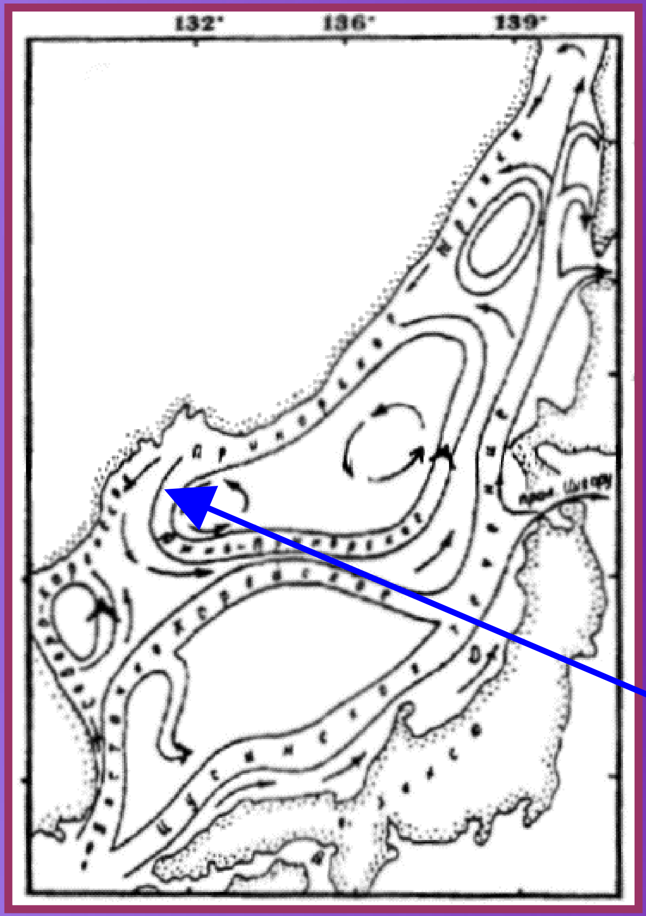
Seasonal and interannual variation of currents in the western Japan Sea: numerical simulation in comparison with infrared satellite imagery

Olga Trusenkova*, Aleksandr Nikitin**,
Vyacheslav Lobanov*, and Svetlana Ladychenko*

*V.I. Il'ichev Pacific Oceanological Institute, Vladivostok, Russia
**Pacific Fisheries Center (TINRO – Center), Vladivostok, Russia

Background



(Yarichin , 1980)

The Japan Sea is

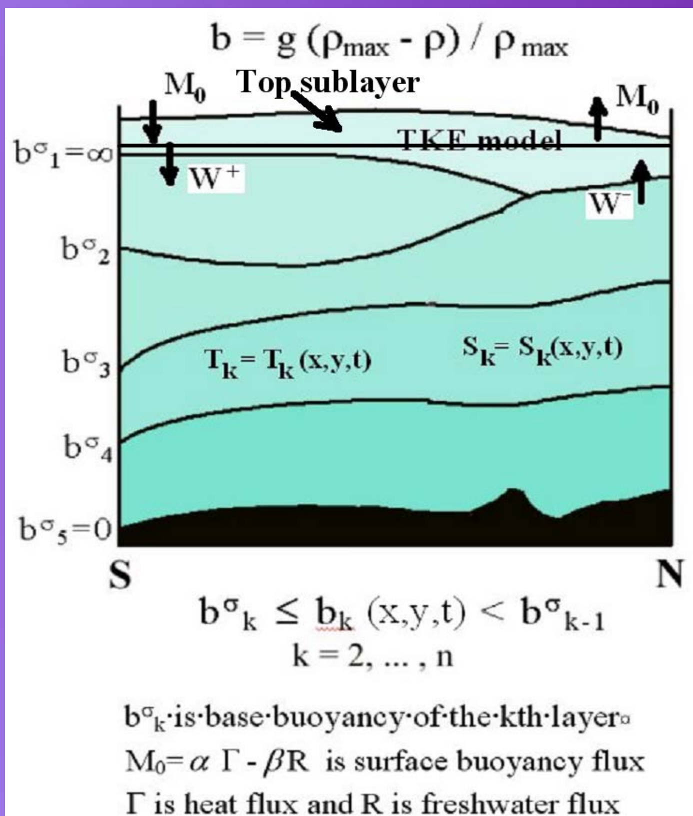
- mid-sized East Asia marginal sea;
- current system similar to the oceanic circulation;
- subtropical and subarctic regions;
- **Subarctic Front**.

The traditional scheme:
the cyclonic circulation in the northwest Japan Sea

Purpose of the study

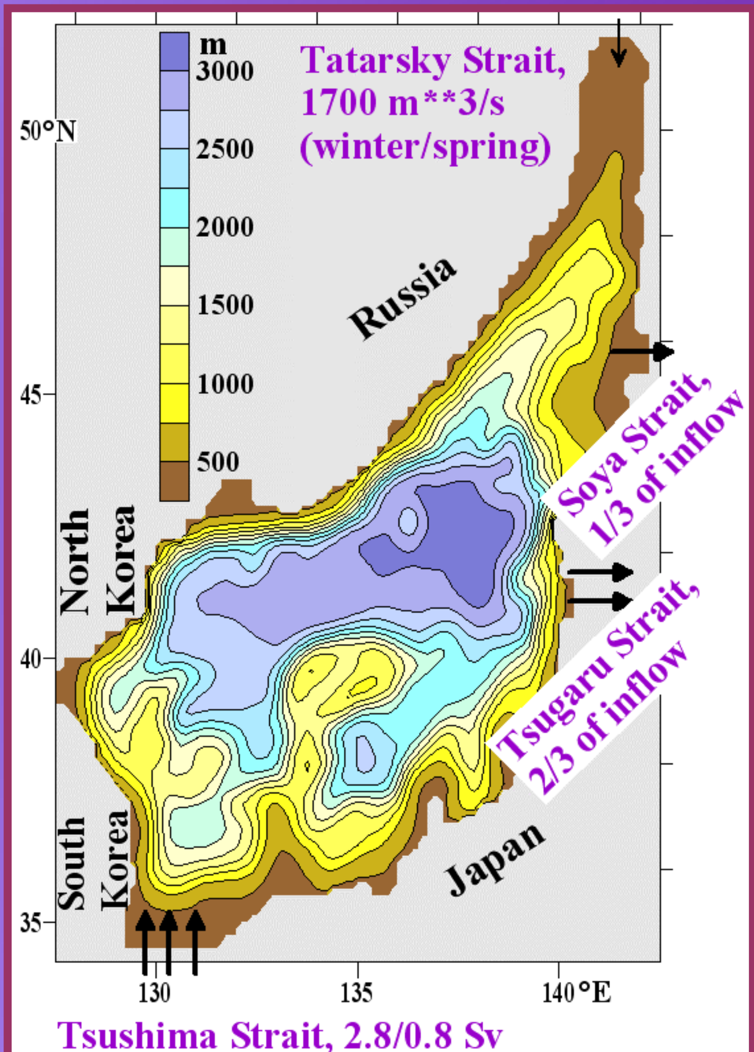
Numerical simulation of circulation in the Japan Sea with application to seasonal and interannual variation of Subarctic Front and currents in the western sea and comparison of modeling results with observational evidence from satellite-based SST

MHI quasi-isopycnic oceanic model
(Shapiro and Mikhaylova, 1992-1998)



- 3D primitive equaion, hydrostatic & Boussinesq
- Interfaces between layers moving in the vertical
- Complete thermodynamics, including
  - surface heat and freshwater balances
  - TKE model for the surface mixed layer, and
  - prognostic equations for T and S
- Variable T, S, and buoyancy in any layer
- Constraint on buoyancy variations in inner (below the mixed) layers (*base buoyancy)*
- Bi-harmonic viscosity in the momentum equations
- Free surface
- Convective adjustment

Model geometry and bottom topography



Simulation setup

- Horizontal resolution of 1/8° (10-14 km)
- 12 layers in the vertical
- 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 ~ 10 m^2/s
- Harmonic lateral diffusivity: 250 m^2/s
- Monthly wind for 1998-2000 from NCEP Reanalysis Project
- Monthly atmospheric variables for surface heat and freshwater balances with the use of data for 1979-1999

Simulation setup - 2

Spinup for 10 years from the laterally homogeneous and vertically stratified state of rest

Simulation 1998: for 1.5 year under the forcing of wind 1998

Simulation 1999: for 1.5 year under the forcing of wind 1999

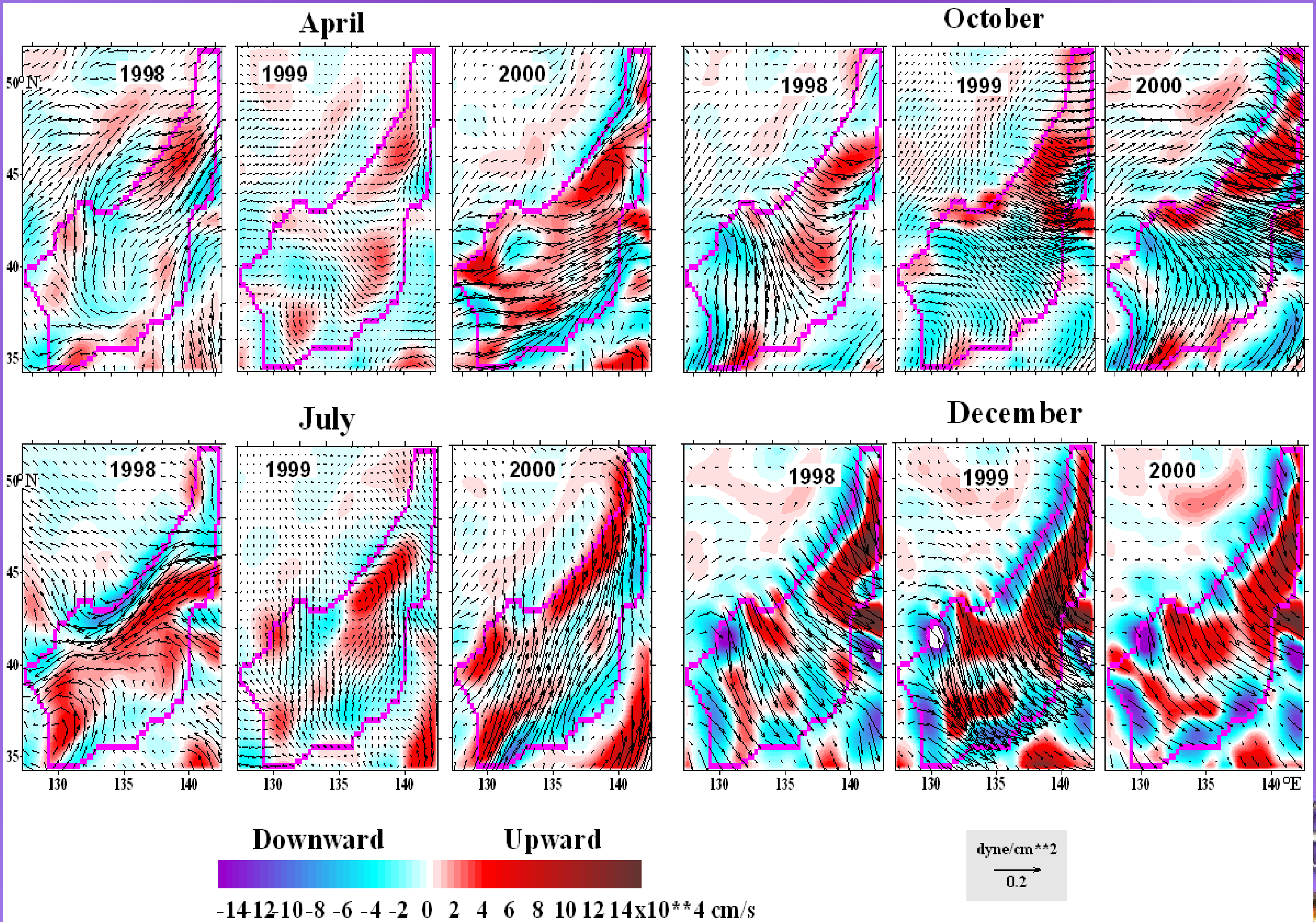
Simulation 2000: for 1.5 year under the forcing of wind 2000

The same buoyancy forcing at the sea surface and through the Tsushima Strait

No kind of restoration condition for temperature or salinity towards observed values

Seasonally varied volume transport in the Korean Strait

NCEP/NCAR Wind stress and Ekman pumping



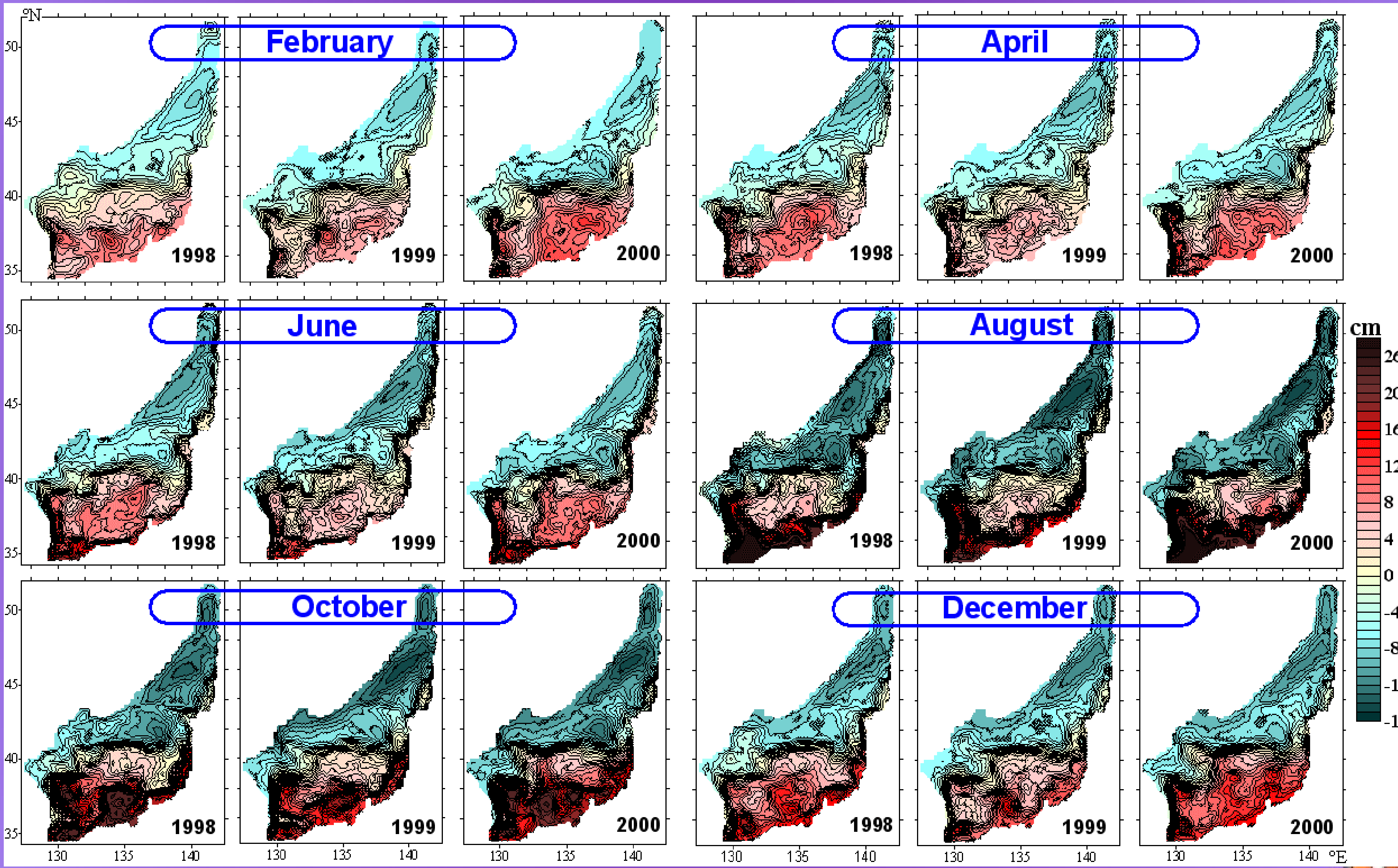
SST data

- **A-HIGHERS SST** (Sakaida et al., 2000): 5 days composites from February 1985 through October 2002, 0.05 x 0.05 degree, obtained by the infrared AVHRR aboard NOAA satellite;

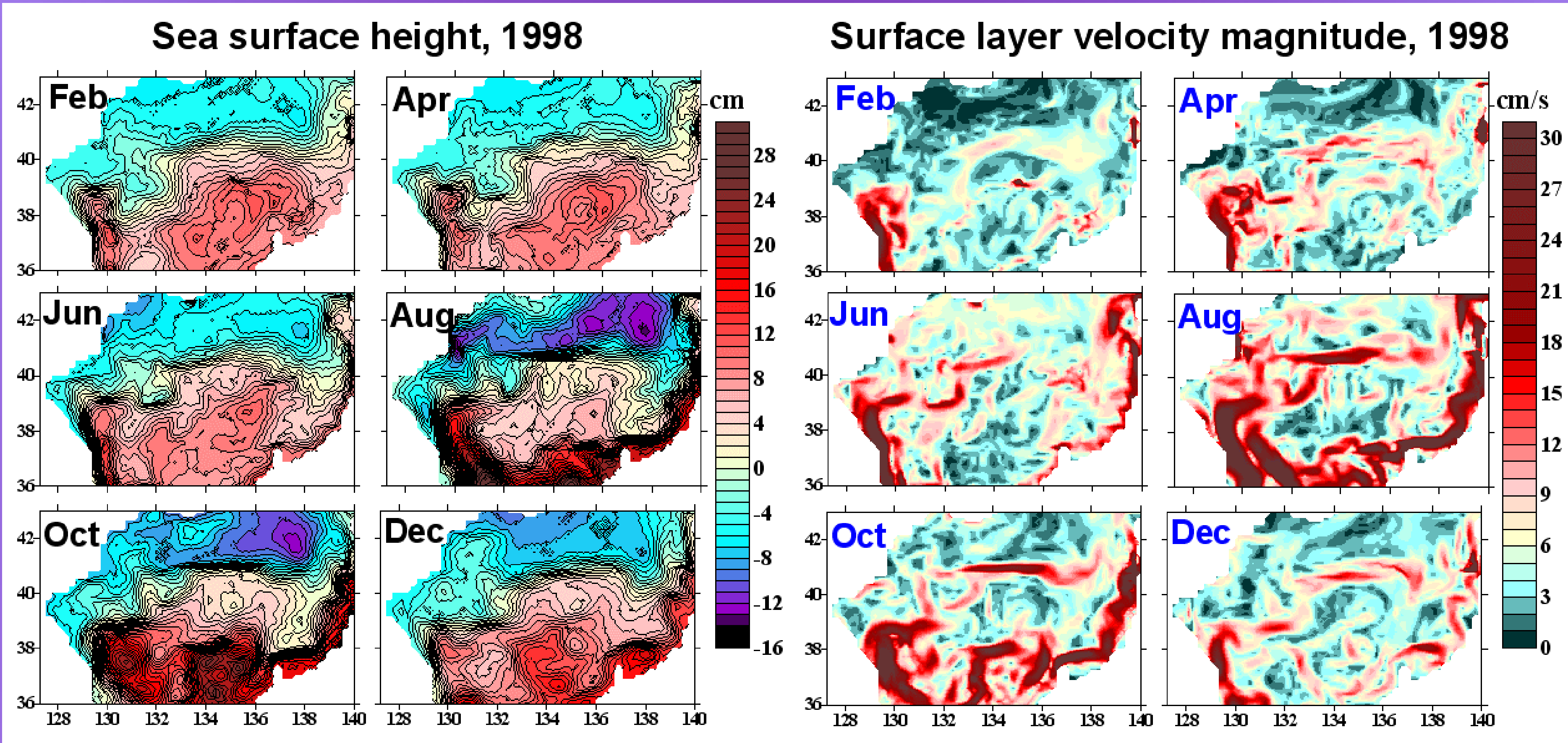
- **New Generation SST** (Guan and Kawamura, 2004): cloud-free daily, smoothed by 5-day running window, from July 2002 through January 2005, 0.05 x 0.05 degree, obtained by merging data from NOAA AVHRR (0.01 degree; infrared), GMS S-VISSR (0.05 degree; infrared), and TRMM MI (50 km; microwave).

- 1977 – 2001 NOAA AVHRR infrared images

SSH for the 1998-2000 simulations



Seasonal variation of Subarctic Front

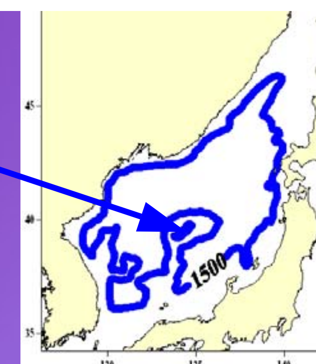


Subarctic Frontal Zone

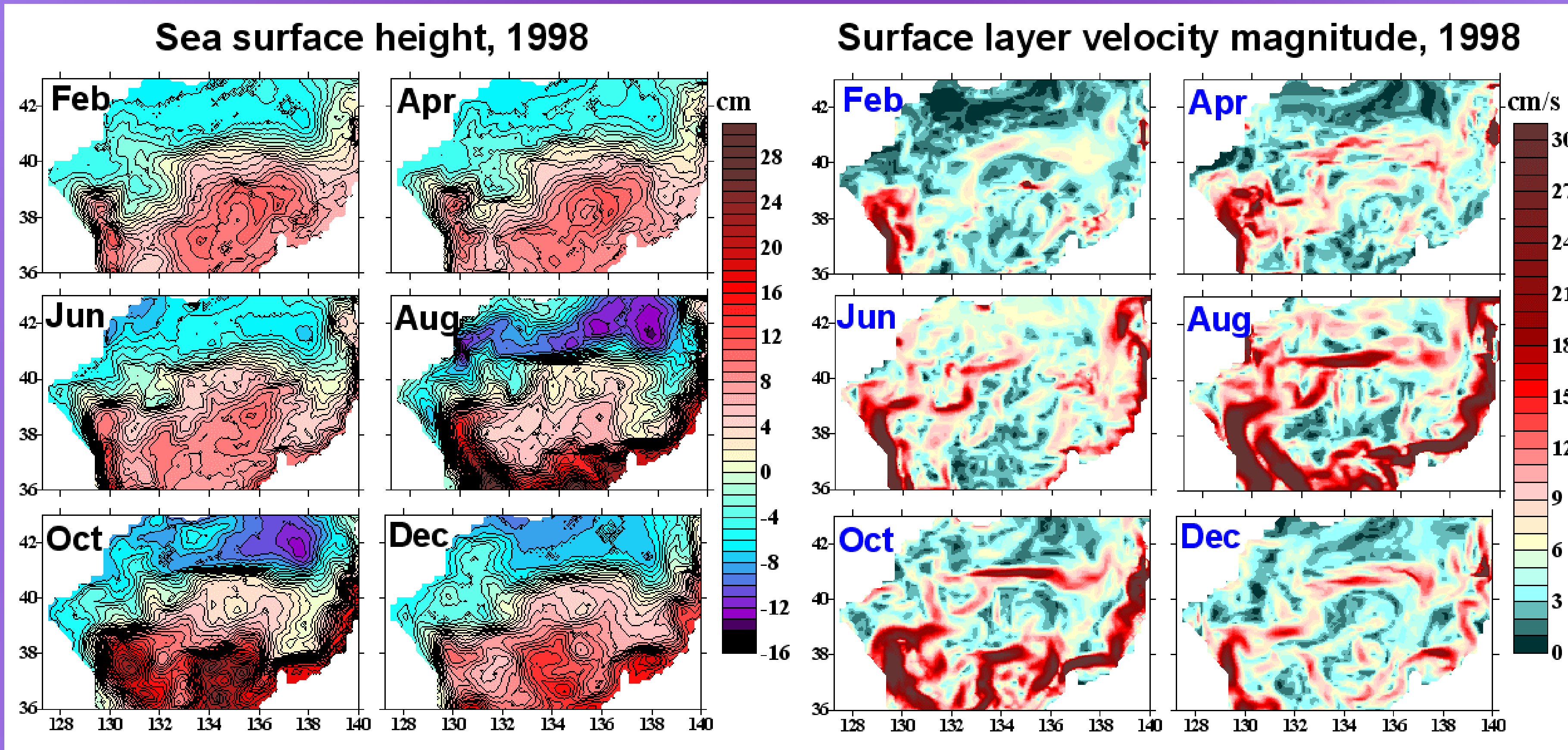
Northwest Branch of Subarctic Front:

- documented by Danchenkov et al., 1997; Lobanov et al., 2001-2003; Nikiin and Kharchenko, 2002
- simulated by Yoon and Kawamura (2002); Trusenkova and Ishida (2005); Yoon et al. (2005)

Yamato Rise

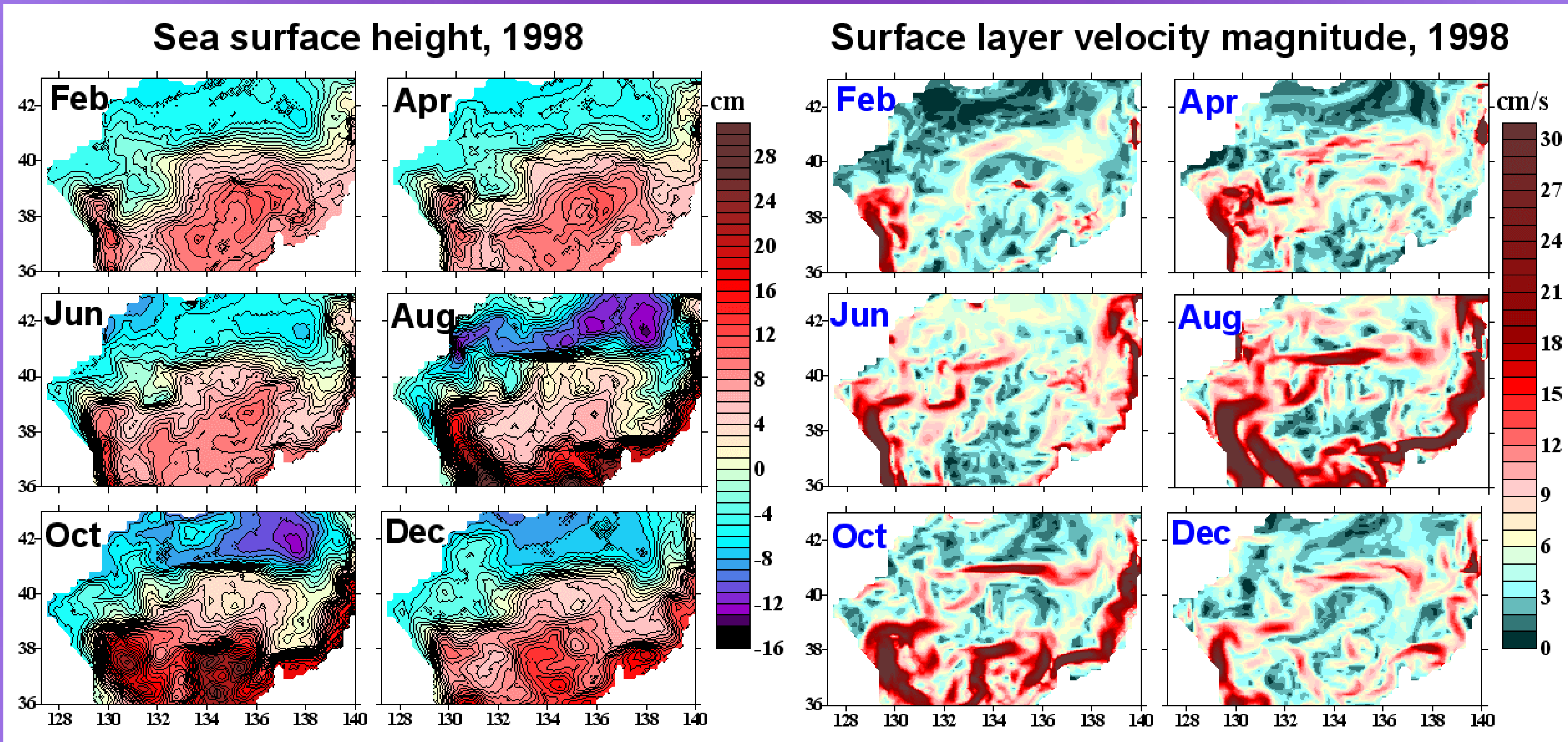


Seasonal variation of Subarctic Front



Filaments of increased velocity;
anticyclonic meandering and eddy formation in the western sea;
undulation and formation of a cyclonic meander in the western sea (winter- spring);
topographic control by the Yamato Rise;
formation of frontal eddies over the Yamato Rise in summer-autumn

Seasonal variation of Subarctic Front



Flow over the western flank of the Yamato Rise and jet across the Yamato Rise :

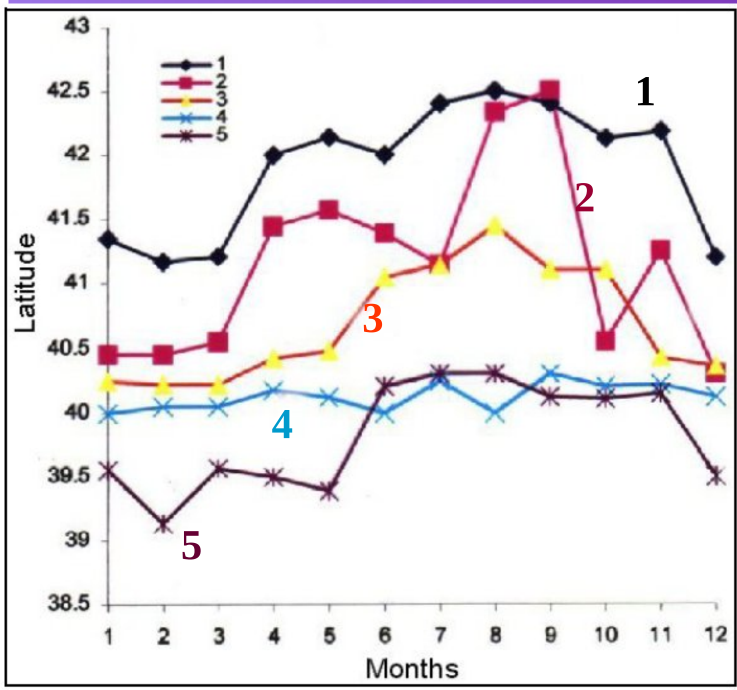
- frequent thermal front documented by Kawabe (1982);

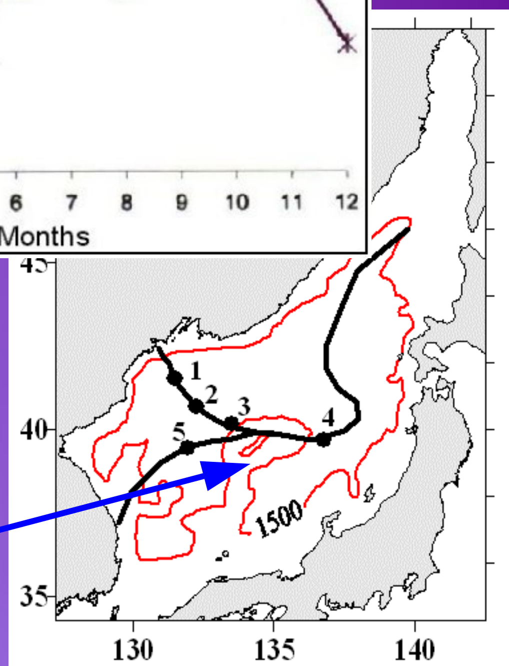
  documented by Nikiin and Kharchenko (2002) from infrared satellite imagery;

- documented from ARGOS drifter observations by Lee and Niiler, 2005

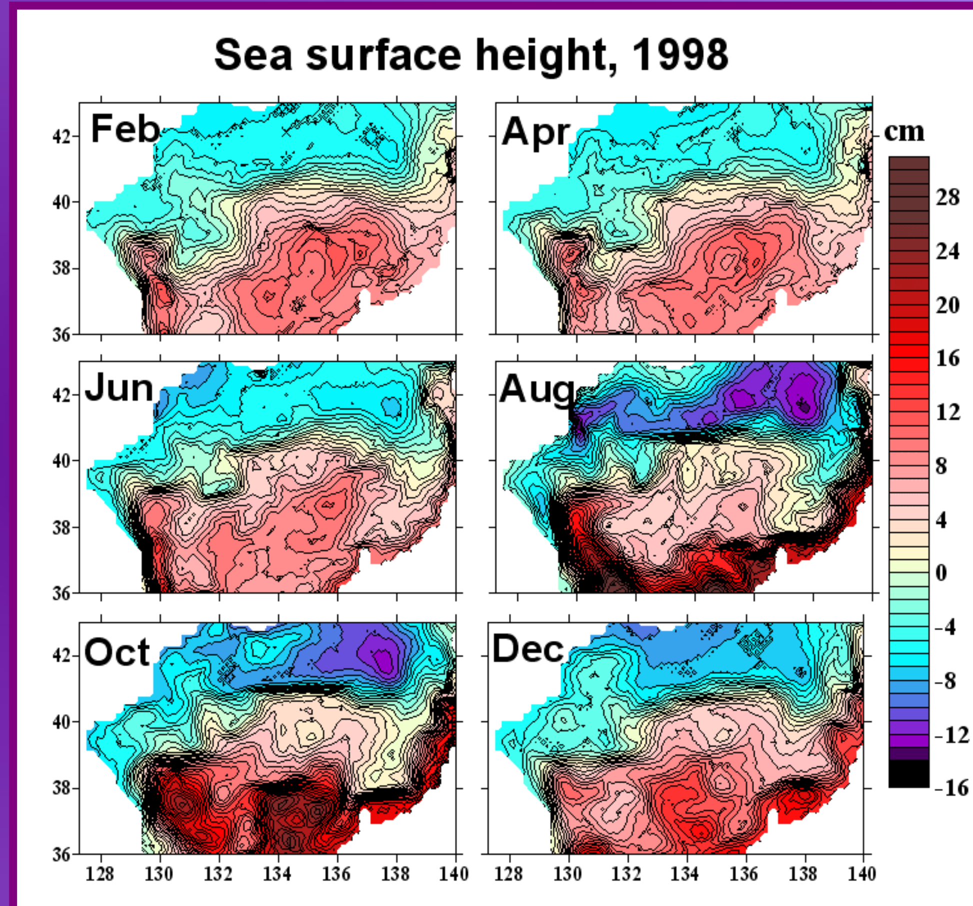
Seasonal variation of Subarctic Front -2

From 1977-2001 satellite imagery (Nikitin, 2004)

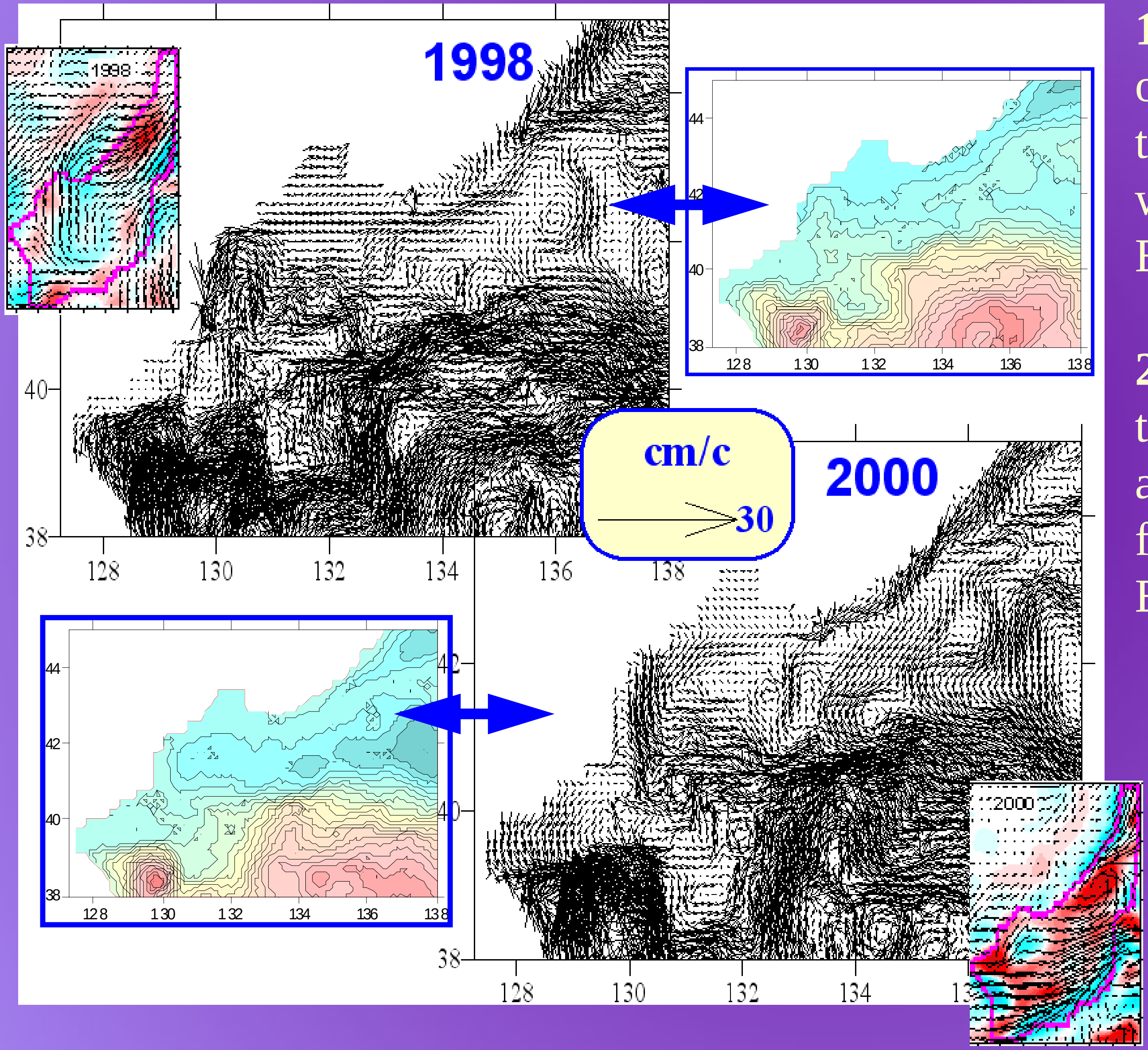


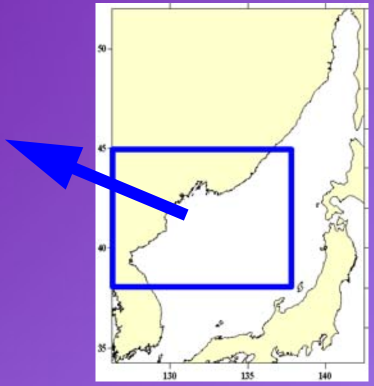


Yamato Rise



Simulated currents in April



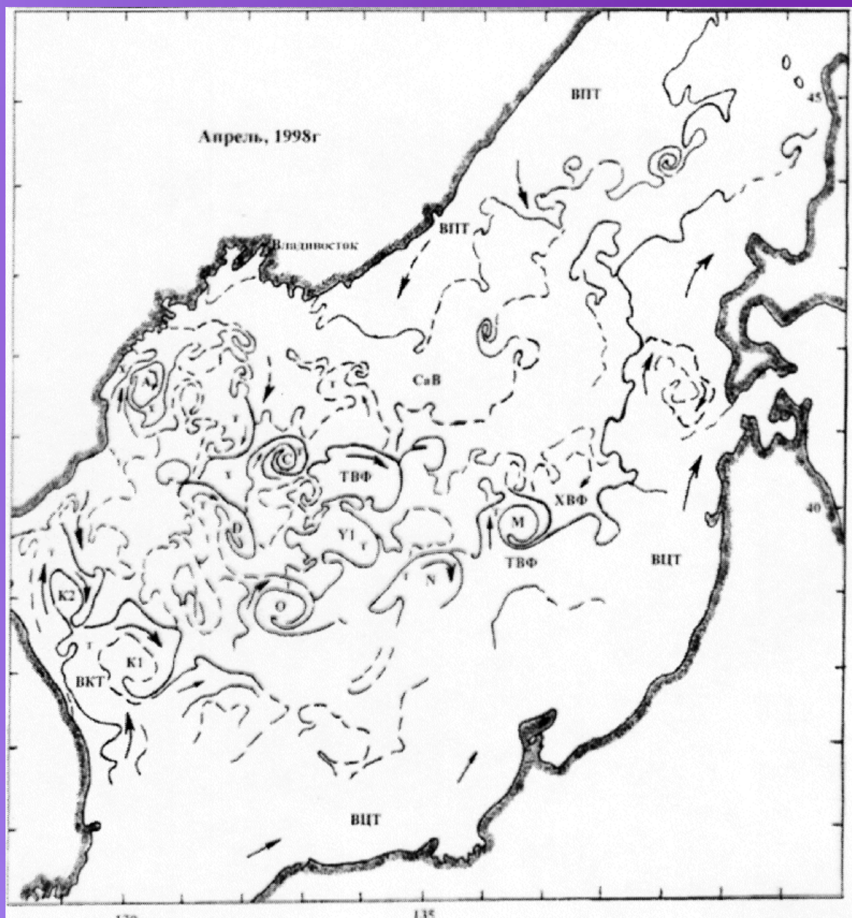


1998: Northwest branch of Subarctic Front under the forcing of southern wind with downward Ekman pumping

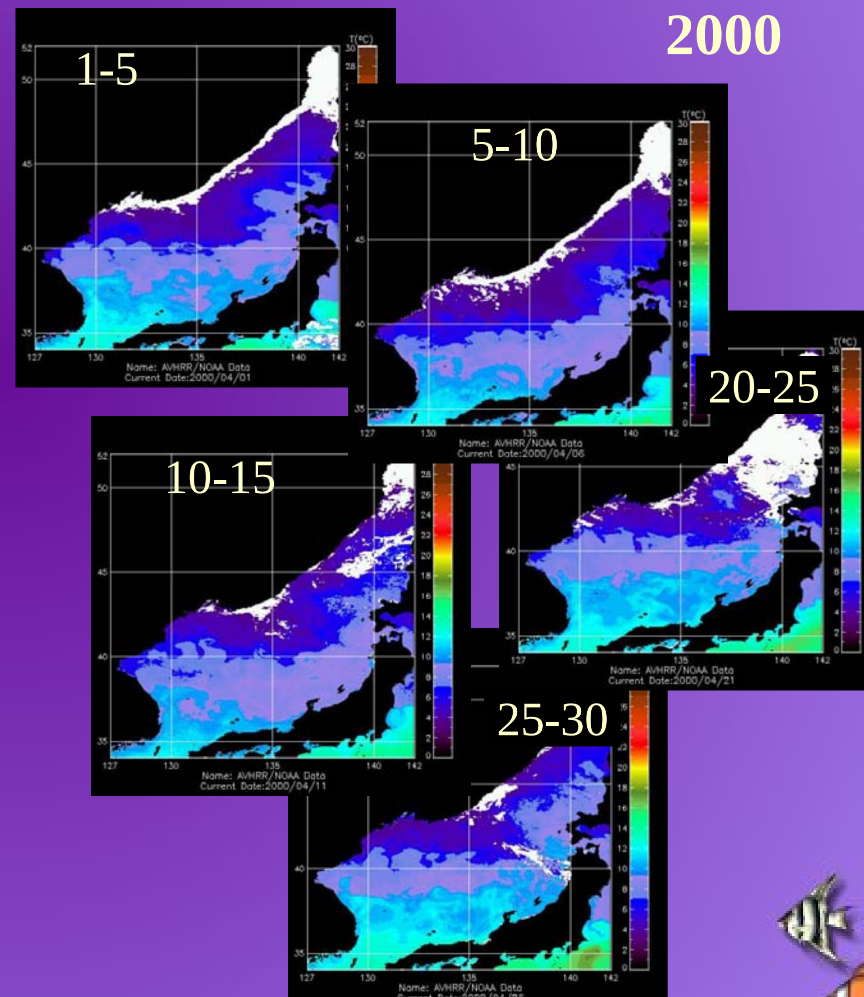
2000: cyclonic gyre in the western subarctic area under the wind forcing with upward Ekman pumping

SST for April 1998 and 2000

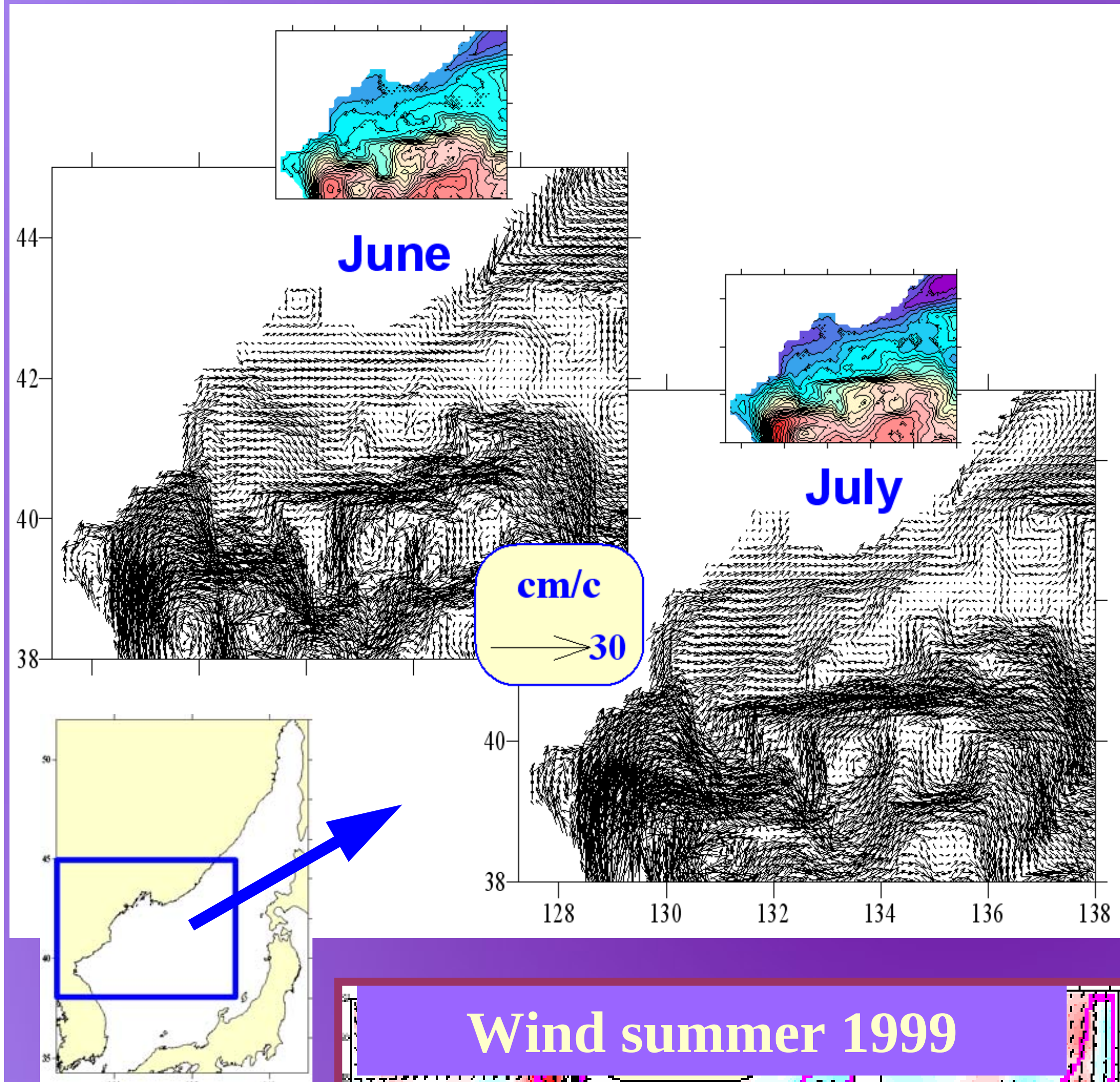
Interpretation scheme of AVHRR images for April 1998

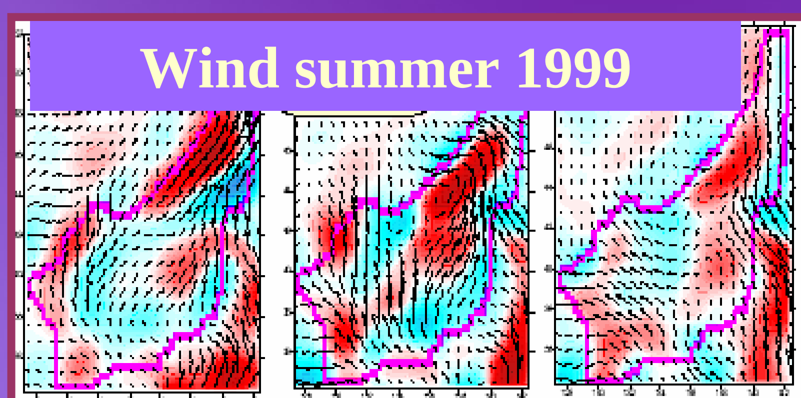


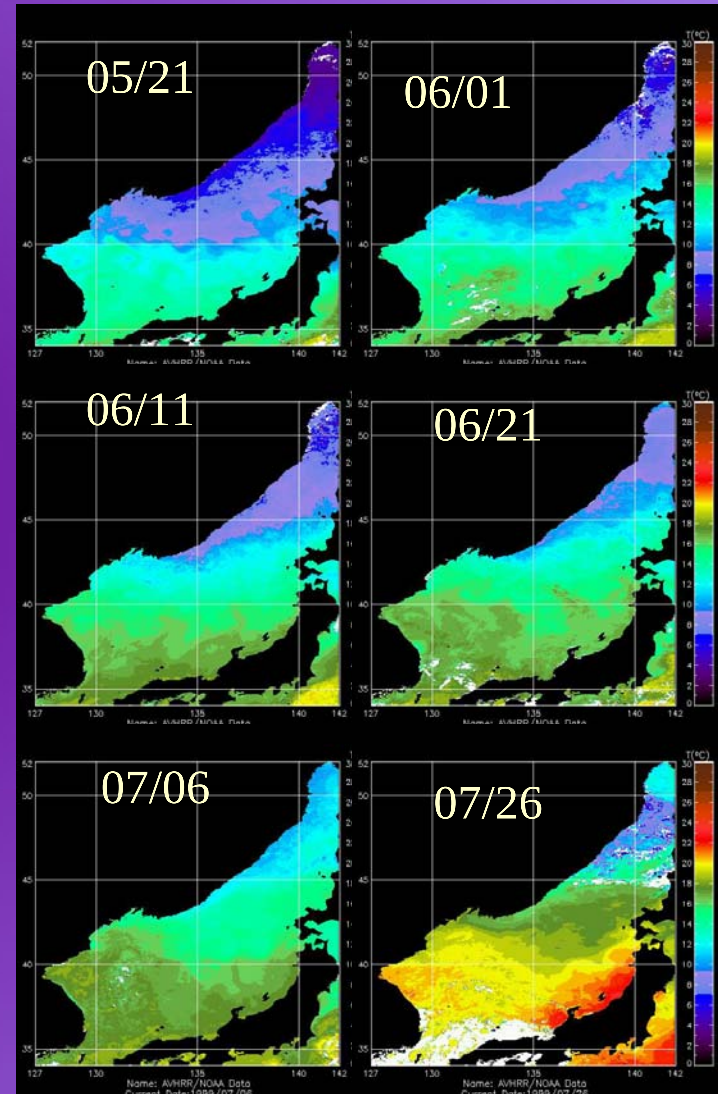
A-HIGHERS SST for April 2000



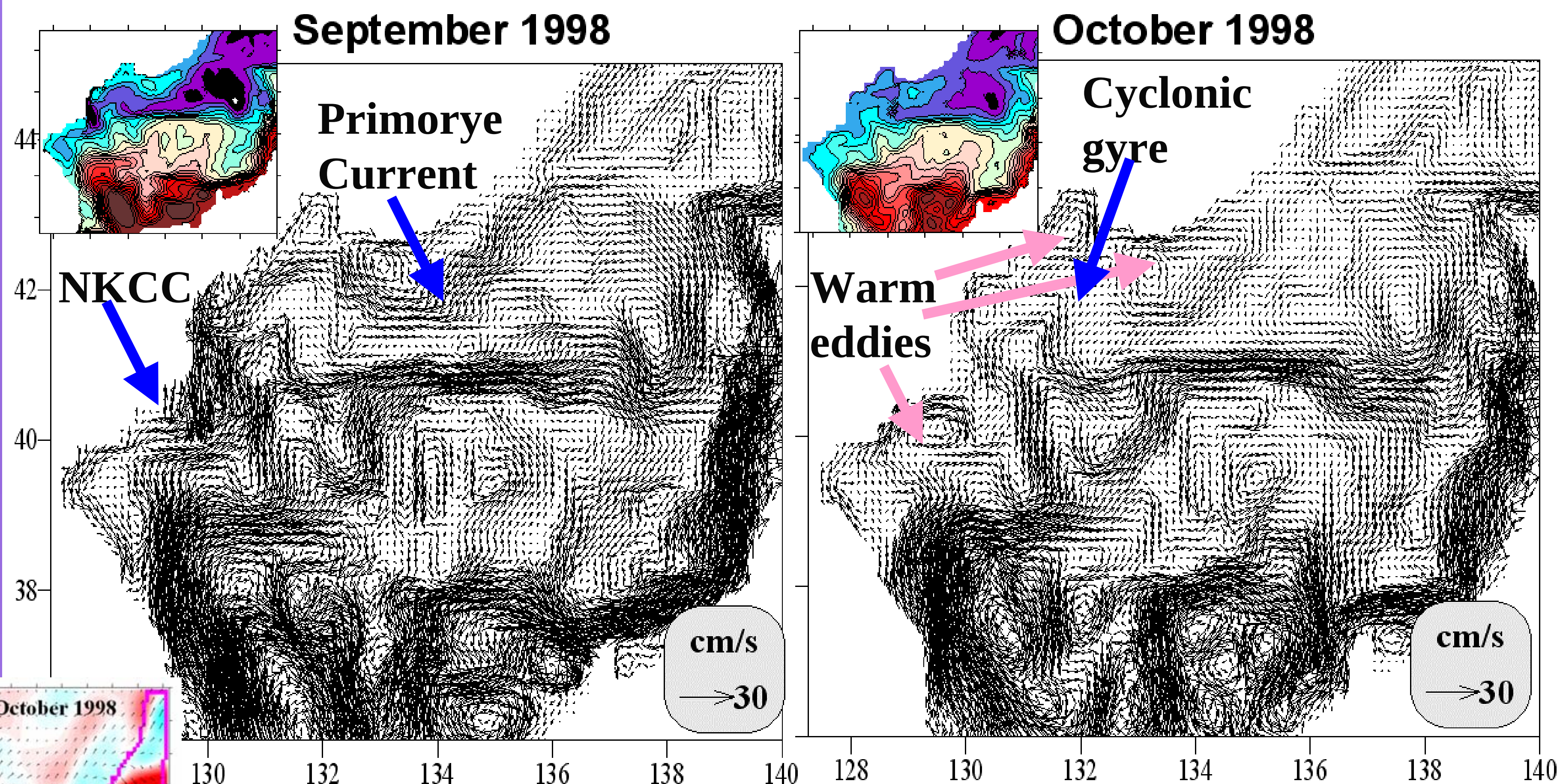
June – July 1999 A-HIGHERS SST

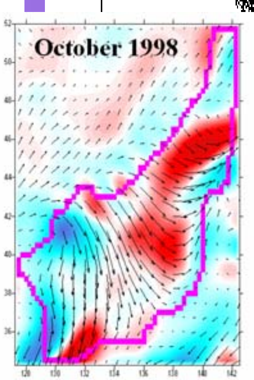






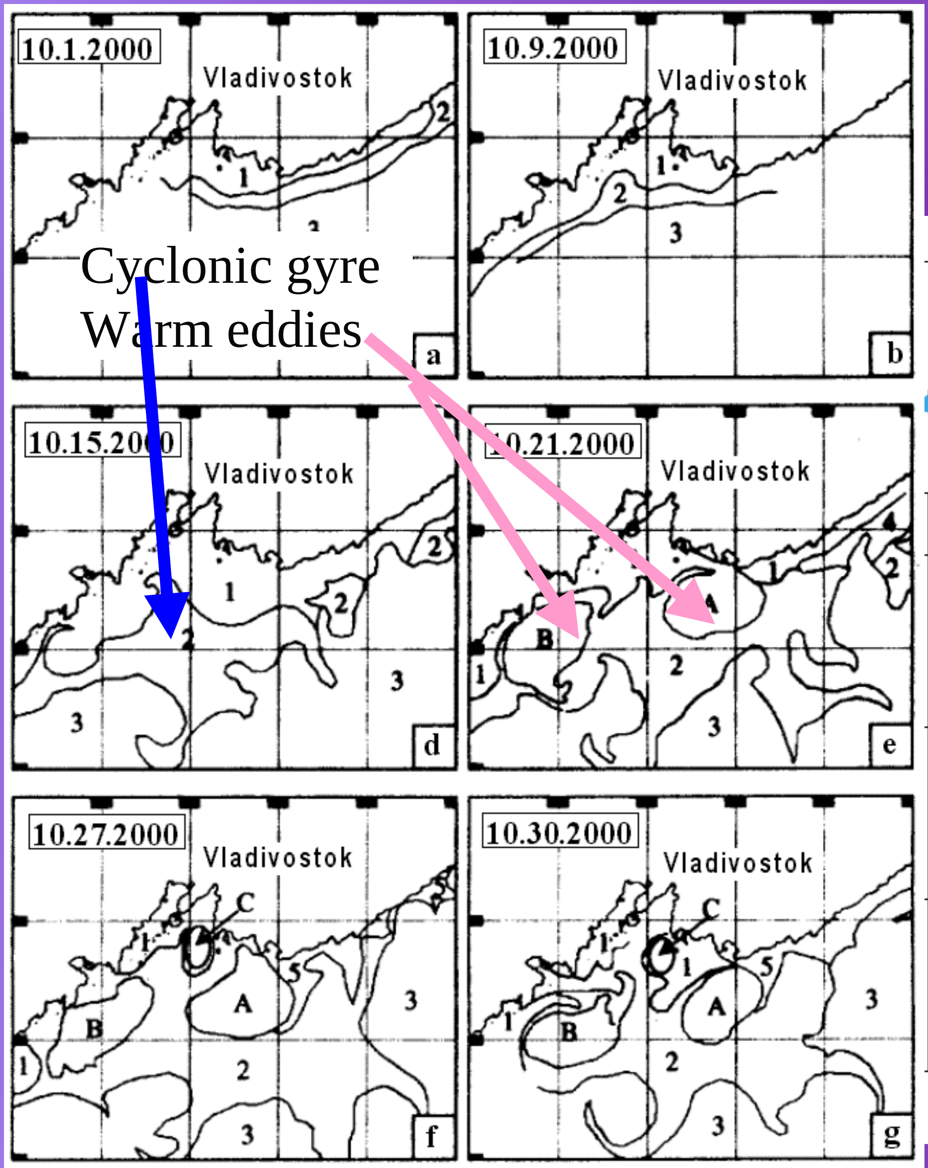
Reversal of currents off North Korea from September to October

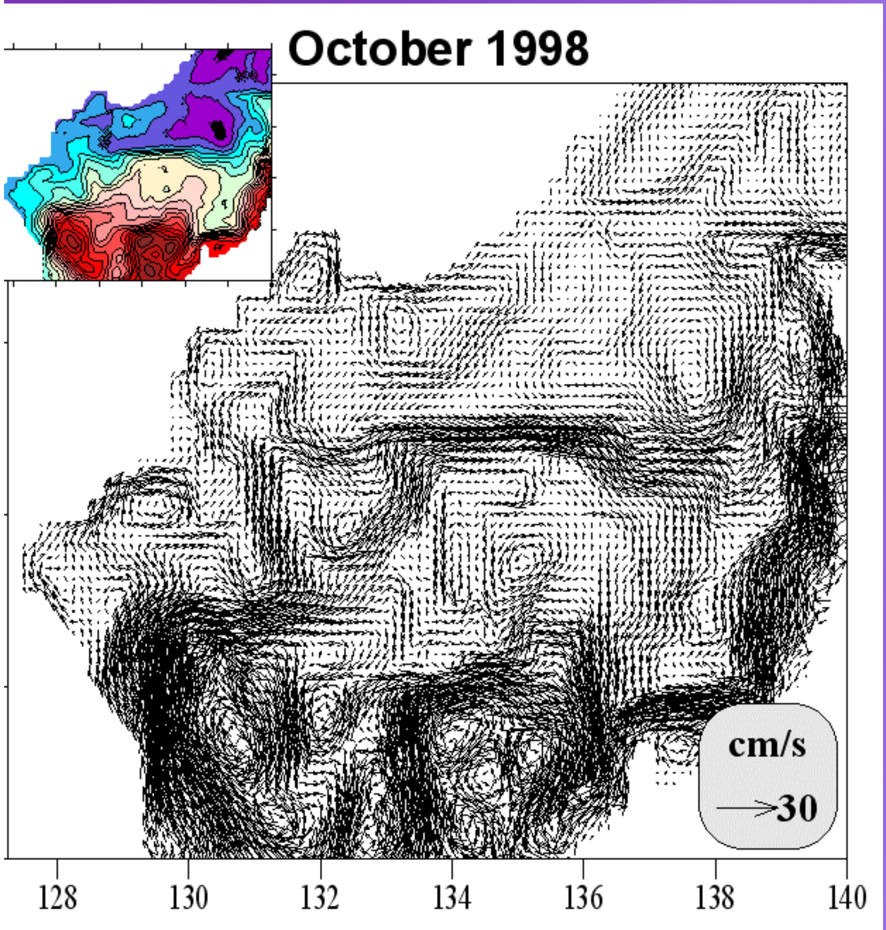




The simulated NKCC is the strongest in August-September
Seasonal NKCC (from AGROS drifters by Lee and Niiler; 2005)
Anticyclonic gyre off North Korea also simulated by Yoon et al. (2005)

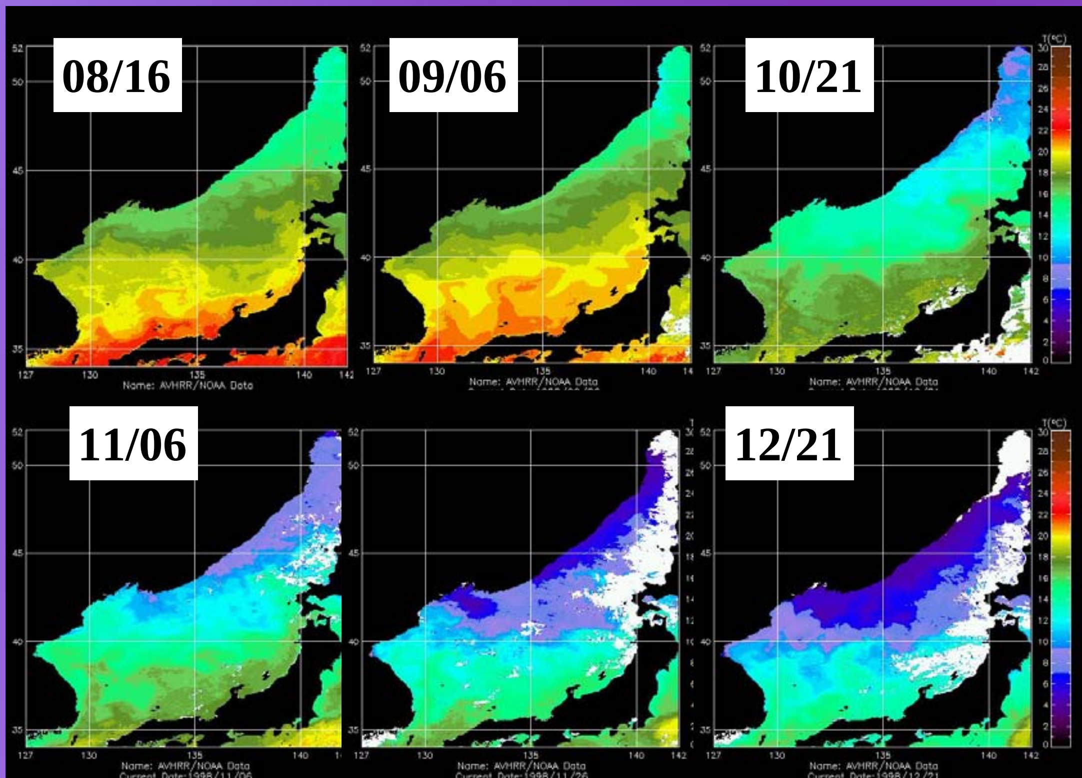
Cyclonic gyre and warm eddies

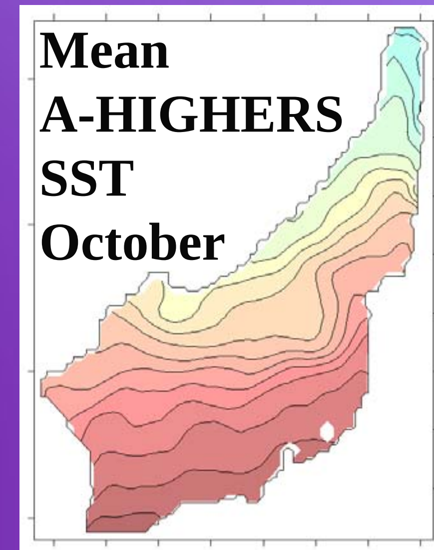




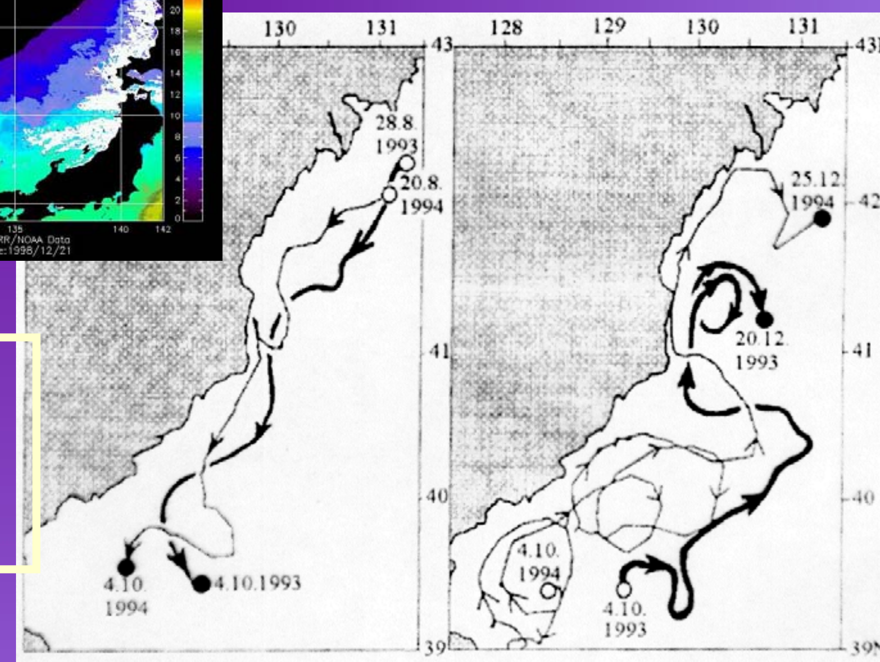
(Lobanov and Ladychenko, 2002)

A-HIGHERS SST for 1998

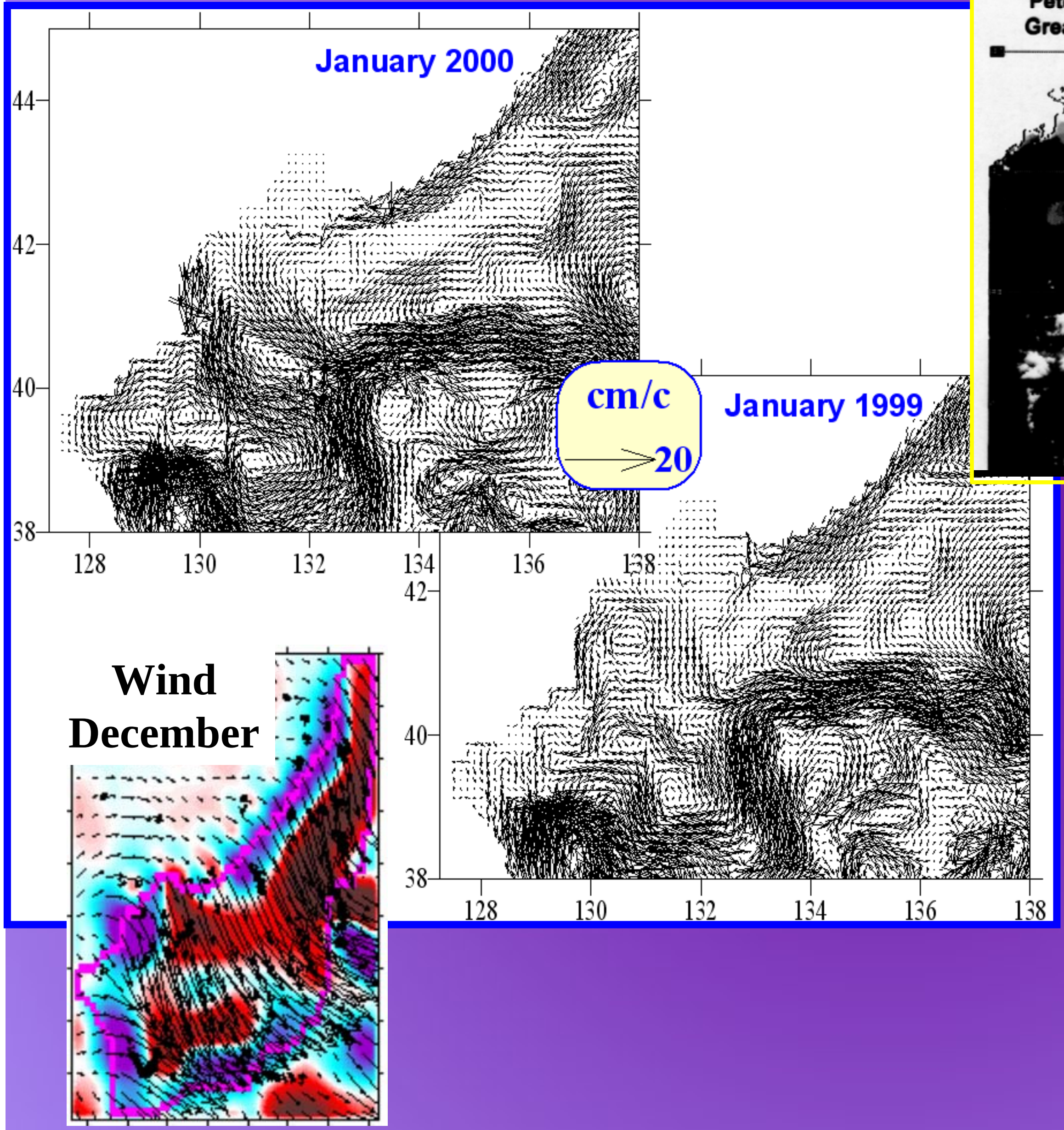


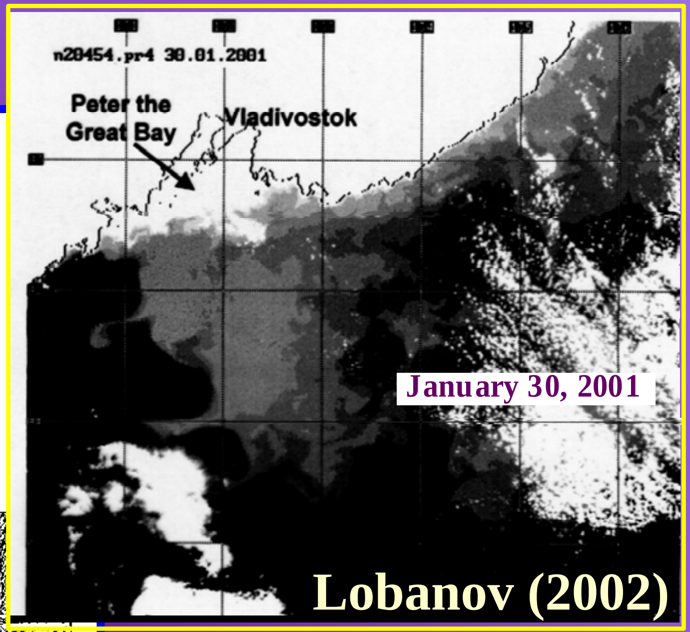


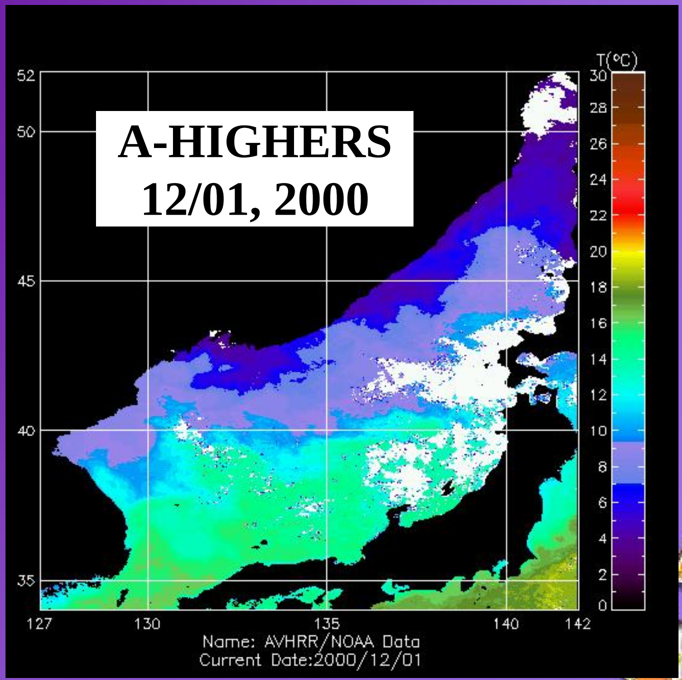
Drift of ARGOS buoys
off North Korea
(Danchenkov et al., 2003)



Northwest front in winter

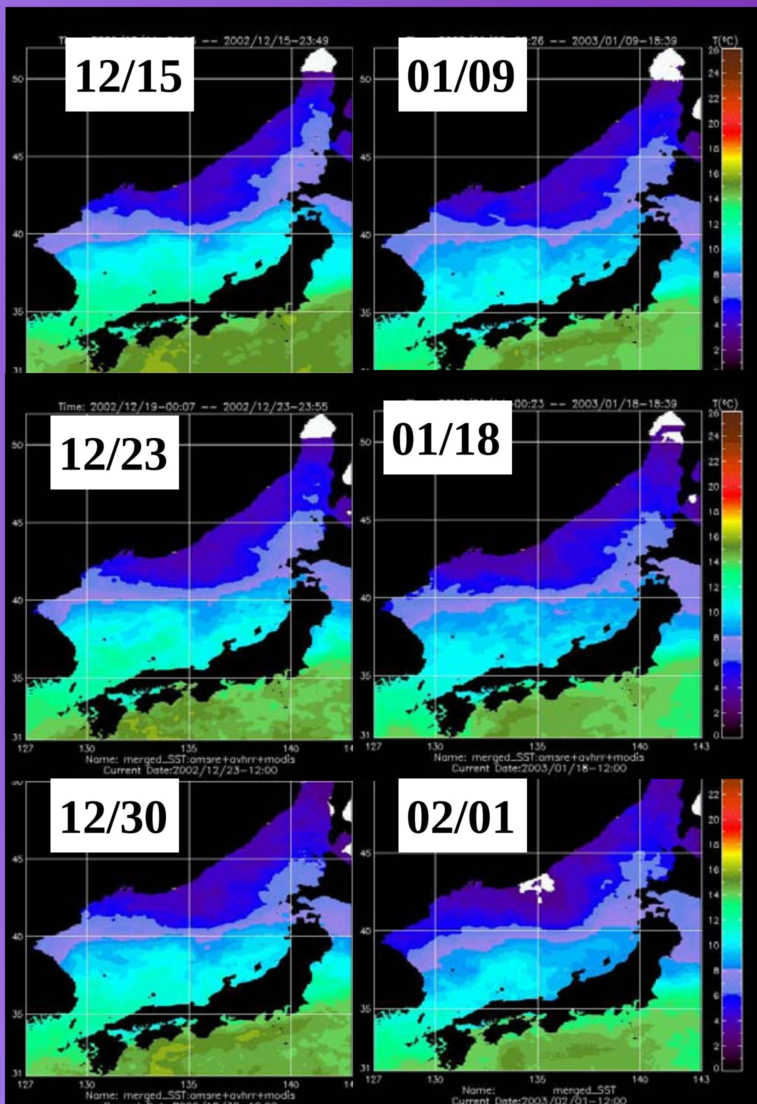




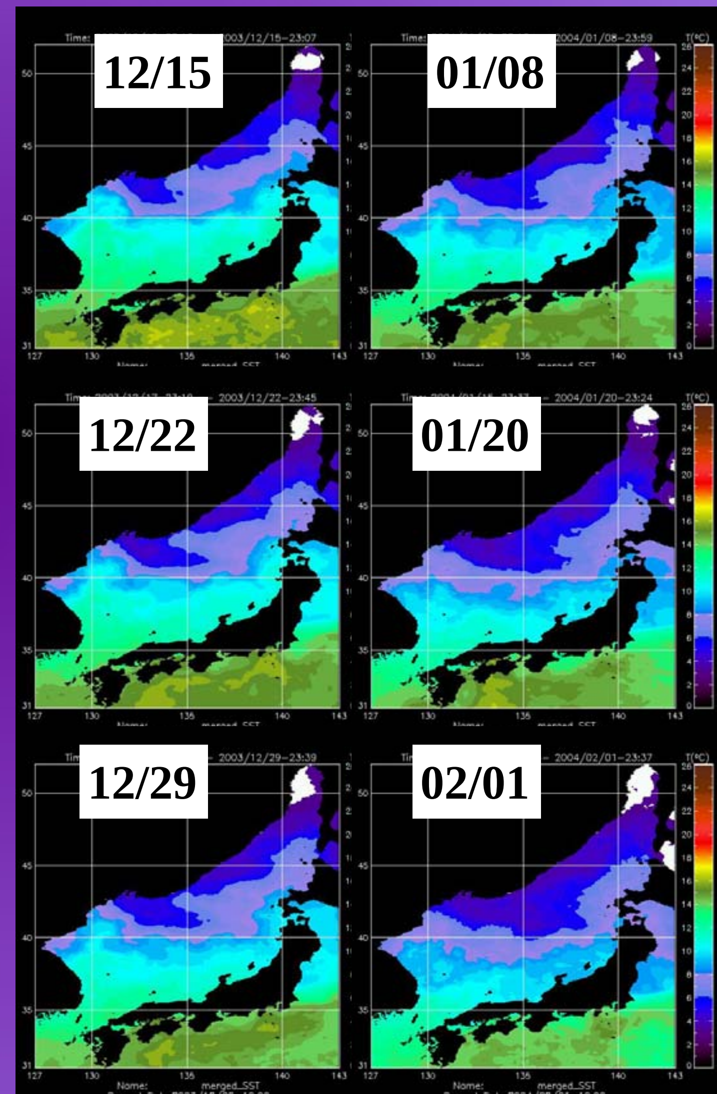


New Generation SST for winter

2002-2003



2003-2004



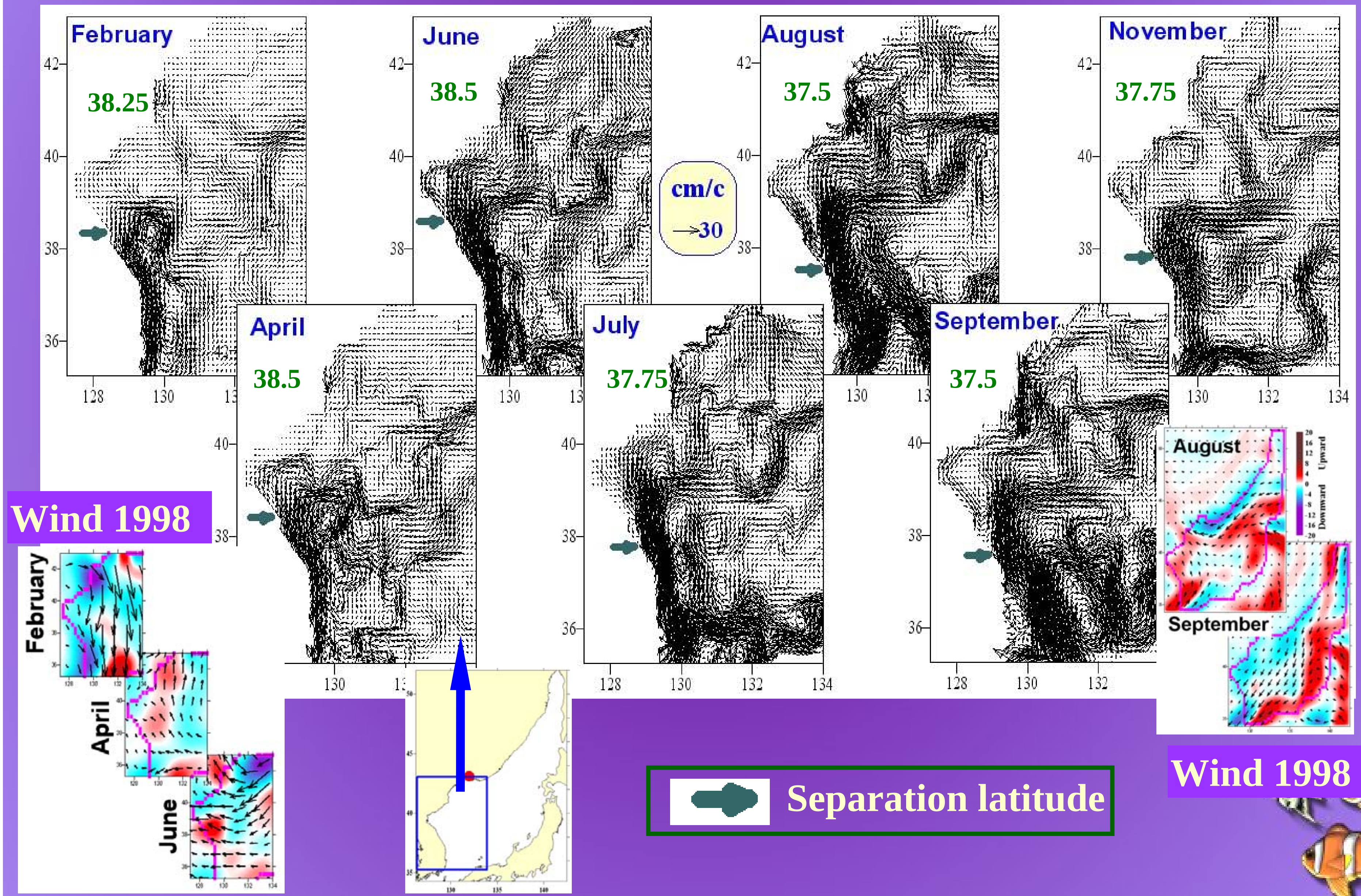
Conclusion

- The simulated seasonal variations of Subarctic Front agrees well with observational evidence from infrared satellite imagery: Subarctic Front is subjected to considerable seasonal variation in the western Japan Sea, while in the eastern Sea it gets trapped by the Yamato Rise.
- Variability of currents in the northwest Japan Sea can be associated, in the considerable extent, with the wind variations.

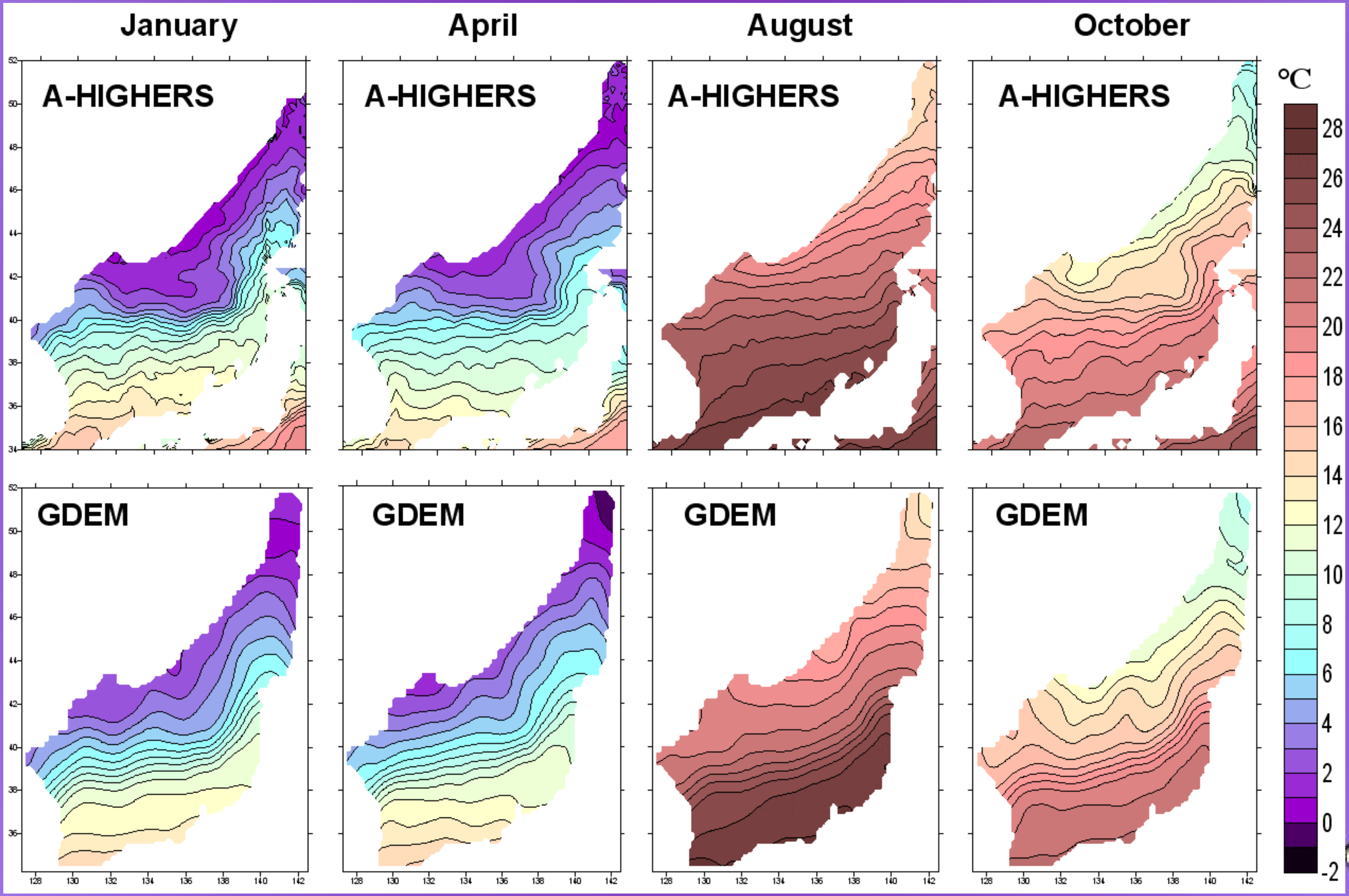
Acknowledgment

- To Prof. Shapiro and Dr. Mikhaylova from Marine Hydrophysical Institute, Sebastopol, Ukraine, for providing us with the MHI model
- To Prof. Kawamura, Center for Atmospheric and Oceanic Studies, Tohoku University, Sendai, Japan, for providing us with the A-Highers and New Generation SST data
- To Drs. Stanichny and Ratner from Marine Hydrophysical Institute, Sebastopol, Ukraine, for preparation of the wind data
- To Dr. Dubina, Pacific Oceanological Institute, Vladivostok, Russia for consultations on the SST data
- To Dr. Kaplunenko, Pacific Oceanological Institute, Vladivostok, Russia, for preparation of SST images

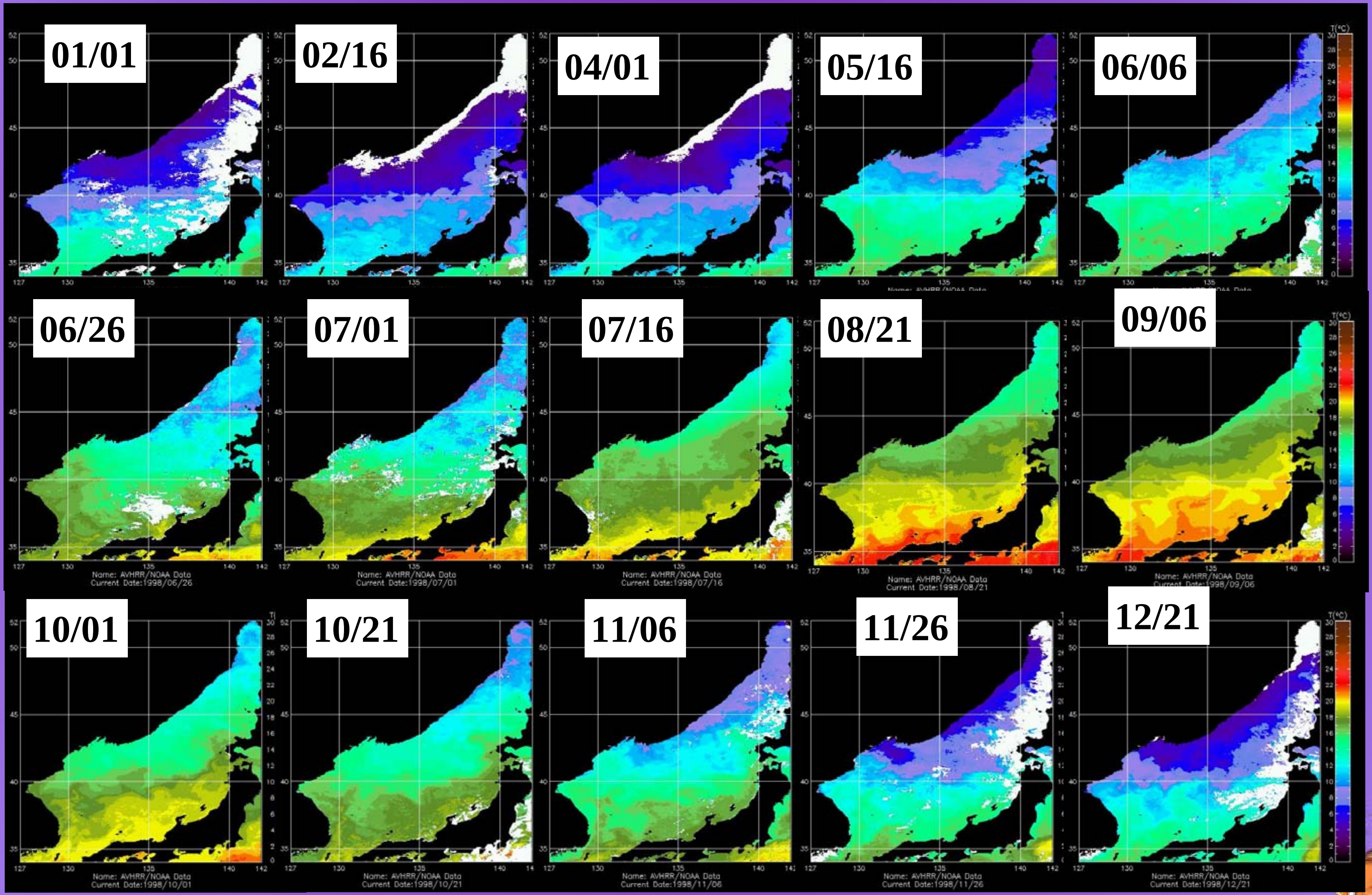
Separation of the EKWC (Simulation 1998)



A-HIGHERS vs. GDEM SST



A-HIGHERS SST for 1998

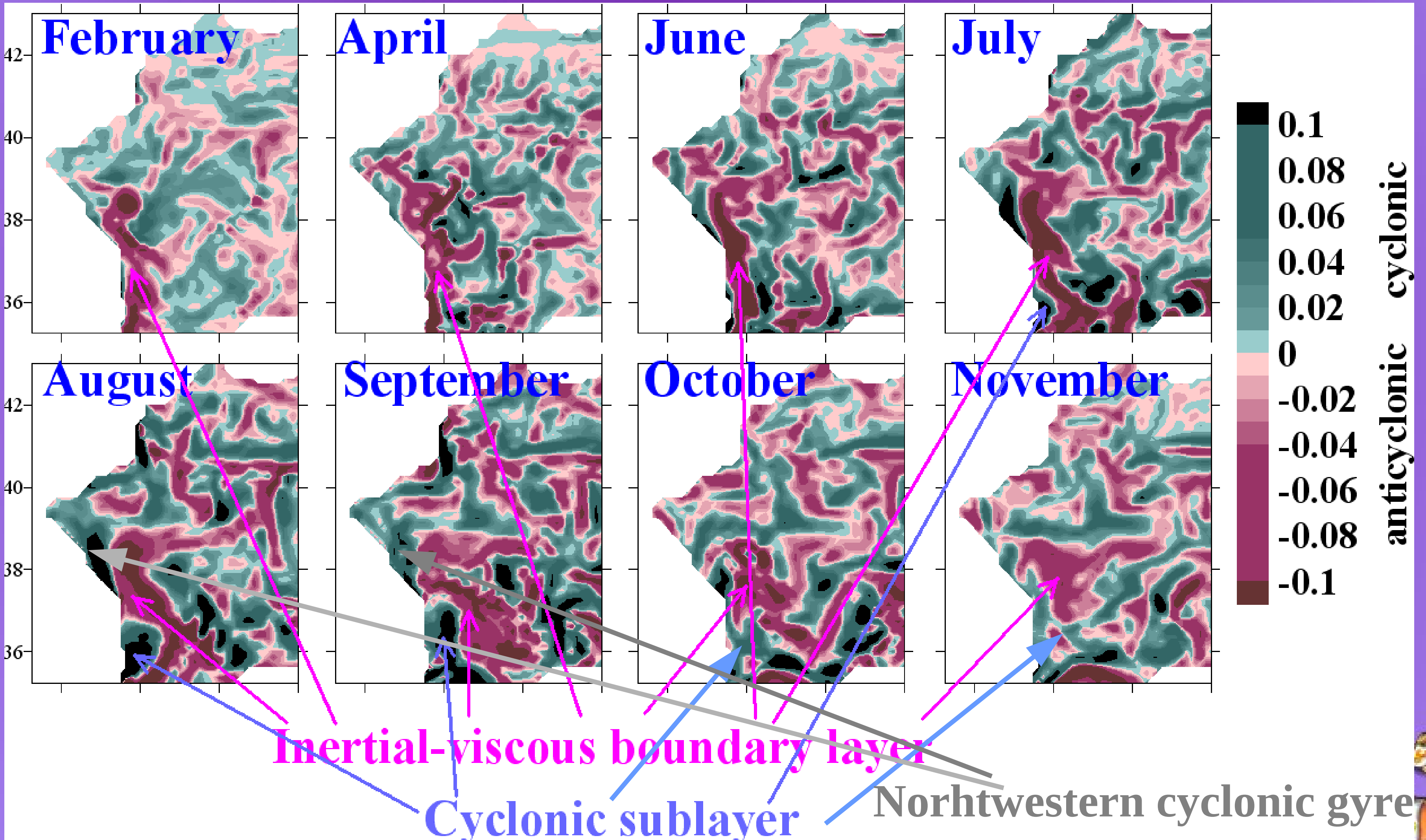


Simple model of the western boundary current (WBC) separation (Kiss, 2002):

- beta-plane
- barotropic
- circular flat-bottom basin
- wind with uniform anticyclonic stress curl

It is shown that if the no-slip boundary condition is accepted at a rigid wall, the WBC separates from the wall in the case of sufficient non-linearity. With the increase of non-linearity, a cyclonic sublayer develops within the inertial-viscous western boundary layer (Ilyin and Kamenkovich, 1963, 1964; Kamenkovich, 1966) and a cyclonic recirculation gyre is formed between the wall and separated WBC at the northwest corner of the basin (Kiss, 2002).

Relative to planetary vorticity (R/f) for 1998 (surface layer)



Conclusion

- The simulation results suggest that non-linearity can be an important factor affecting the seasonal variations of the separation latitude of the EKWC. An increase of non-linearity steers the western boundary layer (WBL) and facilitates the EKWC separation from the coast

- Mesoscale dynamics plays an important part in maintaining the WBL and strengthening the EKWC.

- The wind stress curl can facilitate or impede the onset of separation but wind impact is not always straightforward. In autumn, the increased negative wind stress curl steers the mesoscale dynamics and, therefore, non-linearity, maintaining the WBL. In April-May, the wind over the Japan Sea is often low-gradient, resulting in the non-linearity decrease and the northern separation latitude.

Acknowledgment

- To Prof. Shapiro and Dr. Mikhaylova from Marine Hydrophysical Institute, Sebastopol, Ukraine, for providing us with the MHI model
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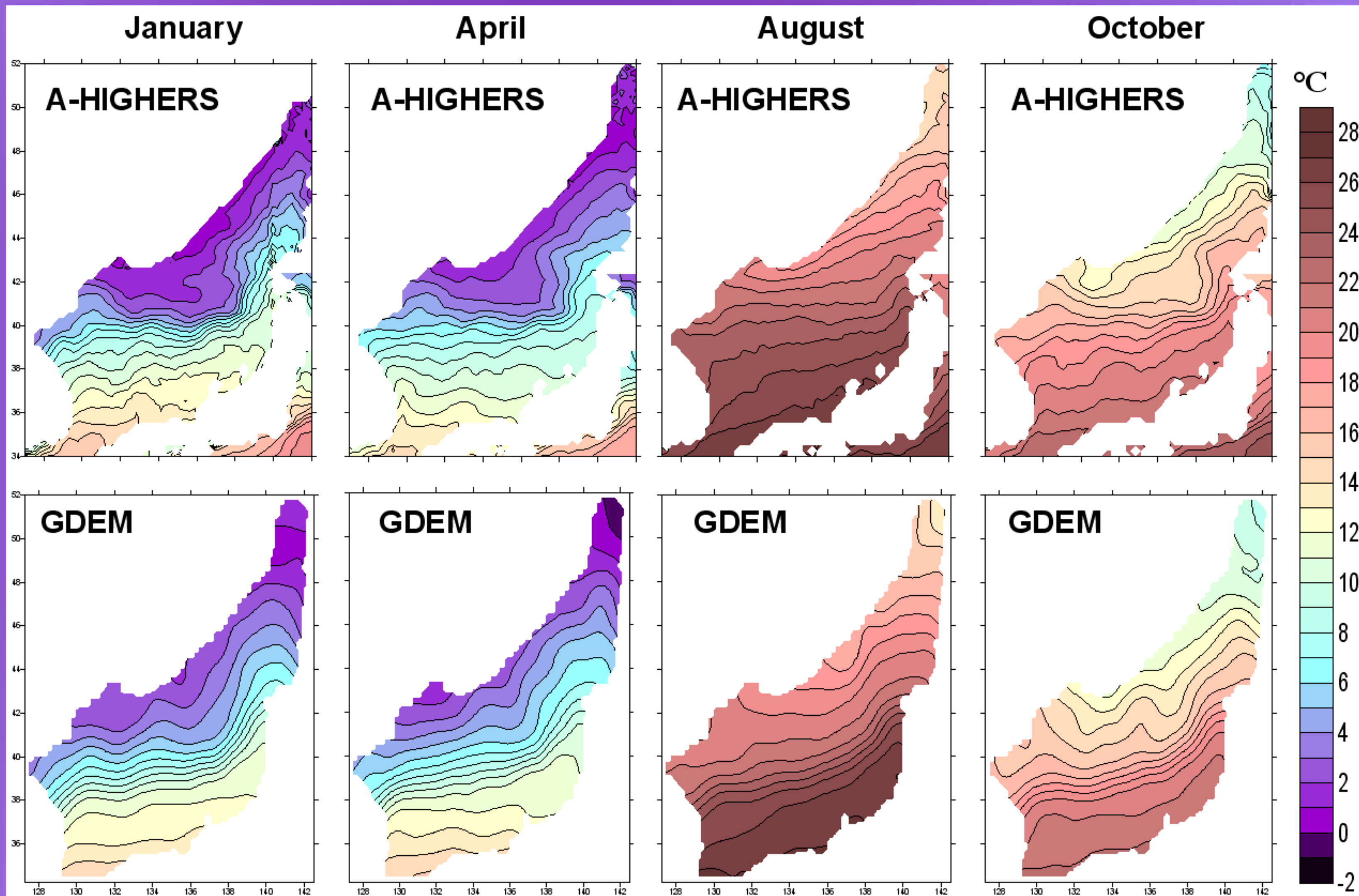
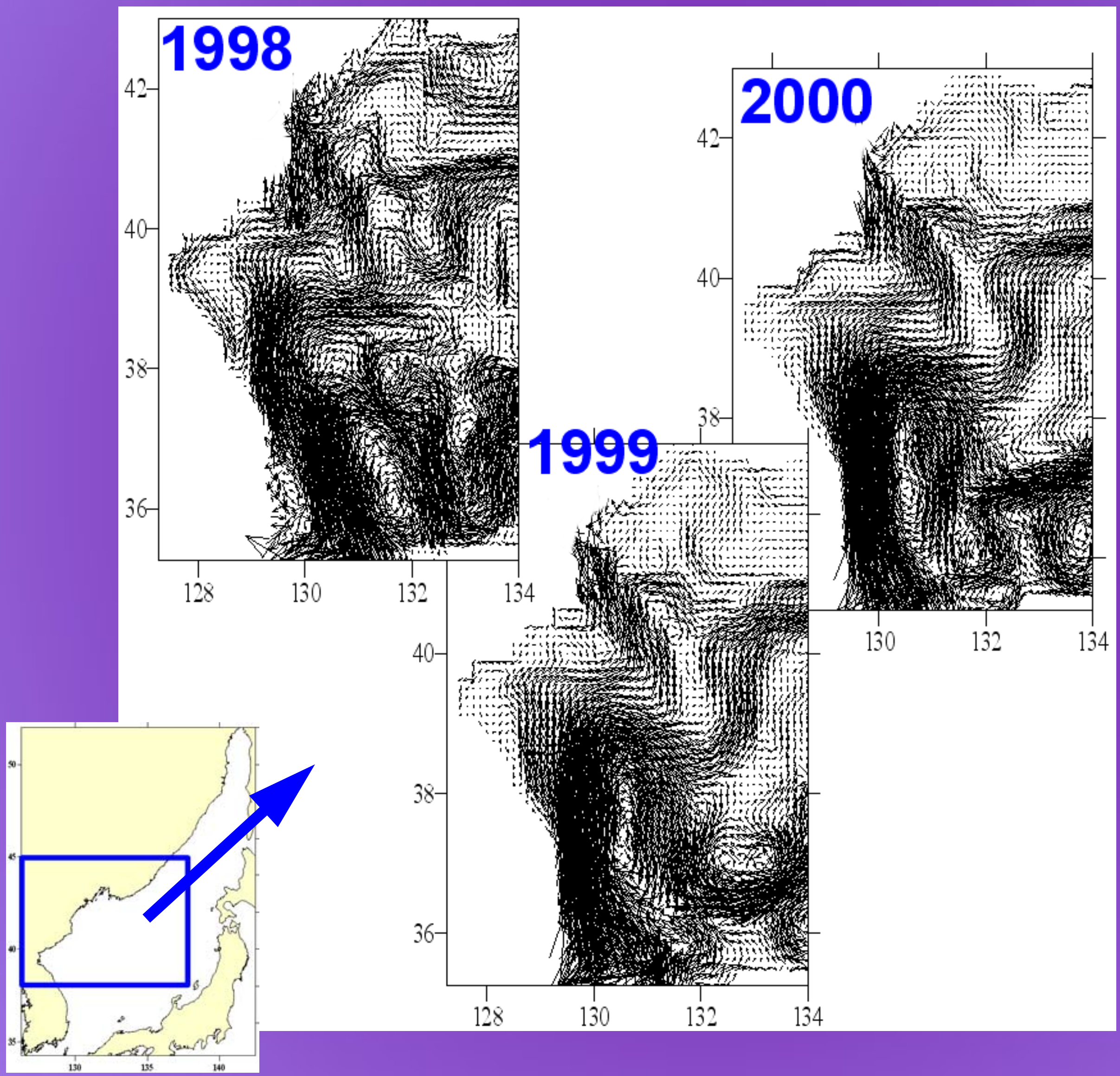
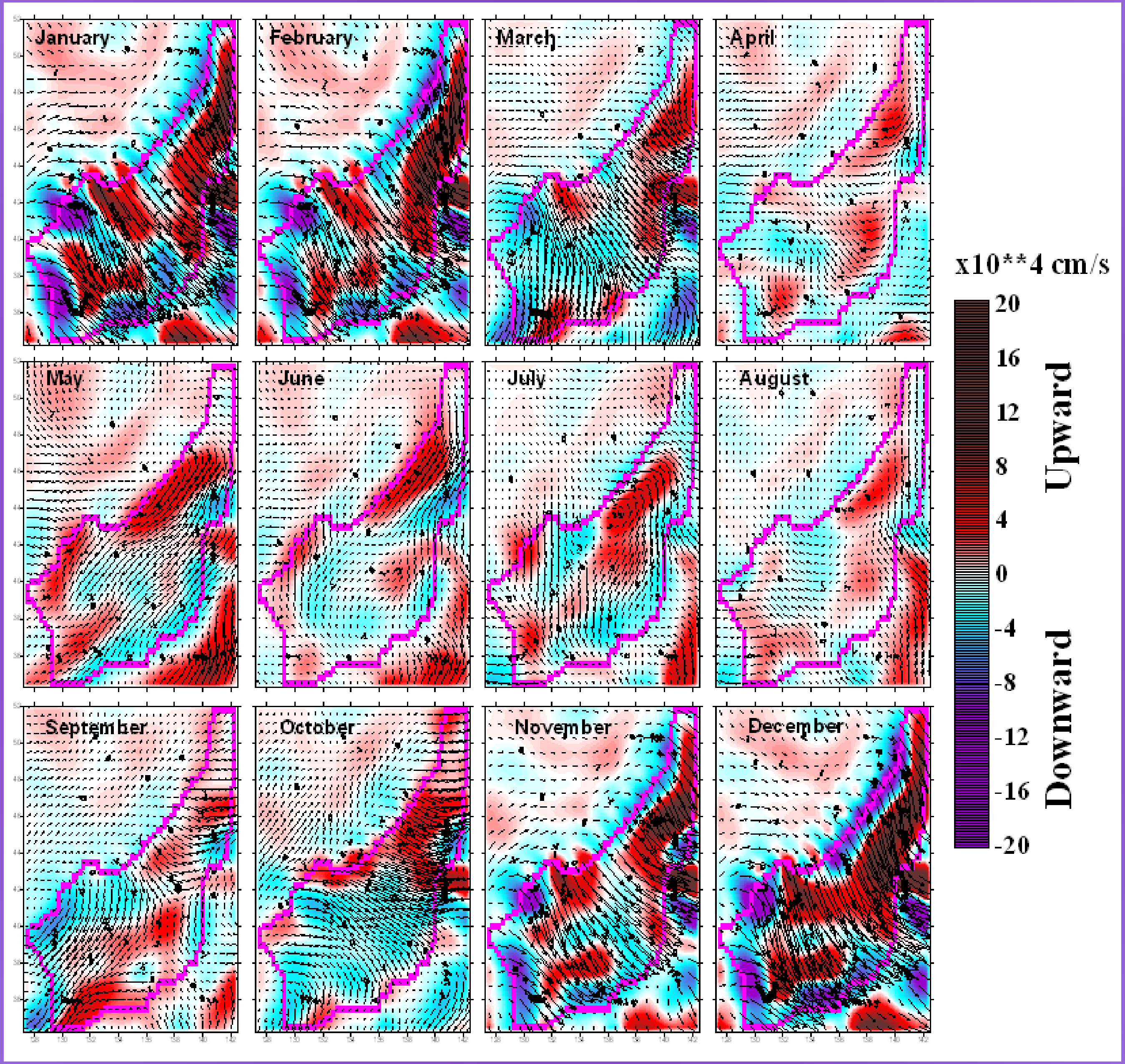
A-HIGHERS (1985-2002) vs. GDEM SST (long-tem)



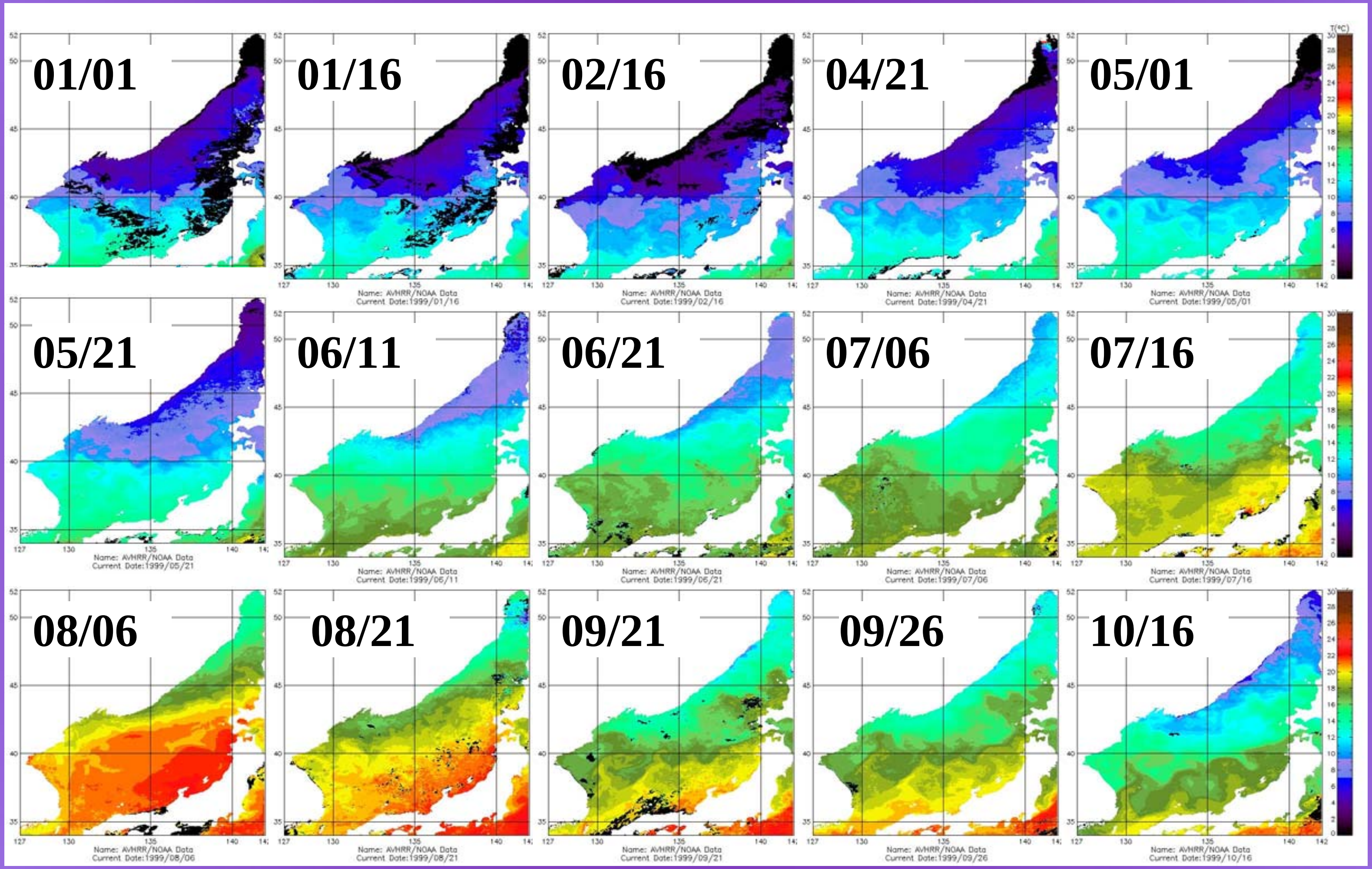
Simulated currents in September



Wind & Ekman pumping 1999



A-HIGHERS SST for 1999



Simulated currents in the northwest Japan Sea in late summer - autumn