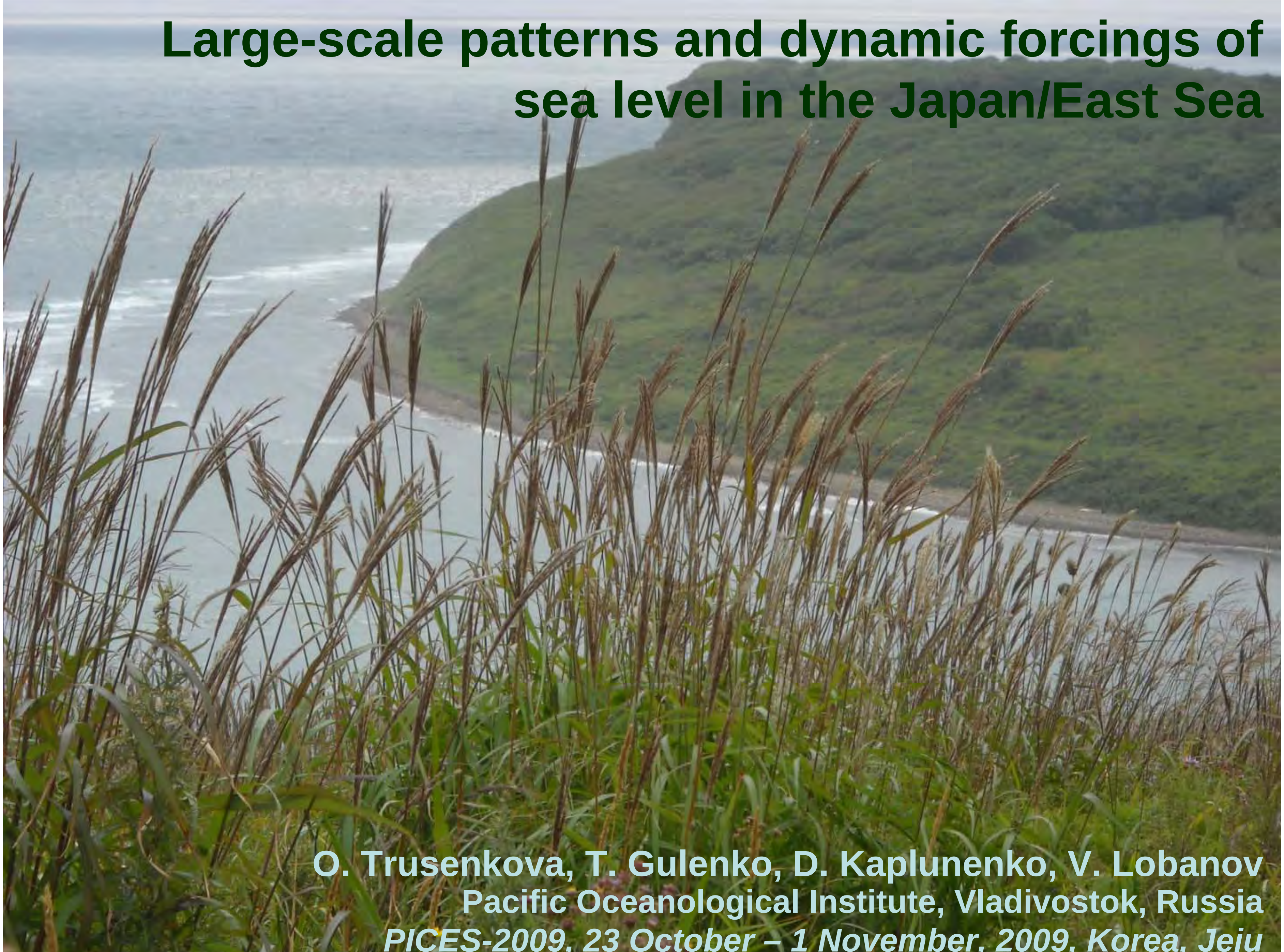
Large-scale patterns and dynamic forcings of sea level in the Japan/East Sea



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PICES-2009, 23 October – 1 November, 2009, Korea, Jeju

Motivation

Sea level as an indicator of climate change, state, and hydrodynamic processes in the ocean.

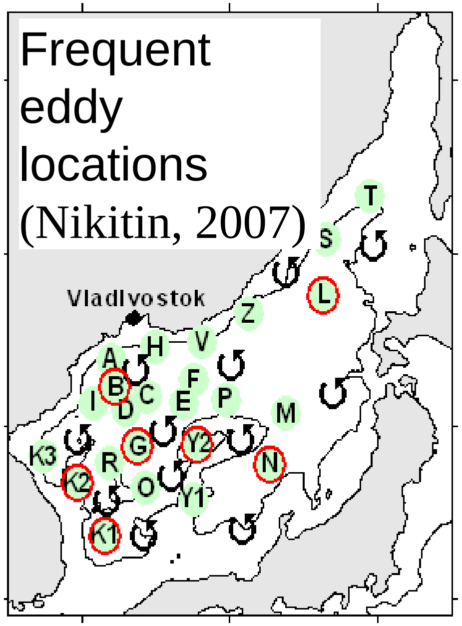
Regular data from satellite altimetry available since early 1990s.

Seasonal signal, QB/decadal variations, and secular trends in the JES estimated from along-track altimetric SLA (Hirose and Ostrovskii, 2000; Gordon and Giulivi, 2004; Teague et al., 2004).

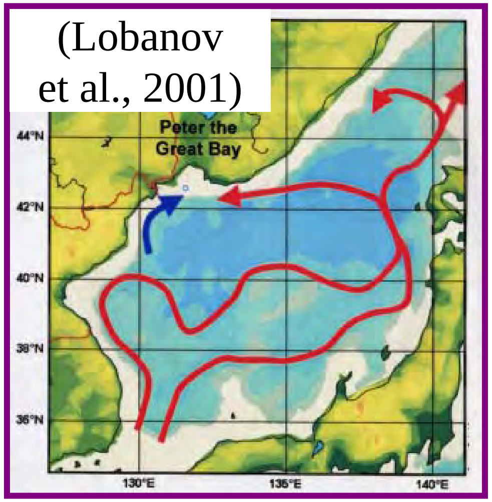
Modes of variability revealed by EOF-analysis from gridded fields (Morimoto and Yanagi, 2001; Choi et al., 2004).

Previous studies are mostly concerned with the southern JES where SLA are large and strongly contribute to EOF modes.

The northern JES: warm eddy formation, transport of warm water from the south by mesoscale features (Lobanov et al., 2001-2007; Nikitin, 2007) induced by AC wind curl (Trusenkova et al., 2007, 2009).



Pathways of warm water transport



Purpose

To revisit the spatial/temporal patterns of sea level in the JES by EOF-analysis of available altimetric gridded SLA, with the emphasis on the northern JES.

Data

AVISO weekly 1/3°-gridded SLA,
October 1992 - July 2006, 35.5°-48°N, 127.5°-142°E.

Error fields for the same dates.

Mean errors 4-4.5 and 3.5-4 cm
in the southern and nothern JES, respectively.

GDEM density climatology for estimation of steric SLA
(gridded dataset generated from individual density profiles).

Techniques of EOF analysis

Traditional EOF analysis: a set of orthogonal patterns focused on areas of large variance.

1) Covariances ~ signal magnitude → anomalies from weaker signals can be lost.

Correlations → detection of small amplitude anomalies, such as SLA in the northern JES

2) Natural patterns are not necessarily orthogonal. However, orthogonality is intrinsic to EOF patterns and larger gap between the eigenvalues, stronger constraint on higher modes.

Successive decompositions after the removal of contribution of a leading mode.

Residual anomalies: $\zeta_2(\mathbf{r}, t) = \zeta_1(\mathbf{r}, t) - A_1(r)\cdot B_1(t)$ →

pre-normalization provided by correlations allows for pattern adjustment in the second decomposition, while covariance-based patterns would not change.

This approach turned out successful for SST in the JES (Trusenkova et al., 2009).

Decompositions

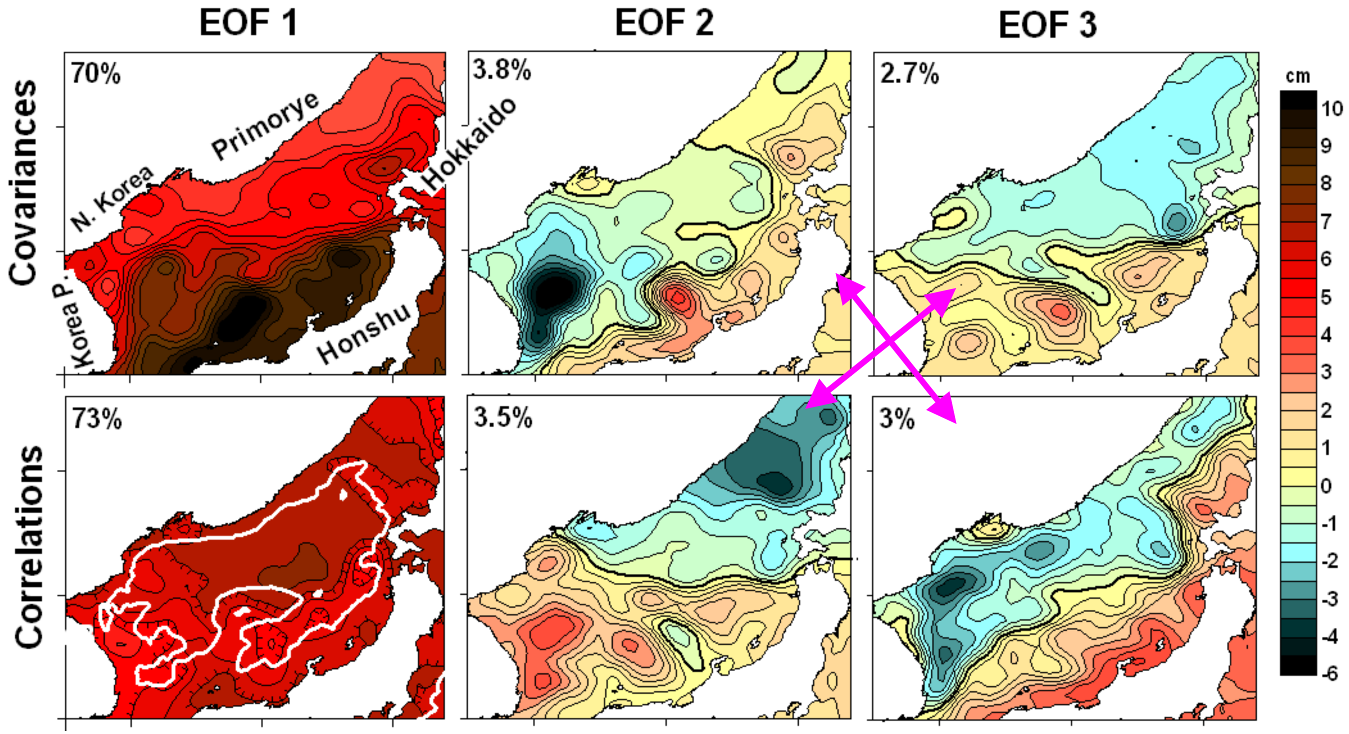
1) Original SLA1, eigenvalues/eigenvectors from covariance matrix.

2) Original SLA1, eigenvalues/eigenvectors from correlation matrix.

3) Residual SLA2, eigenvalues/eigenvectors from correlation matrix.

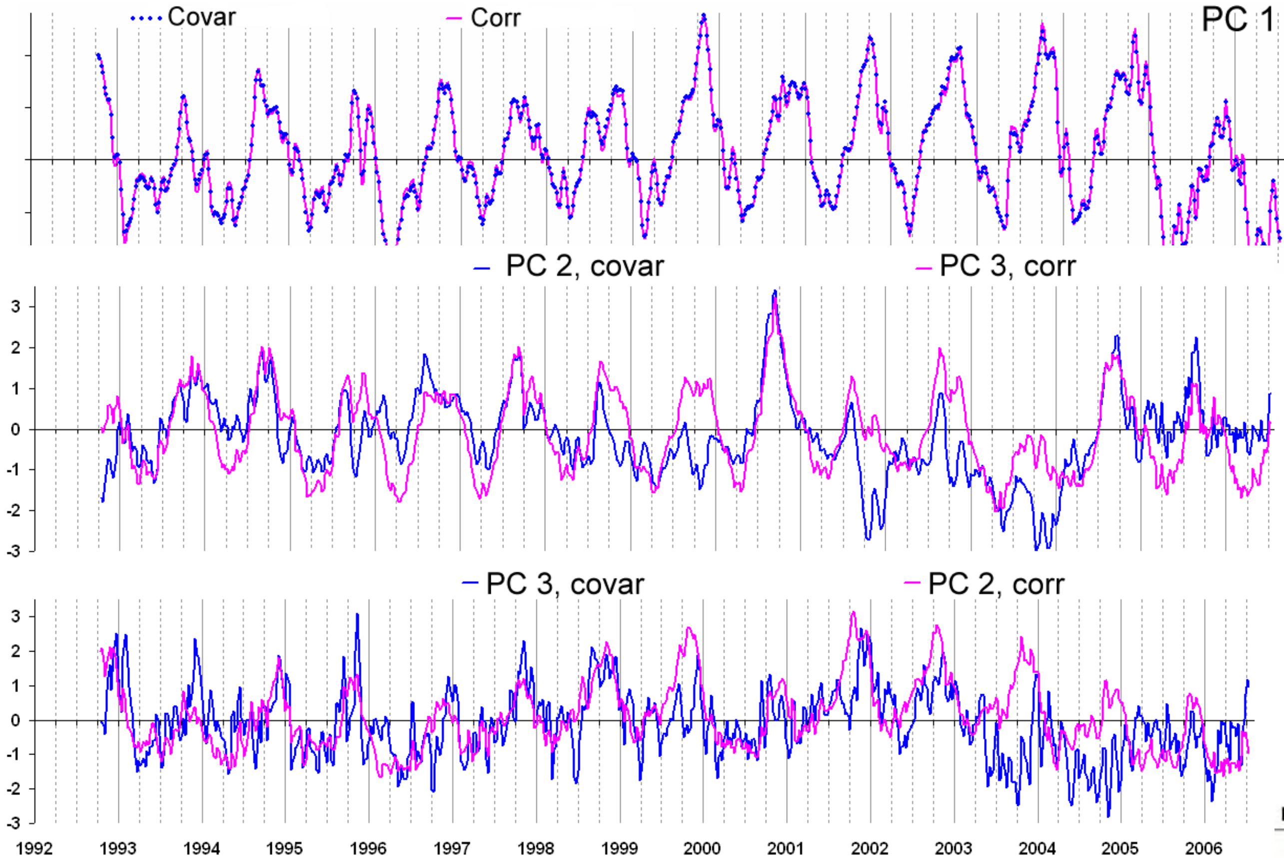
Residual anomalies: $\zeta_2(\mathbf{r}, t) = \zeta_1(\mathbf{r}, t) - A_1(r) \cdot B_1(t)$

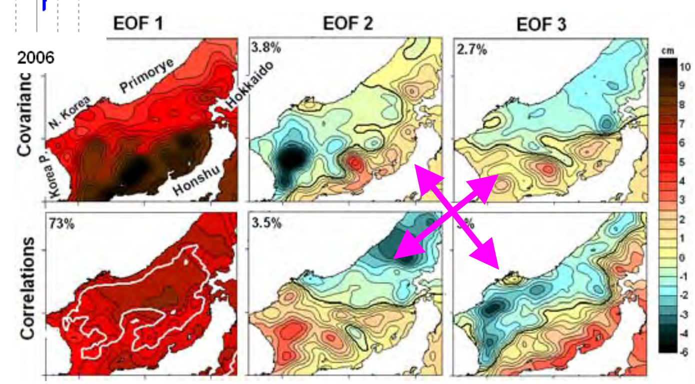
Covariance- and correlation-based decompositions of the original SLA1



Different covariance- and correlation-based EOF 1
Covariance-based EOF 2 ~ correlation-based EOF 3
Covariance-based EOF 3 ~ correlation-based EOF 2

Temporal patterns



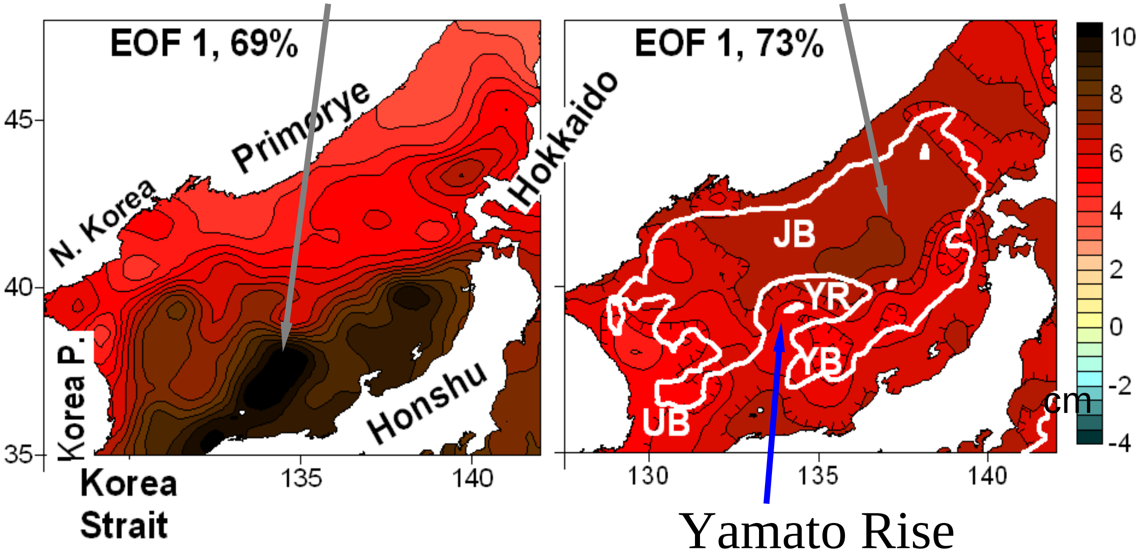


The same PC 1 in both cases but
not quite the same for the higher modes

EOF 1: Synchronous Mode

Covariance-based EOF 1: largest SLA in the southern JES

Correlation-based EOF 1: largest SLA in the northern JES

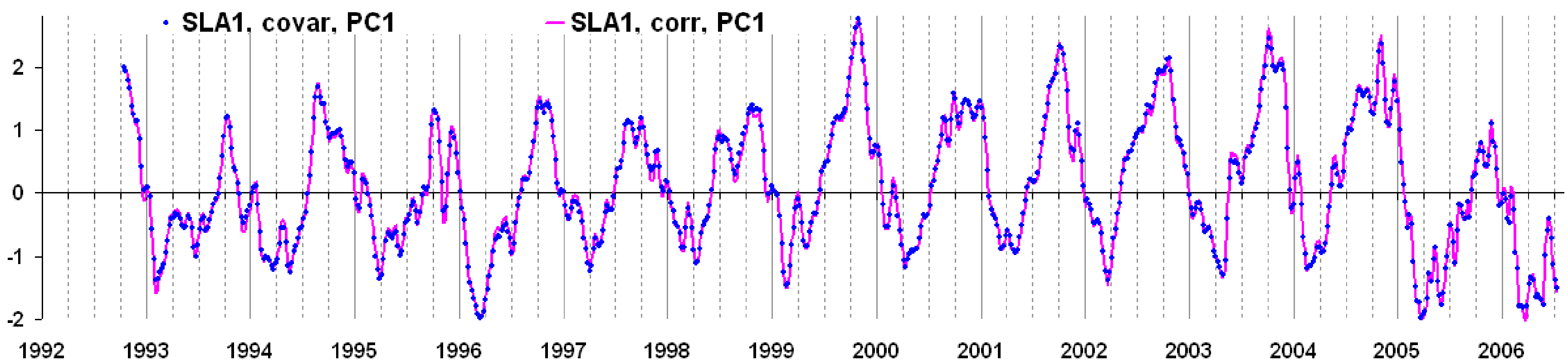


Level above average: summer – autumn.

Level below average: winter – spring.

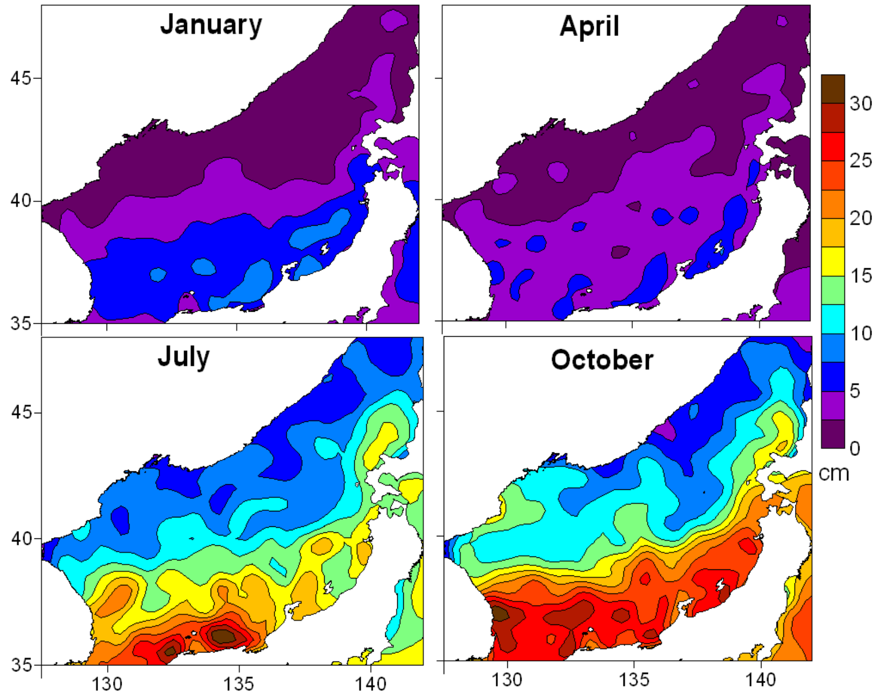
Seasonal extremes: October – March (on average).

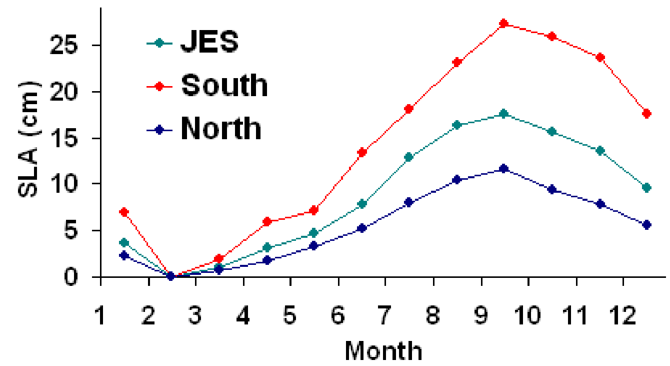
Similar to the spatial mean SLA (Choi et al., 2004) but no secular trend.



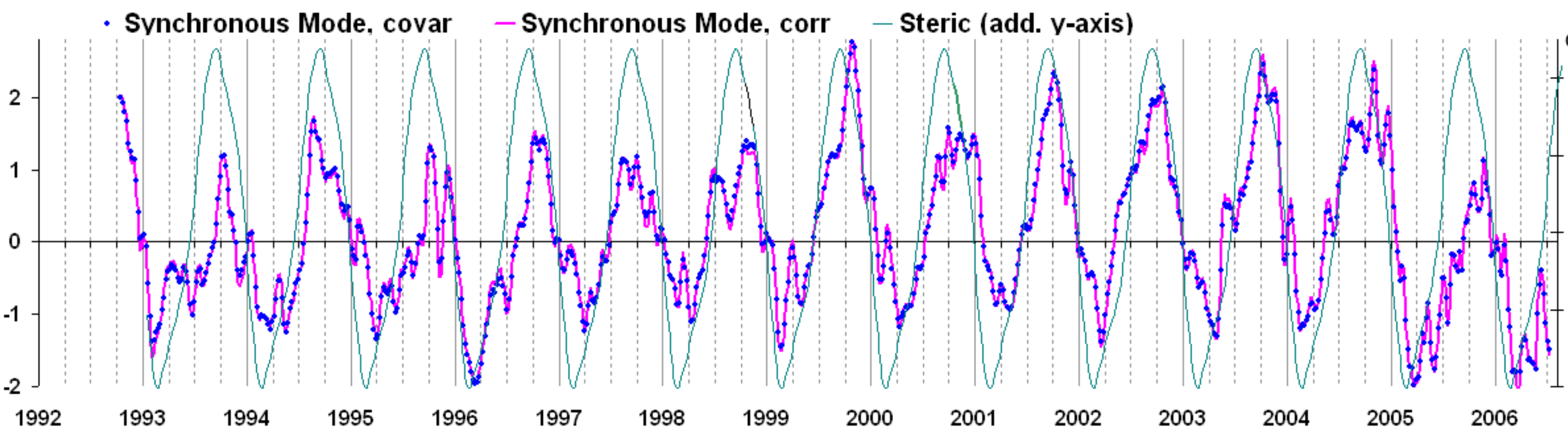
Steric signal from GDEM density climatology

(referenced to February)





Seasonal extremes: September – February.
Steric signal is strongest in the JES
(Gordon and Giulivi, 2004).

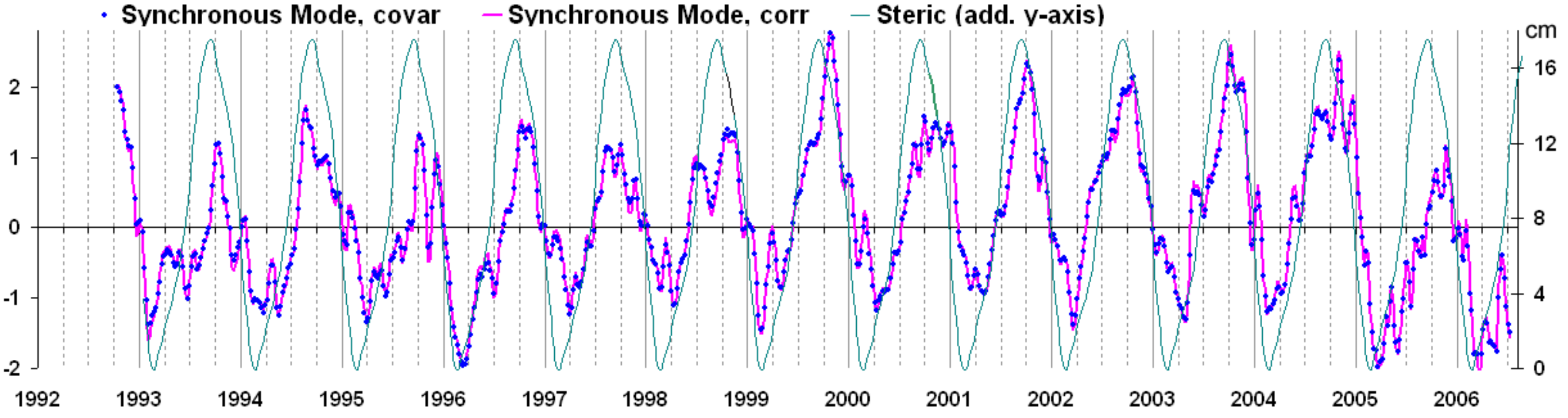


Forcing of Synchronous Mode

Steric signal contributes significantly but cannot be the only forcing, as its extremes (February & September) are a month earlier than those of Synchronous Mode (March & October).

Strong intraseasonal synchronous oscillations:
difference ~11 cm from September to October 1995;
barotropic long waves as suggested forcing (Choi et al., 2004).

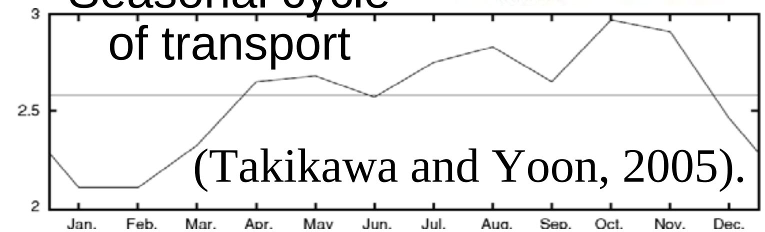
Volume excess/shortage from imbalance of the through-flow transport?



Seasonal transports in the straits

Transport in the **Korea Strait**
is largest in October – November,
smallest in February, with the range of ~ 1 Sv
(long-term data from sea level difference validated by direct measurements).

Seasonal cycle of transport



(Takikawa and Yoon, 2005).

Tsugaru Strait (from 1-2 years of observations): no significant seasonal variability (Shikawa, 1994) or seasonal range of ~ 1 Sv, largest in November to December, smallest in January to February (Ito et al., 2003, Kuroda et al., 2004, Na et al., 2009).
Implications of the strong interannual variability?

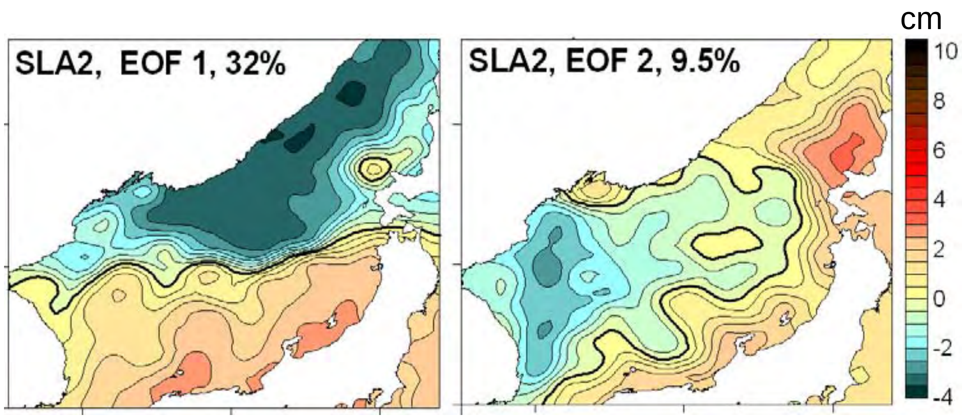
La Perouse (Soya) Strait (from 1-2 years of observations): seasonal range of ~ 1 Sv, largest (smallest) in summer (winter) (Sugimoto, 1990; Shevchenko et al., 2005).

External forcings (mean state and seasonal variation): sea level difference from SLP variations, wind driven circulation in North Pacific, alongshore wind stress, CTW around the Japanese Islands. (Lyu and Kim, 2005; Tsujino et al., 2008).

Can there be seasonal volume imbalances in spring and autumn?

Decomposition of SLA2

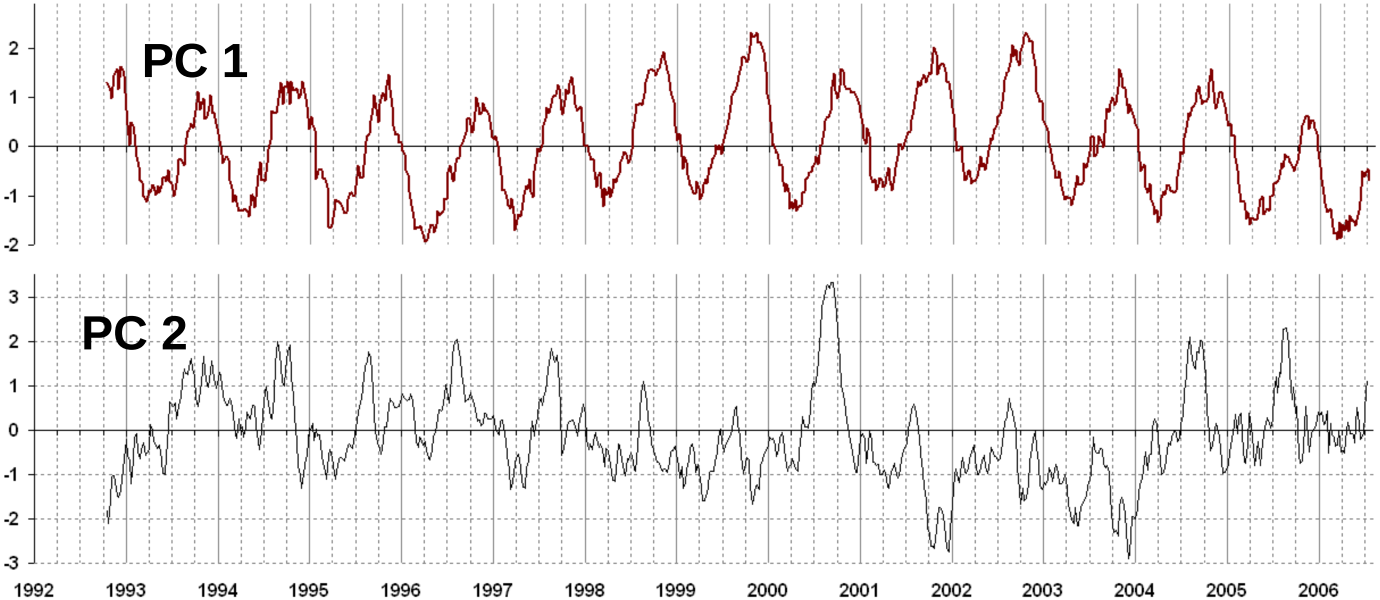
(with the subtracted contribution of Synchronous Mode)



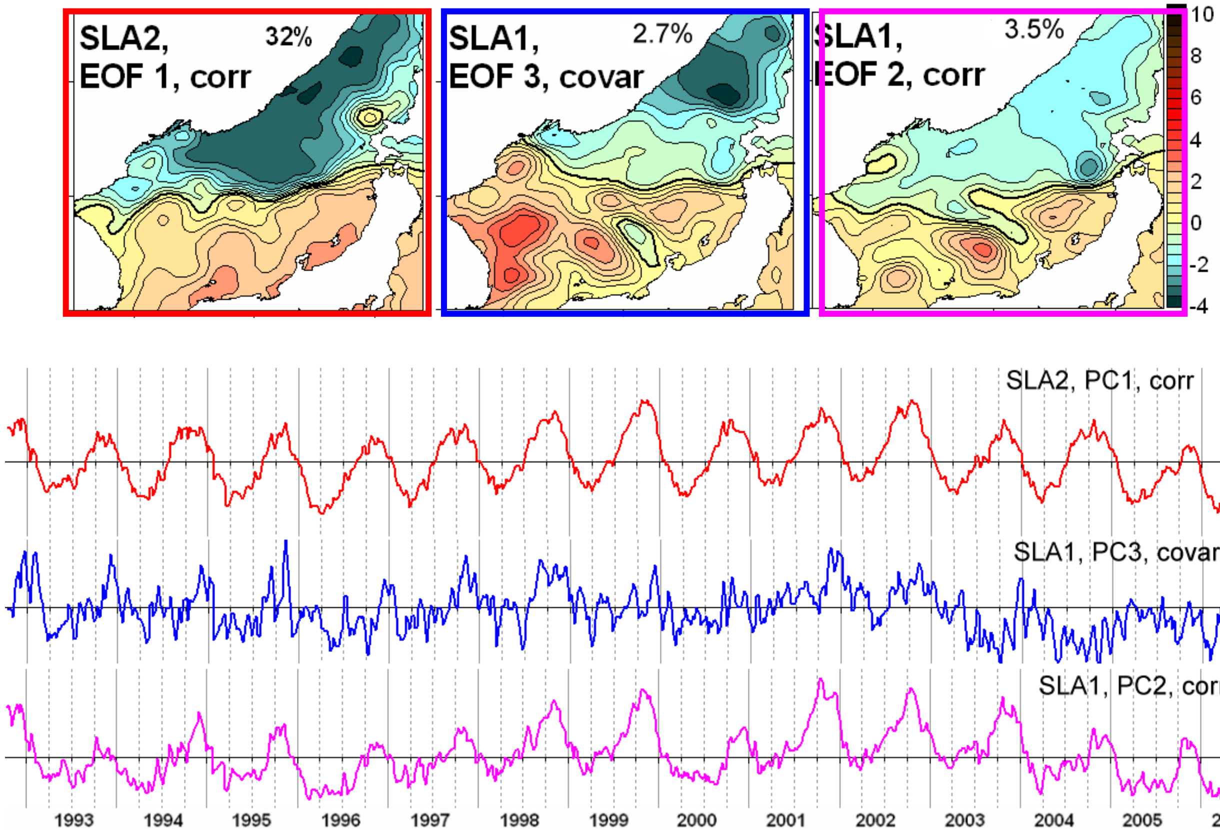
EOF 1, positive phase: increase of the south – north difference ~ 10 cm.

EOF2, positive phase: increase of the east – west difference ~ 7. 5 cm.

Mean error ~ 3.5 – 4.5 cm.



Leading Mode from SLA2 and its counterparts from SLA1



Different and noisy

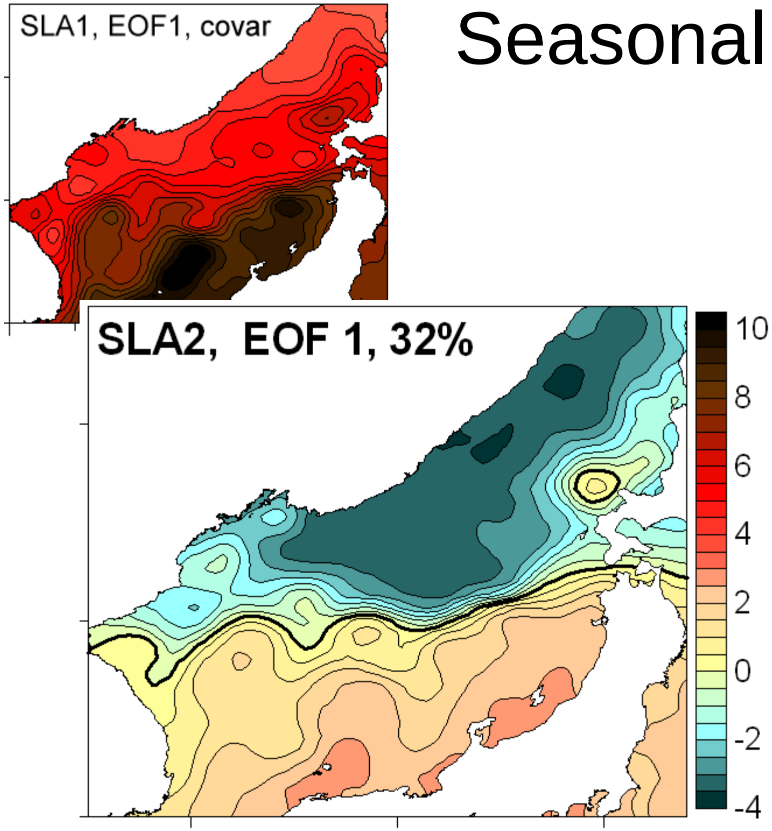
R ~ 0.7

Correlation-based mode from SLA2: spatial pattern improved, regular temporal pattern.

Covariance-based mode from SLA1: large variance within frequent eddy locations; irregular temporal behavior.

Correlation-based mode from SLA1: regular temporal pattern, unclear spatial pattern.

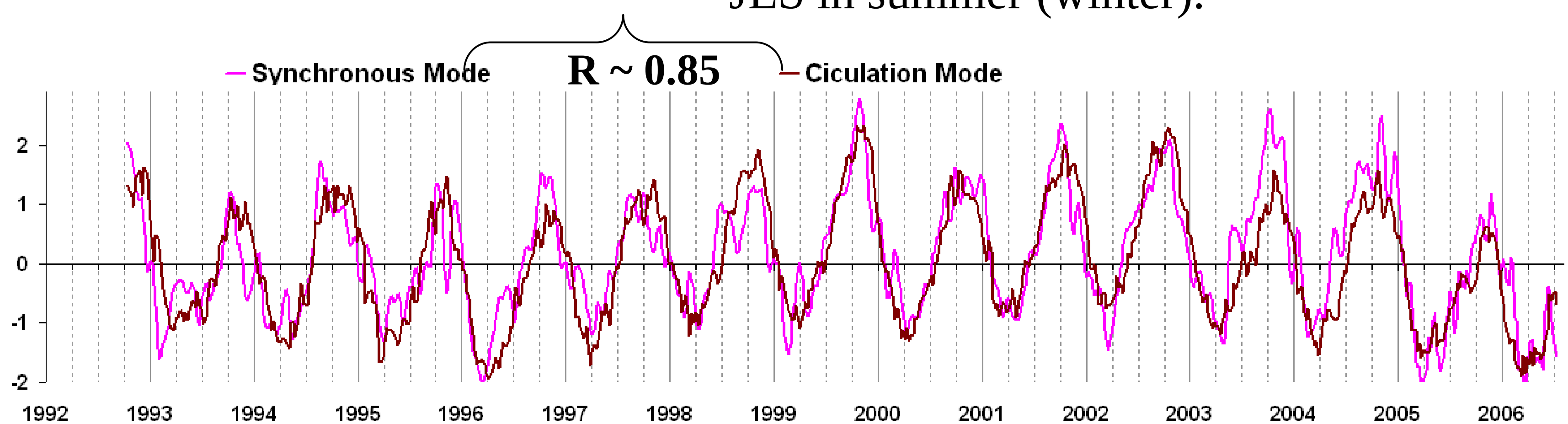
Seasonal variation of surface circulation

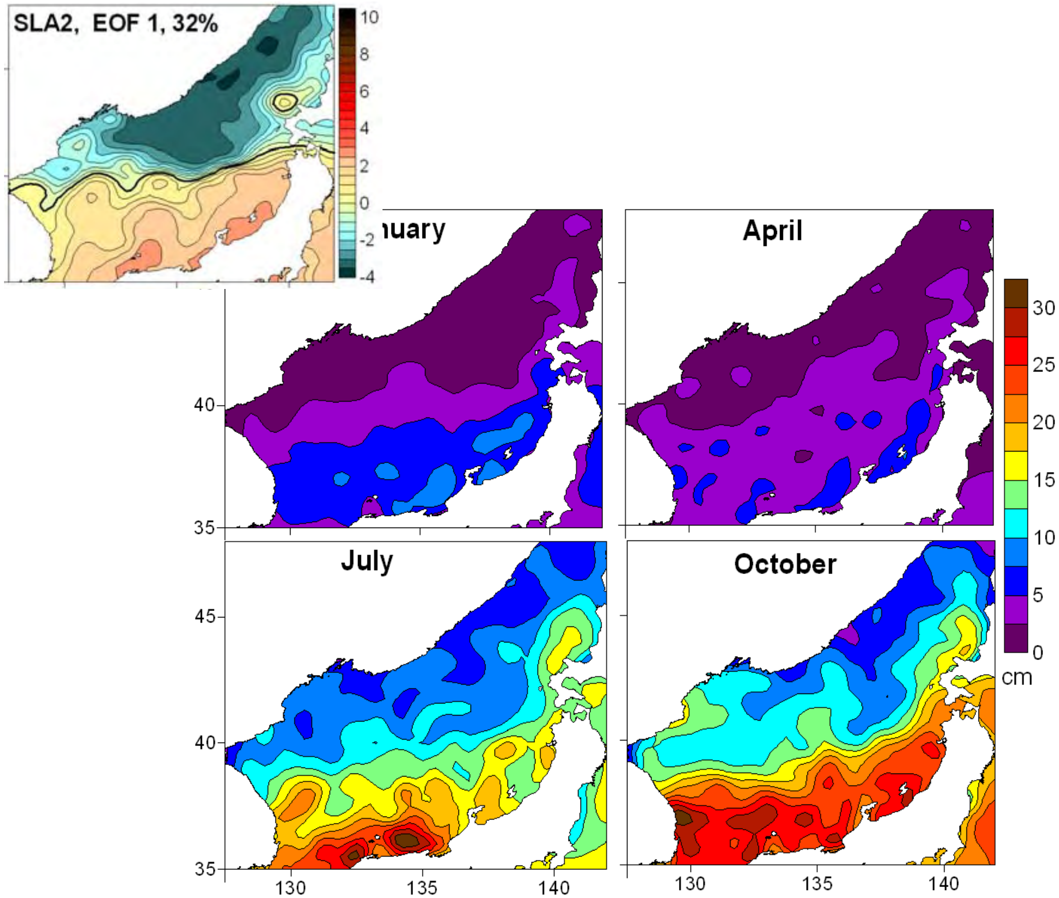


Similar temporal pattern with Synchronous Mode.

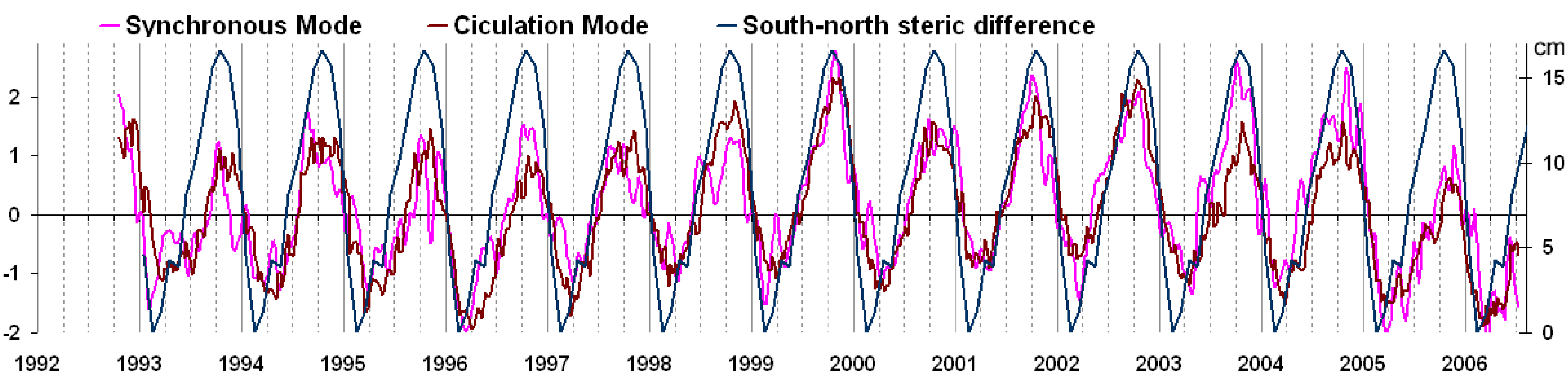
Strengthening of the circulation in the entire JES in summer – autumn and weakening in winter – spring, with the extremes in October and March.

Improvement of the Morimoto and Yanagi's (2001) finding on the strengthening (weakening) of the circulation in the entire JES in summer (winter).





R ~ 0.85



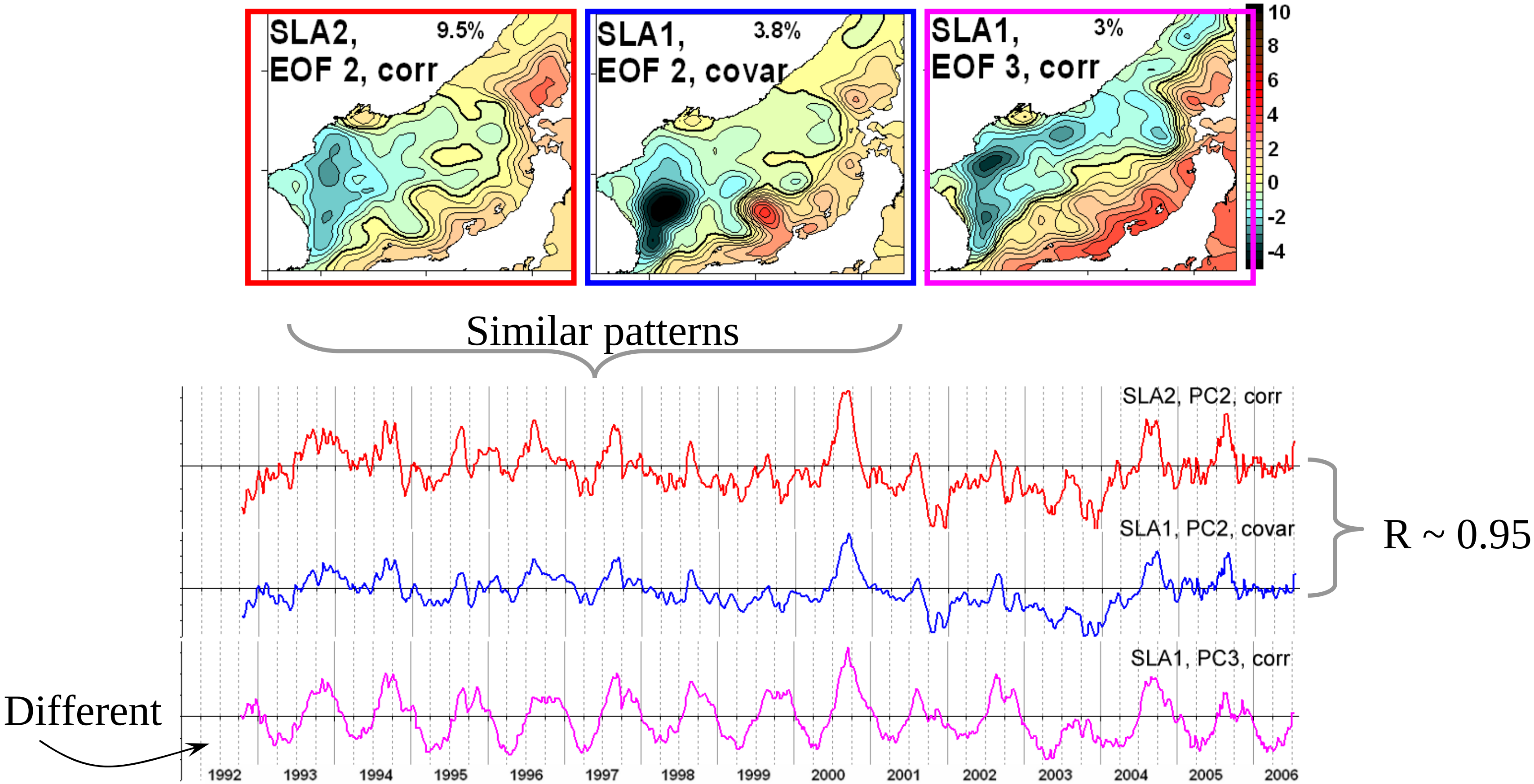
Strengthening of the circulation in the entire JES in summer – autumn and weakening in winter – spring.

Explained by the north-south difference in steric level largest in October.

Large transport in the Korea Strait in autumn, differential cooling.

Similar temporal pattern with Synchronous Mode →
linked forcing –volume imbalance?

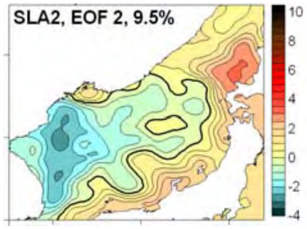
Second Mode of SLA2 and its counterparts from SLA1

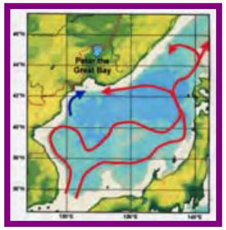


Correlation-based mode from SLA2: largest magnitude in the NW JES.

Covariance-based mode from SLA1: largest magnitude in the SW JES.

Correlation-based mode from SLA1: different pattern in the northernmost JES.





Cyclonicity vs. anticyclonicity

Positive phase (late summer): intensification of the TWC off Honshu, weakening of the AC circulation in the western JES.

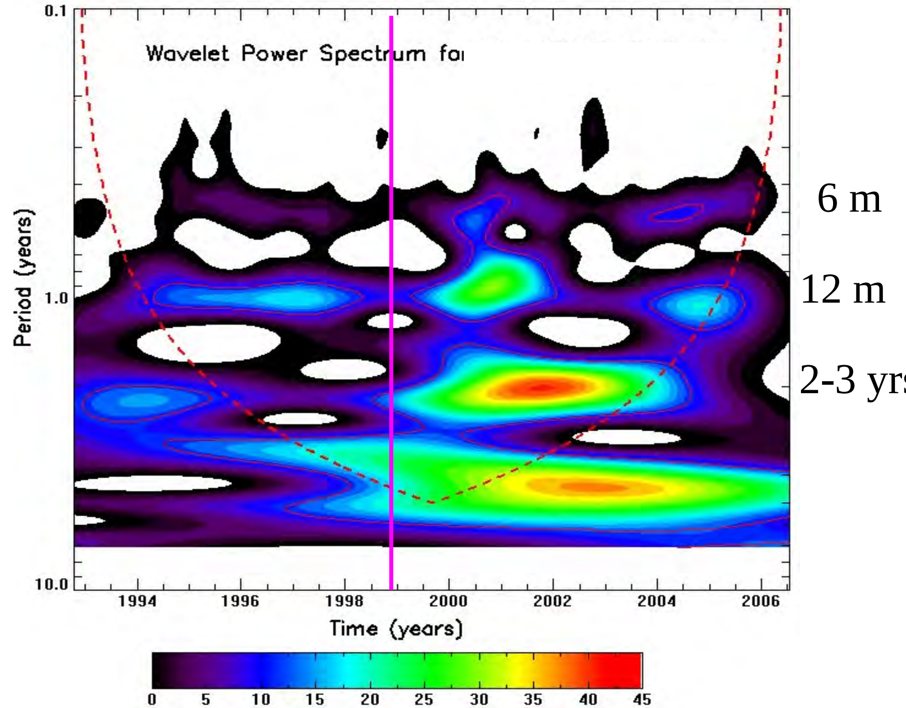
Negative phase (spring and, in some years, autumn): the intensification of the AC circulation in the entire western JES.

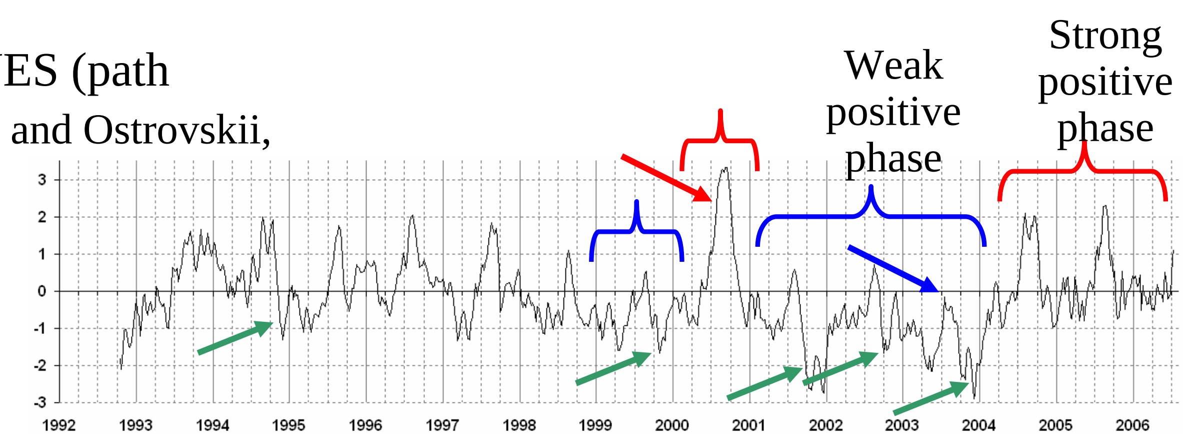
Extreme events:
The strongest positive phase in summer 2000: the absent EKWC from June to October 2000 (Chang et al., 2004). Absent positive phase in summer 2003.

QB variability in the southern JES (path variations of the TWC) (Hirose and Ostrovskii, 2000; Choi et al., 2004).

Different regimes:
2000 and 2005-2006 vs.
1999 and 2001-2004.

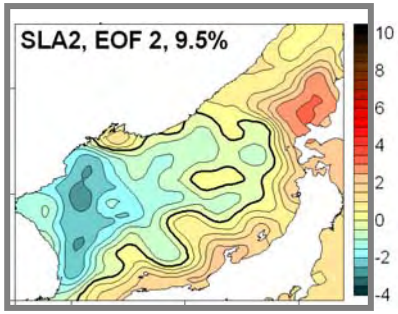
Wavelet



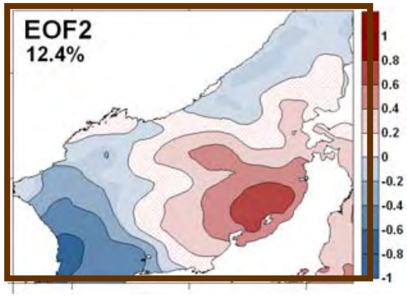


SLA vs. SST

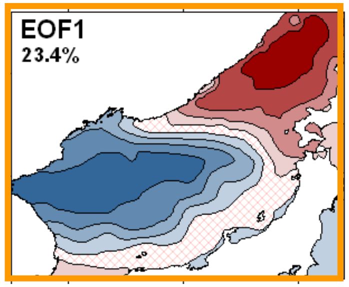
SLA



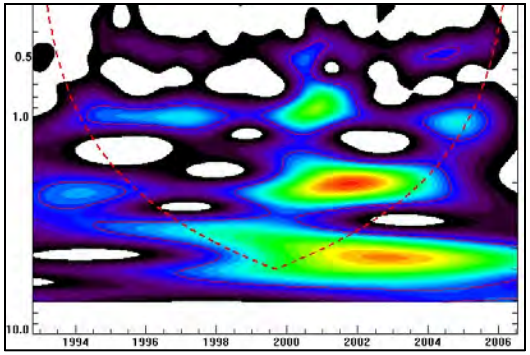
SST: the TWC vs. EKWC

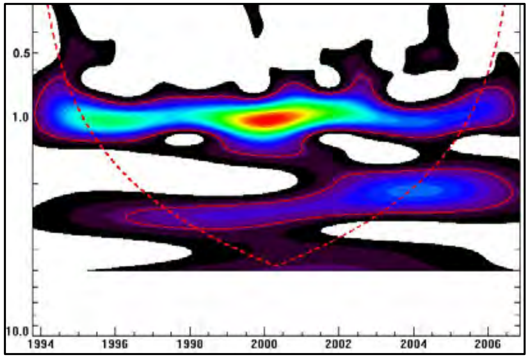


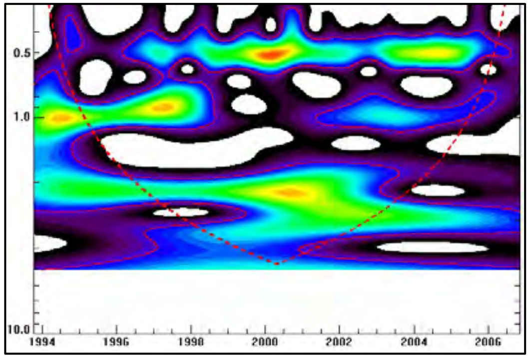
Semiannual SST

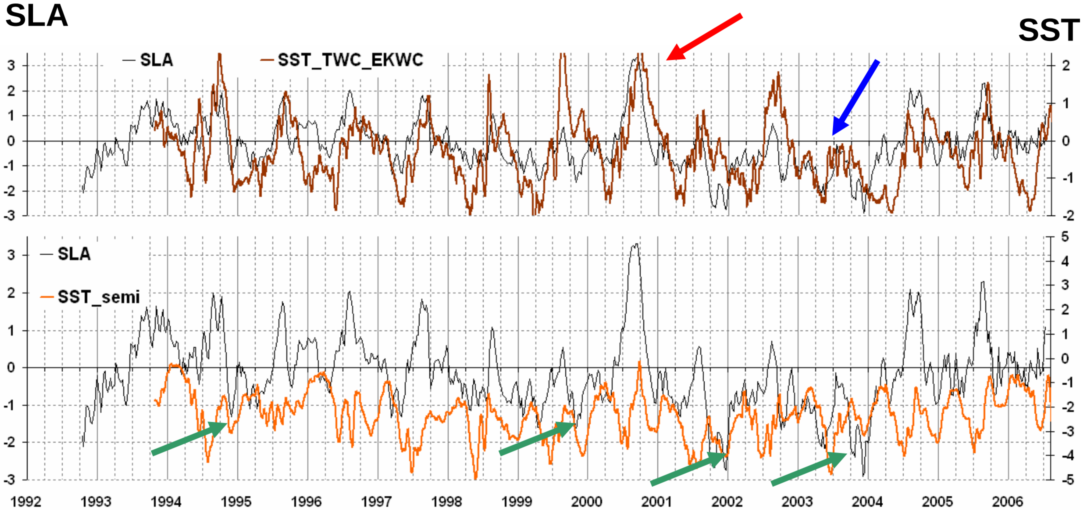


Wavelet









SLA & SST_TWC_EKWC:
positive phase in late summer,
negative phase in spring.

SST_semi:
negative phase in spring & autumn.

SLA: secondary negative phase
in autumn

Suggested forcing: summer wind

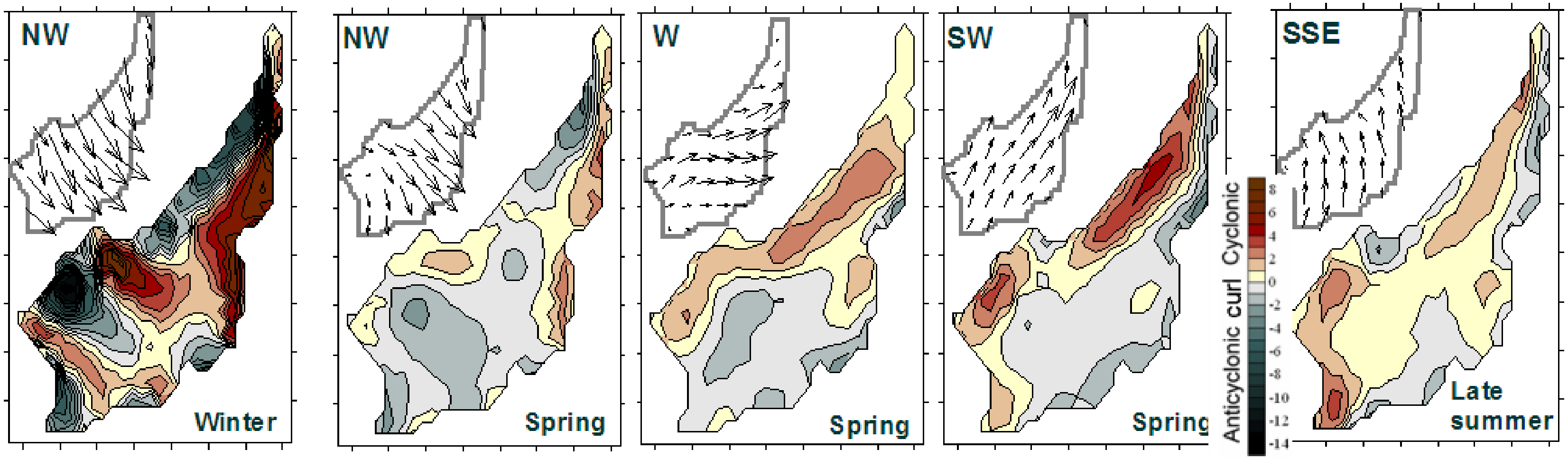
SST anomalies are related to circulation features forced by wind stress curl in the warm season (Trusenkova et al., PICES-2007; 2009, Ocean Polar Res.).

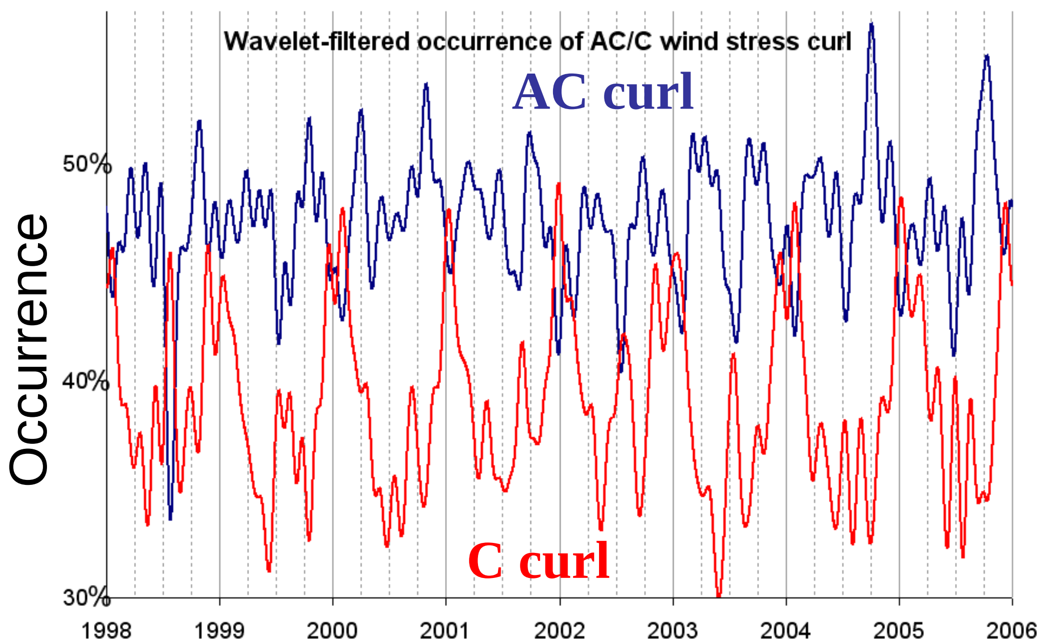
Effect of strong winter wind stress with cyclonic curl is usually considered. (Hogan and Hurlburt, 2005).

Summer wind is weak when averaged on monthly timescale, however…

Statistically derived patterns of wind stress and curl: 2-5 times stronger than monthly fields (within wind jets) and substantially affect the circulation in the JES (Trusenkova et al., 2009, J. Mar. Sys.).

Statistically derived patterns of wind stress and curl



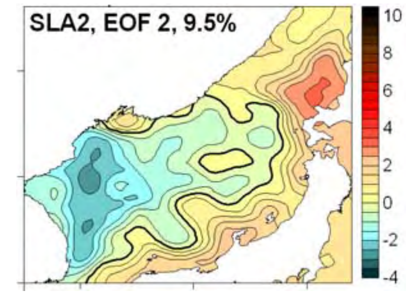


Wind shifts from NW to SW in spring and to SSE in late summer.

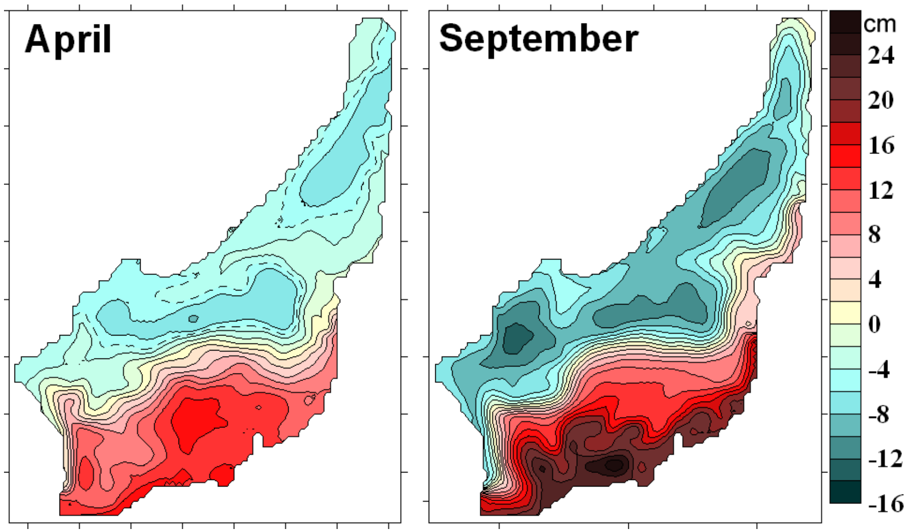
The increased occurrence of AC wind stress curl
in spring and autumn
(from 1°-gridded NCEP data)

Forcing by wind stress curl

SLA



Simulation

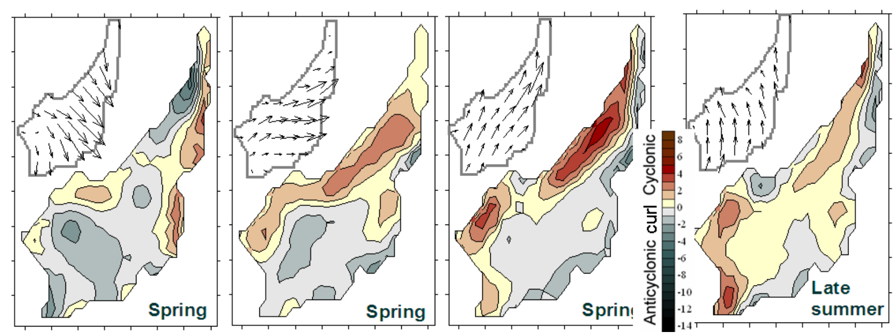


Negative phase (the intensified AC circulation in the western JES) forced by the AC wind curl of frequent westerly winds in spring.

Positive phase (the intensified TWC and its westward branch) forced by the C curl of frequent SE winds in late summer.

Simulated circulation patterns forced by the wind shifting from NW to SW in spring and from SW to SSE in late summer.

NW branch of SAF in spring documented from satellite SST (Nikitin, 2006).



Conclusion

•The EOF techniques based on correlations within data is suitable for finding low-amplitude anomalies and pattern adjustment in successive decompositions.

•The techniques of successive decompositions after the removal of contribution of a leading mode is suitable for finding interrelated patterns.

•The leading Synchronous Mode corresponds to seasonal sea level oscillations simultaneously in the entire JES, with the highest (lowest) level in October (March).
Forcing: steric signal and, possibly, the volume (throughflow transport) imbalance.

•The surface circulation in the entire JES intensifies (weakens) in autumn (early spring), with the same temporal pattern as the Synchronous Mode, and reaches its seasonal extremes in October and March.
Forcing: the south – north level difference associated with the steric signal and induced by the transport in the Korea Strait, differential cooling, and, possibly, by the volume imbalance.

•The strengthened TWC off Honshu and increased cyclonicity in the entire JES develop in late summer, while the AC circulation strengthens in the entire western JES in spring and, in some years, autumn. This mode is subjected to the strong interannual variation: regimes in 2000 and 2005-2006 vs. 1999 and 2001-2004.
Forcing: the seasonally changing cyclonic/anticyclonic wind stress curl.


Thank you!