# The effects of horizontal resolution in a Z-coordinate model of the East/Japan Sea

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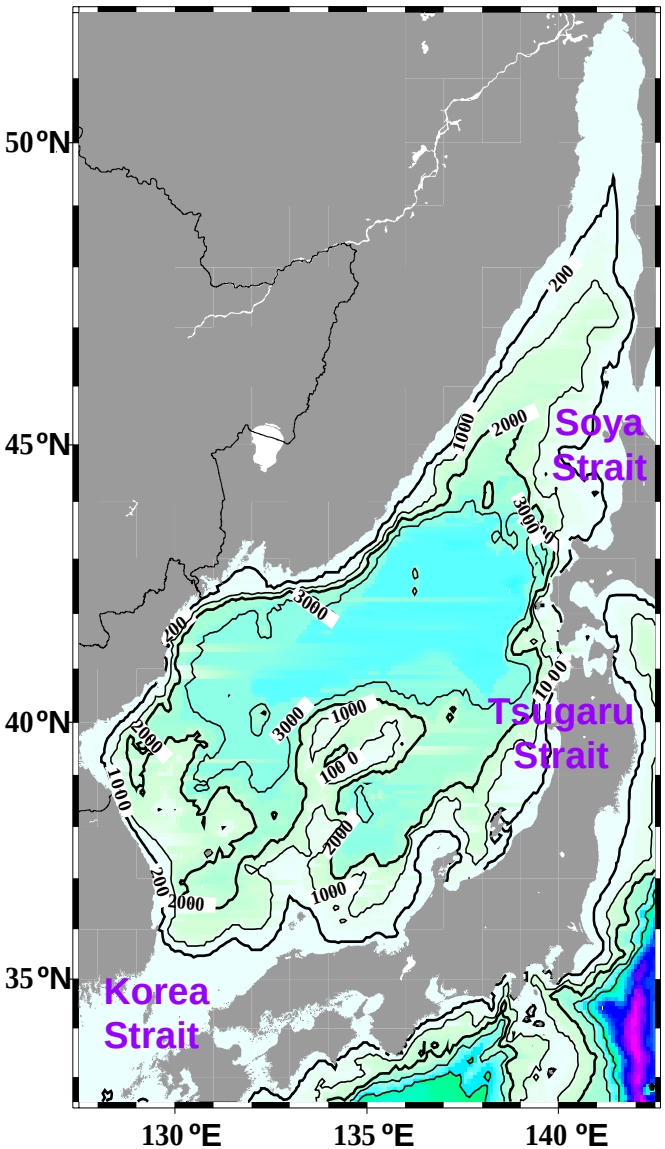
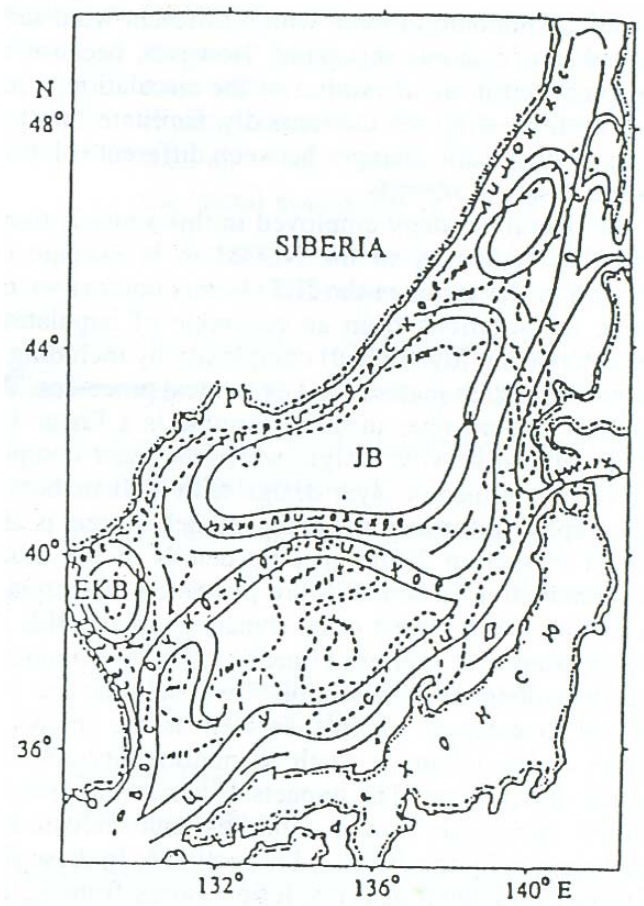



# Two Subjects

1. Branching of the Tsushima Warm Current
   - A single meandering (Moriyasu(1972))
   - The branching path
     and the simgle meandering path alternatively
     (Naganuma, 1973; 1977; 1985)
   - Two Branches (Yoon, 1982; 1991); Yarichin(1980)
   - Three Branches
     - Nearshore Branch, East Korean Warm Current and Offshore Branch Naganuma(1997)

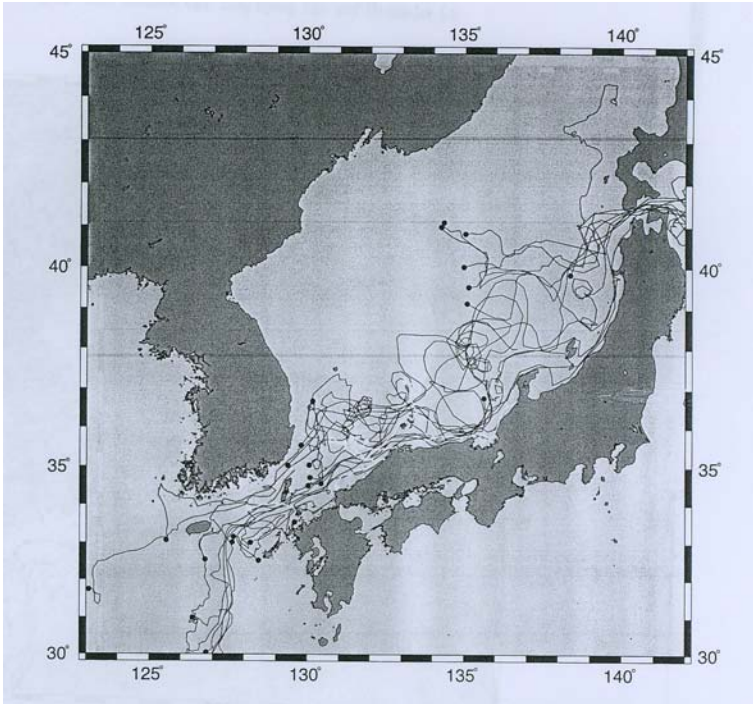
# Branching of the Tsushima Warm Current(1)




Schematic patterns of annual mean surface circulation, Yarichin(1980)

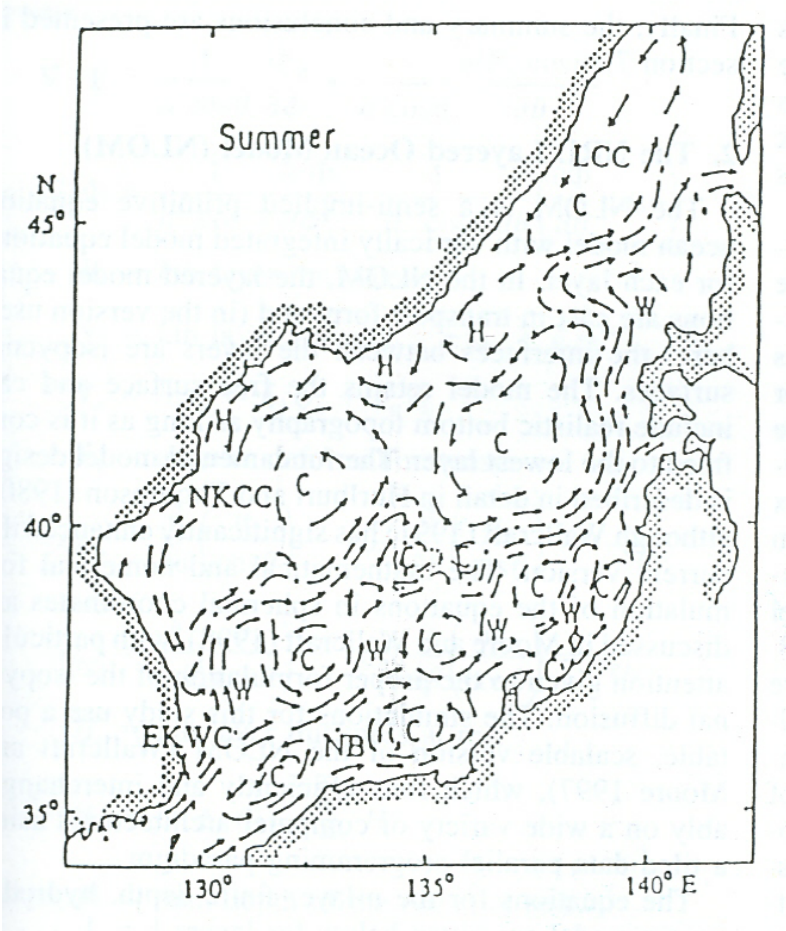
# Branching of the Tsushima Warm Current(2)


Schematic view of
Tsushima Warm Current system
Hase(1999)

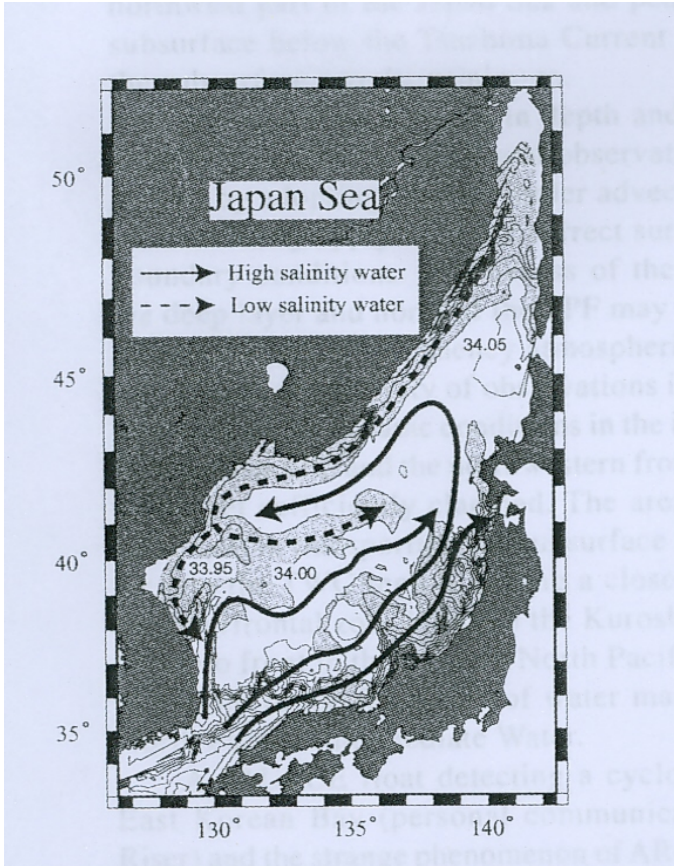



Trajectories of US Navy
and WOCE/SVP drifters, Lee(1997)

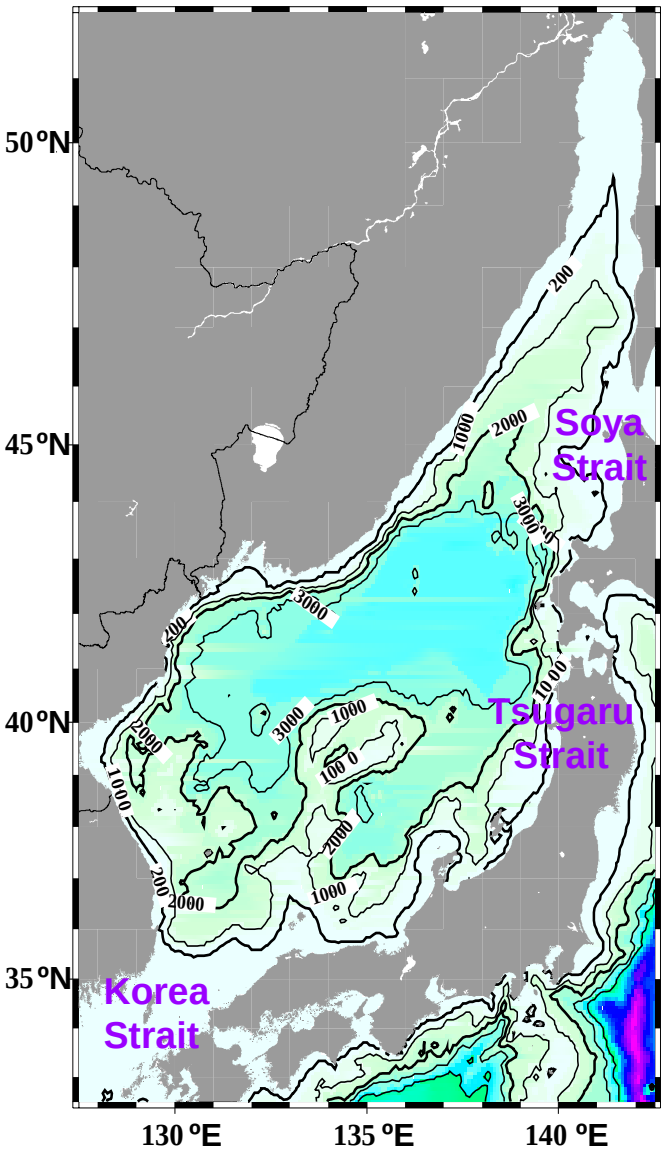
# Branching of the Tsushima Warm Current(3)




Schematic patterns of surface circulation in summer by Naganuma(1997)




Schematic patterns of surface circulation by Yoon and Kawamura(2002)




# Two Subjects

1. Branching of the Tsushima Warm Current
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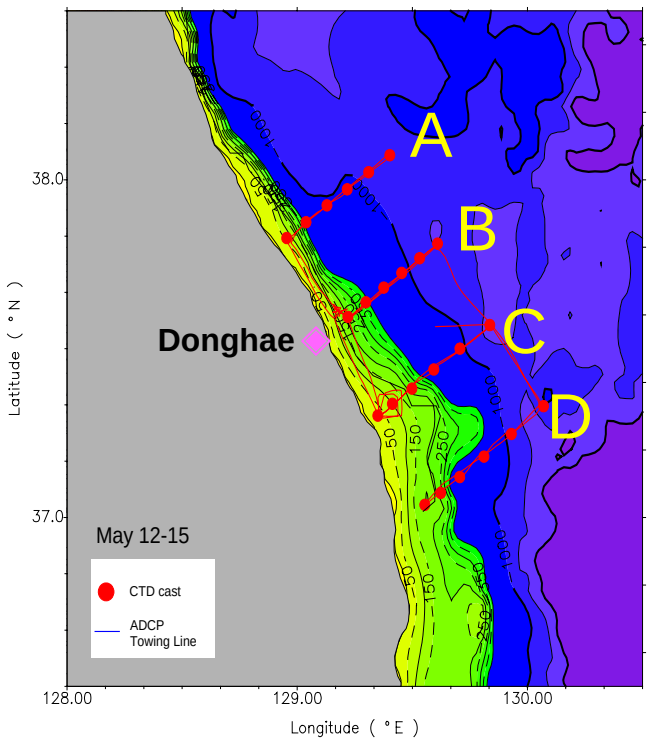
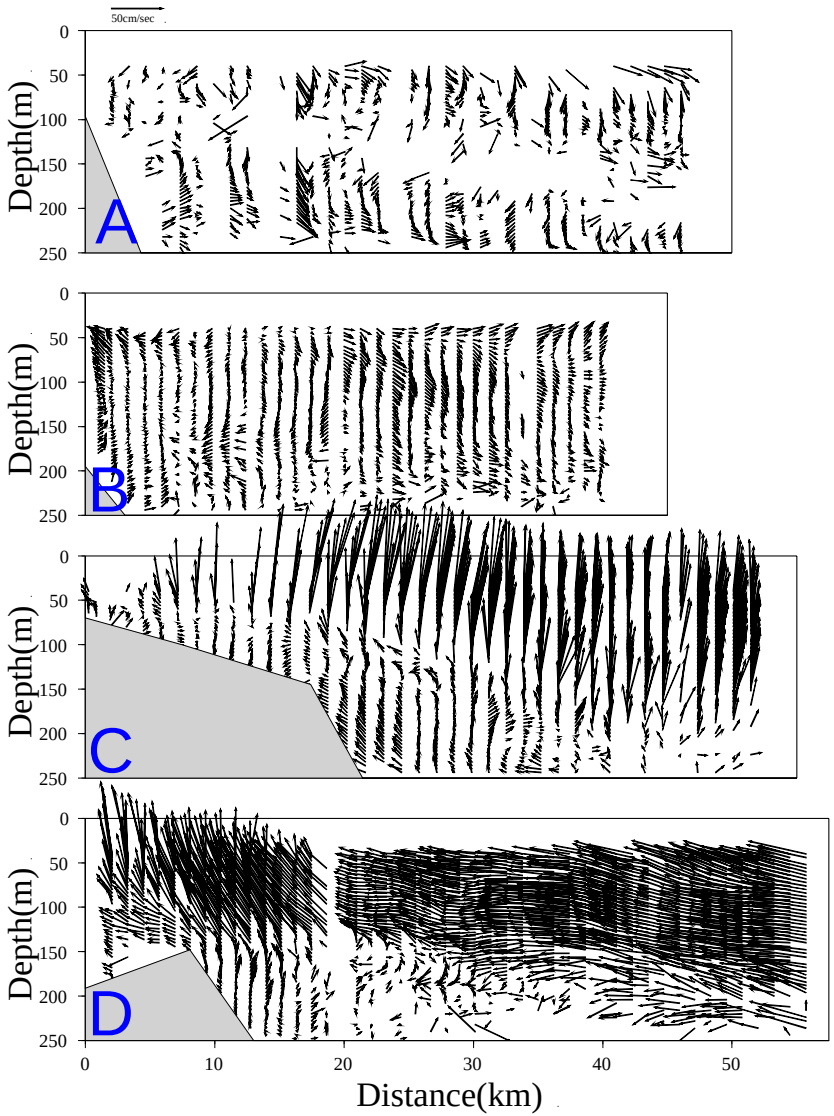
   - Three Branches
     - Nearshore Branch, East Korean Warm Current and Offshore Branch (Hase, 1991)

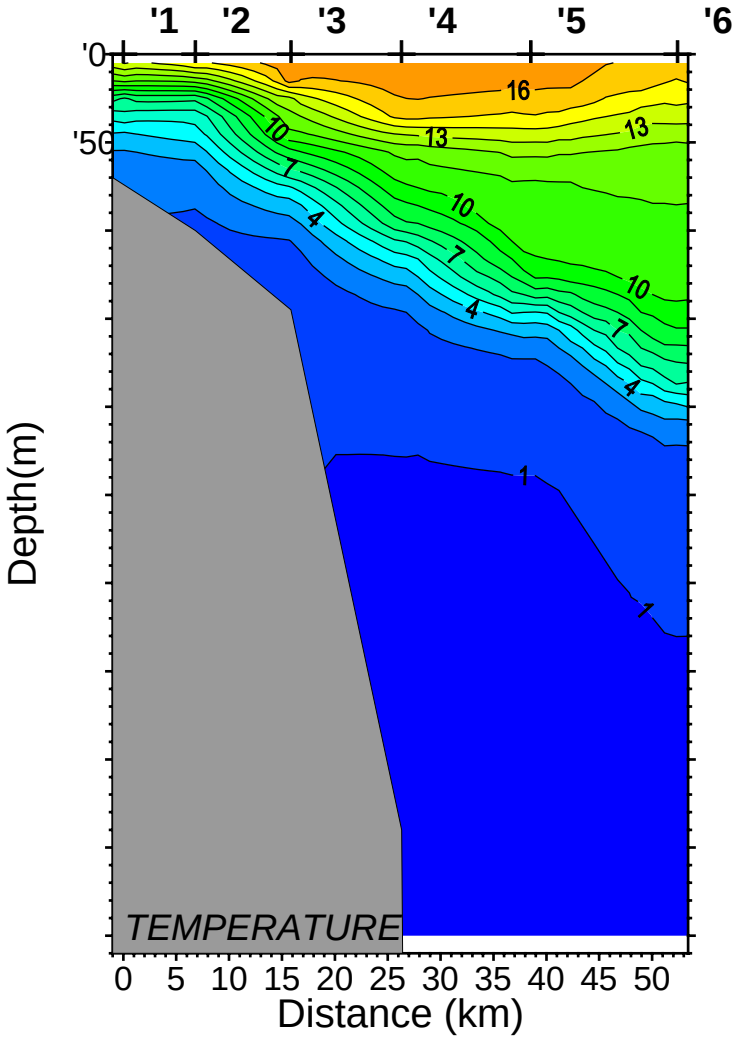
2. Separation of the EKWC
   - Thermal forcing (Seung and Kim, 1989)
   - Positive windstress curl (Seung, 1992)
   - Interaction between eddy
     and topography(Holloway, 1995)
   - Topographic effect (Hogan et. al., 2000)
   - Due to Coastline Curvature (Lee, 1999)

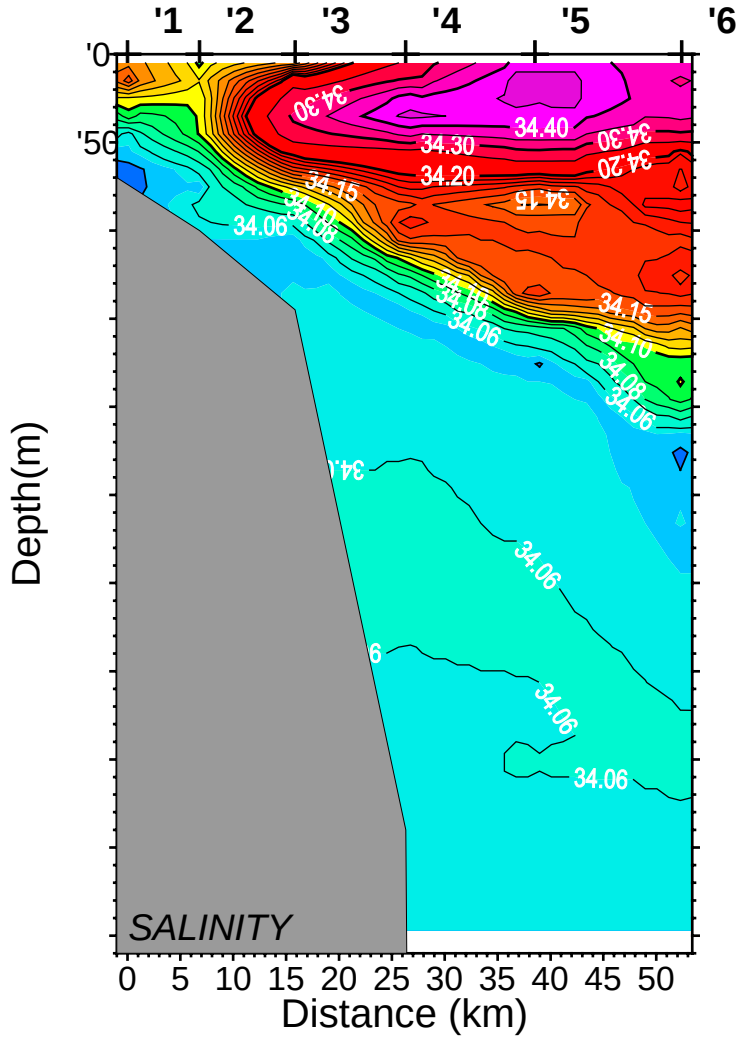
# Current Observation, May of 1999 near the Donghae City

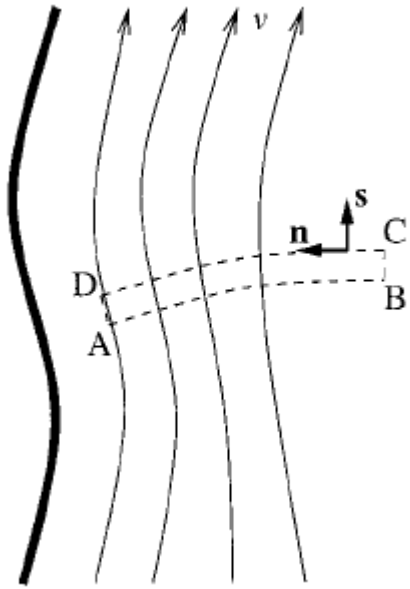


# Hydrography Section of C line, May of 1999






Implicit Formula for Boundary Current Separation (Marshall and Tansley, 2001)

Separation was always coincident with rapid deceleration of t boundary current (Haidvogel et al., 1992) !!

$$\nabla\cdot(\zeta\vec{u})+\vec{u}\cdot\nabla f=\frac{f}{h}\vec{u}\cdot\nabla h+\frac{1}{\rho}\nabla\times\frac{\tau}{H}$$

Where $h$ is isopycnal thickness and $\zeta$, relative vorticity

$$\zeta=\frac{v}{R}-\frac{\partial v}{\partial n}$$

$R$ is the radius of curvature of the streamlines

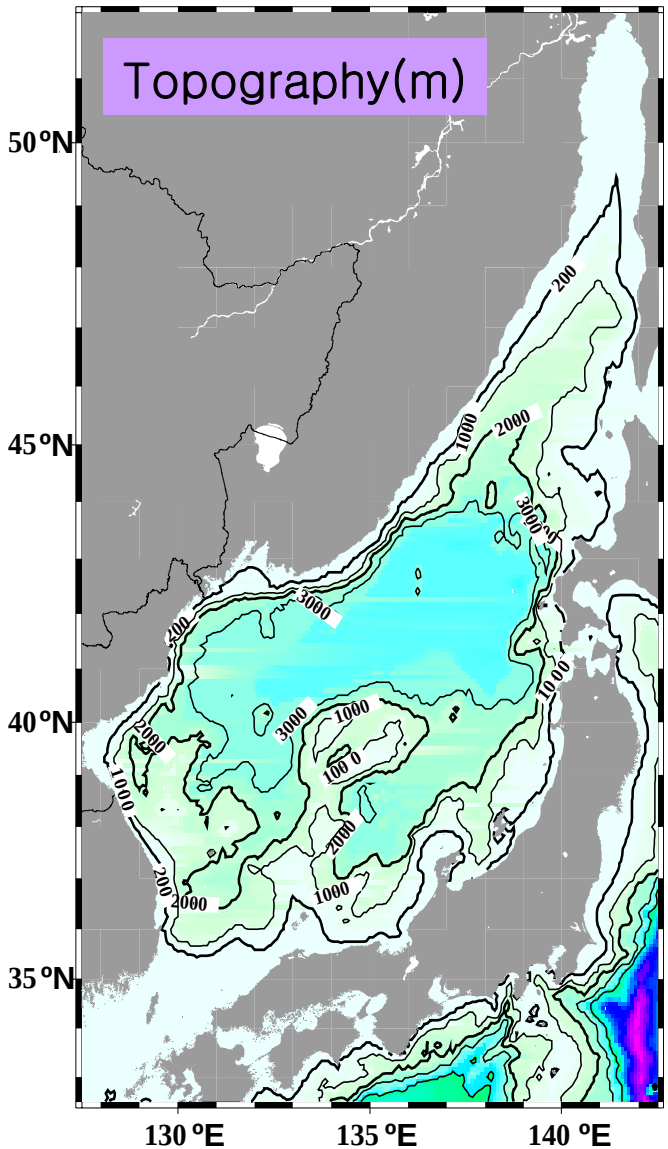
The Formula is

$$\left[\frac{v^2}{2}\right]_A^D\approx\iint_{ABCD}\beta v\,dA-\iint_{ABCD}\frac{f}{h}\vec{u}\cdot\nabla h\,dA+\left[\int\frac{v^2}{R}dn\right]_{BA}^{CD}-\frac{1}{\rho}\iint_{ABCD}\nabla\times\frac{\tau}{H}dA$$

beta effect | vortex stretching | coastline curvature | windstress curl

# Model Description

Horizontal Domain (127.5 ~ 142.5 °E, 33.0 ~ 52.0 °N)
42 vertical cells




- **Based on GFDL MOM3**
  - **Z-coordinate level model**
  - **Parallel Processing (MPI)**
- **Thermal forcing - Bulk Formula calculated from NCEP Reanalysis**
- **Features**
  - **Explicit free surface**
  - **Smagorinsky SGS for momentum**
  - **Gent-McWilliam Isoneutral SGS for tracers**
  - **KPP Vertical SGS Parameterizaton**
  - **Partial cell**
  - **Free Surface Open boundary Condition**

## Model Equations

$$u_t = -\nabla\cdot(u\vec{u}) + v\left(f + \frac{u\tan\phi}{a}\right) - \left(\frac{1}{a\rho_0\cos\phi}\right)p_\lambda + (\kappa_m u_z)_z + F^u$$

$$v_t = -\nabla\cdot(v\vec{u}) - u\left(f + \frac{u\tan\phi}{a}\right) - \left(\frac{1}{a\rho_0}\right)p_\phi + (\kappa_m v_z)_z + F^v$$

Momenturm eq.

$$w_z = -\nabla_h\cdot\vec{u}_h$$

Continuity eq.

$$\theta_t = -\nabla\cdot[\vec{u}\theta + F(\theta)]$$

$$s_t = -\nabla\cdot[\vec{u}s + F(s)]$$

Eq. of state

$$\rho = \rho(\theta, s, z)$$

Boussinesq approx.

$$p_z = -\rho g$$

Hydrostatic approx.

## Bulk Formula

$$Q_{net} = Q_{sw} - (Q_{sen} + Q_{lat} + Q_{lw})$$

$Q_{sw}$ : Net downward shortwave radiation.

$$Q_{sen} = \rho_a C_p^a C_h W_{10}(T_a - \theta_1)$$

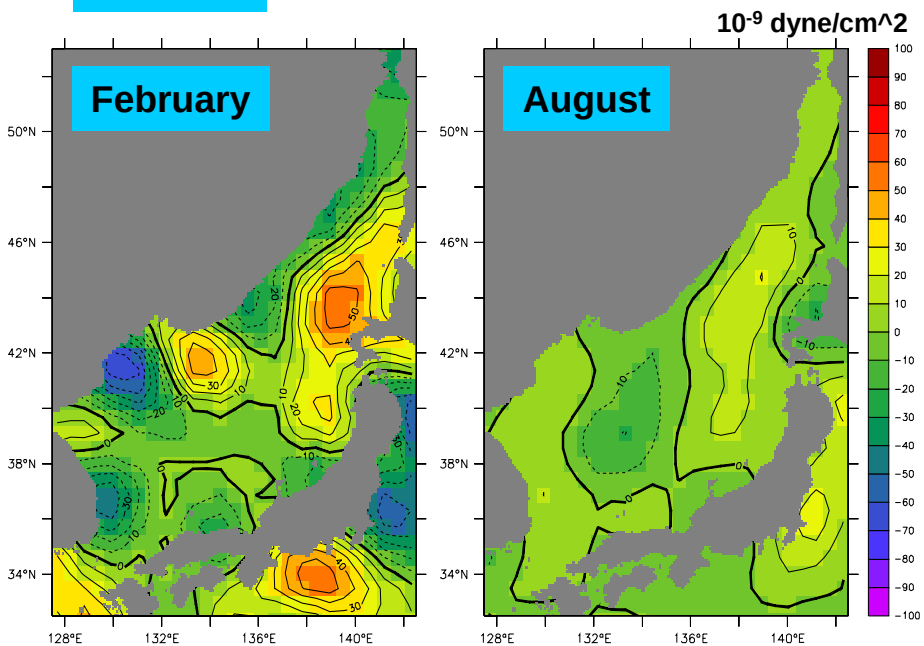
$$Q_{lat} = \rho_a L_e C_E W_{10}(q_a - q_1)$$

$$Q_{lw} = -\varepsilon\sigma_{SB}\left\{T_a^4\left[0.39 - 0.05(e_a)^{0.5}\right]F(c) + 4T_a^3(\theta_1 - T_a)\right\}$$

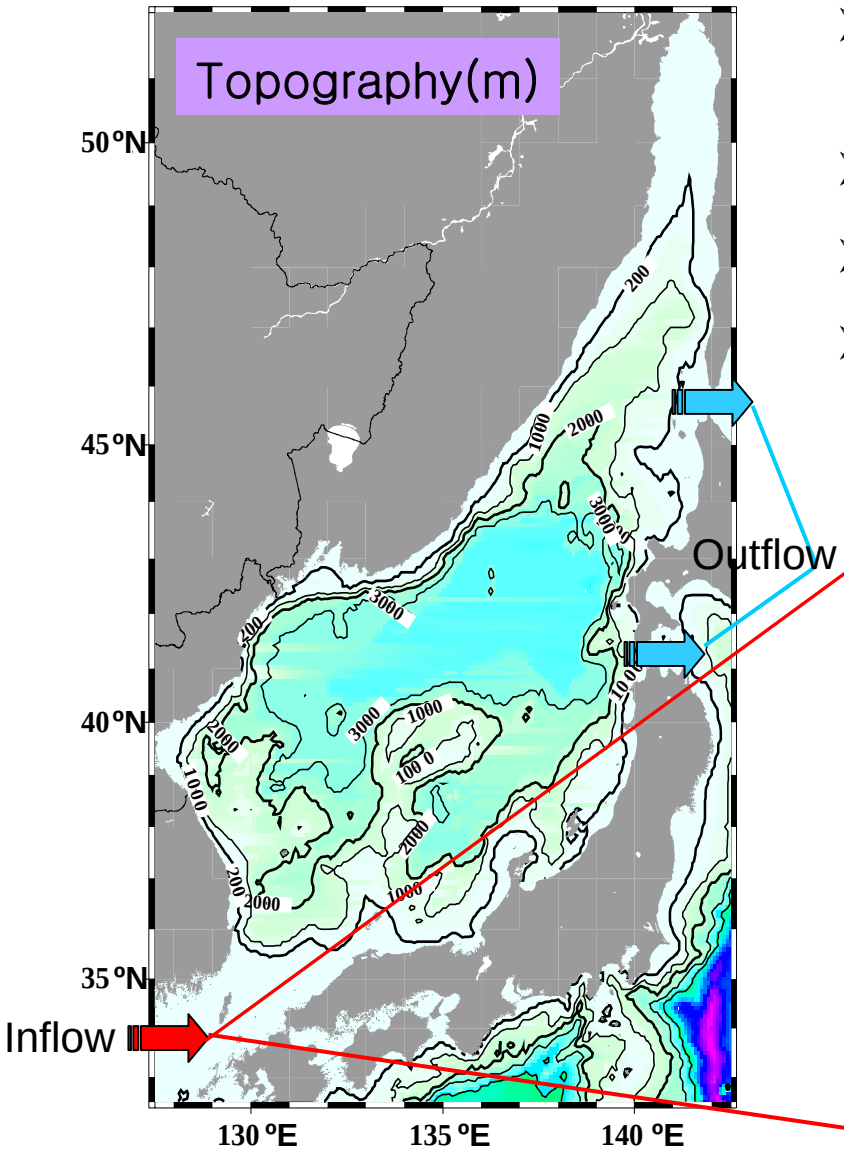
# Three Experiments

| Experiment | Wind stress | Heat Flux | Lateral Boundary | Model Horizontal Resolution | Horizontal Viscosity |
|---|---|---|---|---|---|
| ER_CL_B | ERA15 Climatology | Bulk Formula | Closed | 0.1º × 0.1 º | O($10^6$) $cm^2$/sec |
| ER_OP_C | ERA15 Climatology | Bulk Formula | Open | 0.1º × 0.1 º | O($10^6$) $cm^2$/sec |
| ER_OP_F | ERA15 Climatology | Bulk Formula | Open | 0.06~0.1º × 0.1º | O($10^5$) $cm^2$/sec |

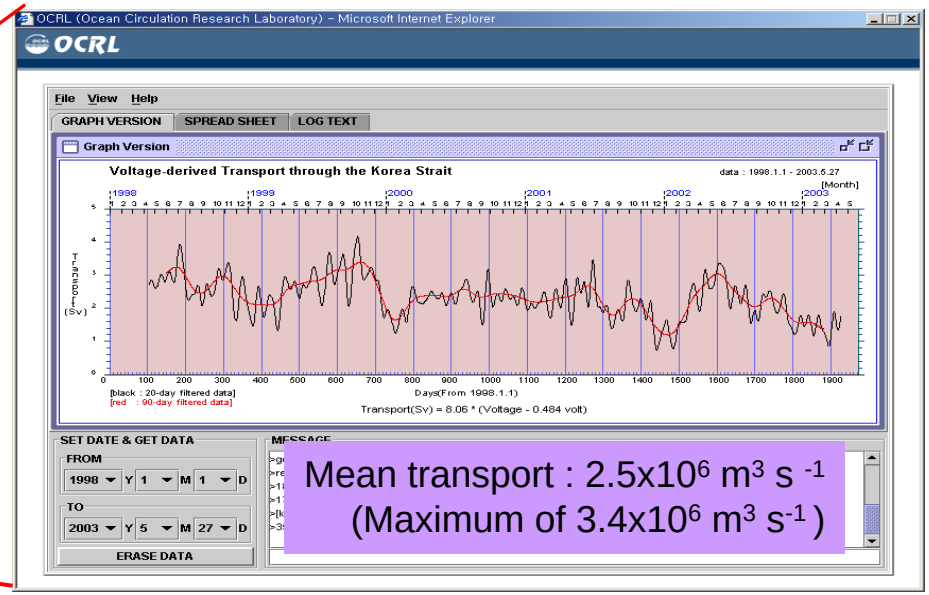
ERA15



# Open Boundary Condition



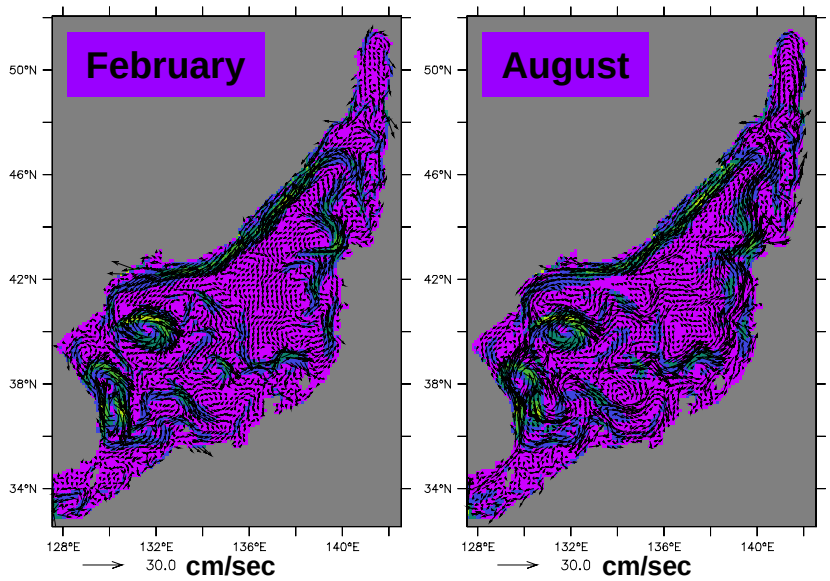

- Wind Stress : monthly averaged ERA15
- Heat Flux : Bulk Formula calculated from monthly averaged NCEP
- Salt Flux : Restoring Condition
- Initial Field : Levitus Hydrography
- Open boundary Condition
  - ✓Hydrography : Levitus
  - ✓Inflow : Voltage Induced Transport



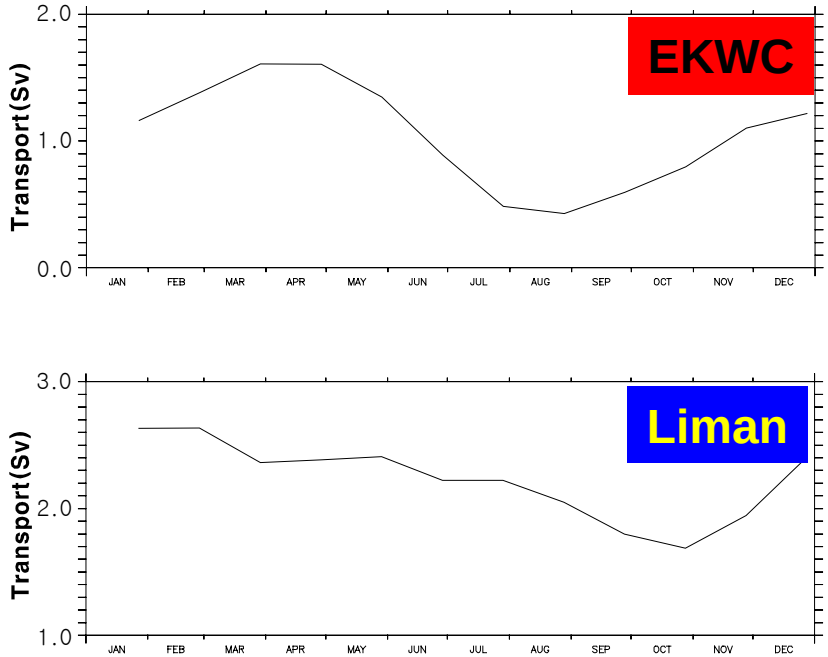

Mean transport : $2.5 \times 10^6$ $m^3$ $s^{-1}$
(Maximum of $3.4 \times 10^6$ $m^3$ $s^{-1}$ )

Model Results **ER_CL_B**

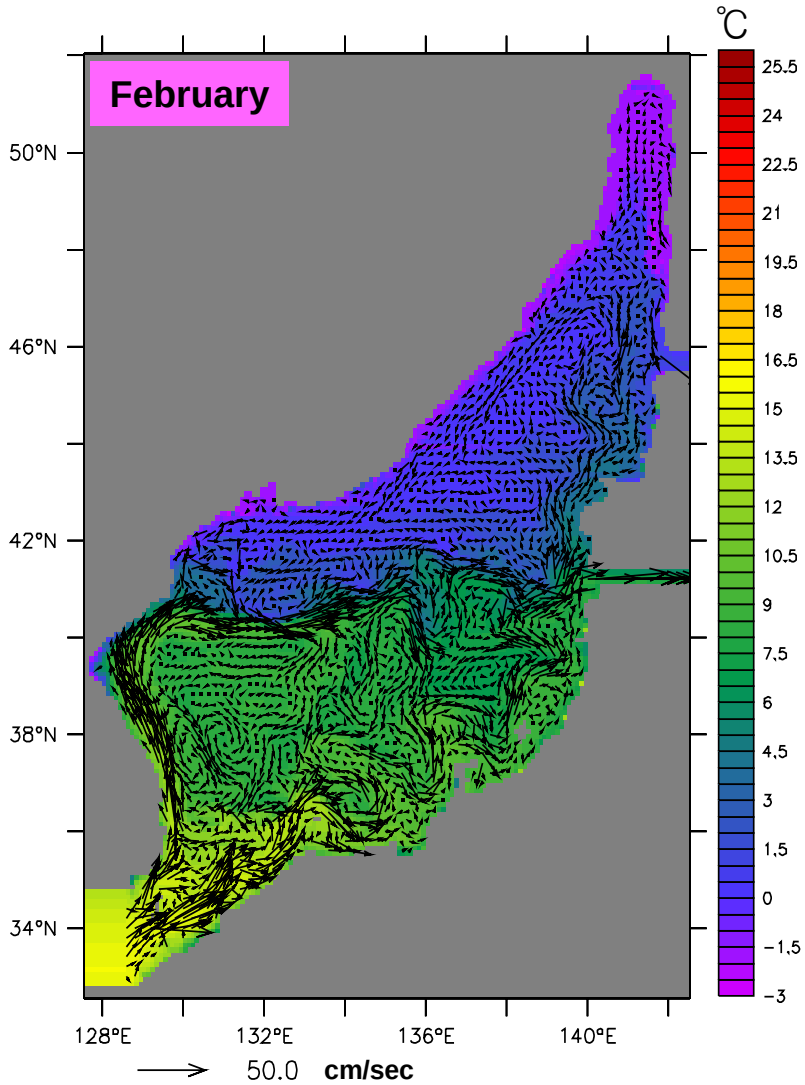
## Surface Current

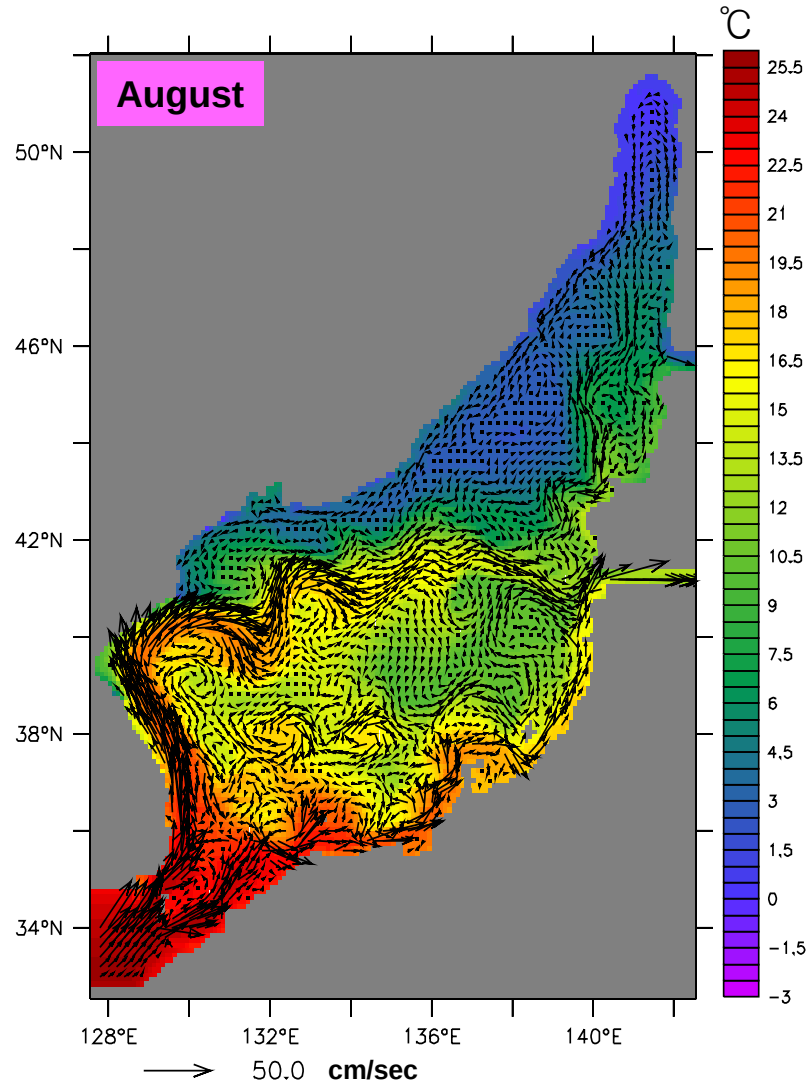



## Transport

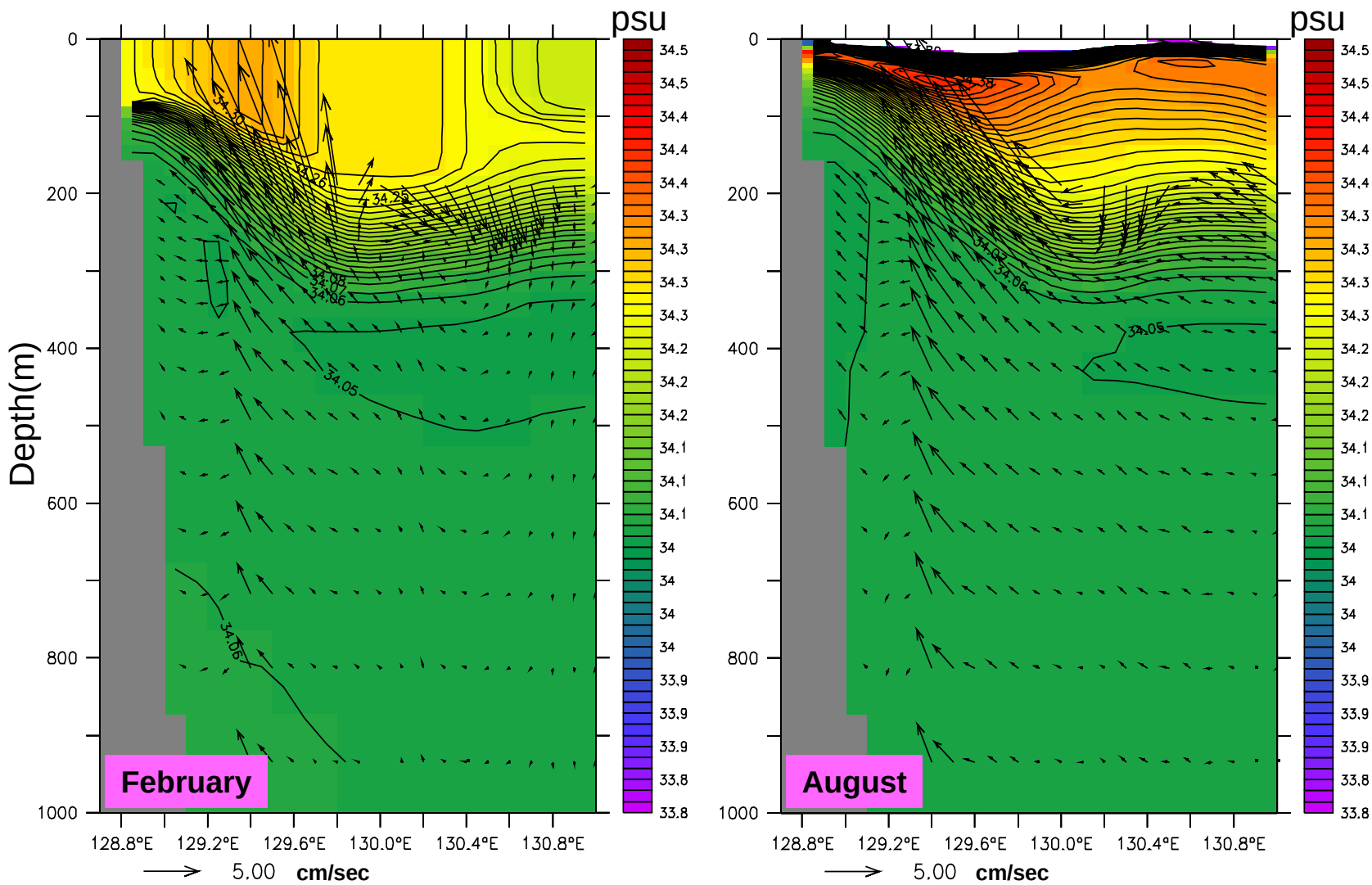


Model Results **ER_OP_C**

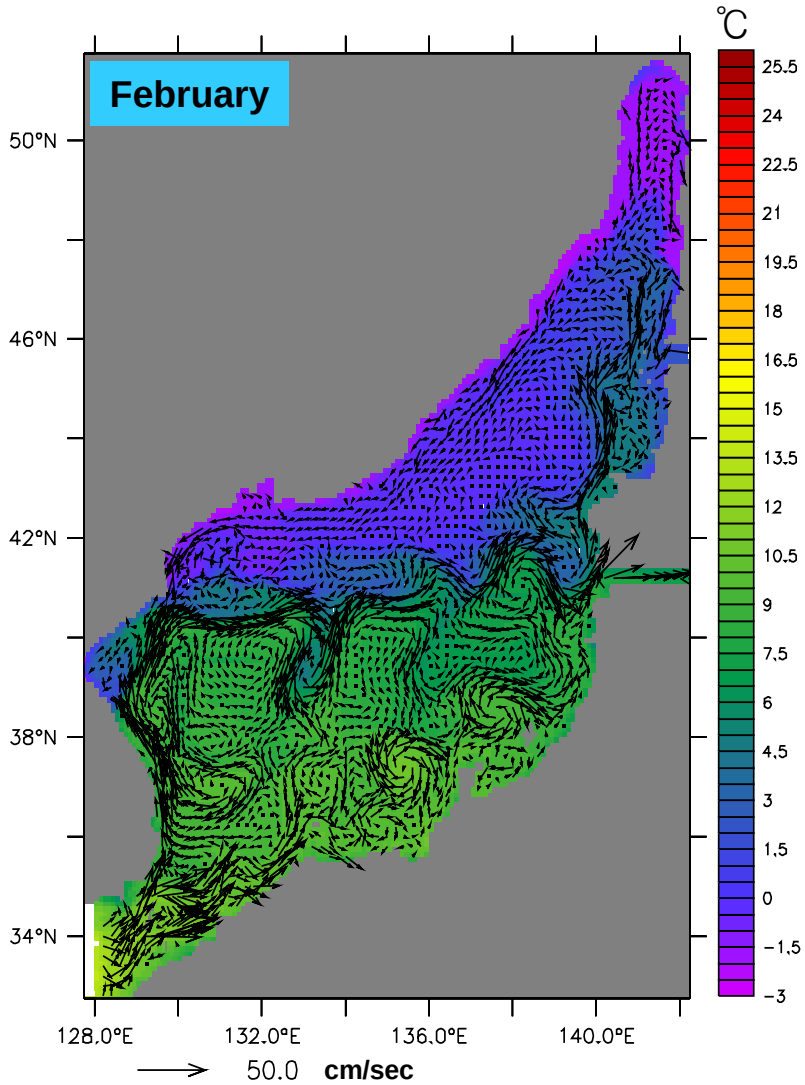


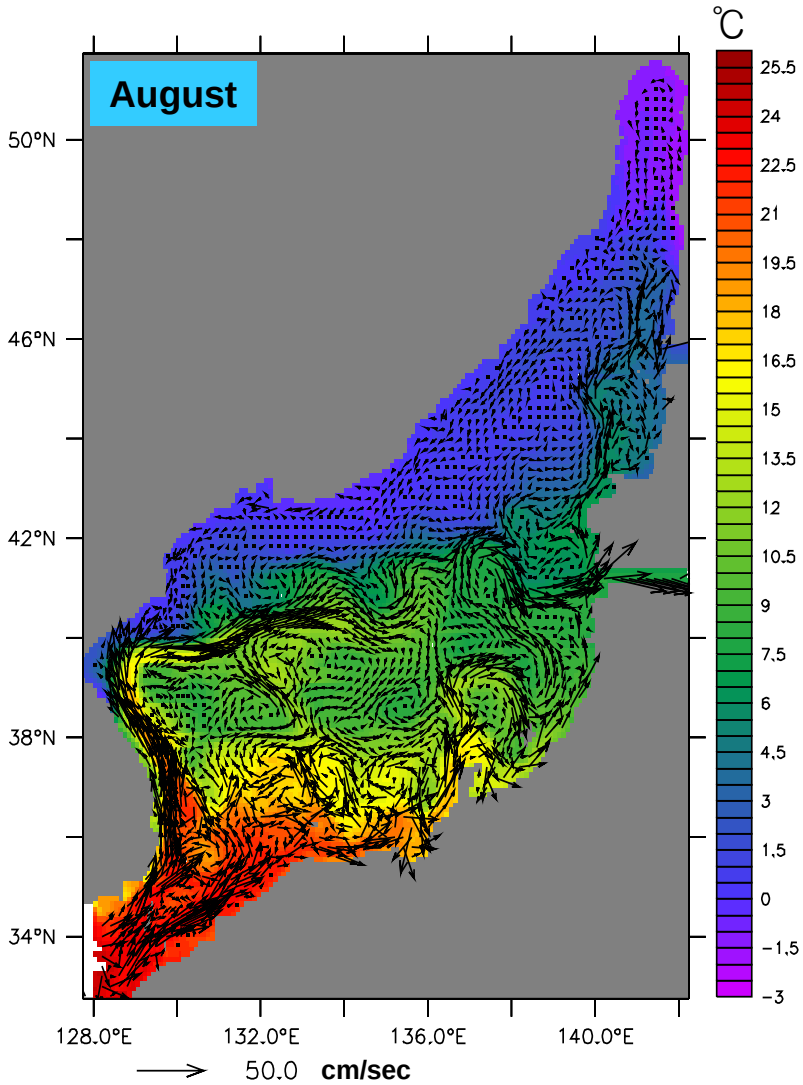



Model Results **ER_OP_C**



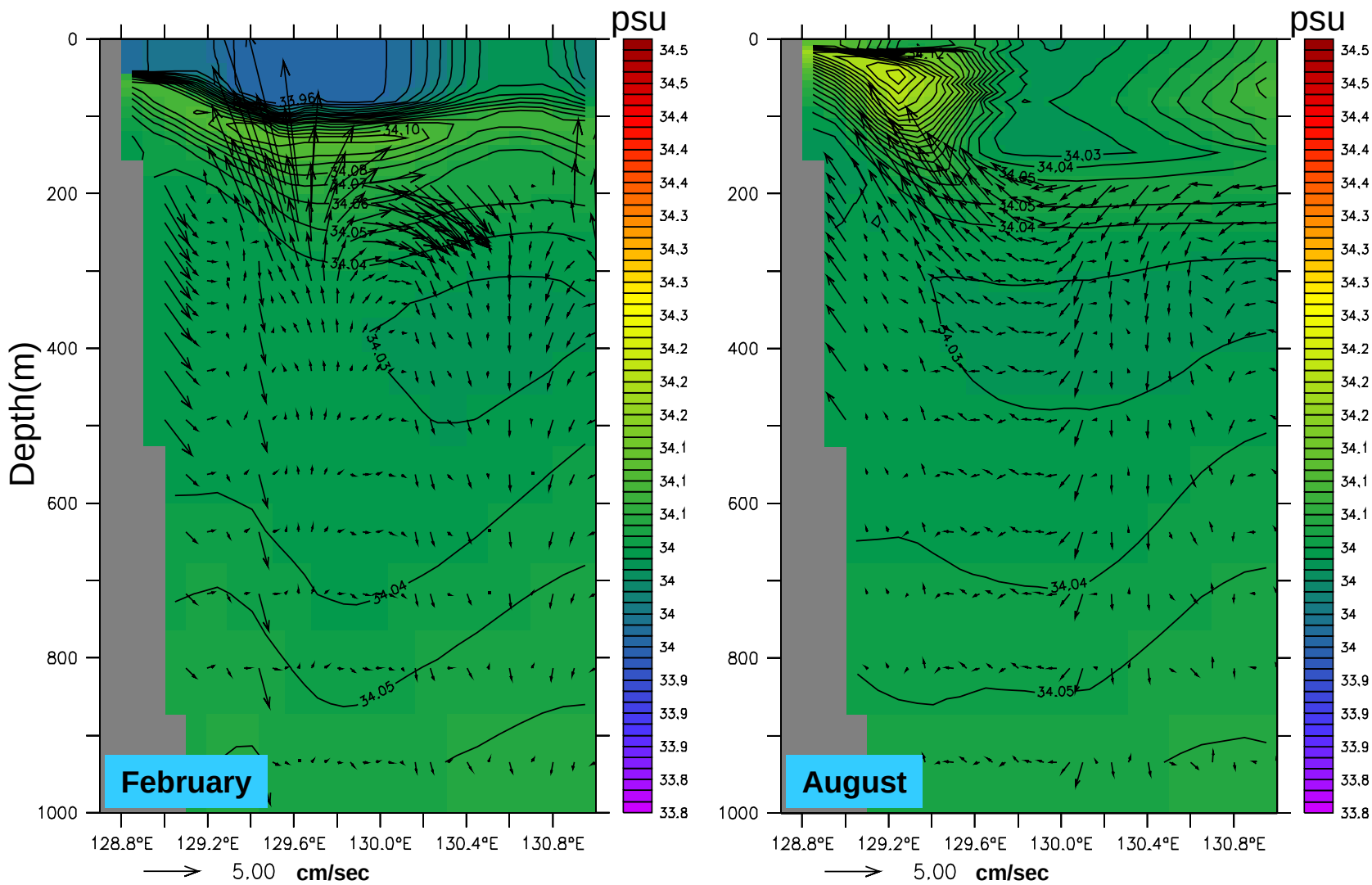
# Surface Current and Temperature



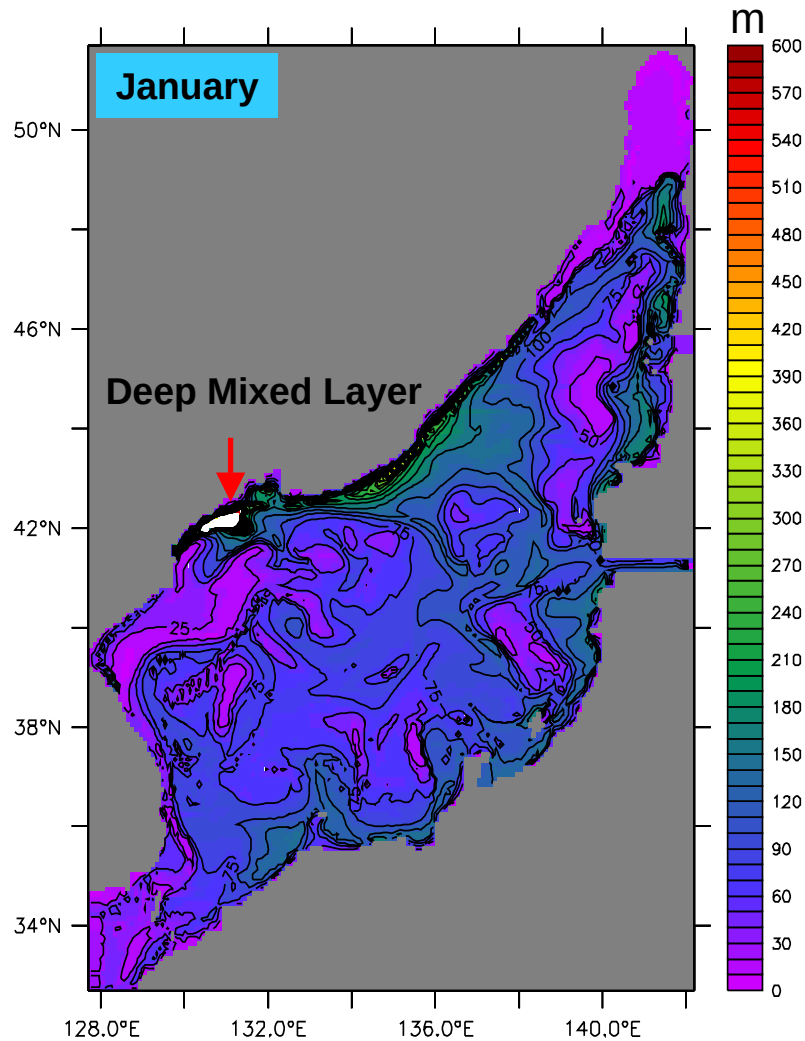
Model Results **ER_OP_F**

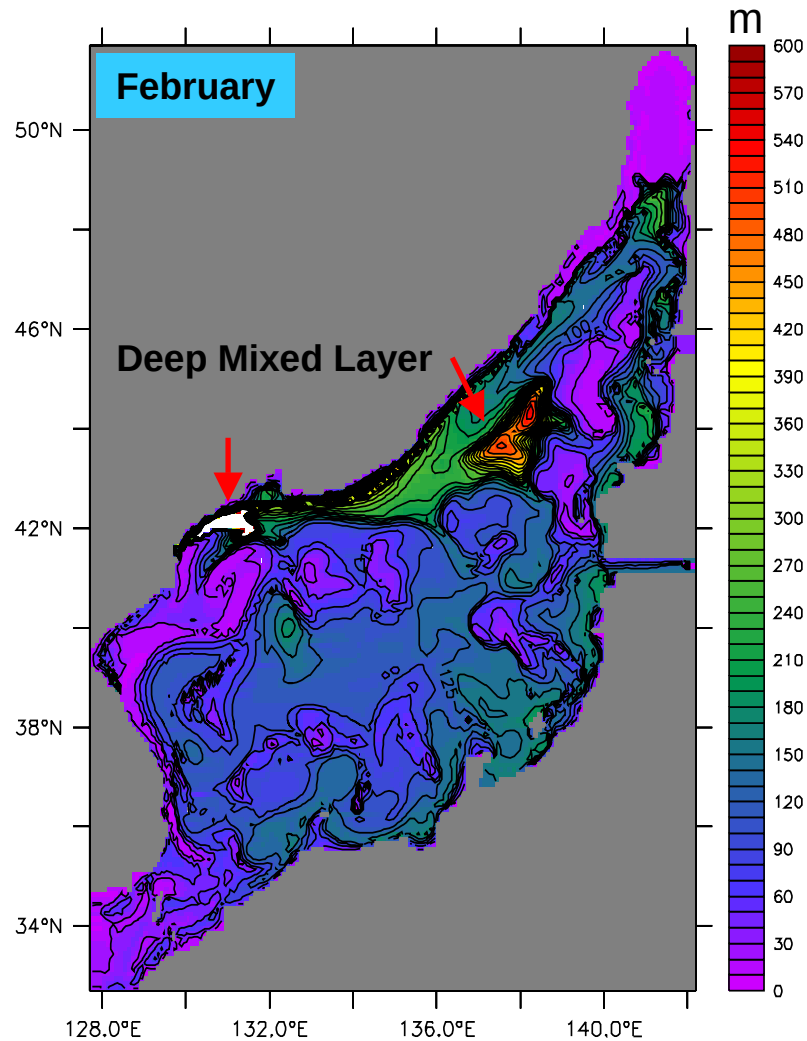
# Salinity and Current Sections along 38ºN



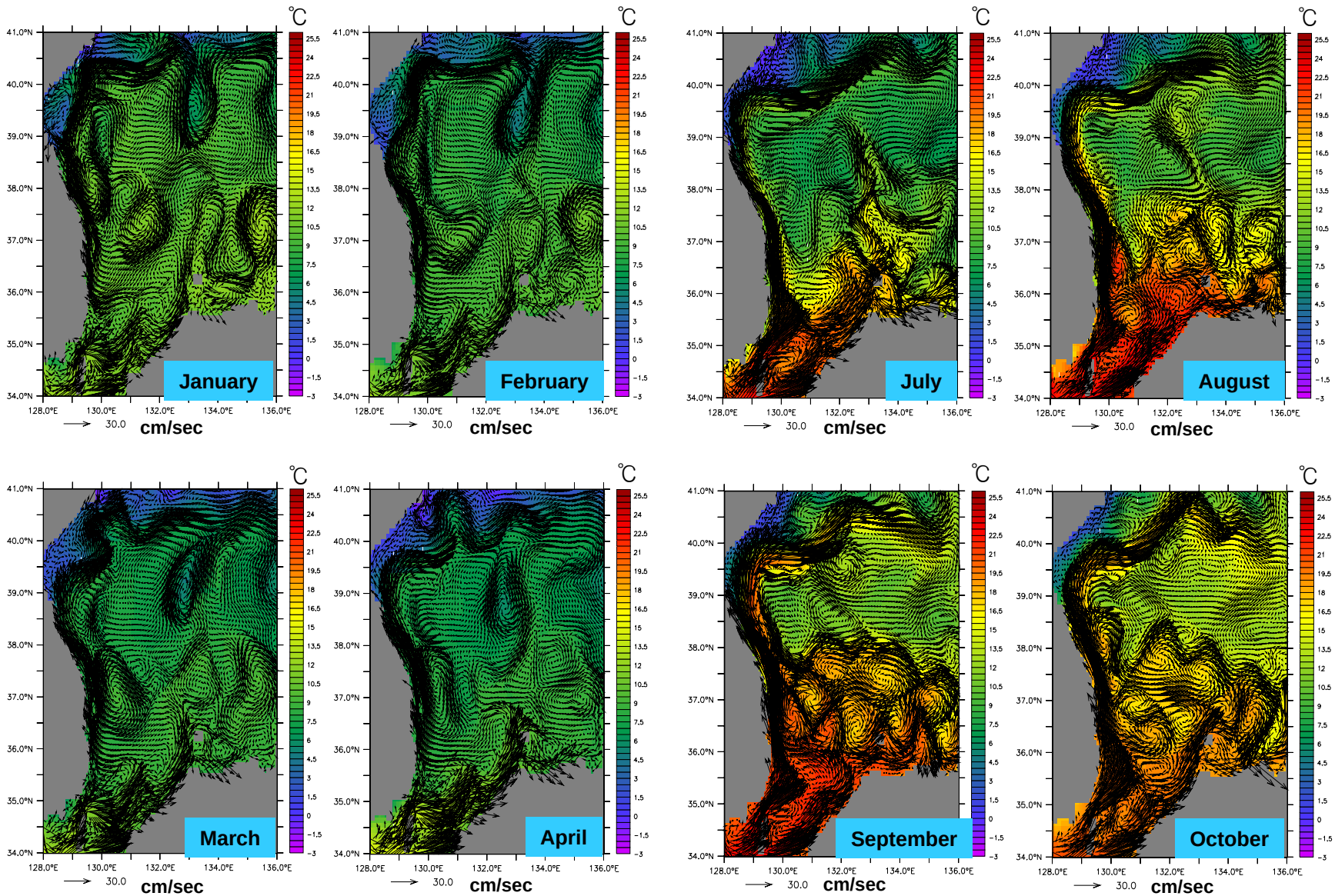
Model Results **ER_OP_F**

# Mixed Layer Depth in Winter



# Surface Current and Temperature in each month



# Implicit Formula

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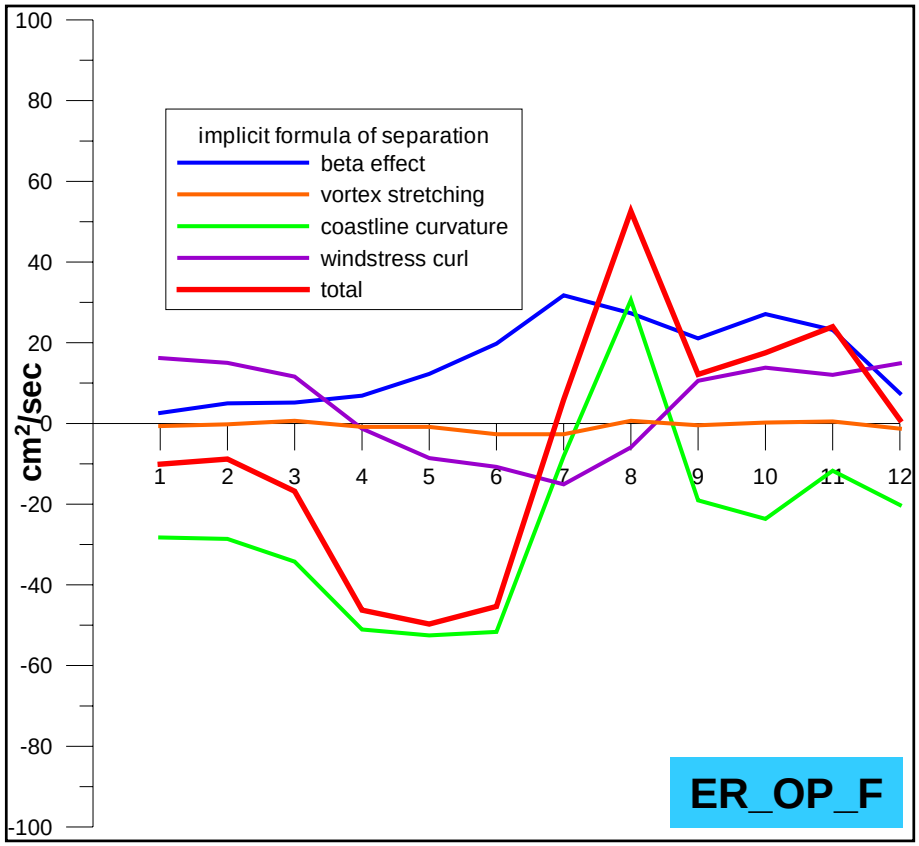


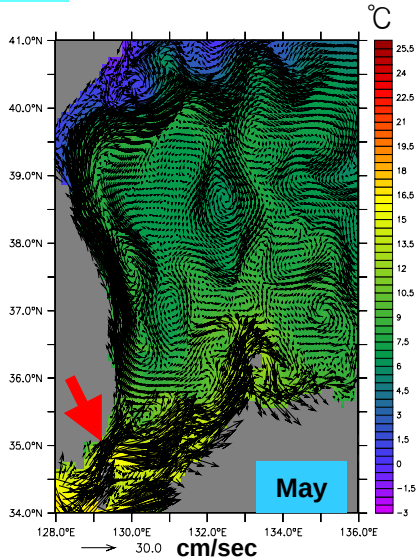


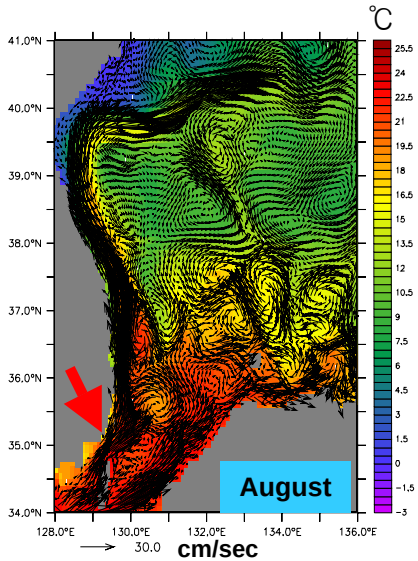

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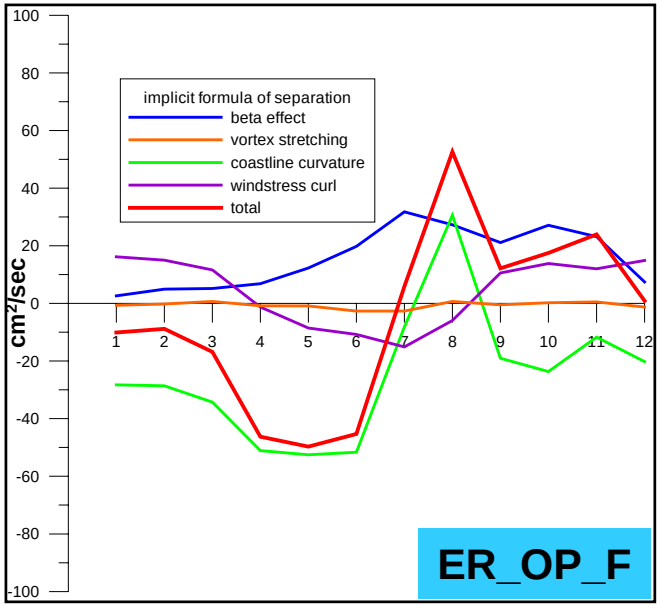


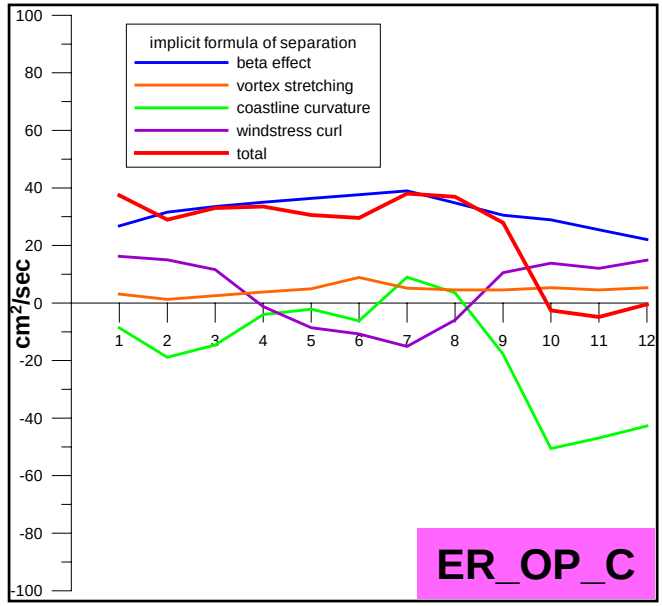


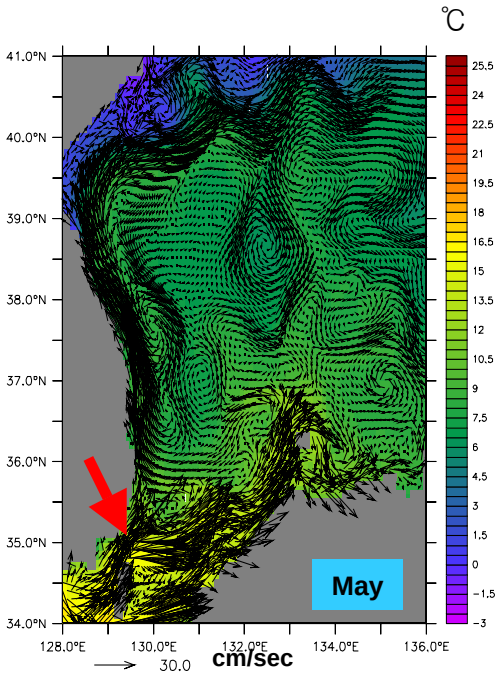


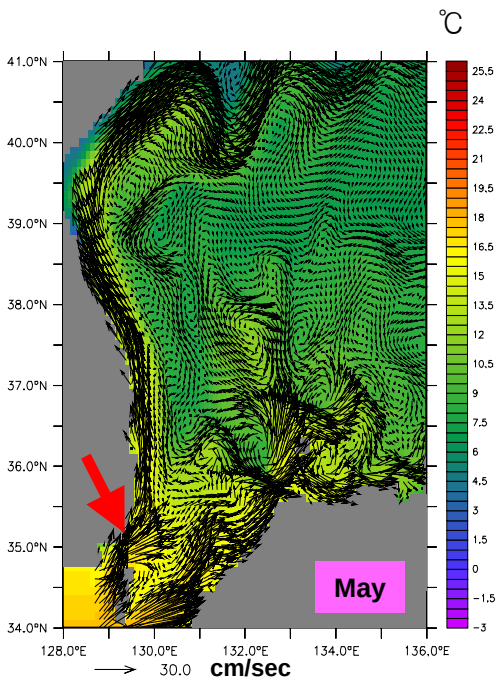

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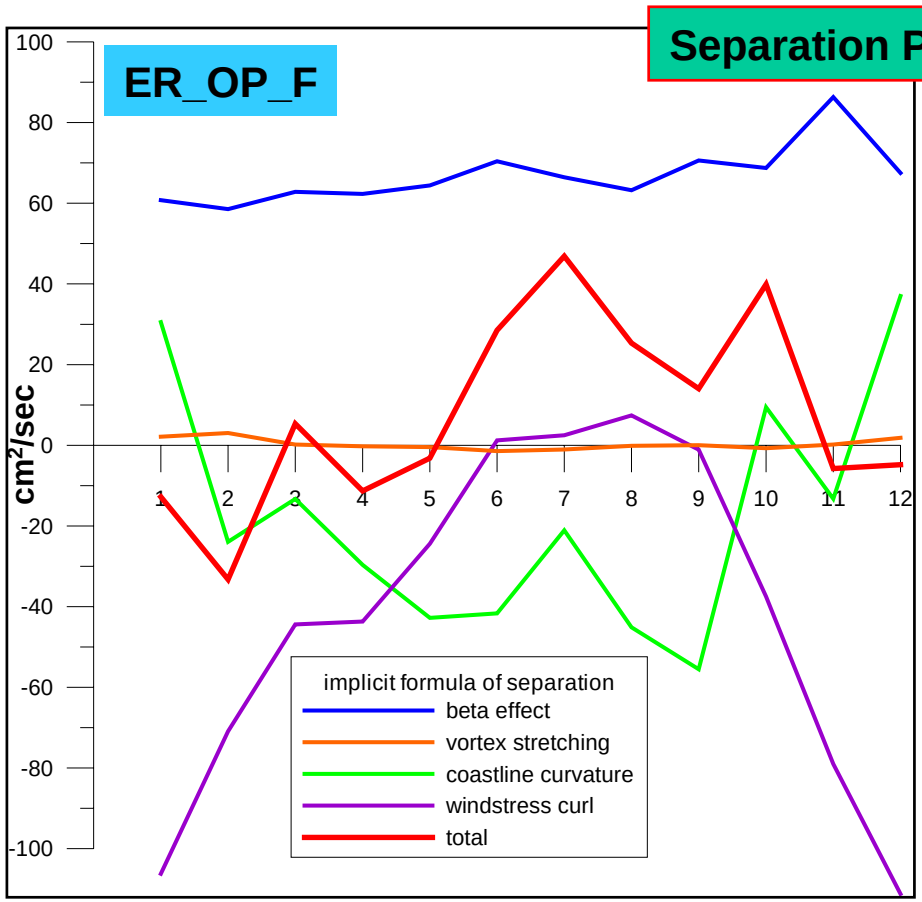
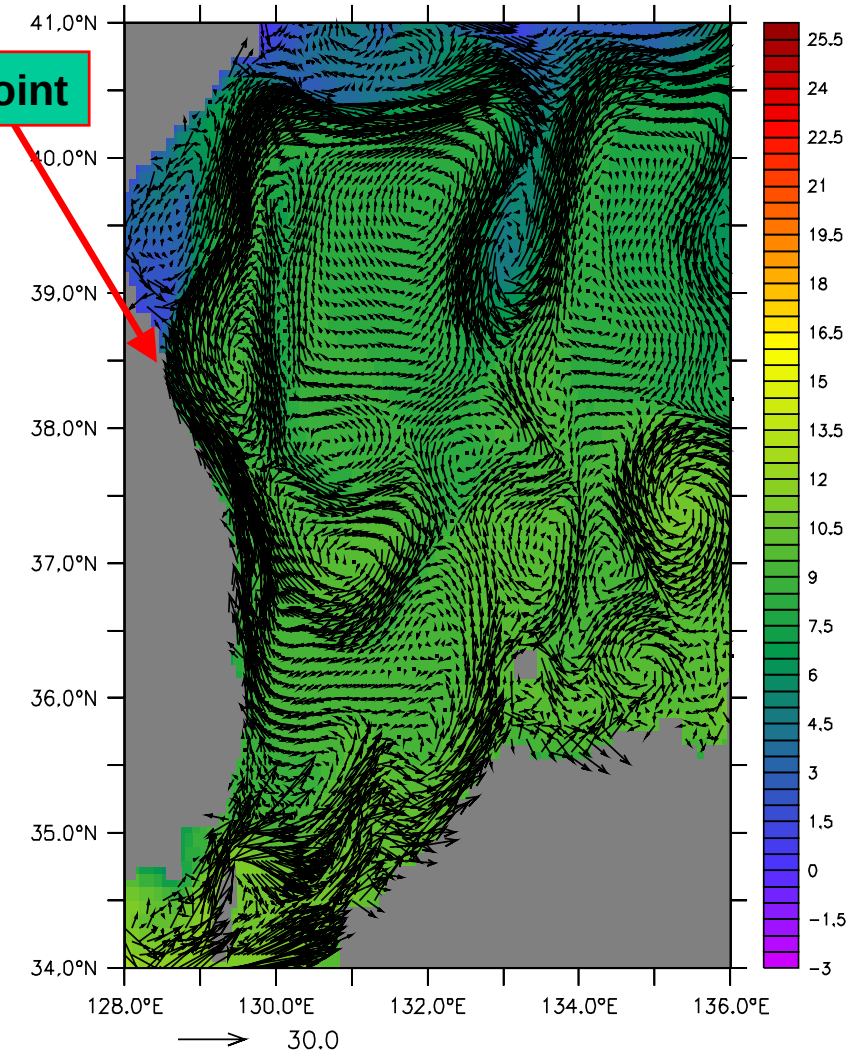


# Summary and Conclusion

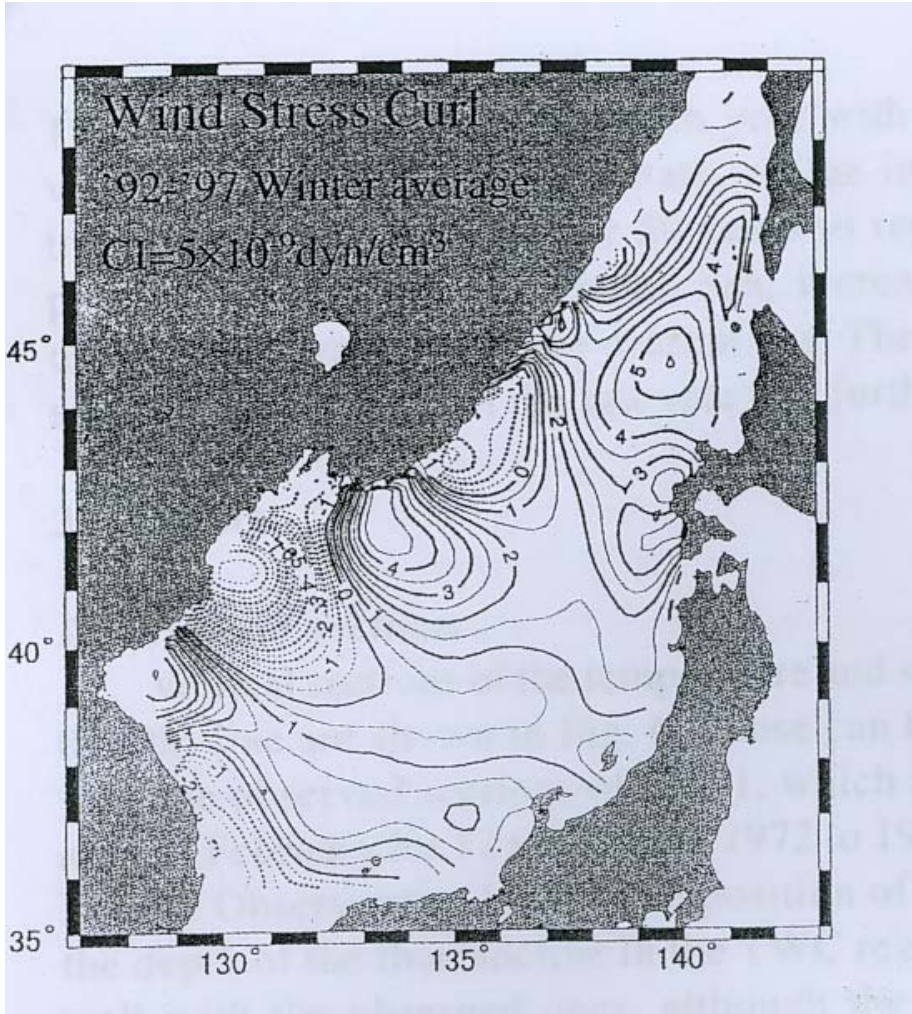
- Two models with Open Boundary Condition resolve the Nearshore Branch(First branch) and the EKWC(Second branch). But, in both of them, the EKWC overshoots.

- Fine grid model with small viscosity coefficient resolves the third branch of the Tsushima Warm Current and the separation point of the EKWC moves to southward rather than in the coarse grid model.

- For the dynamics of the third branch of the TWC, beta effect and coastline curvature are important.

- The positive wind stress curl near the Wonsan Bay enhances the separation of the EKWC.

## Wind stress curl in winter




Wind stress Curl($10^{-8}$ dyne/$cm^2$) in winter (Dec. to Feb.) averaged for 6 years from 1992 to 1997 (ECMWF), Yoon(2002)