Formation process of Antarctic Bottom Water originating from a middle size polynya

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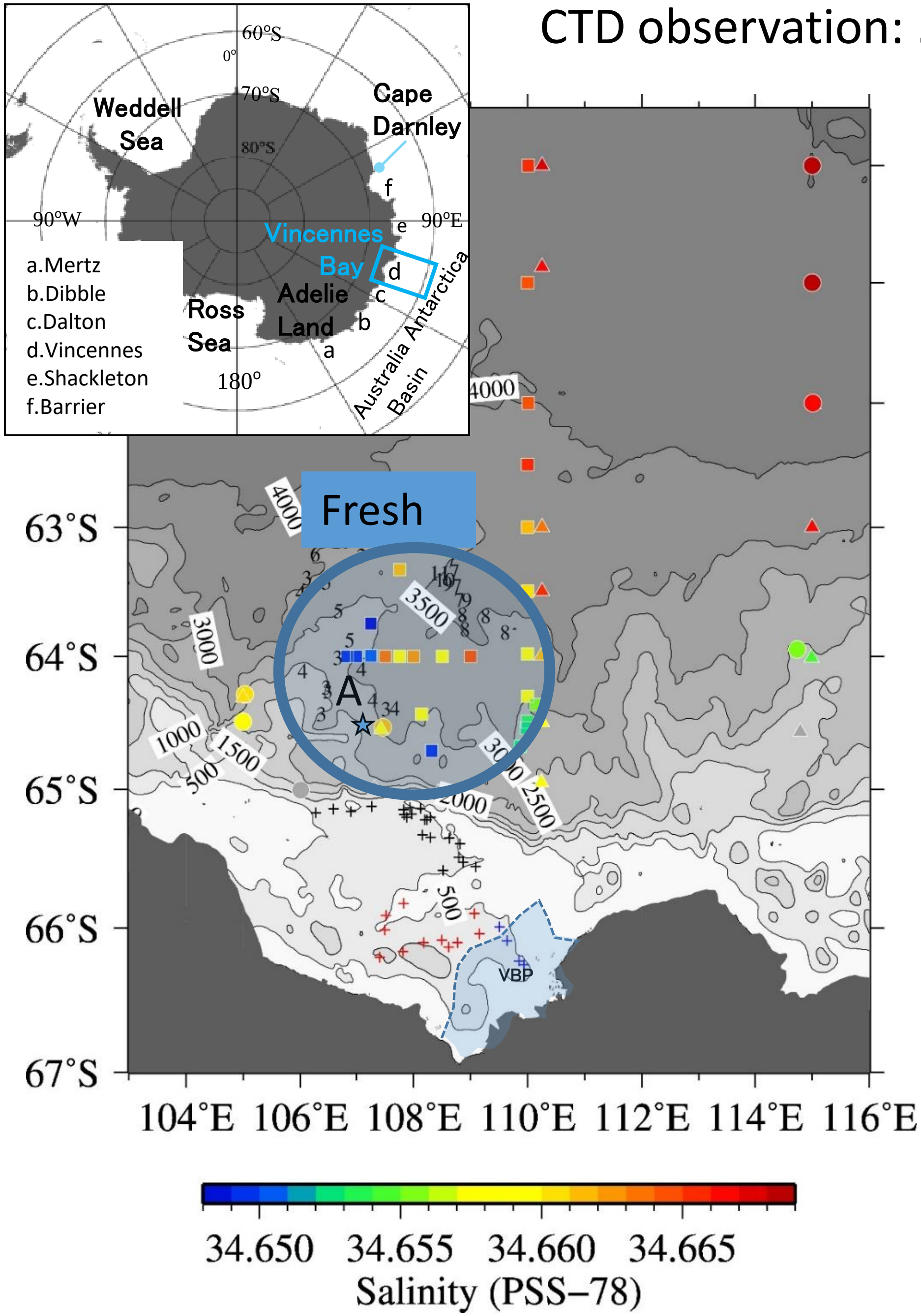
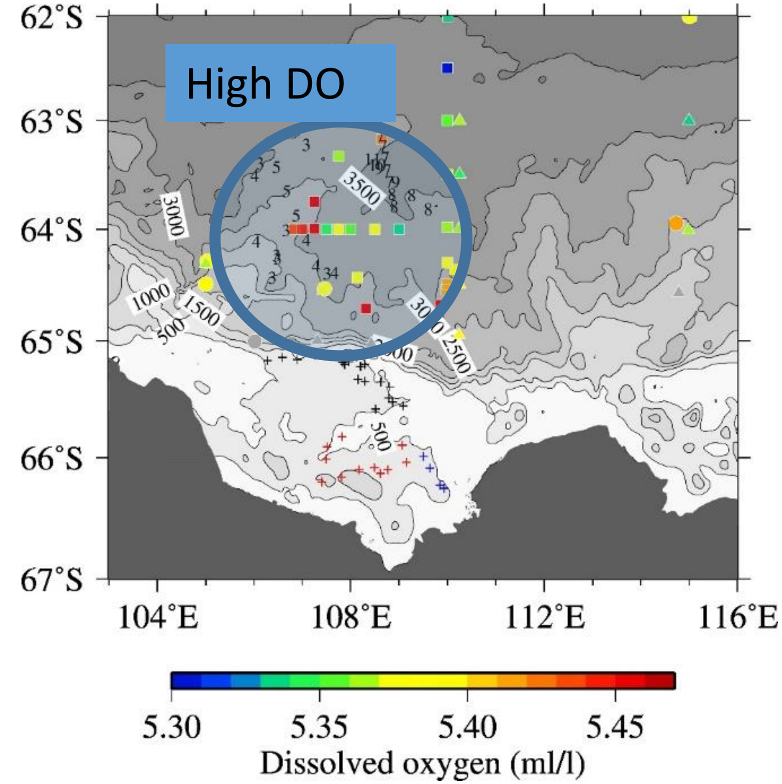
Abstract

Antarctic Bottom Water (AABW) is the densest water in the ocean and globally significant; its production at the Antarctic margin is a key component of the global overturning circulation. AABW originating from a middle size polynya called Vincennes Bay Polynya (VBP) was discovered recently [Kitade et al., 2014]. Although we found some evidences for AABW formation from the VBP, there are many unknown processes on its formation. Furthermore, recent Deep-float data showed no clear evidence of newly formed AABW off Shackleton Polynya where sea-ice production was more active than that of VBP[Kitade et al. 2016]. Thus, we carried out numerical experiments to explain detail process of the AABW formation off middle size polynya. From data analysis and model results, we finally conclude that not only sea-ice production but also oceanic condition off coastal polynya region is important on the process of AABW formation.

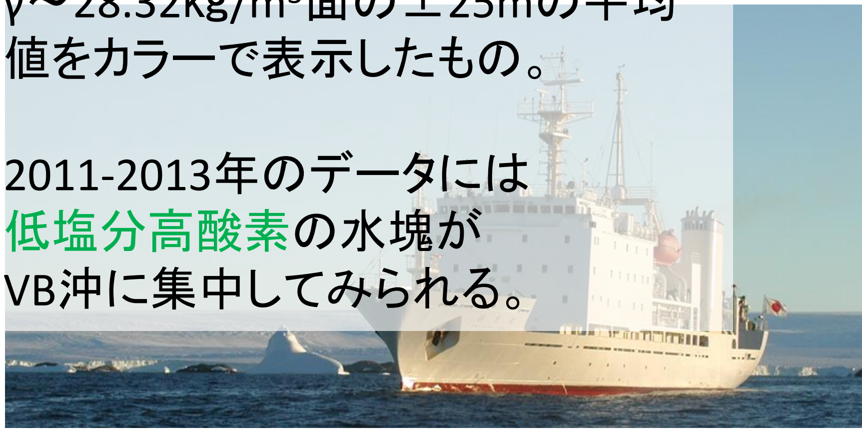
CTD observation: 2011－2013



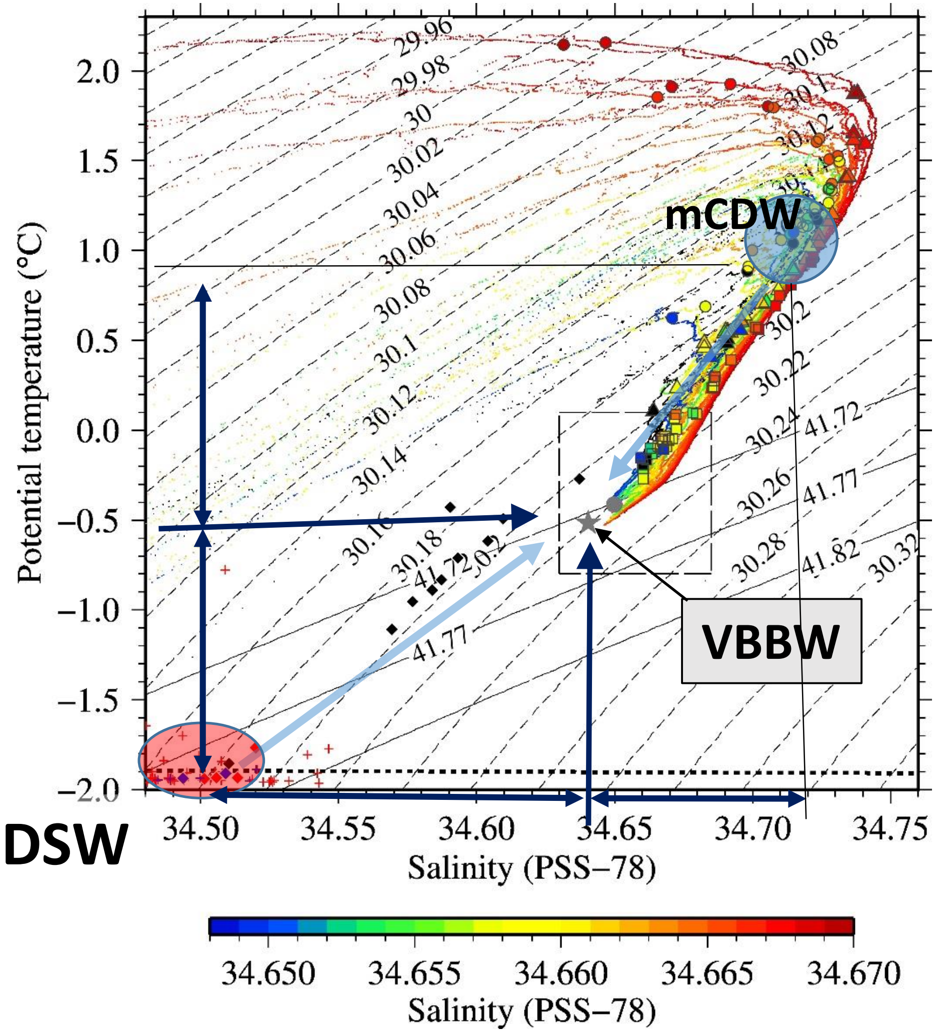


CTD観測より、VBBWの水塊として
γ～28.32kg/m³面の±25mの平均
値をカラーで表示したもの。

2011-2013年のデータには
低塩分高酸素の水塊が
VB沖に集中してみられる。



Water property of VBBW and mixing ratio



--- Potential density at 500 dbar

— Potential density at 3000 dbar (σ_3)

TS relation show that DSW is relatively heavy than the deep water.

However, Mixing ratio of water masses are different by temperature and salinity.

Mixing ratio for temperature

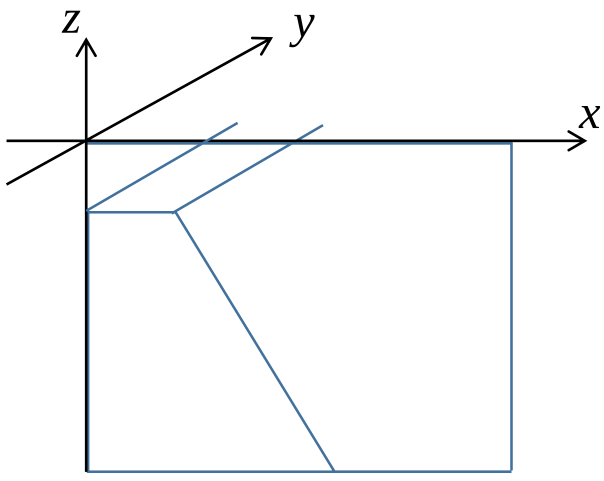
DSW : mCDW = 1 : 1

Mixing ration for salinity

DSW : mCDW = 1 : 1.4

What cause such difference?

Two dimensional model
Basic Equtions



$$\frac{\partial \zeta}{\partial t} - J(\psi, \zeta) + f\frac{\partial v}{\partial z} = -\frac{g}{\rho_0}\frac{\partial \rho}{\partial x} + \nu_h \frac{\partial^2 \zeta}{\partial x^2} + \nu_z \frac{\partial^2 \zeta}{\partial z^2}$$

$$\frac{\partial v}{\partial t} - J(\psi, \zeta) + f\frac{\partial \psi}{\partial z} = \nu_h \frac{\partial^2 v}{\partial x^2} + \nu_z \frac{\partial^2 v}{\partial z^2}$$

$$\frac{\partial \theta}{\partial t} - J(\psi, \theta) = K_h \frac{\partial^2 \theta}{\partial x^2} + K_\theta \frac{\partial^2 \theta}{\partial z^2}$$

$$\frac{\partial S}{\partial t} - J(\psi, S) = K_h \frac{\partial^2 S}{\partial x^2} + K_S \frac{\partial^2 S}{\partial z^2}$$

$$J(A, B) = \frac{\partial A}{\partial x}\frac{\partial B}{\partial z} - \frac{\partial A}{\partial z}\frac{\partial B}{\partial x}$$

$$u = \frac{\partial \psi}{\partial z}, \quad w = -\frac{\partial \psi}{\partial x}$$

$$\zeta = \frac{\partial w}{\partial x} - \frac{\partial u}{\partial z} = -\left(\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial z^2}\right)$$

- ζ : Vortesity
- f: Coriolis parameter
- v: Y component of current
- θ: P temperature、 S:salinity
- ψ: stream function

Viscosity

ν_h＝10(m²/s)

ν_z=5×10⁻³(m²/s)

Evaluation of double diffusion effects

<u>Horizontal diffusivity coefficient</u>

All case

$K_h = 1.0 (m^2/s)$

<u>Vertical diffusivity coefficient</u>

★in the case include double diffusion effect

★Not include double diffusion effect

$K_S = K_\theta = 0.25 \times 10^{-4} (m^2/s)$

＊Density ratio: $R\rho = \alpha\theta / \beta S$

Where α is thermal expansion , β is harine contoraction

＊diffusive coefficient in back grand

$Kb = 0.1 \times 10^{-4} (m^2/s)$

$A = 10 \times 10^{-4} (m^2/s)$

I）Finger type: Schmitt(1981)

$1 < R\rho < 100$

$Ks = A / (1 + R\rho / Rc)^{32}$

$K_\theta = 0.7\, Ks / R\rho$

II)Diffusive type： Kelly(1990)

$0 < R\rho < 1$

$K_\theta = 0.909 * 0.015 \exp(4.6 \exp(0.54 (1/R\rho - 1)))$

$Ks = K_\theta (1.85 - 0.85 / R\rho) R\rho$

$Ks = K_\theta (0.15 R\rho)$

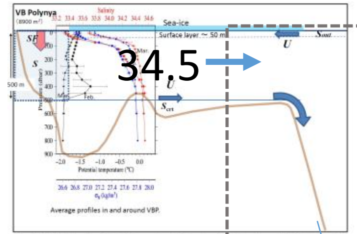
Model

- Two dimension, non-hydrostatic level model (domain: 400 × 300)
- Grid size: 200m in horizontal, 10m in vertical
- Bottom topography : slope 1／10、1／20、1／40

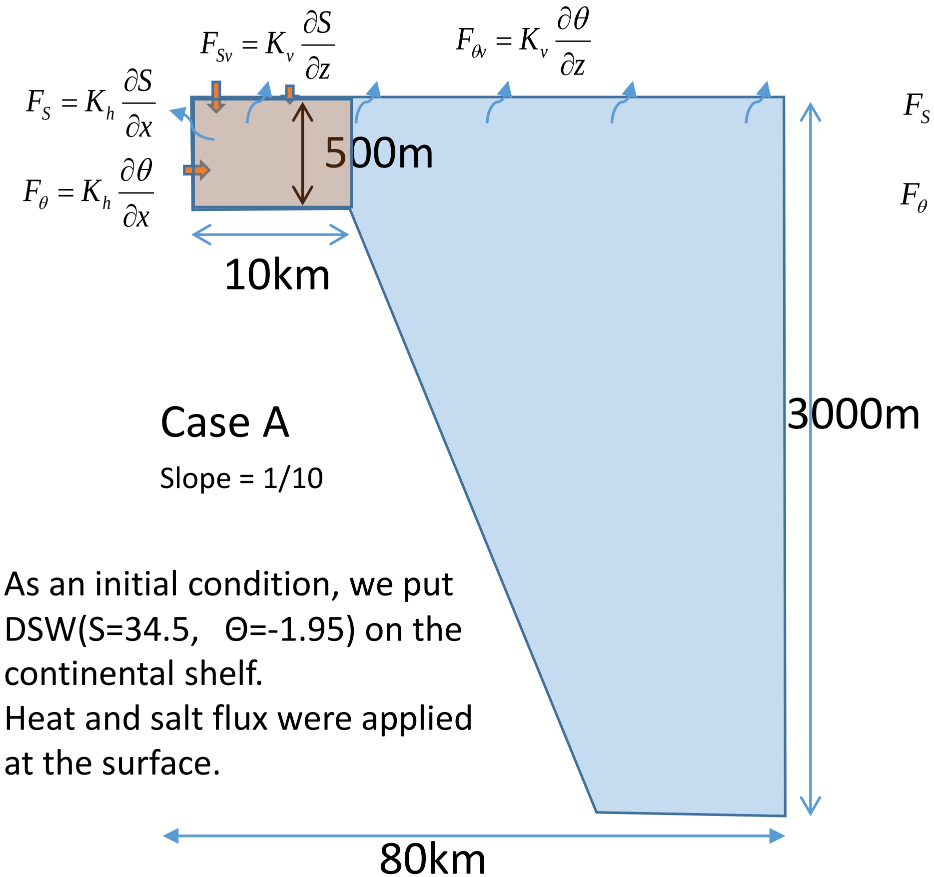
Heat flux => —1.95℃

Salinity flux 6 km=> 34.5

6-10 km=> 34.5 → from observational result



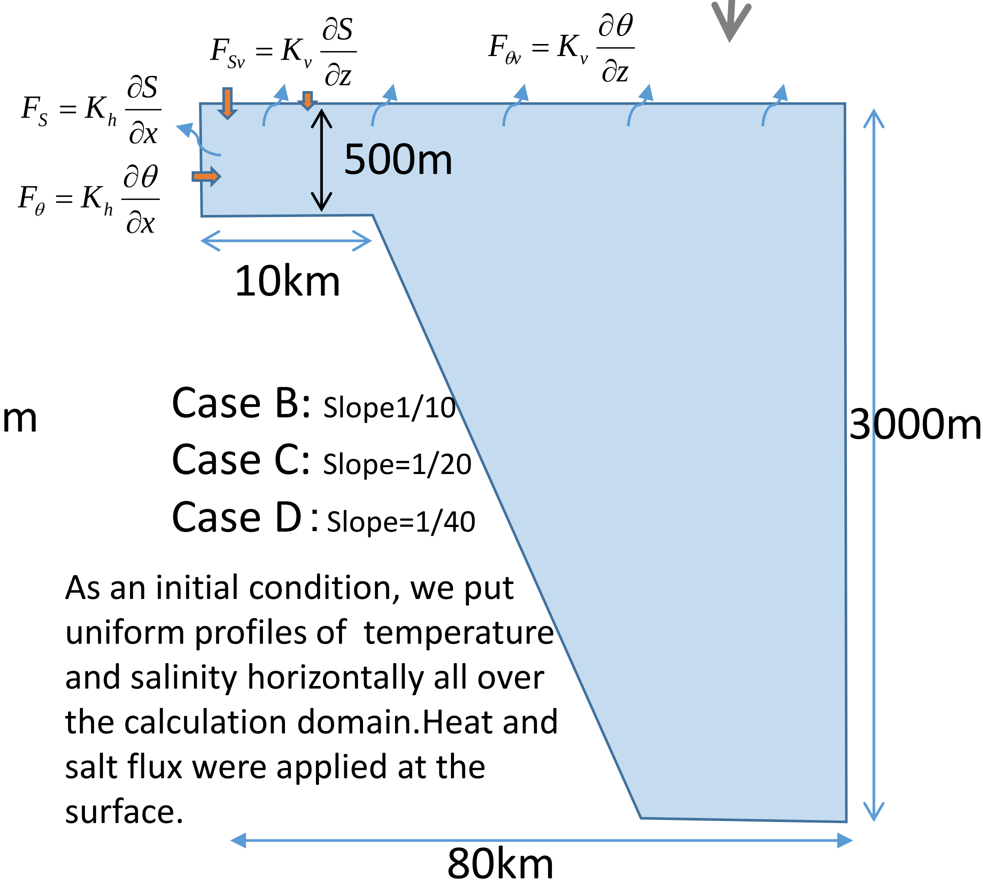
We moded this area to see sinking process of DSW and modification of water property



Case A

Slope = 1/10

As an initial condition, we put DSW(S=34.5, Θ=-1.95) on the continental shelf.
Heat and salt flux were applied at the surface.



Case B: Slope1/10

Case C: Slope=1/20

Case D : Slope=1/40

As an initial condition, we put uniform profiles of temperature and salinity horizontally all over the calculation domain.Heat and salt flux were applied at the surface.

Cases of experiments

As an initial condition, we put DSW(S=34.5, Θ=-1.95) on the continental shelf.
Heat and salt flux were applied at the surface.

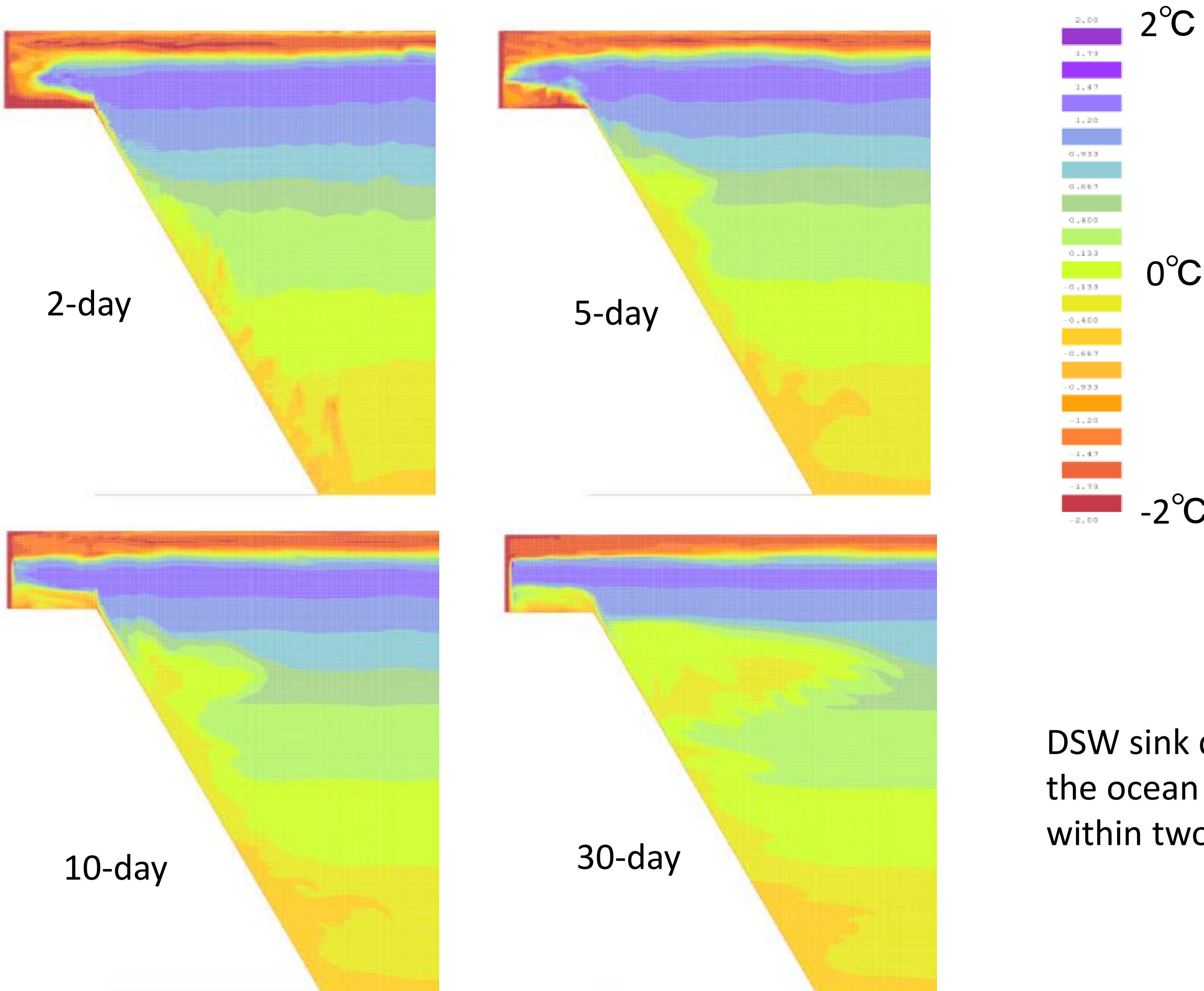
Case	Coriolis	Compressibility	Double diffusion	topography
A1	○	○	○	1/10
A2	×	○	○	1/10
A3	○	×	○	1/10
A4	○	○	×	1/10
A5	×	×	○	1/10

As an initial condition, we put uniform profiles of temperature and salinity horizontally all over the calculation domain.Heat and salt flux were applied at the surface.

Case	Coriolis	Compressibility	Double diffusion	topography
B1	○	○	○	1/10
B2	×	○	○	1/10
B3	○	○	×	1/10
B4	×	○	×	1/10
C1	○	○	○	1/20
C2	×	○	○	1/20
D1	○	○	○	1/40
D2	×	○	○	1/40

Results

Temperature distribution Case A2

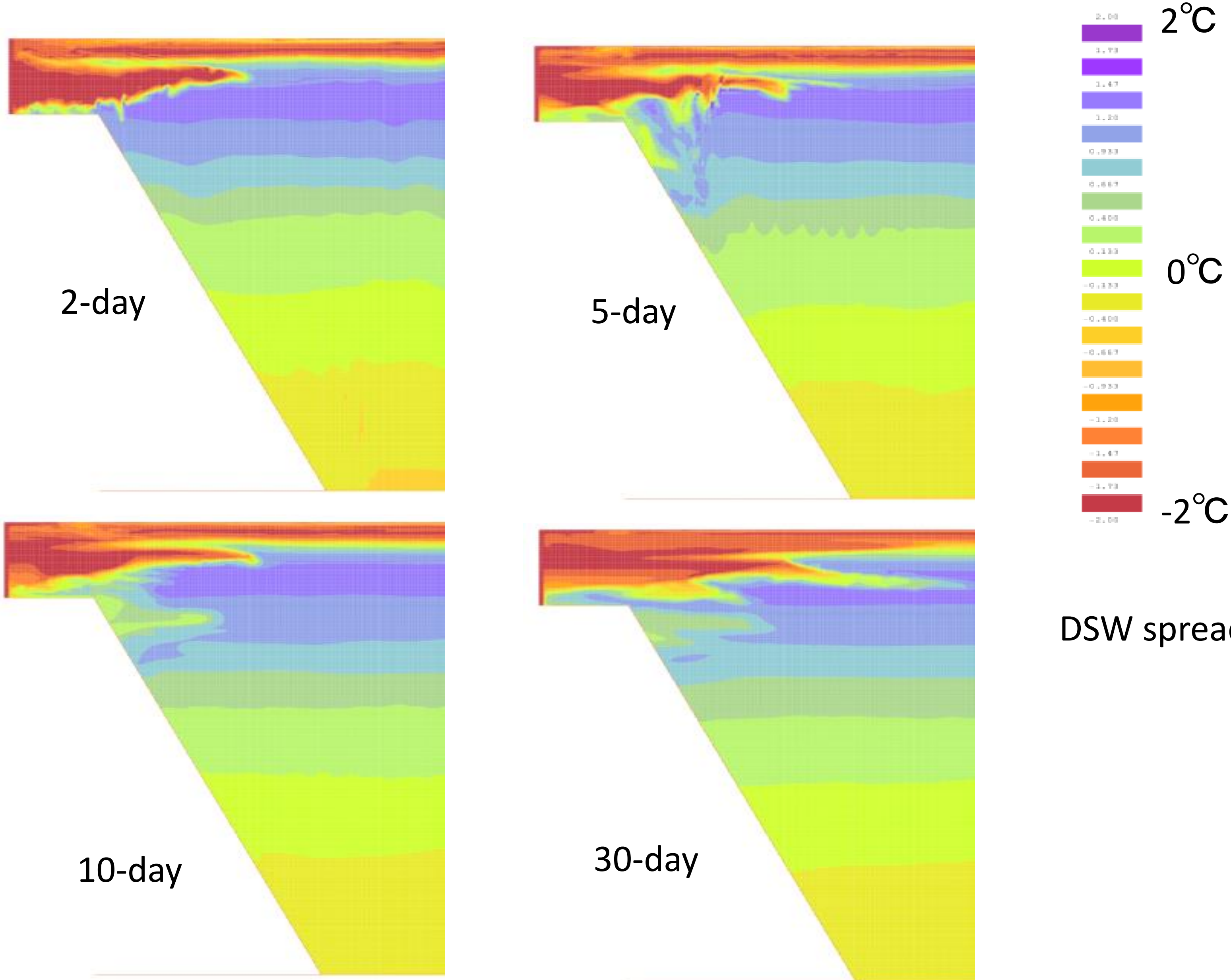


DSW sink down up to the ocean bottom within two days.

Result

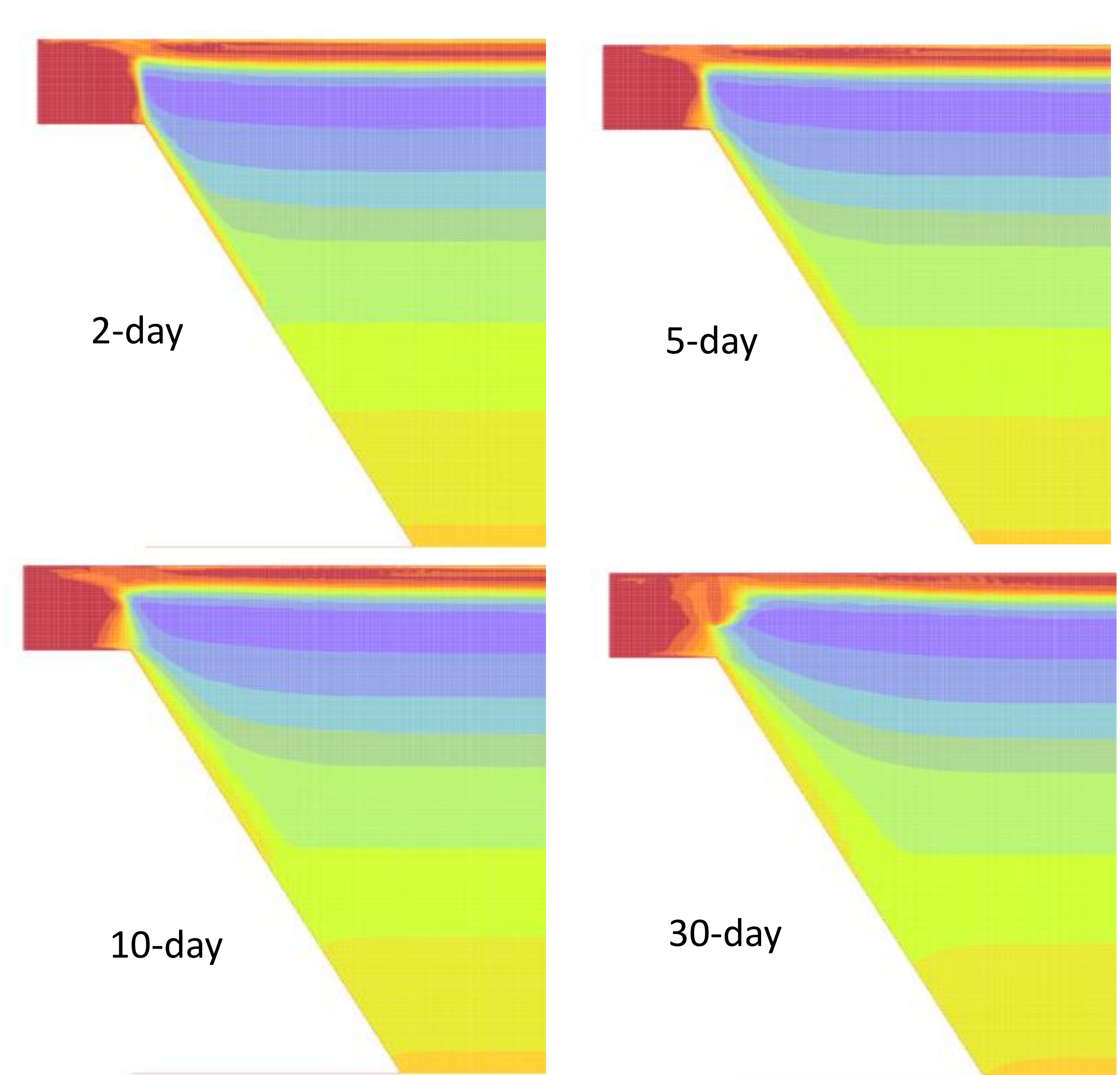
Temperature distribution Case A5

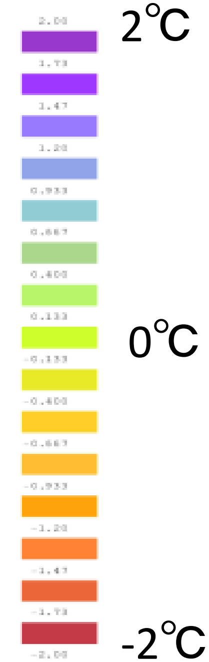
Non-compressibility



DSW spread horizontally.

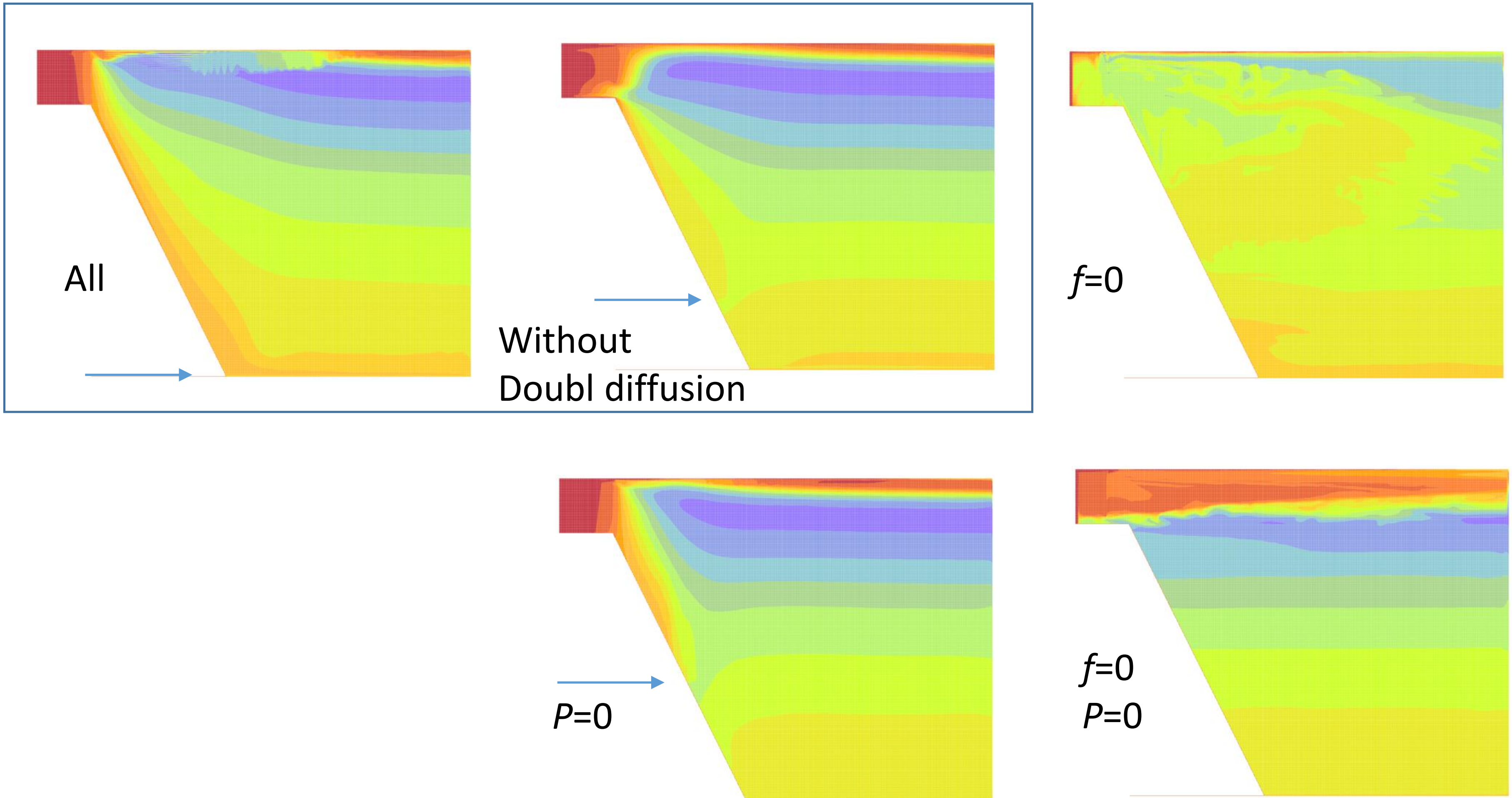
Temperature distribution Case A1 ($f \neq 0$で with double diffusion effect)





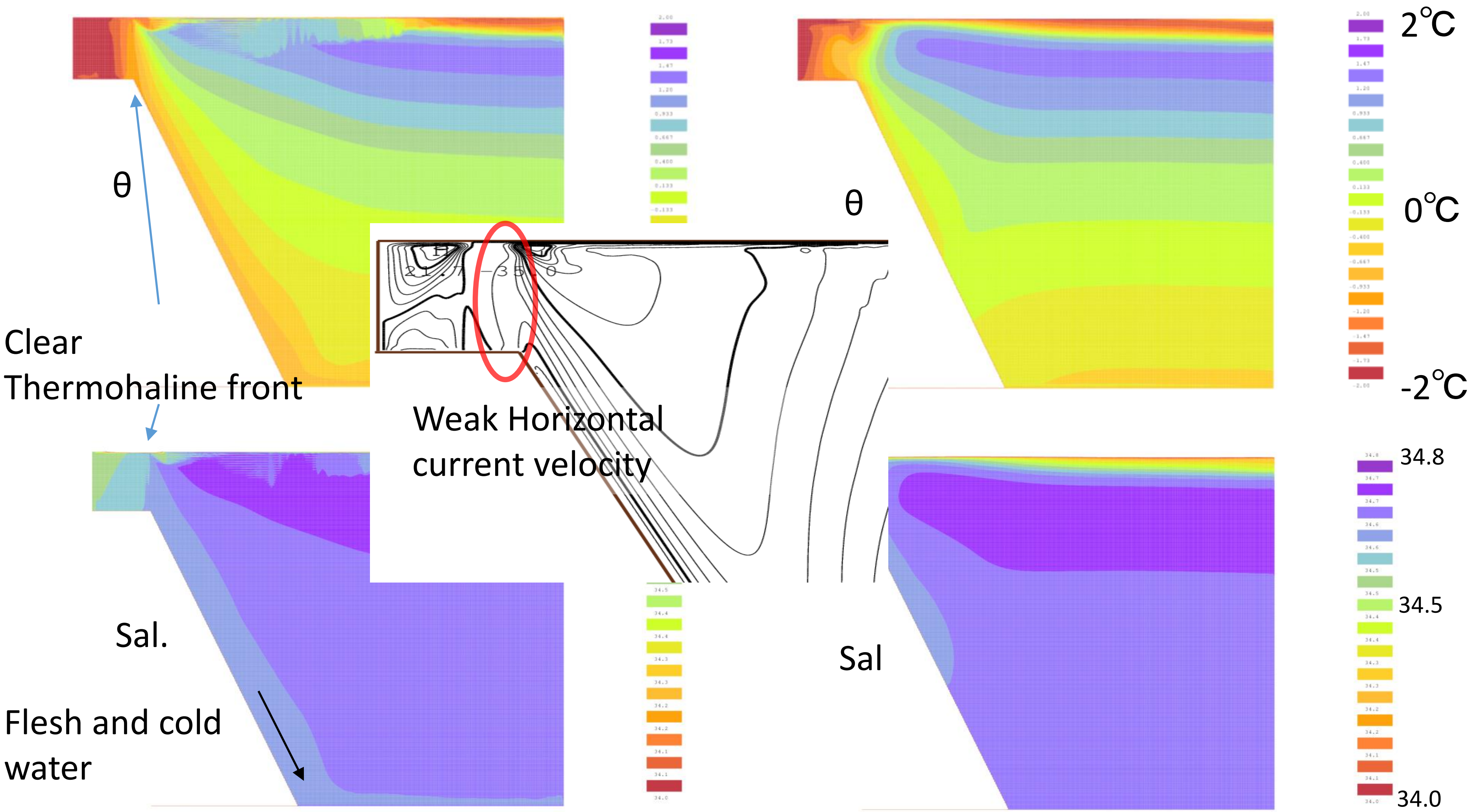
DSW does not sink down up to the ocean bottom.

150-day



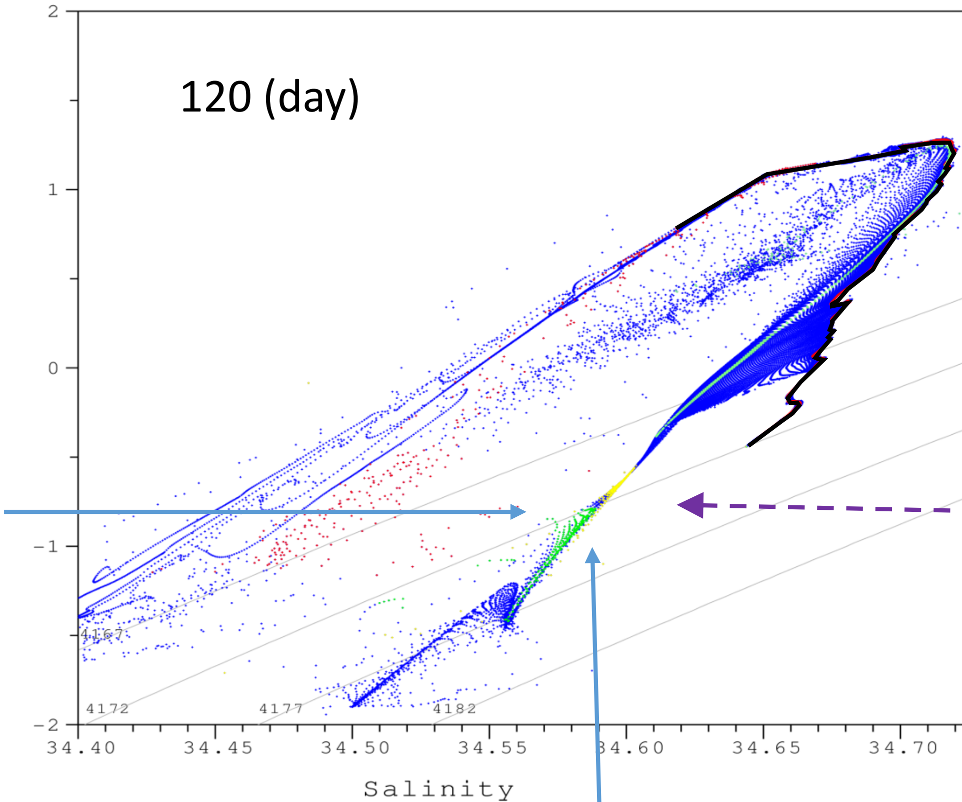
180-day with Double diffusion

without double diffusion

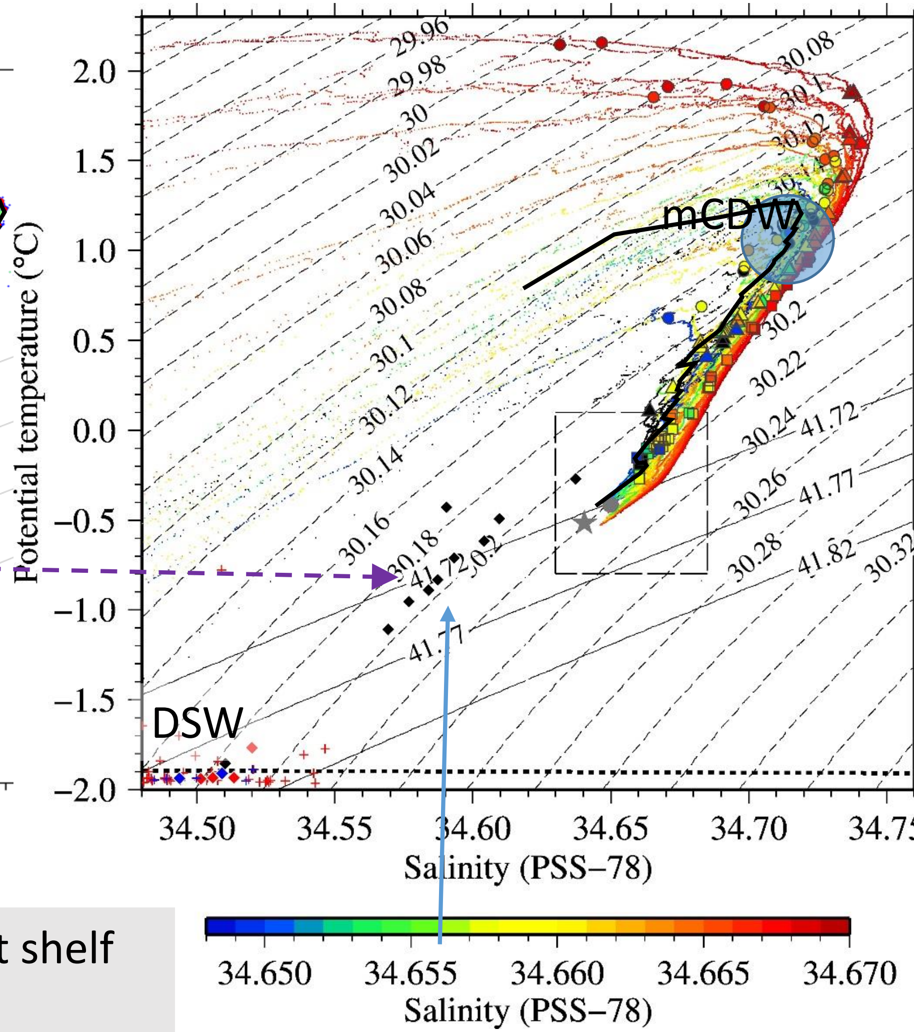


θS relations

Model



Observation



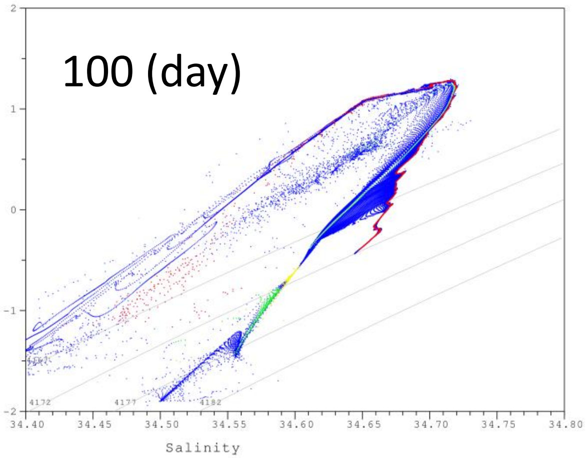
mSW was formed at shelf edge

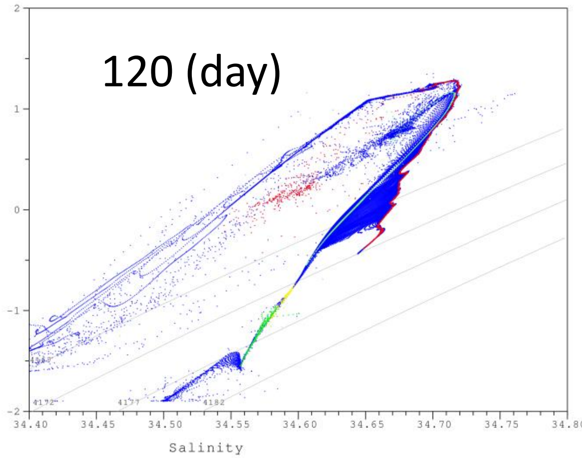
Green: continental shelf

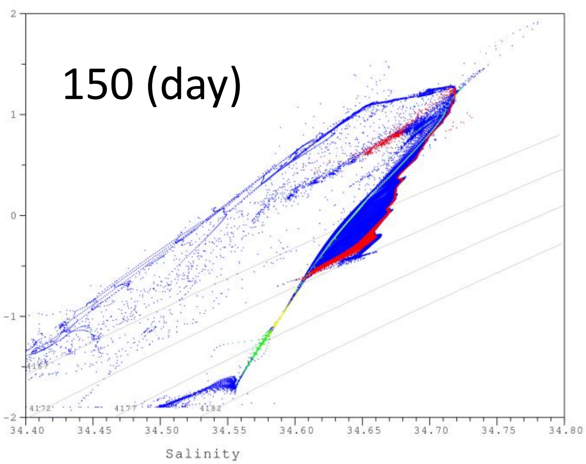
Yellow: middle depth of continental slope

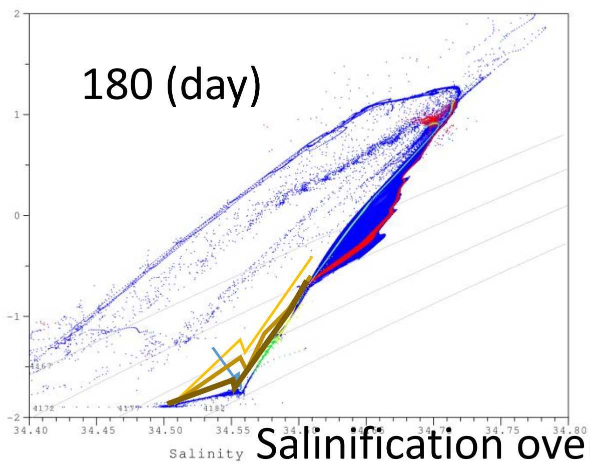
Red: bottom of continental slope

CaseB θS relations









Salinification over the continental shelf

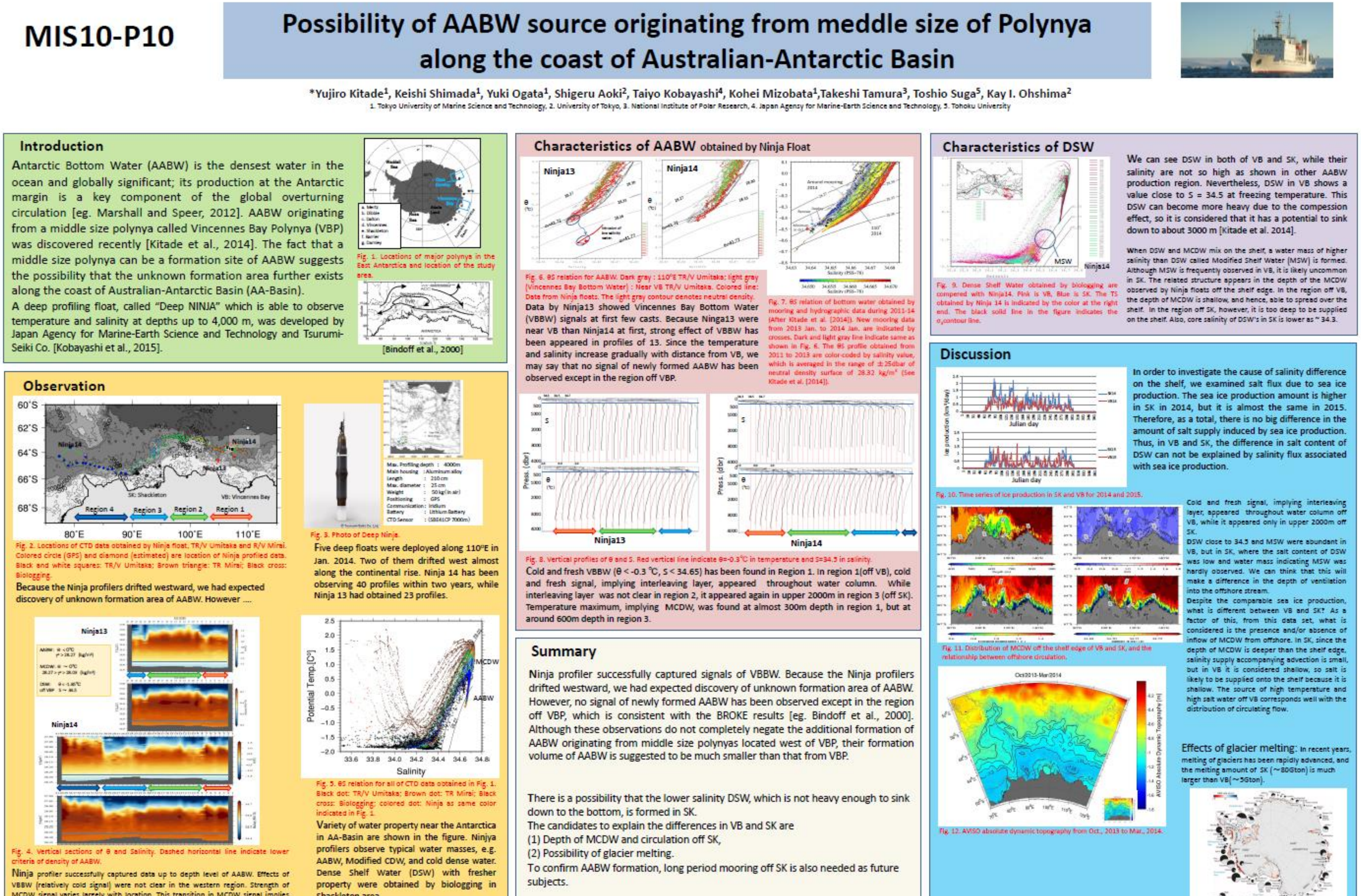
Summary of numerical experiment

We have well reproduced θS-relation observed off VB.

Important process on the formation of VBBW are all of “Compressibility”, “Coriolis effect” and “Double diffusion”.

- **Compressibility: Quite important on the formation of dense water off the middle size polynya.**
- **Coriolis effect: formation of density front at the shelf edge. Conservation of potential vorticity induce deepening of cold water its self at the shelf edge.**
- **Double diffusion: important to form cold and saline water**

Kitade et al. 2017 JPGU



This poster show that no clear evidence of newly formed AABW off Shackleton Polynya where sea-ice production was more active than that of VBP.

Conclusion

- **From these results, we may conclude that not only salinity flux by sea-ice production but also surrounding water conditions are important to form AABW.**
- **These studies should also be taken into account for more good estimation of total volume of AABW formation around Antarctica.**

⇒ **Good estimation of parameters on Global Ocean Circulation increases accuracy of long period prediction of climate change.**

Further study including detailed observation is necessary to clarify the mechanism of AABW modification in Global warming age.