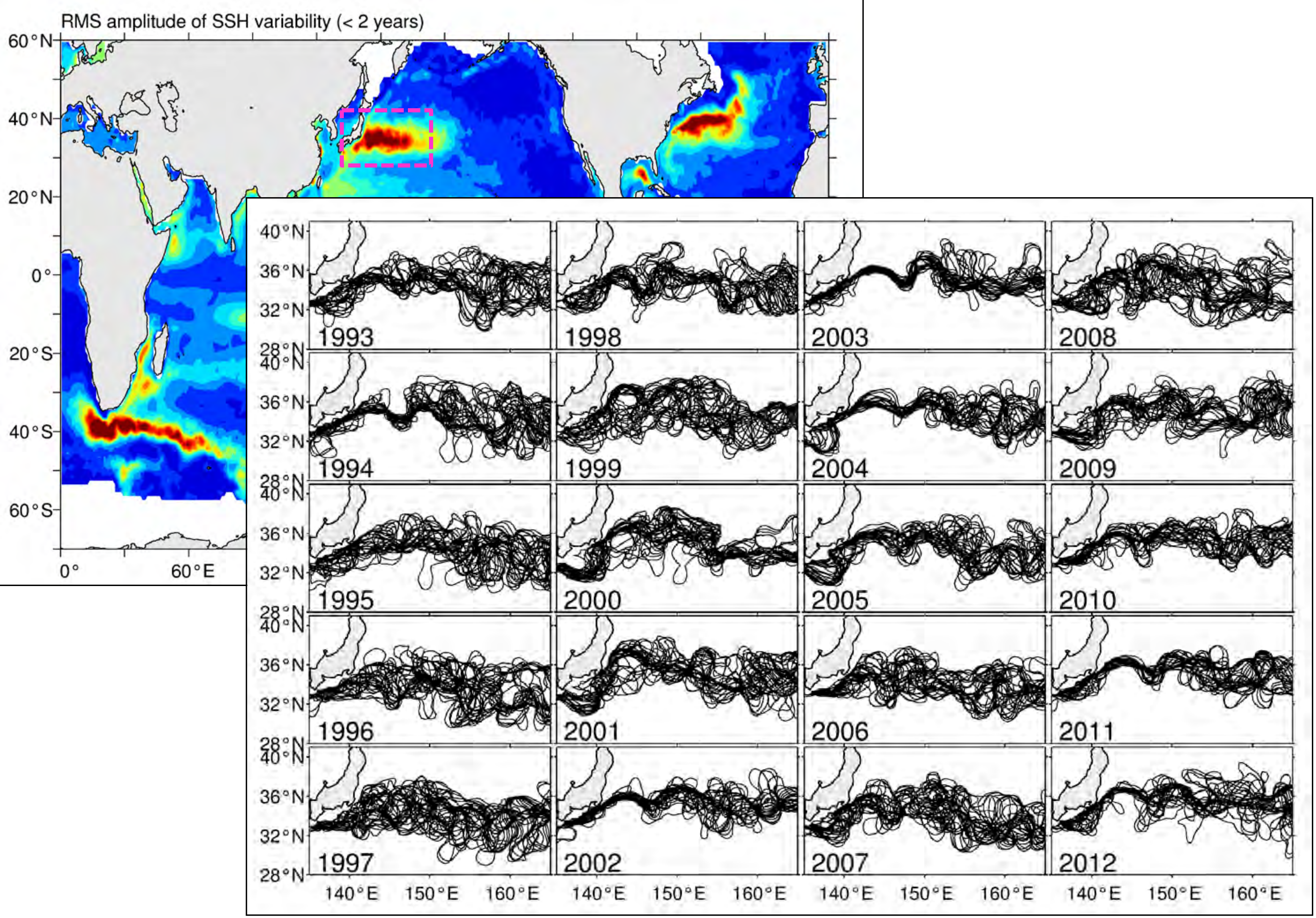


2014 FUTURE Open Science Meeting, Kohala Coast, HI, 14-18 April 2014

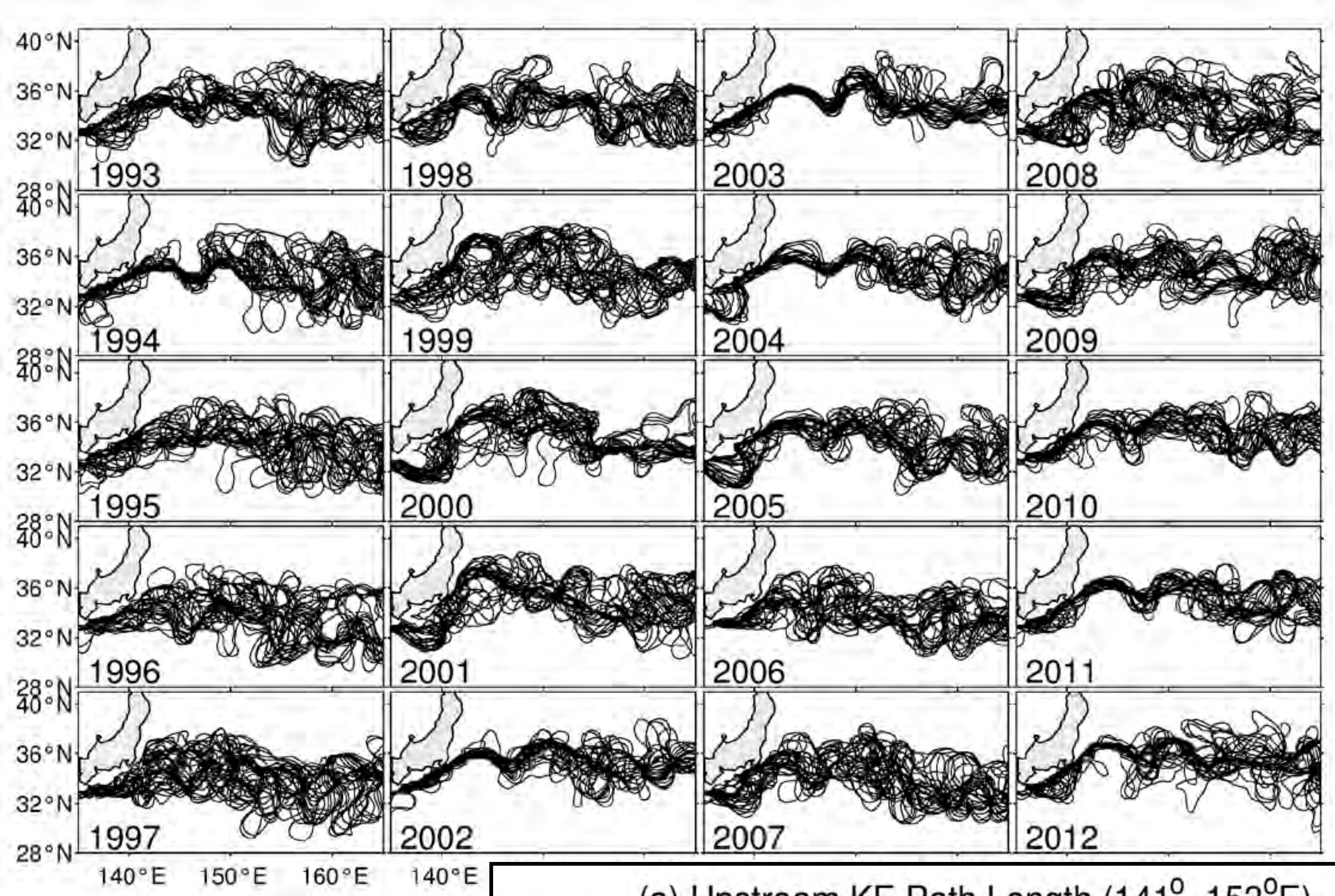
Outlines

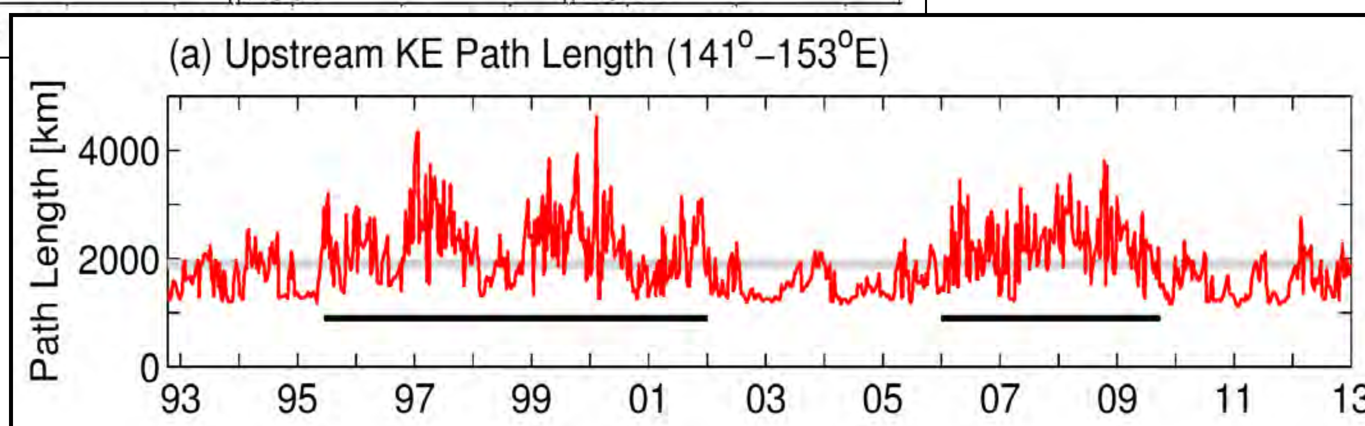
- Observed decadal changes in the Kuroshio Extension system
- Impact on SST front and overlying stormtracks
- KE index and its prediction





Altimeter-derived KE paths: Oscillations between stable and unstable states

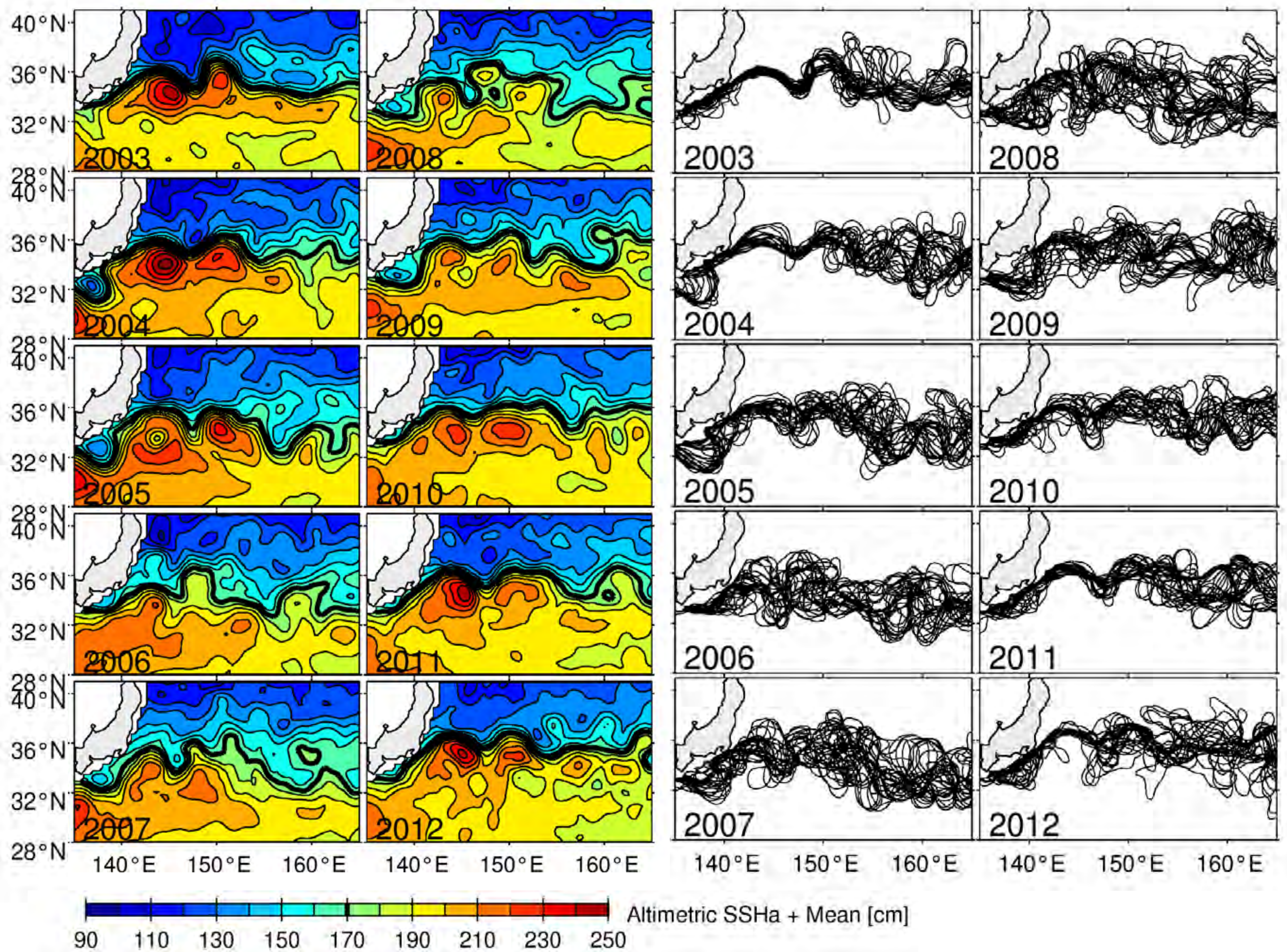




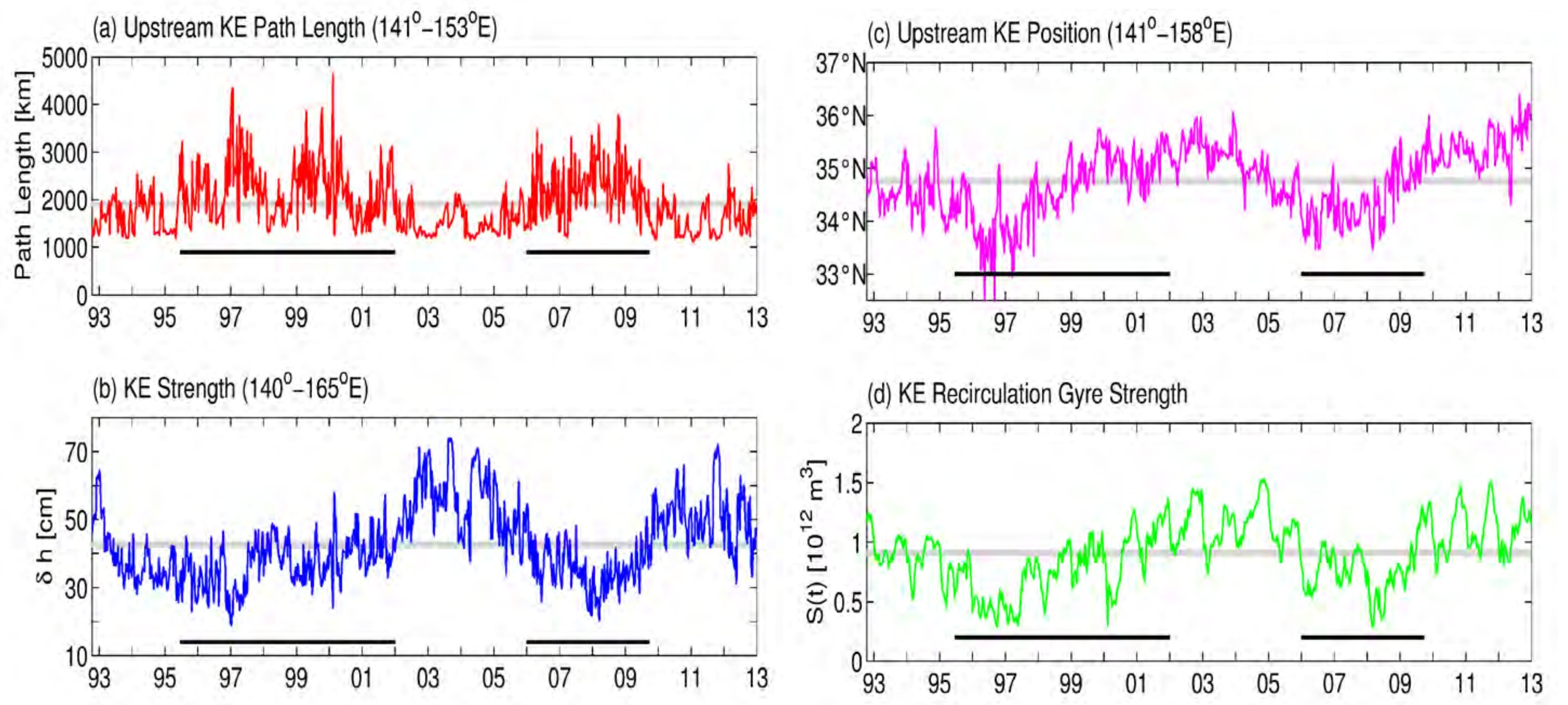
Stable yrs: 1993-94, 2002-04, 2010-2013

Unstable yrs: 1996-2001, 2006-08

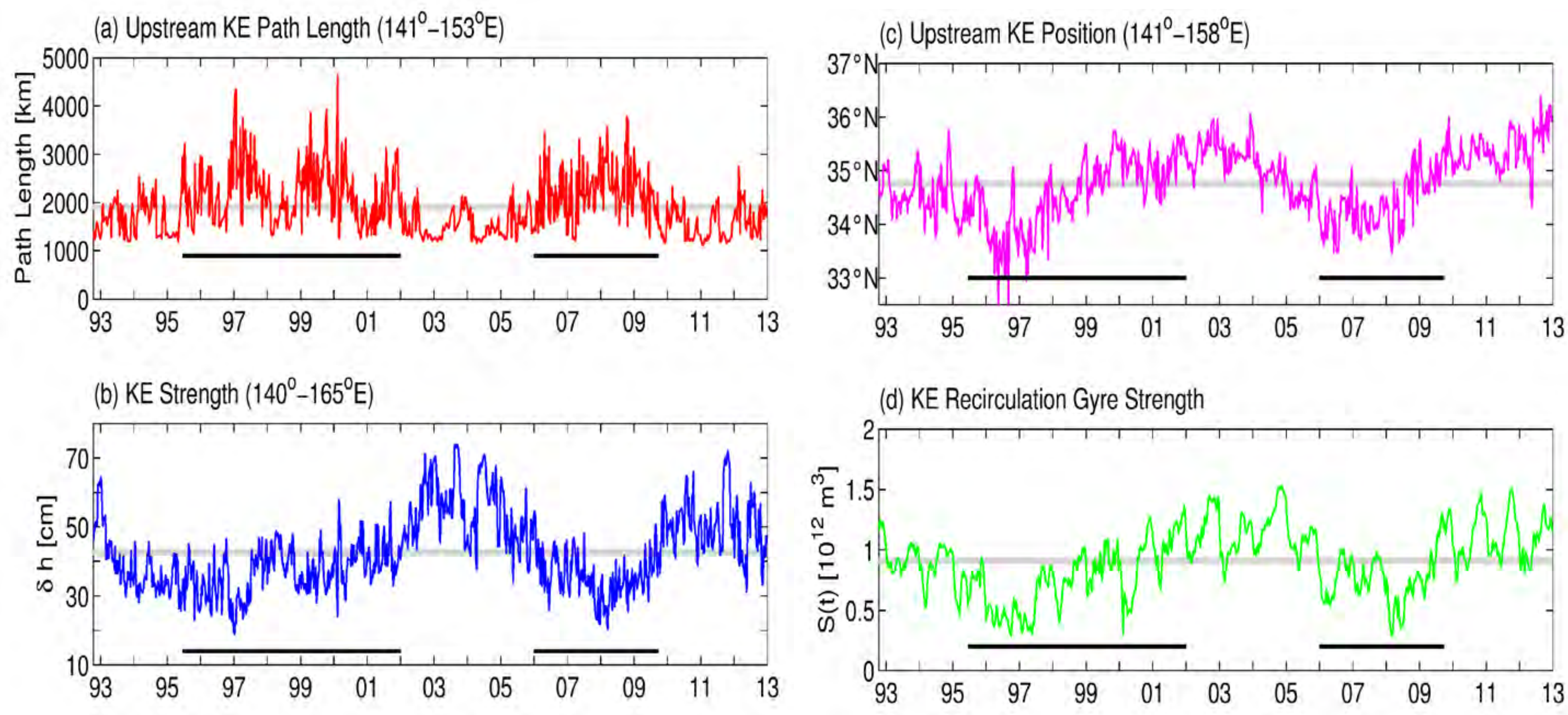
Yearly-averaged SSH field in the region surrounding the KE system



Various dynamic properties representing the decadal KE variability

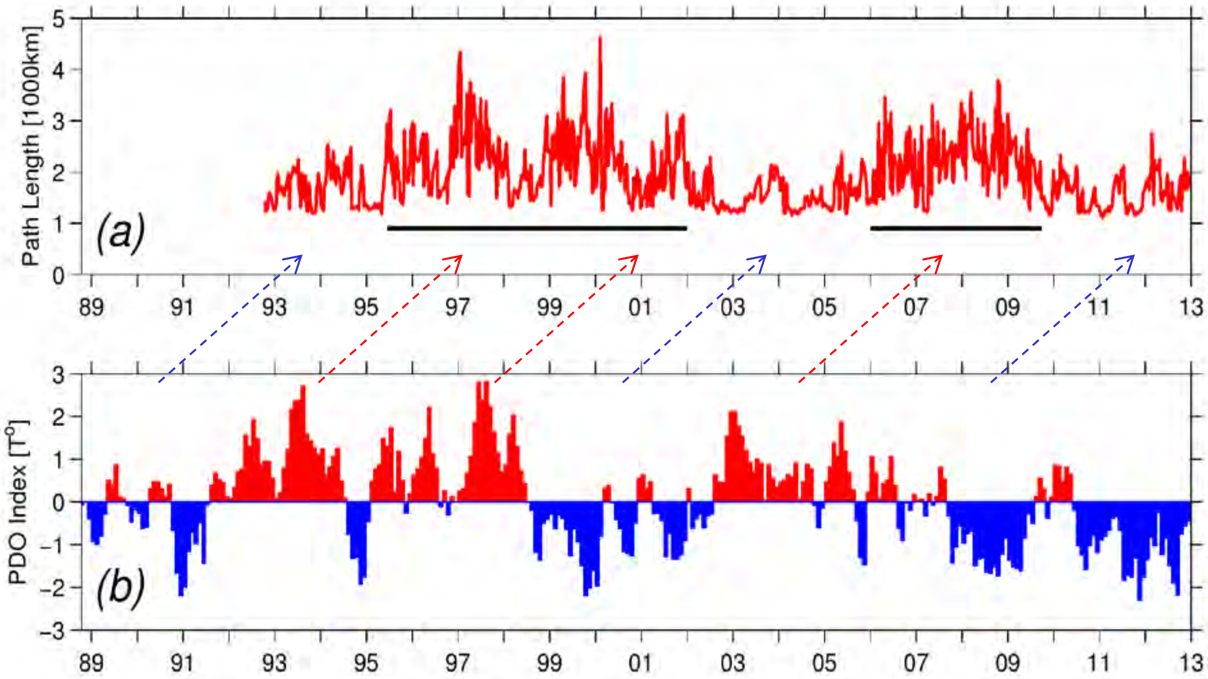


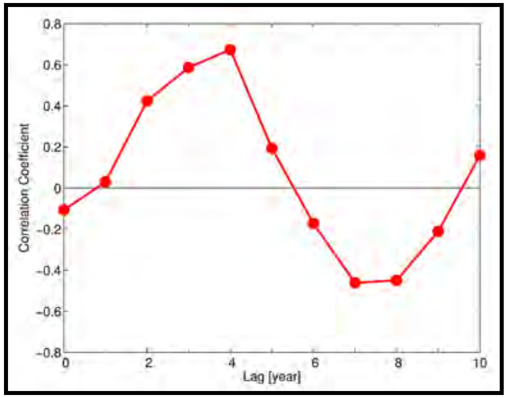
Various dynamic properties representing the decadal KE variability

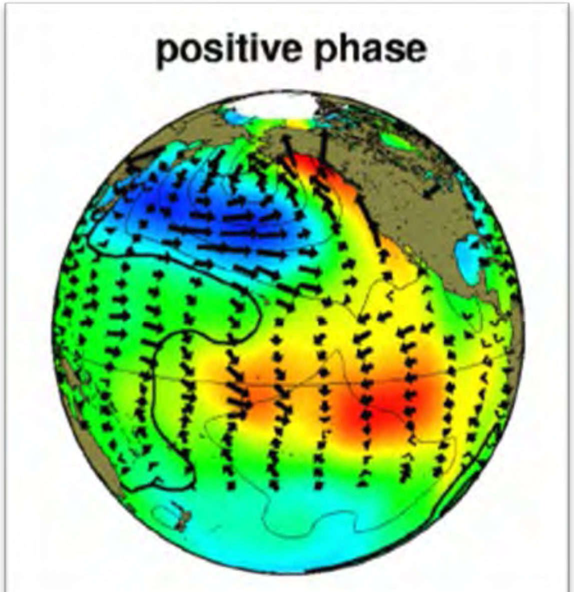


Q1: What causes the transitions between the stable and unstable dynamic states of the KE system?

Decadal KE variability lags the PDO index by 4 yrs (r=0.67)



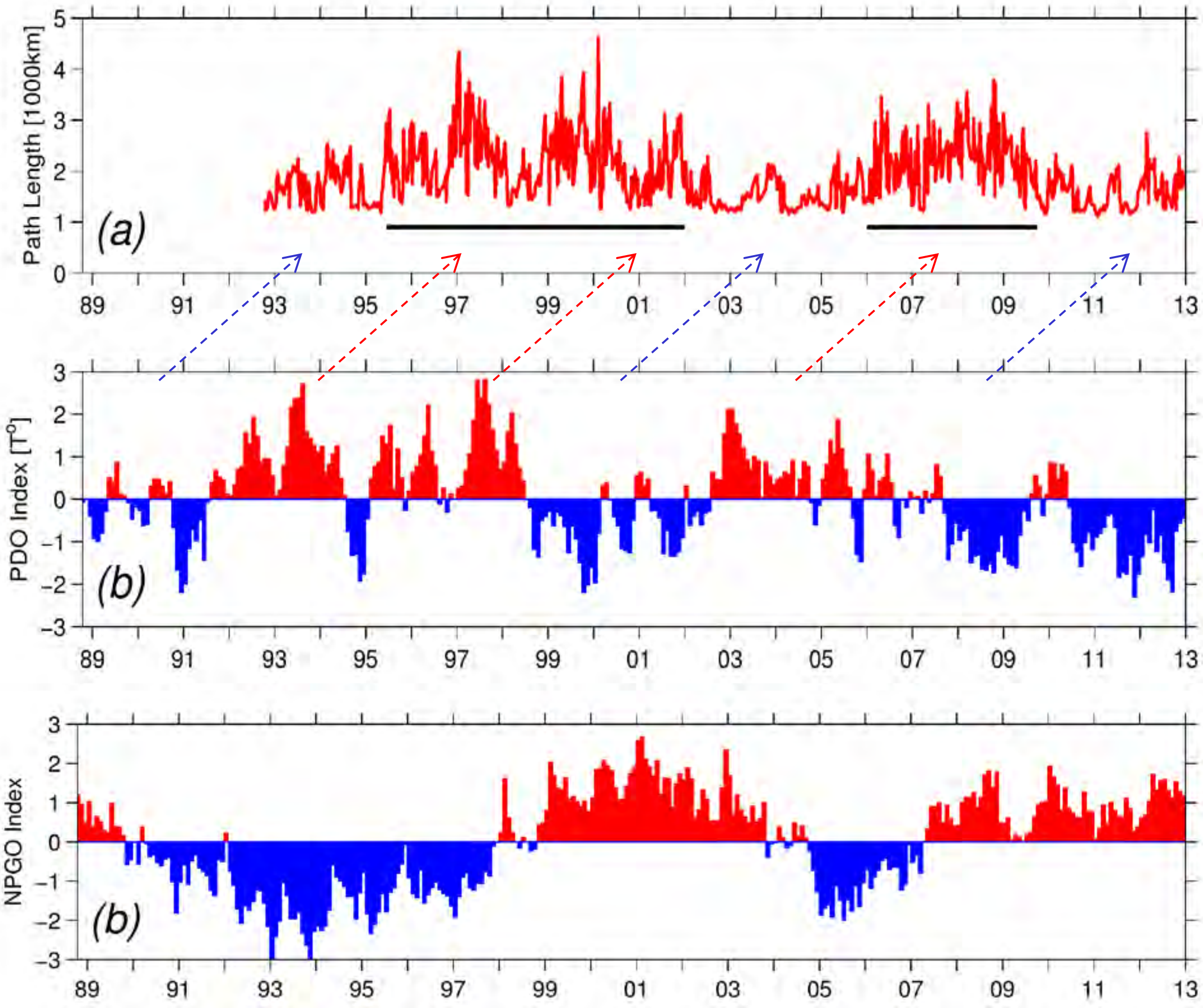


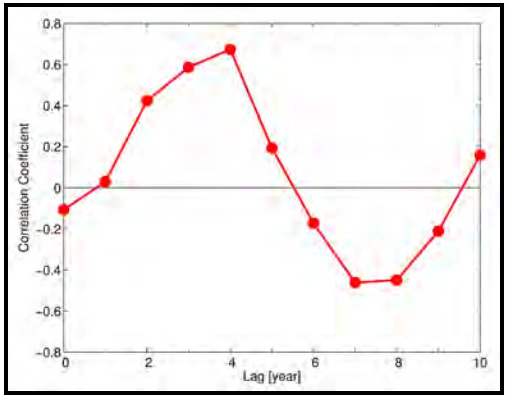


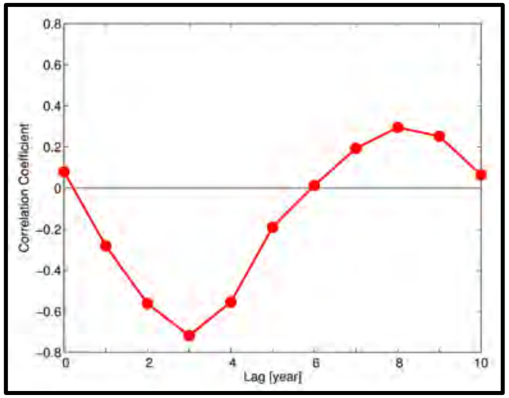
- Center of PDO wind forcing is in the <u>eastern</u> half of North Pacific basin
- + PDO generates negative local SSHAs through Ekman divergence, and vice versa

Mantua et al. (1997, BAMS)

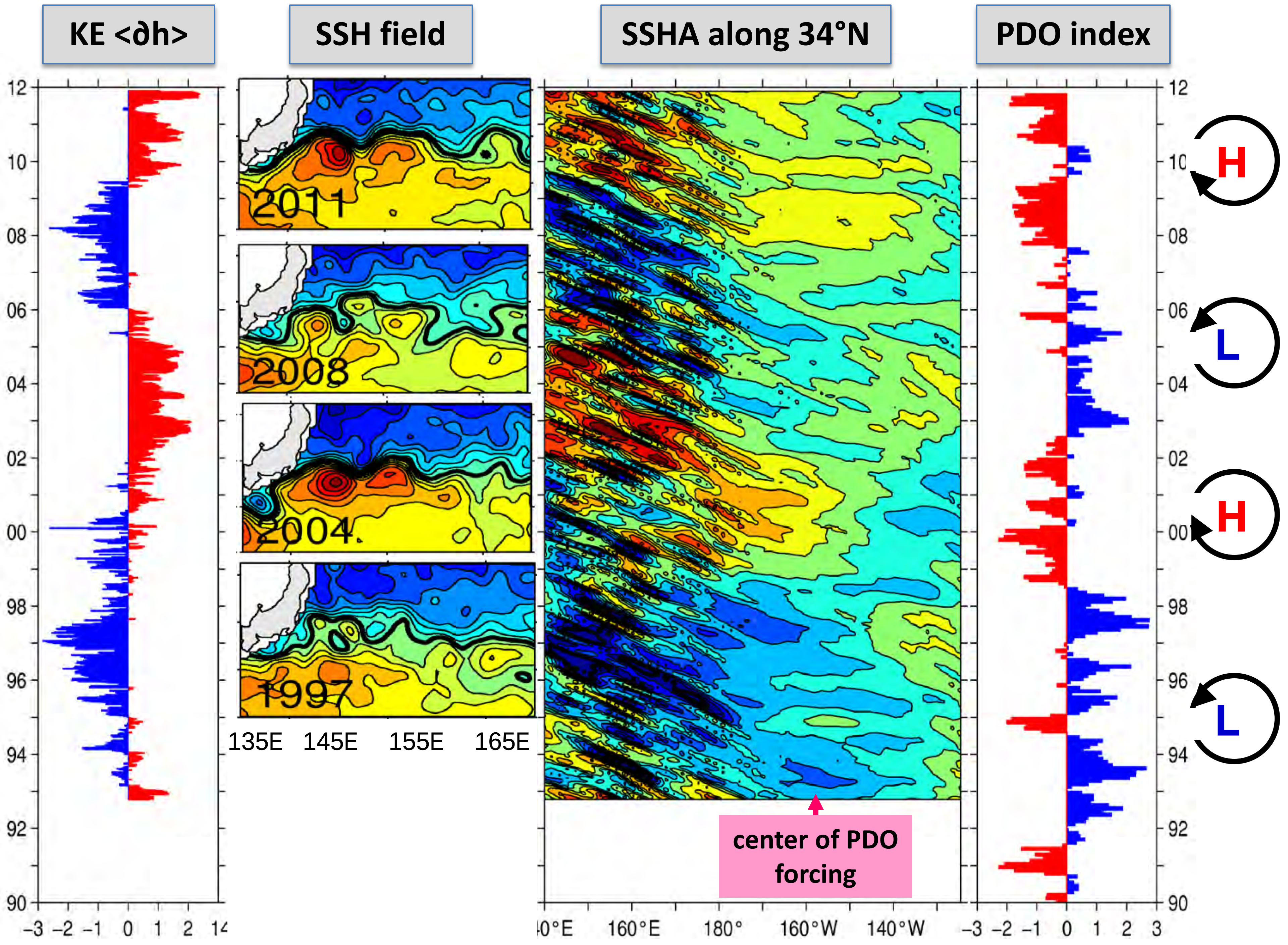
Decadal KE variability lags the PDO index by 4 yrs (r=0.67)







Di Lorenzo et al. (2008, GRL)


KE <∂h>
SSH field
SSHA along 34°N
PDO index
2011
2008
2004
1997
135E
145E
155E
165E
160°E
180°
160°W
140°W
center of PDO forcing
H
L
H
L
12
10
08
06
04
02
00
98
96
94
92
90
−3
−2
−1
0
1
2
3

SSH variability vs wind forcing

- Large-scale SSH changes are governing by linear vorticity dynamics:

$$\frac{\partial h}{\partial t} - c_R \frac{\partial h}{\partial x} = -\frac{g' \nabla \times \boldsymbol{\tau}}{\rho_o g f}$$

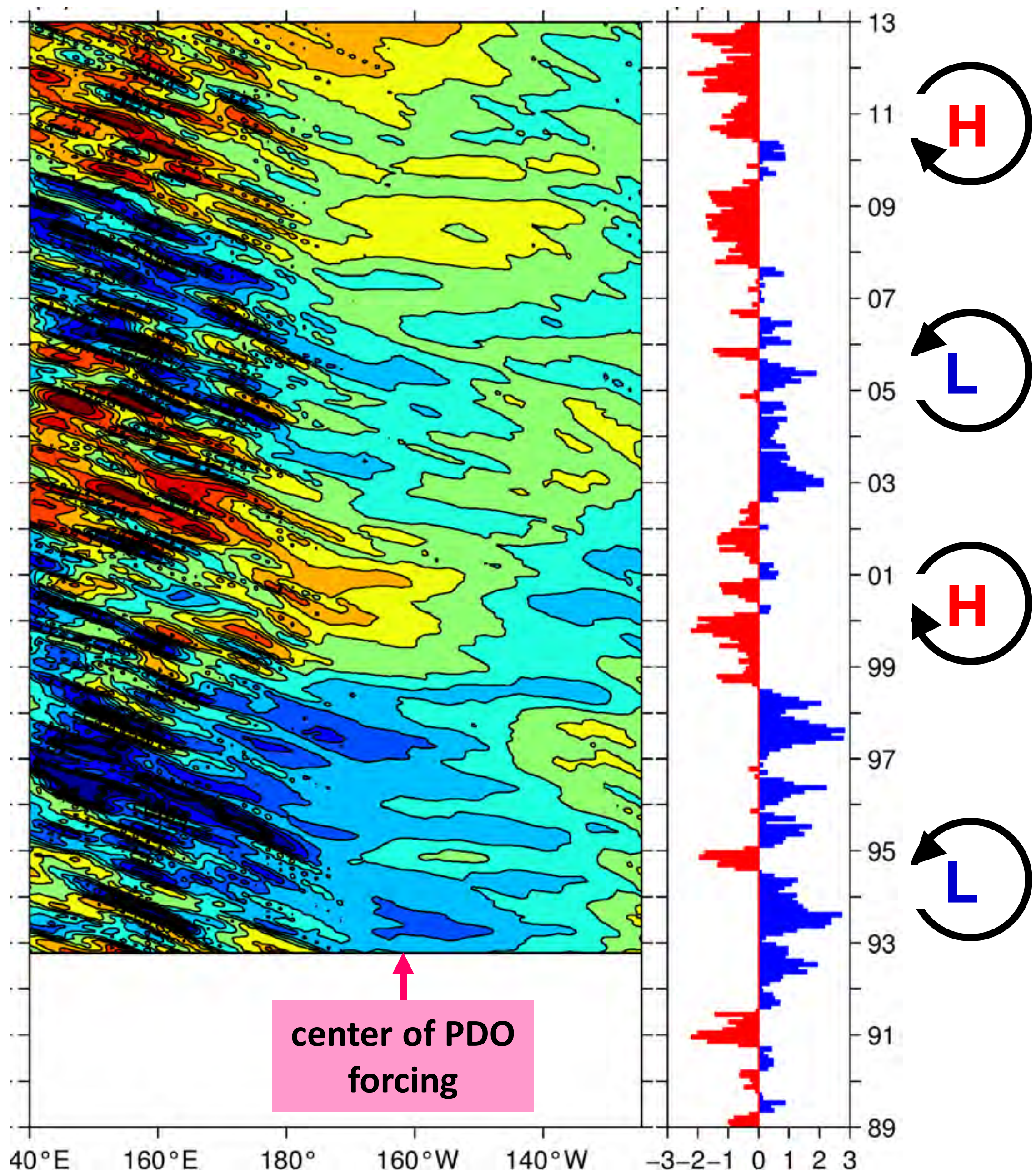
- Given the wind forcing, SSH changes can be found along the Rossby wave paths:

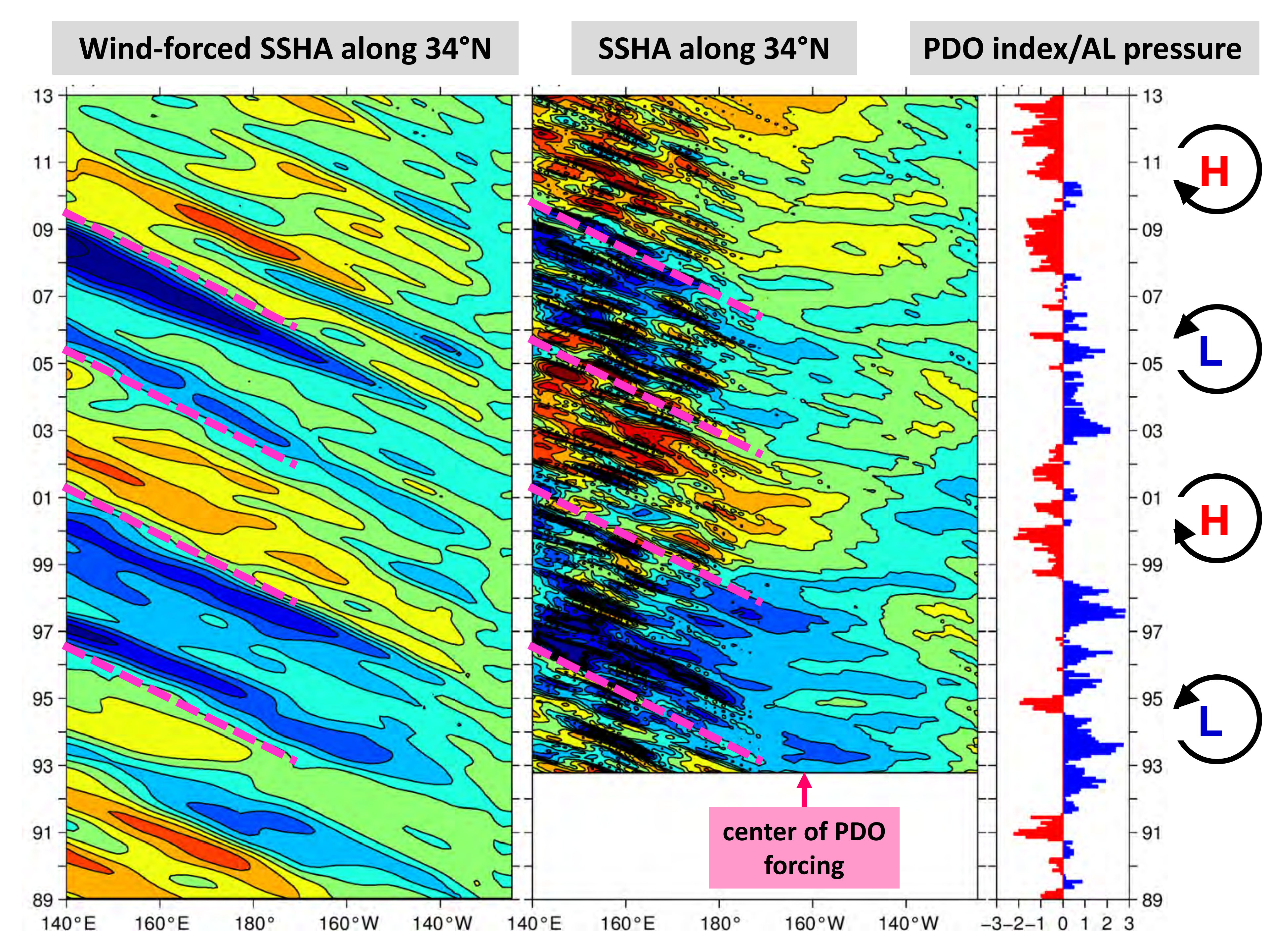
$$h(x,t) = h\left(x_e, t + \frac{x - x_e}{c_R}\right) + -\frac{g'}{\rho_o g f c_R} \int_{x_e}^{x} \nabla \times \boldsymbol{\tau} \left(x', t + \frac{x - x'}{c_R}\right) dx'$$

cf. Qiu and Chen (2005); Taguchi et al. (2007); Ceballos et al. (2009); Sasaki et al. (2013)

SSHA along 34°N

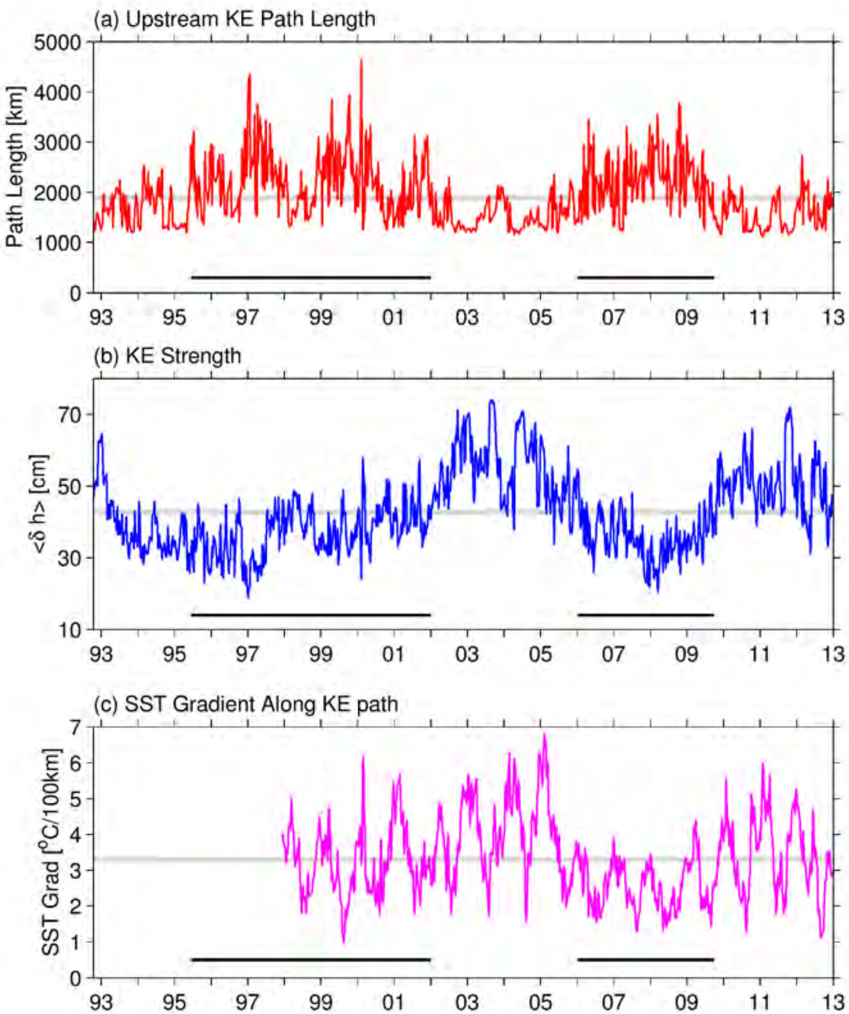
PDO index/AL pressure

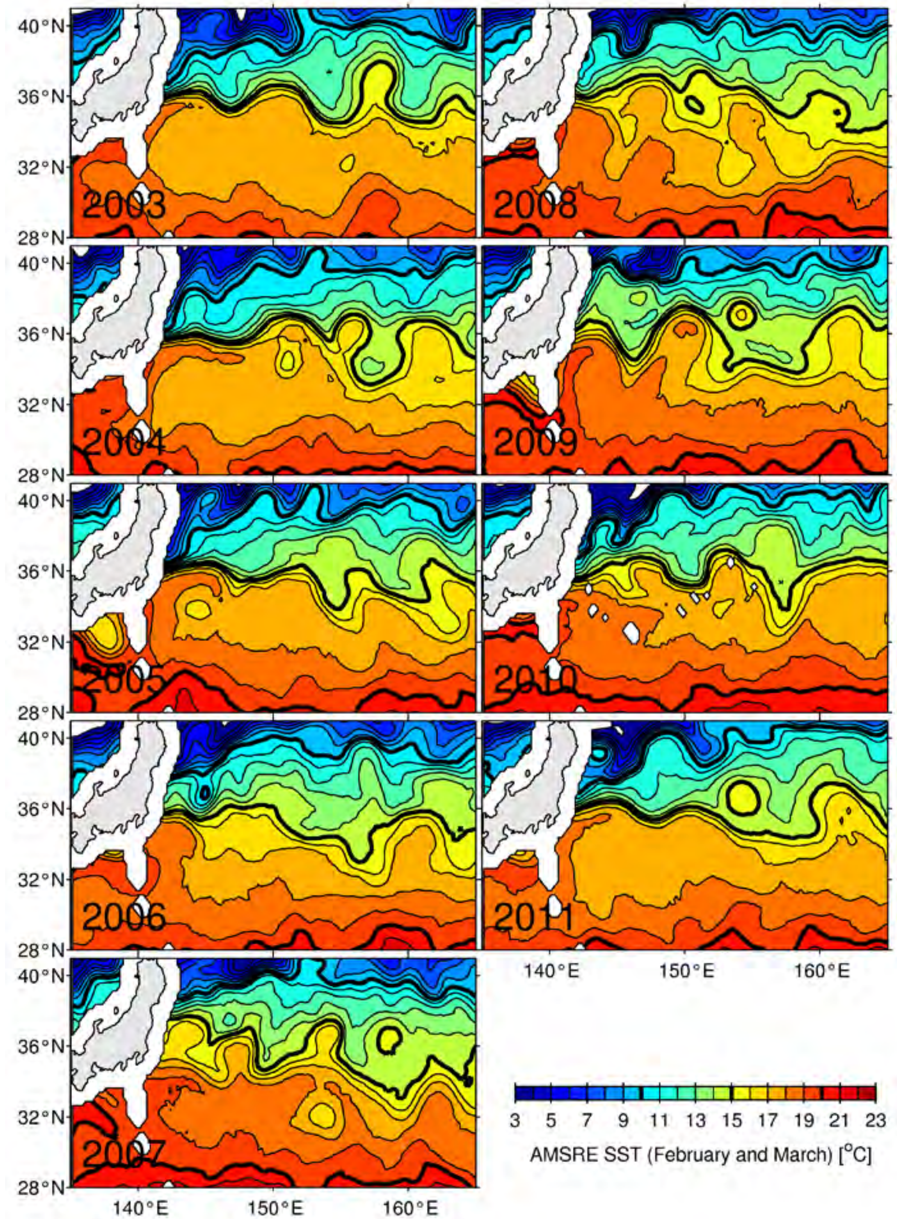




Wind-forced SSHA along 34°N
SSHA along 34°N
PDO index/AL pressure
13
11
09
07
05
03
01
99
97
95
93
91
89
140°E
160°E
180°
160°W
140°W
−3 −2 −1 0 1 2 3
H
L
H
L
center of PDO forcing

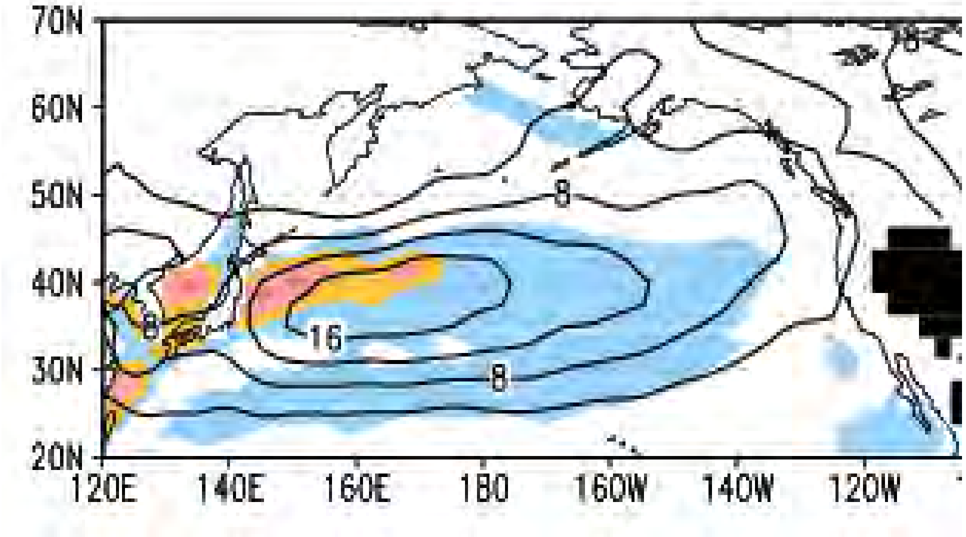
KE dynamic state affects regional SST and cross-front SST gradient



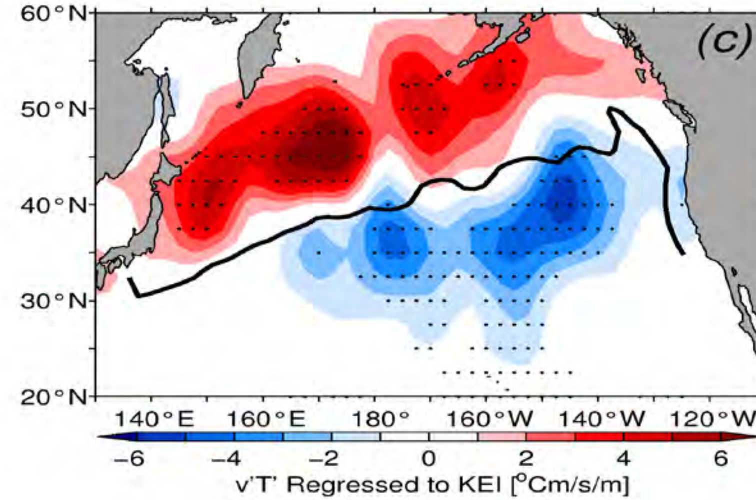


Q2: What are the dynamic implications of the decadal KE variability?

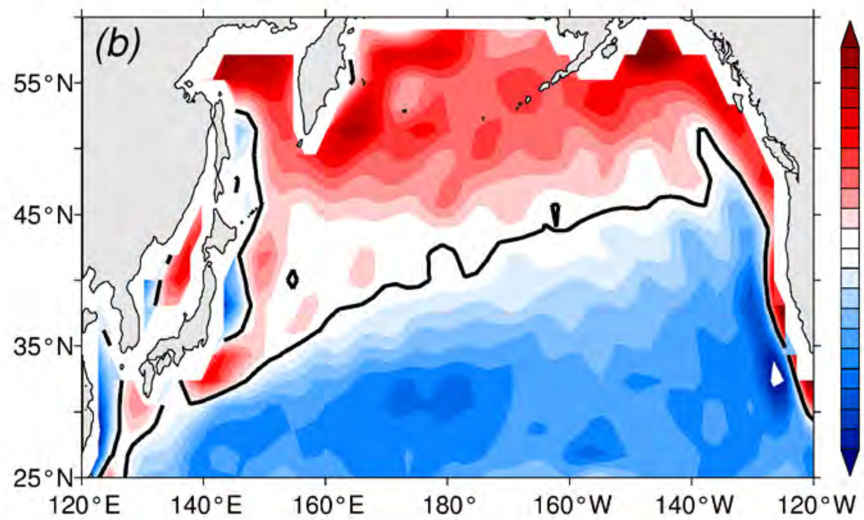
JF rms 850mb v’T’ of stormtrack variability (contours; Nakamura et al. 2004)



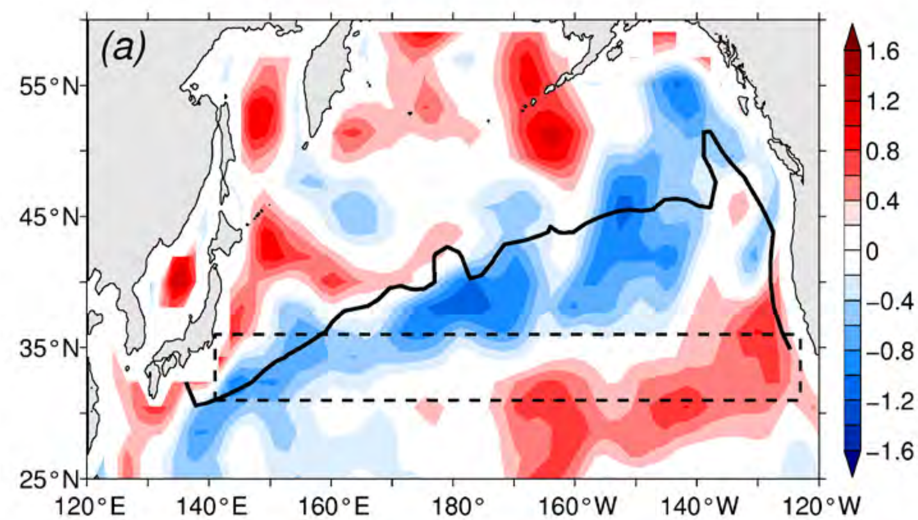
850mb v’T’ and Q’ regressed to the KE dynamic state in 1977-2012



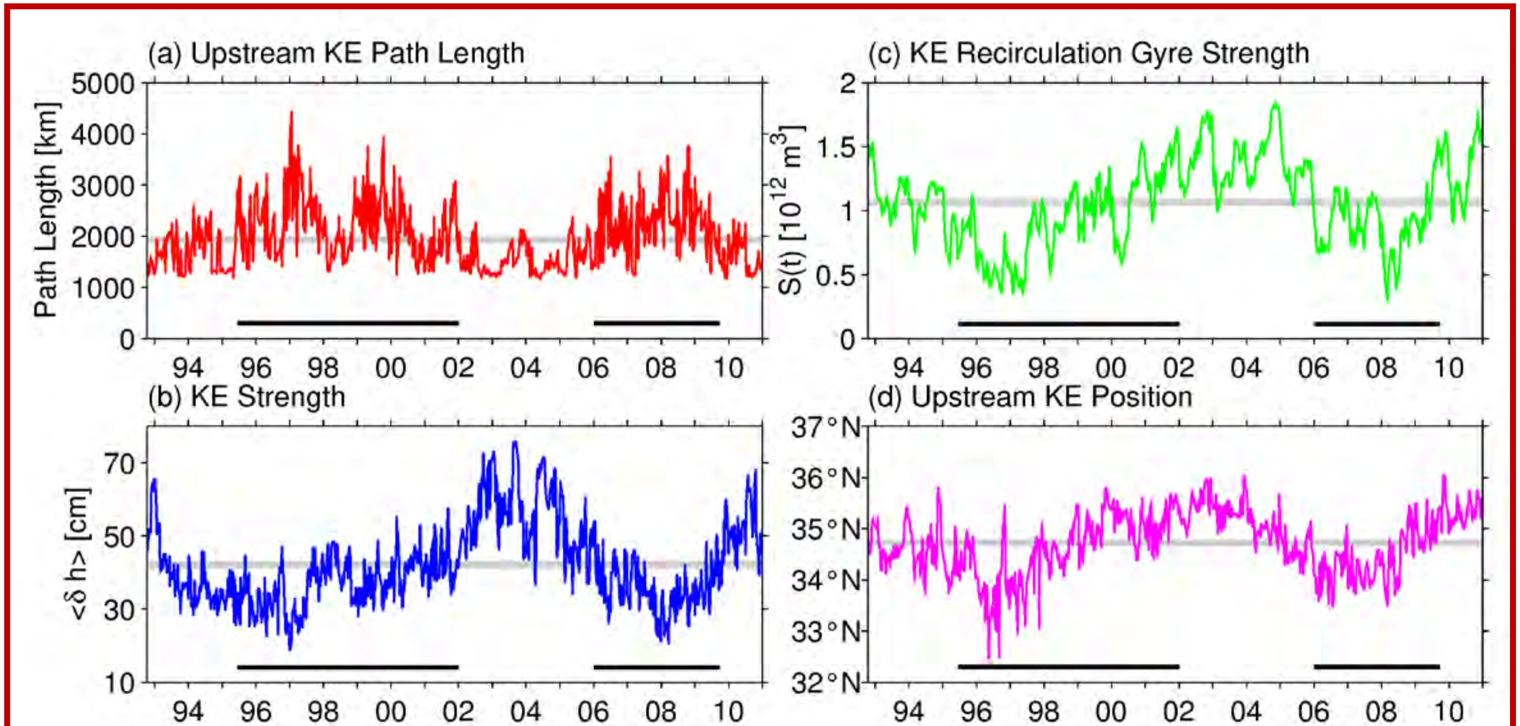
NCEP mean wind stress curl field

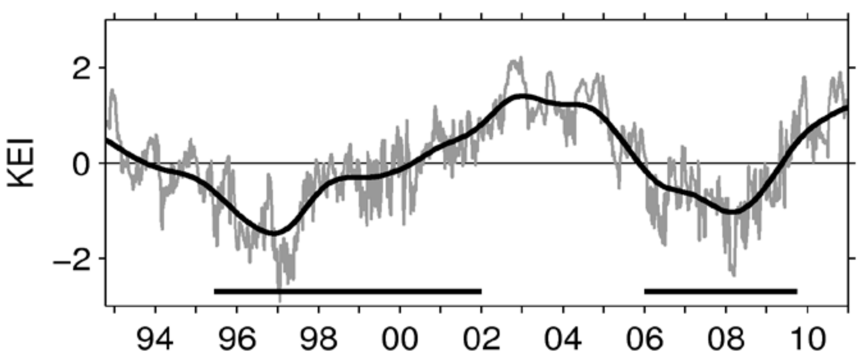


Anomalous wind stress curls regressed to the KE dynamic state in 1977-2012



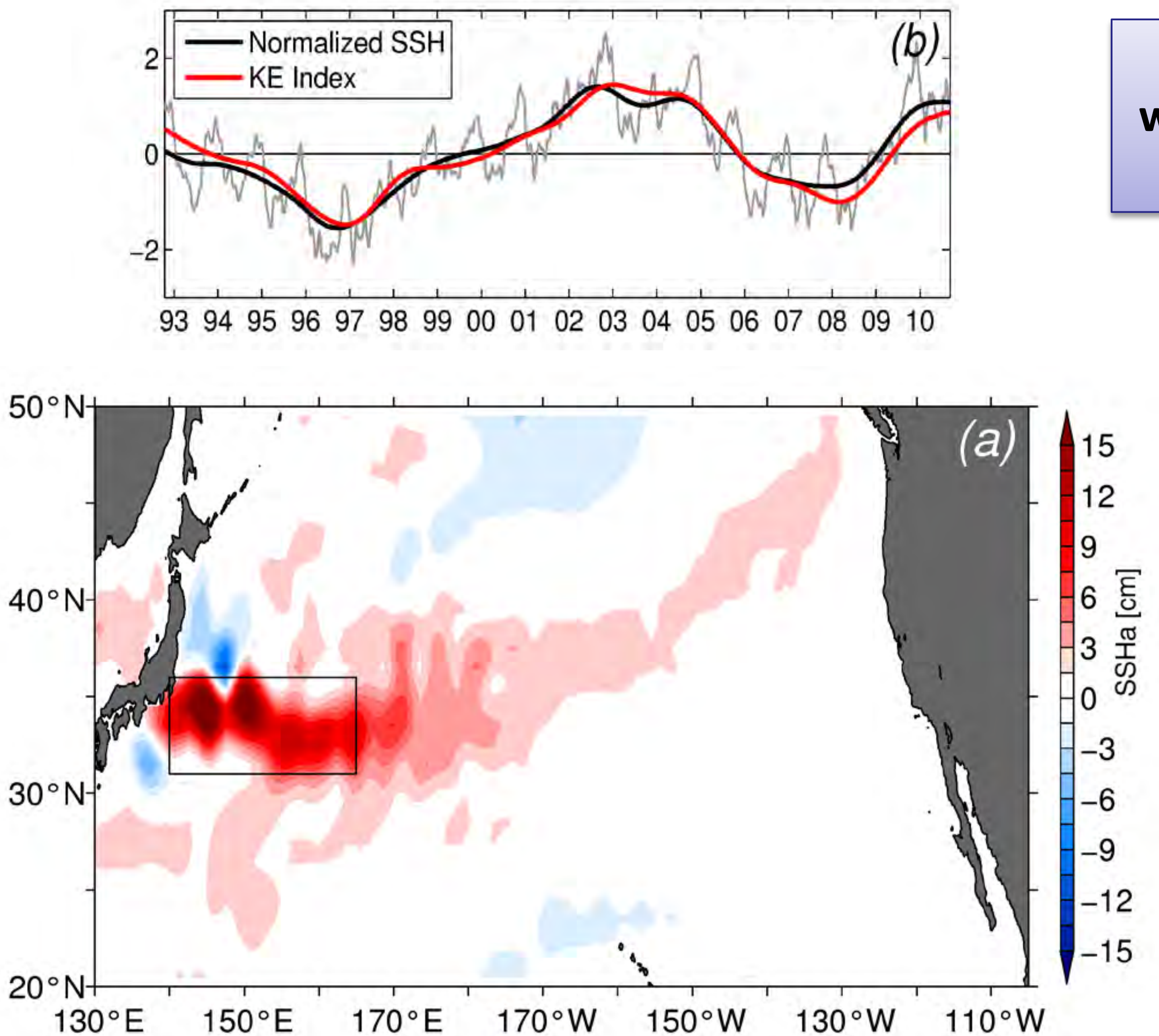
Q3: To what extend can the decadally-modulating KE state be predicted?





KE index : average of the 4 dynamic properties (normalized)

Regression between the KE index and the AVISO SSH anomaly field



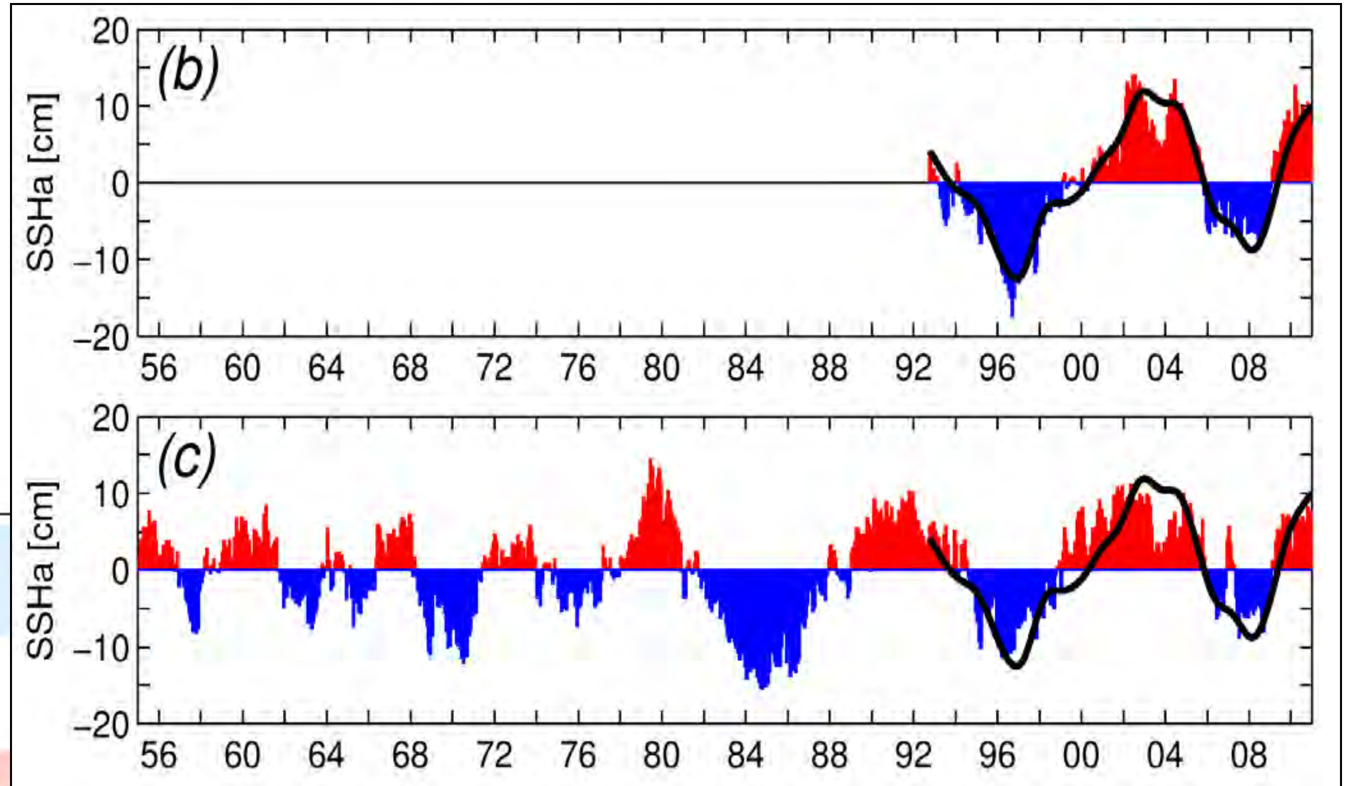
KE index: represented well by SSH anomalies in 31-36°N, 140-165°E

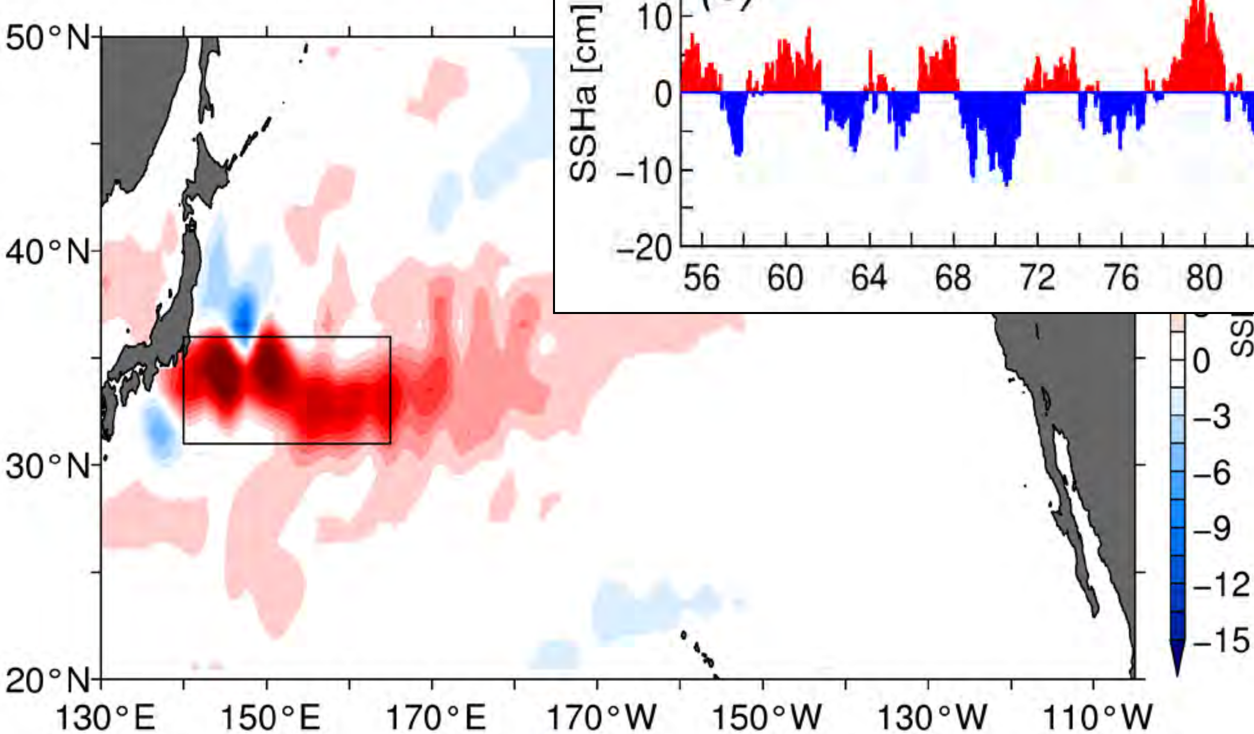
Implications:

Predicting KE index becomes equivalent to predicting SSH anomalies in this key box

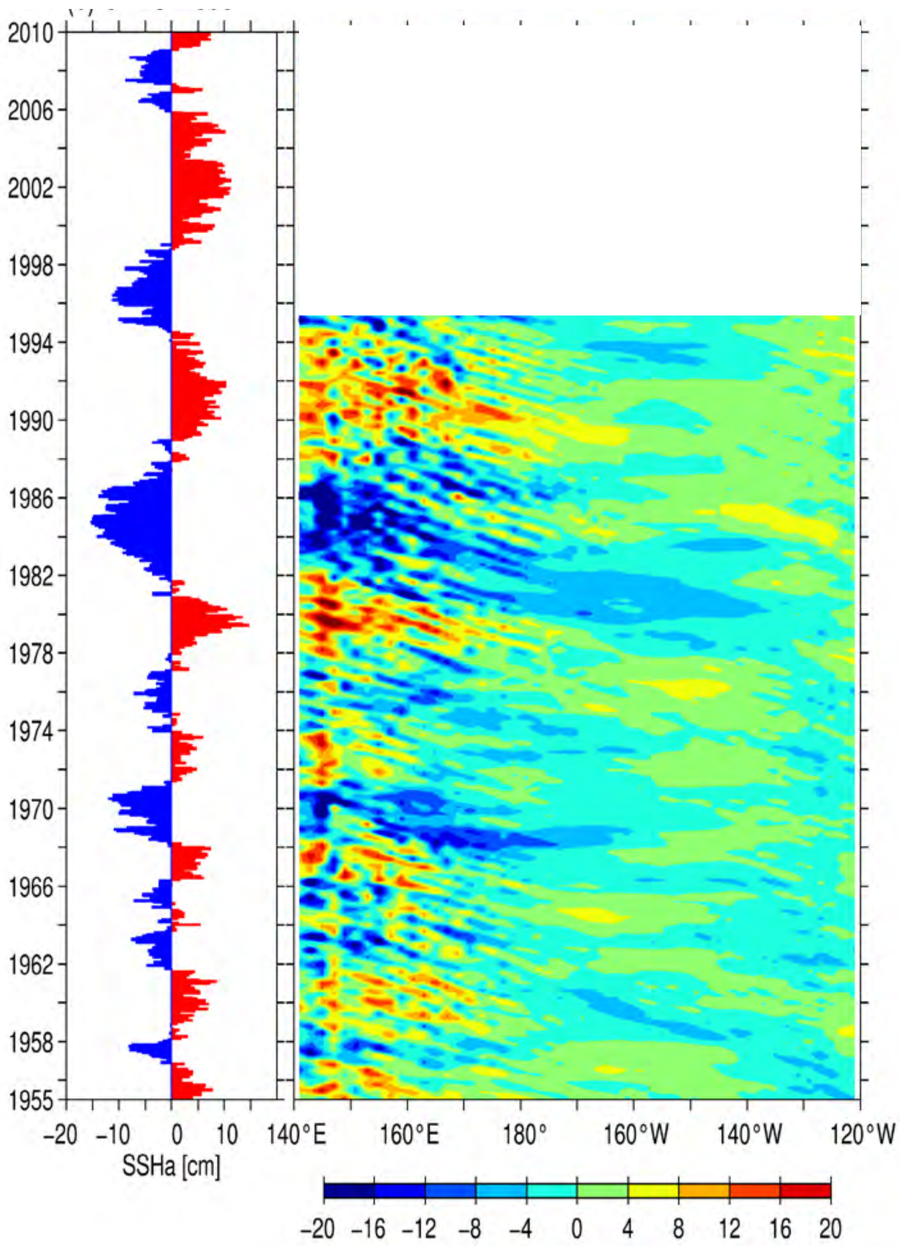
Lengthening the (proxy) KE index using the OFES hindcast results

OFES hindcast run simulates well the observed decadal KE variability (see Taguchi et al. 2007; Nonaka et al. 2008)





KE index and x-t SSHAs



1. Prediction with Rossby wave dynamics

$$h_1(x, t) = h_{obs}\,[\,x+c_R(t-t_0),\, t_0\,]$$

where

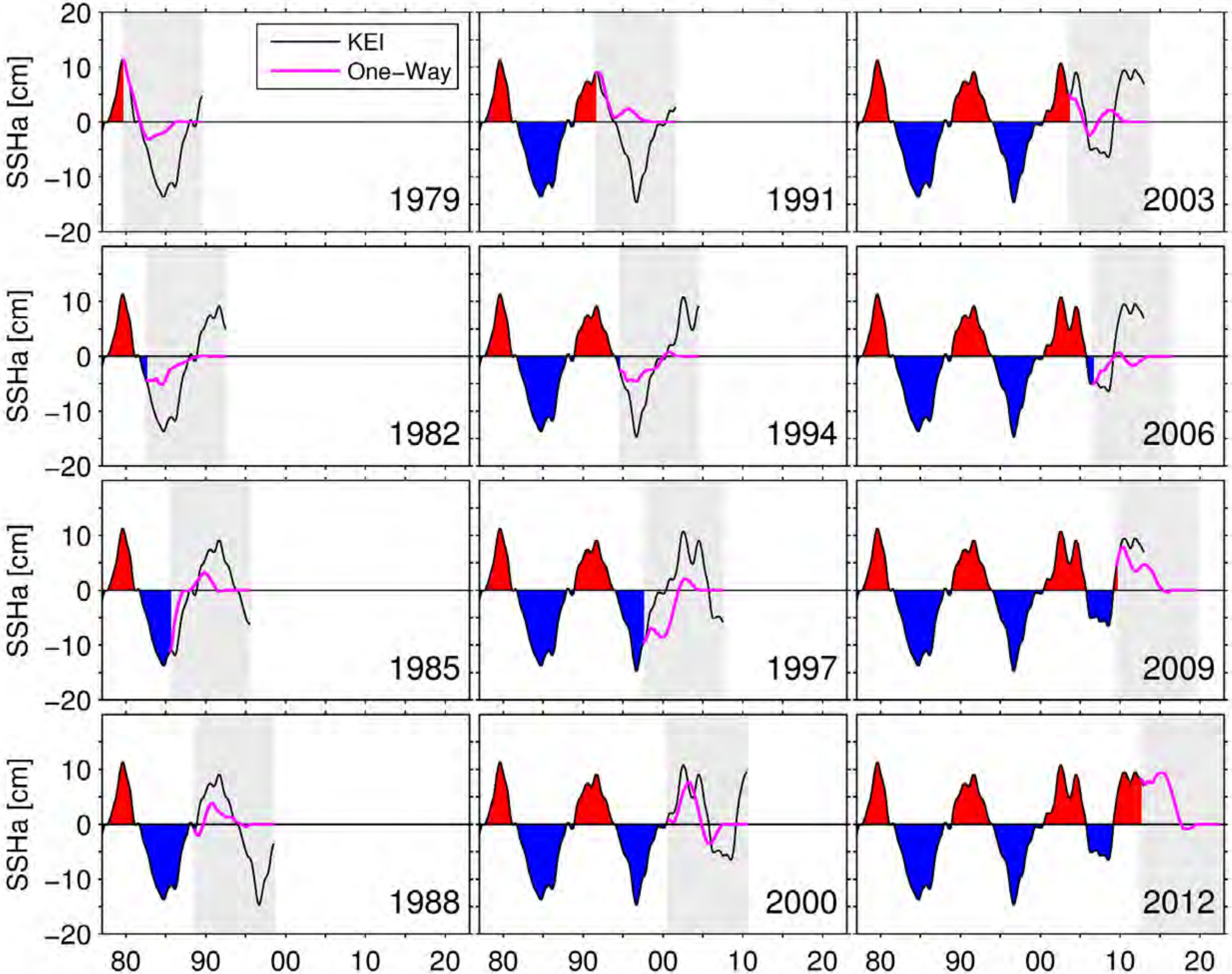
$h_{obs}(x, t_0)$ **: initial SSHAs**

c_R **: Rossby wave speed**

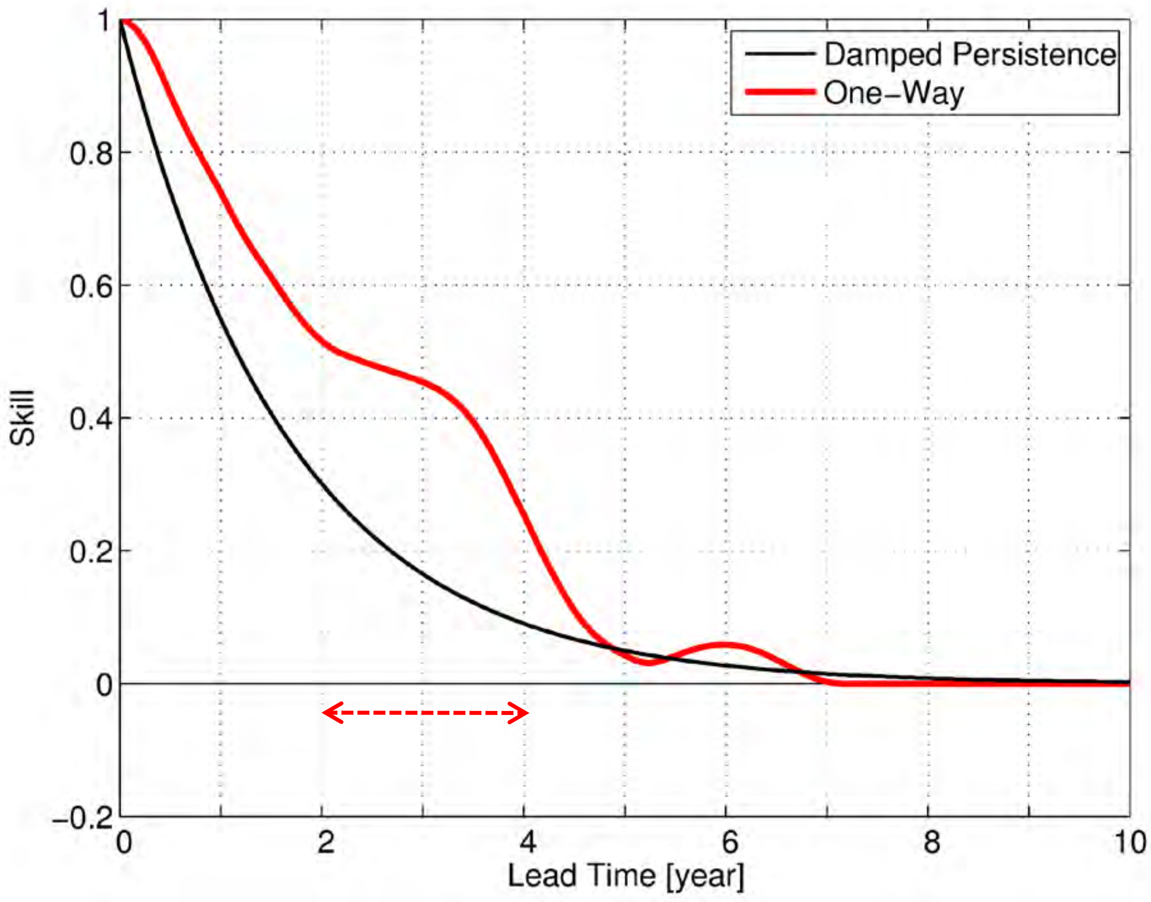
The basis for long-term KE index prediction rests on 2 processes:

1. Oceanic adjustment in mid-latitude North Pacific is via slow, baroclinic Rossby waves

Examples of decadal KE index predictions and verifications

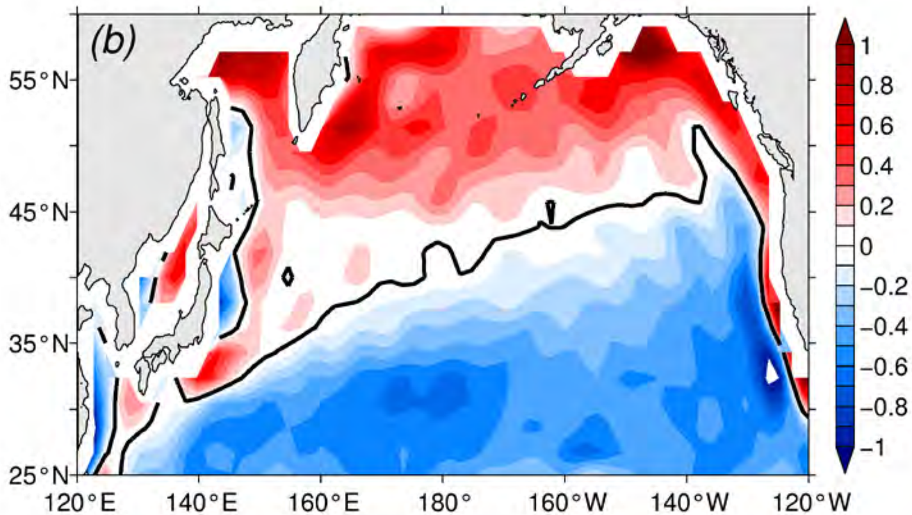


Mean square skill of the predicted KE index



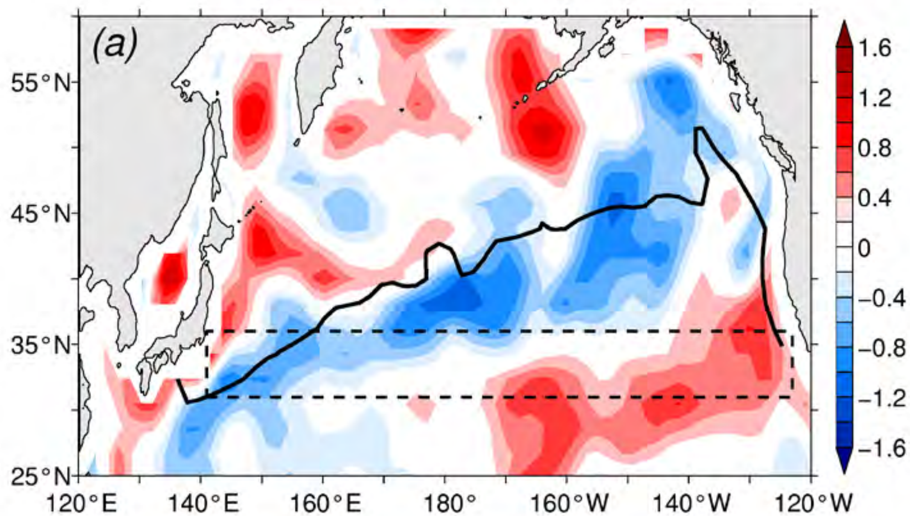
- **Compared to damped persistence, wave-carried SSHAs increase predictive skill with a 2~3 yr lead (Schneider and Miller 2001)**

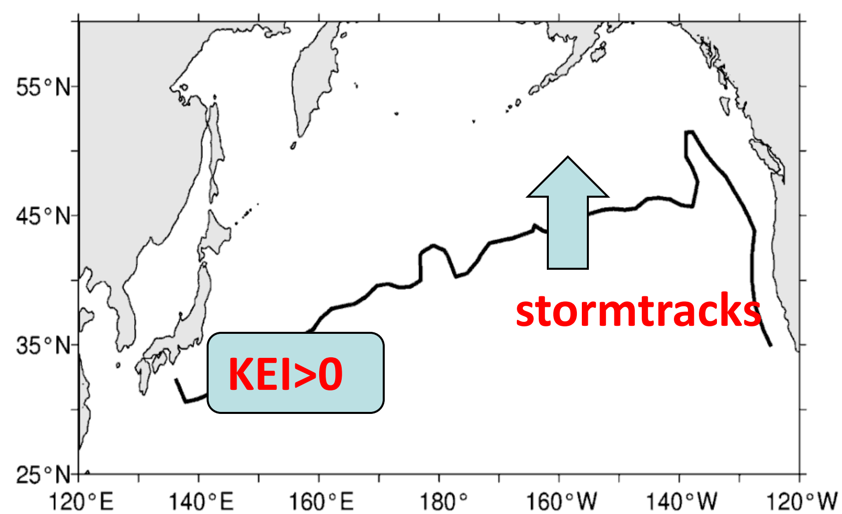
NCEP mean wind stress curl field



The basis for long-term KE index prediction rests on 2 processes:

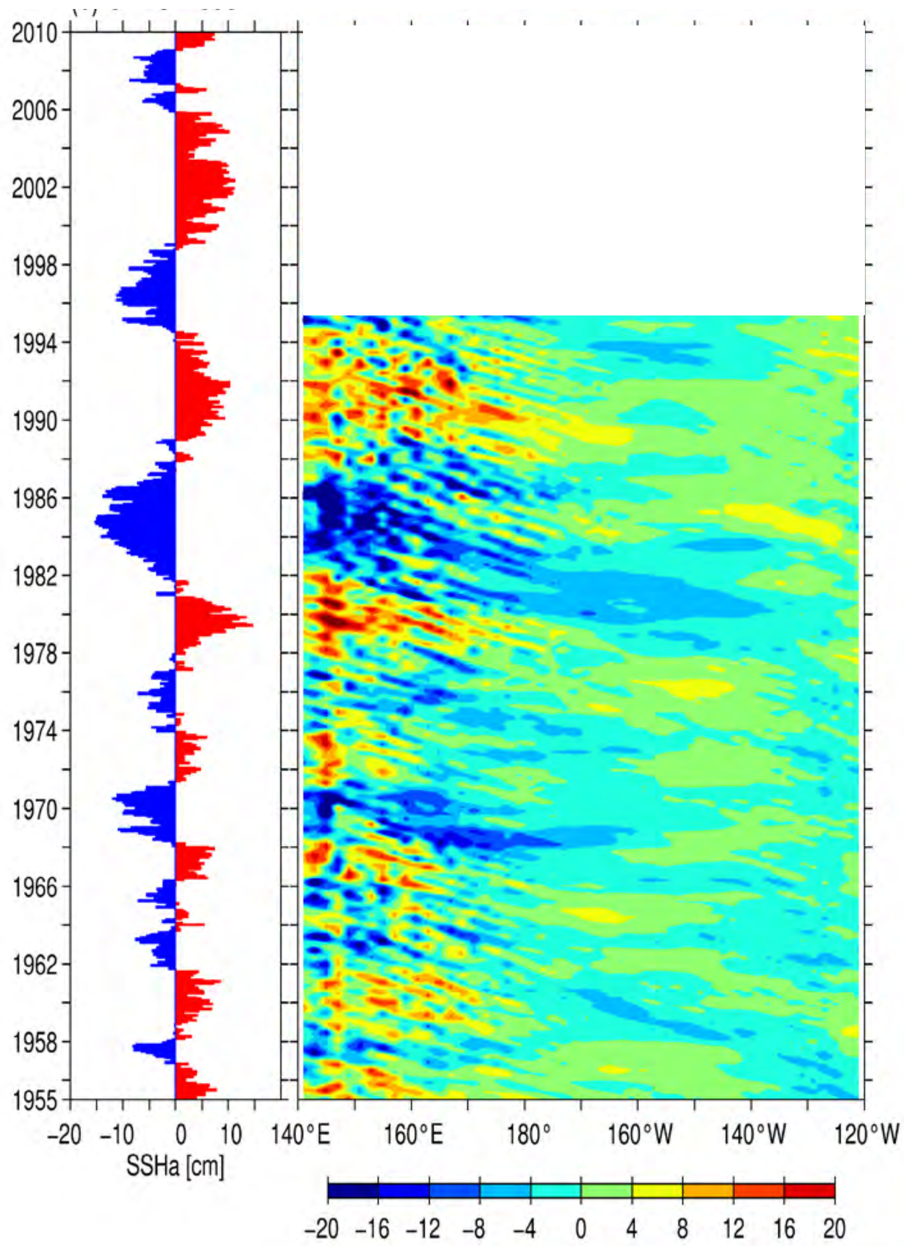
2. The KE decadal variability affects the basin-scale wind stress curl field





KE index-regressed curl field (tropical influence removed)

KE index and x-t SSHAs



1. Prediction with Rossby wave dynamics

$$h_1(x, t) = h_{obs} [\, x+c_R(t-t_0), t_0 \,]$$

where

$h_{obs}(x, t_0)$ **: initial SSHAs**

c_R **: Rossby wave speed**

2. Prediction with Rossby wave dynamics + KE feedback to wind forcing

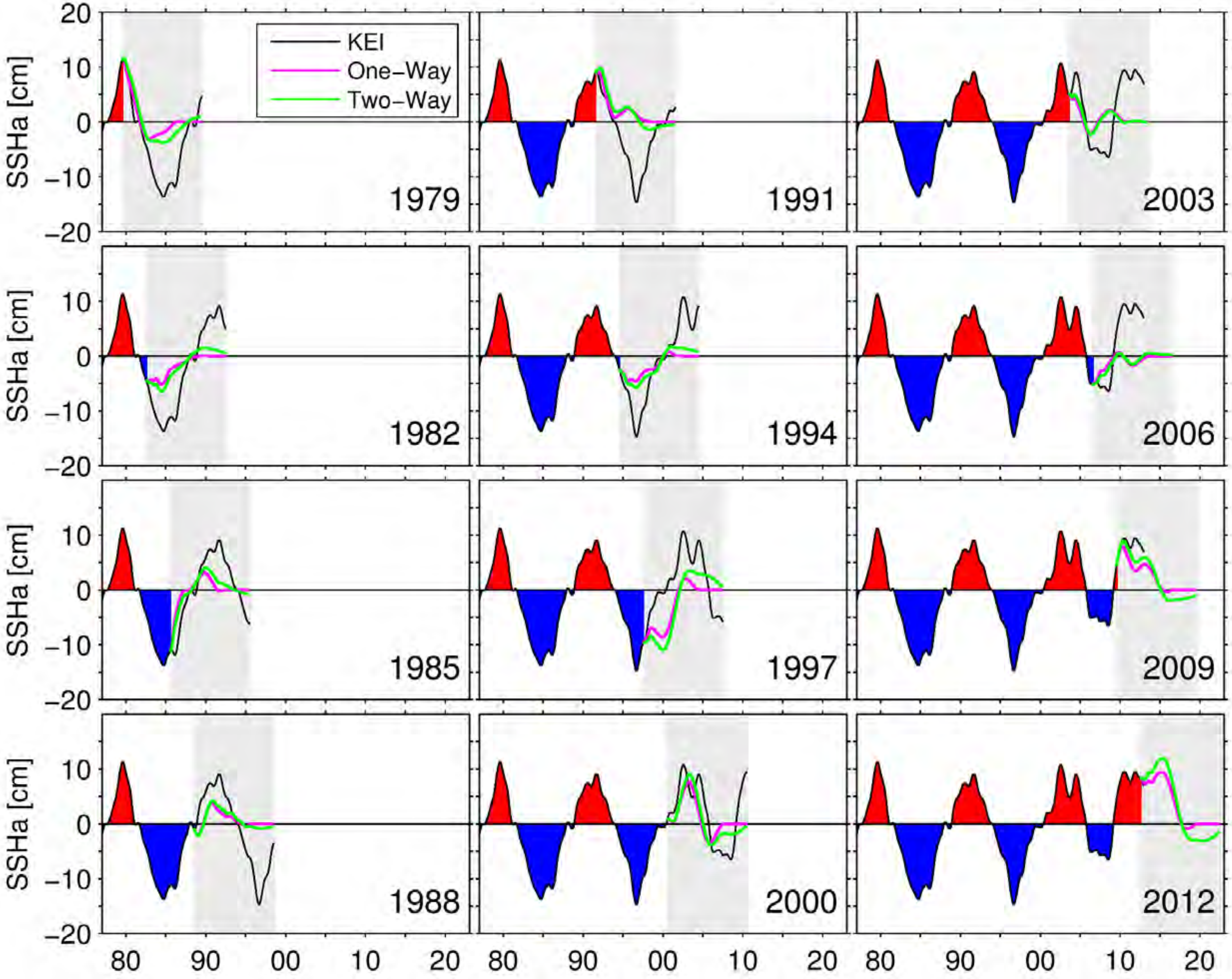
$$h_2(x, t) = h_1(x, t) + \int_{t_0}^{t} b[\, x+c_R(t'-t_0) \,]\, K(t')\, dt'$$

where

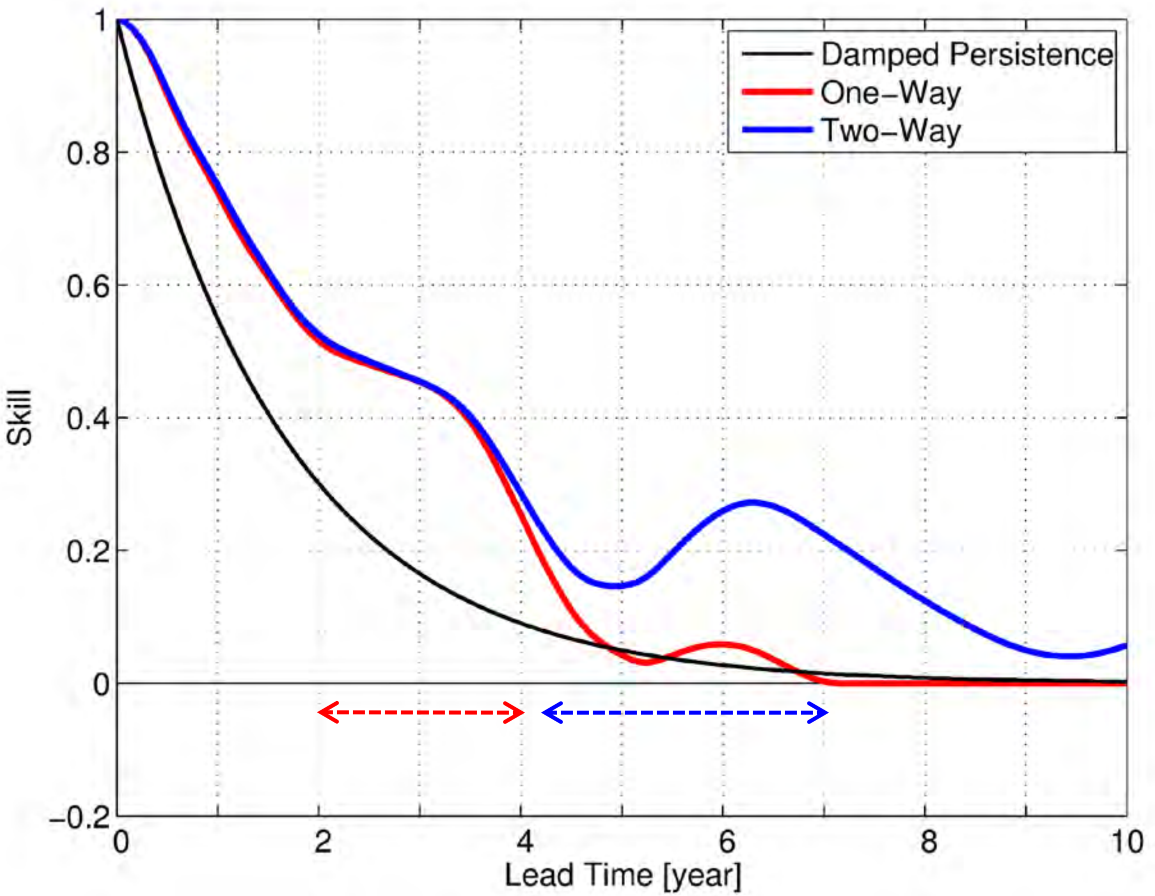
$b(x)$ **: feedback coefficient**

$K(t)$ **: forecast KE index**

Examples of decadal KE index predictions and verifications

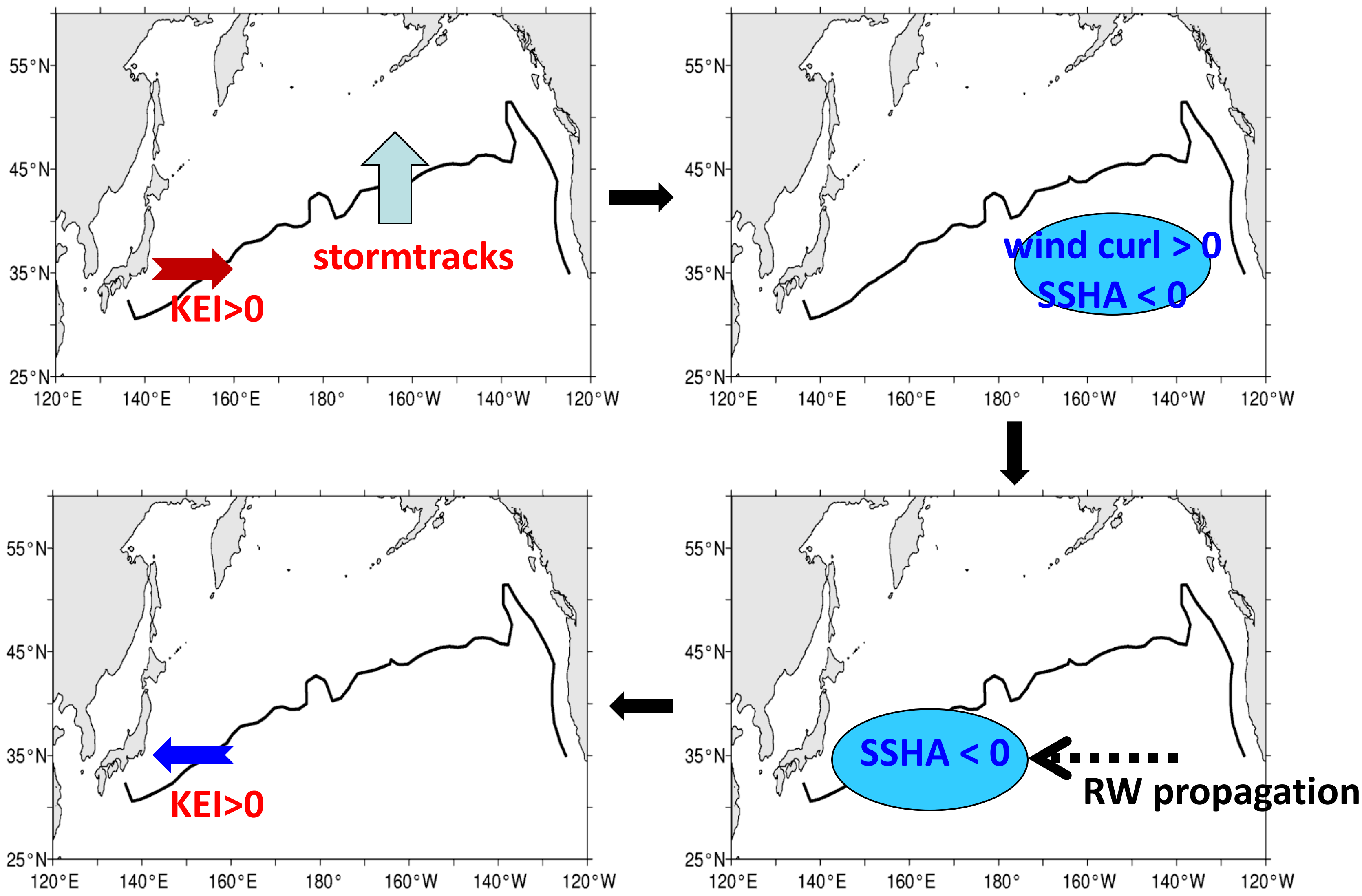


Mean square skill of the predicted KE index



- Compared to damped persistence, wave-carried SSHAs increase predictive skill with a 2~3 yr lead (Schneider and Miller 2001)
- Additional skill is gained with the 4~6 yr lead by considering the wind forcing due to KE feedback

The reason behind enhanced predictive skill with the 4~6 yr lead: delayed negative feedback mechanism



half of the oscillation cycle: ~5 yrs in the N Pacific basin

Summary

- KE dynamic state (i.e. EKE level, path, and jet/RG strengths) is dominated by decadal variations. It impacts the cross-front SST gradient and overlying stormtracks.
- SSH anomaly signals in 31-36°N, 140-165°E provide a good proxy for the decadally-varying KE system.
- A positive KE index induces overlying-high and downstream-low pressure anomalies. This feedback favors a coupled mode with a ~10 yr timescale.

  → Oscillatory nature of this mode enhances predictability
- Compared to Rossby wave dynamics, inclusion of the KE-feedback wind forcing increases predictive skill with a lead time from 2~3 to 4~5 yrs.
- Due to the persistent negative PDO phase, a prolonged stable KE dynamic state (until 2017) is predicted.