Influence of the variability of the Kuroshio Extension on the atmospheric circulation

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Thanks to Bo Qiu, University of Hawaii, for providing the KE time series
Frontal zones in the North Pacific Western Boundary Current extensions

\[ T \text{ (contour), } \partial T / \partial y \text{ (color)} \]

Winter conditions
OFES hindcast 0.1° x 0.1°
Subarctic frontal zone (Oyashio Extension)
Kuroshio Extension
Large deep temperature gradient

Cyclogenesis density
Pronounced generation of storm in KOE region

Hoskins and Hodge 2002
Nonaka et al. 2006

KOE
Frontal zones in the North Pacific Western Boundary Current extensions

Winter conditions
OFES hindcast 0.1° x 0.1°

Subarctic frontal zone (Oyashio Extension)
Shallow, strong SST gradient
Kuroshio Extension
Large deep temperature gradient

Nonaka et al. 2006

KOE

The observed interannual to decadal meridional shifts of the OE and the KE seem to have a significant influence on the wintertime atmospheric circulation and transient eddy activity

Frankignoul et al. 2011; Taguchi et al. 2012
Joyce and Kwon 2009, Kwon and Joyce 2013

Hoskins and Hodge 2002
WBC indices in Frankignoul et al. (2011)

KE index: PC1 of latitude of 14°C isotherm anomalies at 200m in 142-160°E from historical T profiles, 6 to 12 month-resolution

Not deep enough, poor temporal resolution

OE index: PC1 of latitude of maximum monthly SST anomaly gradient in 145-170°E
WBC indices in Frankignoul et al. (2011)

KE index: PC1 of latitude of 14°C isotherm anomalies at 200m in 142-160°E from historical T profiles, 6 to 12 month-resolution

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OE index: PC1 of latitude of maximum monthly SST anomaly gradient in 145-170°E

KE index, courtesy of Bo Qiu
1979 - 2012 (ERA Interim)

monthly SSH anomalies in 31-36°N, 140-165°E

1979-1992: OFES
1993-2012: altimetry

Positive SSH: northward KE shift, increased transport, shorter path length, strengthened recirculation gyre strength

Correlation with previous index 0.5

Univariate analysis neglects weak collinearity
Winter response to KE variability (NDJFM)

Similar signal between NDJ and JFM

Black contour: 10% significance

ERA interim monthly anomalies

ENSO influence removed (asym. seasonal regression on 2 rotated EOFs)

Large equivalent barotropic response

Typically 35 m at 250 hPa

Largest signal at lag 2
Stable with lag
Winter response to KE variability (NDJFM)

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Largest signal at lag 2
Stable with lag

Westward tilt with height at high latitude
Winter response to KE variability (NDJFM)

Similarity with the Arctic Oscillation (AO)

SLP NDJFM Lag: 2 mois

Z250 NDJFM Lag: 2 mois

Black contour: 10% significance

SLP Lag: 2 months

Z250 Lag: 2 months

ERA interim monthly anomalies
Oceanic forcing associated with the KE variability

Regression on KE index

1.5K SST resolution

Basin-scale SST pattern with warming in KE, cooling in subpolar gyre and eastern Pacific

Very persistent

Anomalous heat release in western part of KE

Negative heat flux feedback in western North Pacific (persistent when HF lags KE by 3 to at least 6 mo)

Turbulent heat flux from OAflux
\[
\frac{\partial T}{\partial y}
\]

**Strengthened, extended SST gradient**

**Climatology in green or dashed line**

**Regression on KE index**

**Eady growth rate at 850 hPa in \(10^{-2} \text{ day}^{-1}\)**

\[
\sigma_B = 0.31 \frac{f \left| \frac{\partial U}{\partial z} \right|}{N}
\]

**Northeastward shift**
Regression on KE index

\[ \frac{\partial T}{\partial y} \]

Strengthened, extended SST gradient

Climatology in green or dashed line

\[ \sigma_{BI} = 0.31 \frac{f}{N} \frac{\partial U}{\partial z} \]

ERA interim

Eady growth rate at 850 hPa in \(10^{-2}\) day\(^{-1}\)

Northeastward shift

Storm track

(rms Z500 2-6 day)
Climate impact of KE variability

Significant temperature impact in North America, Europe, and East Asia

Broadly consistent with AO signature, but for N Pacific warming

Significant P changes in Pacific sector and Southern Europe
Wind stress forcing of the KE variability

KE changes largely driven by prior wind stress changes over North Pacific

Yearly data, atmosphere leads

Pompage d'Ekman annuel Lag: -3 ans

Climatological Ekman pumping zero line in green

Wind stress forcing in central and eastern North Pacific
Wind stress forcing of the KE variability

KE changes largely driven by prior wind stress changes over North Pacific

As the lag decreases, the atmospheric forcing of the KE becomes less remote
Is there any feedback on the KE variability?

KE leads the atmosphere

Yearly data, atmosphere leads

KE lags the atmosphere

Climatological Ekman pumping zero line in green

Similar forcing and response patterns

Positive feedback
Spring - summer response to KE variability (AMJJA)

There are links to the tropics that we are investigating

Slight westward tilt with height
Atmospheric response to the subpolar front (OE) variability 1982-2012

**Cold season**

NPO-like response for all months (weaker than in FSKA)

Reflects strong cold season NPO/WP-like response

Different, weaker summer response

**Spring - summer**
Cold season response OE meridional shifts (1982-2012)

Large NPO-like equivalent barotropic response
Typically 45/25 m at 250 hPa

NPO/WP teleconnection pattern
Oceanic forcing associated with the OE variability

Turbulent heat flux in Wm$^{-2}$

Local negative Feedback

HF response may cool SST north of OE

1.5K SST resolution

Climatology in green

Shift of OE front and/or basin-scale SST pattern?
Regression on OE index

SST

1.5K SST resolution

Climatology in green

\[ \frac{\partial T}{\partial y} \]

Northward shift and eastward extension of cyclogenesis

\[ \text{Turbulent heat flux in Wm}^{-2} \]

Local negative Feedback

HF response may cool SST north of OE

\[ \text{Eady growth rate in 10}^{-2}\text{ day}^{-1} \]
Regression on OE index

Slight northward shift and eastward extension of cyclogenesis

Storm track
(rms 2-6 d)

Northeastward shift

Climatology in green

Eady growth rate
in $10^{-2}$ day$^{-1}$

SST NDJFM Lag: 0 mois

Z500 filtré NDJFM Lag: 2 mois

$\frac{\partial T}{\partial y}$

Gradient méridien SST NDJFM Lag: 0 mois

Baroclinicité NDJFM Lag: 3 mois

1.5K SST resolution

Partial differential equation for temperature in the meridional direction.
Conclusions (work in progress)

The variability of the KE leads an AO-like signal in the cold season
  Different from FSKA 2011, leading to a positive feedback on the KE

The meridional shifts of the OE lead a NPO-like signal in the cold season
  As in FSKA 2011, but seasonal dependence better seen using 1982-2012

The responses seem linked to SST-induced changes in baroclinity and cyclogenesis
  SST patterns not very different. Different dynamics (broad forcing versus sharp front)?

Different, weaker responses in spring and summer
  Links to tropics and dynamics need to be clarified
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Linear analysis. Asymmetry?

Results based on univariate regressions, but likely to hold in multivariate analysis

Some dependence on the choice of WBC indices
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Some dependence on the choice of WBC indices

The analysis does not distinguish between the influence of WBC shifts and of concomitant basin-scale SST anomalies or other boundary forcing (sea ice, snow)
KE index is highly auto-correlated, OE index more noisy
**Estimating the atmospheric response**

Assume, after cubic detrending

\[ X(t) = F T(t - d) + b e(t - c) + n(t) \]

\( X(t) \) atmosphere, \( T(t) \) WBC index, \( d \) atmospheric response time (1 to 2 mo?)
\( e(t) \) ENSO time series, \( c \) teleconnection delay (1 mo), \( n(t) \) intrinsic atmospheric variability

Define

\[ \hat{X}(t) = X(t) - A e(t-c) \]

\[ \hat{T}(t) = T(t) - B e(t + d - c) \]

with \( A \) and \( B \) determined by regression. Then

\[ \hat{X}(t) = F \hat{T}(t - d) + n(t) \]

ENSO removed by asymmetric seasonally varying regression on first 2 rotated tropical Pacific SST EOFs.
Atmospheric “response” obtained by regression when the WBC index leads by more than the intrinsic atmospheric persistence
Summary

In the cold season, large response to northward shifts of North Pacific WBCs

Kuroshio Extension

Oyashio Extension

AO-like

NPO-like
Associated SST pattern

Kuroshio Extension

Oyashio Extension

Multivariate analysis needed, but weak colinearity ($r = 0.2$)

OE forcing is more localized

not very different SST patterns

(smoothed 1.5° data)
Regression onto AMJJA KE index

- Elongated tripolar pattern
- Some negative heat flux feedback

Turbulent heat flux
Radiation flux?

There are links to the tropics that we are investigating.
Cold season response OE meridional shifts

Large NPO-like equivalent barotropic response

Typically 45/25 m at 250 hPa

Slight westward tilt with height at high latitude

Similar to response in FSKA
Oyashio Extension index

13% of monthly variance
32% of yearly variance