Patterns of temperature anomalies at the Japan/East Sea surface, simulated under different kinds of wind forcing

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Motivation

SSTA are usually considered as
related to local air – sea heat exchange, however….

EOF analysis of the observed SST revealed that

•there is the statistical relationship between SSTA and wind stress curl;

•large-scale SSTA patterns in the Japan/East Sea can be related to dynamic processes – Ekman suction, front migrations, heat advection, etc…;

•supported by qualitative considerations of simulation results from an oceanic model.

(Trusenkova et al., 2008).

What if
we do EOF analysis of the simulated SST and
compare with EOF modes of the observed SST?

Purpose of the study

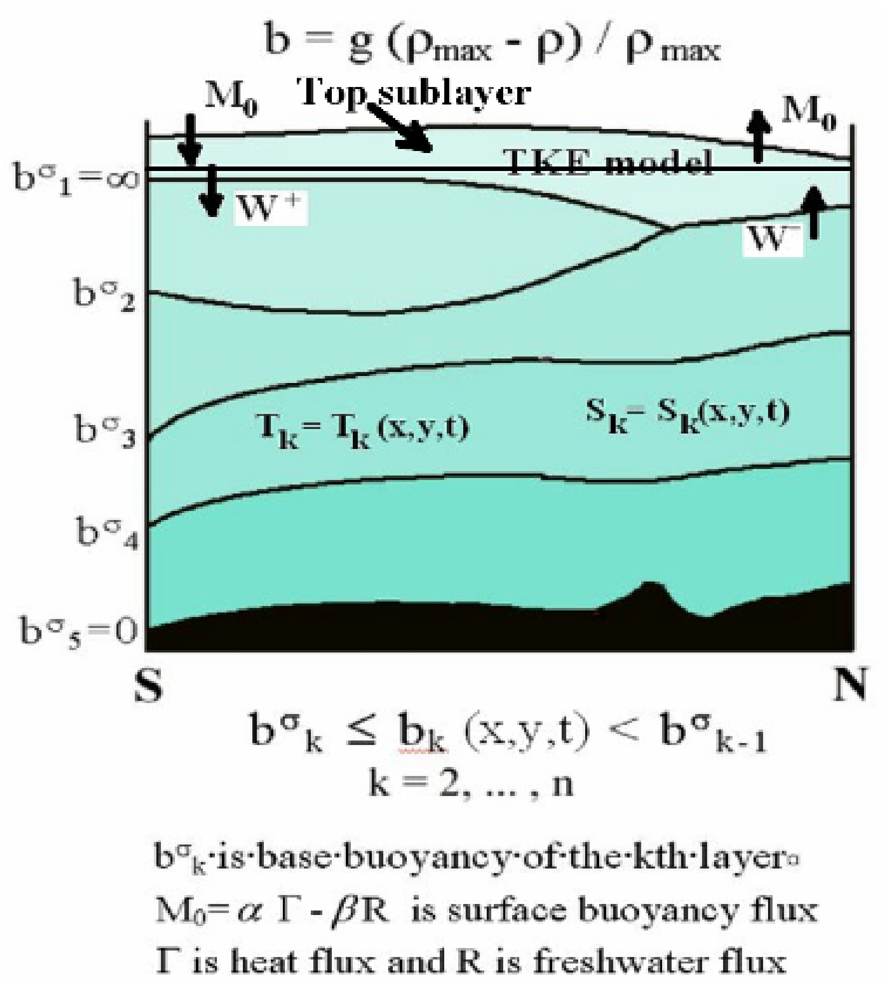
To simulate currents and tracers (temperature, salinity, etc) in the Japan/East Sea, using an oceanic model forced by different patterns of wind stress curl.

To compare EOF modes of the observed and simulated SST.

To support suggested dynamic forcings of SST variability.

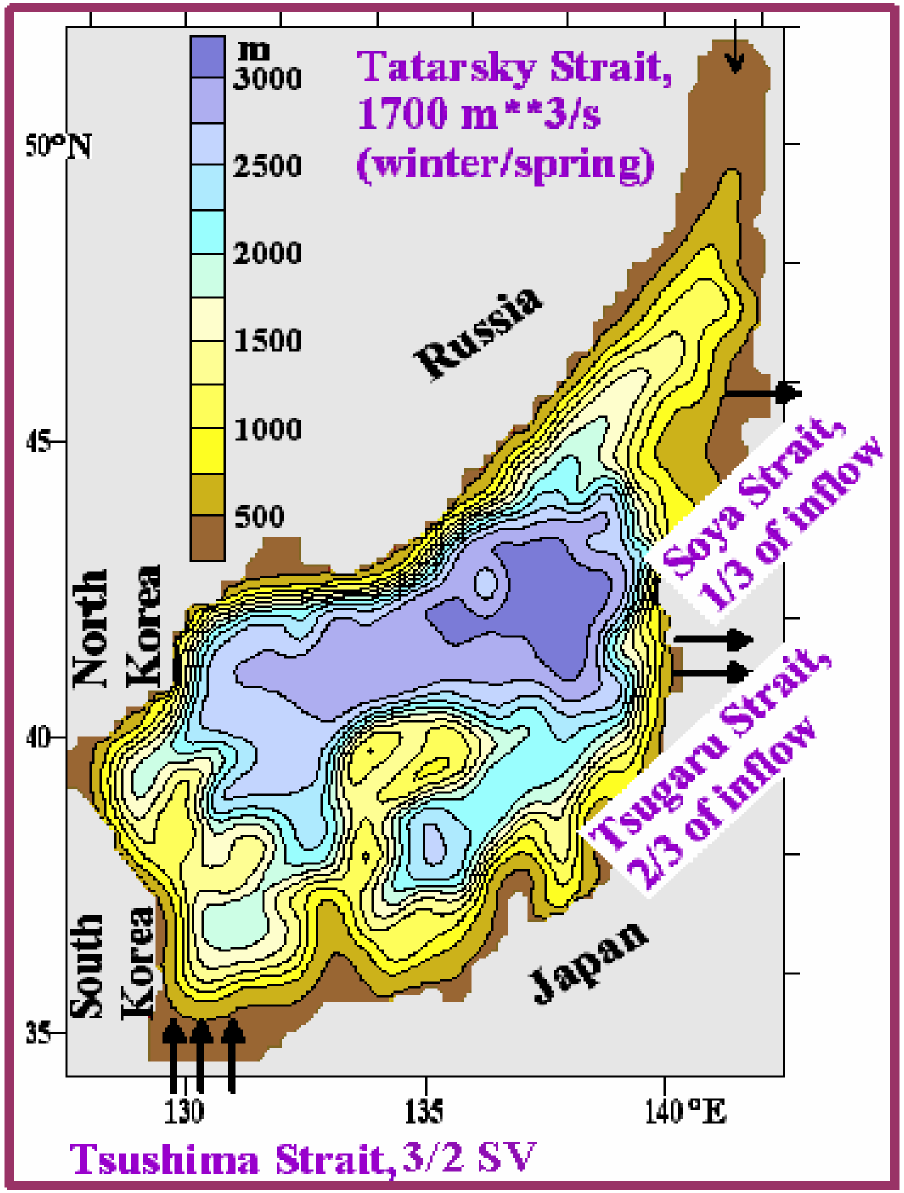
MHI oceanic model

(Shapiro and Mikhaylova, 1992-1998)



- 3D primitive equation, hydrostatic & Boussinesq
- Quasi-isopycnic co-ordinate in the vertical
- **Complete thermodynamics**, including
  - **surface heat/freshwater balances**,
  - TKE model for the surface mixed layer,
  - prognostic equations for T and S,
  - diapycnal exchange of T and S between the layers
- Variable T, S, and buoyancy in any layer
- Constraint on buoyancy variations in the inner layers (below the mixed layer)
- Bi-harmonic viscosity in the momentum equations
- Free surface
- Convective adjustment

Simulation setup



- Lateral mesh of 1/8° (10-14 km) ~ **marginally eddy resolving**;
- 12 layers in the vertical;
- Bathymetry scaled by factor of 0.75;
- Depth of initial flat interfaces : 10, 25, 50, 75, 100, 150, 250, 350, 500, 700, 900 m;
- Initial T and S from average vertical profiles;
- Time step: 7.5 min;
- Bi-harmonic lateral viscosity: 2.5×10^8 m^4/s, harmonic lateral diffusivity: 250 m^2/s;
- Inflow transport in the Korean Strait after Takikawa and Yoon (2005), outflow in the Tsugaru and Soya Straits;
- Monthly atmospheric variables (1979-1999) for surface heat and freshwater balances;
- Wind stress from 1°-gridded NCEP/NCAR data;
- **No restoration to the observed temperature or salinity**.

Simulation setup - 2

•**Wind data**:

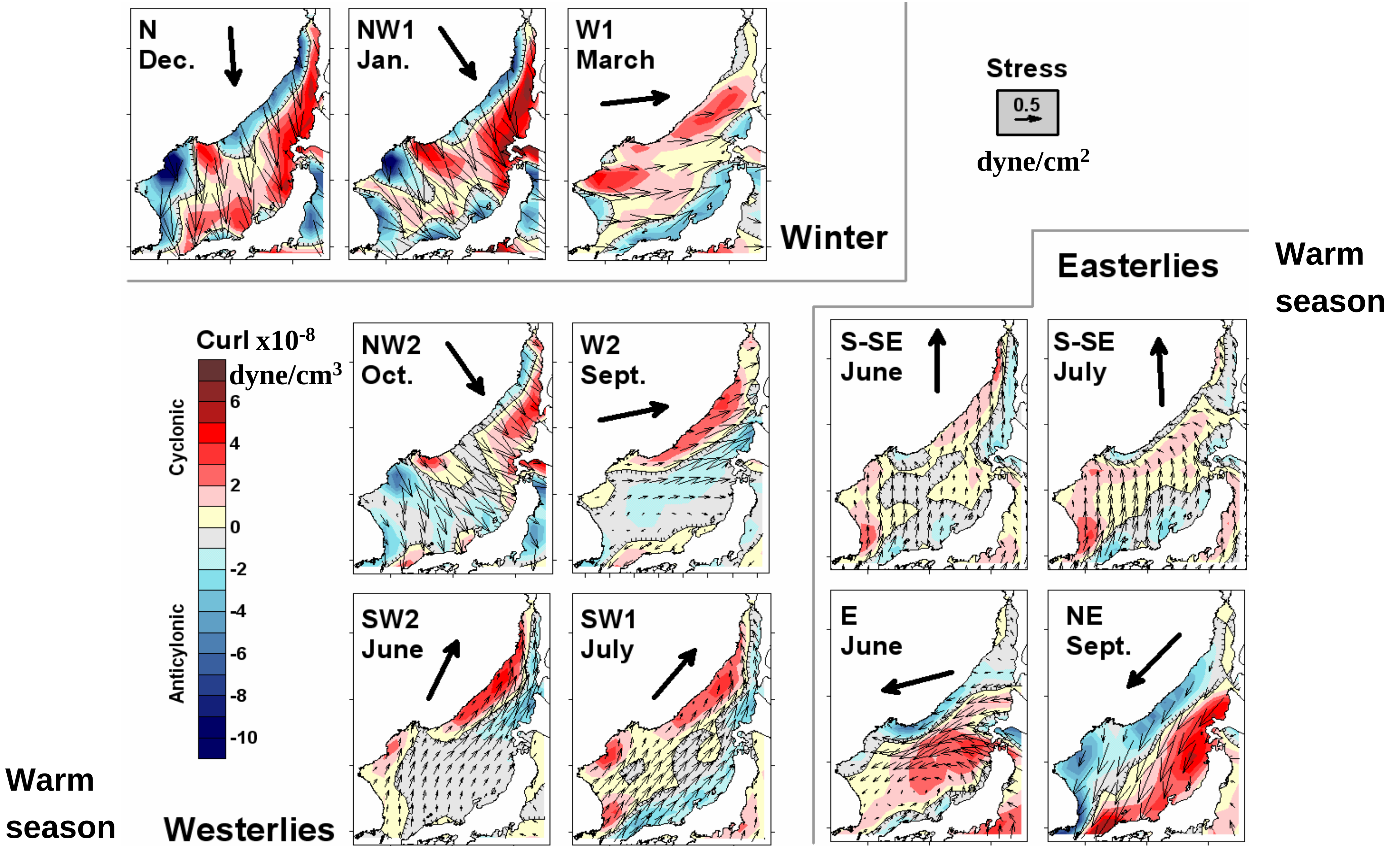
NCEP/NCAR special product, SeaWiFS Project Ancillary Data, 6h, 1°x1°-gridded wind, 1998-2005,

34°-53°N, 127°-143°E (JES and adjacent land).

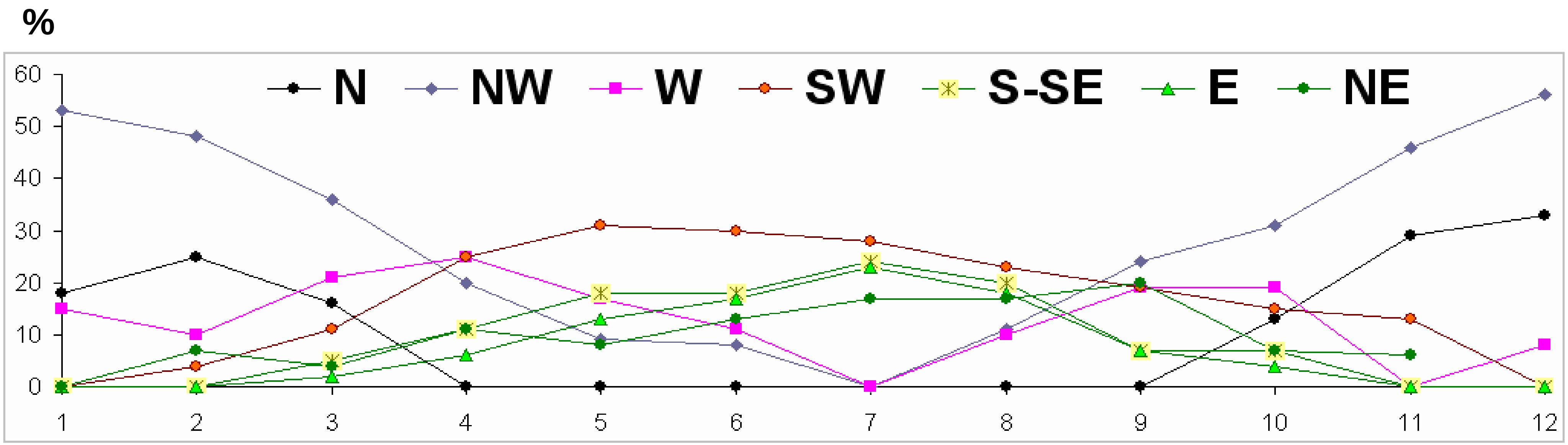
•**Model runs**:

- 11 years spin-up under the forcing of monthly wind 2000,
- 3 runs for 4 years under the forcing of different wind patterns but under <u>the same surface buoyancy forcing and transports through the straits</u>;
- results from 15th year of integration are analyzed.

Typical wind patterns
(Trusenkova et al., 2007)



Monthly occurrence of the typical patterns



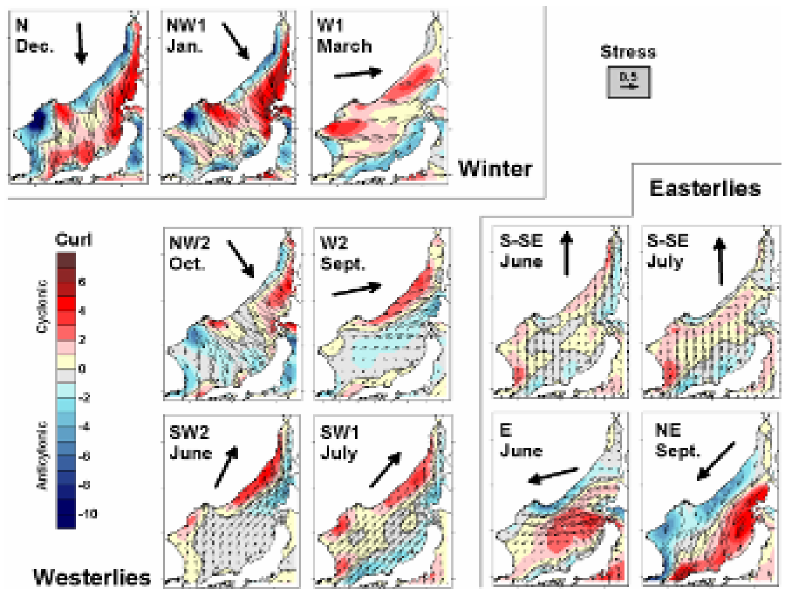
November – March and May →

most frequent pattern

April, June, July, October ??? →

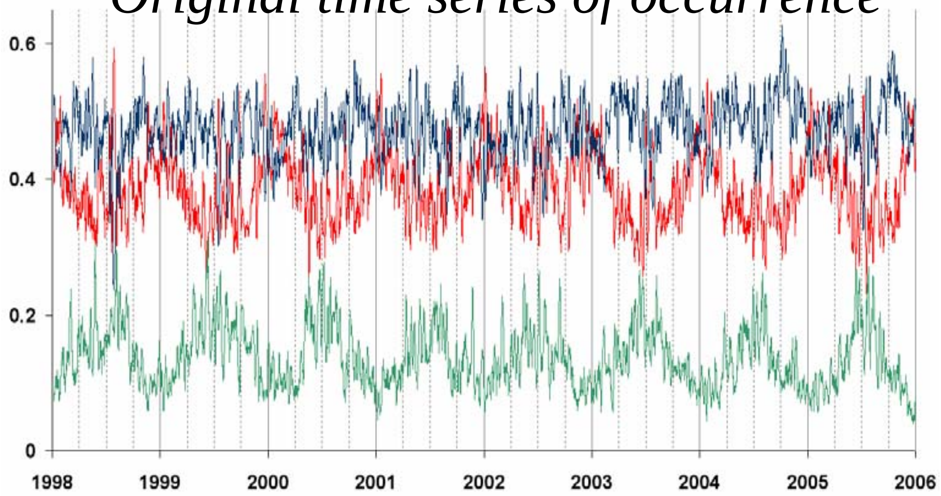
needs some additional considerations →

analysis of seasonal variations of wind curl

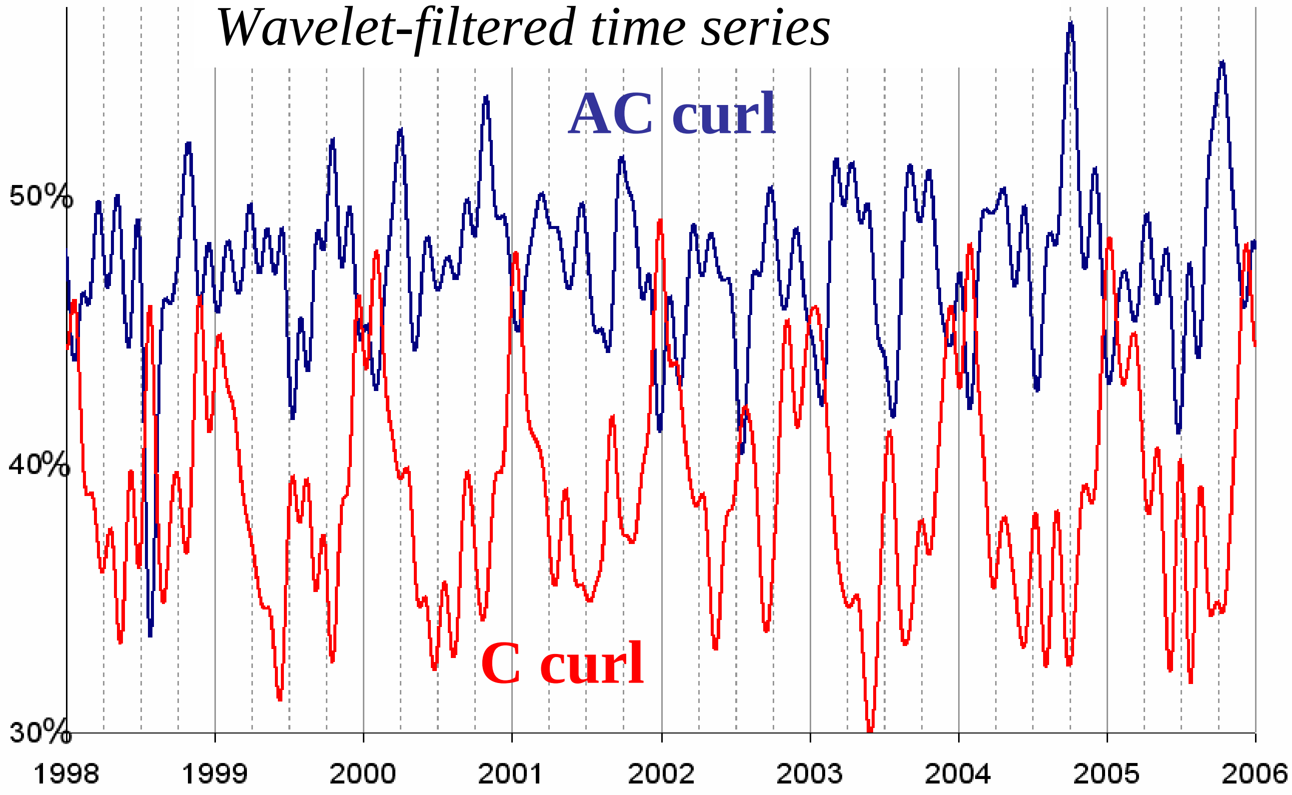


Seasonal variation of wind stress curl

Original time series of occurrence



Wavelet-filtered time series



The smallest scale ~ 40 days

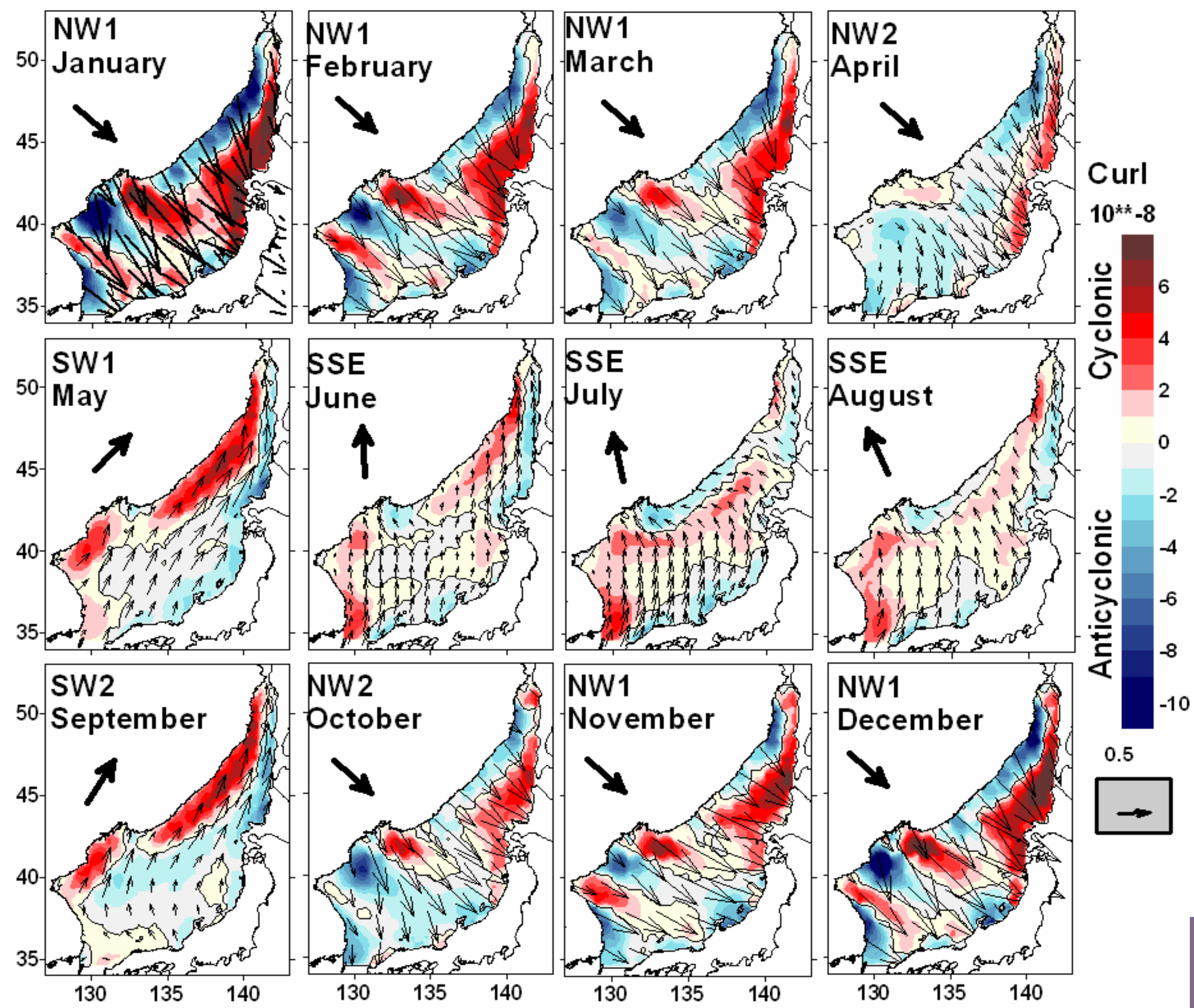
- Instantaneous occurrence: % of boxes over the JES, not including the adjacent land. A box adds to **C curl occurrence** if rotτ > C_1; **AC curl occurrence** if rotτ < $-C_1$; **weak wind occurrence** if $-C_1$ < rotτ < C_1.

- Time series of occurrence for 1998-2005.

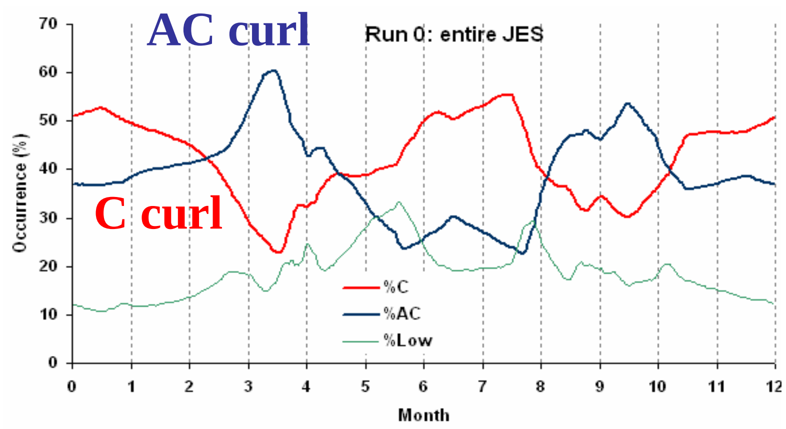
- Features:
  - opposition of C vs. AC curl occurrence (R = -0.67);
  - semiannual periodicity;
  - annual periodicity of the weak wind occurrence.

Run 0:

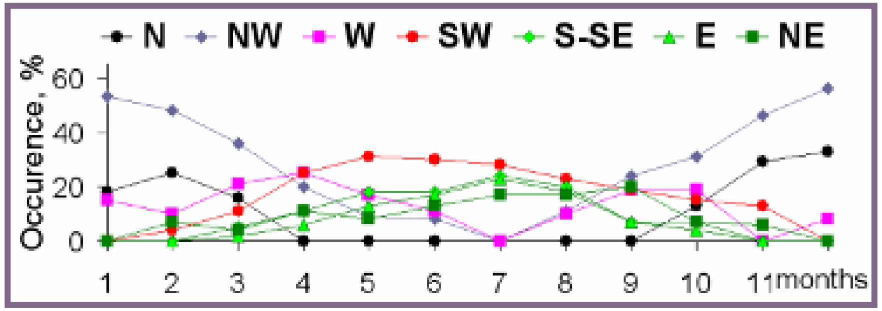
forcing by the semiannually varying wind stress curl



Occurrence of C/AC curl in wind patterns applied in Run 0



Occurrence of typical wind patterns

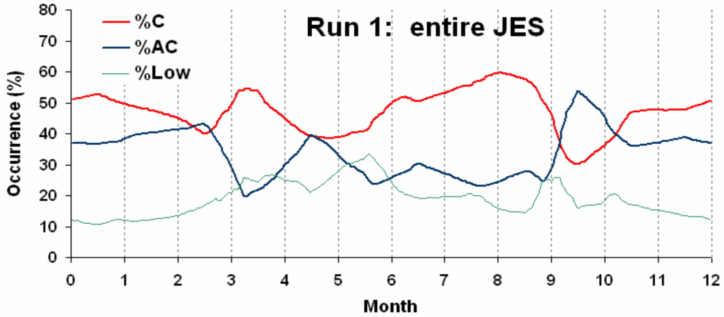


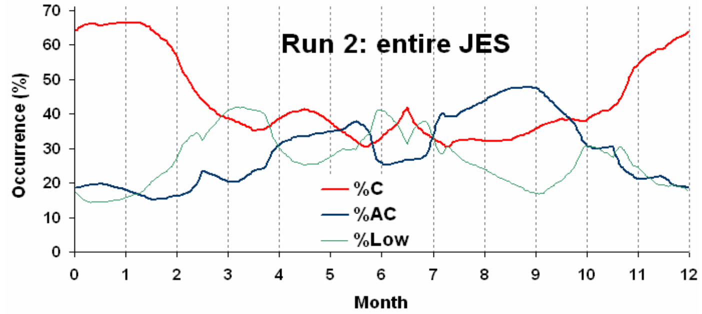
Wind patterns are timed at mid-months and linearly interpolated to every time step

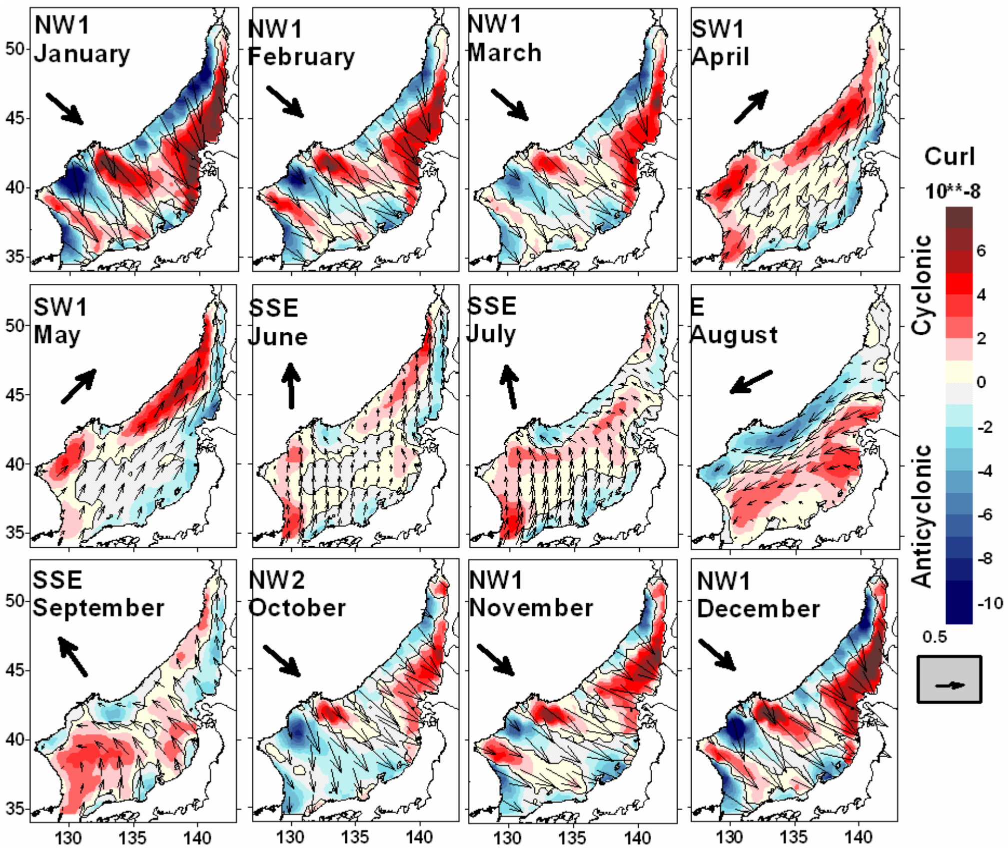
Run 1: forcing by the prevailing cyclonic curl

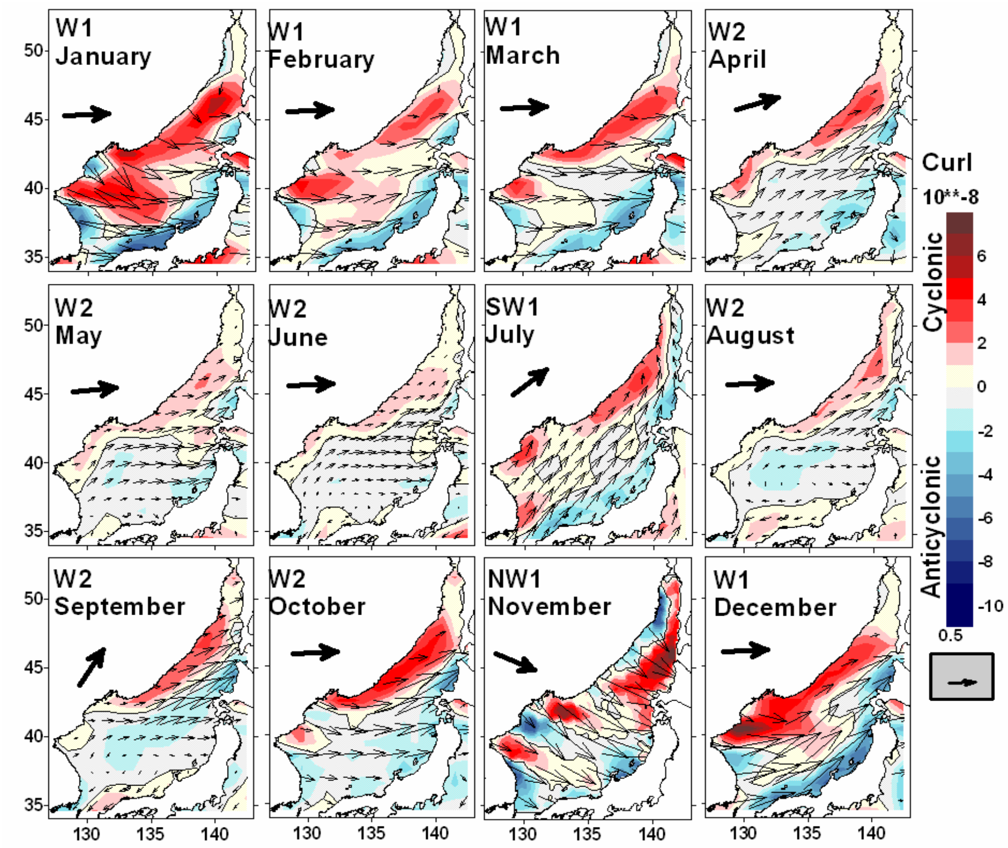
Run 2: forcing by the westerlies

Occurrence of C/AC curl and weak wind

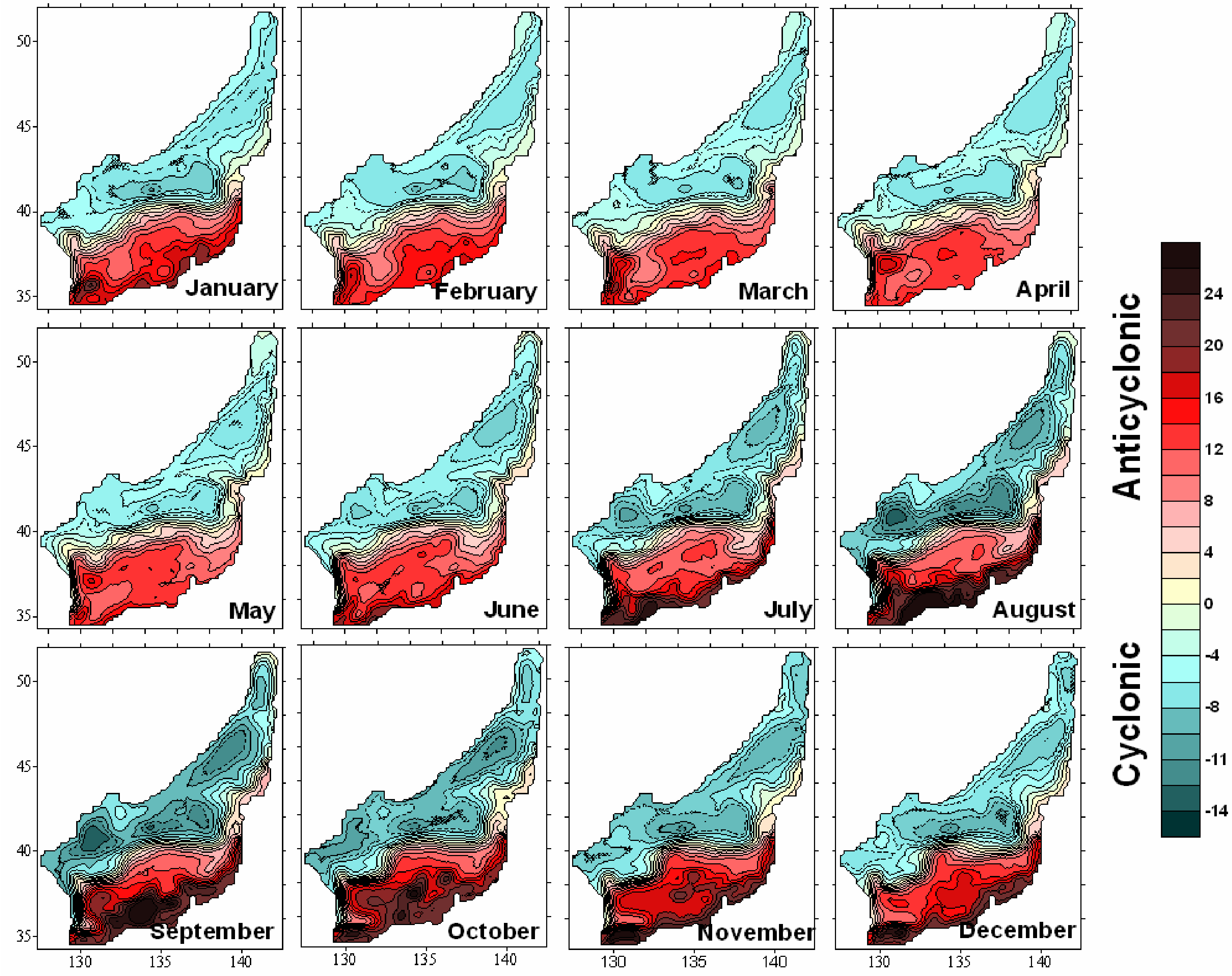




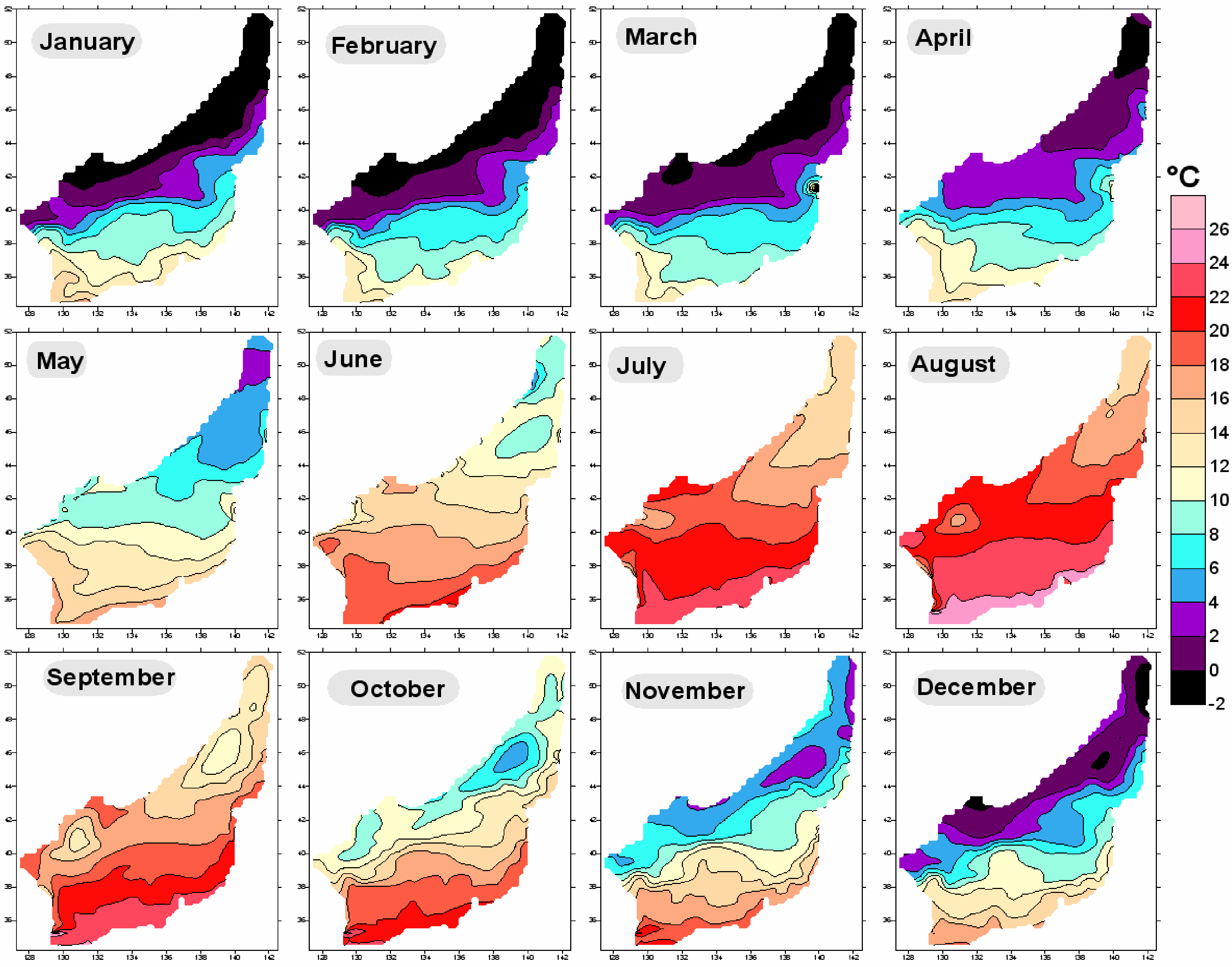




Run 0: monthly mean SSH



Run 0: monthly mean SST



Observed and simulated SST

Daily New Generation (NG) **SST**, Tohoku University, Sendai, Japan,
July 1, 2002 - July 7, 2006, 34.5°- 48°N, 127.5°- 142°E,
0.05°-gridded, smoothed to 0.25° for computational purposes,
satellite IR & MK

Daily Japan Meteorological Agency (JMA) **SST**,
October 12, 1993 – November 8, 2006, 35°- 48°N, 127.5°- 142°E,
0.25°-gridded, satellite IR & MK + *in situ*

similar patterns from both datasets (Trusenkova et al., 2008) →
JMA SST compared to the simulated SST

Daily SST in the 15th year of integration from Runs 0 - 2.

Data processing

Decomposition to EOF:

$X(r, t) = \sum A_k(r)\cdot B_k(t)$,

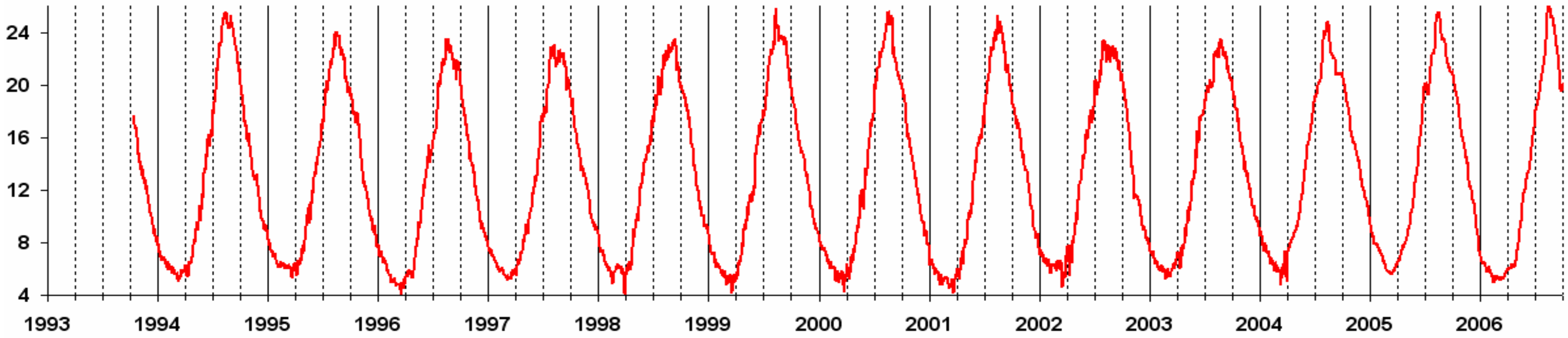
where r stands for the spatial coordinates and t for time,

$X(r, t)$ is the original SST.

•Correlations, not covariances → detection of low amplitude SSTA in the northern JES.

•Residual anomalies: $X_a(r, t) = X(r, t) – A_1(r)\cdot B_1(t)$,

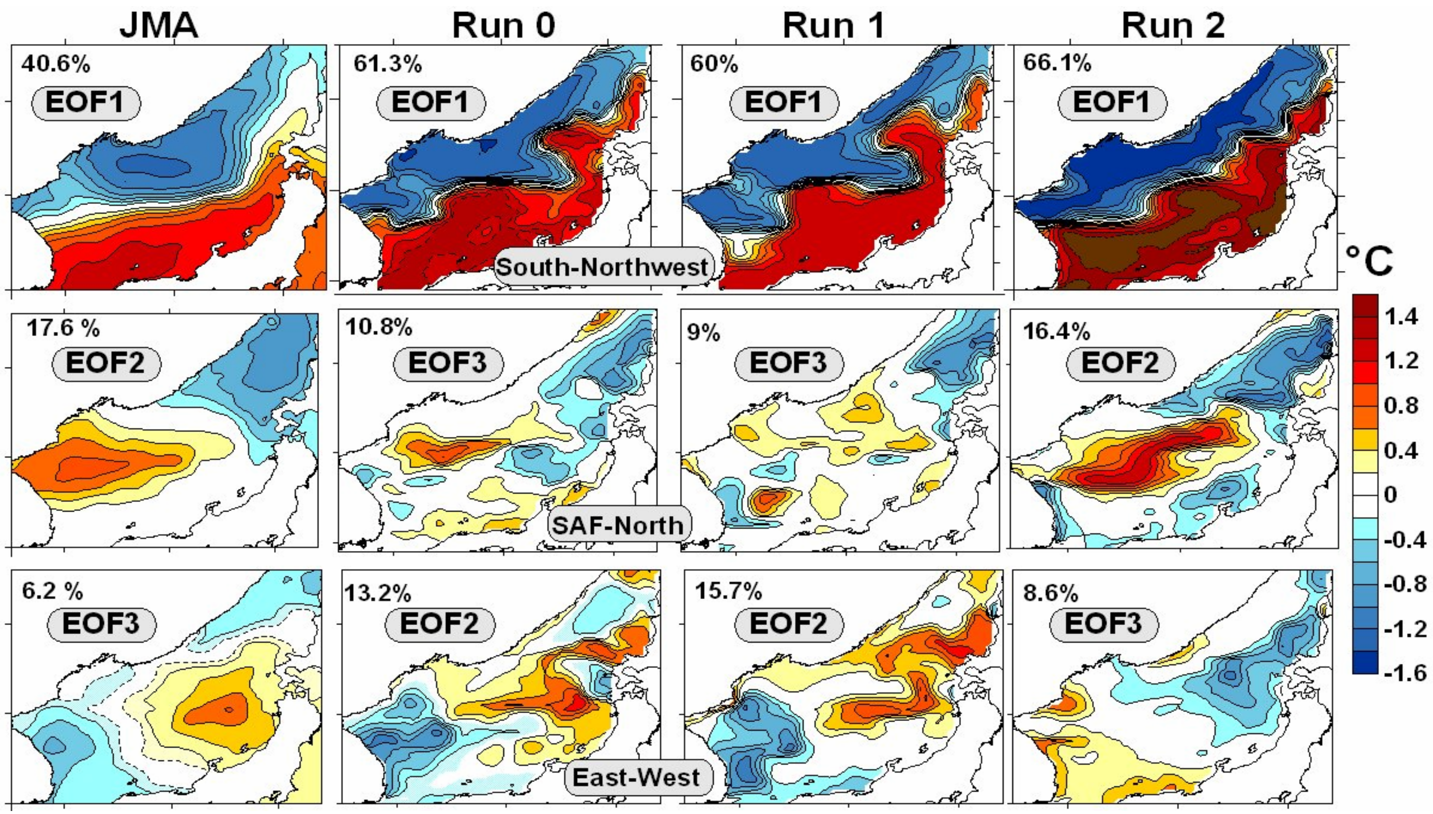
where $B_1(t)$ is the seasonal signal:



•Anomaly related to the kth mode: $X_r(t) = A_k(r_0)\cdot B_k(t)$,

where r_0 is characteristic location, usually within the spatial core.

EOF of JMA and simulated SST: spatial patterns

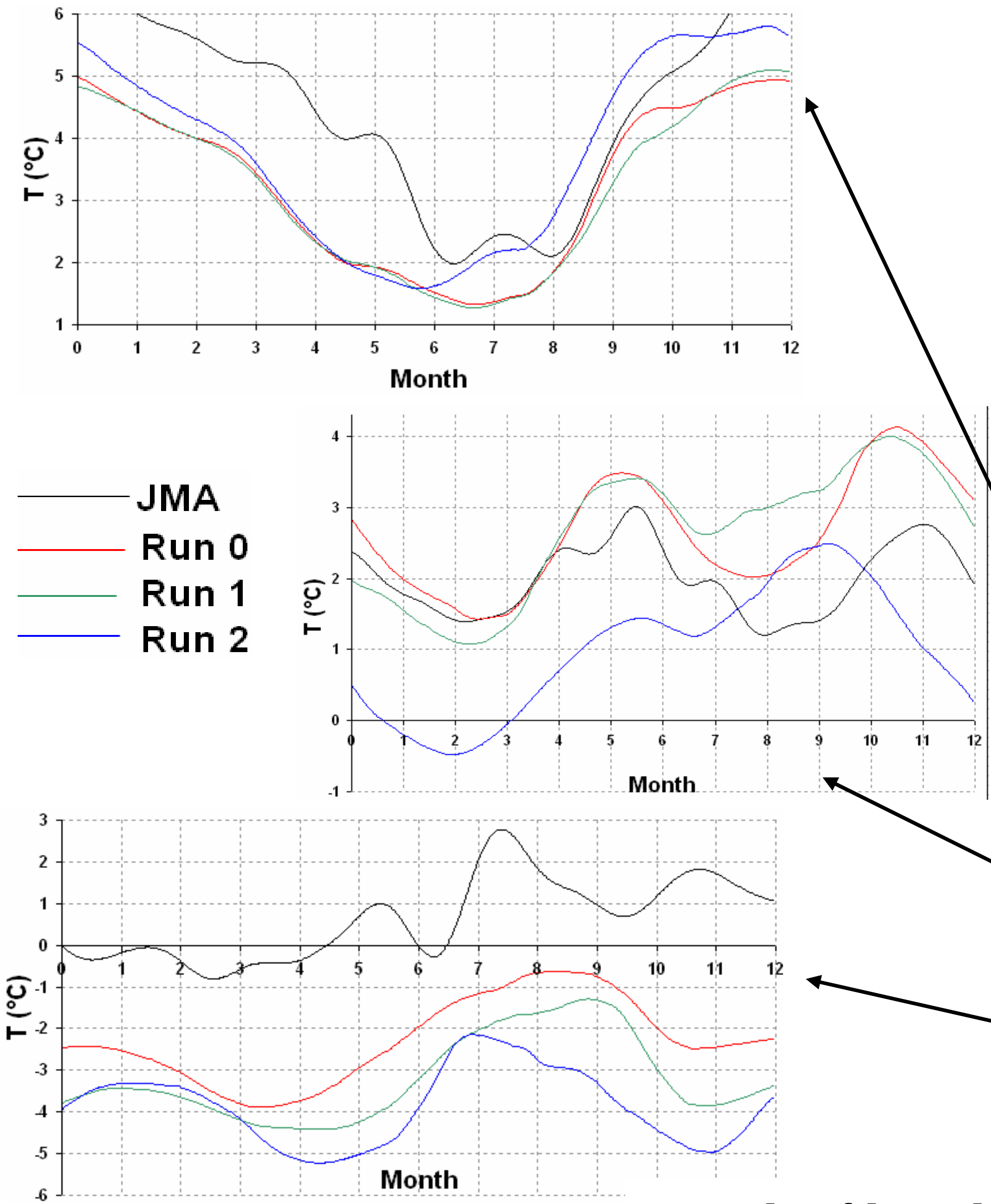


Compare spatial patterns:

- Mode 1 of JMA vs. Mode 1 of Runs 0 - 2.
- Mode 2 of JMA vs. Mode 3 of Run 0.
- Mode 3 of JMA vs. Mode 2 of Runs 0 & 1.
- Mode 3 of Run 1 and Modes 2 & 3 of Run 2 are different from JMA and Run 0.

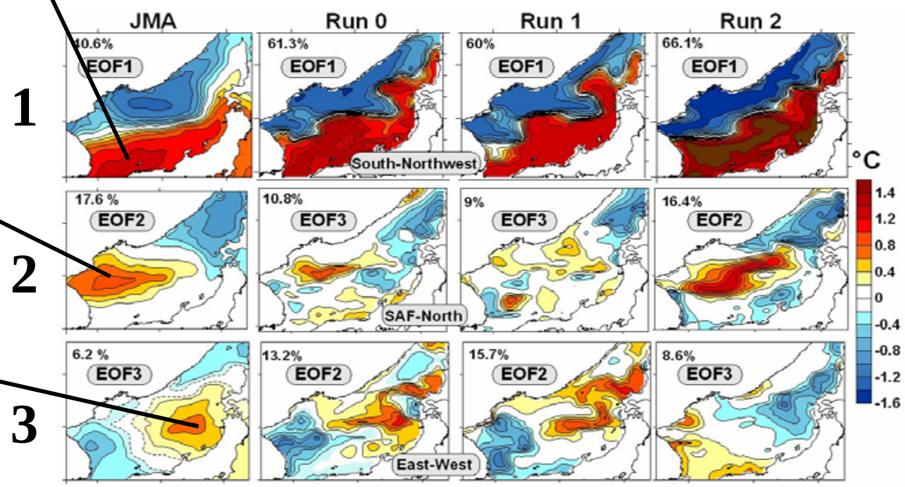
- Modes 2 and 3 are degenerate in Run 0.
- Modes 2 and 3 are switched in Runs 0 & 1.
- Statistically significant Modes 1 – 3 of JMA SST.
- Simulated SST: interannual variability is absent, mesoscale variability is low.
- High fraction of variance accounted for by Mode 1 of the simulated SST.
- Spatial cores are diffused for JMA SST and are stretched out along currents/fronts for the simulated SST.

EOF of JMA and simulated SST: temporal patterns



Compare temporal patterns:

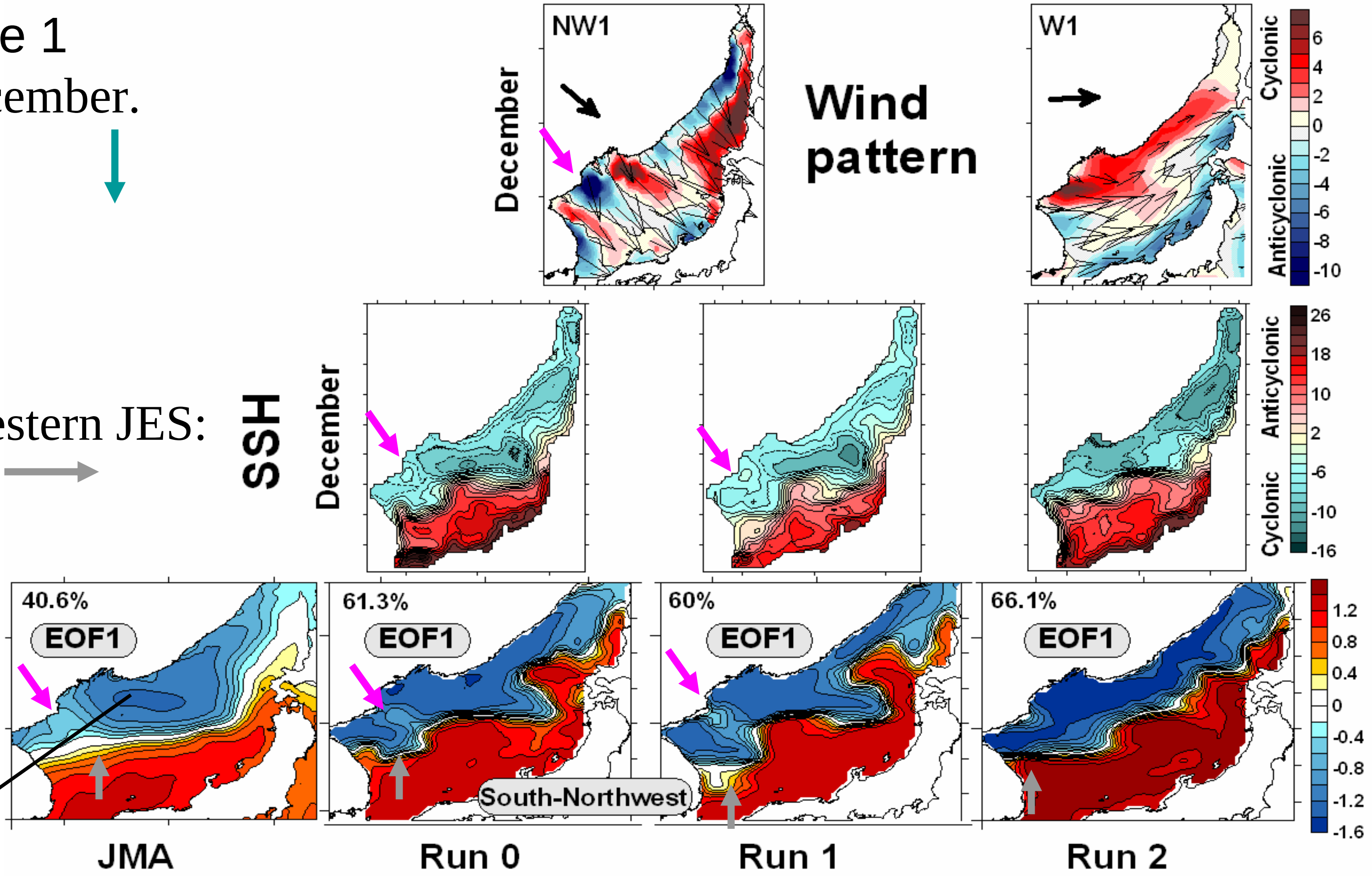
- Mode 1 of JMA vs. Runs 0 - 2.
- Mode 2 of JMA vs. Mode 3 of Runs 0 and 1.
- Mode 3 of JMA vs. Mode 2 of Runs 0 & 1.
- Modes 2 & 3 of Run 2 are different!



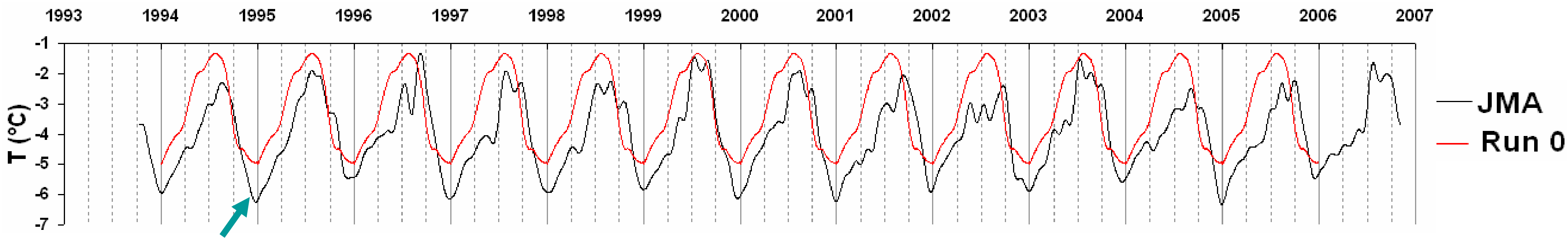
Wavelet-filtered JMA PCs for 1999

Mode 1: forcing by Ekman suction/pumping

- Anomaly related to Mode 1 is largest in December.
- Negative SSTA in the northwestern Japan Sea, positive SSTA in the southern Japan Sea.
- Subarctic Front in the western JES: JMA and Run 0 vs. Run 1
- Weaker SSTA off North Korea: JMA, Run 0, and Run 1 but not Run 2



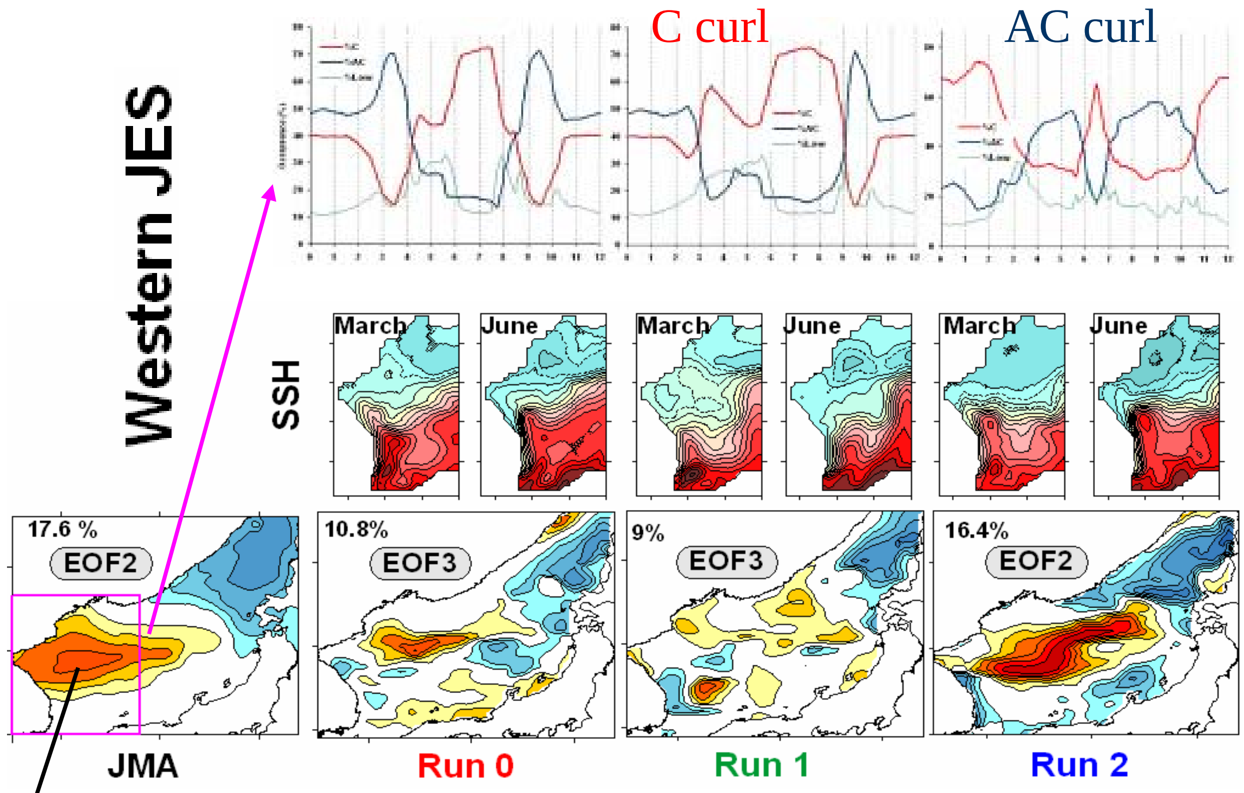
SSTA related to Mode 1 in the NW Core

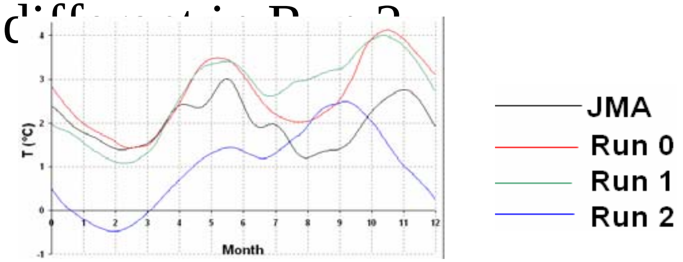


Mode SAF – North: forcing by AC wind stress curl

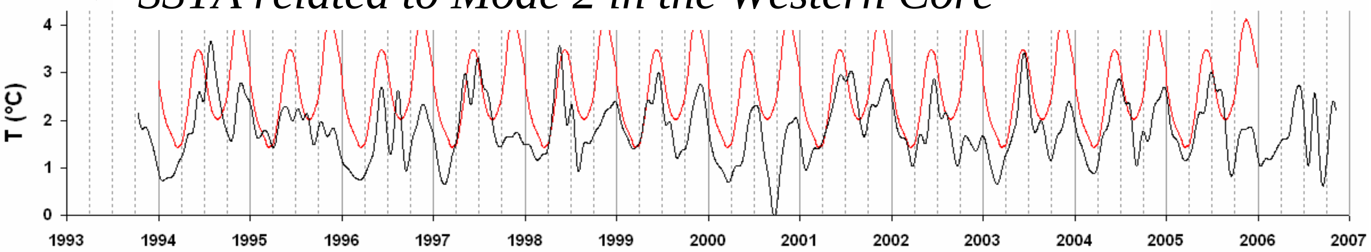
- SSTA is largest in May-June & November-December and smallest in February-March & August-September.
- Northward shift of Subarctic Front in spring (Nikitin, 2002); formation of the Northwestern Branch in autumn (Danchenkov et al., 1997).
- Western core around Subarctic Front in Run 0 is forced by the AC curl in spring and autumn.
- No western core in Run 1 under the forcing of the prevailing C wind curl.
- Spatial/temporal patterns are different in Run 2.

Occurrence of the AC & C wind curl in the western JES

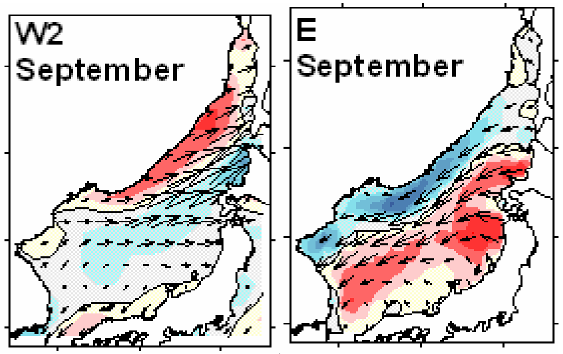




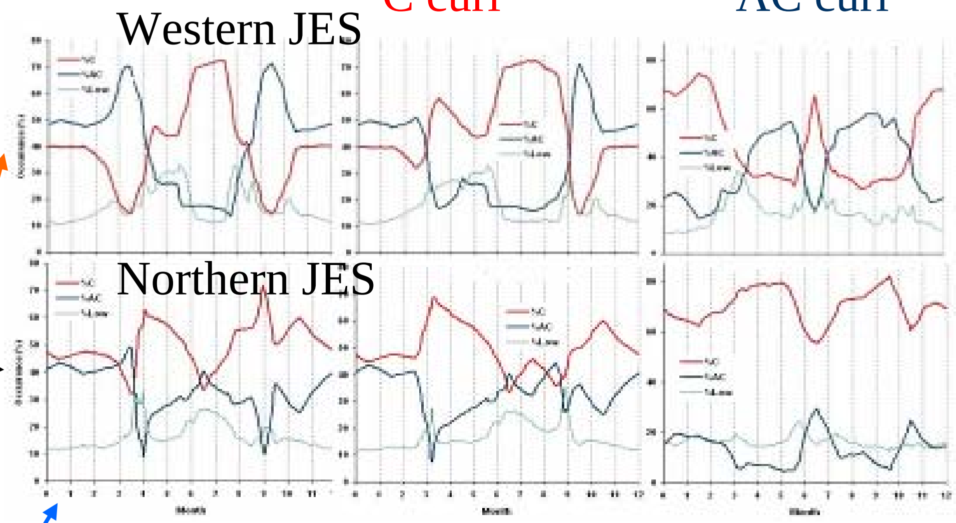
SSTA related to Mode 2 in the Western Core



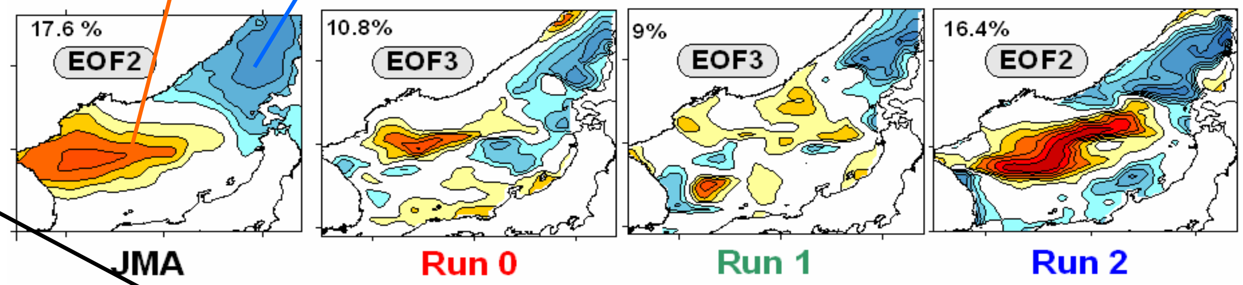
Northern vs. Western Cores: opposition in wind curl and SSTA

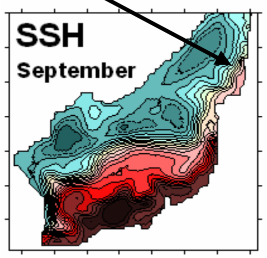


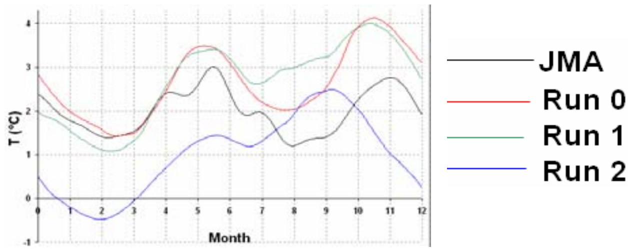
Occurrence of the AC/C wind stress curl



- •Opposition of wind stress curl over the central and northernmost JES.
- •Semiannual wind stress curl in the northernmost JES in Runs 0 & 1.
- •Variability around the eastern margin of the cyclonic gyre in Runs 0 & 1.
- •Spatial/temporal patterns are different in Run 2.
- •AC eddy formation (Nikitin, 2007) and variety of circulation patterns (Dyakov, 2006) in the northernmost JES

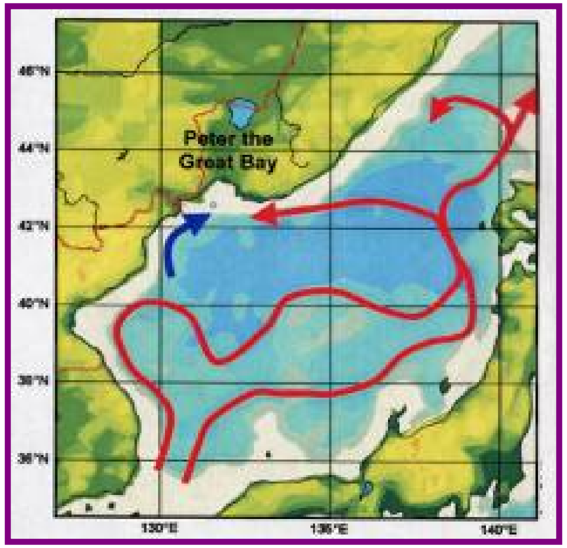






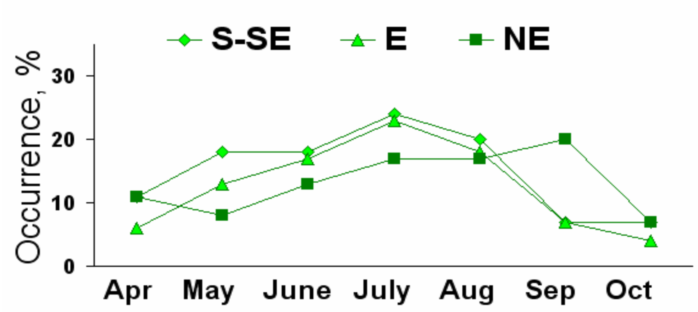
Pathways of warm water transport to the Russian coast

West – East Mode: forcing by the C wind stress curl

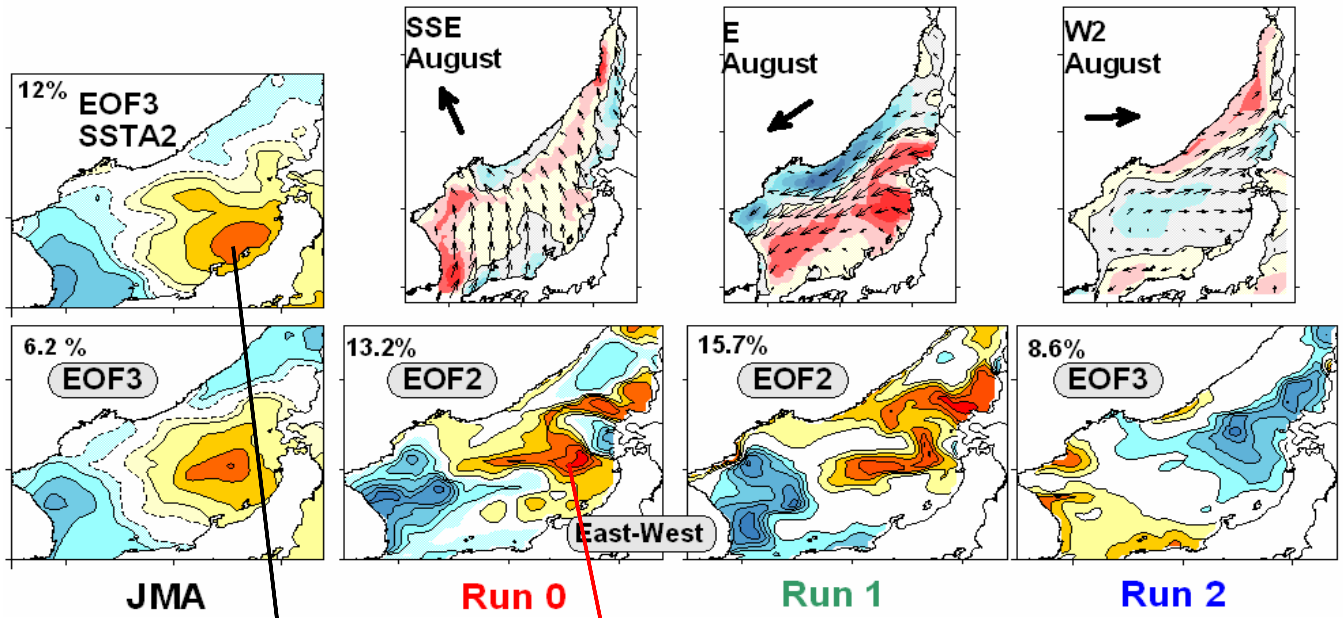


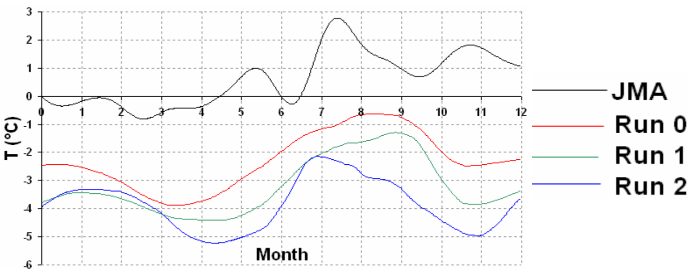
(Lobanov et al., 2001)

Occurrence of the easterly wind patterns is increased in late summer

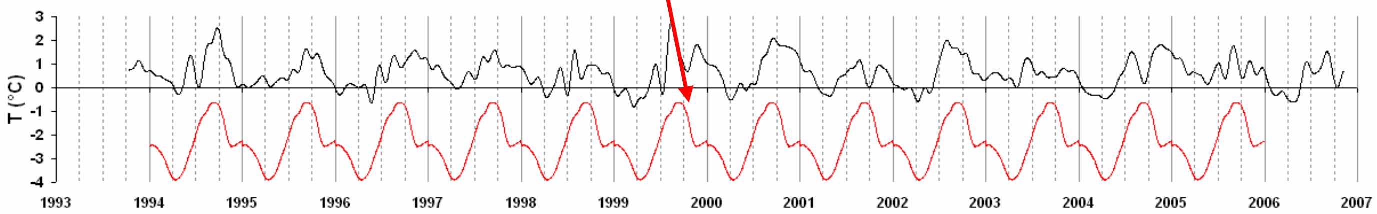


Forcing by the prevailing C wind stress curl in Runs 0 & 1 but not in Run 2





SSTA related to Mode 3 in the Honshu Core



Conclusion

•EOF modes of SST simulated under the forcing of realistic wind are consistent with those of the observed SST.

•Northward shift and a secondary branch of Subarctic Front in the western JES are simulated under the forcing of the local AC wind stress curl. These processes result in formation of positive SSTA.

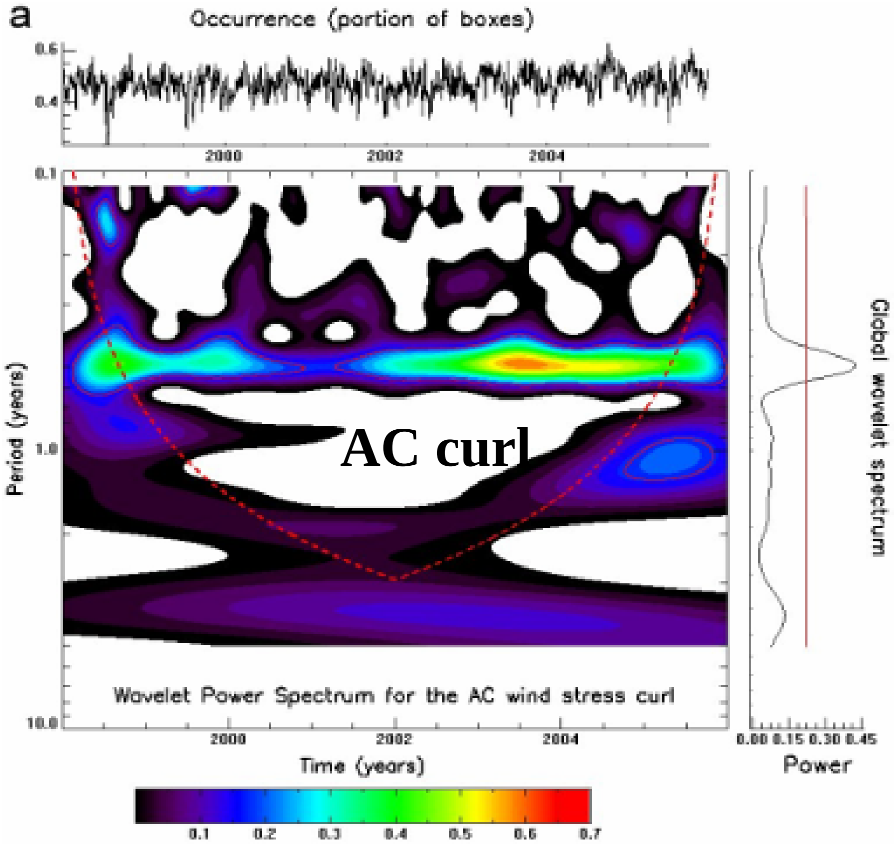
•Semiannual periodicity in SST is simulated under the forcing of the semiannually varying wind stress curl.

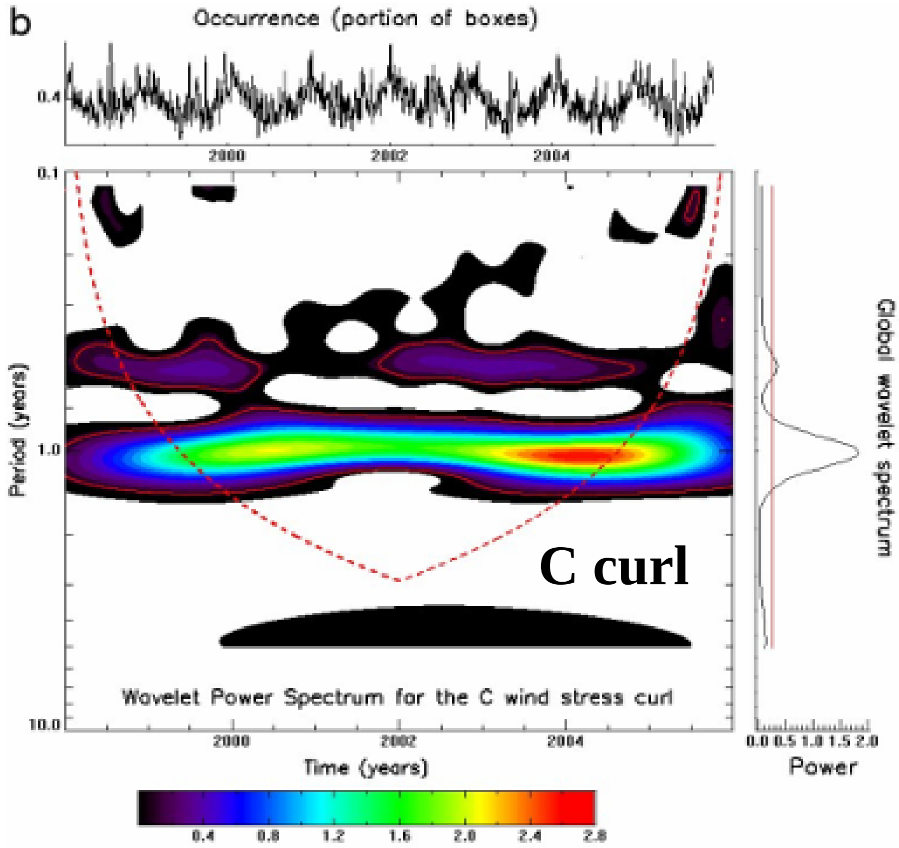
•Northward transport of warm water along the Honshu coast is increased and accompanied by the decreased transport in the western JES in late summer – autumn under the forcing of easterly wind patterns with the prevailing C curl.

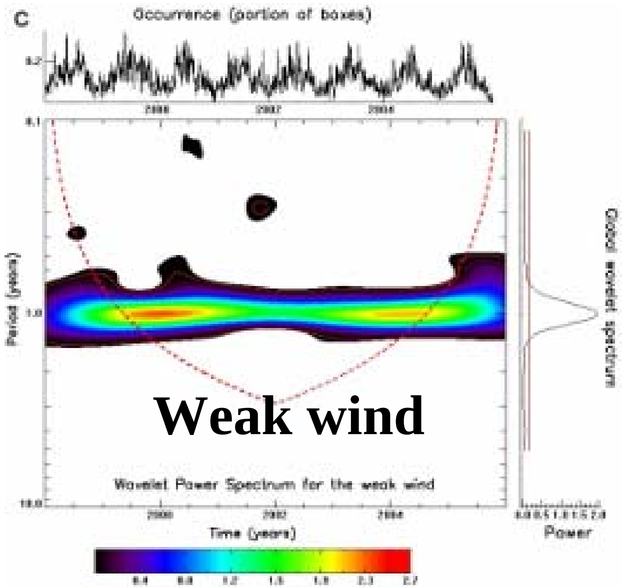
•To estimate a contribution of mesoscale dynamics to the large-scale SST modes, truly eddy-resolving simulations are necessary.

•Interannual variability of the observed SST can be related to the interannual wind variations.

Wavelet analysis of the occurrence of wind curl



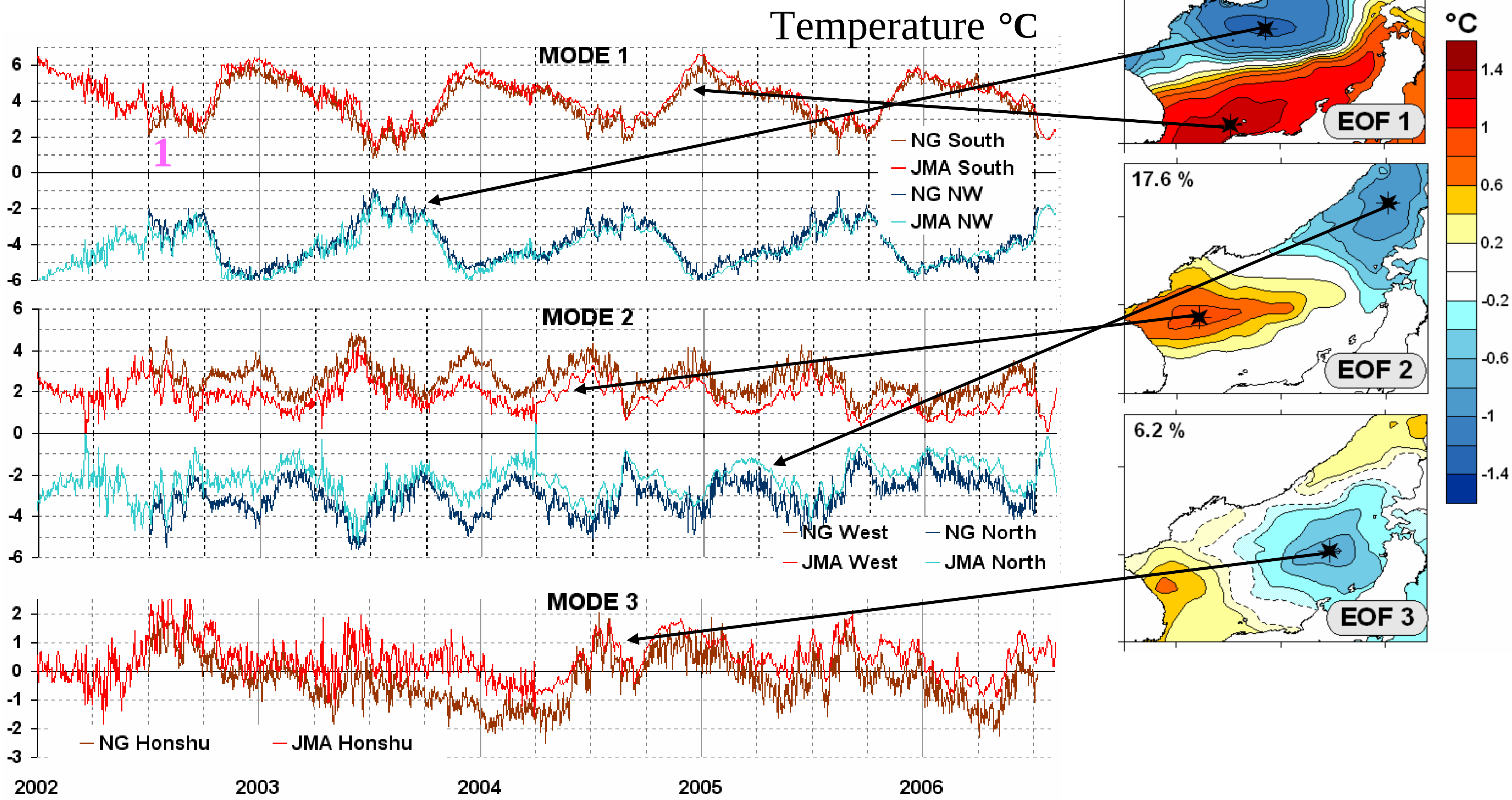




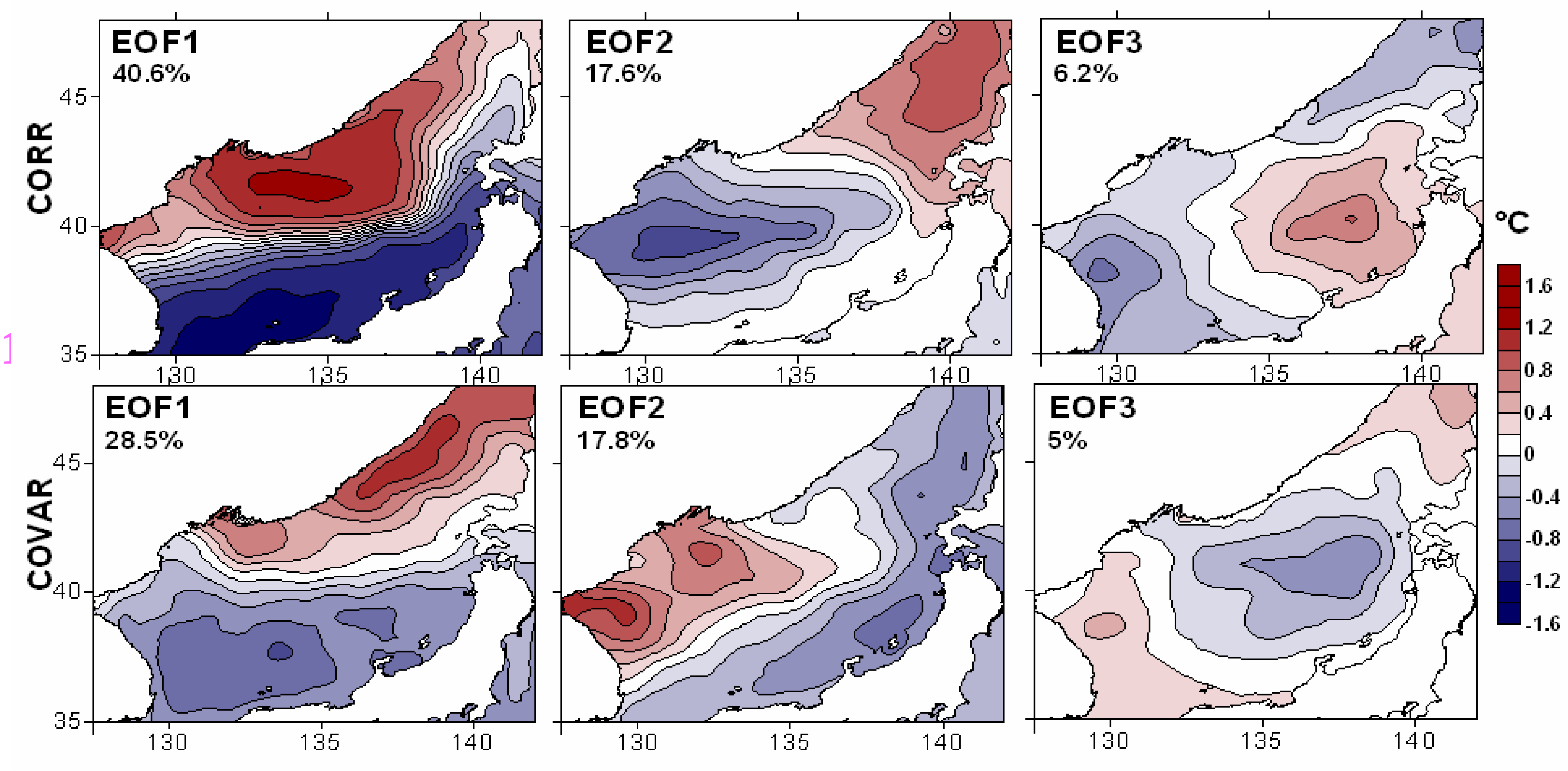
Residual anomalies SSTA: JMA vs. NG

Residual anomalies calculated by subtraction of an average annual cycle:

$$\mathbf{X_a}^{(\mathbf{1})}(\mathbf{r}, \mathrm{t}) = \mathbf{X}(\mathbf{r}, \mathrm{t}) - \mathrm{A}_1^{(0)}(\mathbf{r})\mathrm{B}_1^{(0)}(\mathrm{t})$$



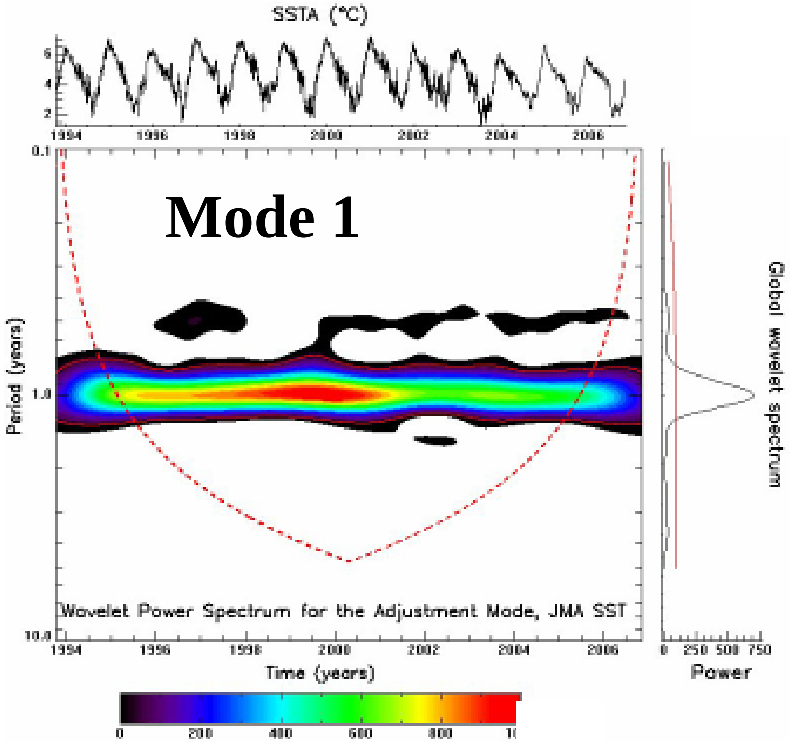
JMA SSTA: correlations vs. covariances

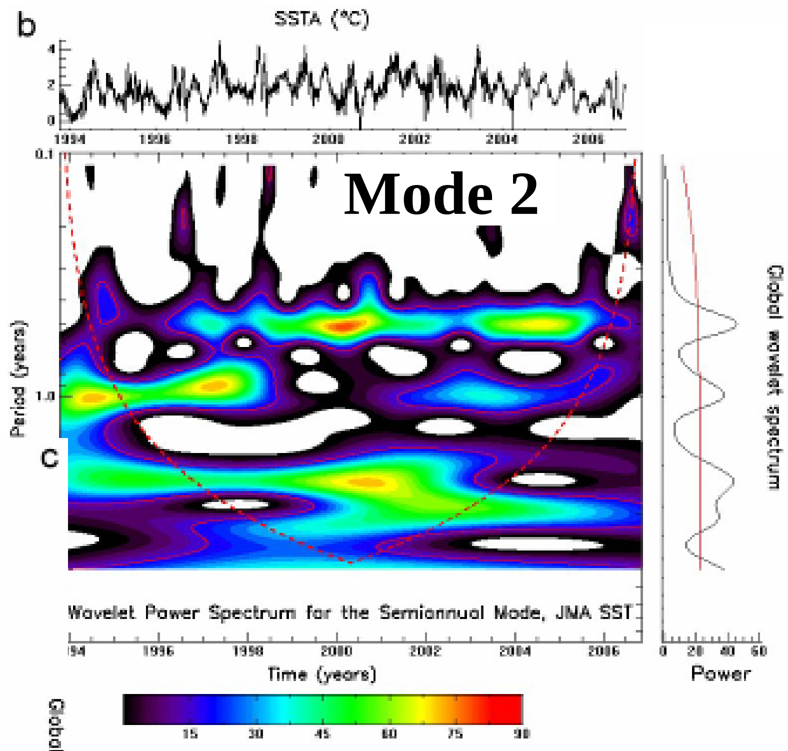


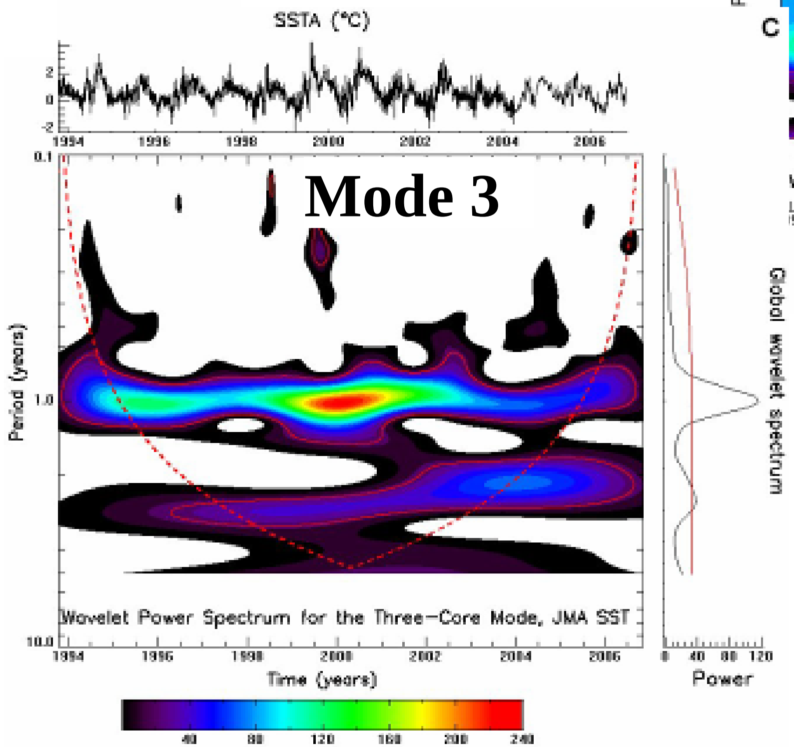
Residual anomalies calculated by subtraction of an average annual cycle:
$\mathbf{X_a}^{(1)}(\mathbf{r}, t) = \mathbf{X}(\mathbf{r}, t) - A_1^{(0)}(\mathbf{r})B_1^{(0)}(t)$

Mode 1 – 3 JMA SSTA:

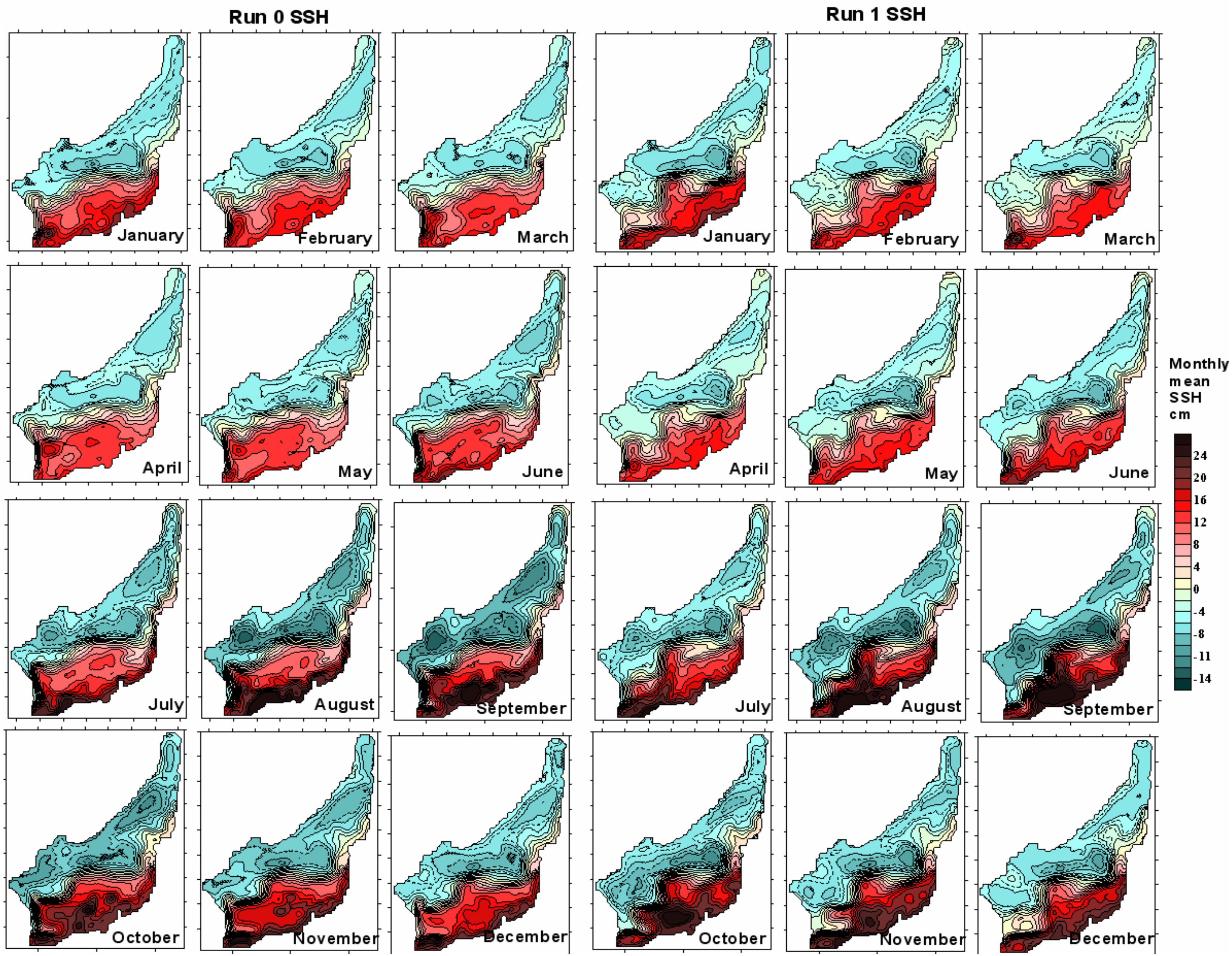
Annual, semiannual, and quasi-biennial time-scales







SSH: Run 0 vs. Run



Run 1:

No seasonal shift of Subarctic Front

Subarctic region extends far south in the western Japan Sea