Modeling of deep currents in the Japan/East Sea

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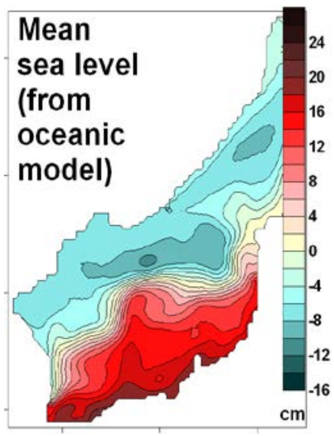
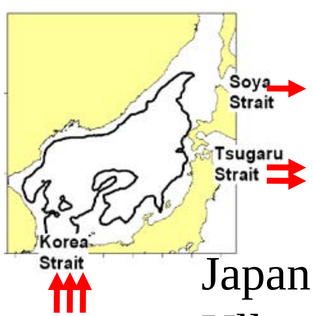
Deep currents in the Japan/East Sea

Surface circulation

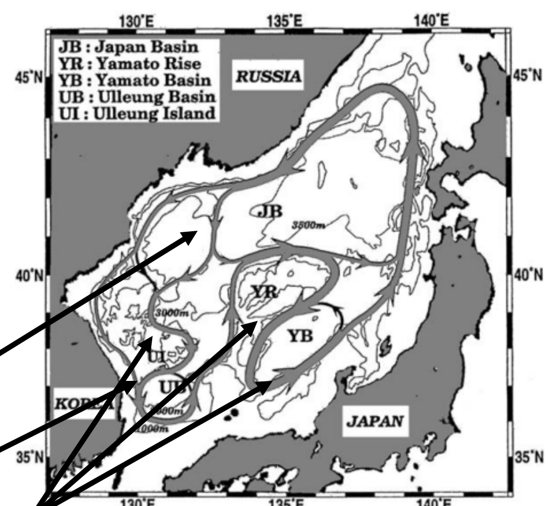


(Trusenkova, 2003-2012)



Deep currents:
- quasi-barotropic,
- intense,
- geostrophic (in the mean sense),
- deep eddies.

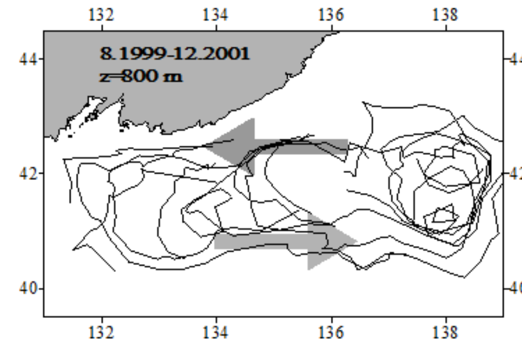
(from deep moorings; Takematsu et al., 1999)



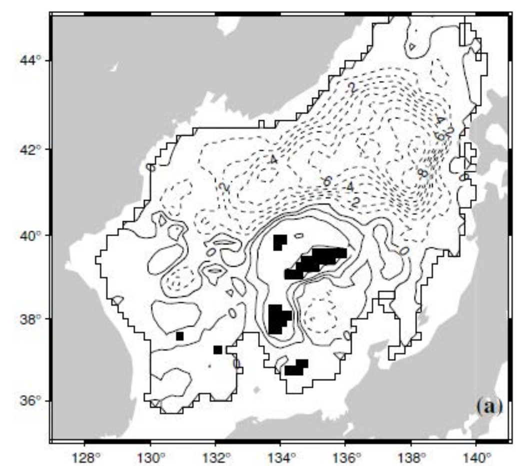
Japan Basin
Ulleung Basin
Yamato Basin
Yamato Rise
Korea Plateau

(Senjyu et al., 2005)

ARGO buoys, 800 m



(Danchenkov et al., 2003)



(Choi, Yoon, 2010)

Forcings

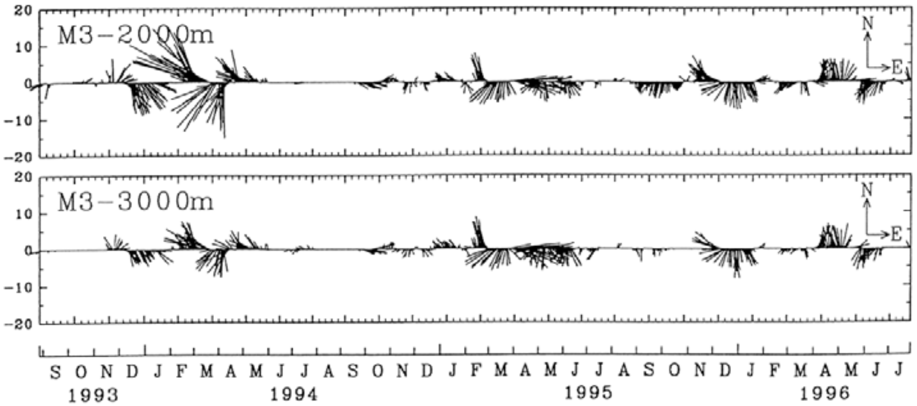
Wind stress curl (Yoon t al., 2005), in particular, interannual variation of wind stress curl (Stepanov et al., 2014).

Upper ocean – topographic steering (Hogan, Hurlburt, 2000, 2008).

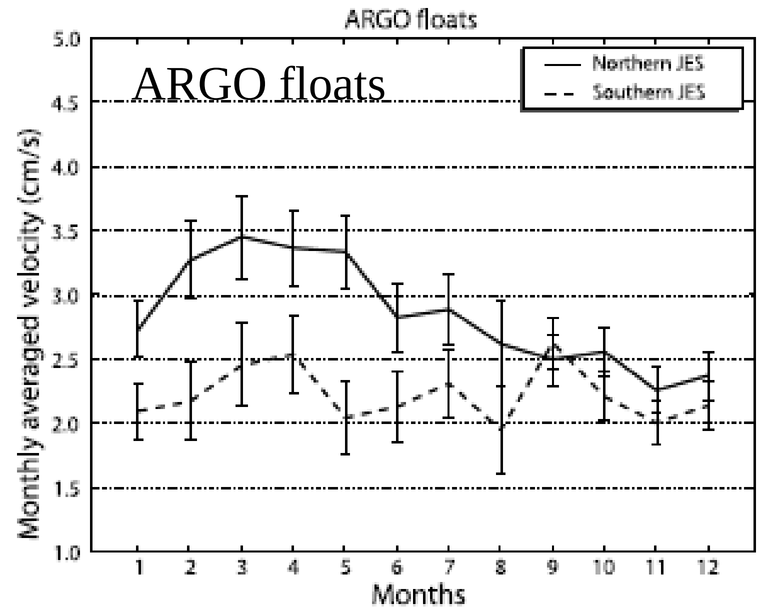
Deep convection events (of 2000-2001; Takematsu et al., 1999). Eddy-driven abyssal circulation by theoretical layered modes (Shin et al., 2009; Yoshikawa, 2012).

Seasonal variation of the deep currents

M3 mooring site, 41°29.7′ N, 134°21.4′ E



Intensification in winter – early spring but not at every site (Takematsu et al., 1999)



In the numerical models: strengthening in winter, weakening in summer in the entire Sea (Kawamura et al., 2010)

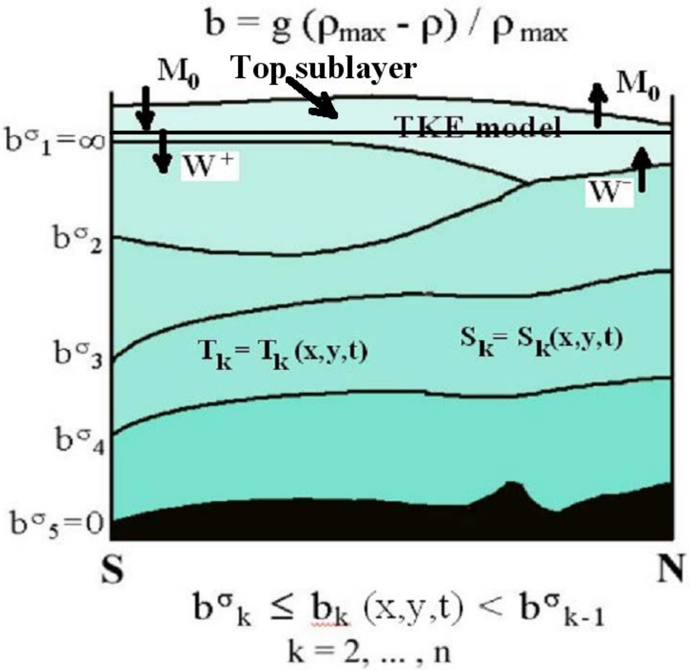
In the northern Sea: intensification in late winter, weakening in fall.
In the southern Sea: no clear pattern (Choi, Yoon, 2010)

Purpose of the study

to clarify seasonal variation of the deep circulation in the Japan/East Sea and its forcings

Oceanic model

(Shapiro and Mikhaylova, 1992-1998)



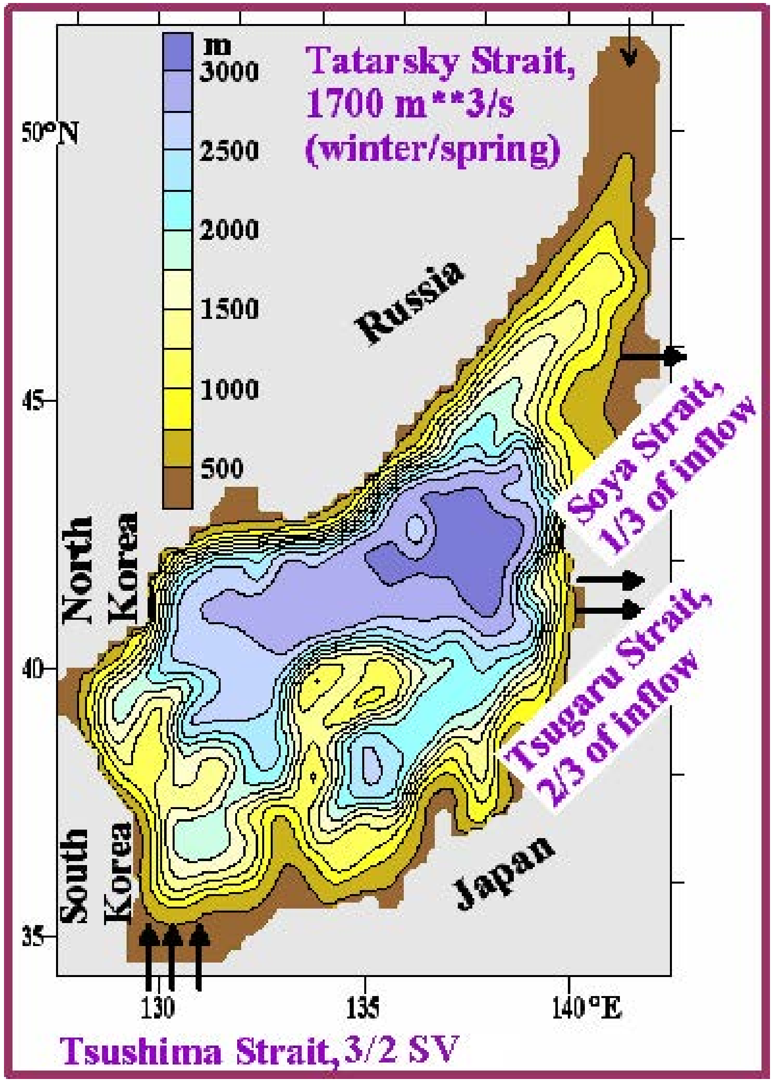
b^{σ}_{k} is base buoyancy of the kth layer

$M_0 = \alpha\,\Gamma - \beta R$ is surface buoyancy flux

Γ is heat flux and R is freshwater flux

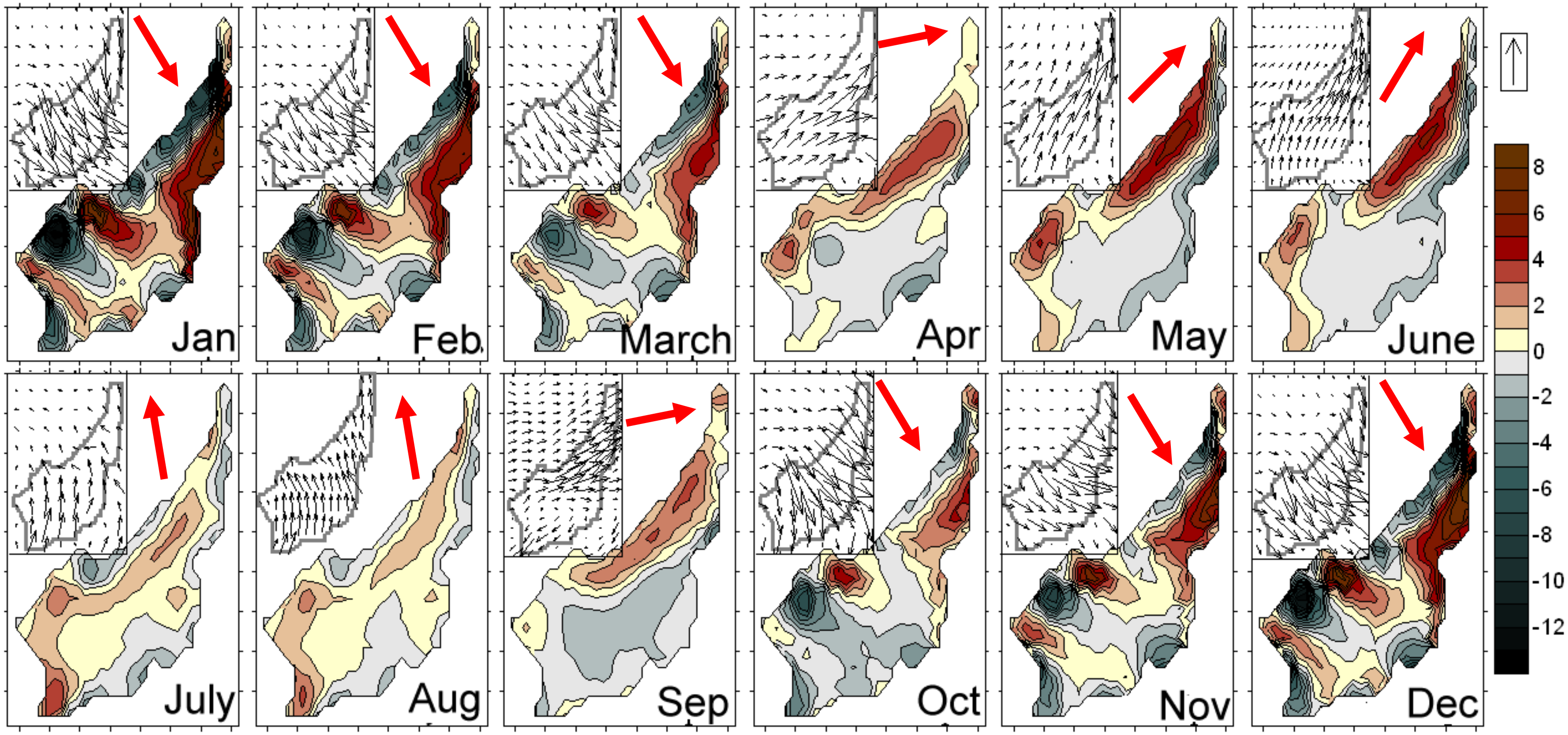
- 3D primitive equation, hydrostatic & Boussinesq.
- Isopycnic coordinate in the vertical.
- Free surface.
- Thermodynamics:
  - bulk parameterization of surface heat/freshwater fluxes,
  - TKE model for the surface mixed layer with entrainment and subduction at its base,
  - cyclic regimes of the surface mixed layer,
  - prognostic depth of the surface mixed layer,
  - prognostic T, S, and density in every layer,
  - diapycnal diffusion of T and S.
- *Base buoyancy (density)* – a constraint in internal layers.
- Vanishing and restoring internal layers.
- Bi-harmonic viscosity in the momentum equations.
- Winter convection through 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 fields (1979-1999) for parameterization of surface fluxes;
- Wind stress from 1°-gridded NCEP/NCAR data;
- Fully prognostic temperature and salinity.

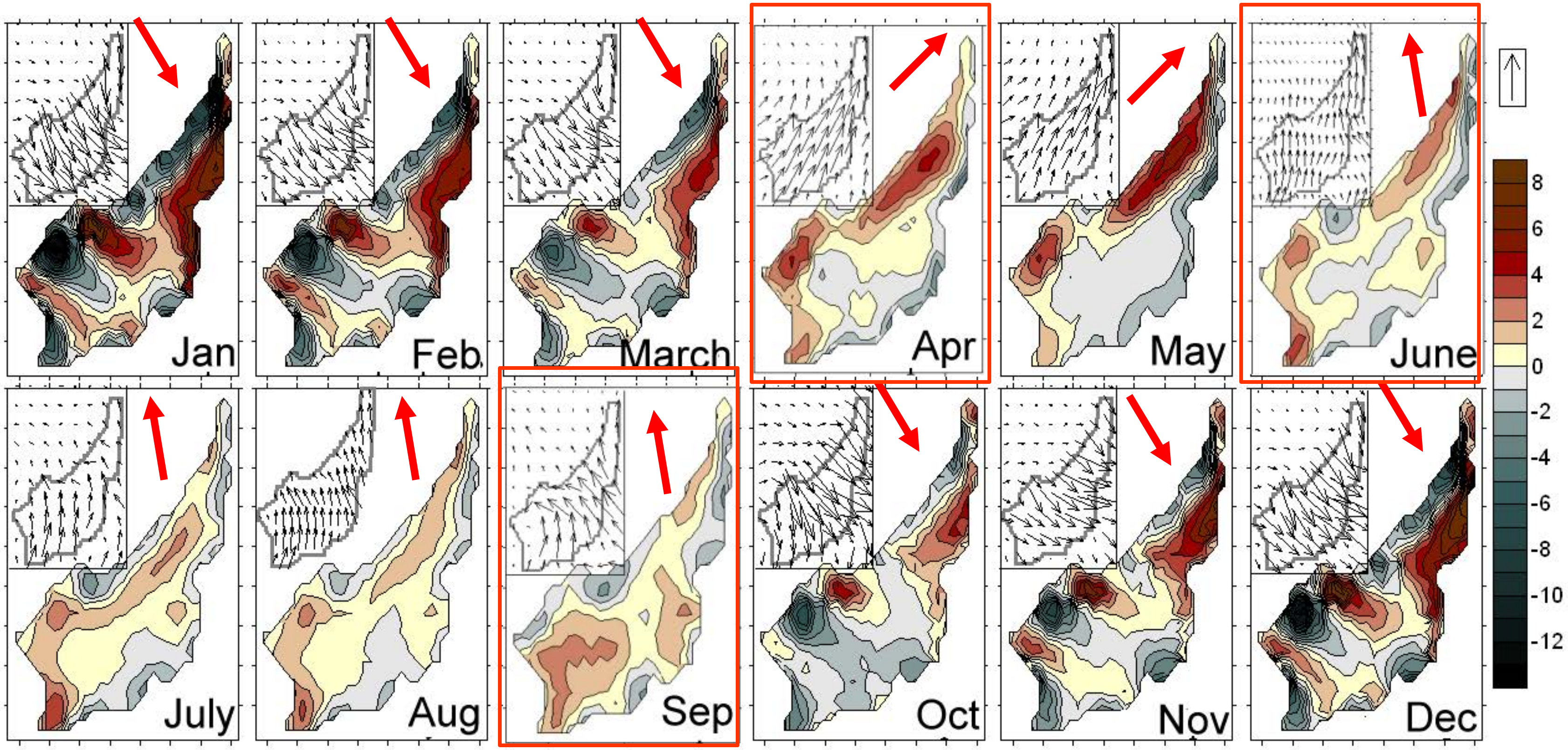
Wind stress and curl, Run 1 – typical monsoon



The general wind direction is shown by red arrows

Seasonal change of general wind directions over the Japan/East Sea from multivariate analysis of satellite scatterometry data (Trusenkova, 2011)

Wind stress and curl, Run 2 – strong summer monsoon



The general wind direction is shown by red arrows, patterns different from Run 1 are in the red frames.

Simulations

•Run 1a:

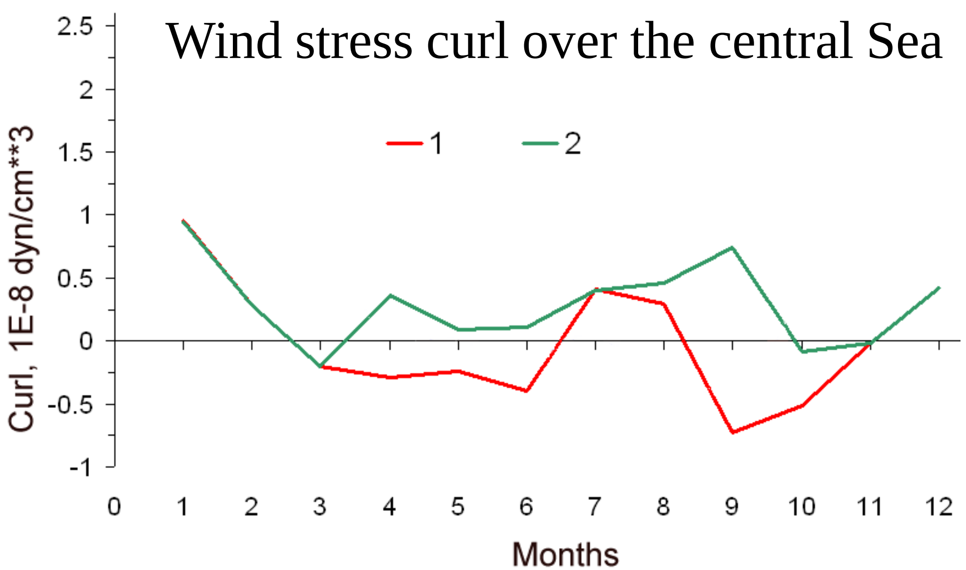
Typical monsoon (cyclonic/anticyclonic wind stress curl), modern transport in the Korea Strait (2–3 SV)

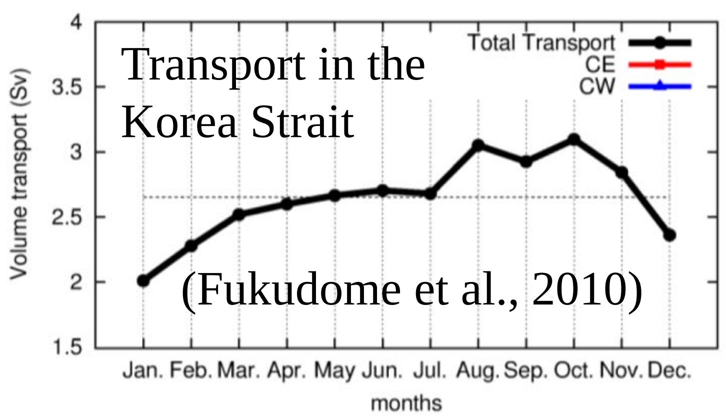
•Run 1b:

Typical monsoon (cyclonic/anticyclonic wind stress curl), decreased transport in the Korea Strait (1.5–2.5 SV)

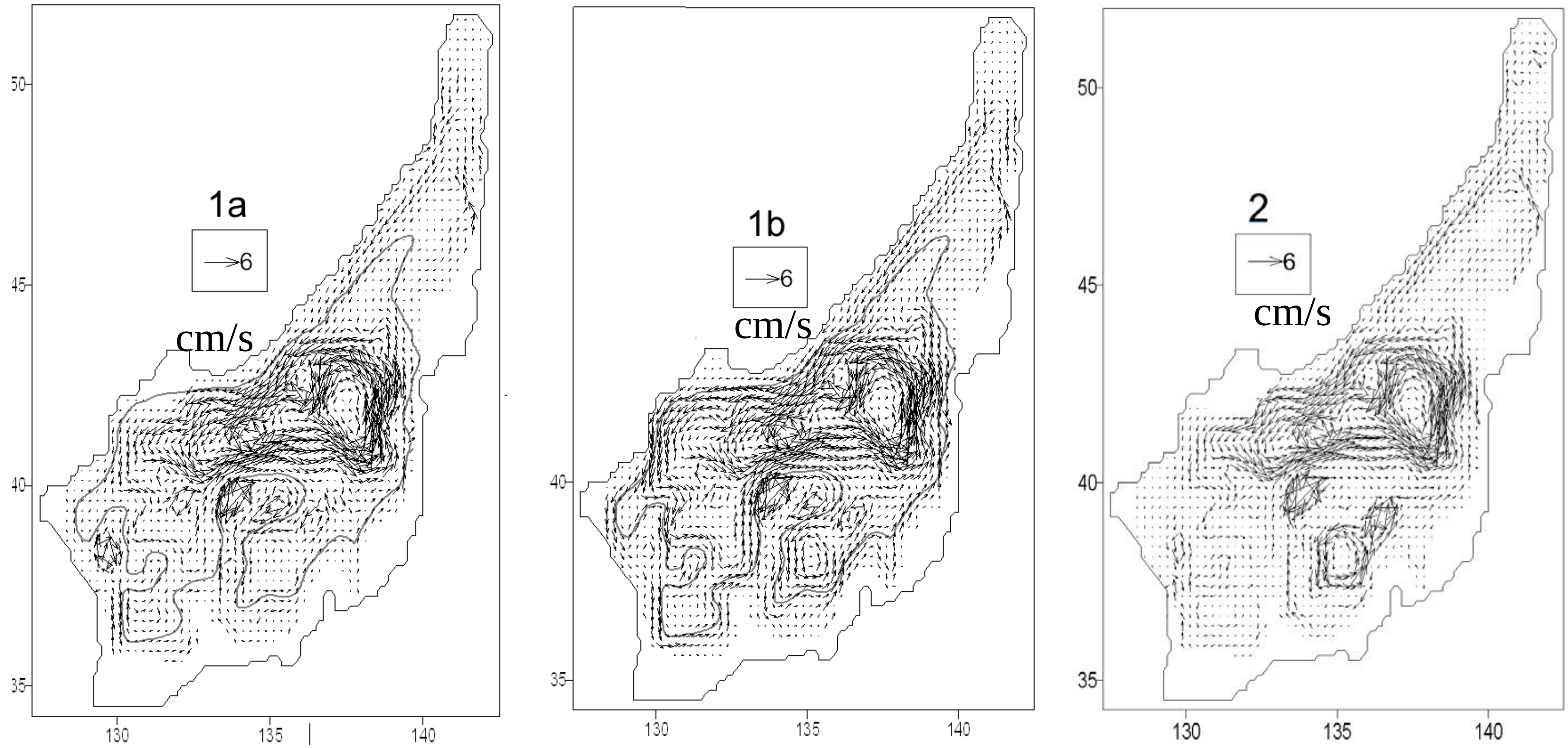
•Run 2:

Strong summer monsoon: early onset, late termination (prevailing cyclonic curl throughout the year)



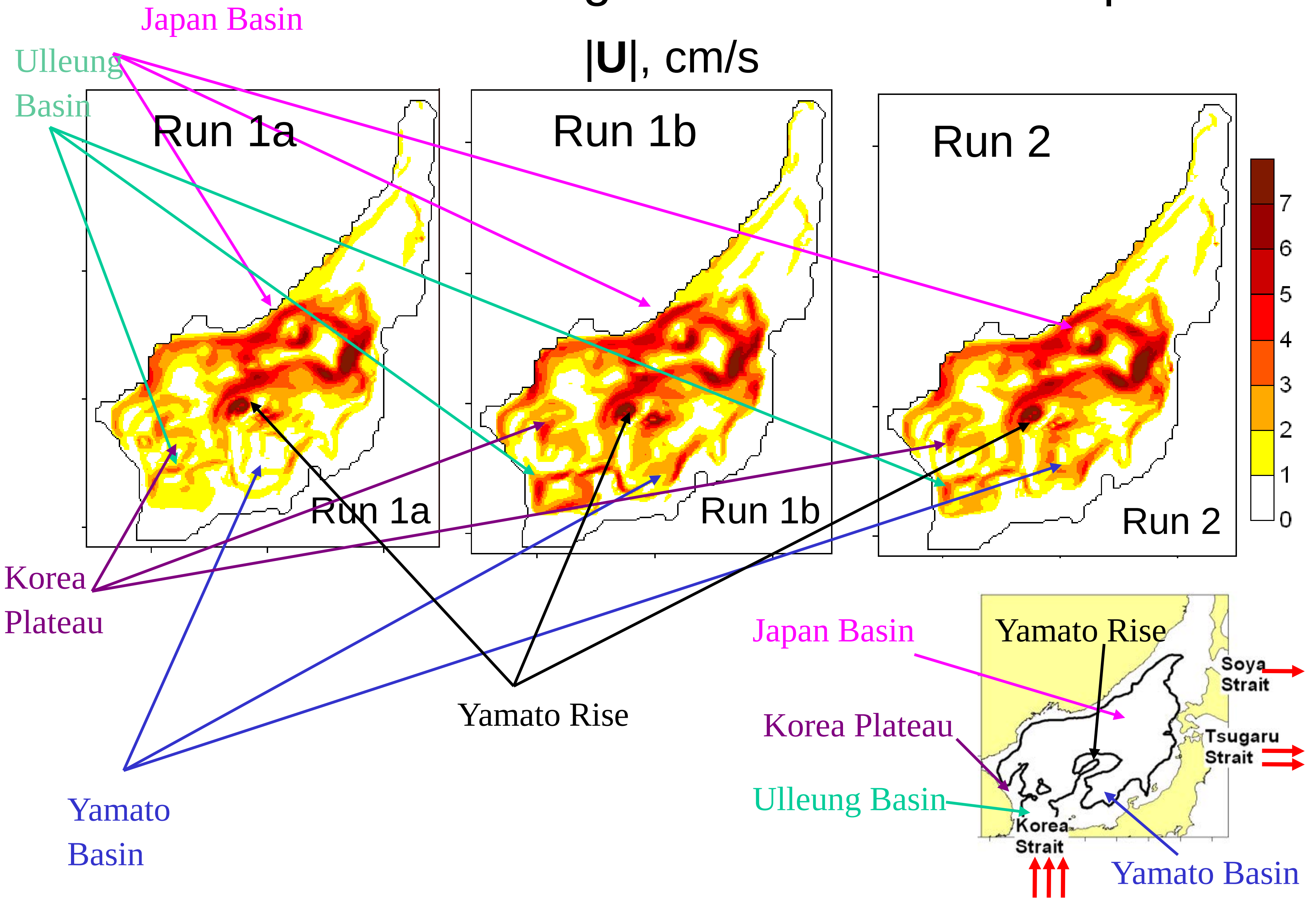


Geostrophic circulation (bottom layer)

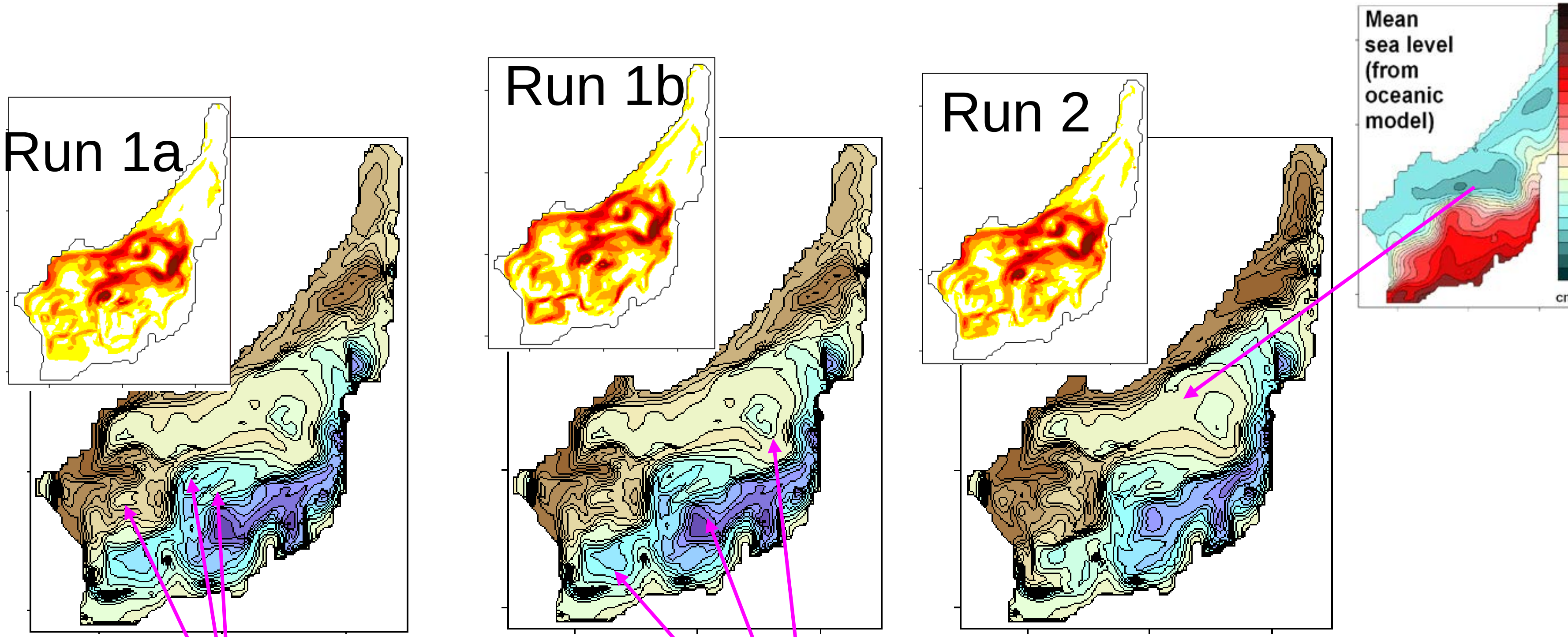


1500 m isobaths shown

Strong currents over the slopes



Interface topography between the lowest layers

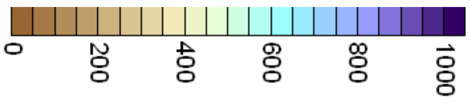


Initially flat interface at 900 m

Cold deep anticyclonic eddies
(shallow interfaces)

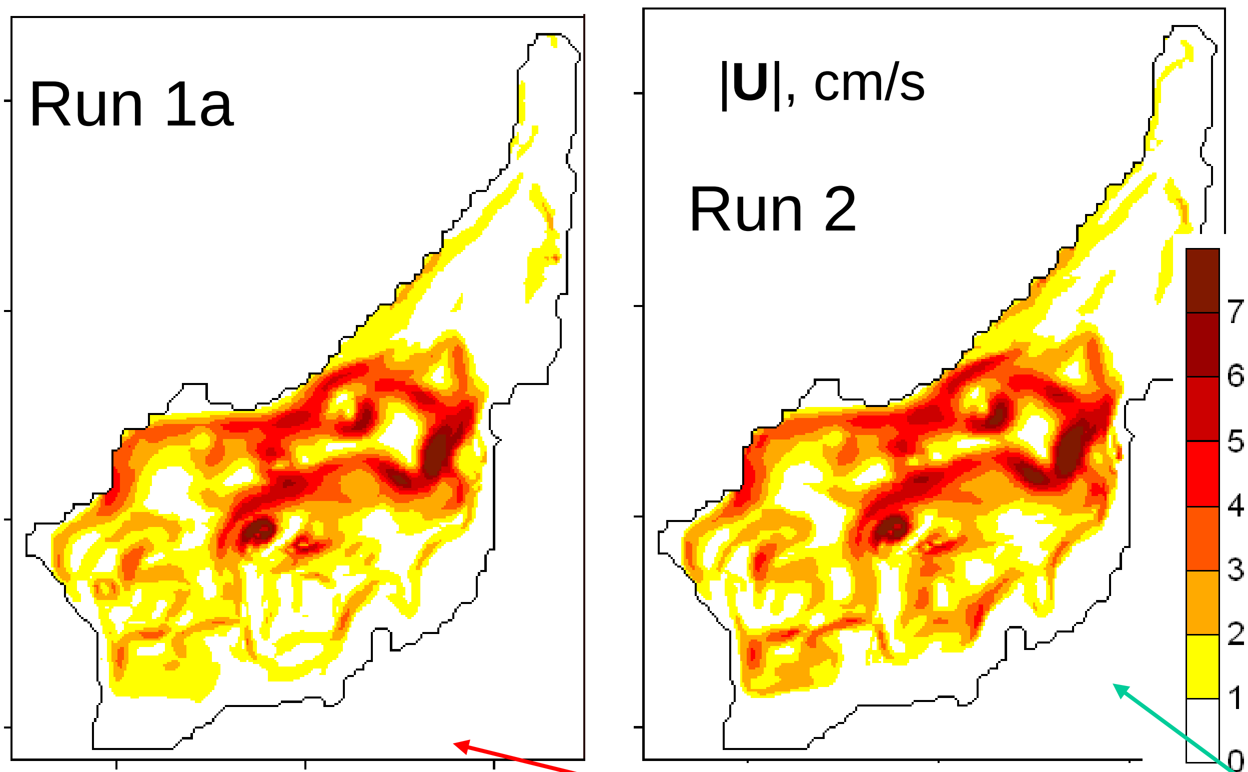
Warm deep cyclonic eddies (deep interfaces)

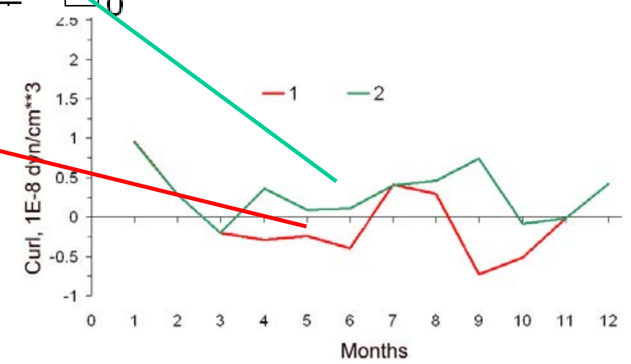
Interface depth, m



Taylor columns in the Northern Sean, Taylors cones in the Southern Sea, in accordance with (Hogg, 1973)

Forcing by wind stress curl

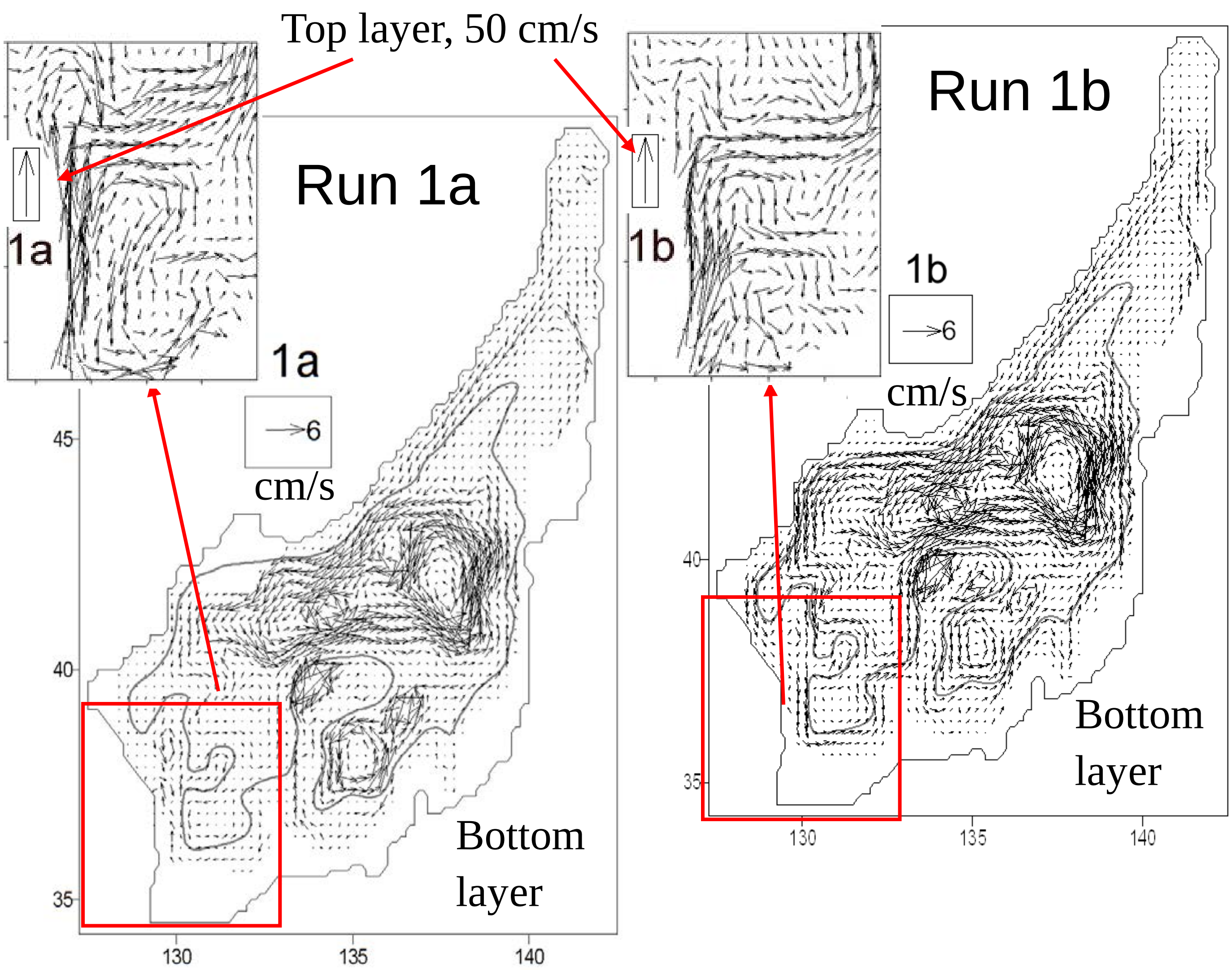




The prevailing cyclonic curl in Run 2 → stronger deep circulation

Interaction between the surface and deep currents

(upper ocean – topographic steering; Hogan, Hurlburt, 2000, 2008)

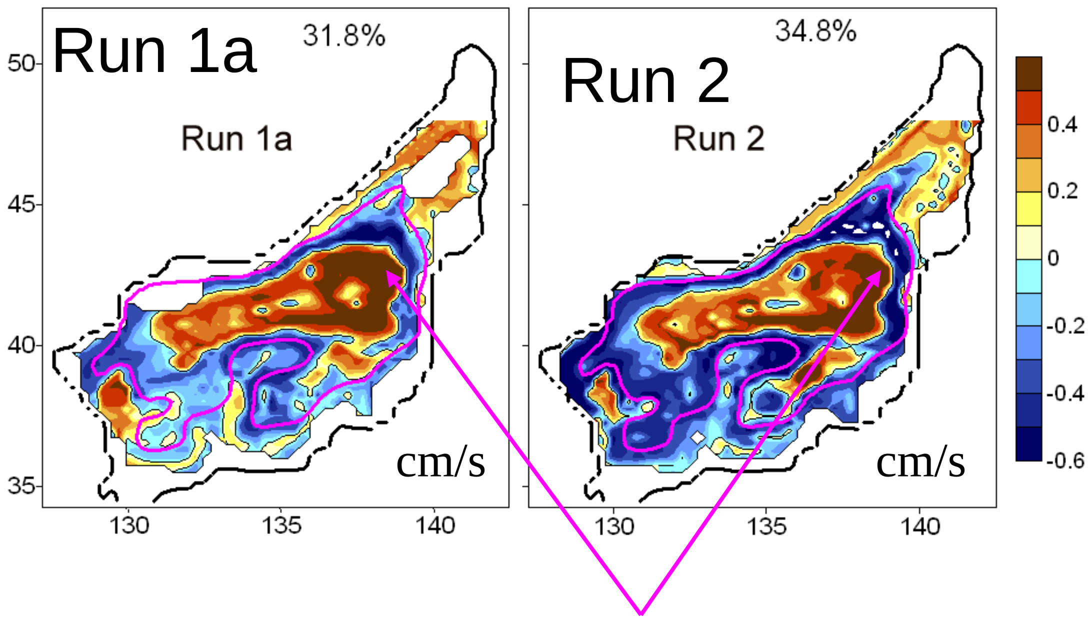


Run 1a:
larger transport,
stronger EKWC
weaker deep currents

Run 1b:
smaller transport,
weaker EKWC,
stronger deep currents

Surface and deep currents at the large angle

Seasonal variation: EOF analysis

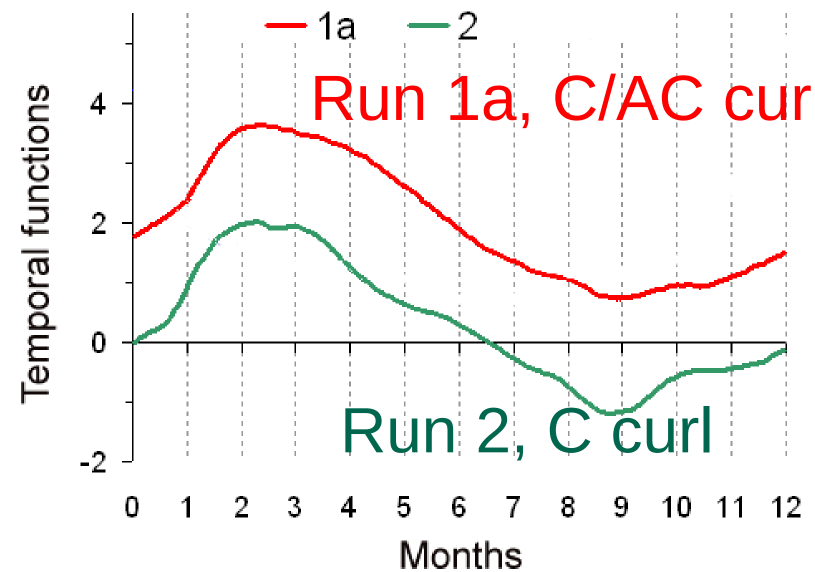


The leading EOF mode of daily speed (|**U**|) in the bottom model layer

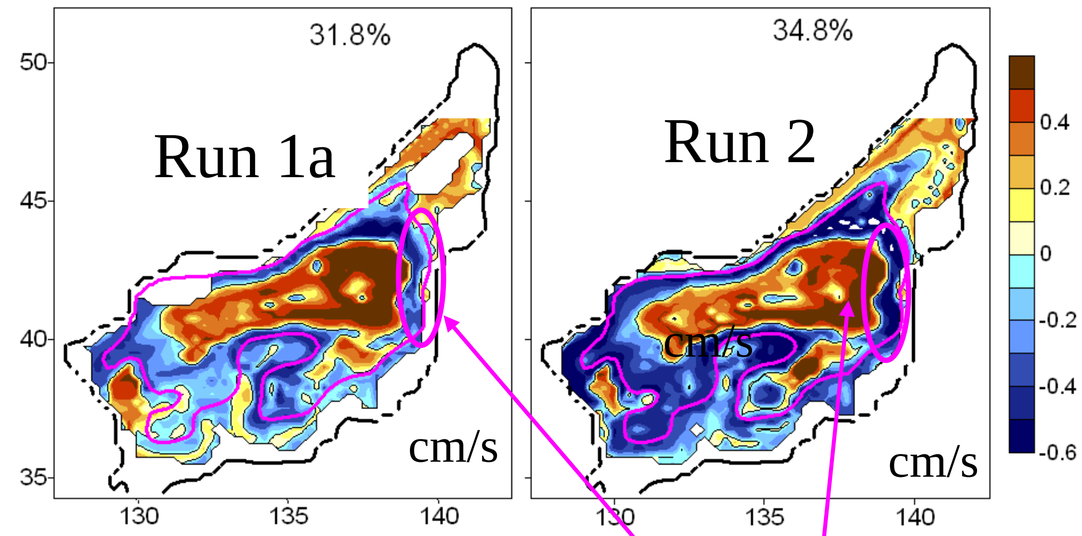
The deep currents in the Japan Basin and Tatarsky Strait are strongest in March, weakest in late September – October, in agreement with results from the ARGO buoys (Choi, Yoon, 2010) .

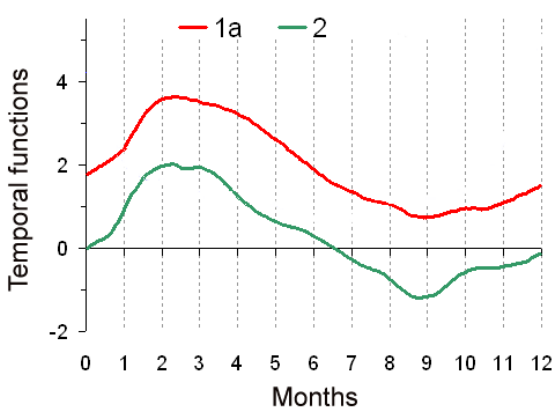
Δ|**U**| ~ 1.5– 2 cm/s, ~30% .

In the southern Sea the seasonal cycle is reversed and, in Run 1, weak.



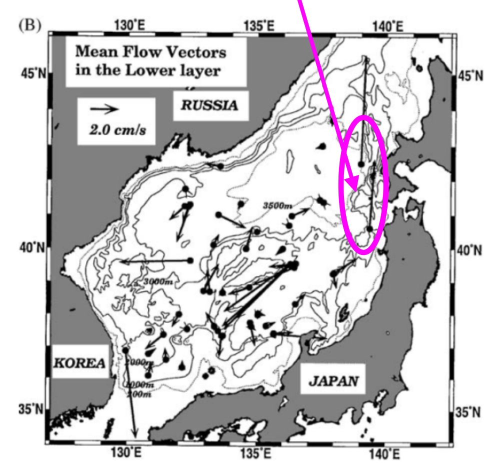
Variation in the Japan Basin





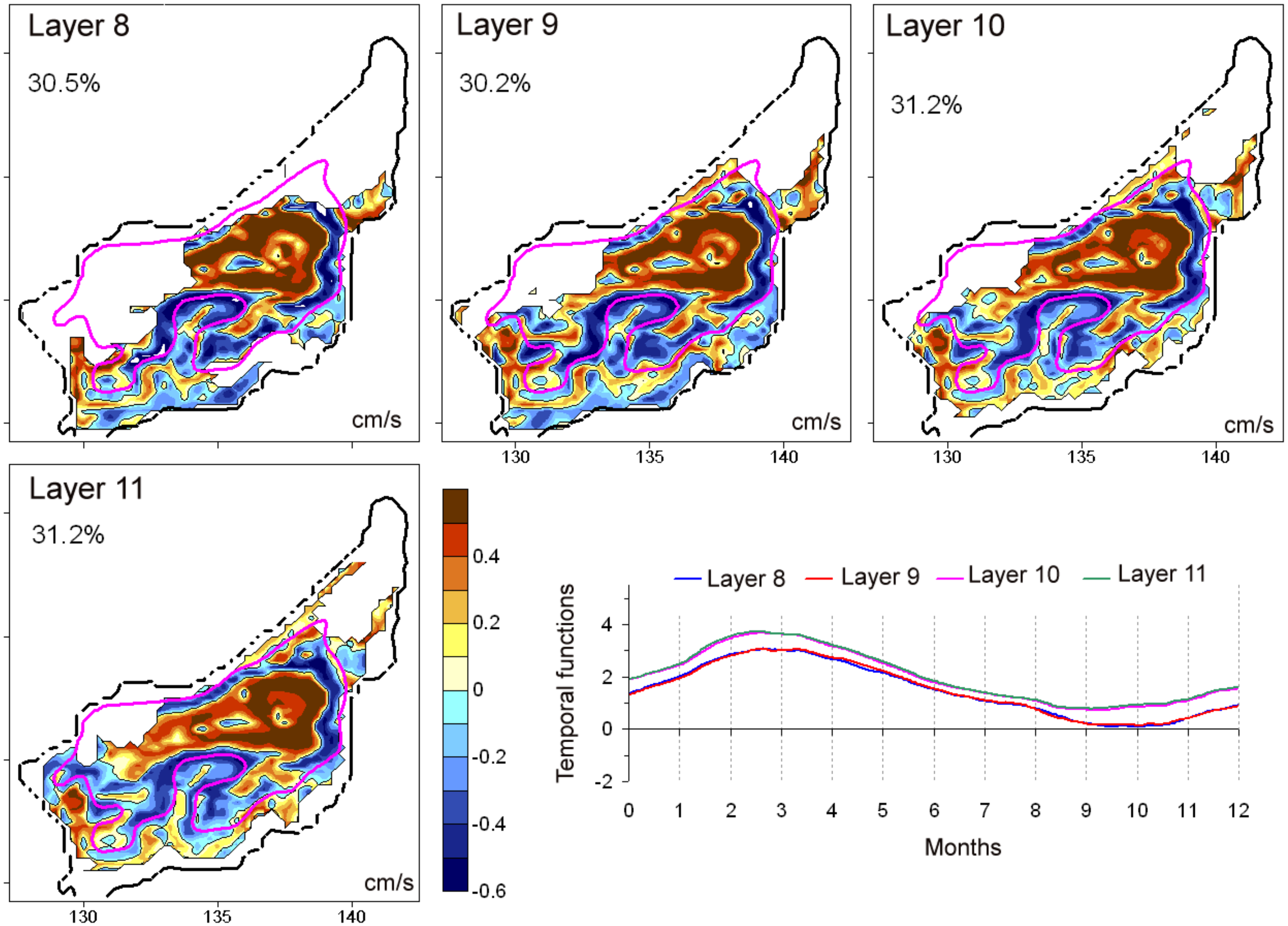
The deep cyclonic gyre in the Japan Basin contracts when intensifies, expands when weakens

Seasonal variation is unclear at the sites at the eastern margin of the Japan Basin



(Senjyu et al., 2005)

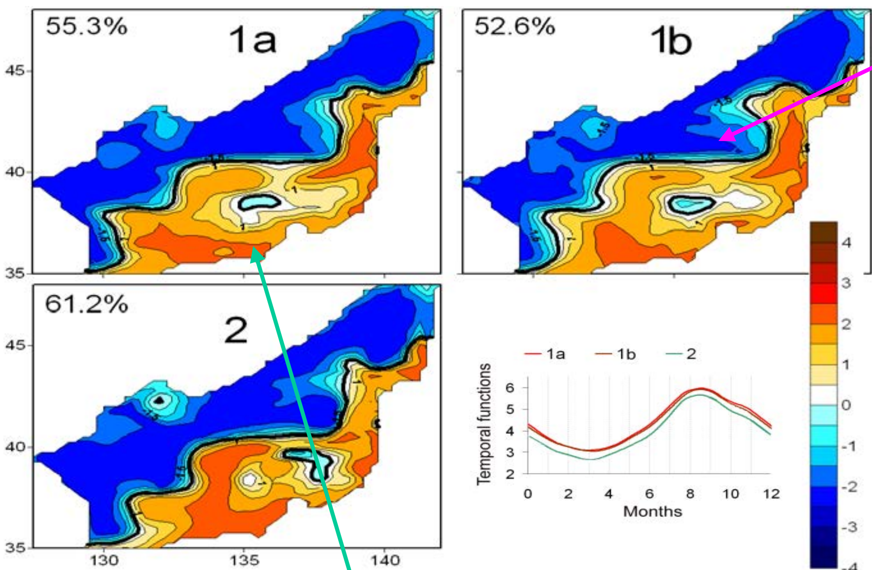
Run 1a: intermediate and deep layers



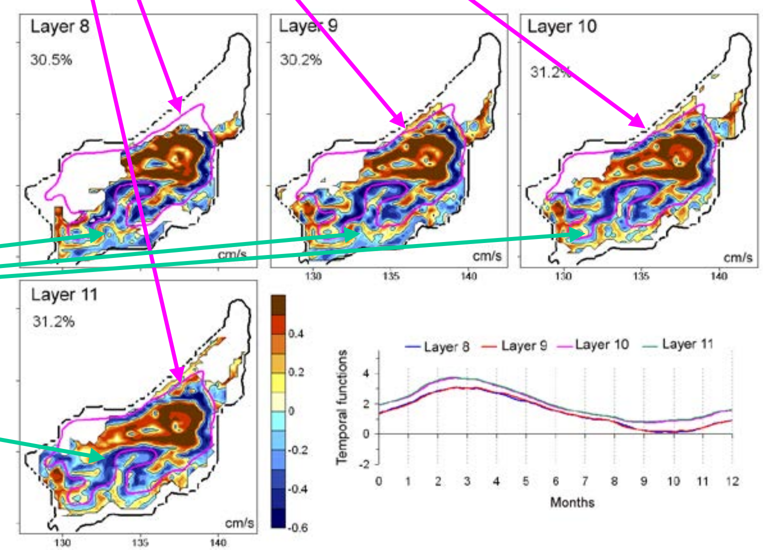
The same seasonal variation in the intermediate (8, 9) and deep (10-12) layers (below the winter convection depth)

The surface vs. deep currents

Run 1a: seasonal variation of surface currents (sea level)



The northern Sea: in the upper layer the cyclonic gyres strengthen in summer and from top to bottom they strengthen in winter (wintertime strengthening of the surface circulation shown by Kim and Yoon, 2010).



The southern Sea: surface and deep circulation strengthens in the warm season, weakens in the cold season

Conclusion

-The Shapiro – Mikhaylova model captures the intense, quasi-barotropic, geostrophic deep circulation in the Japan/East Sea.

-Deep cyclonic gyres intensify under the forcing of the cyclonic wind stress curl and due to the surface – abyssal coupling, in accordance with (Hogan and Hurlburt, 2000, 2008).

-The deep cyclonic gyre in the Japan Basin intensifies by the late winter (March) and weakens by the end of warm season (September - October).

- The gyre in the Japan Basin shrinks when it intensifies, thus explaining the unclear seasonal variation at the mooring site at the Basin eastern margin.

-The deep circulation in the Southern Sea is in the reversed phase compared to the Northern Sea.