Effect of water mass structure on the spring bloom in the Oyashio Region revealed by sequential observations

Tokihiro **Kono**[1] and Masatoshi Sato[2]

1 Department of Marine Biology and Sciences, School of Biological Science and Engineering, Tokai University, Minamisawa, Sapporo, Hokkaido, Japan
e-mail: tkono@tspirit.tokai-u.jp
2 Unified Graduate School of Earth and Environmental Science, Tokai University, Minamisawa, Sapporo, Hokkaido, Japan

Introduction

OECOS-WEST field program

Sequential Observation was made

to obtaine

Temporal Change of Biological Variables

to clarify

Dynamics of Lower Trophic Ecosystem

associated with Spring Bloom

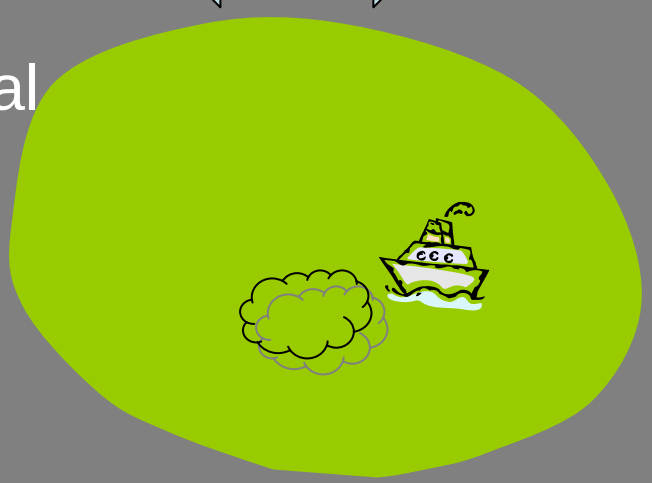
However

Sequential Observation at fixed stations

has a difficulty to clarify .

perturbation

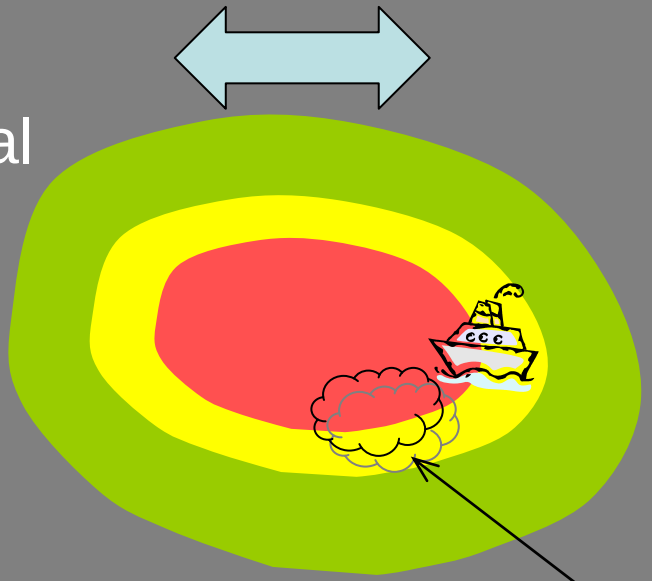
Low Horizontal Grad.



Chl.

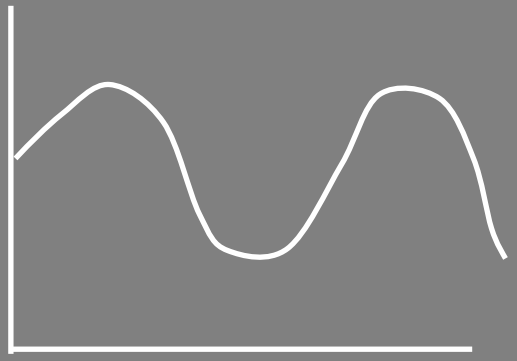
time

High Horizontal Grad.



mixing

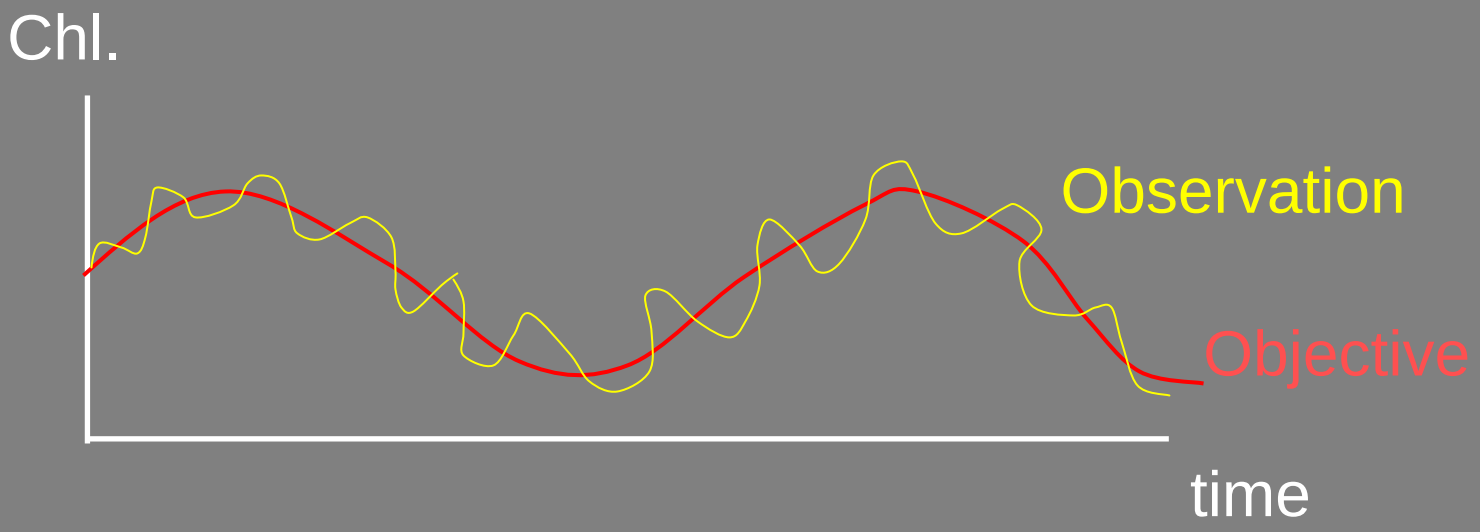
Chl.



time

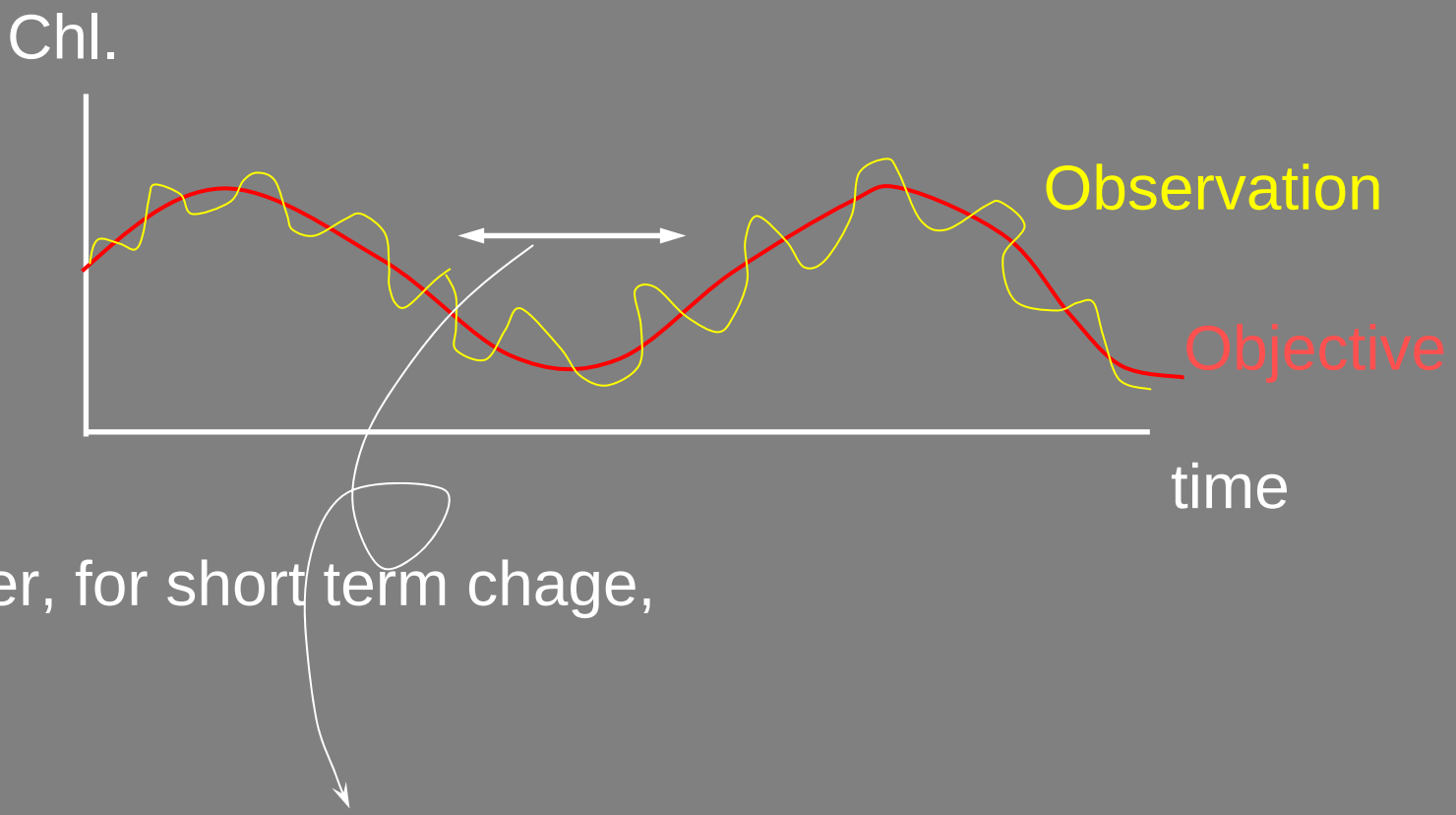
Even if the gradient is high, that’s OK

for the long term change analysis.



Even if high gradient area, that's OK.

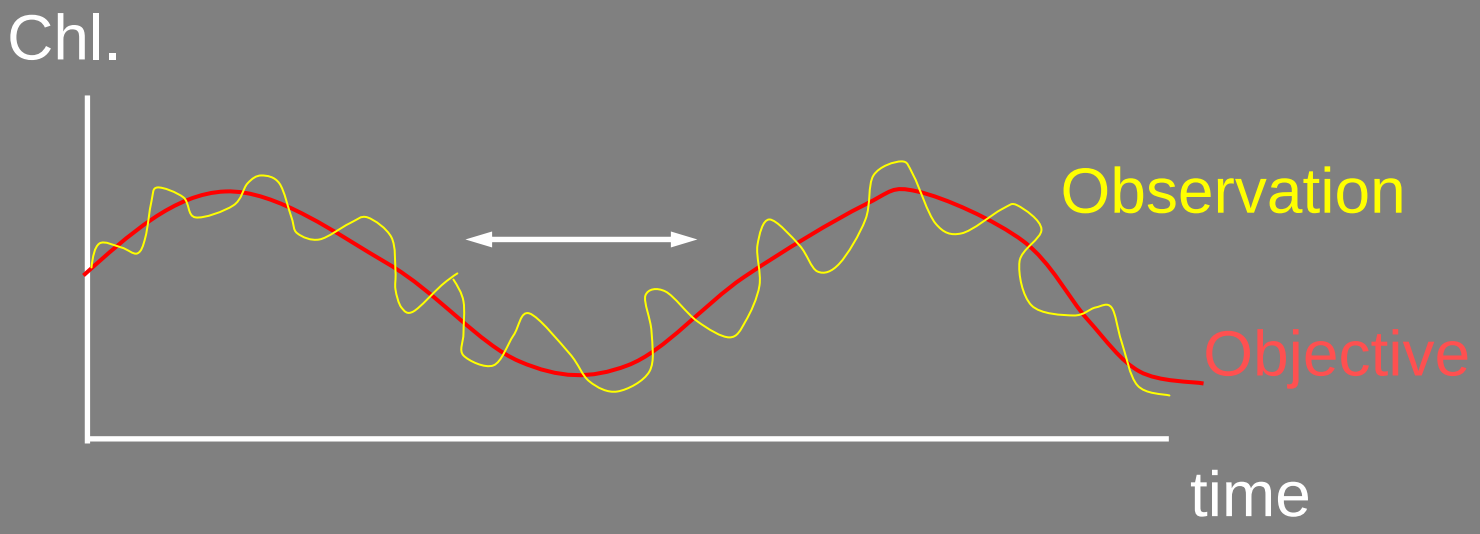
for the long term change analysis.



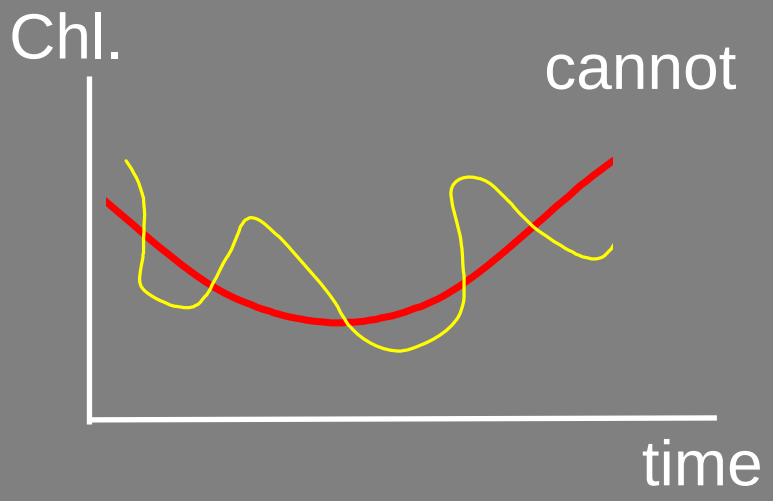
Hoever, for short term chage,

Even if high gradient area, that's OK.

for the long term change analysis.



Hoever, for short term change, the physical processes cannot be ignored.



Therefore, we have developed the methods of

Numerical Models, Laboratory Experiments,

and Satellite Observation,

which were successful to clarify the dynamics

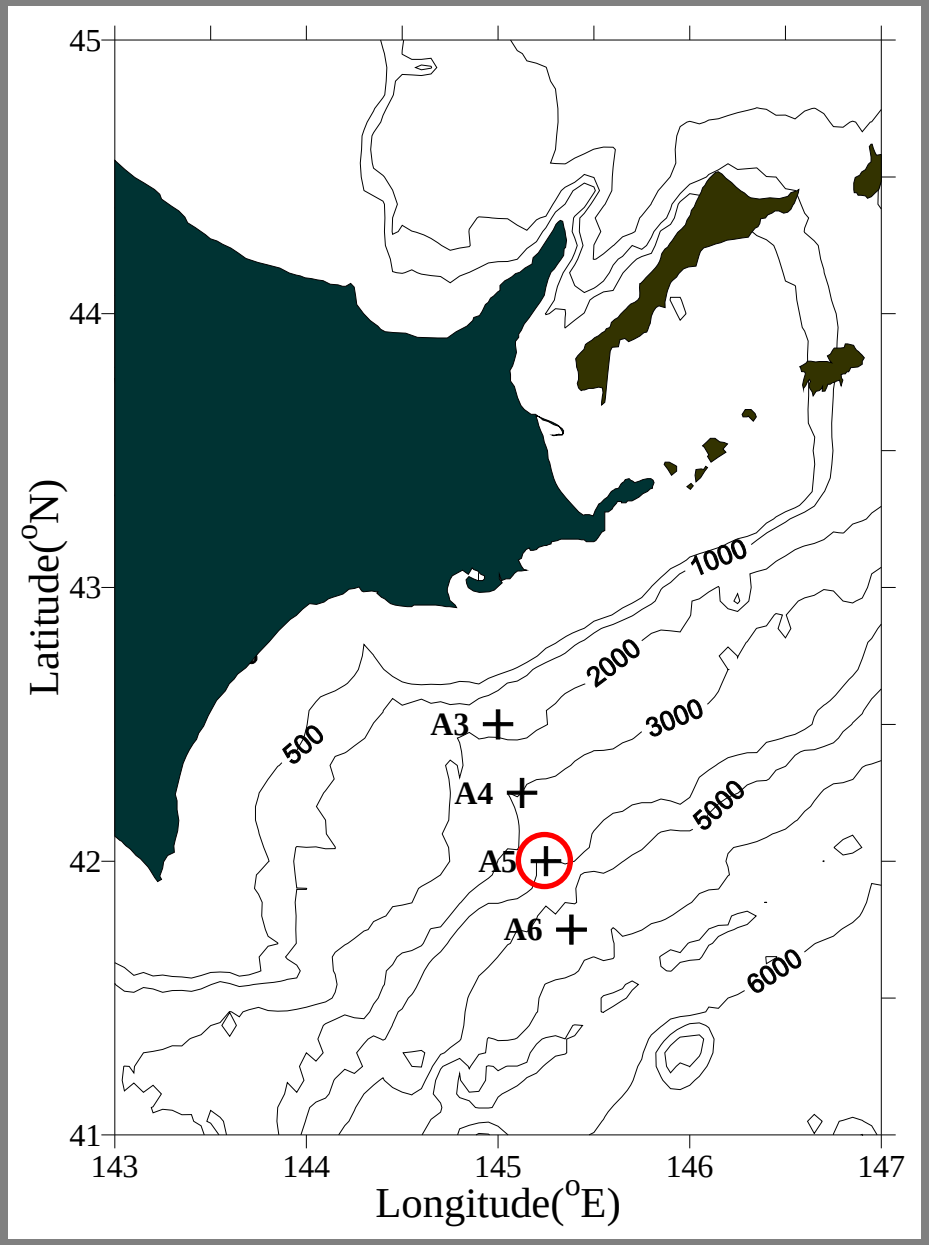
and waiting for the verifications and tuning.

Purpose of this study is

to separate the biological variables from the sequential observational data.

(to remove the physical processes.)

Observations

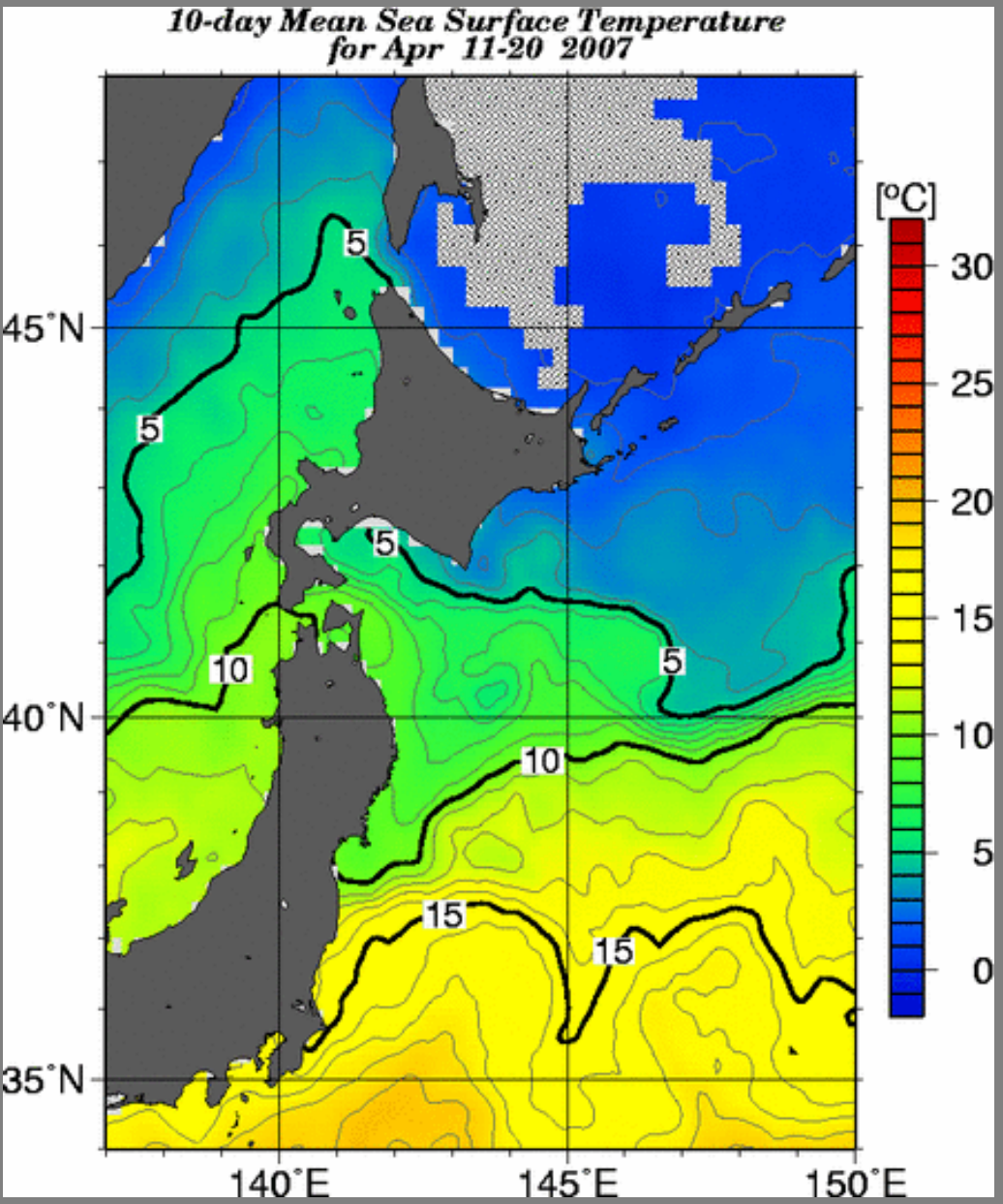


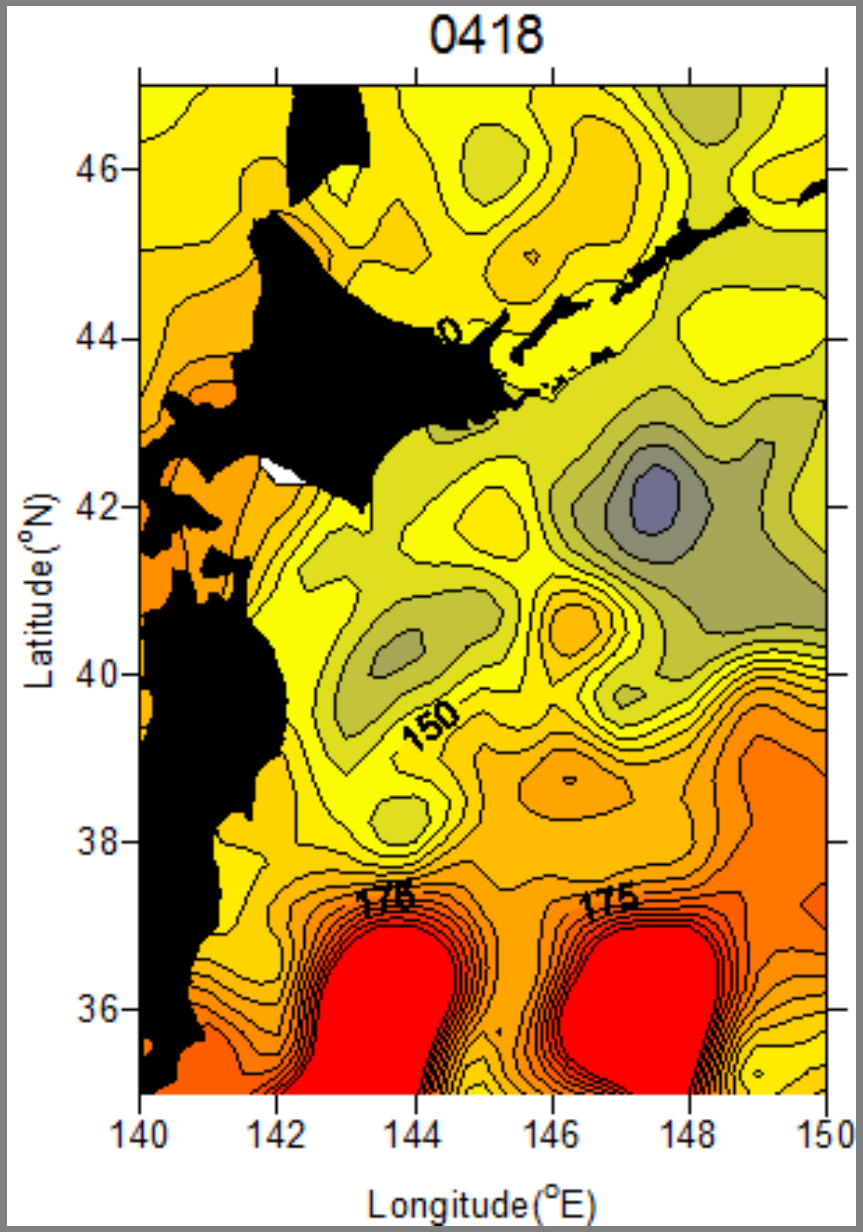
2007
March 8th - March 15th
Oshoro (Hokkaido Univ.)
Section March 8th

2007
April 5th - Mat 1st
Hakuho Maru
Section Arpil 5 , 11 , 23 , 2
A5 every day

SST

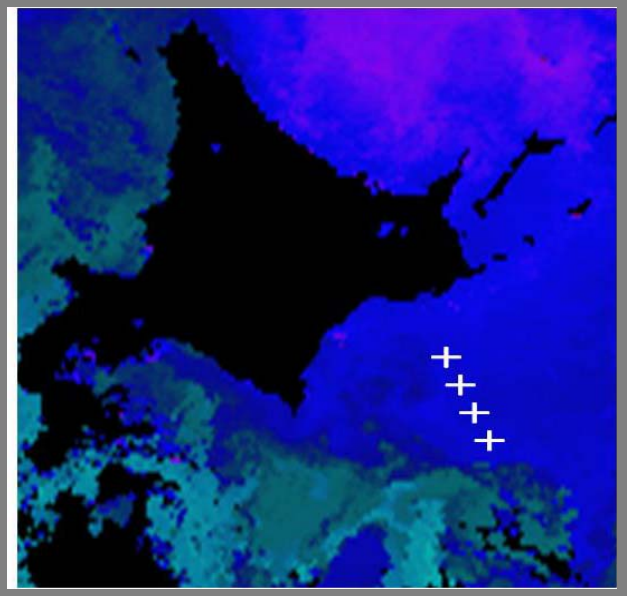
SSH


10-day Mean Sea Surface Temperature
for Apr 11-20 2007
[°C]
30
25
20
15
10
5
0
45°N
40°N
35°N
140°E
145°E
150°E
5
5
5
5
10
10
15
15

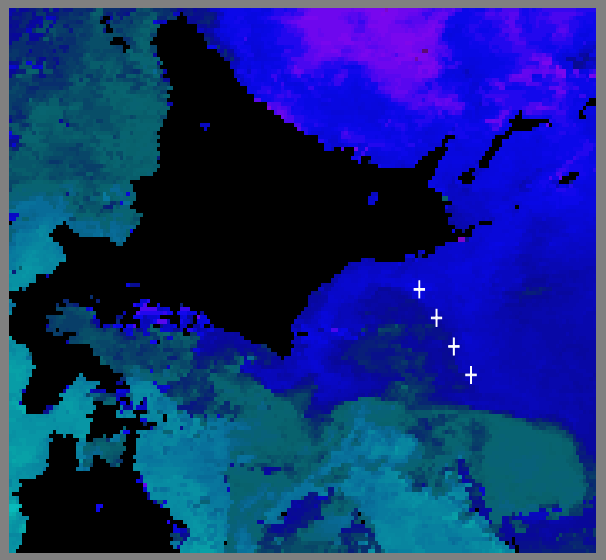

0418
46
44
42
40
38
36
Latitude(°N)
140
142
144
146
148
150
Longitude(°E)
0
150
175
175

SST

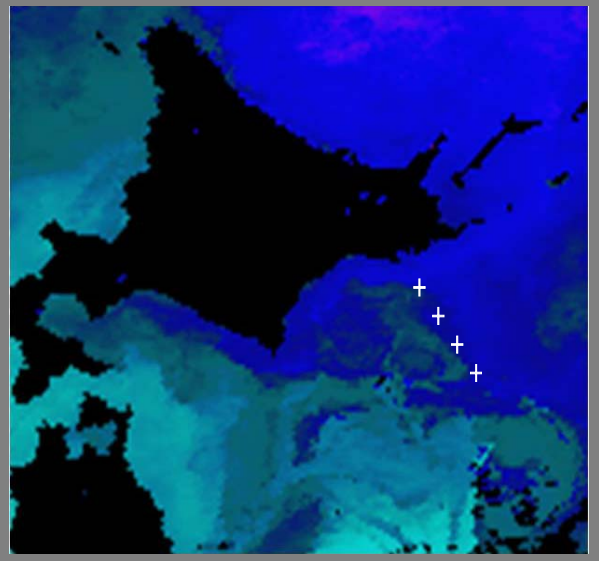
30Mar2007 to 06Apr2007



15Apr2007 to 22Apr2007



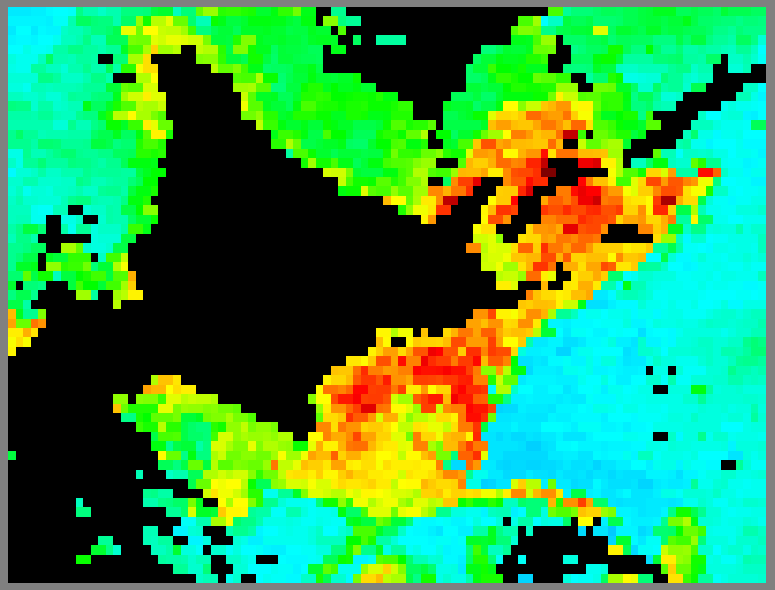
15Apr2007 to 22Apr2007



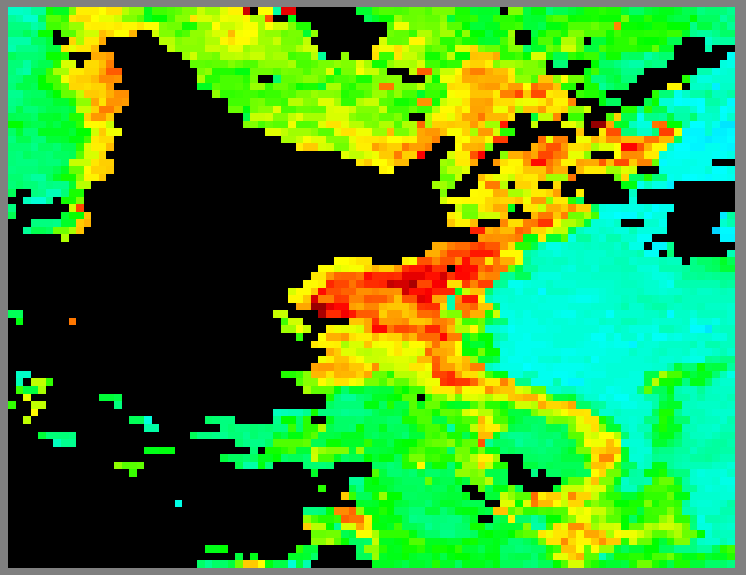
23Apr2007 to 30Apr2007

Chl.

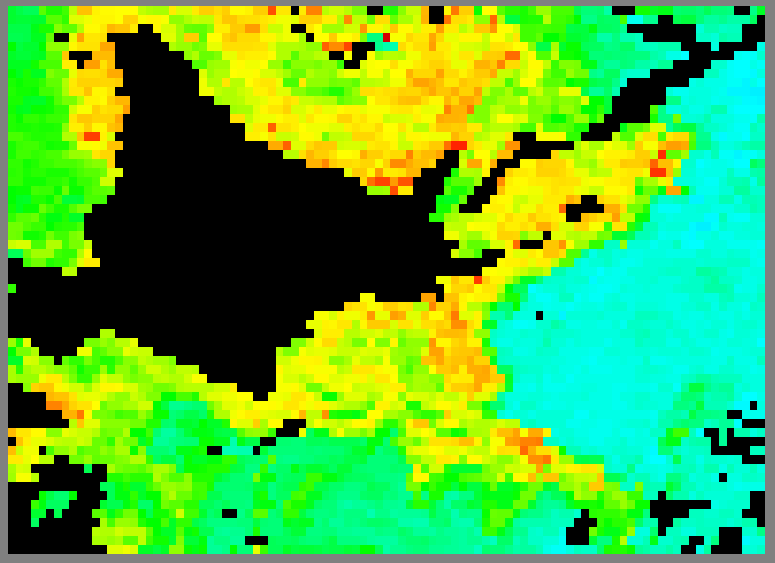
30Mar2007 to 06Apr2007



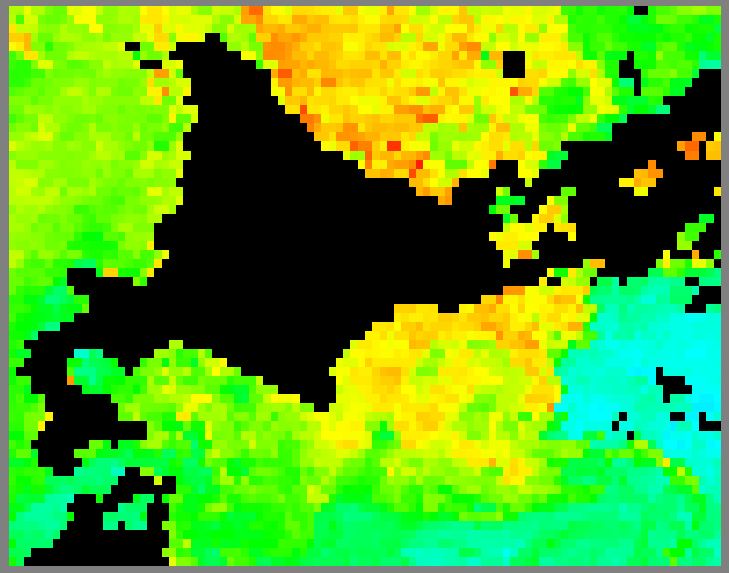
07Apr2007 to 14Apr2007



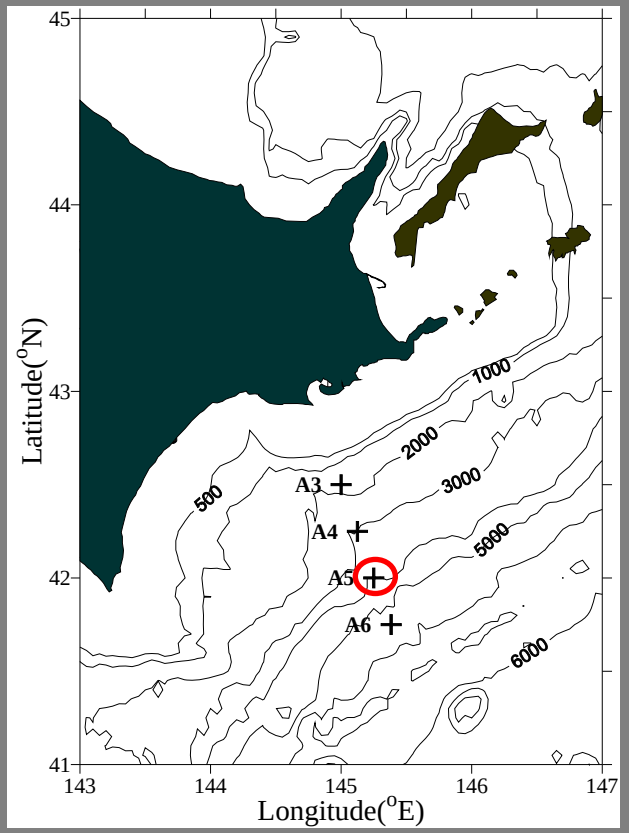
15Apr2007 to 22Apr2007

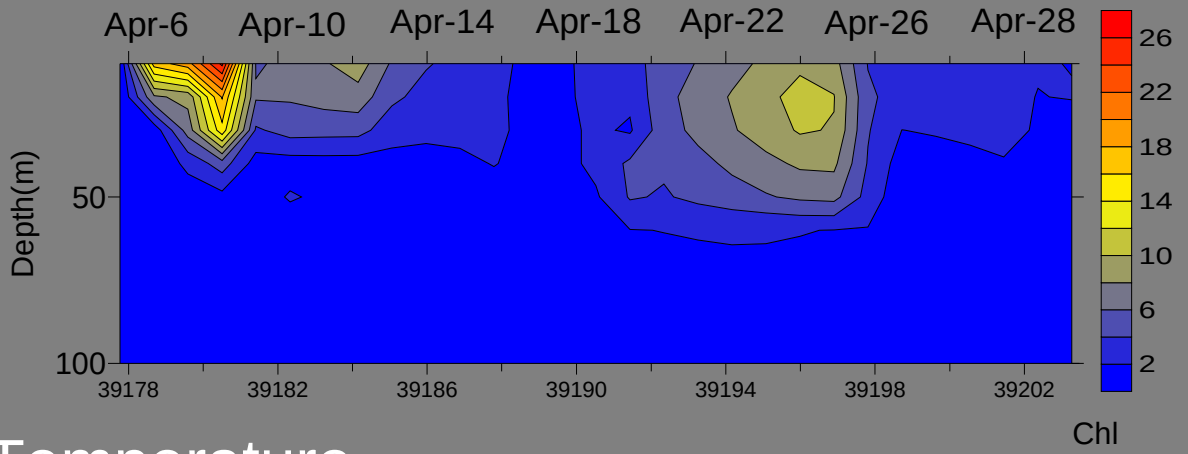


23Apr2007 to 30Apr2007

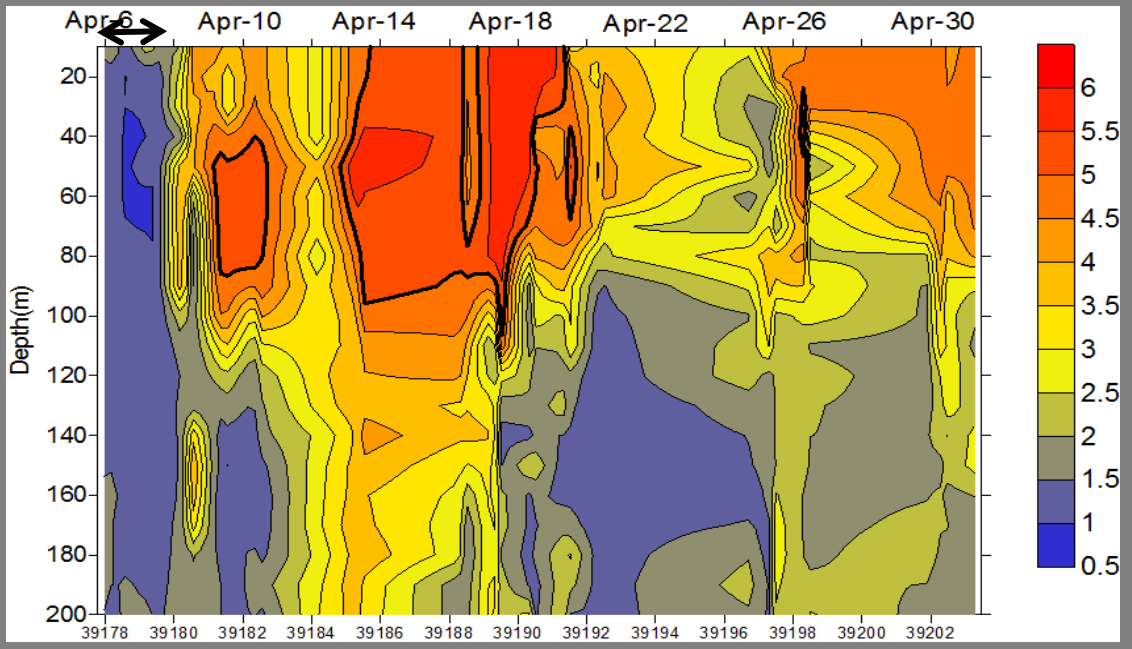


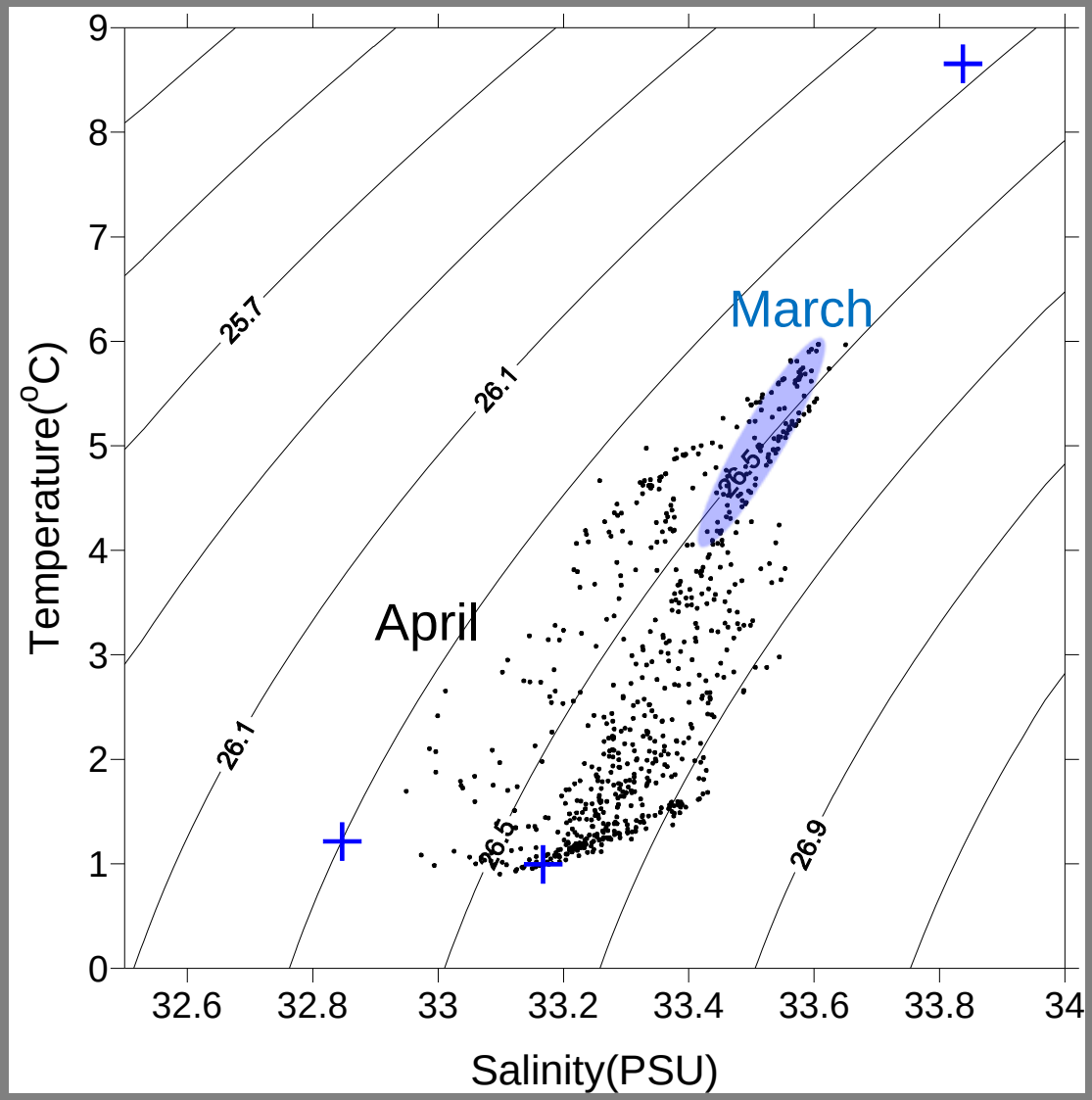
Chlorophyll

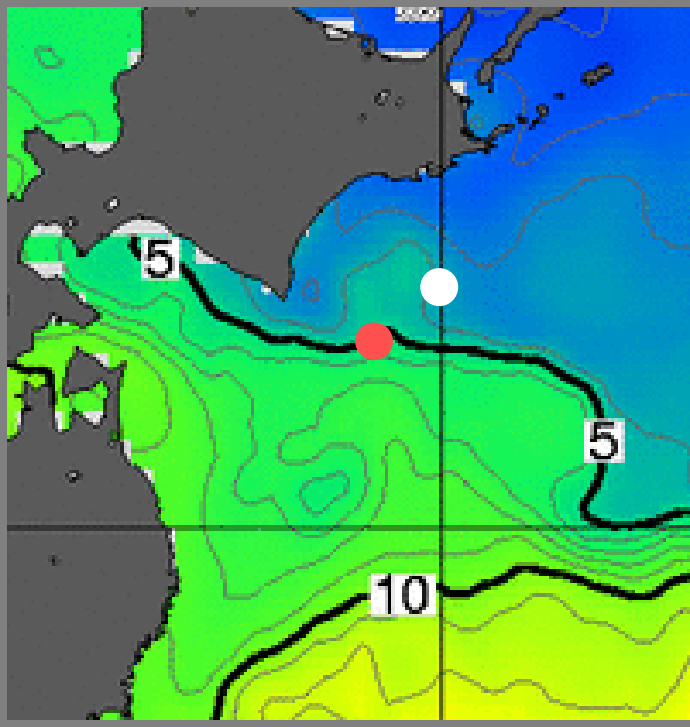


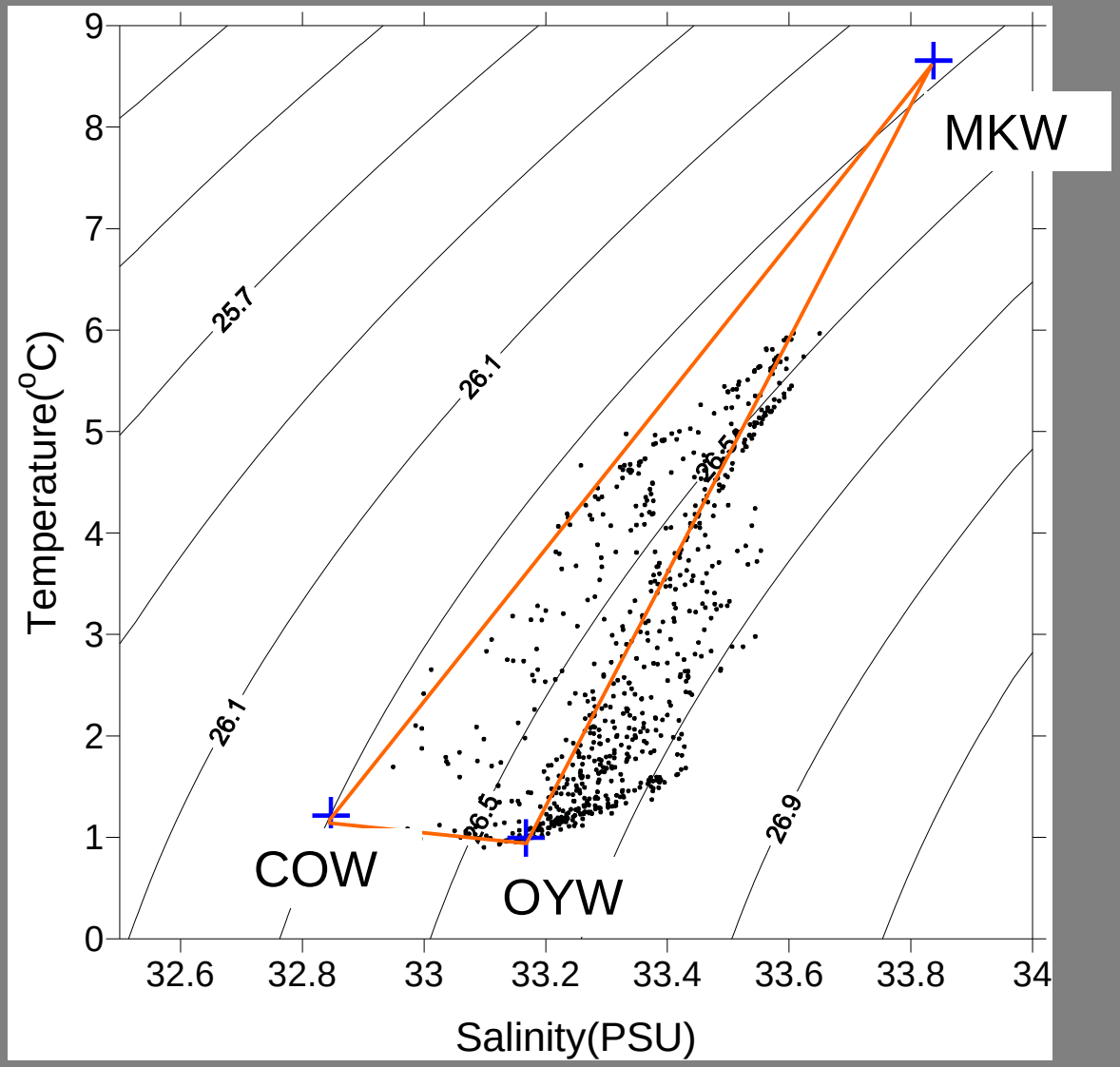


Temperature




Temperature(°C)
Salinity(PSU)
March
April
25.7
26.1
26.5
26.9
0
1
2
3
4
5
6
7
8
9
32.6
32.8
33
33.2
33.4
33.6
33.8
34


5
5
10


MKW
COW
OYW
25.7
26.1
26.1
26.5
26.5
26.9
Temperature(°C)
Salinity(PSU)
0
1
2
3
4
5
6
7
8
9
32.6
32.8
33
33.2
33.4
33.6
33.8
34

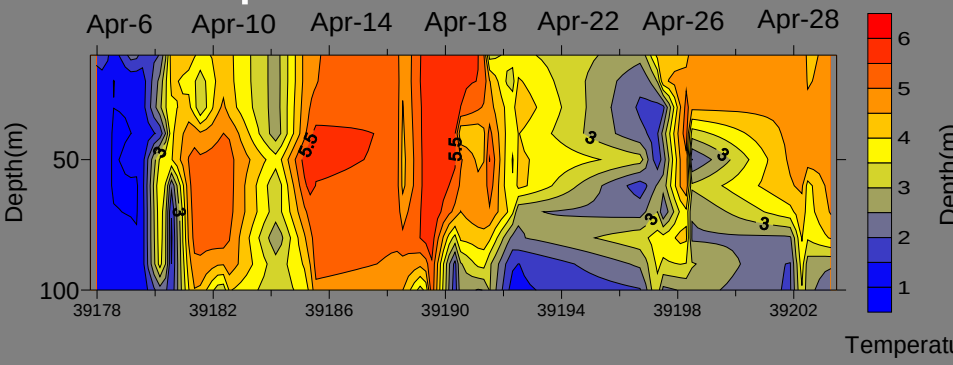
A water mass having (T, S) is expressed by the mixing ratios of the three waters having the properties of $(T_1, S_1), (T_2, S_2), (T_3, S_3)$. The ratios are calculated as

$$r_1 T_1 + r_2 T_2 + r_3 T_3 = T$$

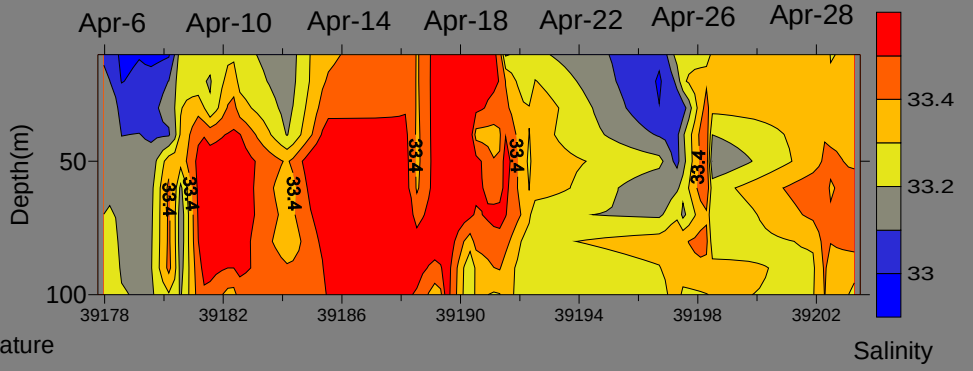
$$r_1 S_1 + r_2 S_2 + r_3 S_3 = S$$

$$r_1 + r_2 + r_3 = 1$$

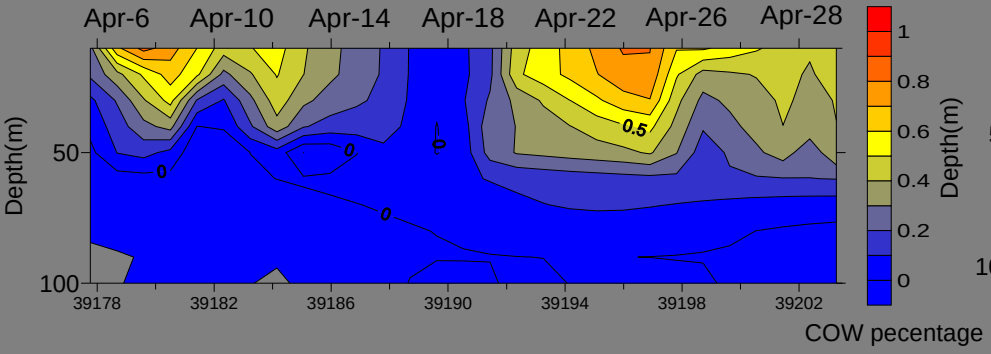
Temp



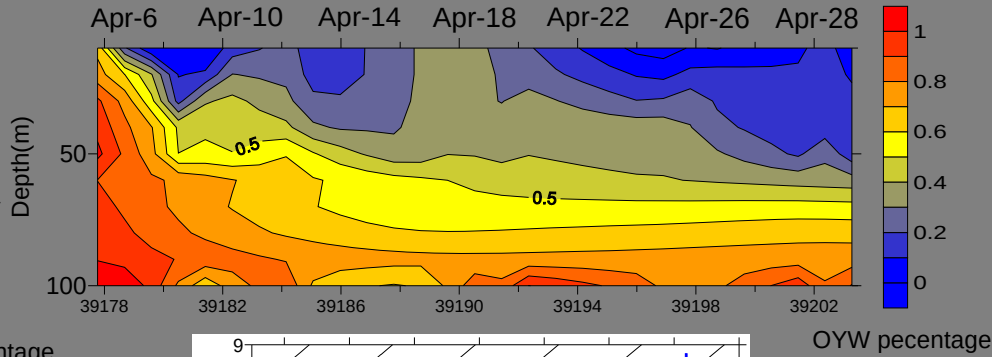
Sali



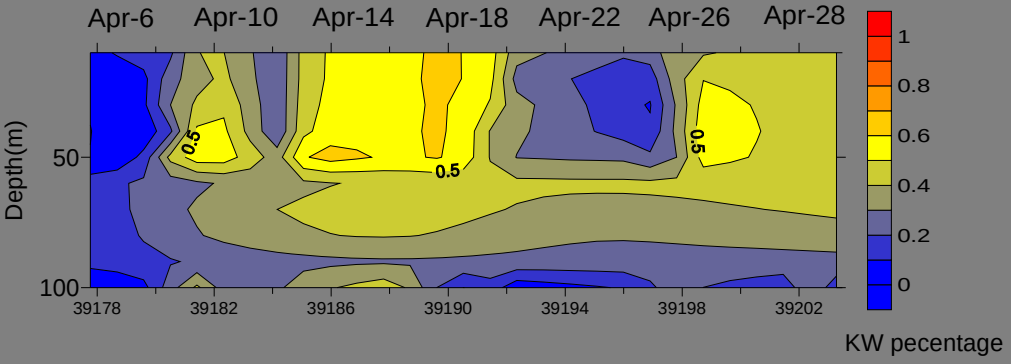
COW

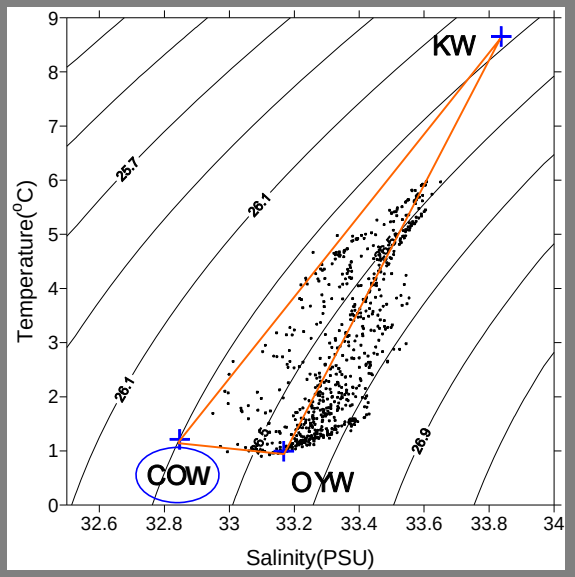


OYW

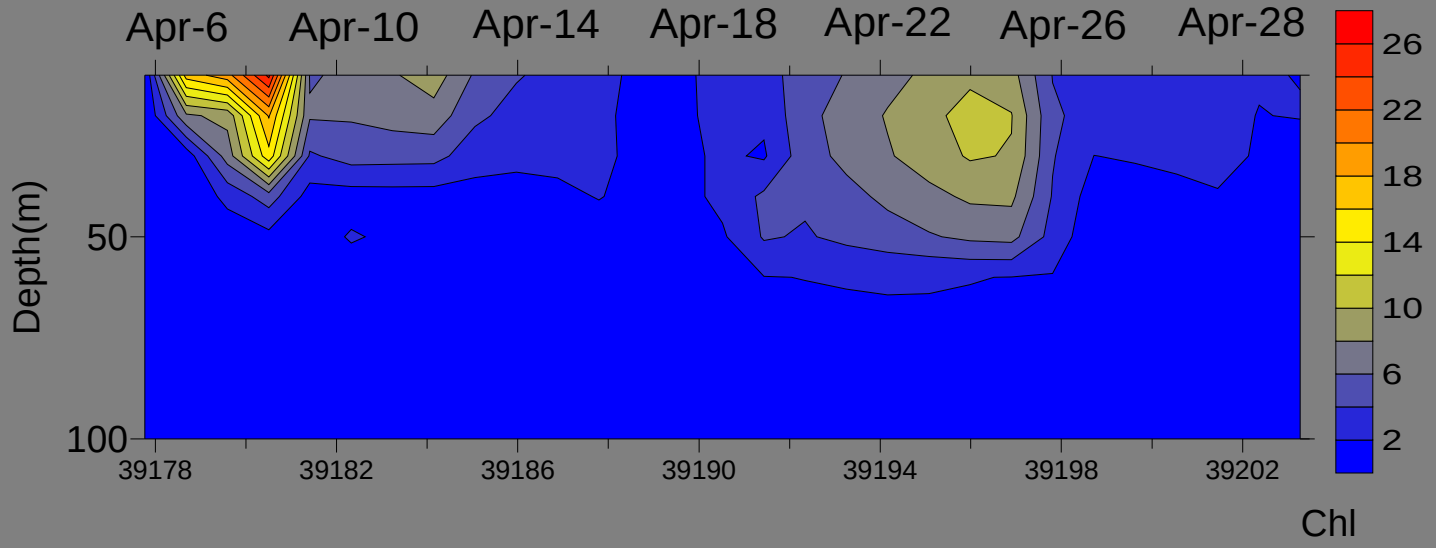


MKW

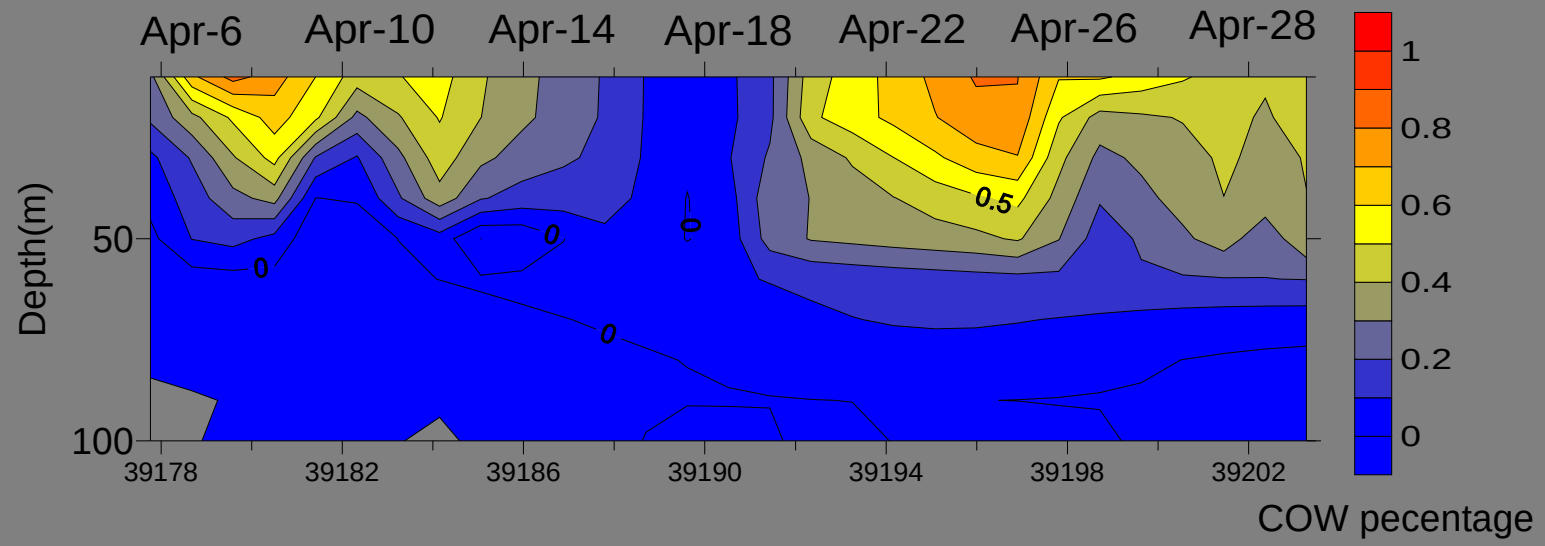




Chl


Apr-6
Apr-10
Apr-14
Apr-18
Apr-22
Apr-26
Apr-28
Depth(m)
50
100
39178
39182
39186
39190
39194
39198
39202
26
22
18
14
10
6
2
Chl

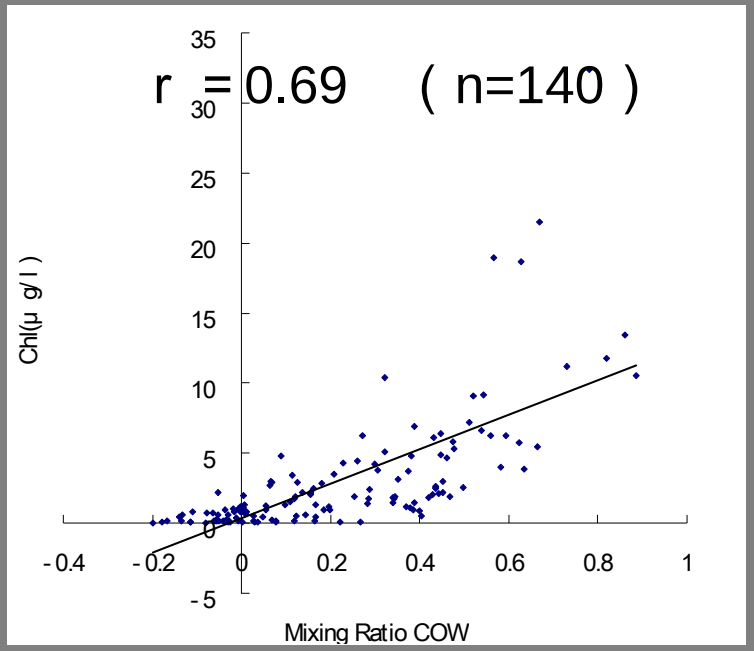
COW

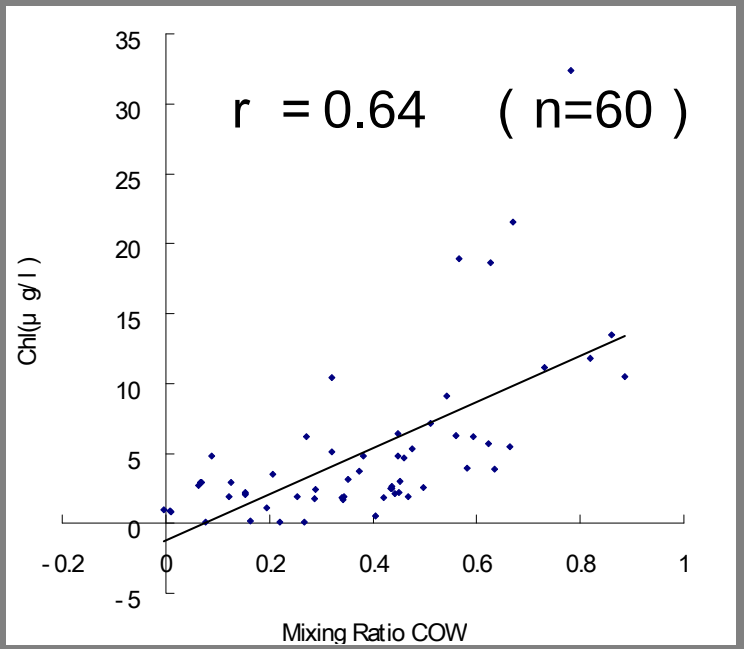

Apr-6
Apr-10
Apr-14
Apr-18
Apr-22
Apr-26
Apr-28
Depth(m)
50
100
39178
39182
39186
39190
39194
39198
39202
0
0
0
0
0.5
1
0.8
0.6
0.4
0.2
0
COW pecentage

10-100m depth

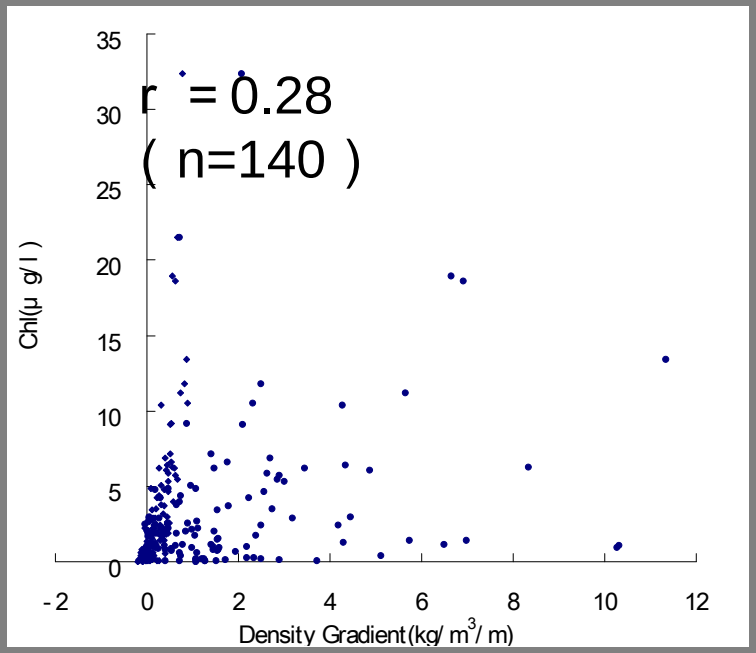
10-30m depth

Chl vs R_{COW}





Chl vs Density Grad



$$Chl = Chl_0 \times R_{COW}$$

Chl is proportional to Mixing Ratio of COW.

That is,

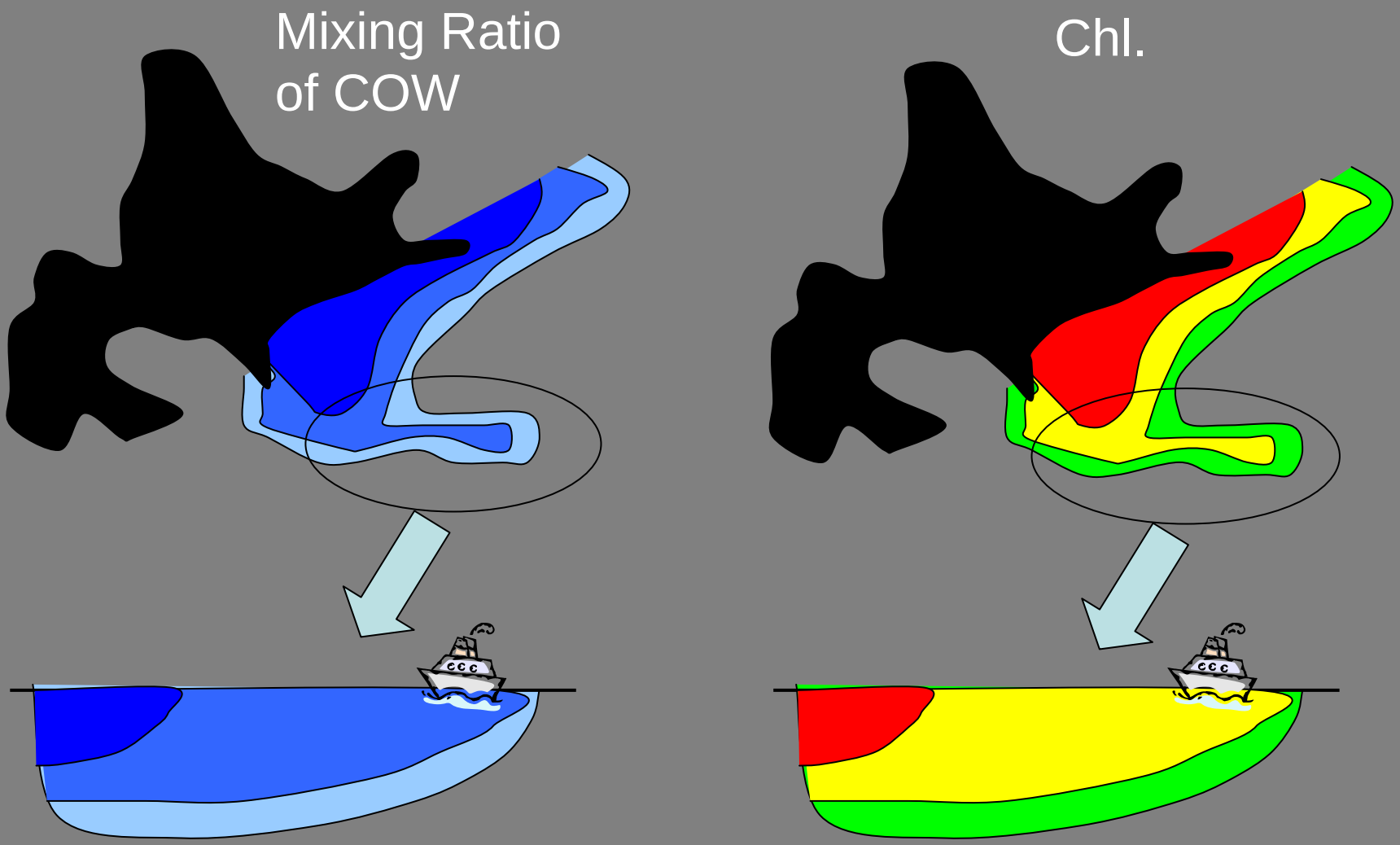
In a scale of 30days

Chl. changed depending

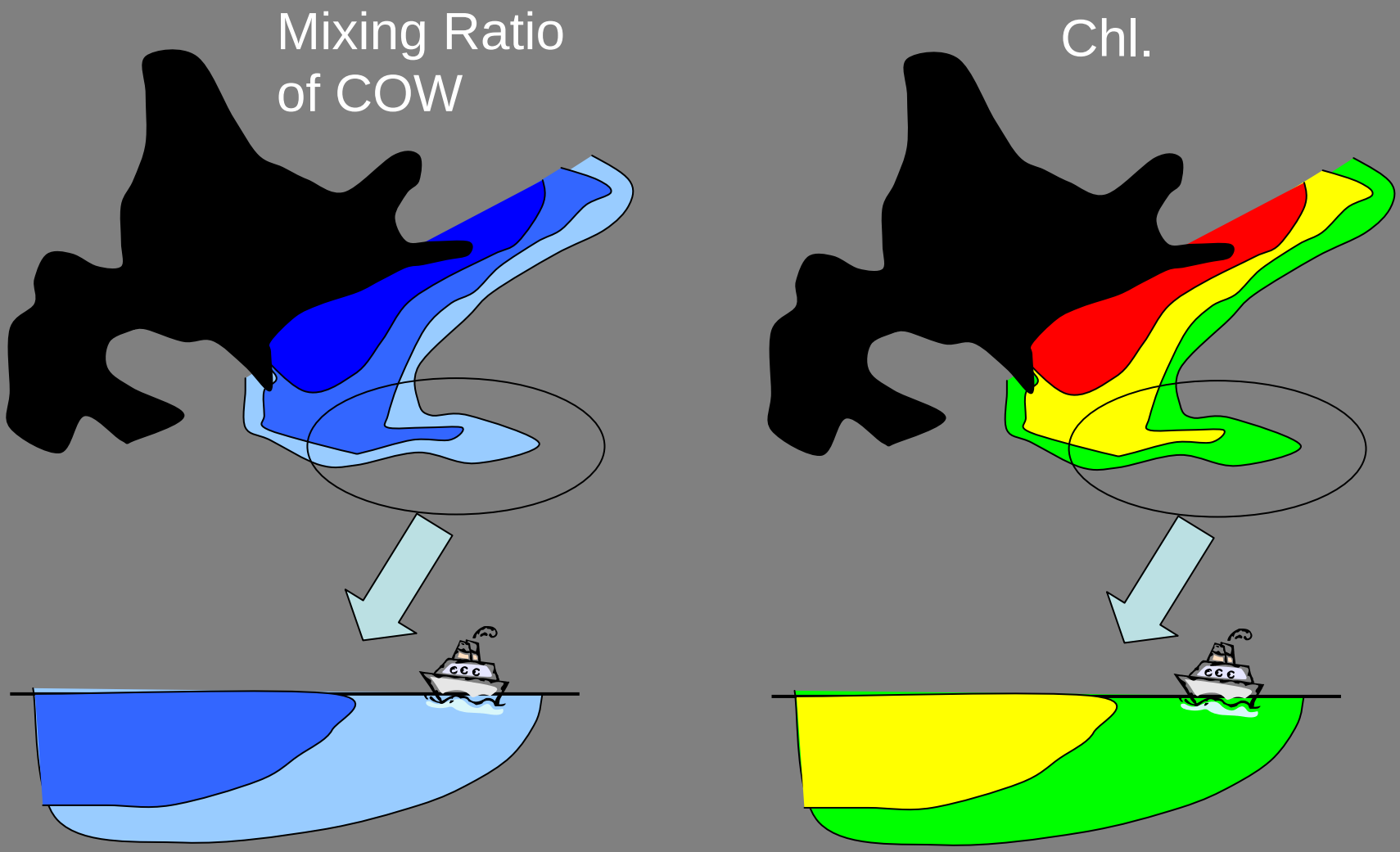
mainly on Mixing Ratio of COW.

In COW, Chl reaches the maximum Chl_0.

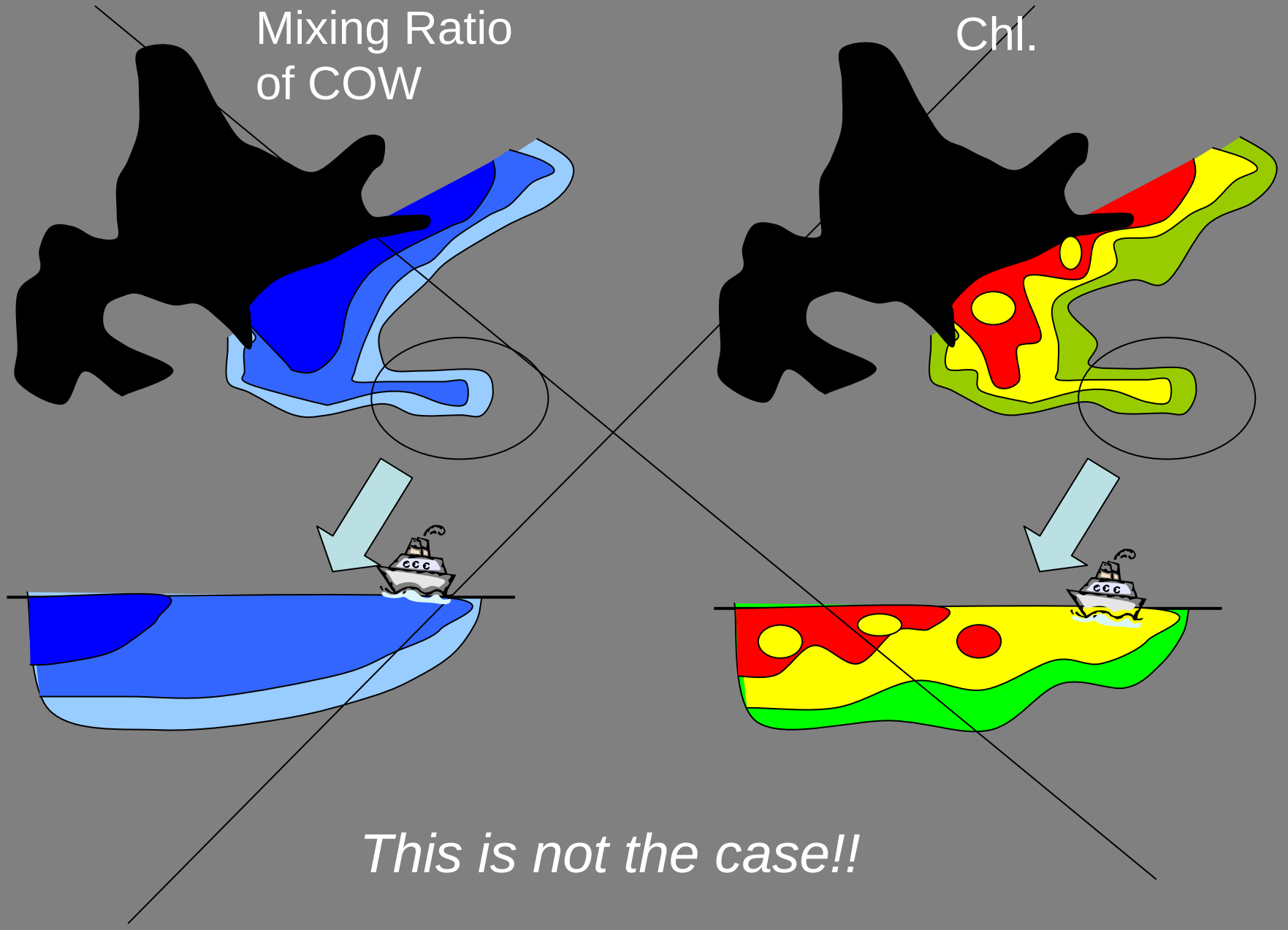
In the other waters, Chl is ZERO.



The patterns of COW and Chl. changes by the physical processes but they are always almost similar.



The patterns of COW and Chl. changes by the physical processes but they are always almost similar.


Mixing Ratio
of COW
Chl.
CCC
CCC
This is not the case!!

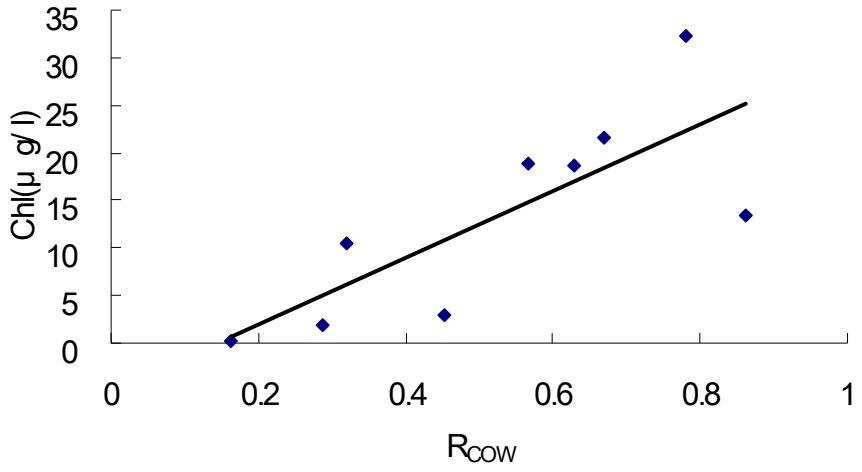
To clarify temporal change of Chl in COW,

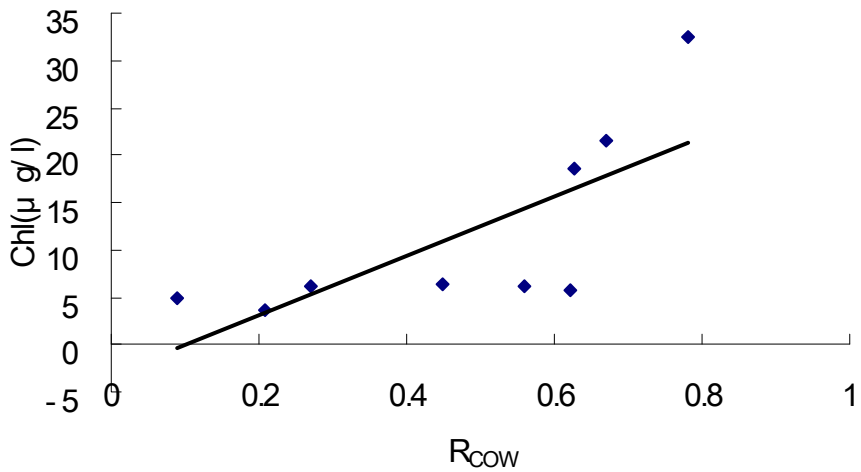
Chl. and R_{COW} were fitted to

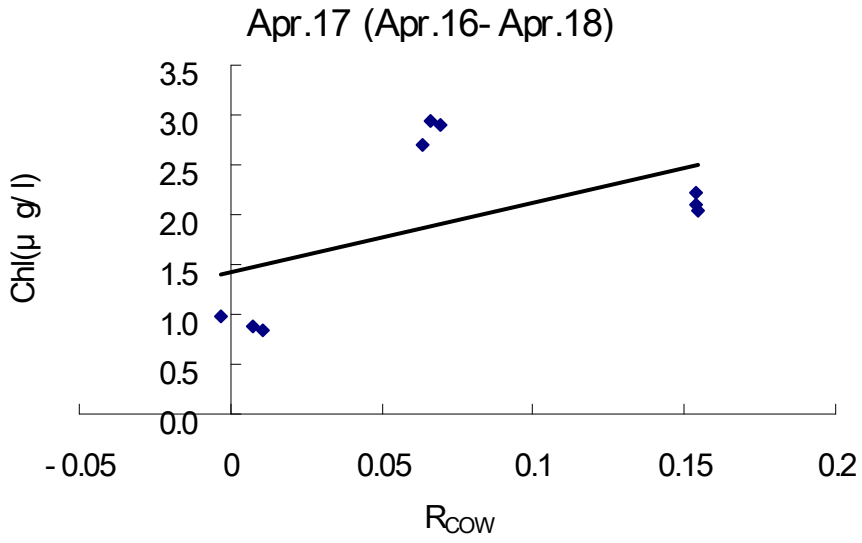
$$Chl = a \times R_{COW} + b$$

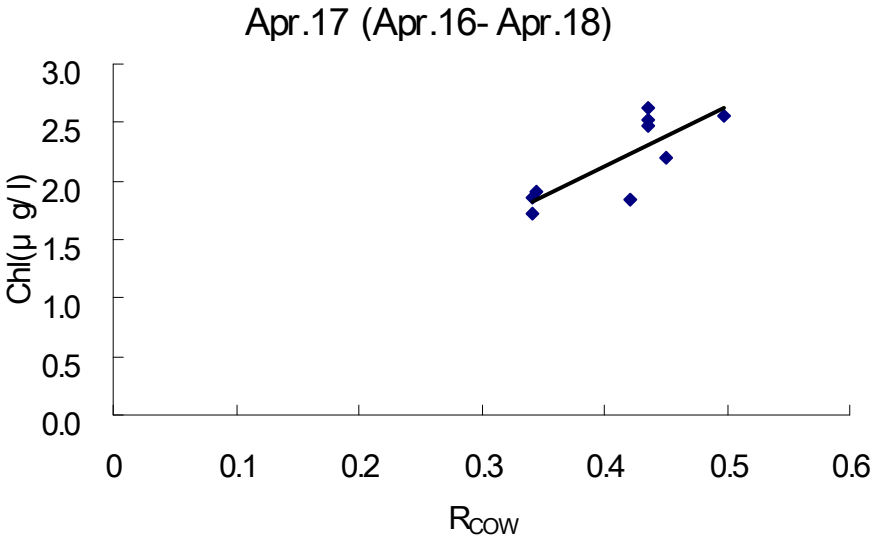
for each 3days data with a day interval.

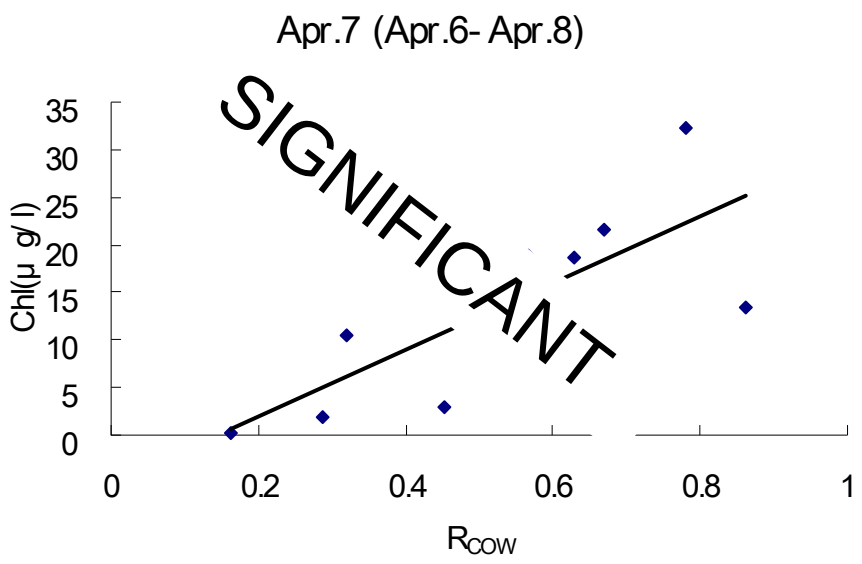
We assumed Chl is representative of COW when R_{COW} is 1.

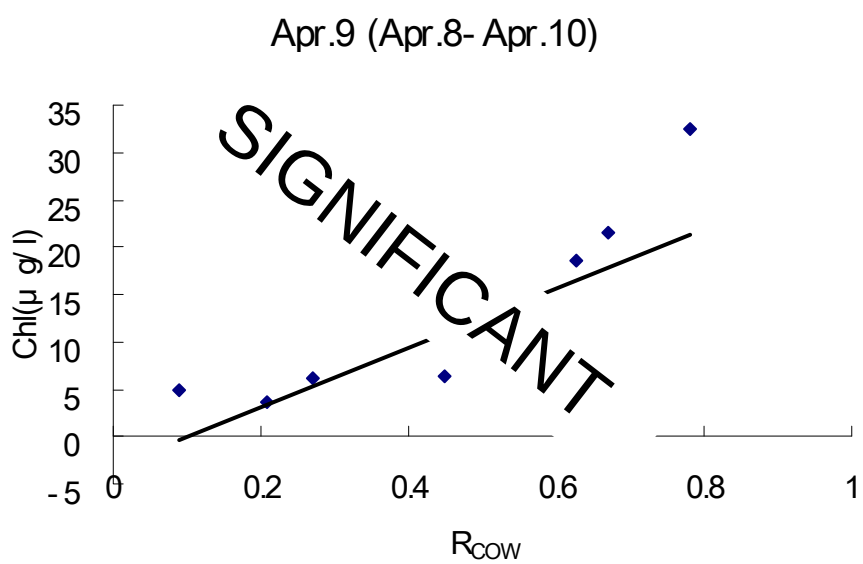

Apr.7 (Apr.6- Apr.8)
Chl(μ g/l)
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
Rcow

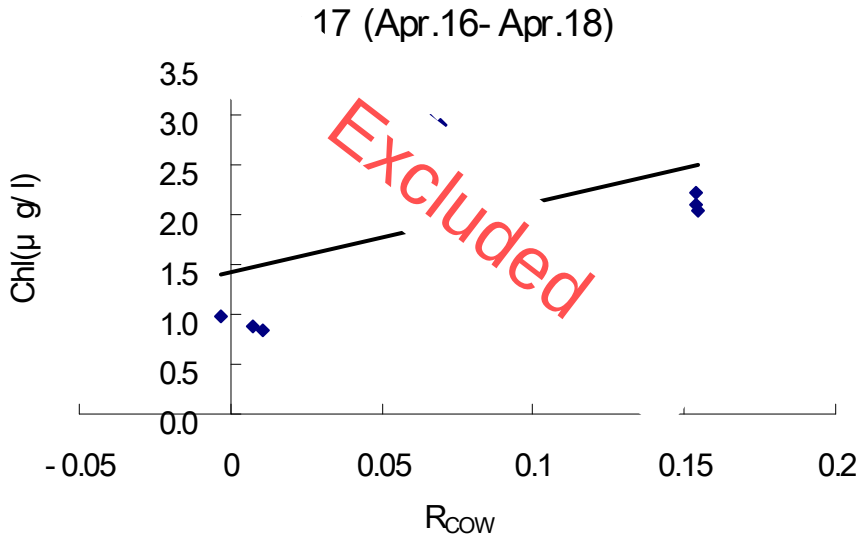

Apr.9 (Apr.8- Apr.10)
Chl(μ g/l)
35
30
25
20
15
10
5
0
-5
0
0.2
0.4
0.6
0.8
1
Rcow

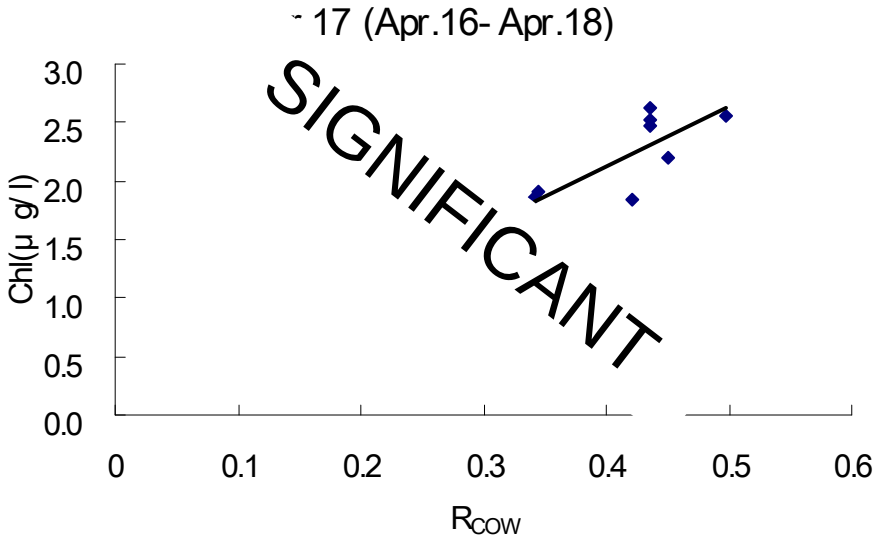

Apr.17 (Apr.16- Apr.18)
Chl(μ g/l)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.05
0
0.05
0.1
0.15
0.2
Rcow

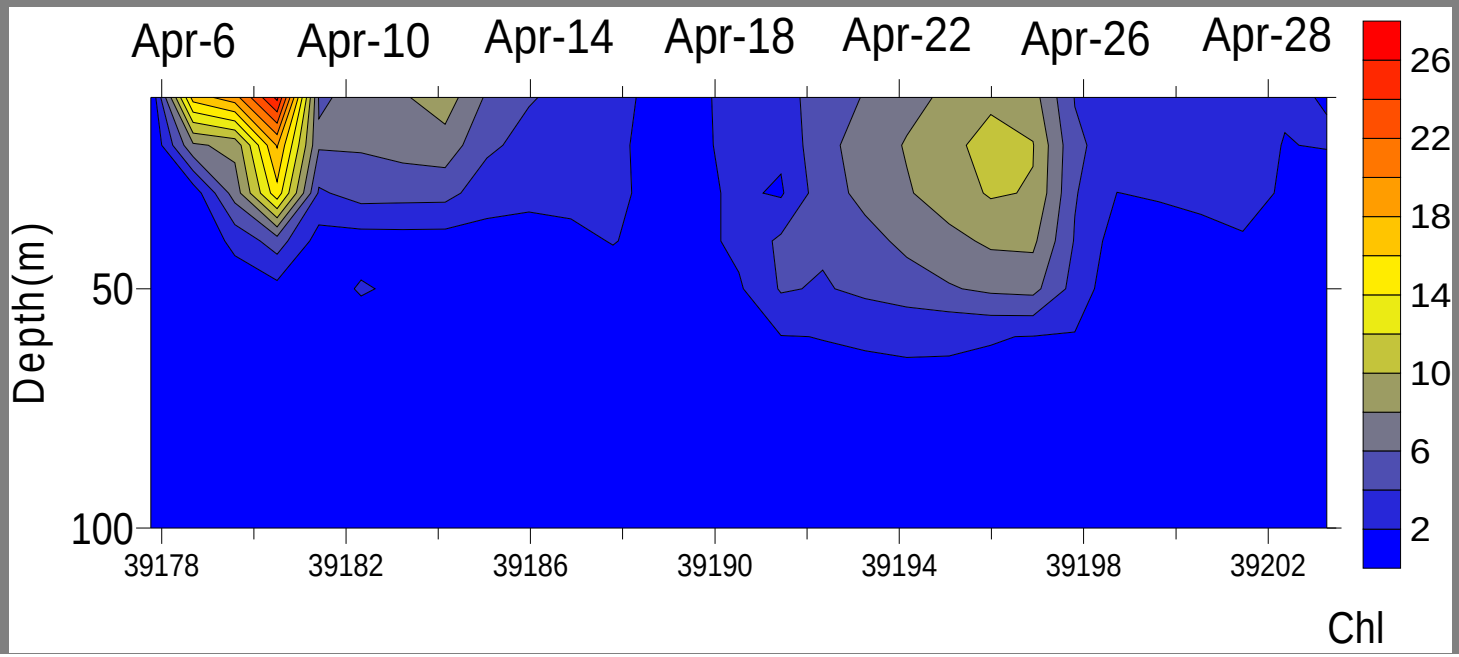

Apr.17 (Apr.16- Apr.18)
Chl(μ g/l)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
Rcow

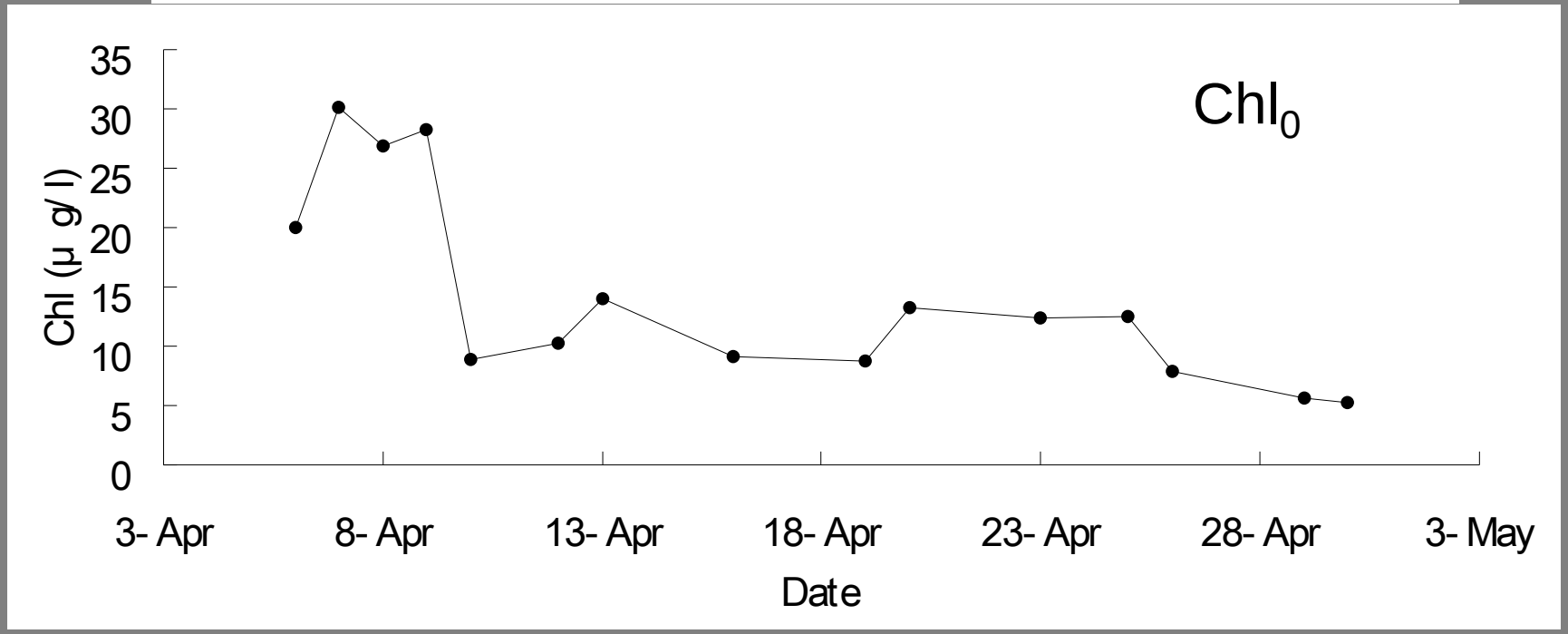

Apr.7 (Apr.6- Apr.8)
SIGNIFICANT
Chl(μ g/l)
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
Rcow


Apr.9 (Apr.8- Apr.10)
SIGNIFICANT
Chl(μ g/l)
35
30
25
20
15
10
5
0
-5
0
0.2
0.4
0.6
0.8
1
Rcow


17 (Apr.16- Apr.18)
Excluded
Chl(μ g/l)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.05
0
0.05
0.1
0.15
0.2
Rcow

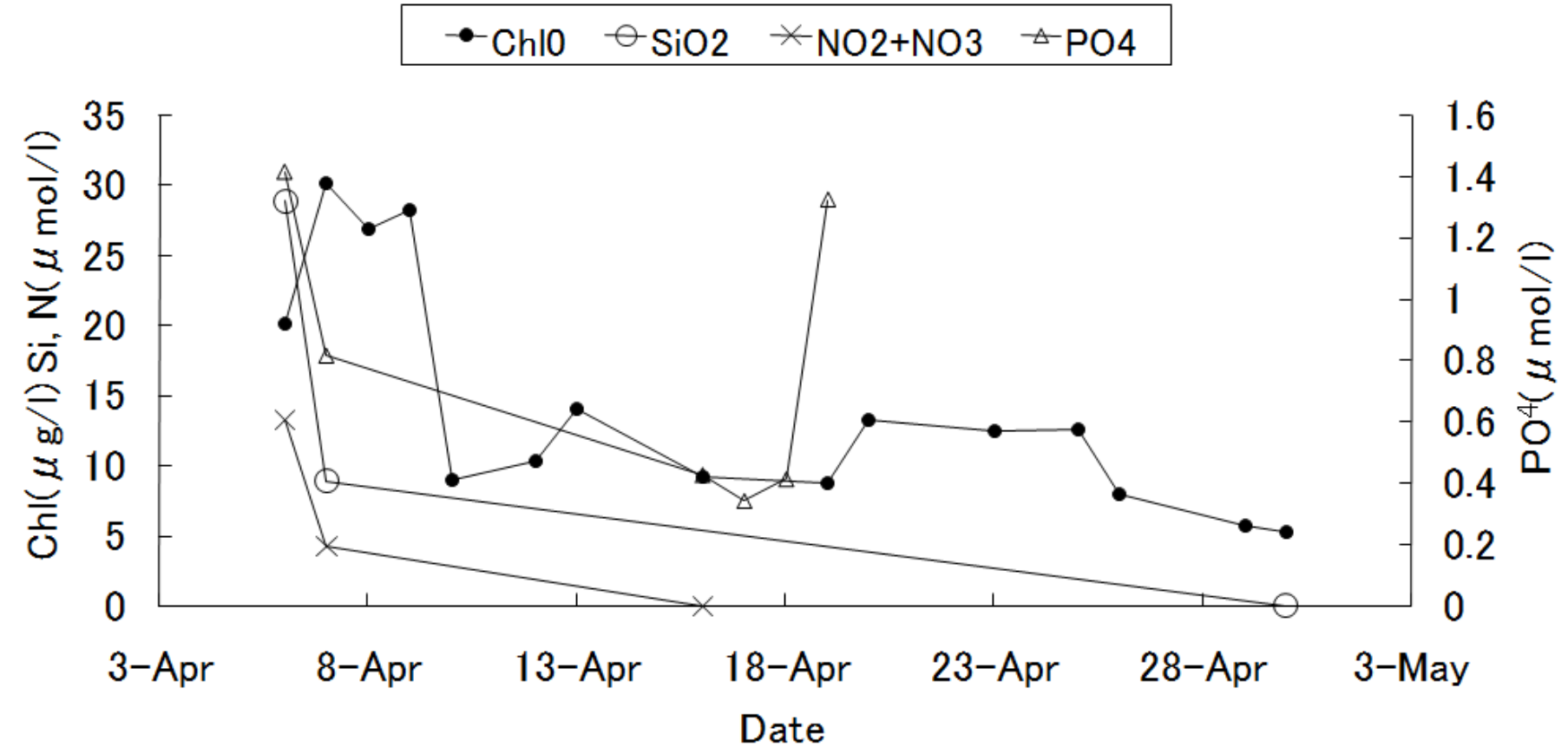

17 (Apr.16- Apr.18)
SIGNIFICANT
Chl(μ g/l)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
Rcow


Apr-6
Apr-10
Apr-14
Apr-18
Apr-22
Apr-26
Apr-28
Depth(m)
50
100
39178
39182
39186
39190
39194
39198
39202
26
22
18
14
10
6
2
Chl


Chl0
Chl (µ g/ l)
35
30
25
20
15
10
5
0
3- Apr
8- Apr
13- Apr
18- Apr
23- Apr
28- Apr
3- May
Date

The same analysis was conducted

for the Nutrients.



Nutrients were depleted after Apr.7.

Discussion

	(mmol/l)			(microg/l)
	PO_4	SiO_2	NO_3+NO_2	Chl_0
Apr-6	1.4	28.9	13.2	20.1
Apr-7	0.8	8.9	4.3	30.1
Dif.	-0.6	-21.0	-8.9	10.0
Ratio	1	33.3	14.9	
Redfield	1	15	16	

	N:P	Si:P	Si:N	
Obs.	14.9	33.3	2.2	
H&B			3.0 (1.0)	HNLC (Fe added)
K&M	15.6	30.5	1.9	

H&B: Hutchins and Bruland (1998)

K&M: Kudo and Matsunaga (1999)

$$\frac{d}{dt}Chl = (\text{Photosyn.}R - \text{Graze}R - \text{Resp.}R) \times Chl$$

$$\text{Photosyn.}R \times Chl = (C:N) \times \frac{dN}{dt} \times (Chl:C)$$

Substituting the values of

$$\frac{d}{dt}Chl = 10.0\,(\mu g/l/day),\ Chl = 25.0(\mu g/l),$$

$$(C:N) = 6.7 \text{ from K \& M},\ \frac{dN}{dt} = 8.9\,(\mu mol/l/day)$$

$$\text{Photosyn.}R = 28.6 \times (Chl:C)$$

$$\text{Graze}R + \text{Resp.}R = \text{Photosyn.}R - 0.4$$

Estimated Production Rate for the Various Chl:C

Chl :C	0.01	0.02	0.03
Photosyn.R	0.29	0.57	0.86
Graz.R+Resp.R	-0.11	0.17	0.45

Summary

Chl. and Nutrients were estimated for the Coastal Oyashio Water using Mixing Ratio.

Chl. was successfully estimated because Chl. of COW is much higher than the other waters, whereas Nutrients was not.

Chl. increased in Apr.6-7, suddenly decreased in Apr. 9-10, decreasing gradually till the end of April.

Using the results in the increasing period, the Dynamics was discussed. Results agree with the literature.

COW is not so Iron-Poor as in HNLC region, but not enough.

This is also COW

Thank you!

To clarify temporal change of Chl in COW,

Chl. and R_{COW} were fitted to

$$Chl = a \times R_{COW} + b$$

for each 3days data with a day interval.

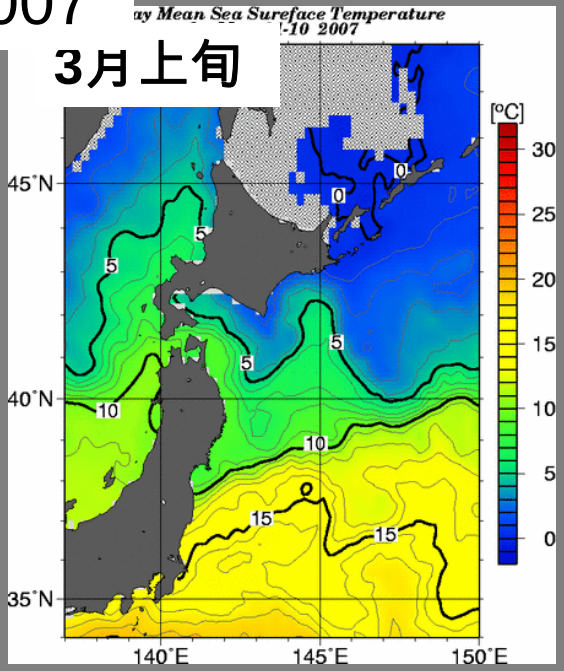
We assumed Chl is reresentative of COW when R_{COW} is 1.

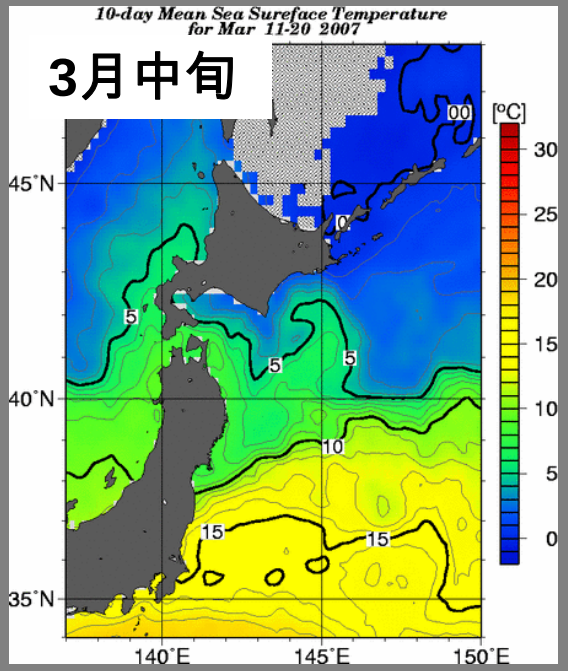
$$Chl = Chl_0 \times R_{COW} + (1 - R_{COW})Chl_{other}$$

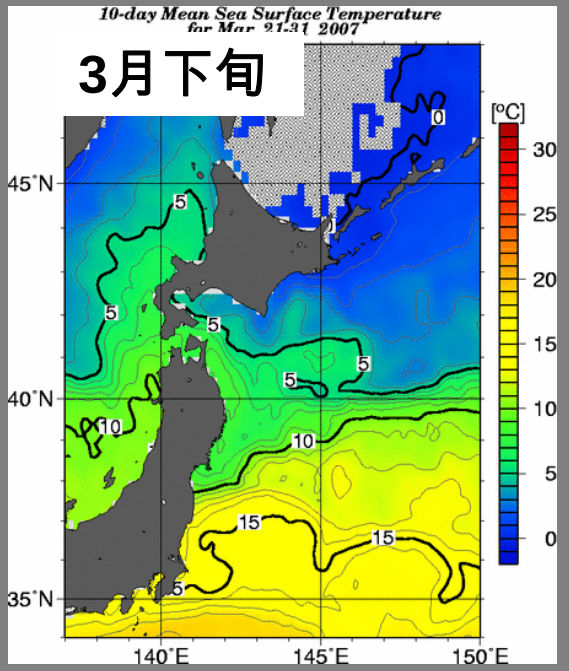
$$= R_{COW}(Chl_0 - Chl_{other}) + Chl_{other}$$

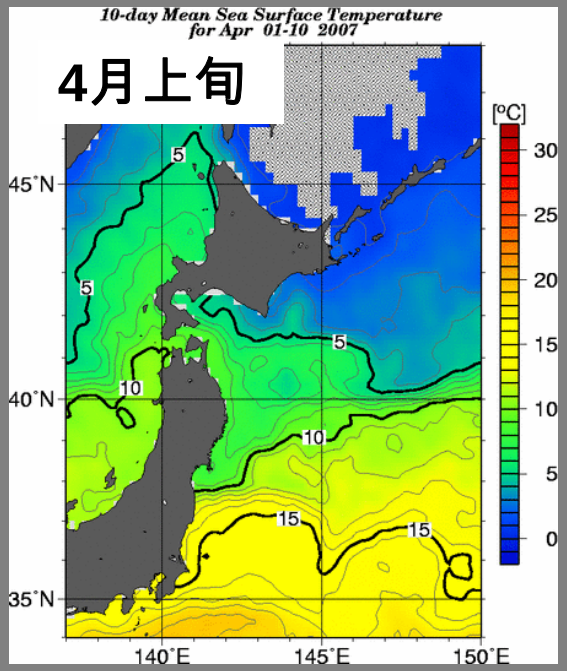
Mean Chl_{other} is 15% of Chl_0

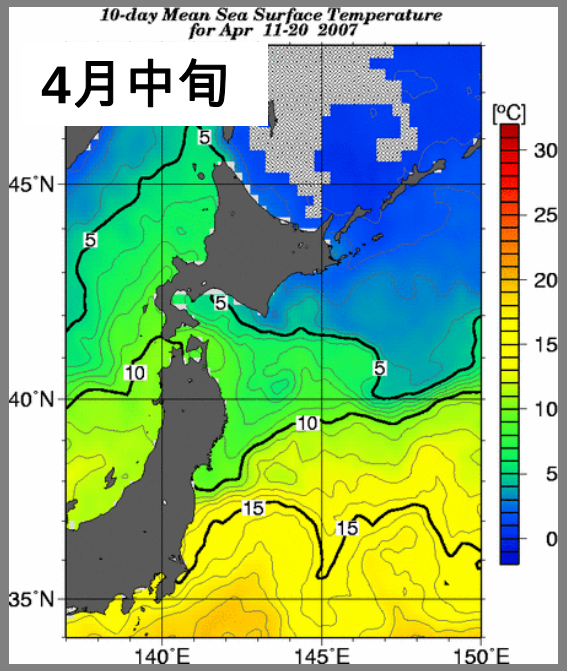
2007

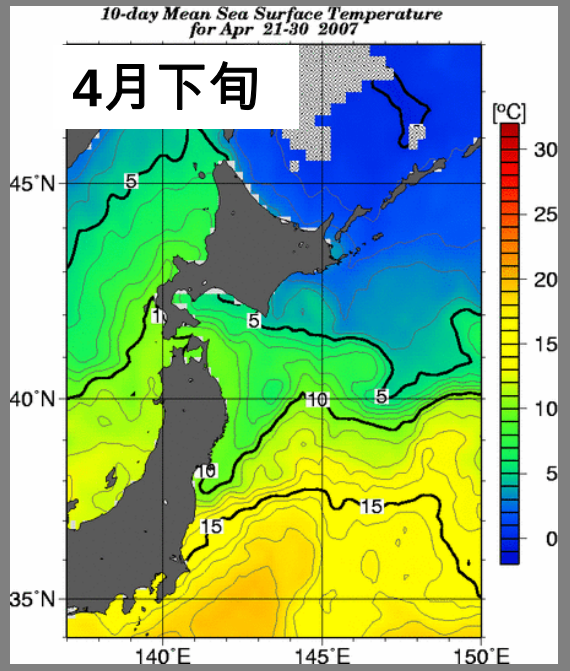

3月上旬
[°C]
45°N
40°N
35°N
140°E
145°E
150°E


10-day Mean Sea Sureface Temperature
for Mar 11-20 2007
3月中旬
[°C]
45°N
40°N
35°N
140°E
145°E
150°E


10-day Mean Sea Surface Temperature
3月下旬
[°C]
45°N
40°N
35°N
140°E
145°E
150°E

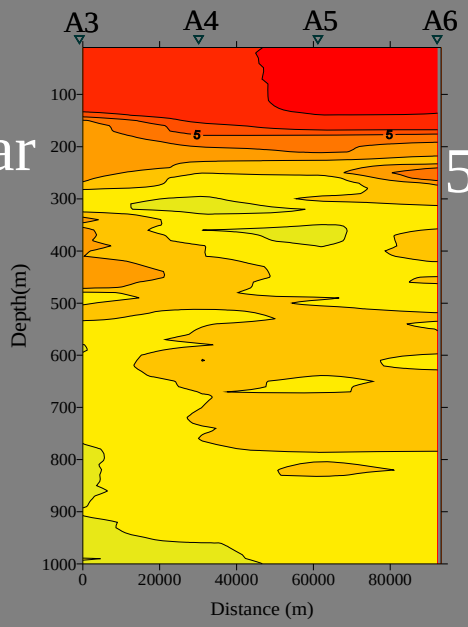

10-day Mean Sea Surface Temperature
for Apr 01-10 2007
4月上旬
[°C]
45°N
40°N
35°N
140°E
145°E
150°E


10-day Mean Sea Surface Temperature
for Apr 11-20 2007
4月中旬
[°C]
45°N
40°N
35°N
140°E
145°E
150°E

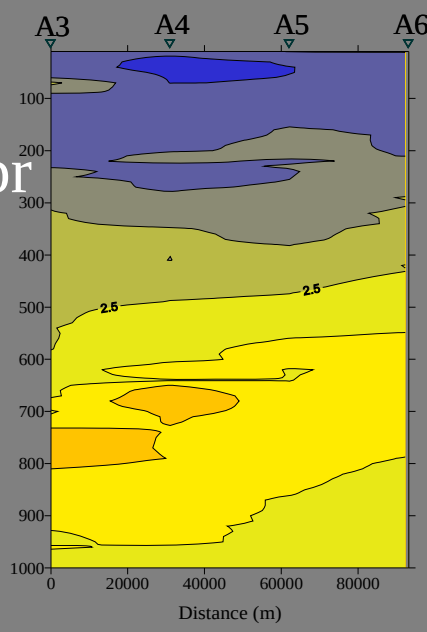

10-day Mean Sea Surface Temperature
for Apr 21-30 2007
4月下旬
[°C]
45°N
40°N
35°N
140°E
145°E
150°E

Temperature Section

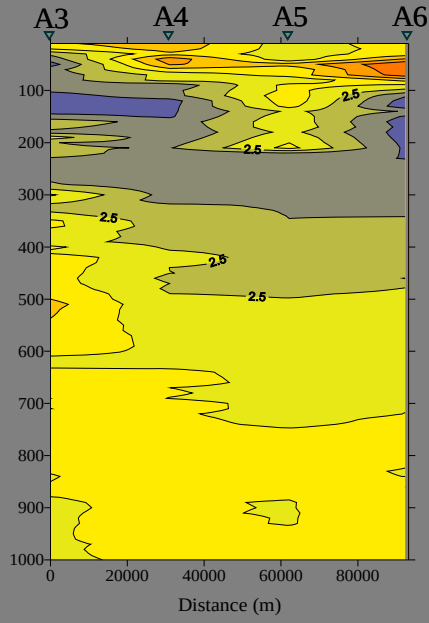
8-Mar

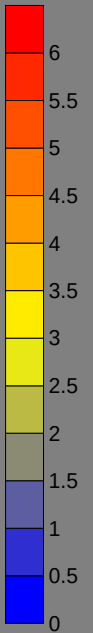


5-Apr

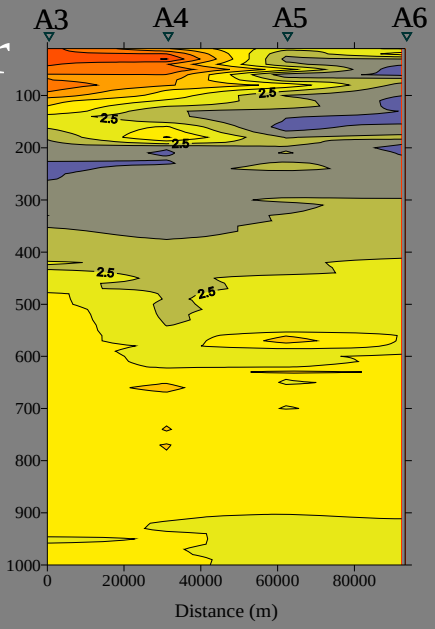


11-Apr

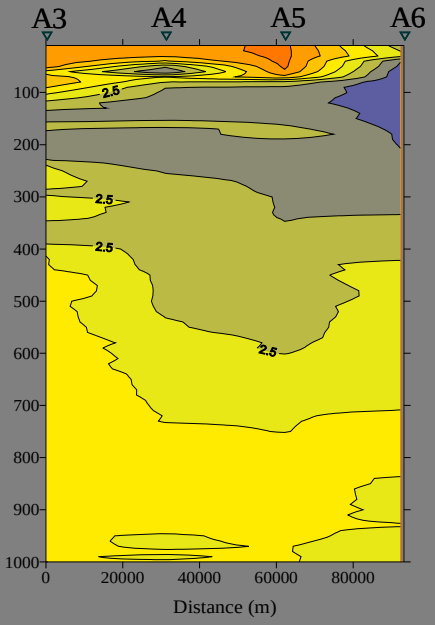




23-Apr

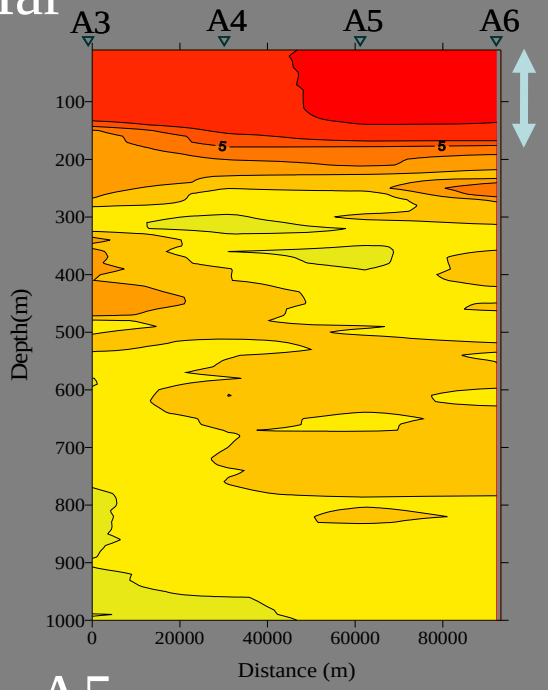


28-Apr

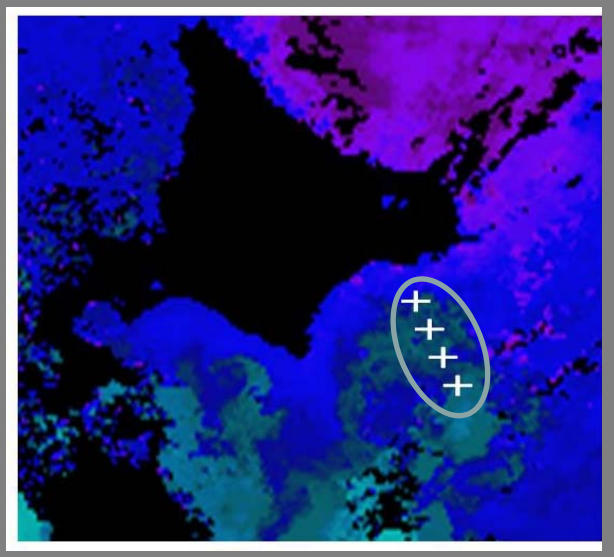


定点の暖水

8-Mar

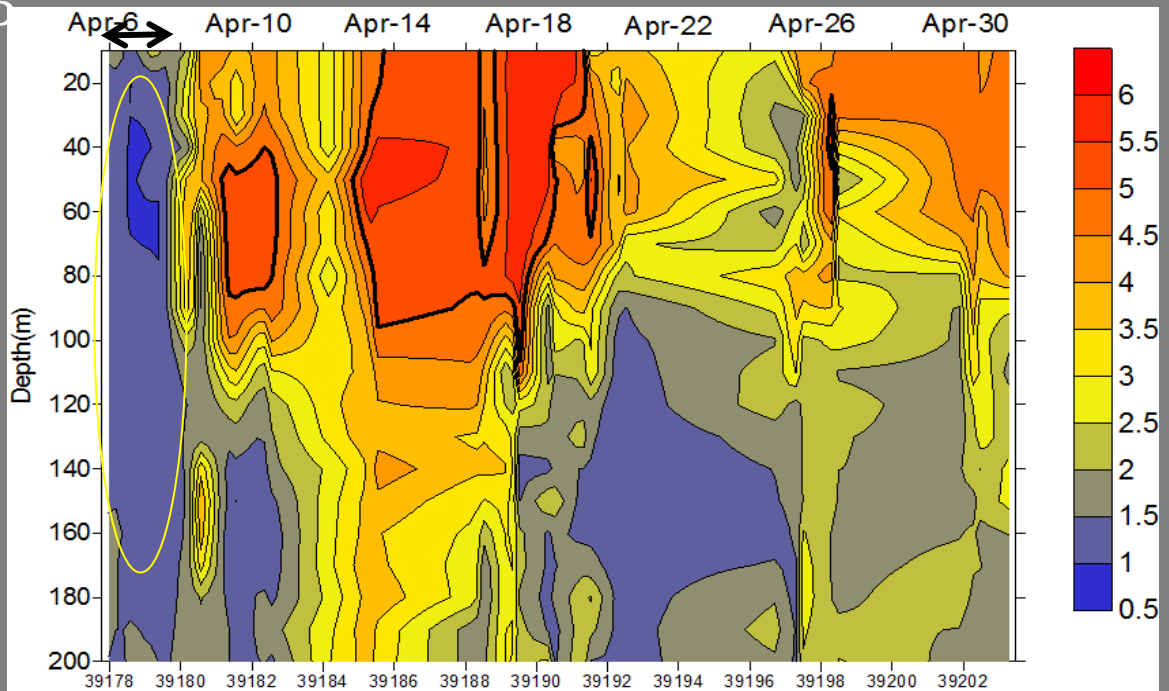


06Mar2007 to 13Mar2007

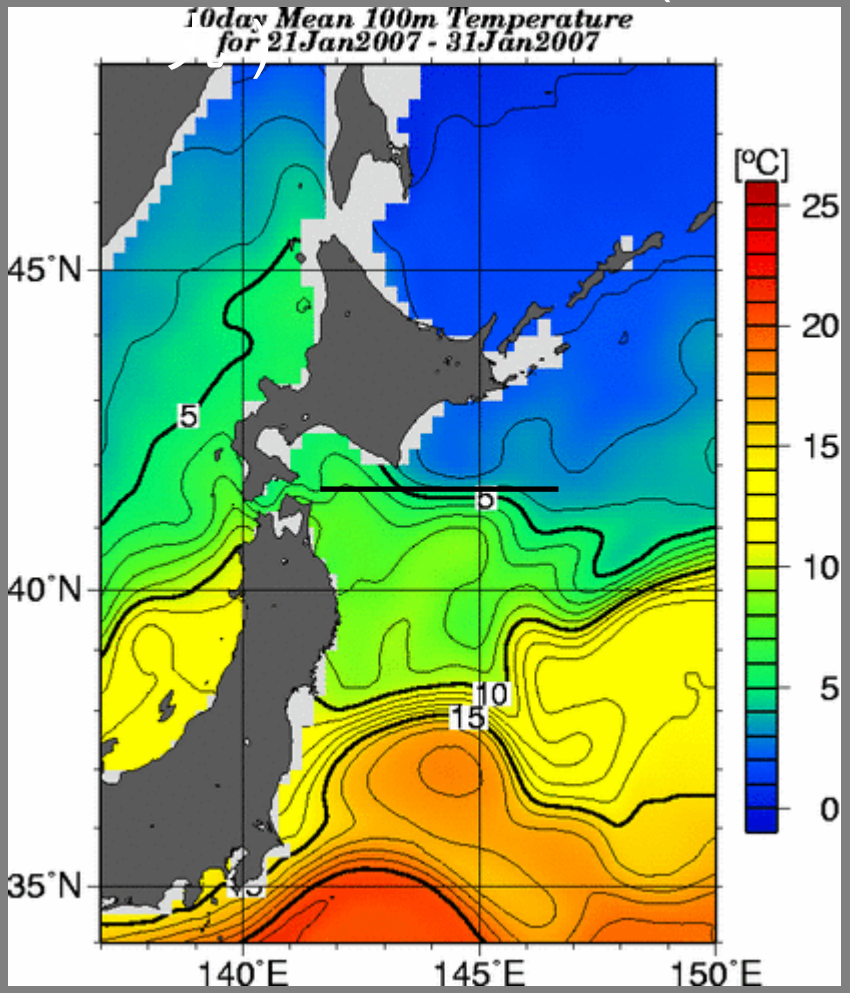


親潮

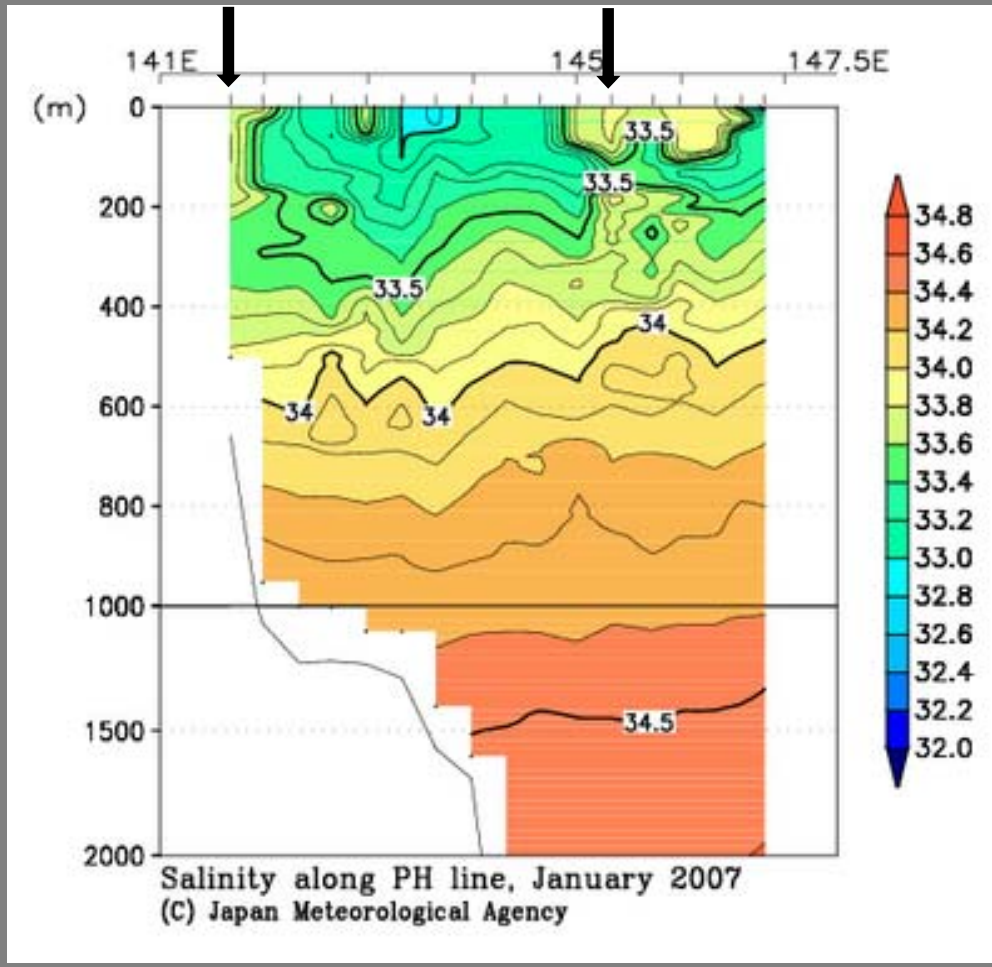
A5



気象庁PHライン（ 高風



津軽暖水　北上暖水



現存量Pは主に特定水塊の移流と拡散に依存している

→P'の水平傾度は大きくない

$$u \cdot \nabla P' << u \cdot \nabla P, \nabla_h^2 P' << \nabla_h^2 P$$

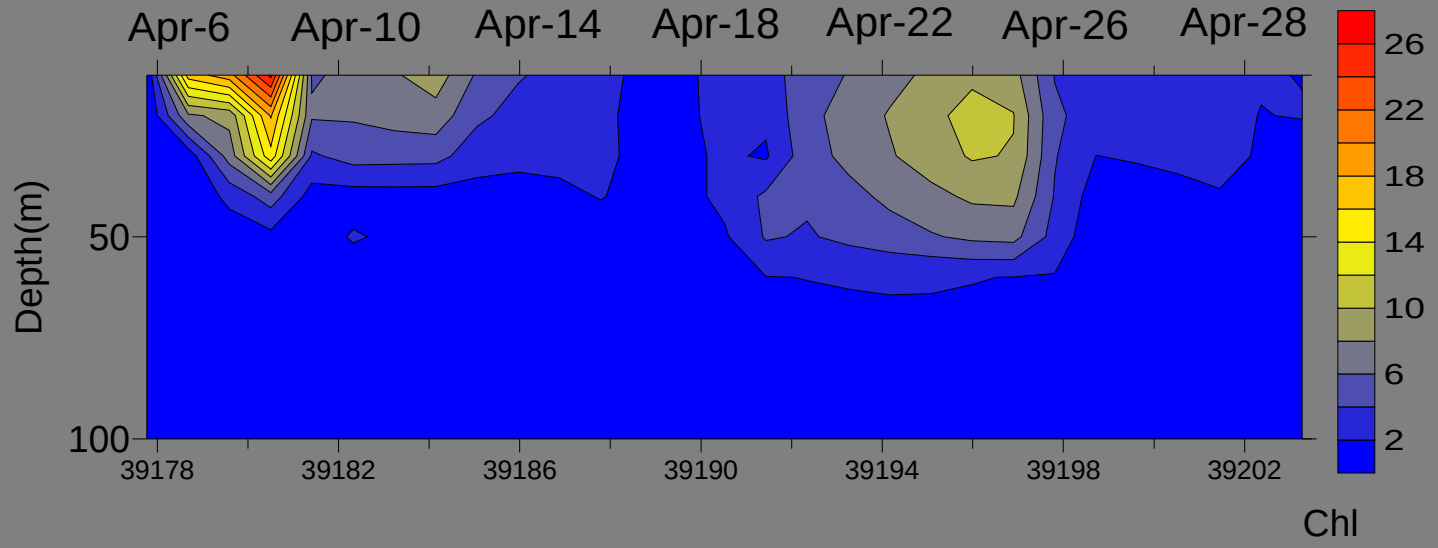
（４）は次のようにまとめられる

$$\frac{\partial P}{\partial t} = \frac{\partial P'}{\partial t} - u \cdot \nabla P + K_H \nabla_h^2 P \quad (5)$$

（５）を（１）に代入すると

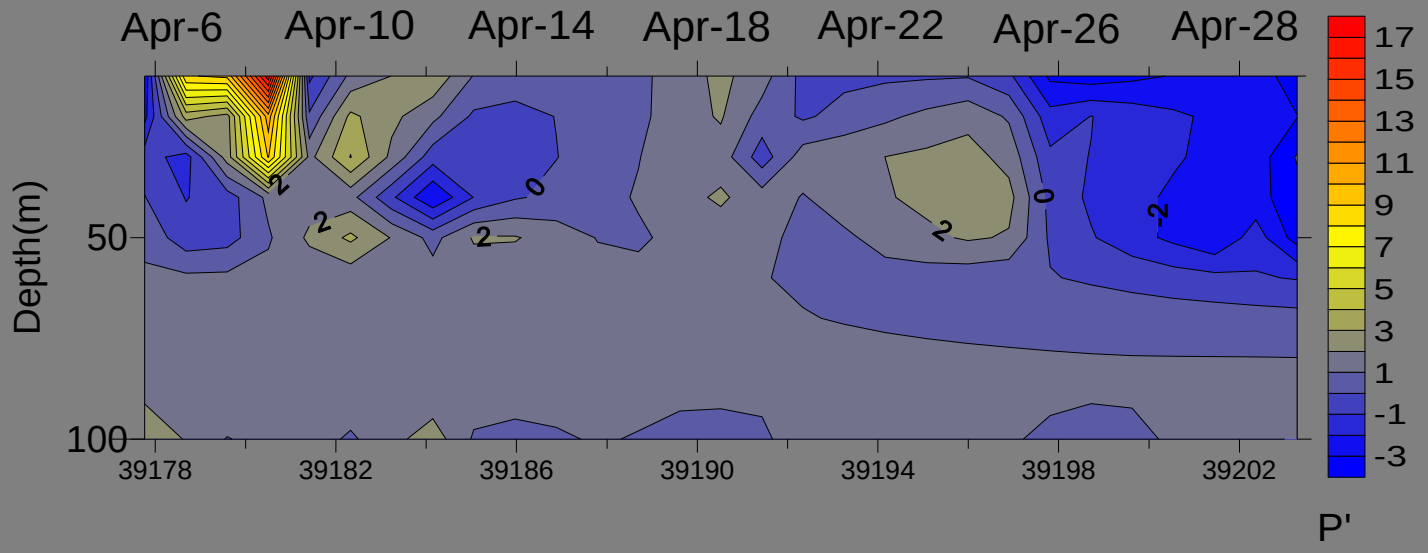
$$\frac{\partial P'}{\partial t} = \frac{\partial}{\partial z} Kz \frac{\partial P}{\partial z} + F_{MM} - G_R \quad (6)$$

Chl

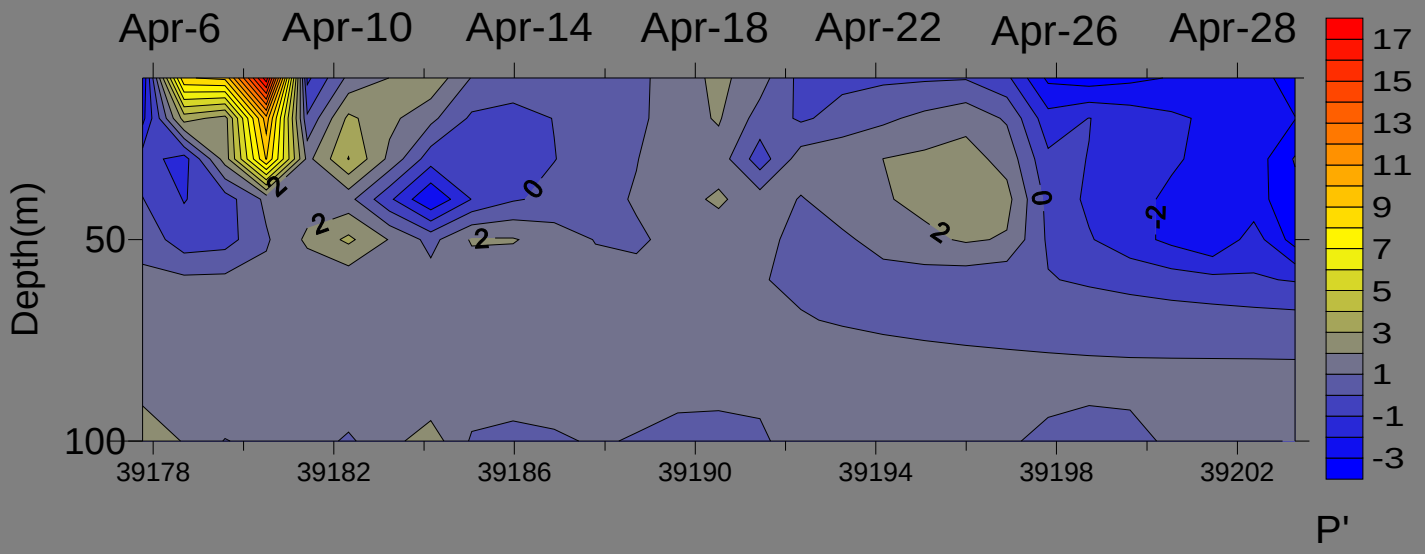

Apr-6
Apr-10
Apr-14
Apr-18
Apr-22
Apr-26
Apr-28
Depth(m)
50
100
39178
39182
39186
39190
39194
39198
39202
26
22
18
14
10
6
2
Chl

P’

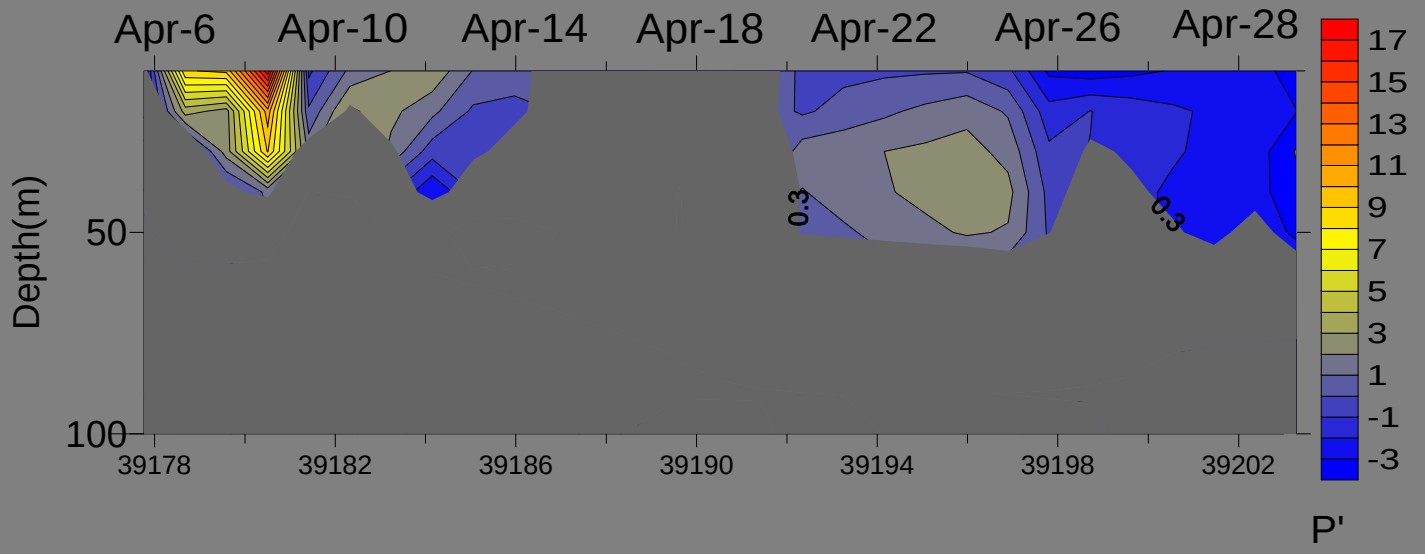
$$P' = P - aR - b$$


Apr-6
Apr-10
Apr-14
Apr-18
Apr-22
Apr-26
Apr-28
Depth(m)
50
100
39178
39182
39186
39190
39194
39198
39202
2
2
2
0
2
0
-2
17
15
13
11
9
7
5
3
1
-1
-3
P'

P’



P’ when COW>0.3



Ｐ´の代表性について

Ｐ´の時間変化にはＲの変化に依存する成分もみられるものの、Ｐ´は数日のスケールでは独立に変化している

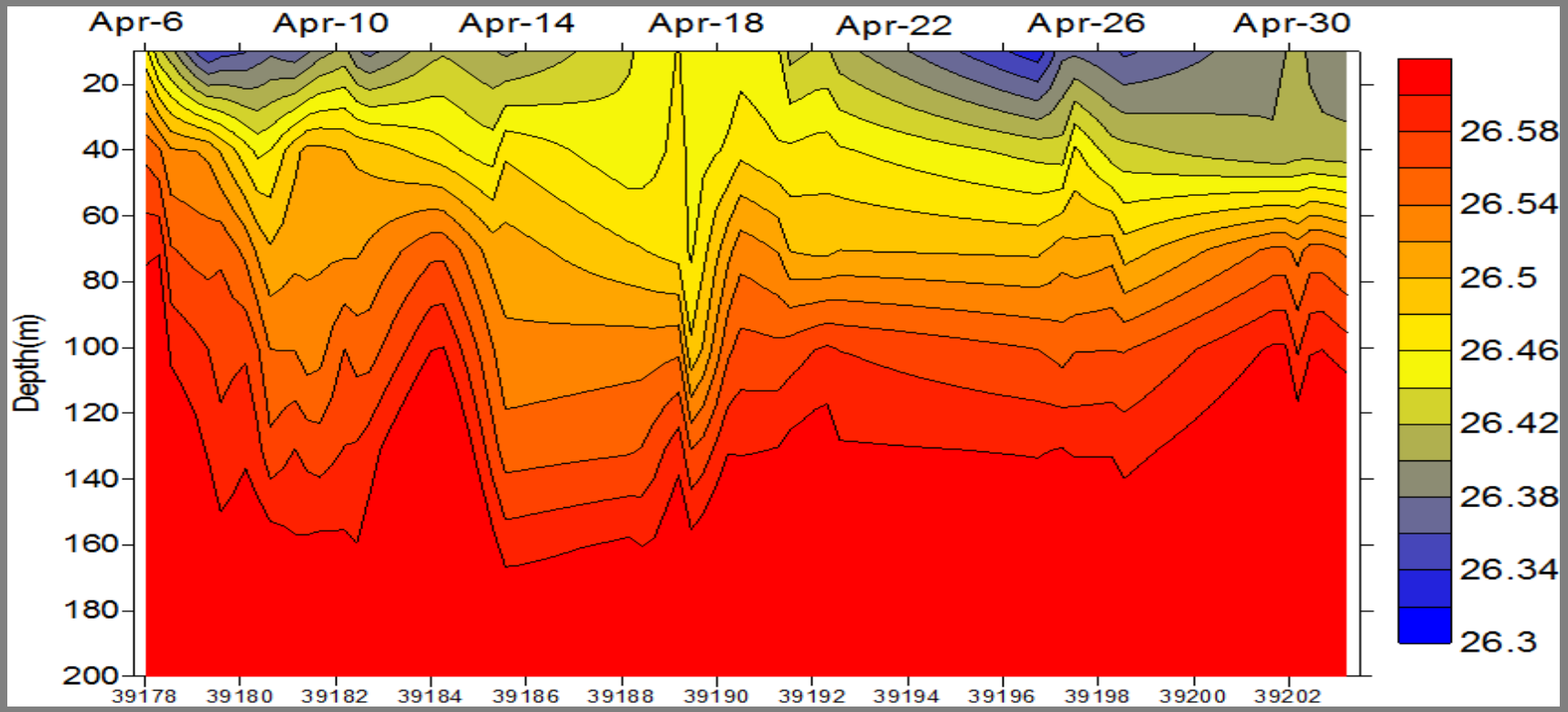
移流･拡散を除去することで明らかになったこと

１．春季ブルーミングのピークは4月8日。

２．水深１０ｍ、２０ｍ、３０ｍではピークのあと5月3日まで減少する傾向にある。時間変化率は浅い方が大きい。

３．水深４０ｍではその上層と変化傾向が異なる。ピークが１~２日遅れ、４月中旬にいったん増加する。

鉛直混合


Apr-6
Apr-10
Apr-14
Apr-18
Apr-22
Apr-26
Apr-30
Depth(m)
20
40
60
80
100
120
140
160
180
200
39178
39180
39182
39184
39186
39188
39190
39192
39194
39196
39198
39200
39202
26.58
26.54
26.5
26.46
26.42
26.38
26.34
26.3

問題

P’はPに比べて水平変化が十分に小さいかどうか

同一水塊内部では生物過程は水平一様である近似は適当かどうか

$$\rho \vec{u} \cdot \nabla P' << \rho \vec{u} \cdot \nabla P,\ \nabla_h^2 P' << \nabla_h^2 P$$

課題

P’の動態についての診断

$$\frac{\partial P'}{\partial t} = \frac{\partial}{\partial z} Kz \frac{\partial P}{\partial z} + F_{MM} - G_R \quad (6)$$

診断の目的

ブルーミングを制御する要素を特定する

鉄、捕食、栄養塩、光

F_{MM}とG_Rの見積もり

Ａ５における局所的な観測値を用いる

これで正しいか？！

この方法を他の生物量に適用させることが可能か

①水塊指標と生物量のよい対応がみられる

$$P = aR + P' \quad (3)$$

a の有意性の確保のため

②P’を含む生物過程を表現するパラメタの時系列が作成できる

$$\frac{\partial P}{\partial t} + \underset{\rho}{\vec{u}} \cdot \nabla P = \frac{\partial}{\partial z} Kz \frac{\partial P}{\partial z} + F_{MM} - G_R$$

$$\frac{\partial R}{\partial t} = -\underset{\rho}{\vec{u}} \cdot \nabla R$$

$$P = aR + b + P'$$

$$R = (P - P')/a - b/a$$

$$\frac{\partial P}{\partial t} - \frac{\partial P'}{\partial t} = -\underset{\rho}{\vec{u}} \cdot \nabla P + \underset{\rho}{\vec{u}} \cdot \nabla P'$$

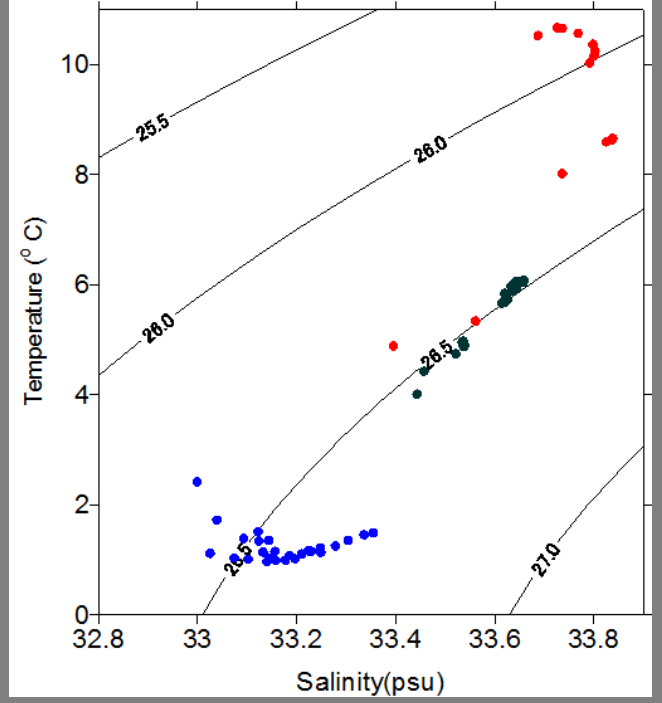
$$P' = P'(t)$$

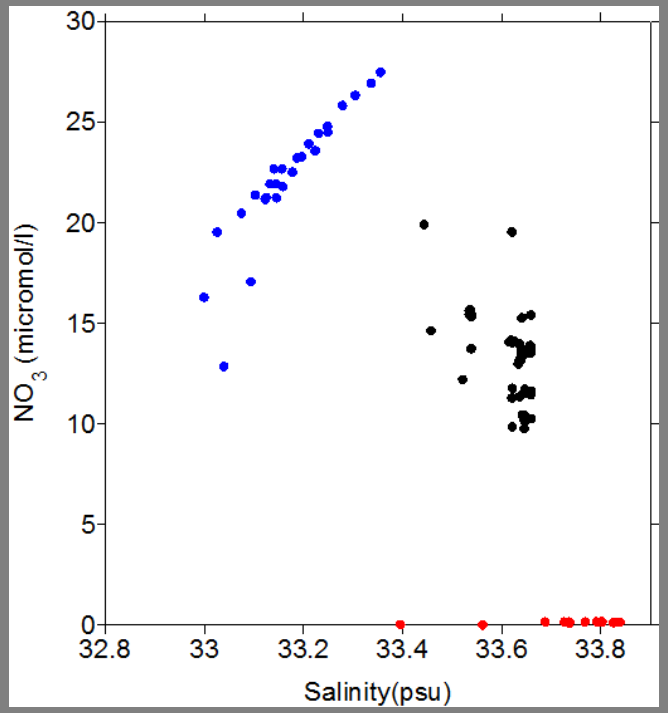
$$\frac{\partial P}{\partial t} + \underset{\rho}{\vec{u}} \cdot \nabla P = \frac{\partial P'}{\partial t}$$

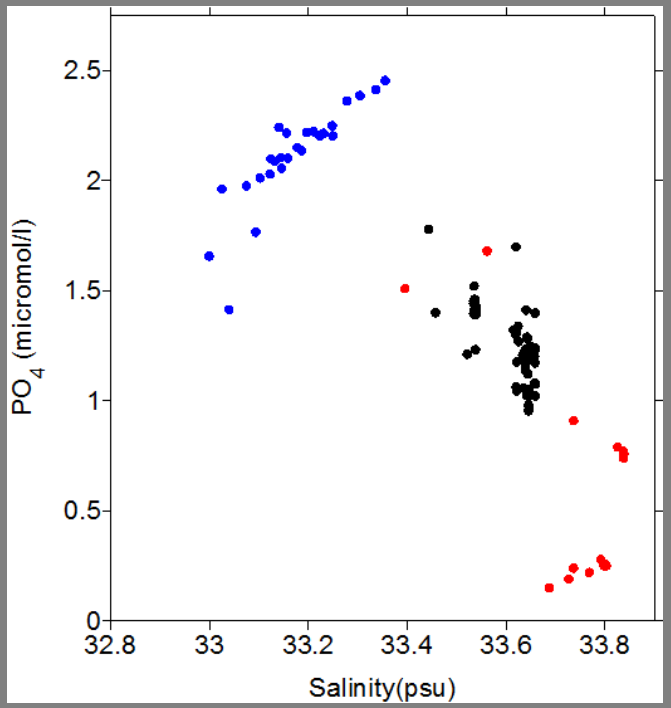
$$\frac{\partial P'}{\partial t} = \frac{\partial}{\partial z} Kz \frac{\partial P}{\partial z} + F_{MM} - G_R$$

- Oshoro March 12-15th
- Hakuho April 6-7th
- Kofu January 29th

0-150m

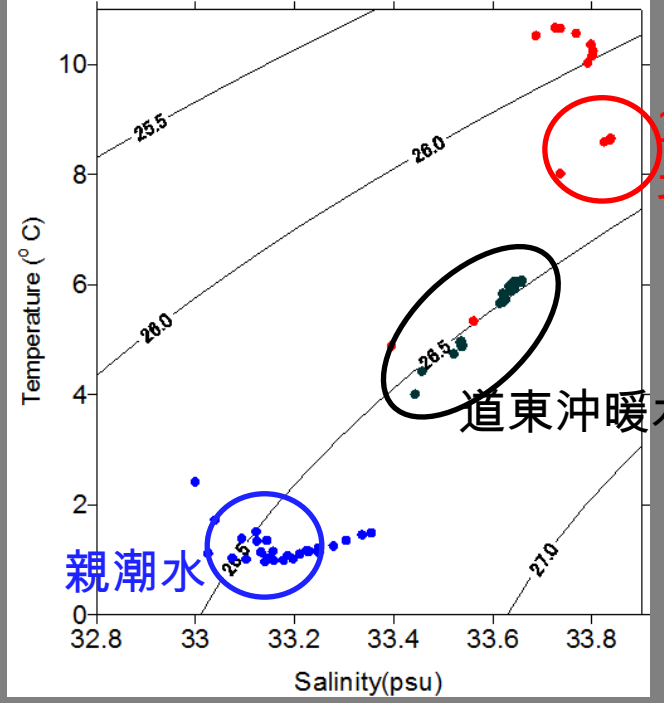


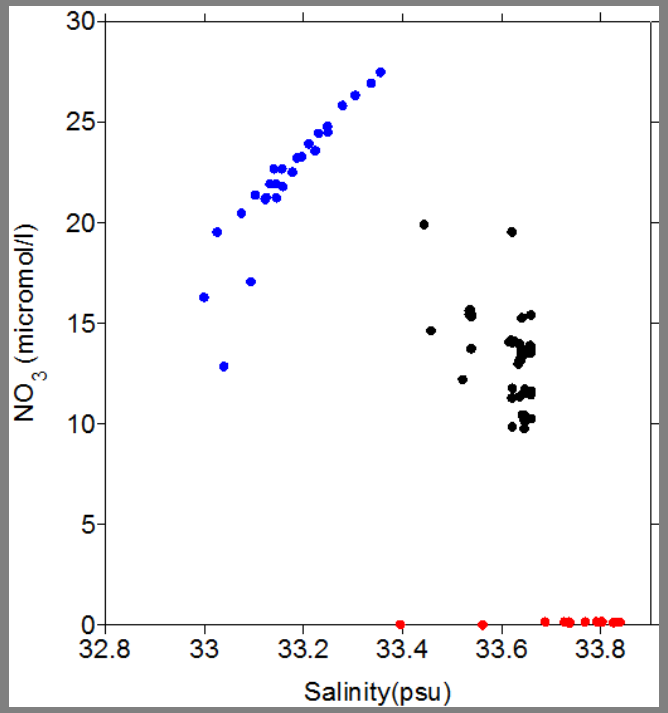


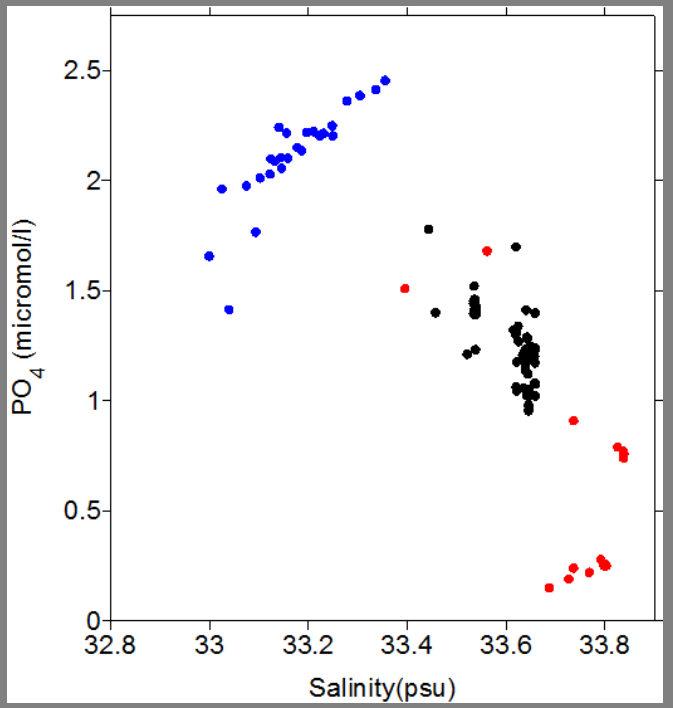


- Oshoro March 12-15th
- Hakuho April 6-7th
- Kofu January 29th

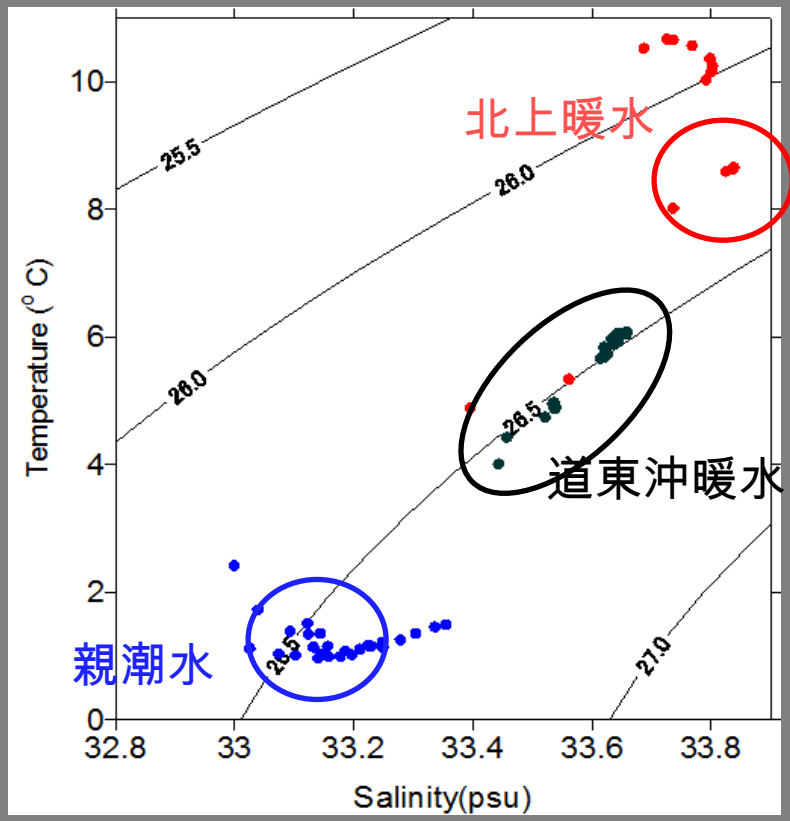
0-150m





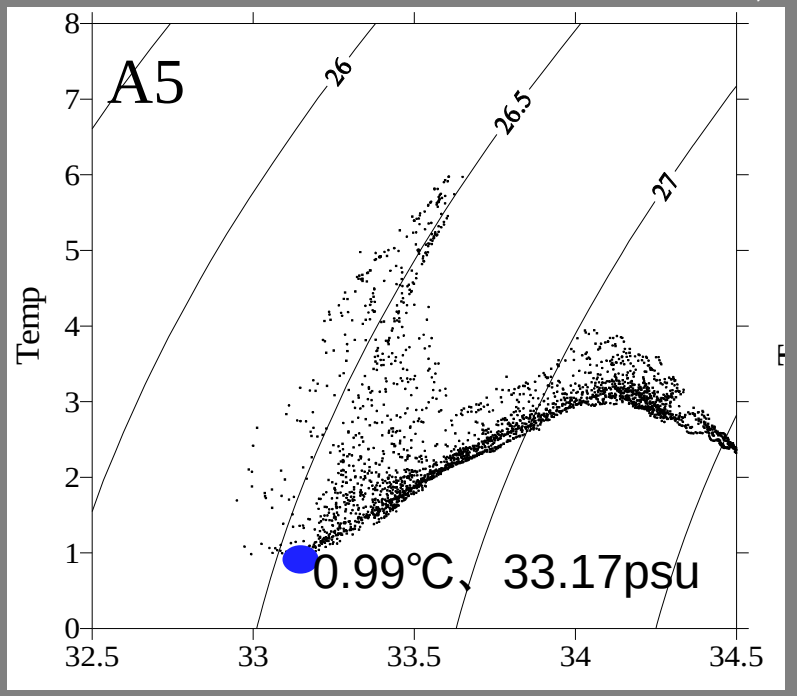


3月おしょろ観測結果 A5

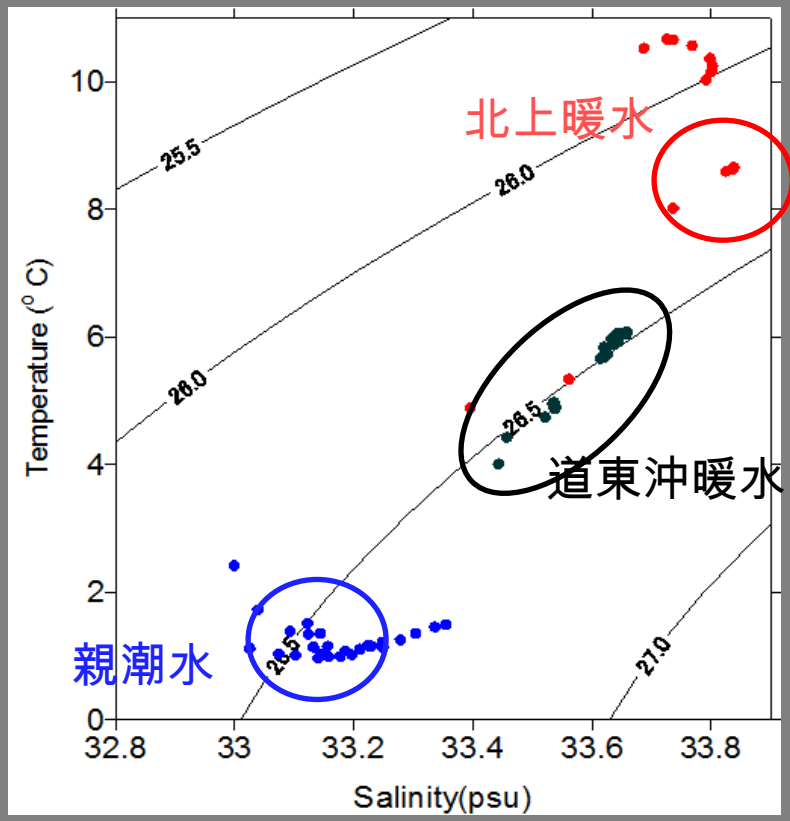


4月白鳳丸観測結果A5

8.66℃、33.84psu

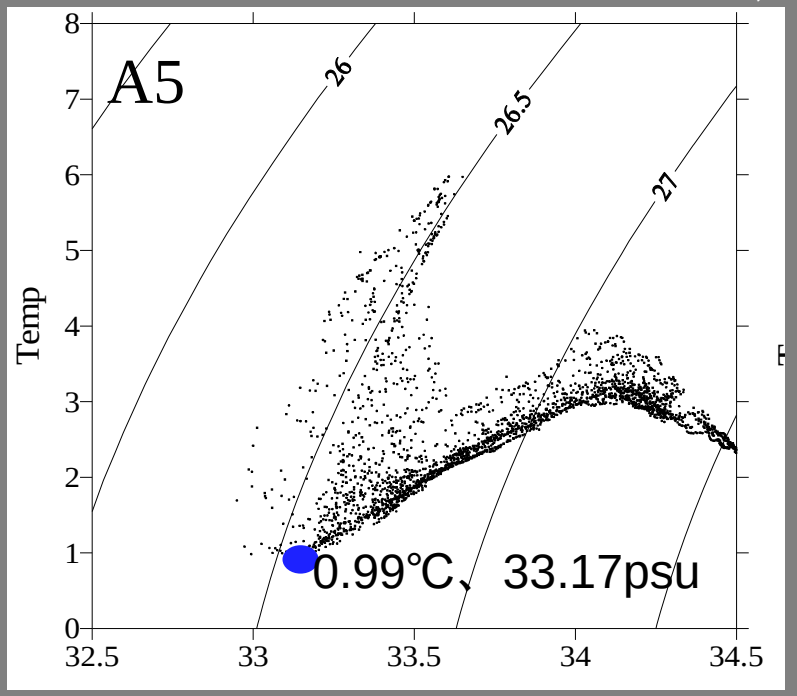


3月おしょろ観測結果 A5



4月白鳳丸観測結果A5

8.66℃、33.84psu



Effect of Advection and Diffusion