Coordinated Observing in Western Canada Basin


1979-1982
Catastrophic reduction of sea ice and changes in ecosystem
from the Pacific Sector of the Arctic Ocean
Pacific Water
Heat & Nuts
©NASA

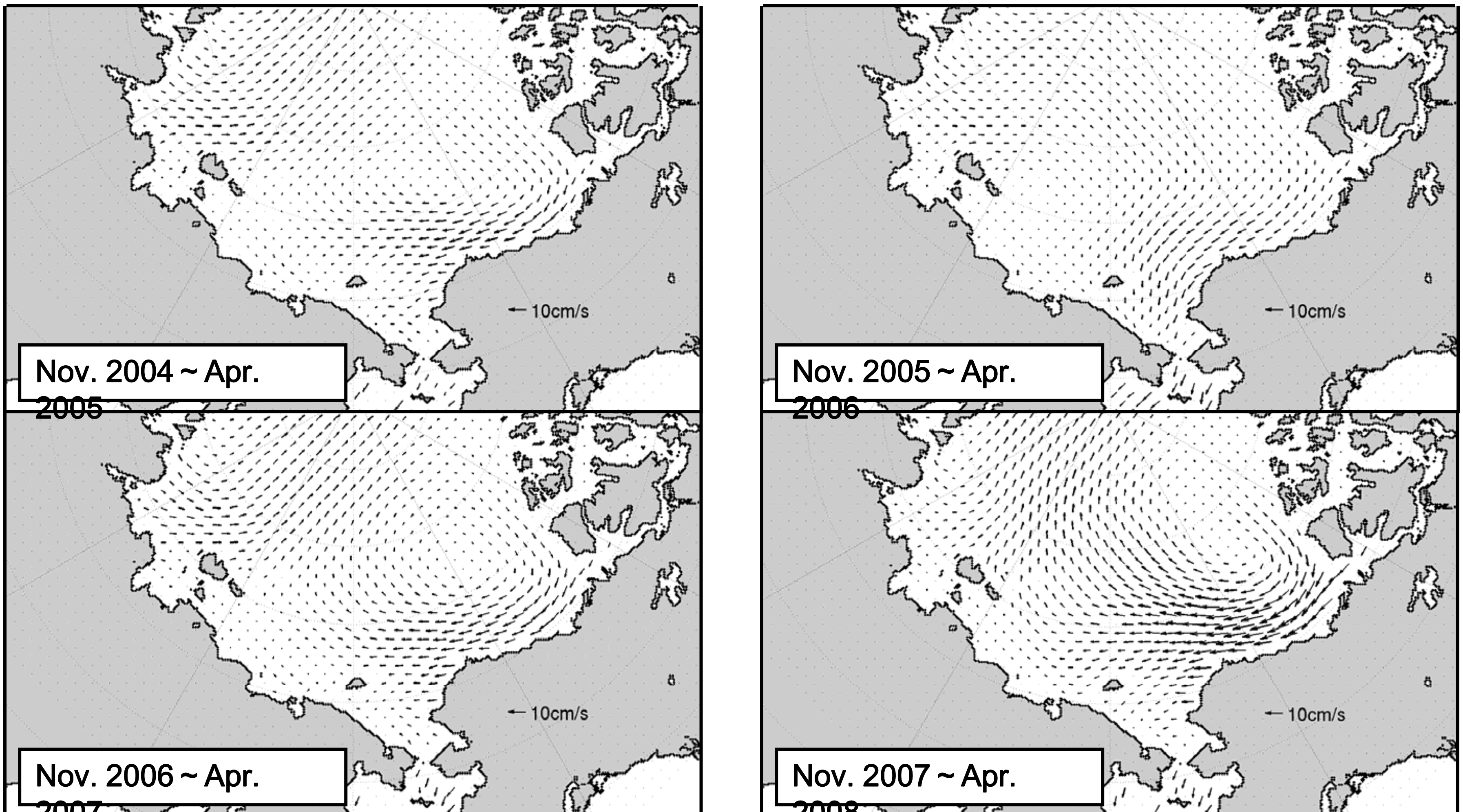
Key issue

Activation of sea ice motion

Ice cream theory is still key to understand the rapid reduction of sea ice

Photo by Koji Shimada

Change in sea ice motion: An insight

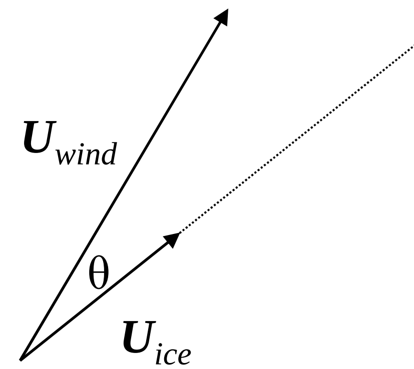


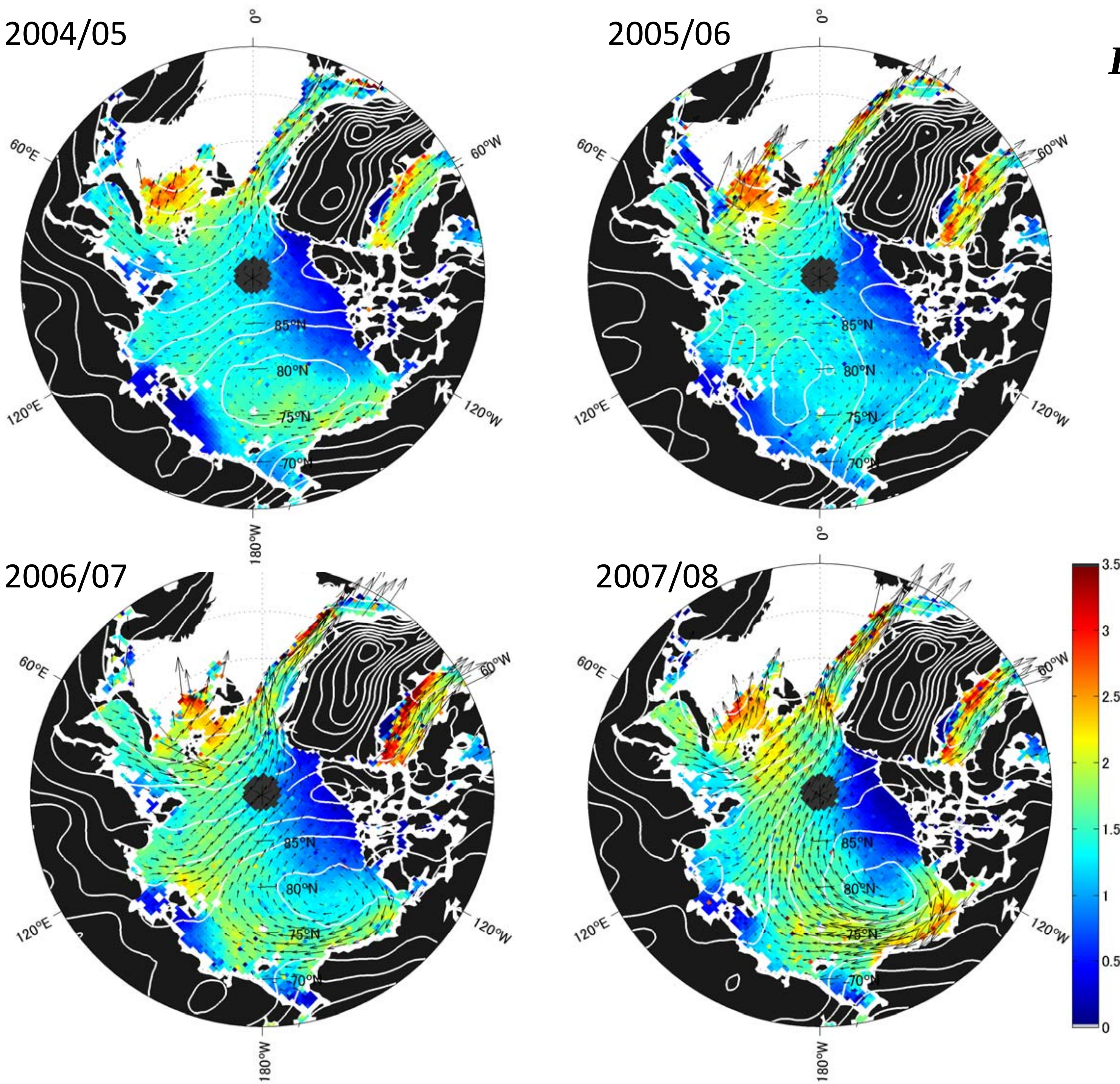
Shimada (2010)

Background color:

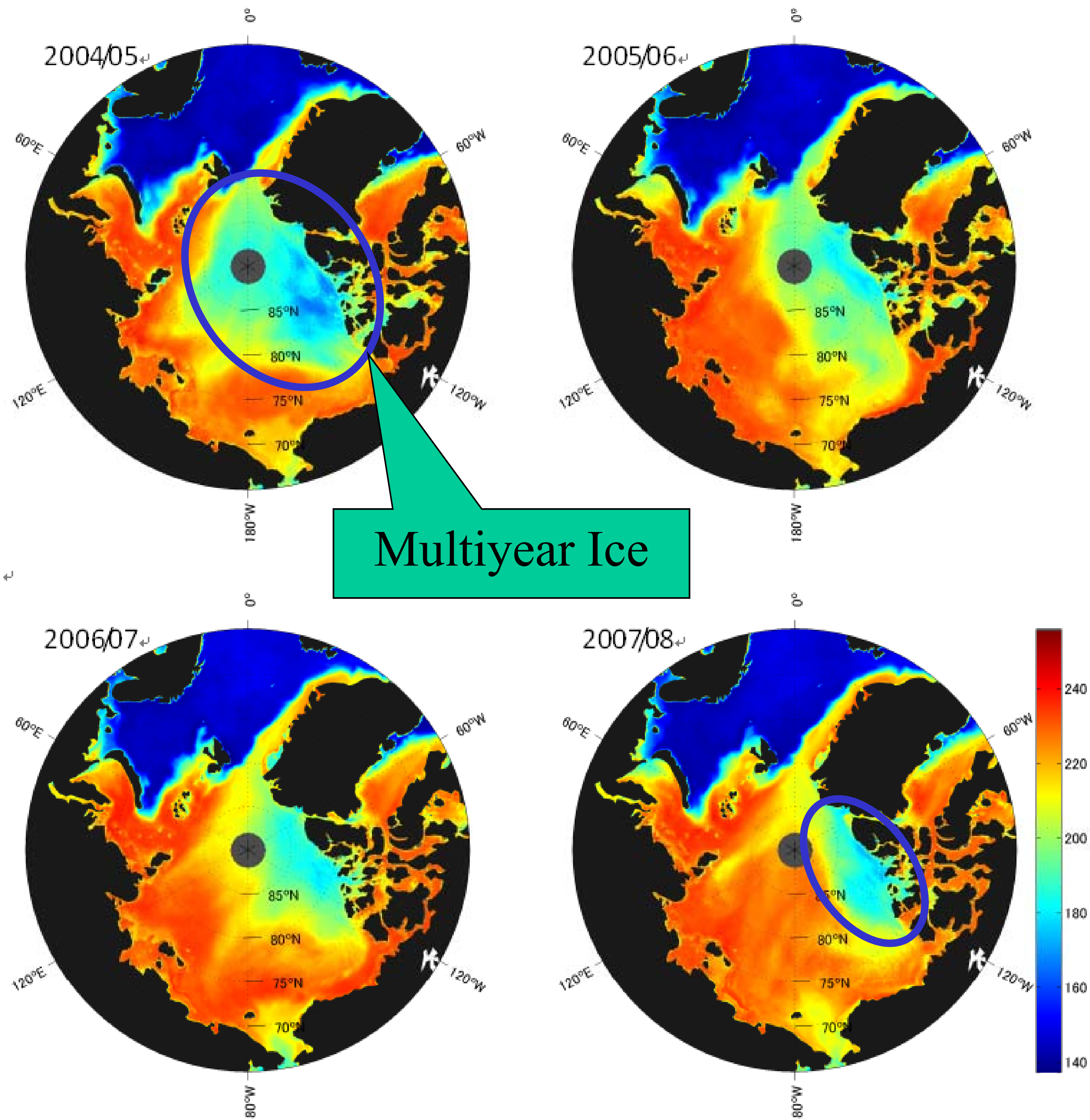
Wind Factor

$=|\boldsymbol{U}_{ice}|/|\boldsymbol{U}_{wind}\cos\theta|$





Yoshizawa, 2011
ASSW Poster



Brightness temperature of 36GHz horizontal channel (AMSR-E)

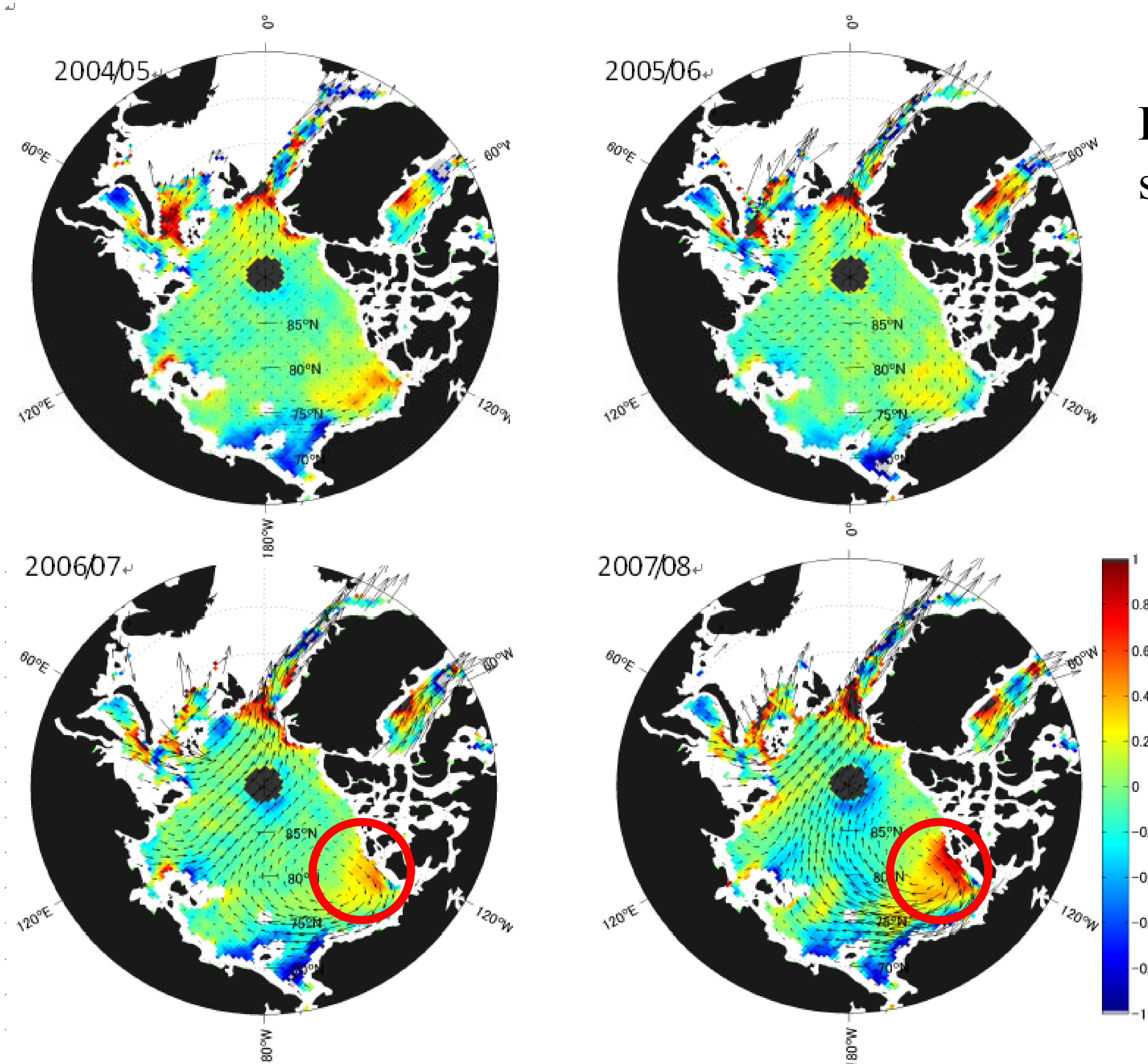
Yoshizawa, 2011
ASSW Poster

Ice cream, just picked out from the refrigerator, is difficult to be rotated.

10 minutes later, it is easy to rotate!

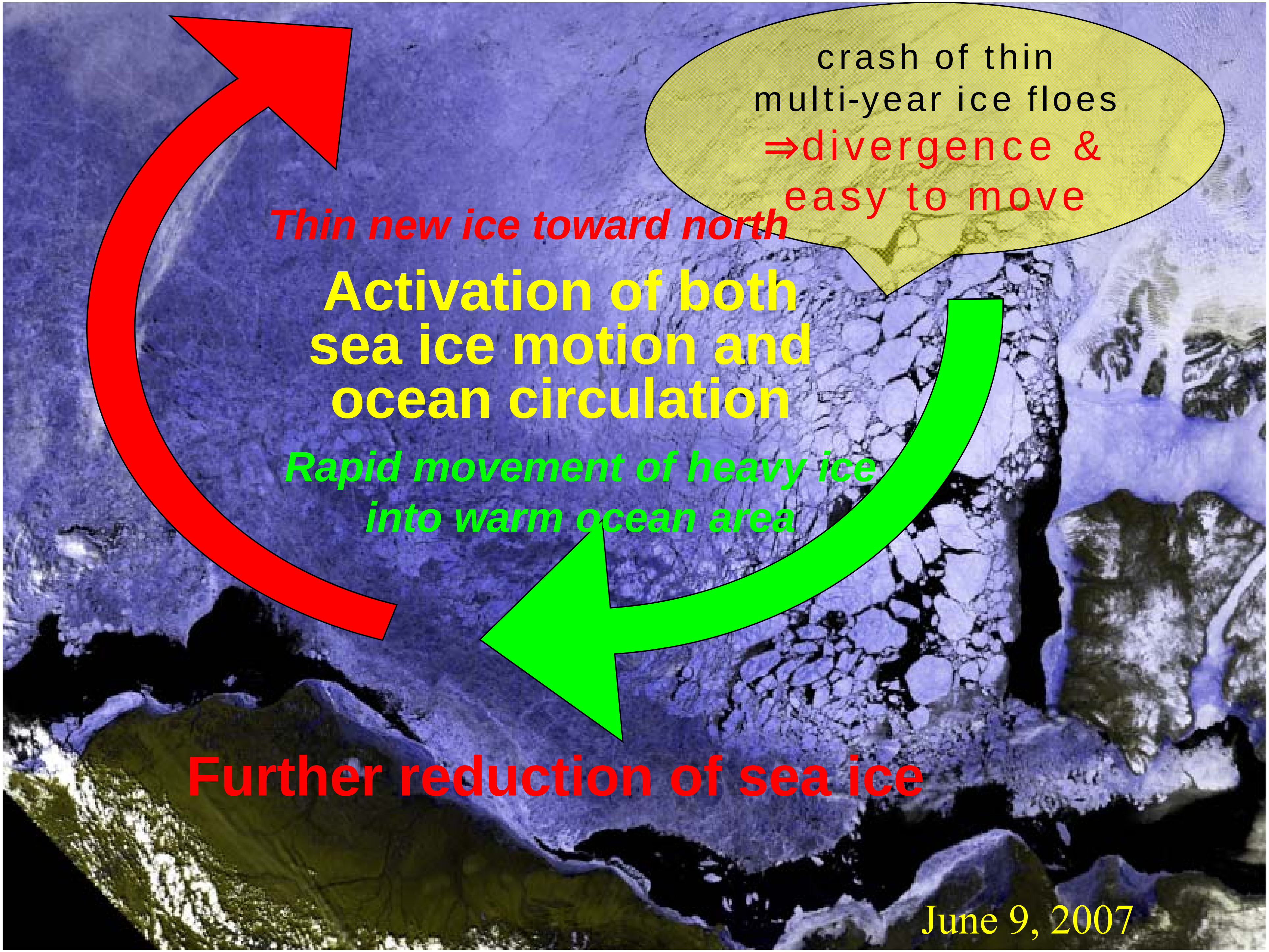
Ice cream theory

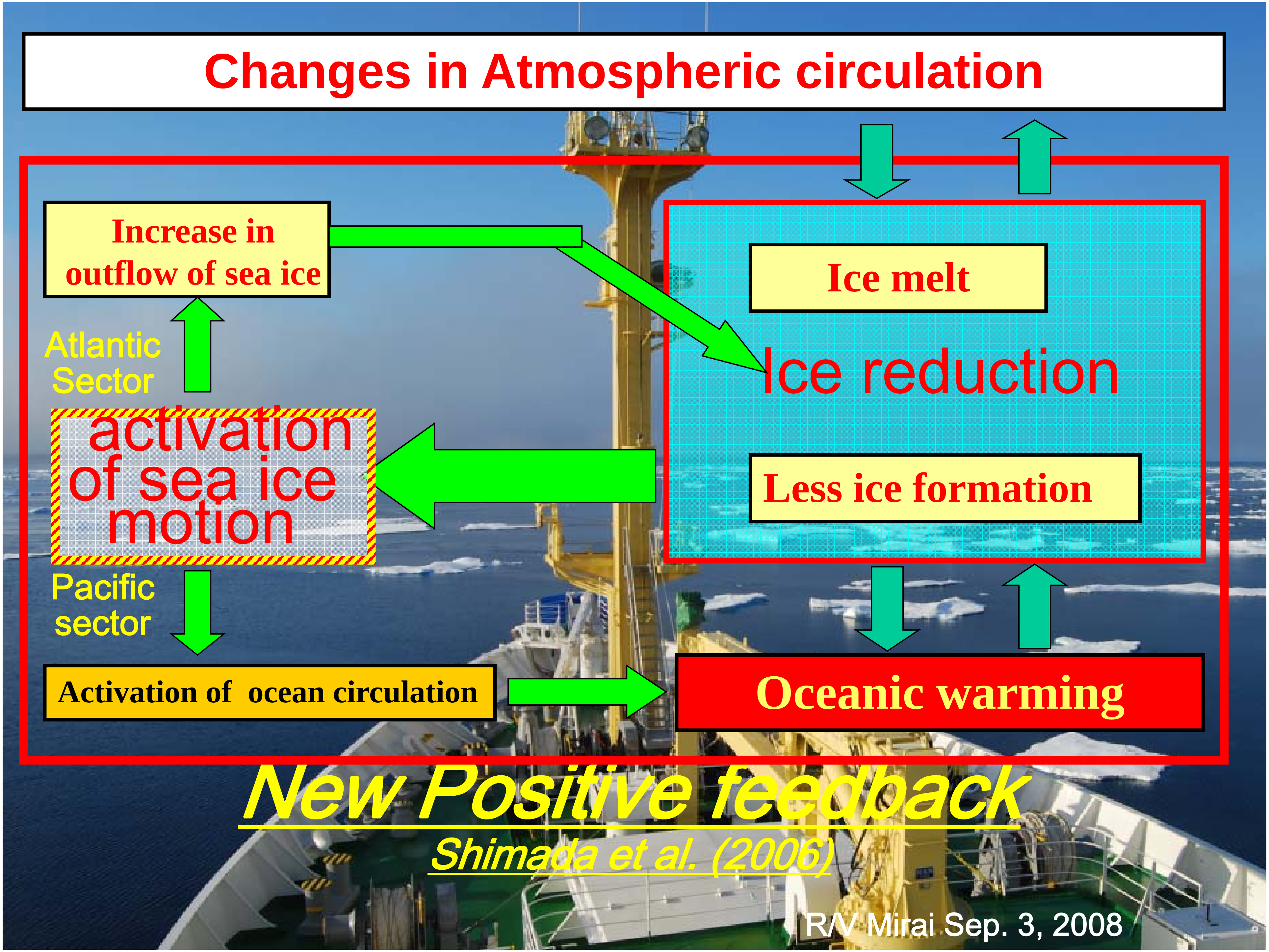
Conceptual idea into quantitative understanding using satellite data



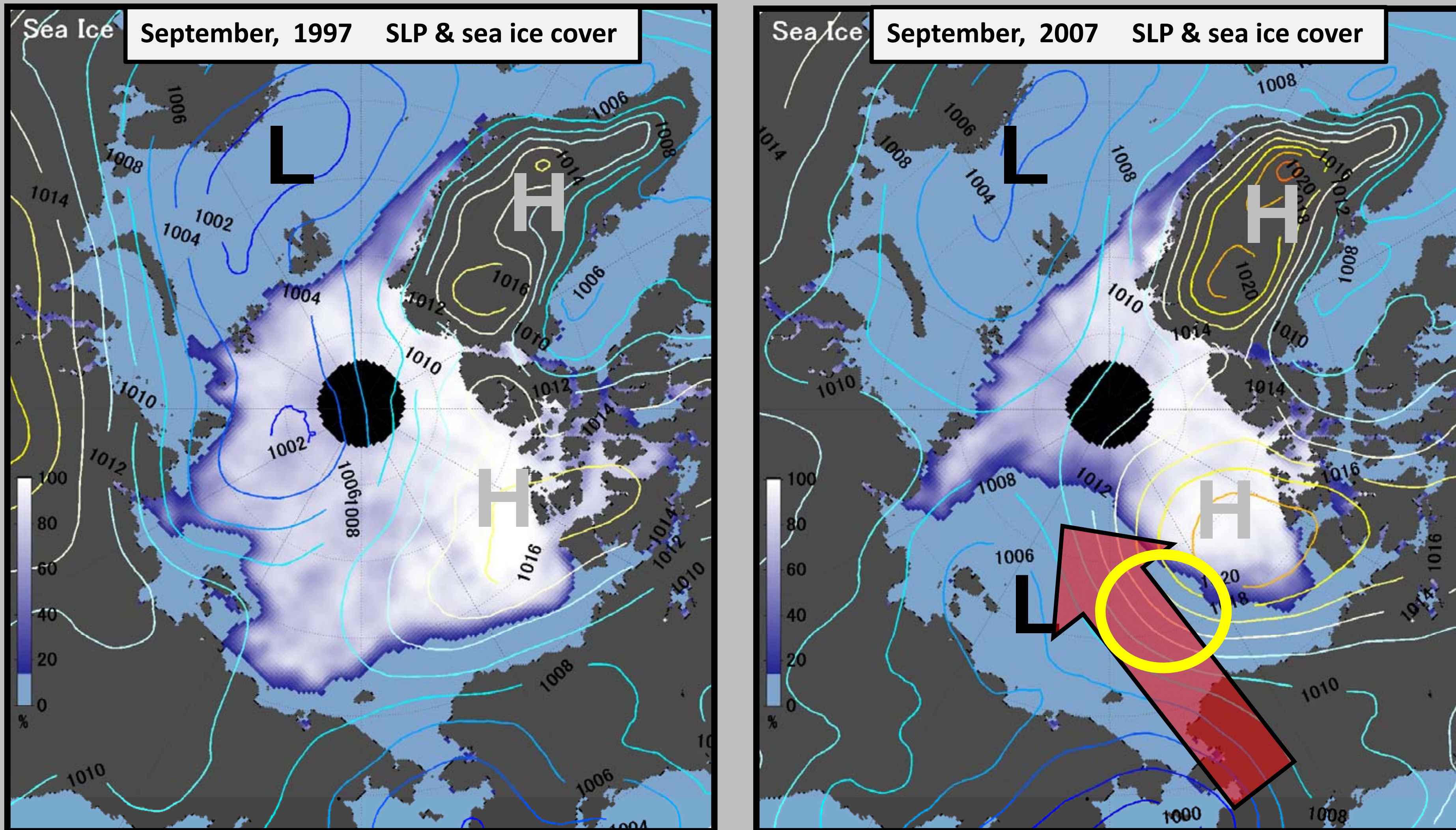
Divergence of sea ice motion

Yoshizawa, 2011
ASSW Poster

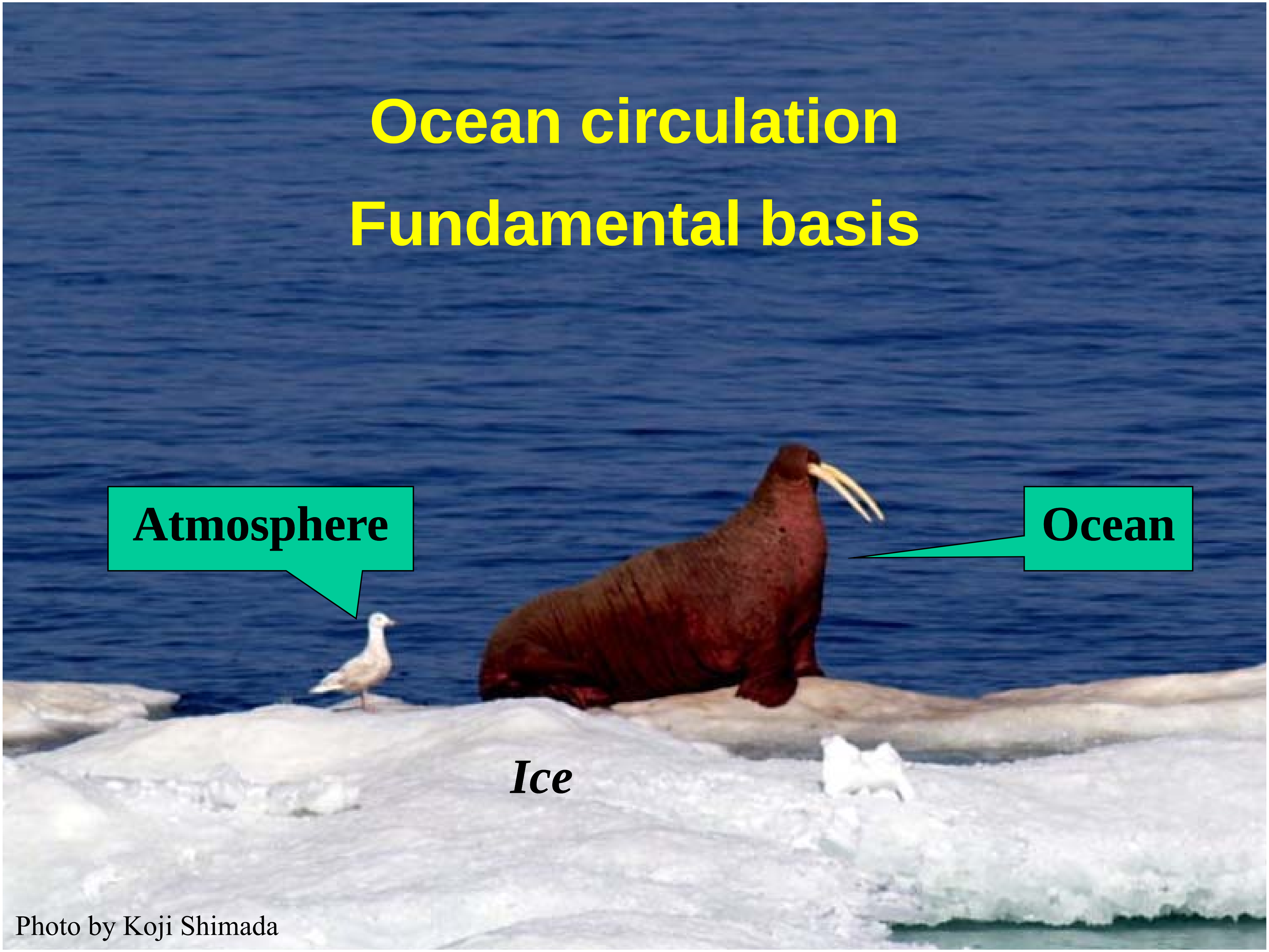

crash of thin
multi-year ice floes
⇒divergence &
easy to move
Thin new ice toward north
Activation of both
sea ice motion and
ocean circulation
Rapid movement of heavy ice
into warm ocean area
Further reduction of sea ice
June 9, 2007

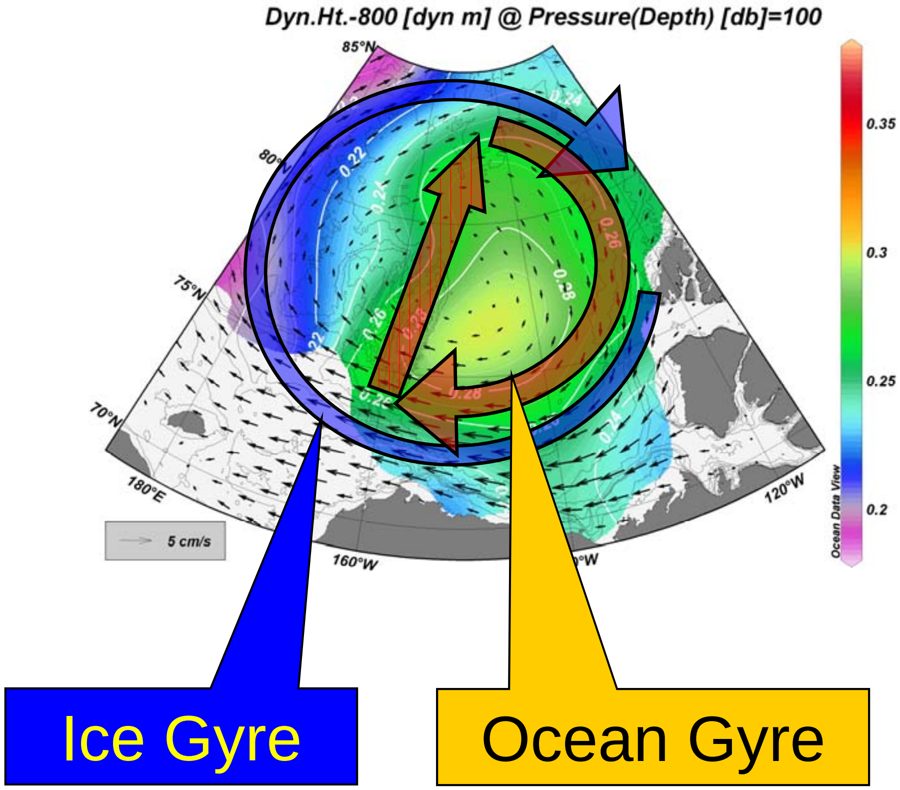


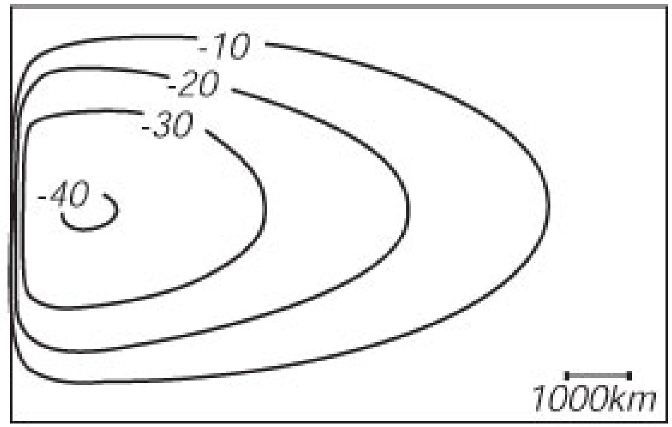
Changes in Atmospheric circulation
Increase in outflow of sea ice
Atlantic Sector
activation of sea ice motion
Pacific sector
Activation of ocean circulation
Ice melt
Ice reduction
Less ice formation
Oceanic warming
New Positive feedback
Shimada et al. (2006)
R/V Mirai Sep. 3, 2008



Southerly wind affected sea ice retreat. This was true.
However, what established the dipole pattern in SLP?
This is much more important to understand the catastrophic change rather than correlation between wind and sea ice extent

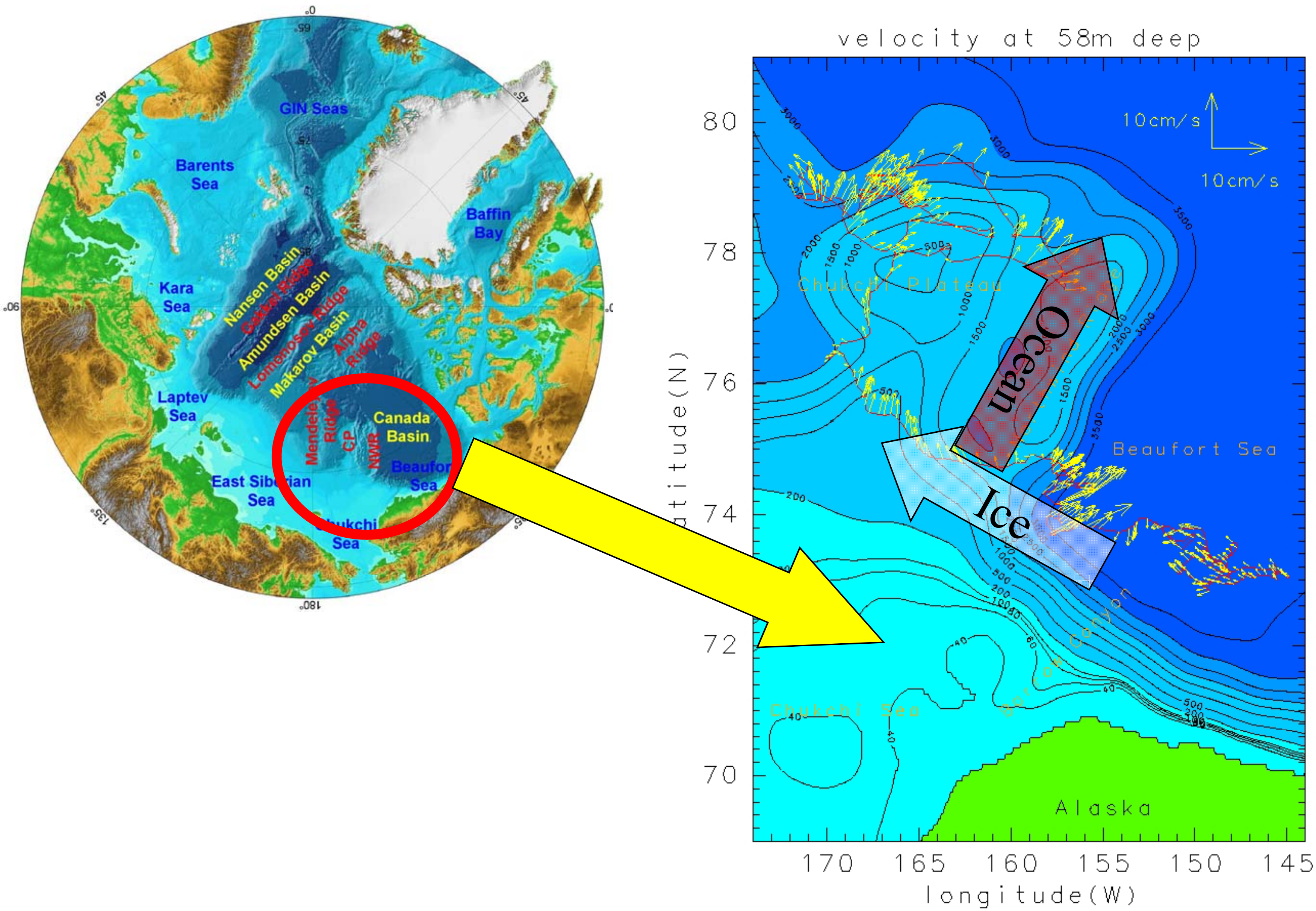

Ocean circulation
Fundamental basis
Atmosphere
Ocean
Ice
Photo by Koji Shimada





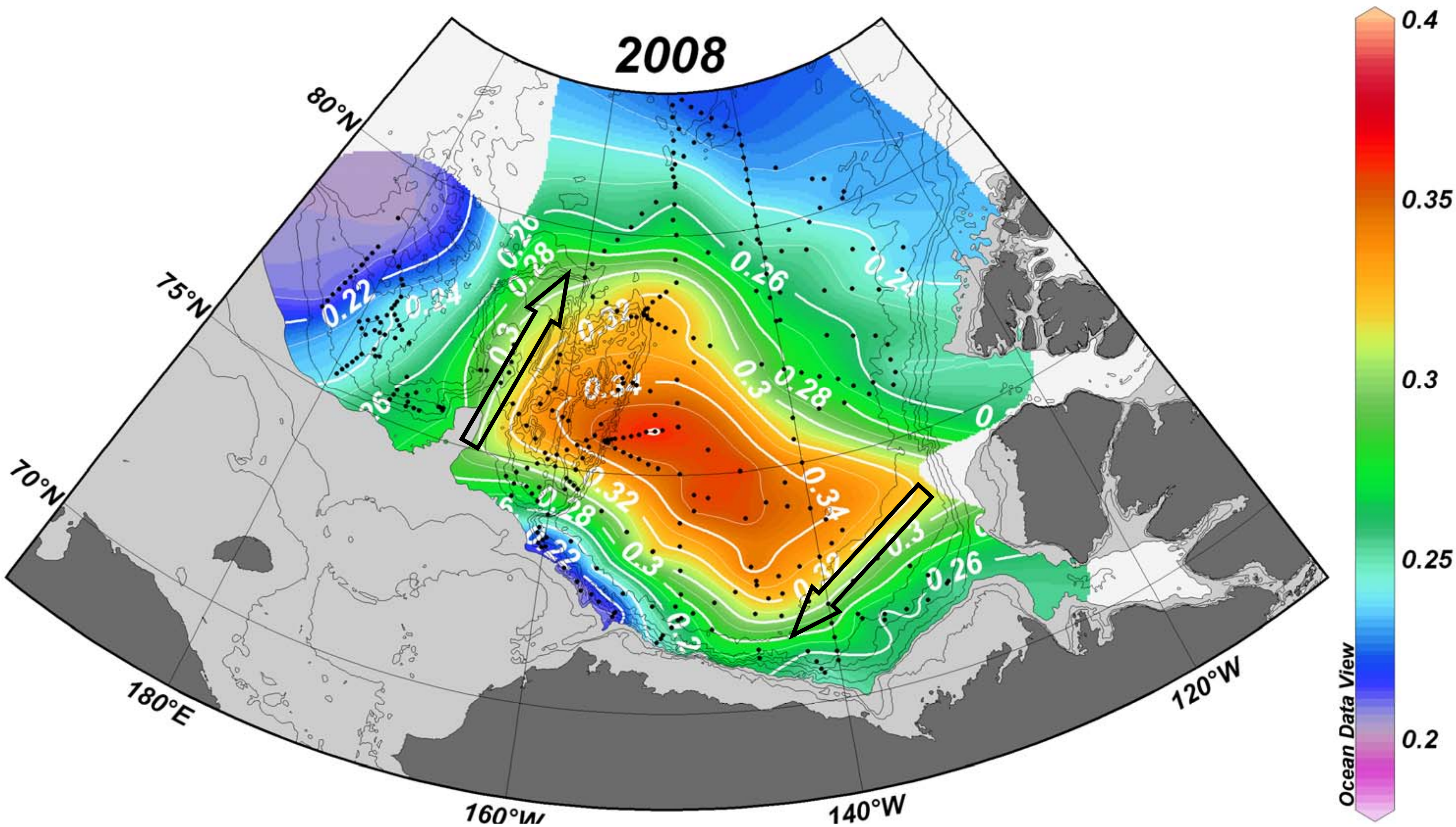
β-plane

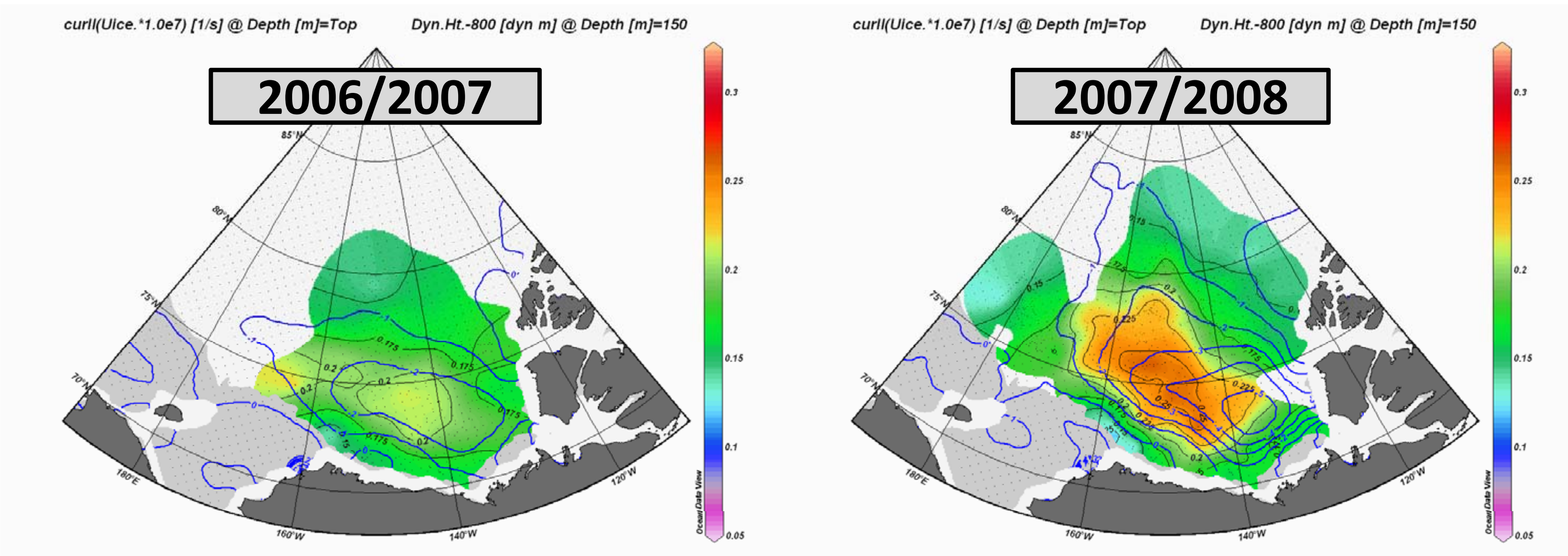
This is principal "Oceanic Beaufort Gyre" established by surface forcing and wave dynamics.
It is different from Beaufort High and Beaufort Ice Gyre.



Sumata & Shimada (2007)

Ocean circulation is steered by seafloor topography



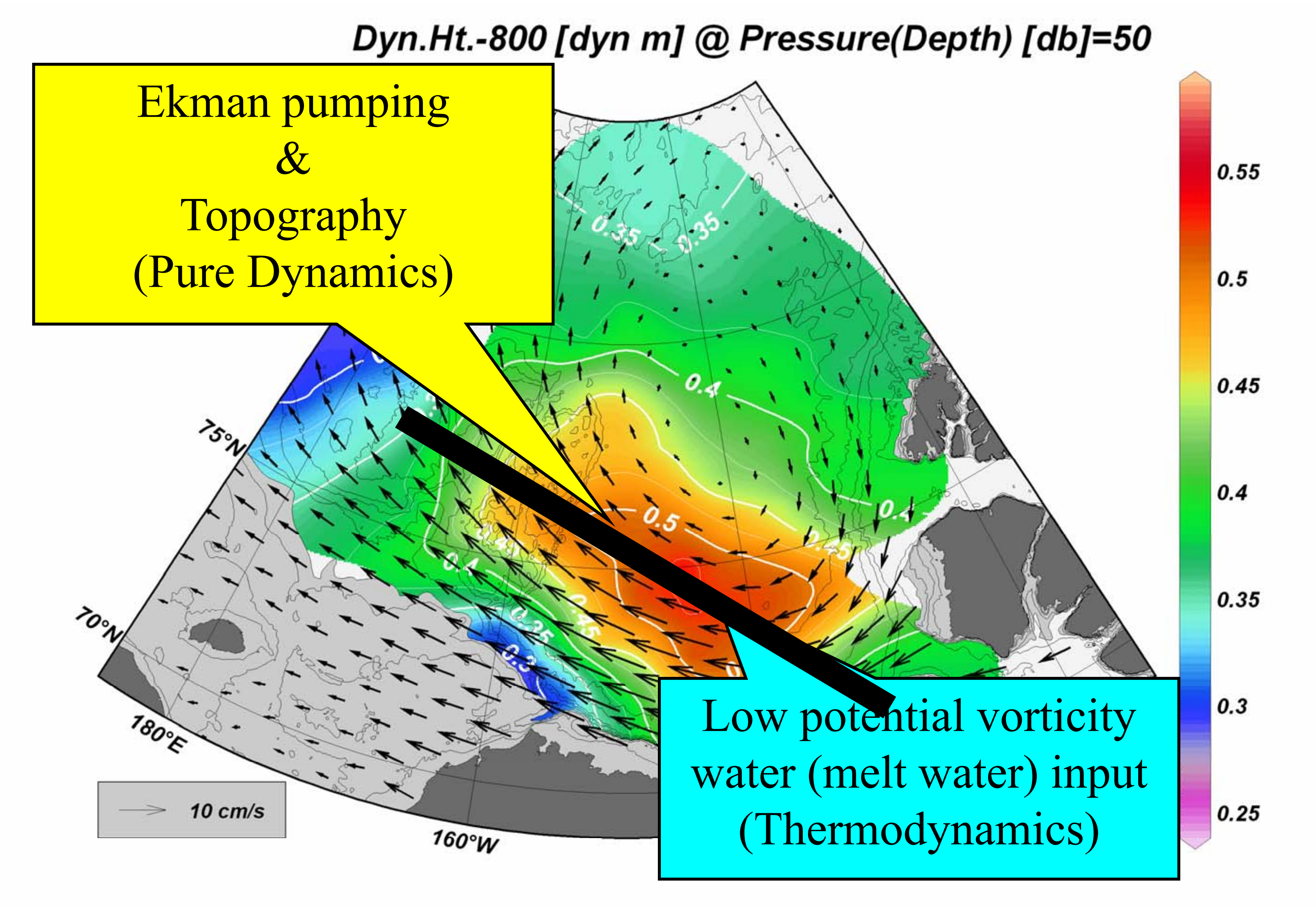


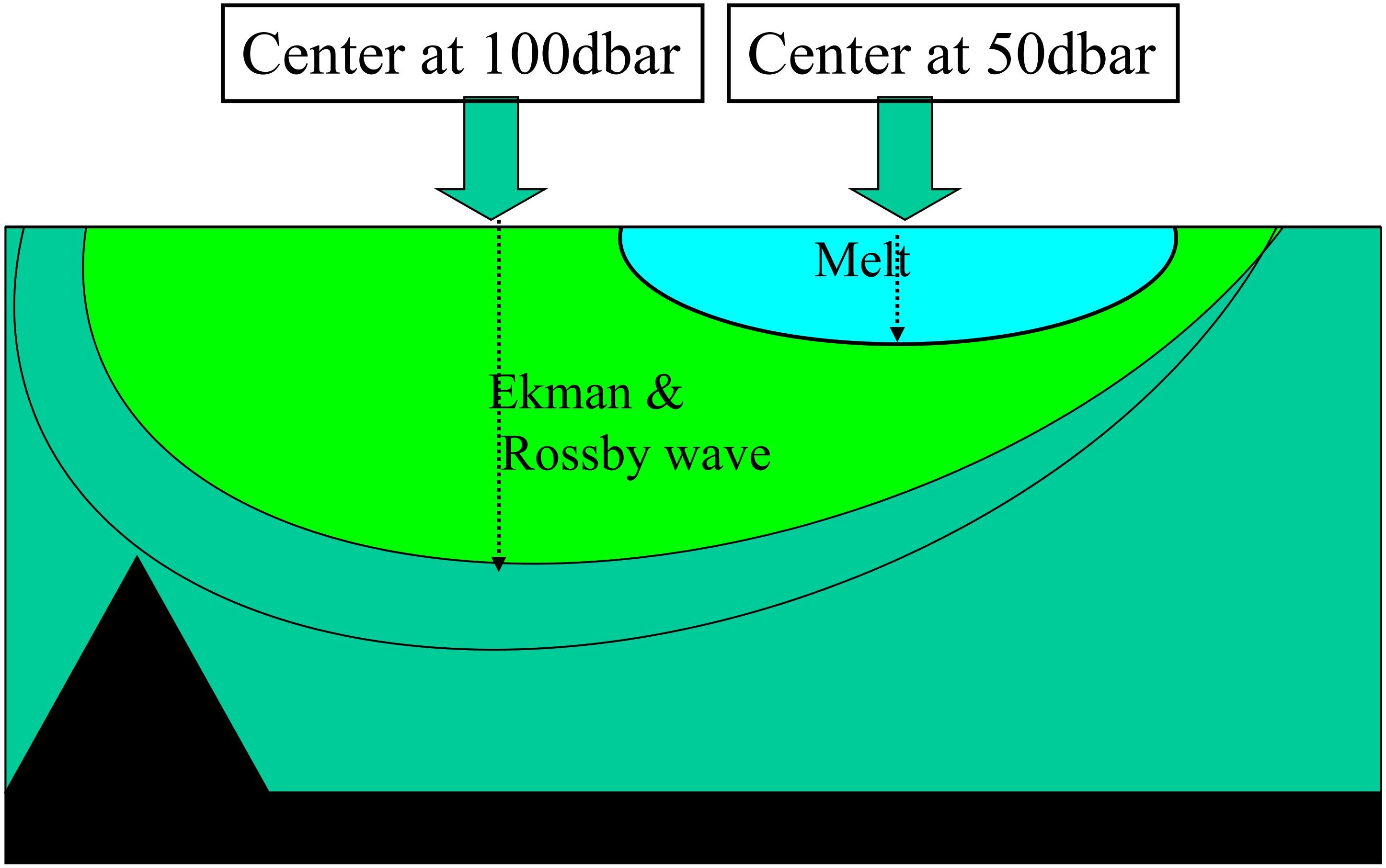
Ocean dynamic height (colors) & curl of sea ice motion (contours)

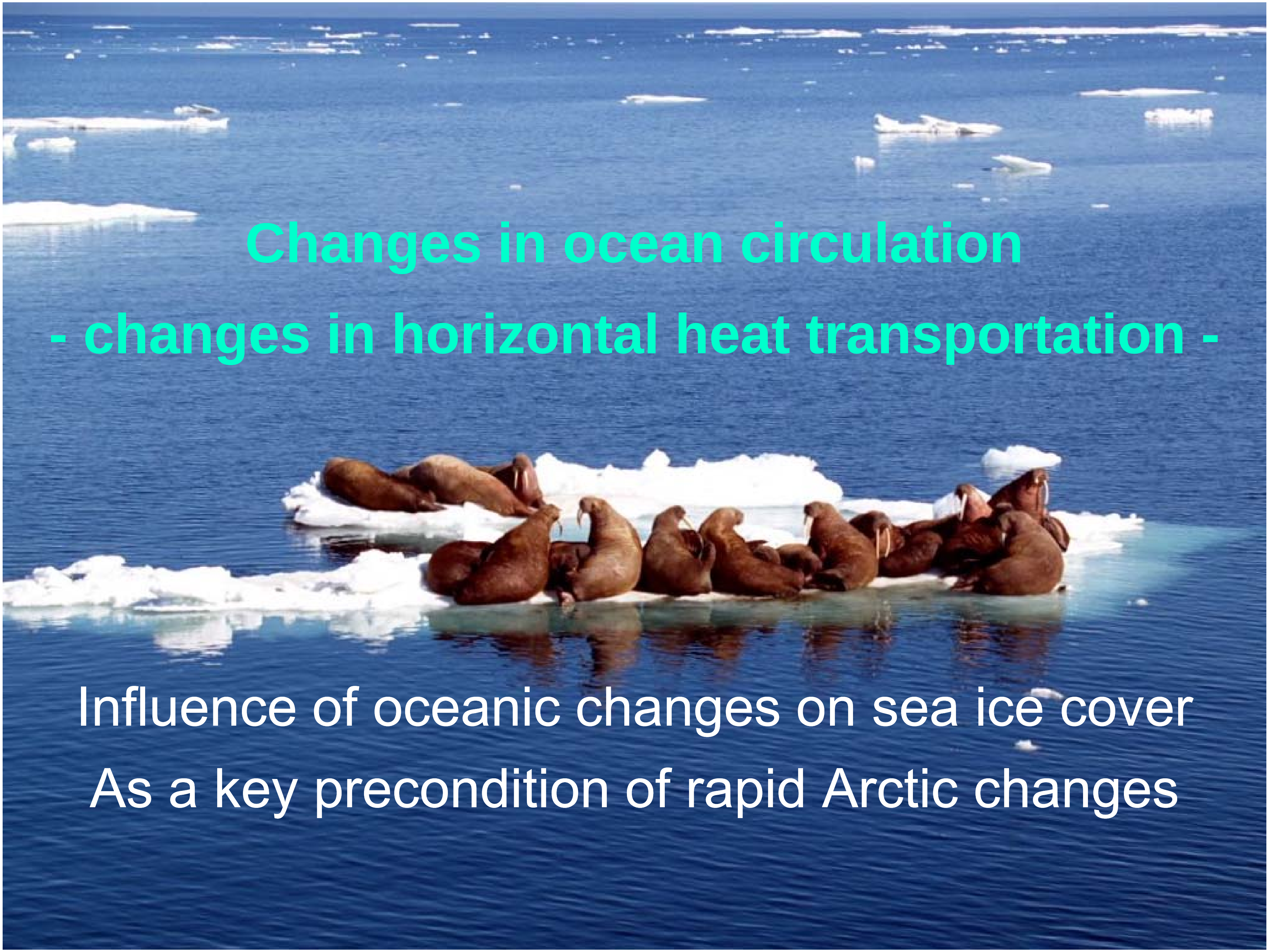
★ Strength of upper ocean circulation does not linearly respond to strength of Ekman Pumping caused by sea ice motion driven by wind.

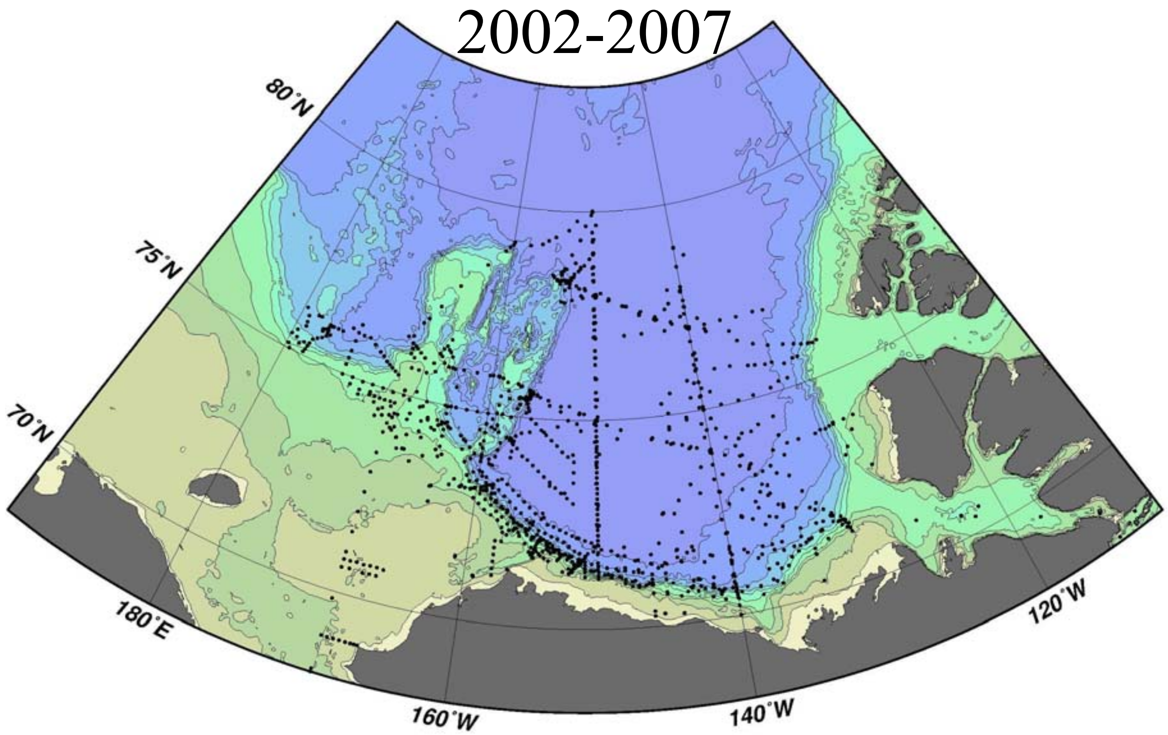
★ We should recall basic dynamics toward precise understanding and responding.

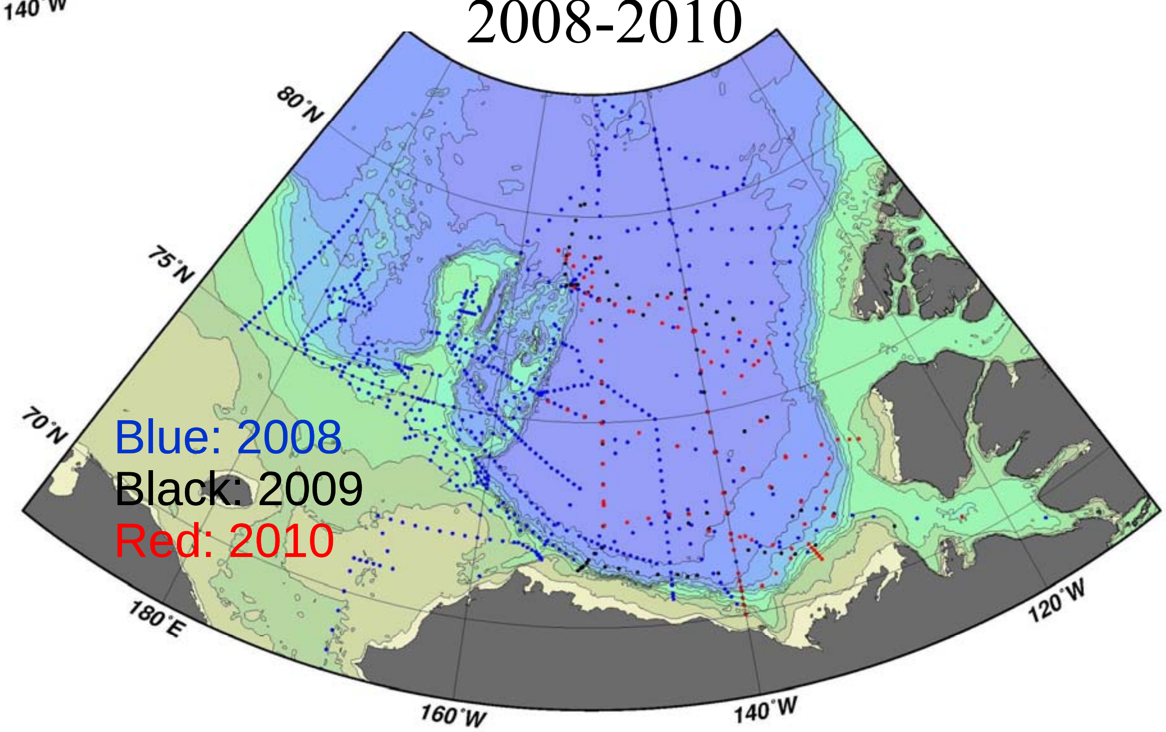
Ocean circulation at 50 dbar and 150 dbar



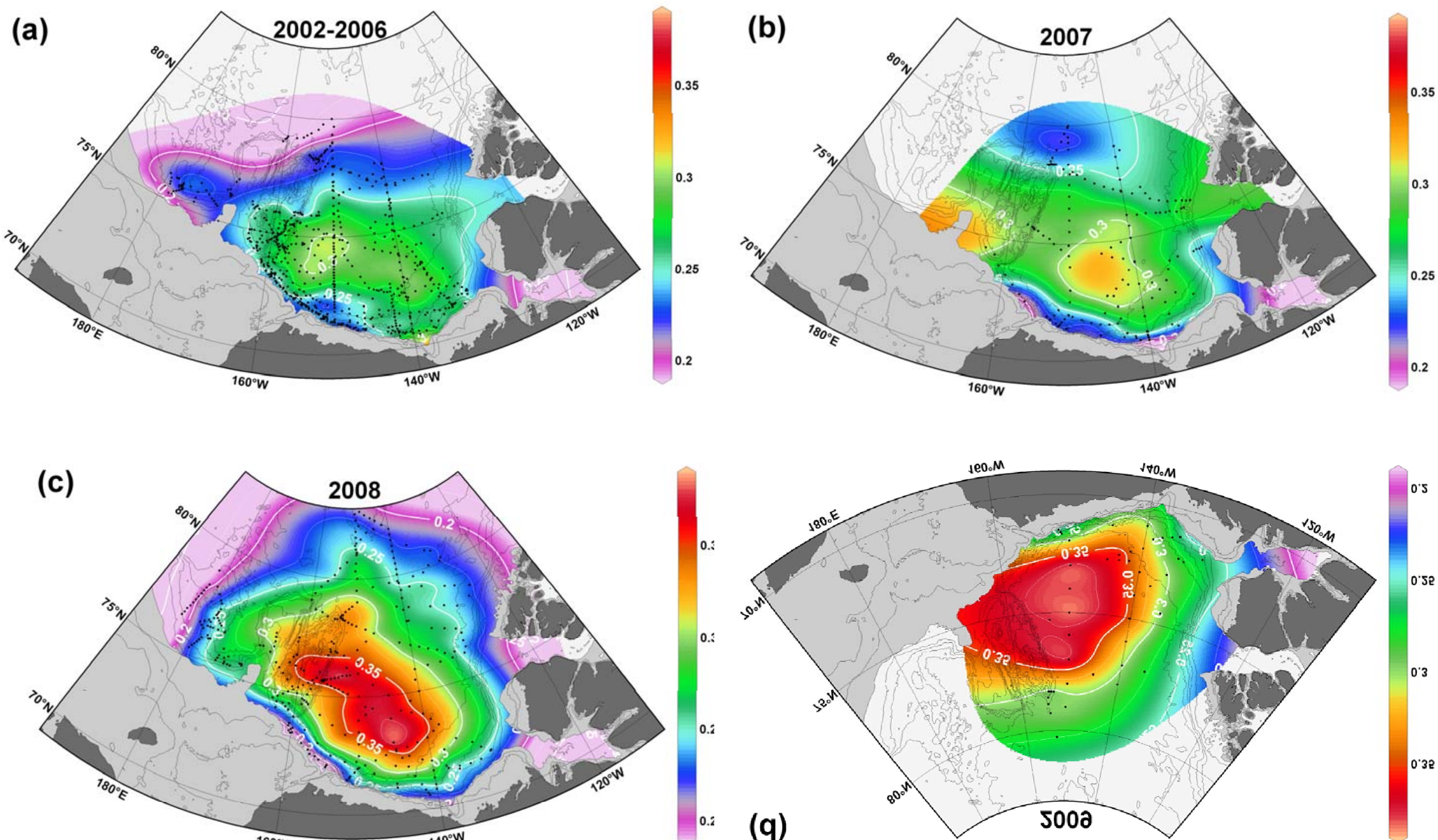

Center at 100dbar
Center at 50dbar
Melt
Ekman &
Rossby wave


Changes in ocean circulation
- changes in horizontal heat transportation -
Influence of oceanic changes on sea ice cover
As a key precondition of rapid Arctic changes


2002-2007
80°N
75°N
70°N
180°E
160°W
140°W
120°W

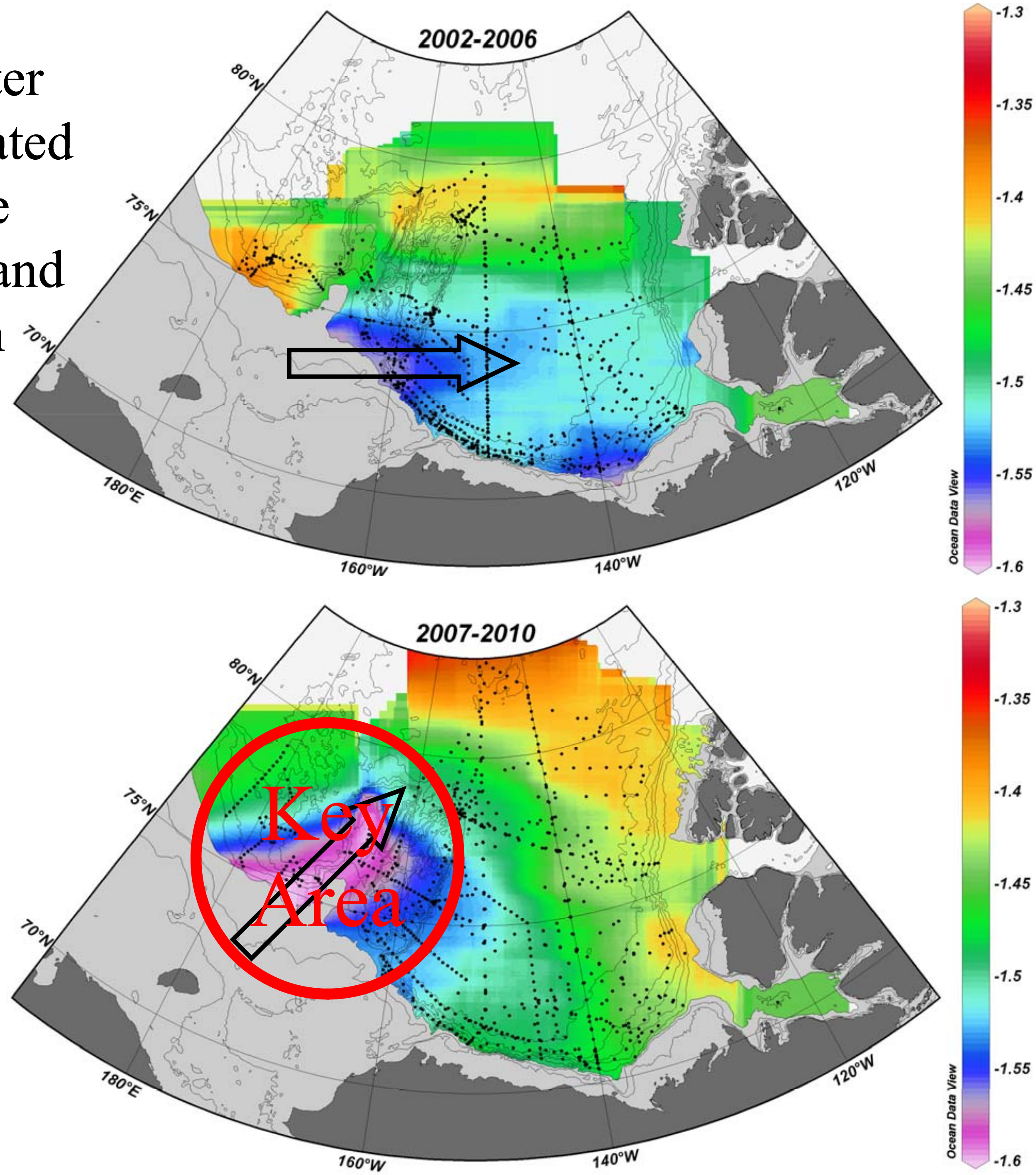

2008-2010
80°N
75°N
70°N
Blue: 2008
Black: 2009
Red: 2010
180°E
160°W
140°W
120°W

Changes in geostrophic ocean circulation at 100dbar (~100m)
reference pressure: 800dbar

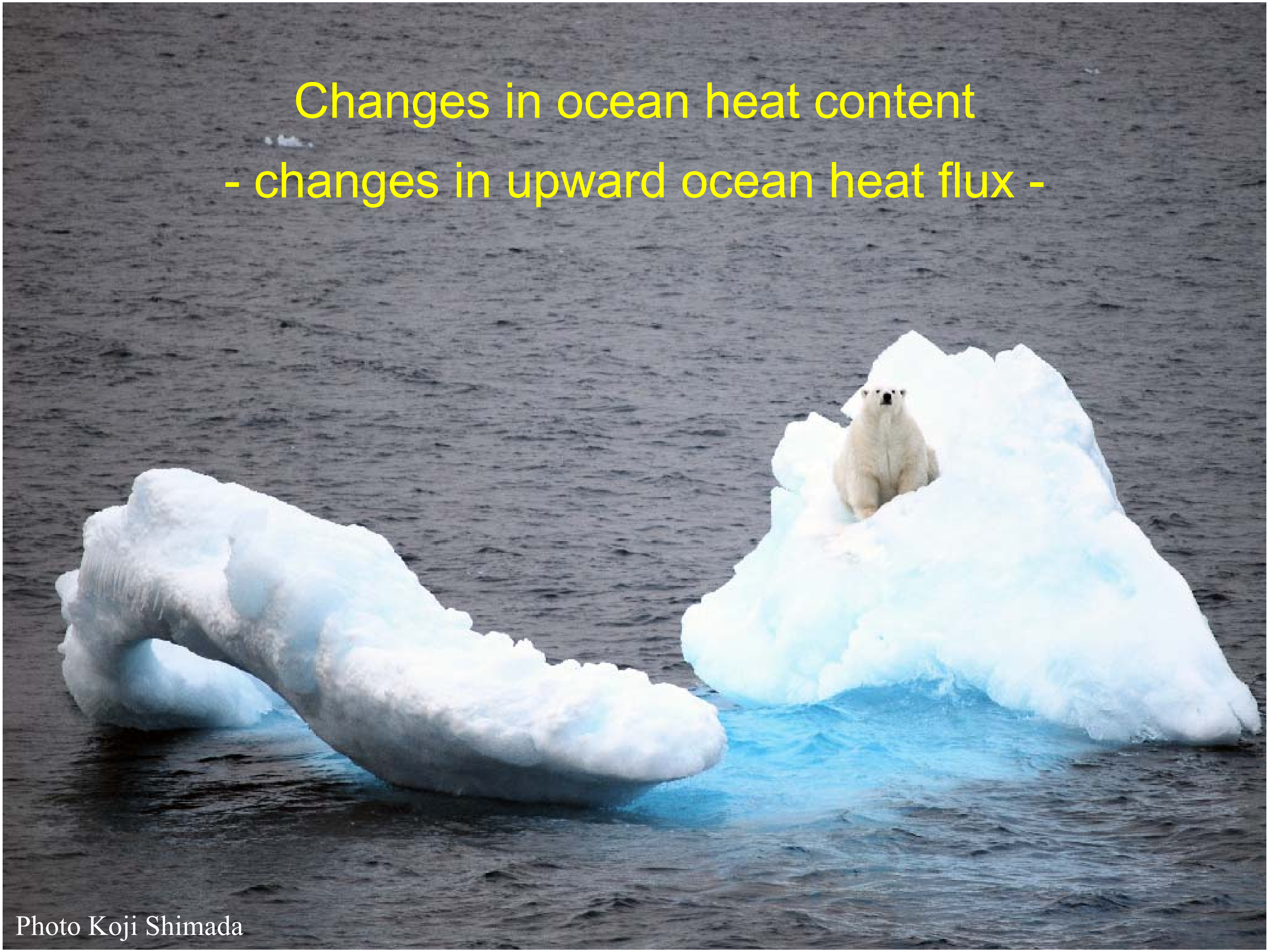


Shimada (2010)

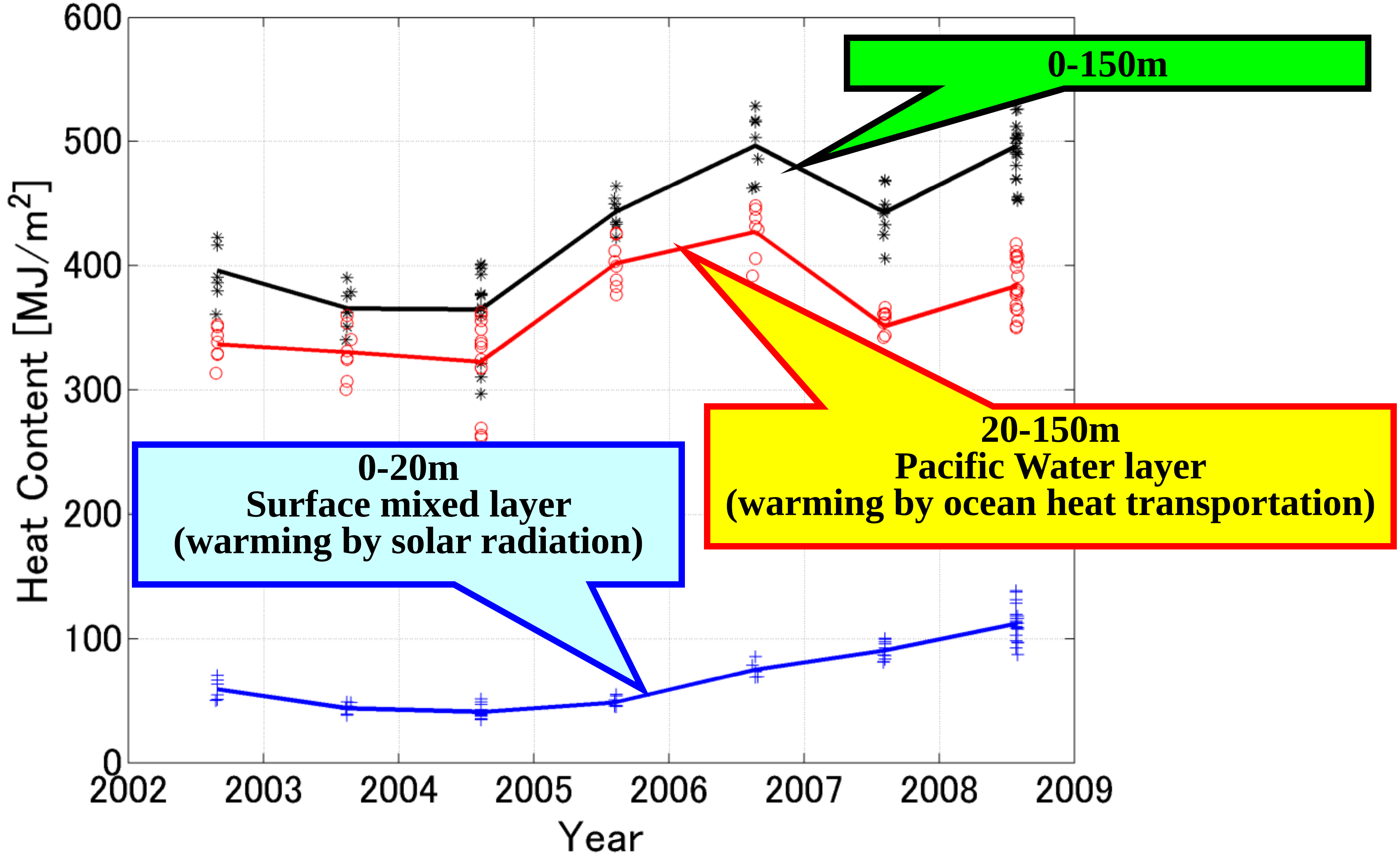
Changes in Pacific Winter Water distribution associated with the changes of the upper ocean circulation and freshwater distribution



- Spreading pathway of nutrient rich Pacific Winter Water has moved west after IPY in the basin.

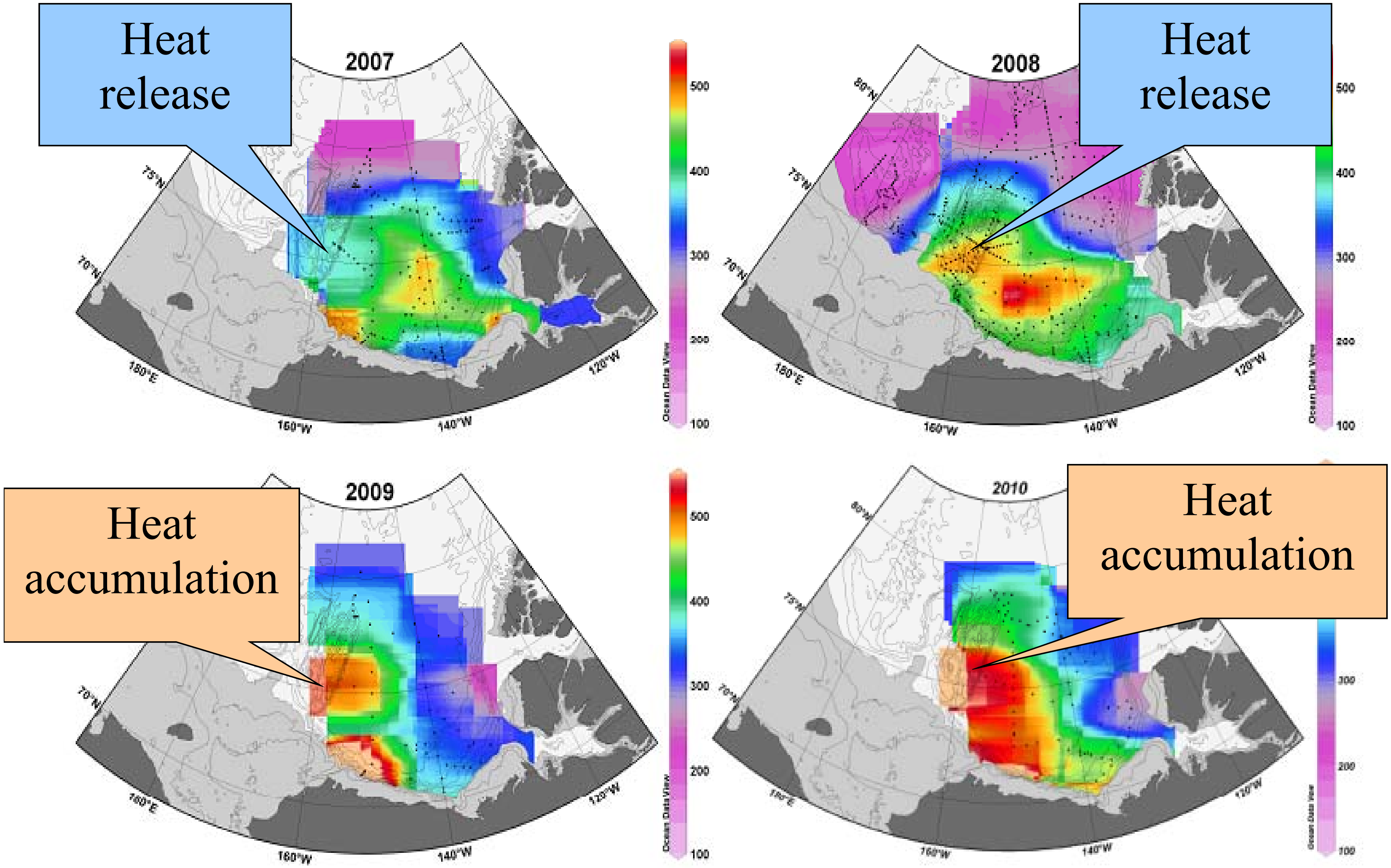

Changes in ocean heat content
- changes in upward ocean heat flux -
Photo Koji Shimada

Changes of ocean heat content



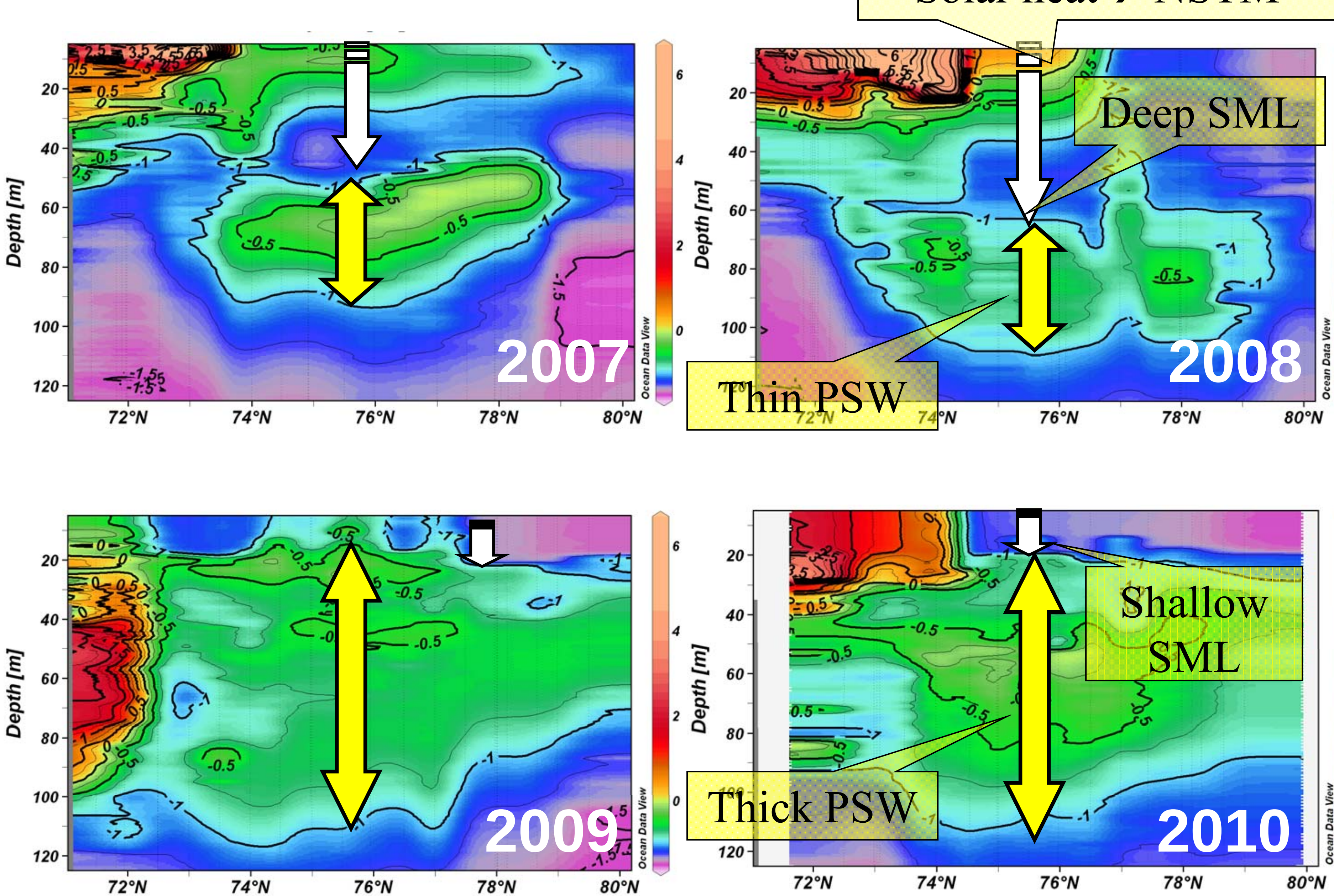
Ocean heat content(74-76°N, 150-158°W).

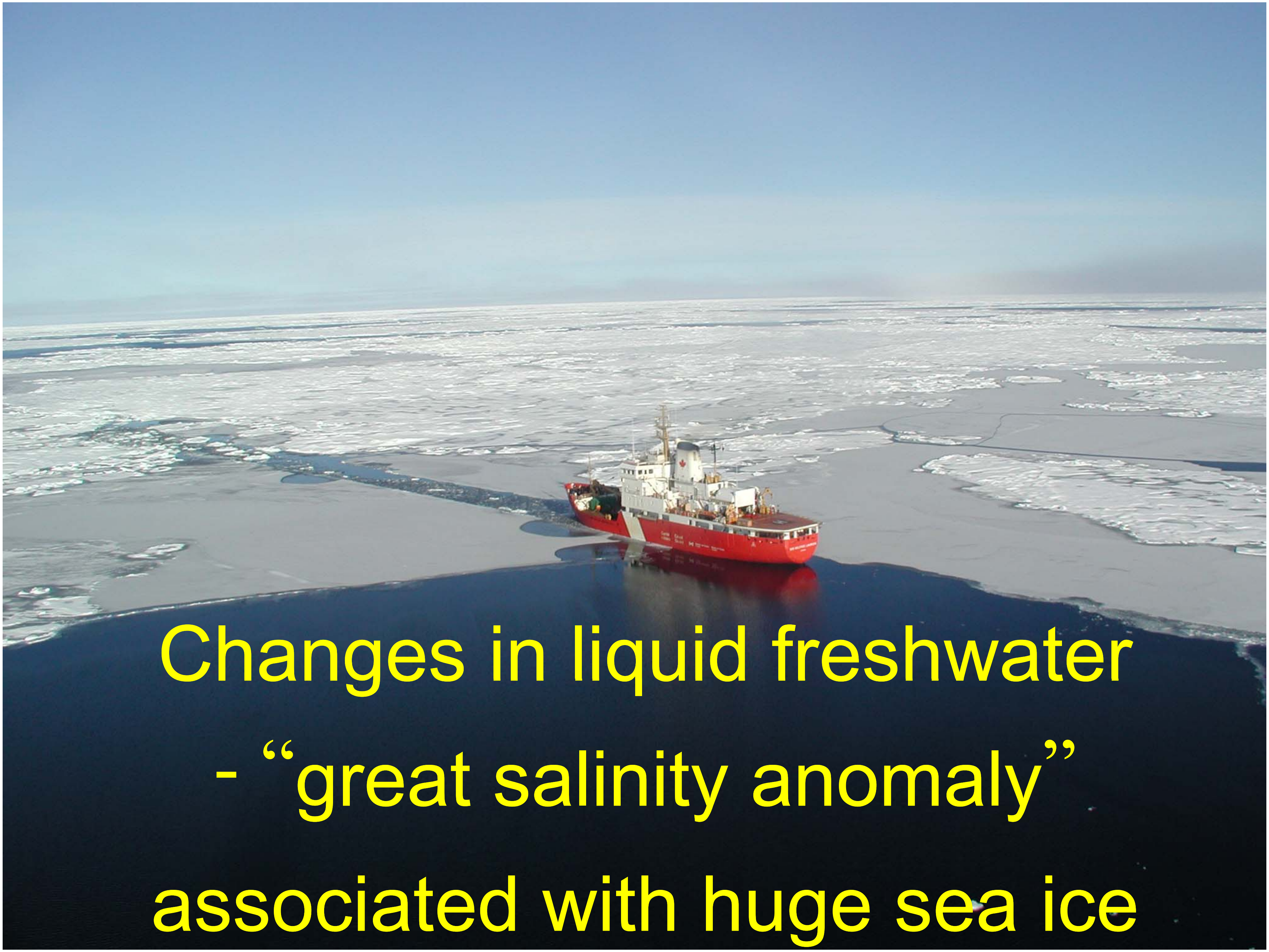
Changes in heat content [MJ/m^2] within Pacific Water layer (20-150m)



Shimada (2010)

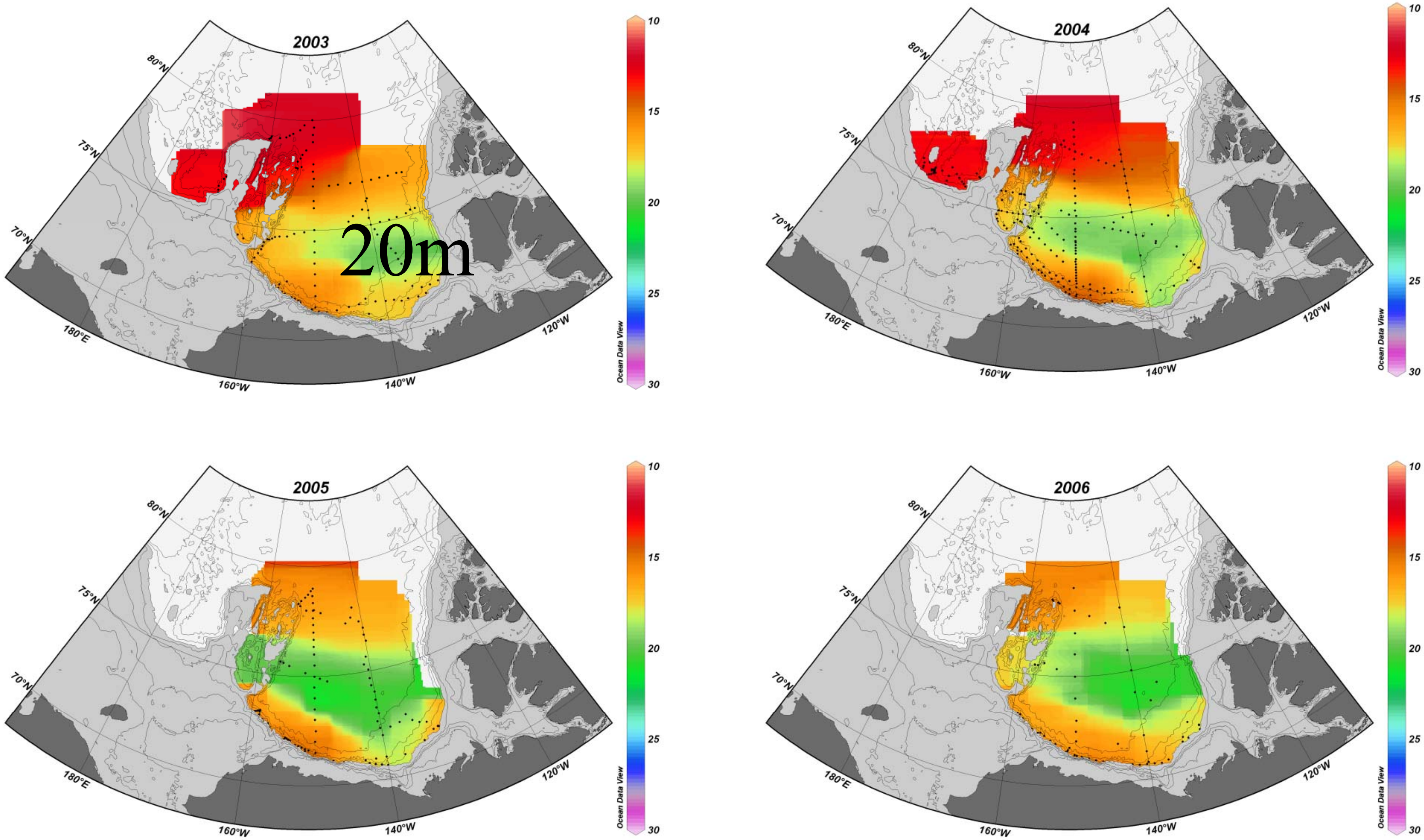
Changes in temperature along 150W



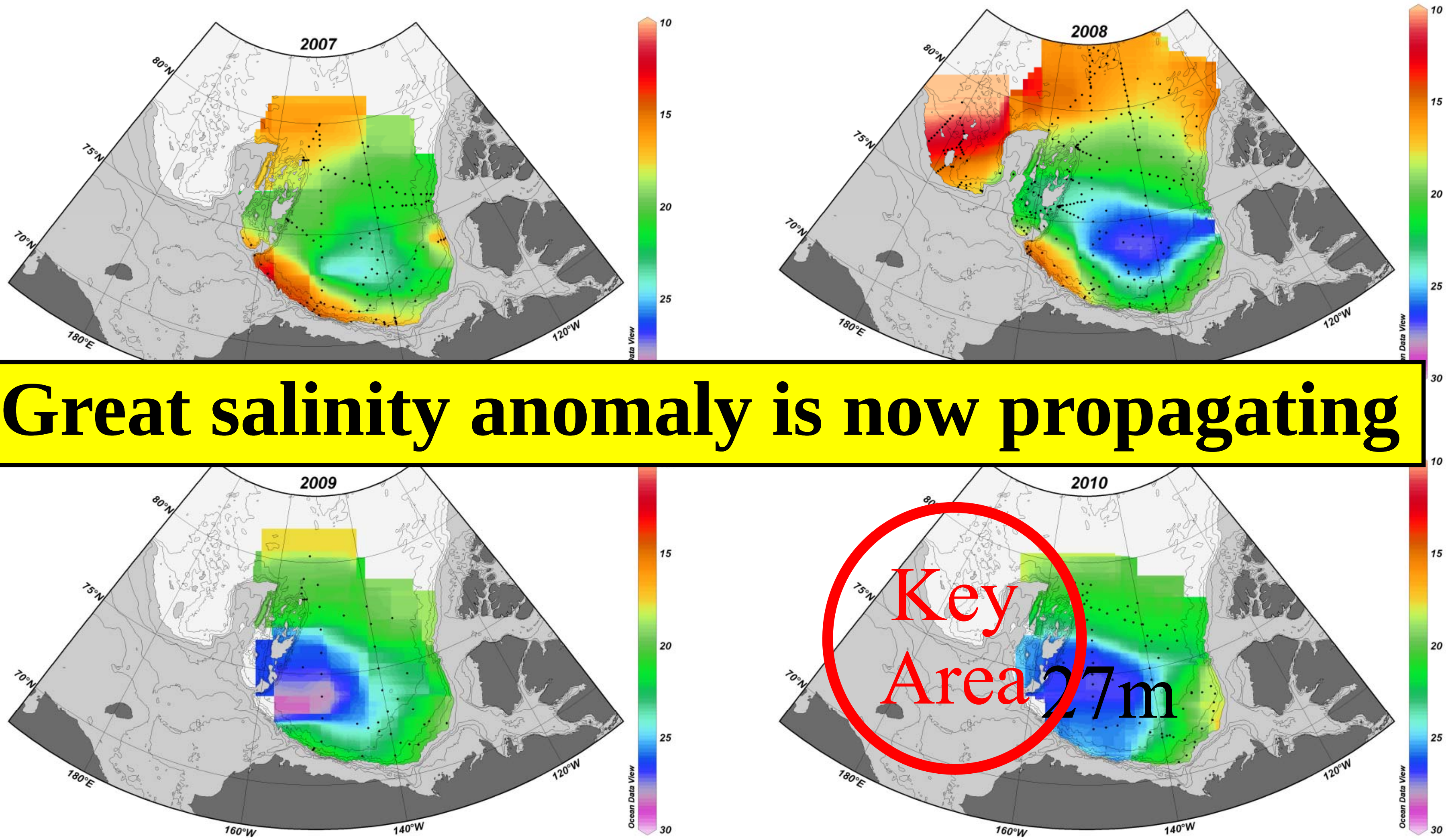

Changes in liquid freshwater
- “great salinity anomaly”
associated with huge sea ice

Changes in freshwater (0-1000m)

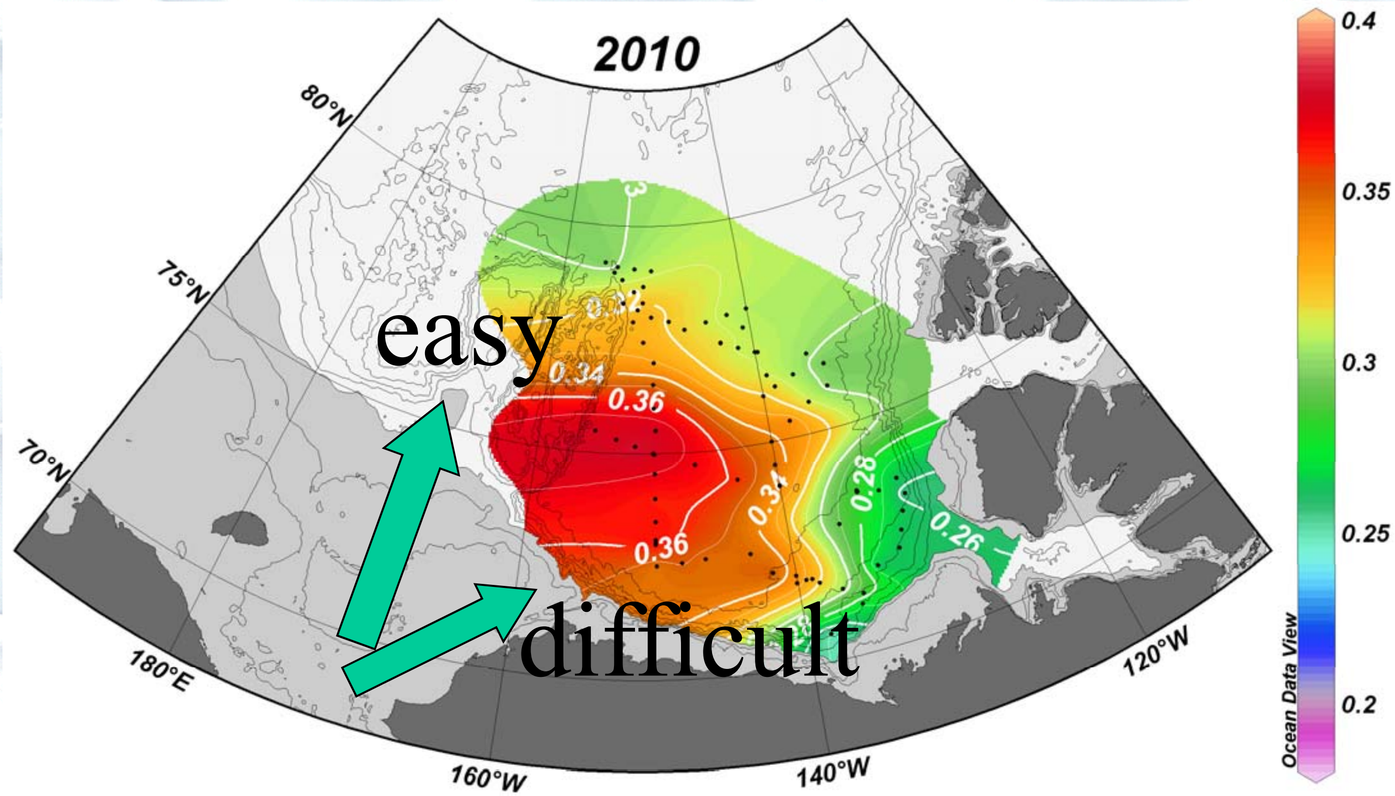
reference salinity 34.8psu



Ice motion is fast, but ocean circulation is tardy.
Huge accumulation of melt water was occurred in the southwestern Canada Basin (biologically hot spot).

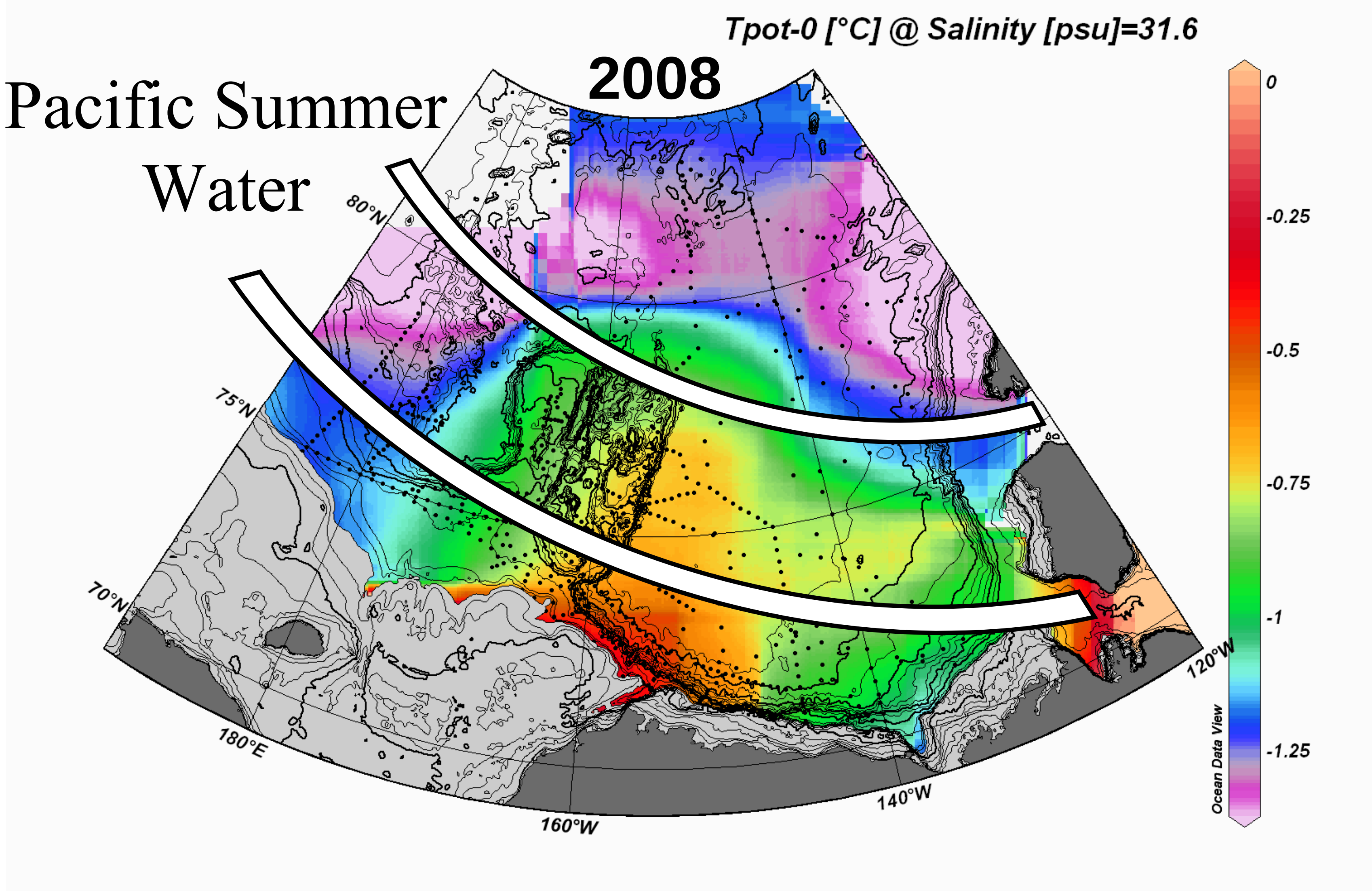


Great salinity anomaly is now propagating



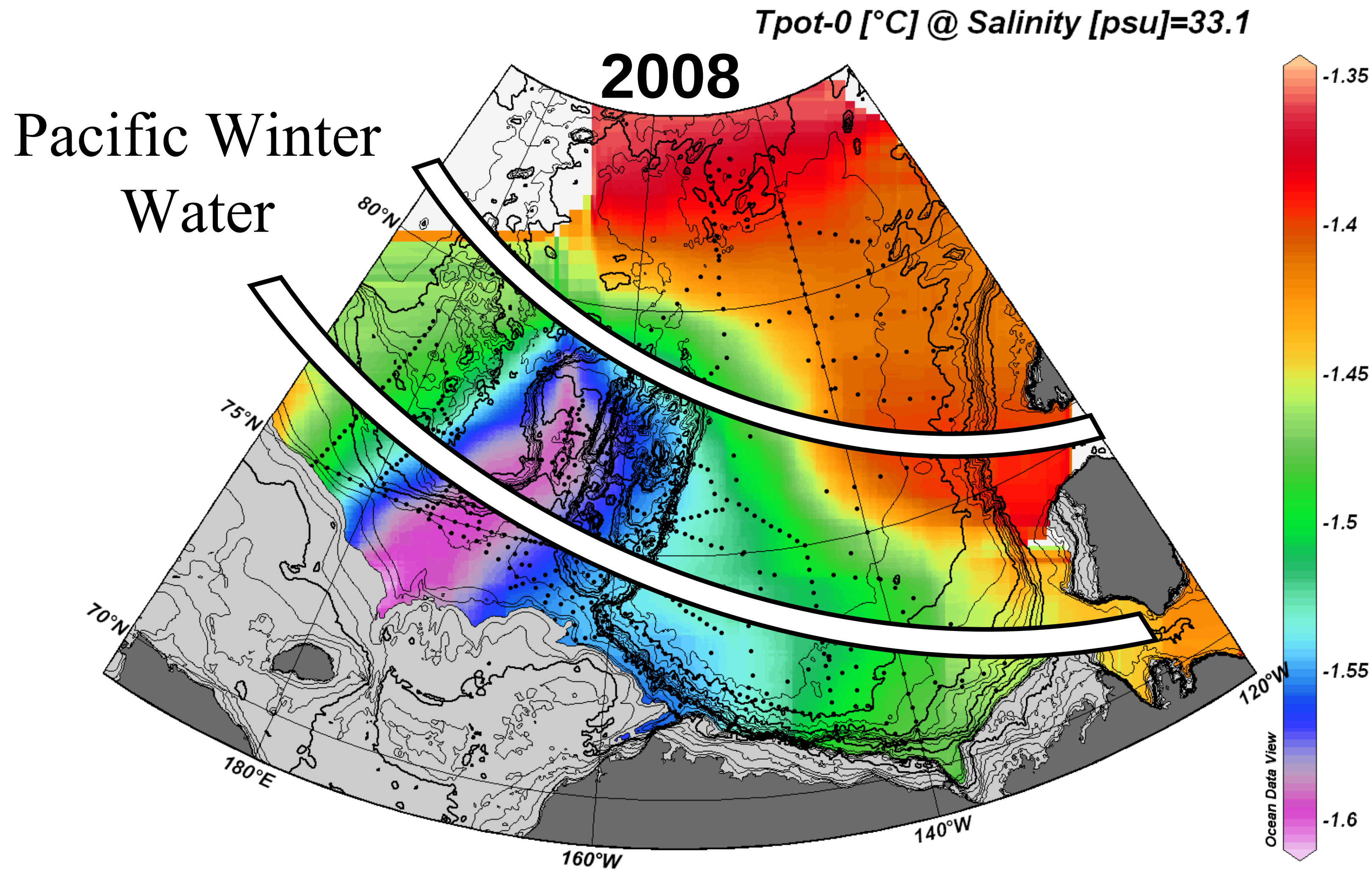
- If we need to understand the circulation of Chukchi Sea, model domain should involve Canada Basin, since the pressure filed in the basin is crucial role to determine spreading pathways of shelf water into the basin.

Recommended hydrographic sections in the Pacific Sector to cover the inter annual variations in PSW distribution - Joint effects of wind and buoyancy dominant forcing -

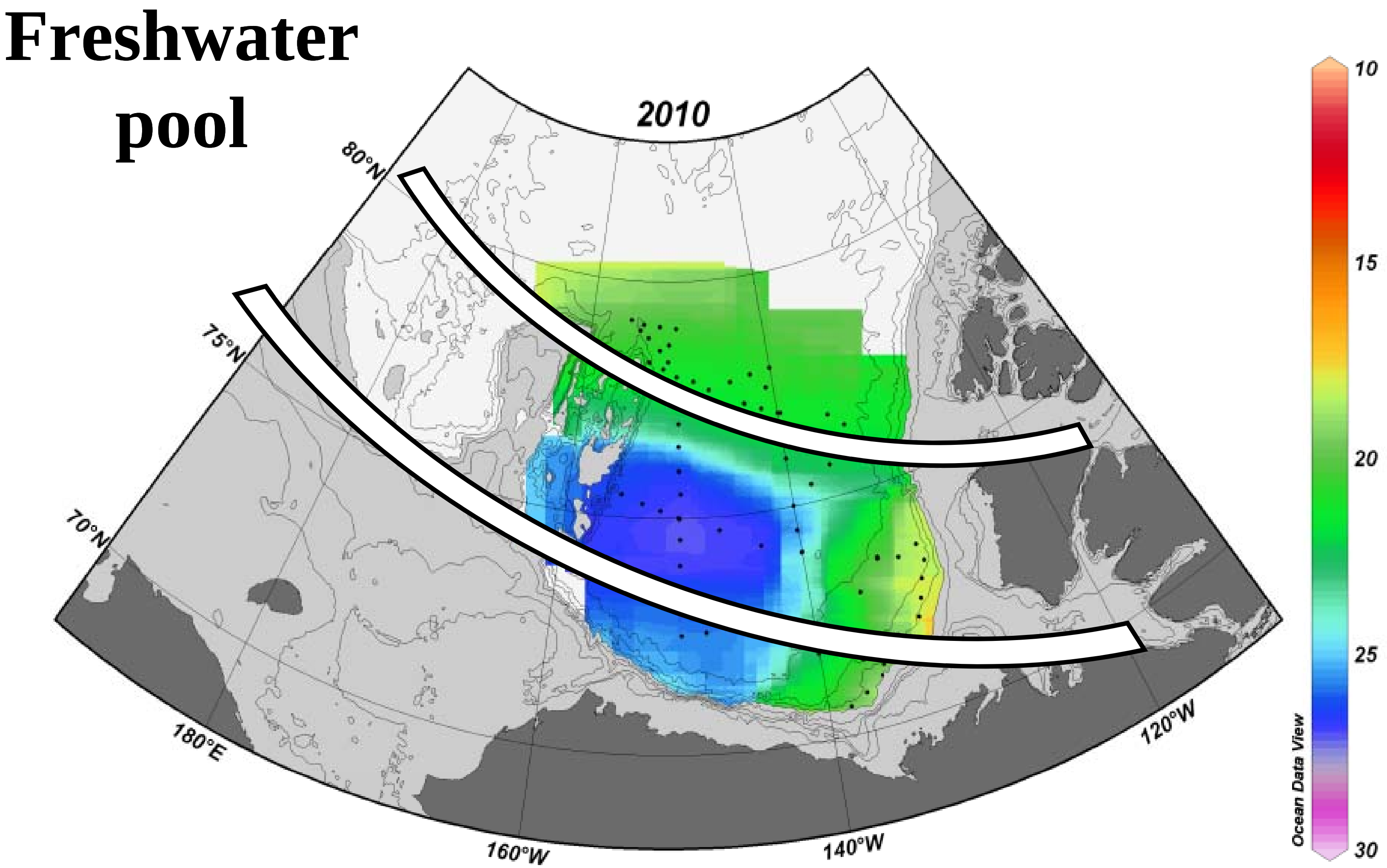


Recommended hydrographic sections in the Pacific Sector to cover the inter annual variations in PWW distribution

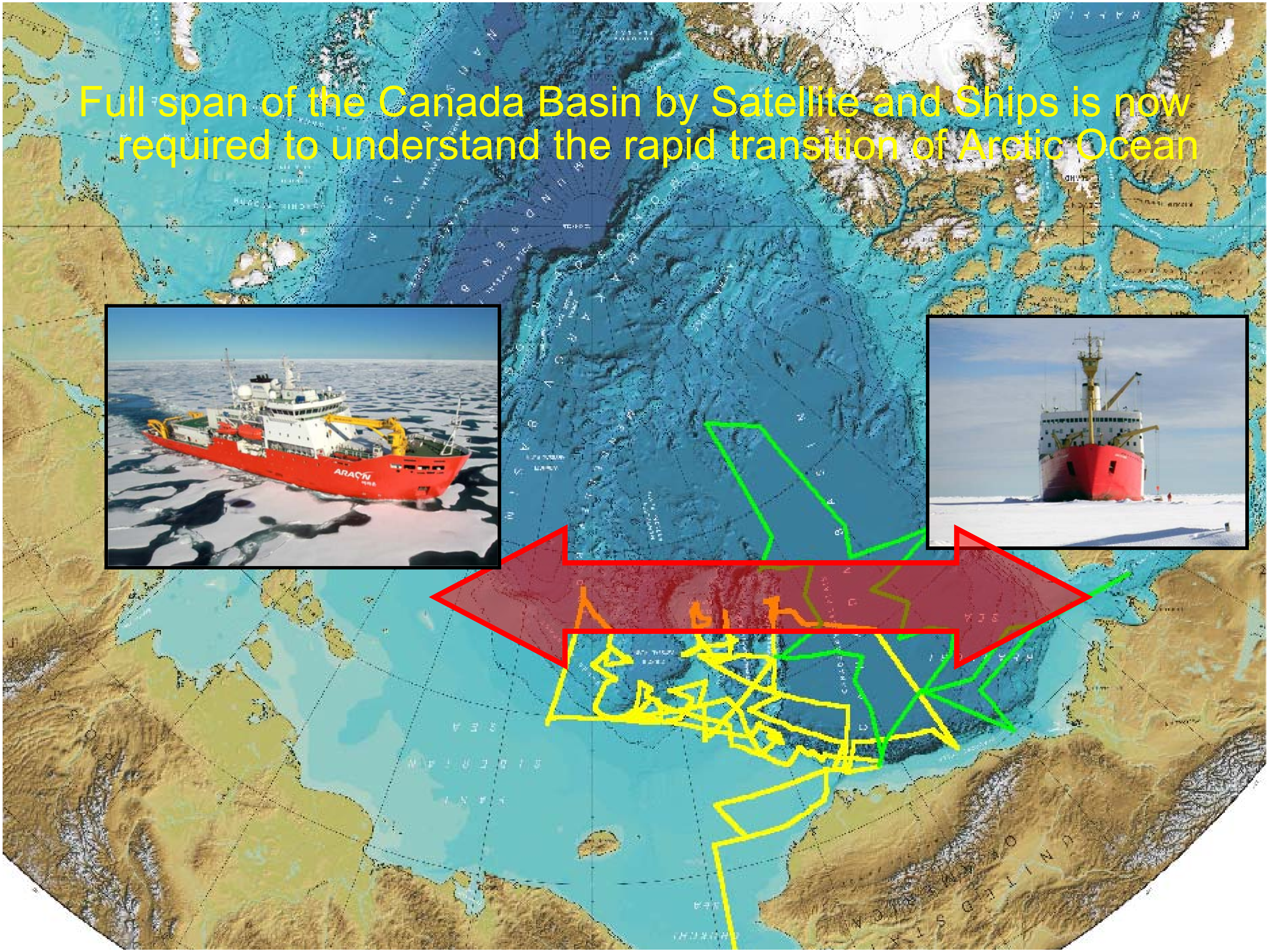
- Joint effects of wind and buoyancy dominant forcing -



Recommended hydrographic sections in the Pacific Sector
to monitor the propagation and influences of great freshwater pool.

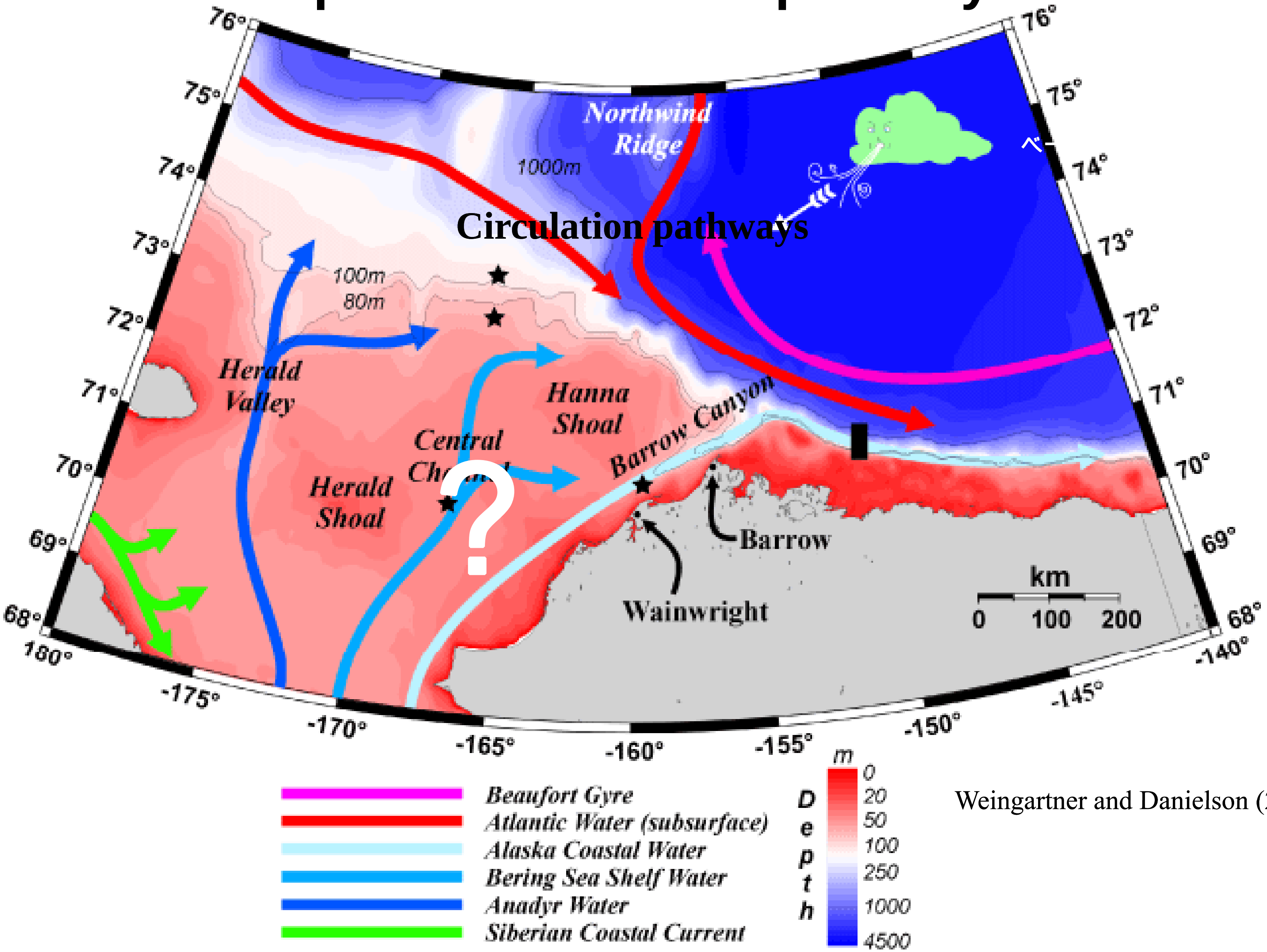


Full span of the Canada Basin by Satellite and Ships is now required to understand the rapid transition of Arctic Ocean



A comment on DBO strategy
Seasonal variation of Pacific Water transportation through the Barrow Canyon

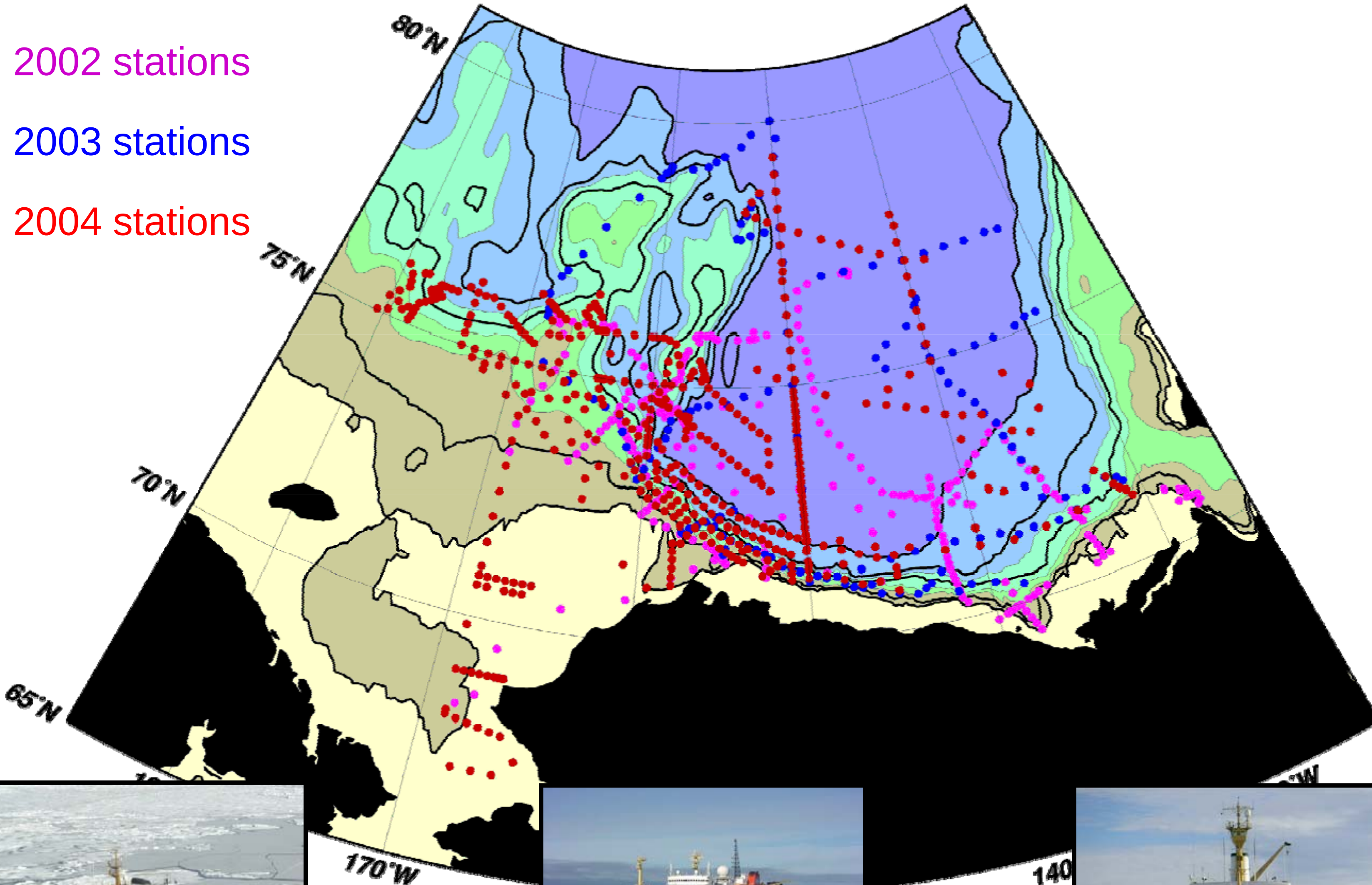
Proposed circulation pathway



Weingartner and Danielson (2002)

JWACS 2002 - 2004 stations in the Western Arctic

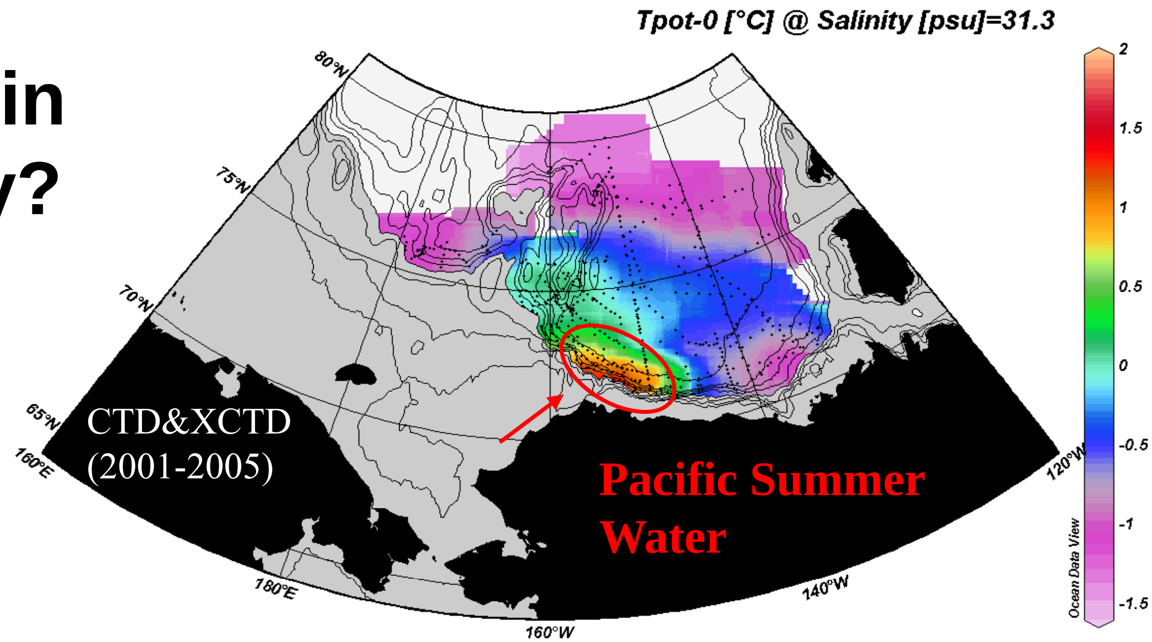
- 2002 stations
- 2003 stations
- 2004 stations

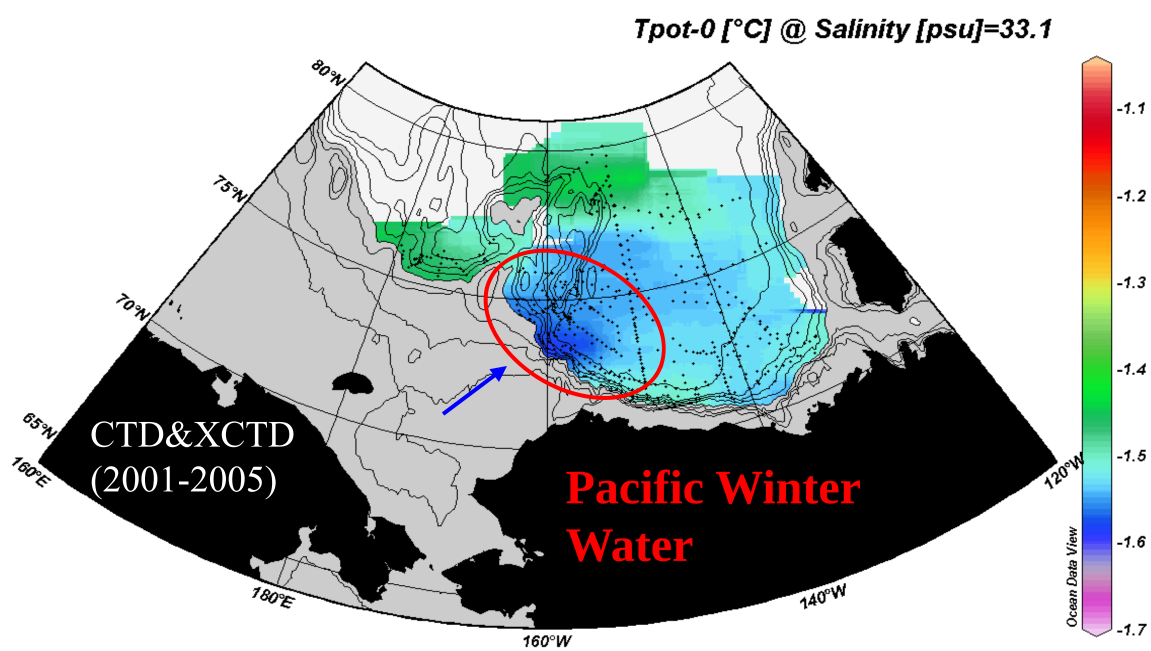


Seasonal variation in circulation pathway?

Summer Water ：30～32[psu]

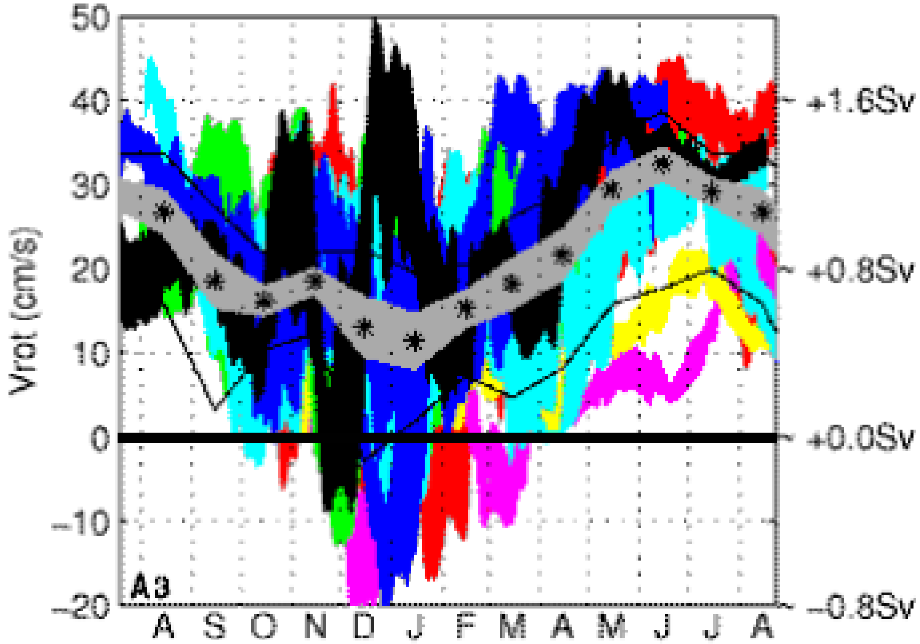
Winter Water ：33～34[psu]

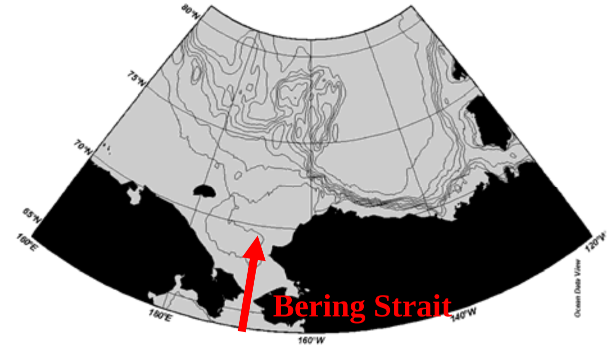




Transportation through Bering Strait

(Woodgate et al,2005 GRL)

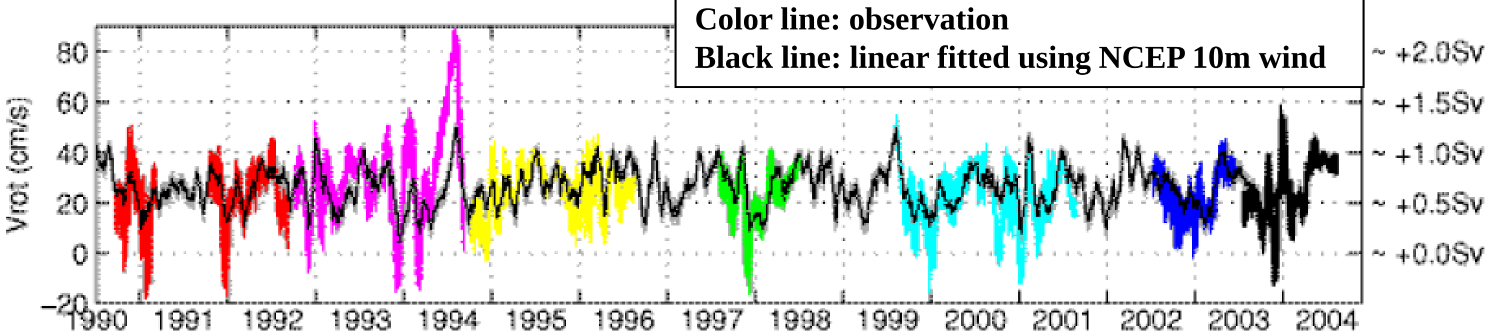




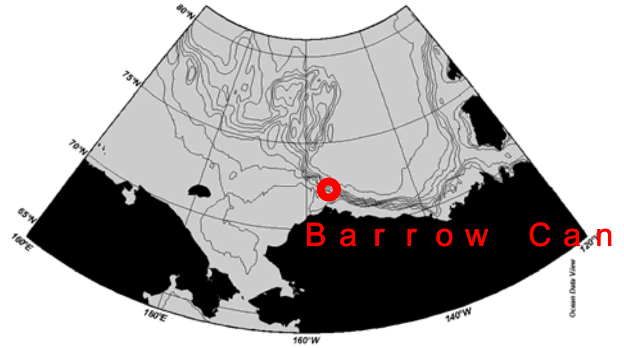
- Annual mean：**0.8Sv （northward）**
- Variation：

  0.4 ～ 1.2 Sv （northward）
- Transportation at zero wind forcing：**0.8 Sv （northward）** **by Roach**

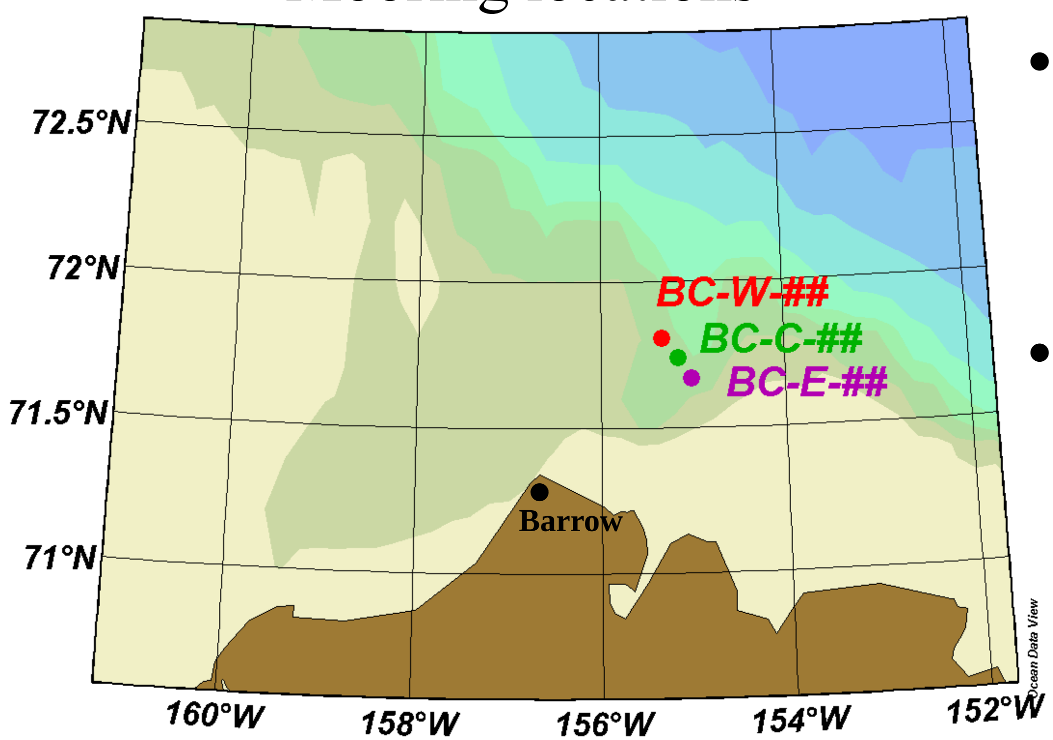
Color line: observation
Black line: linear fitted using NCEP 10m wind



Measurements in the mouth of the Barrow Canyon



Mooring locations



- Duration:

  Oct., 2001 ~ Sept., 2005

- instruments：

  RCM-7/8/9(AANDERAA)

  WH-/BB-/NB-ADCP(RDI)

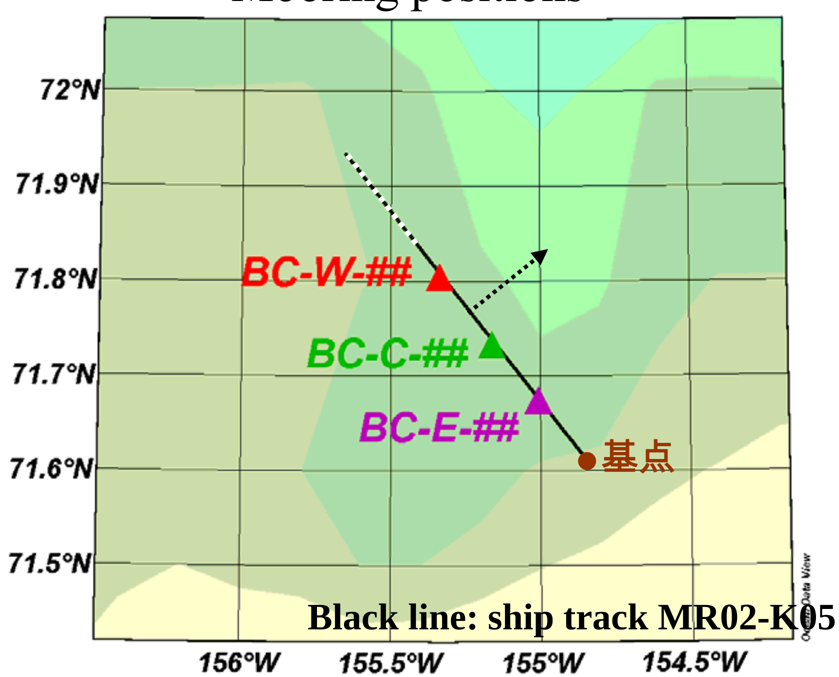
  CTD,…

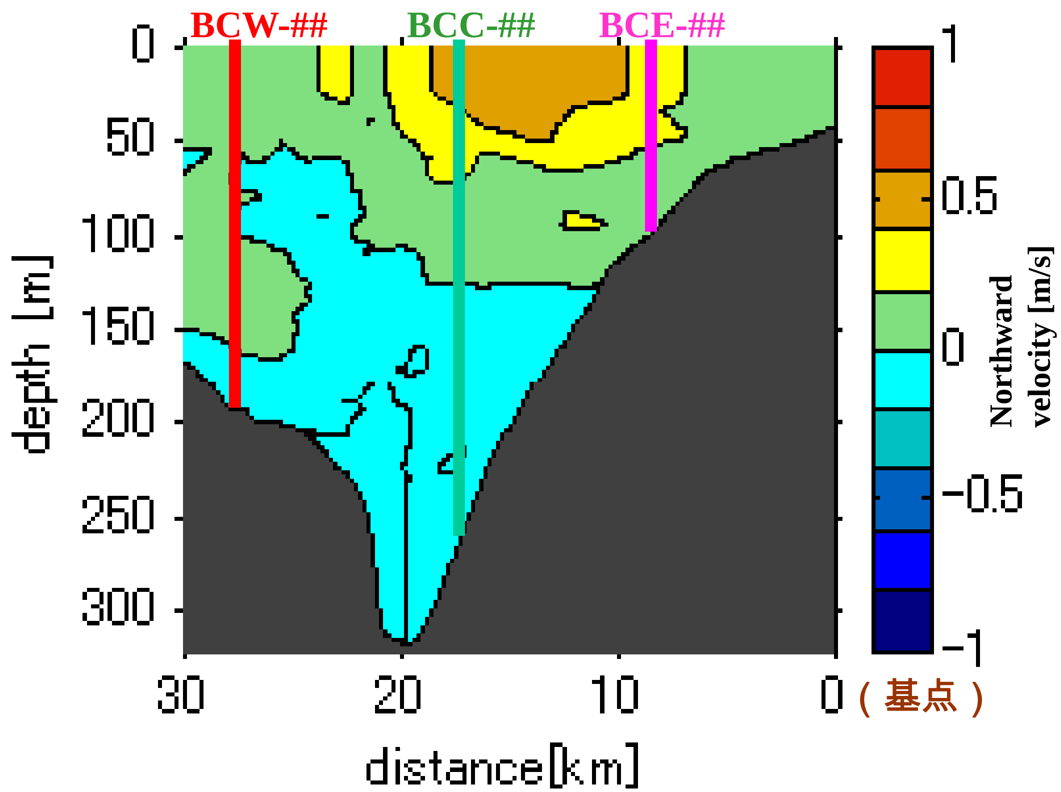
Evaluation of transportation

（ SeaBeam bottom topography measured R/V Mirai is used for the calculation ）

計算範囲
水平距離：30km
鉛直方向：海面～海底

Mooring positions

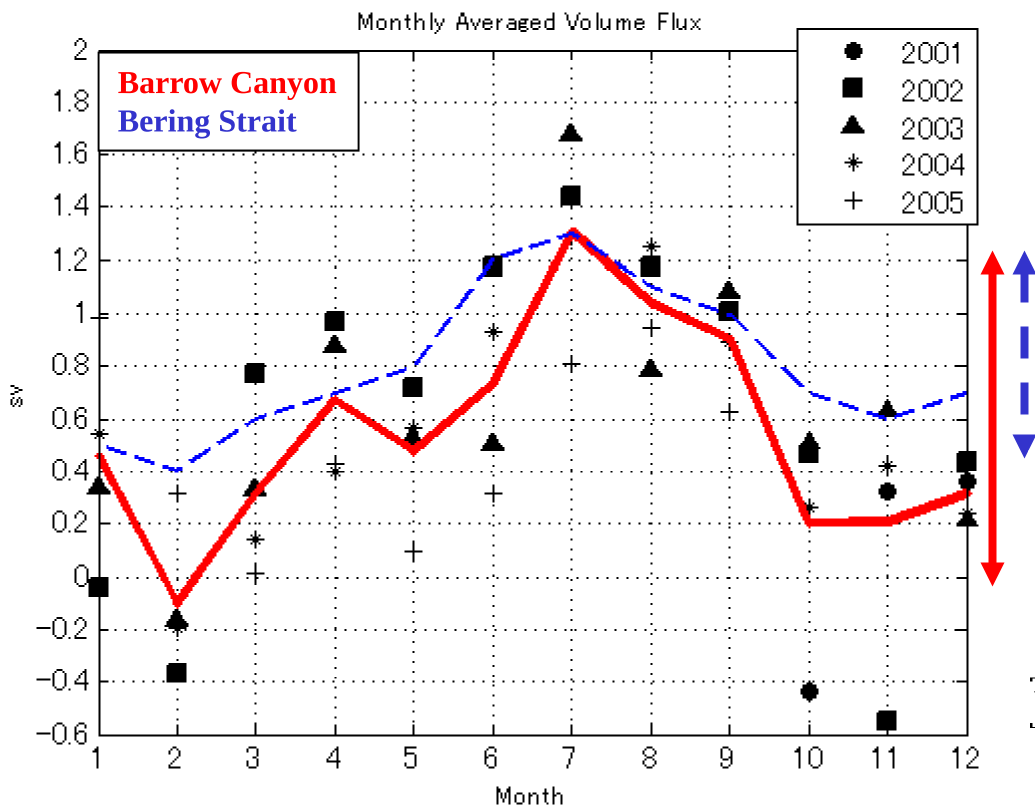




Cross section velocity measured by shipboard ADCP (R/V Mirai) in September 2002

Seasonal Variation

Monthly mean transportation

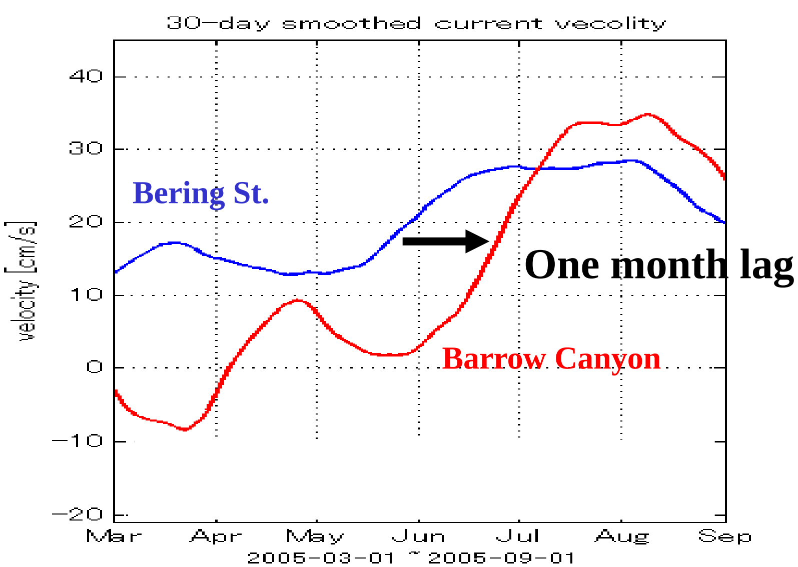


•Variation： **0 ~ 1.2Sv**

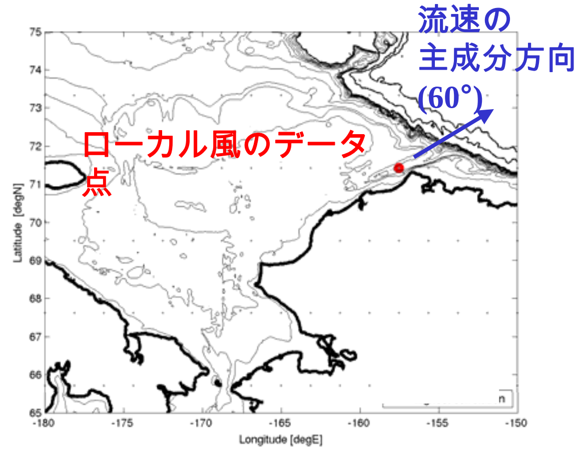
- Seasonal variation in the Barrow Canyon is greater than in the Bering Strait.

•Maximum transportation through the Barrow Canyon is near the same value as through the Bering Strait

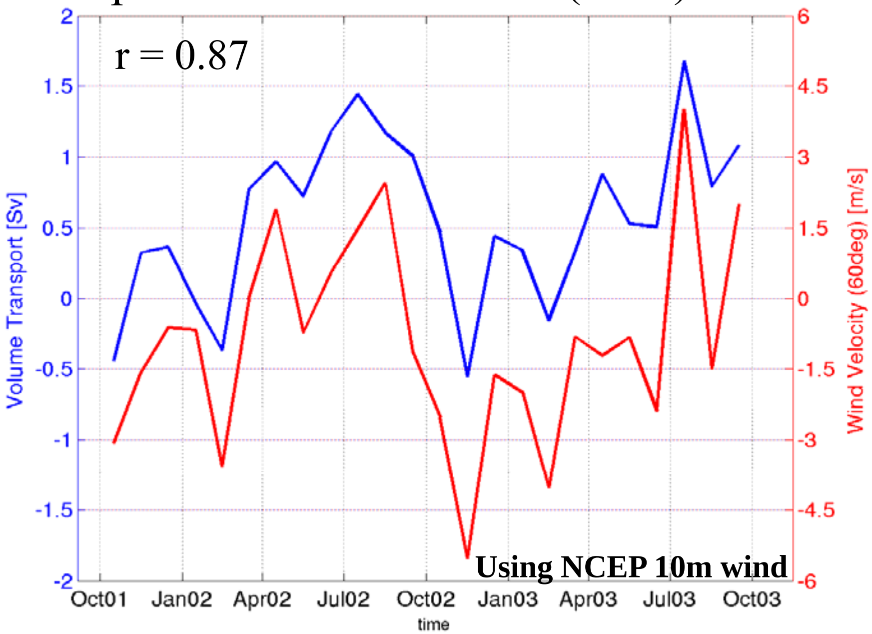
•One month phase lag

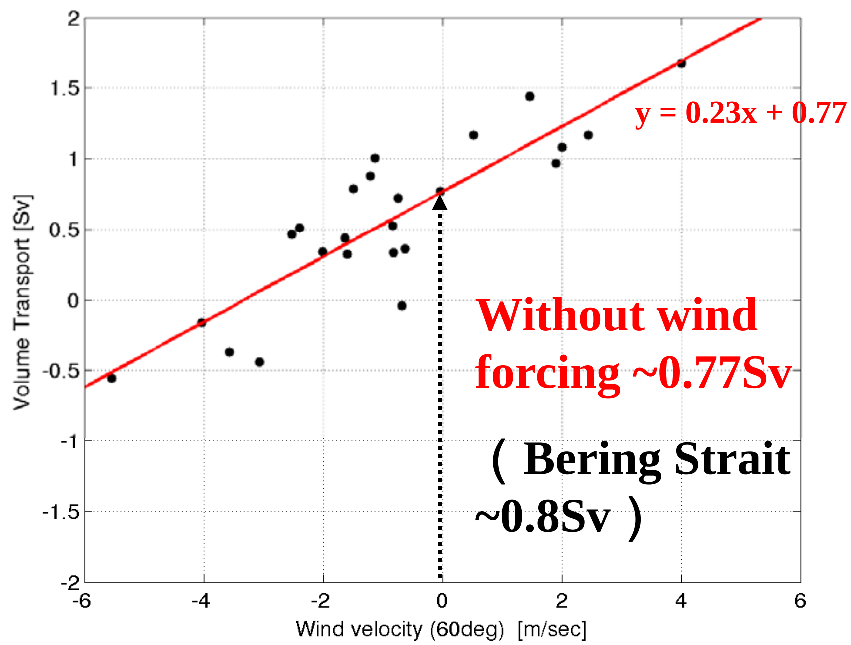


Transportation without wind forcing



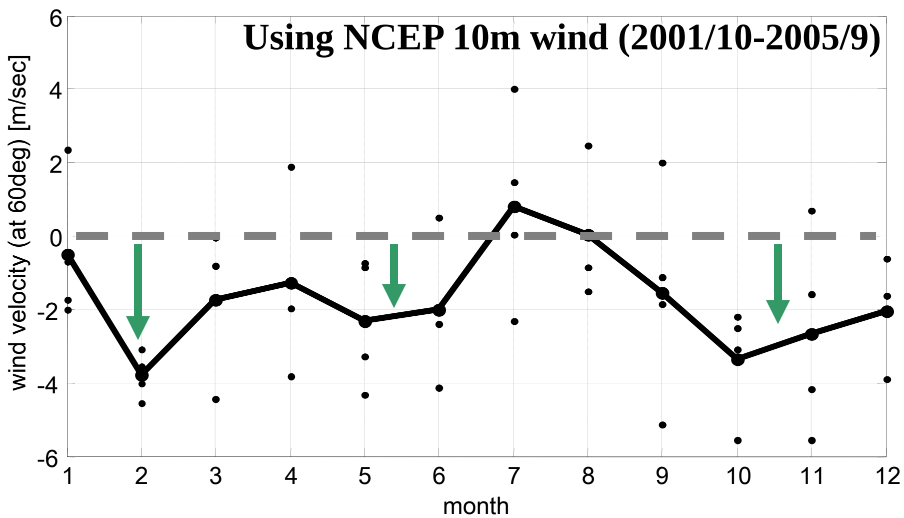
Transportation vs local wind (60°T)



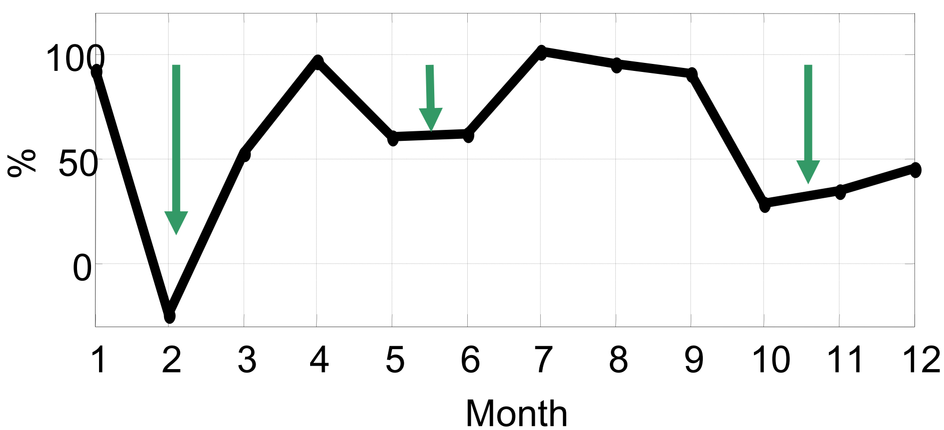


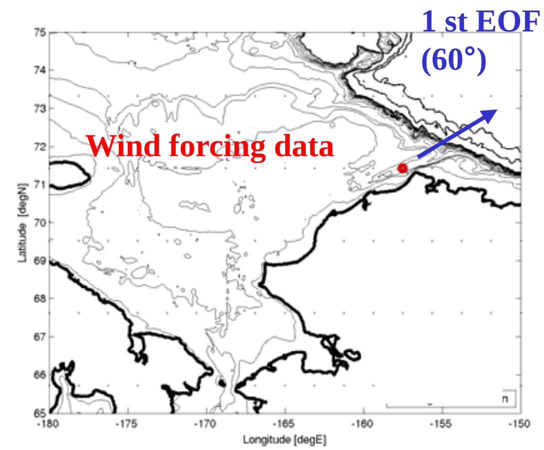
Variation in local wind

Wind (60°T)



Transport through the Barrow Canyon / through the Bering Strait





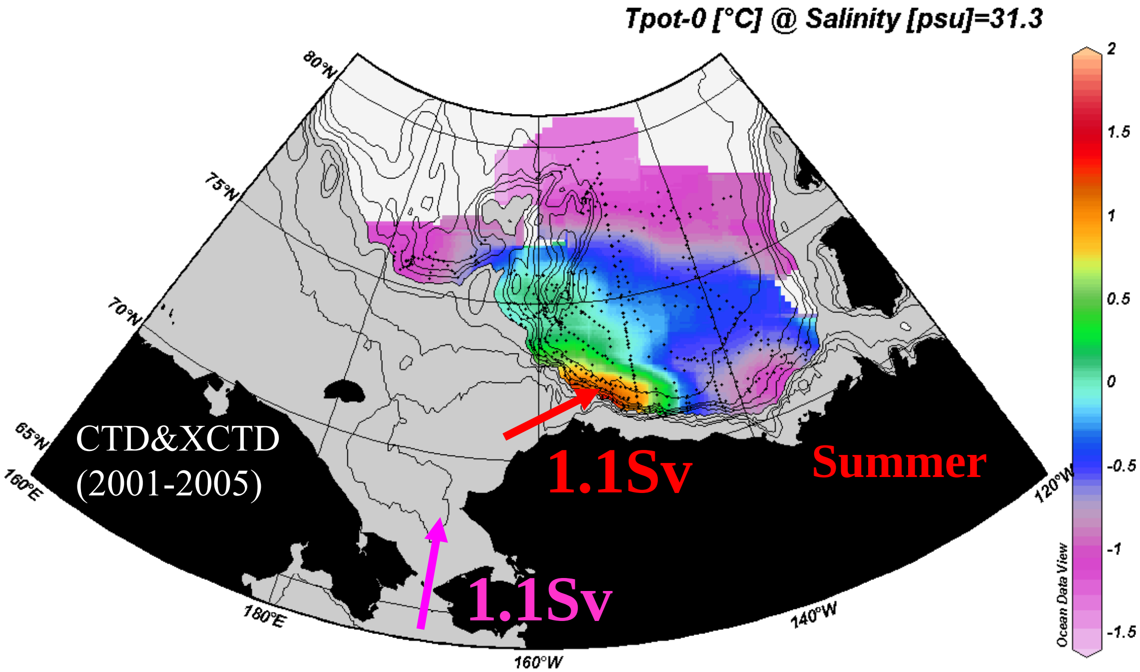
No wind or westerly (summer)：

Most of water is delivered into the basin via Barrow Canyon

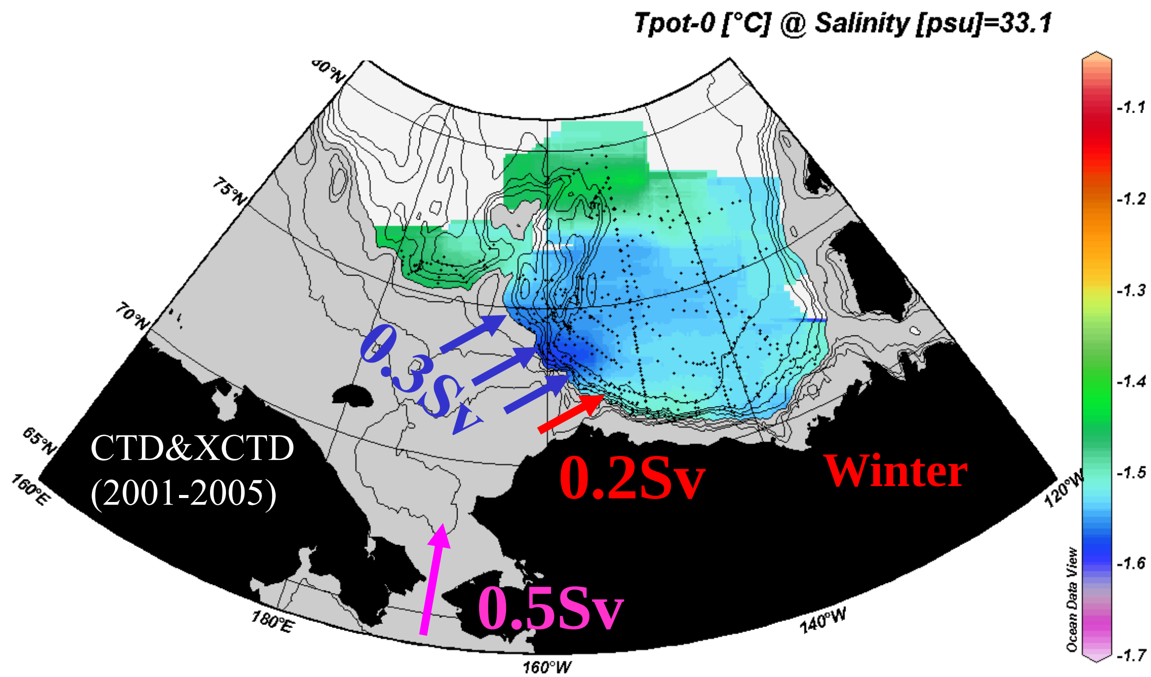
Strong easterly (winter)：

Not only Barrow Canyon!

Summary

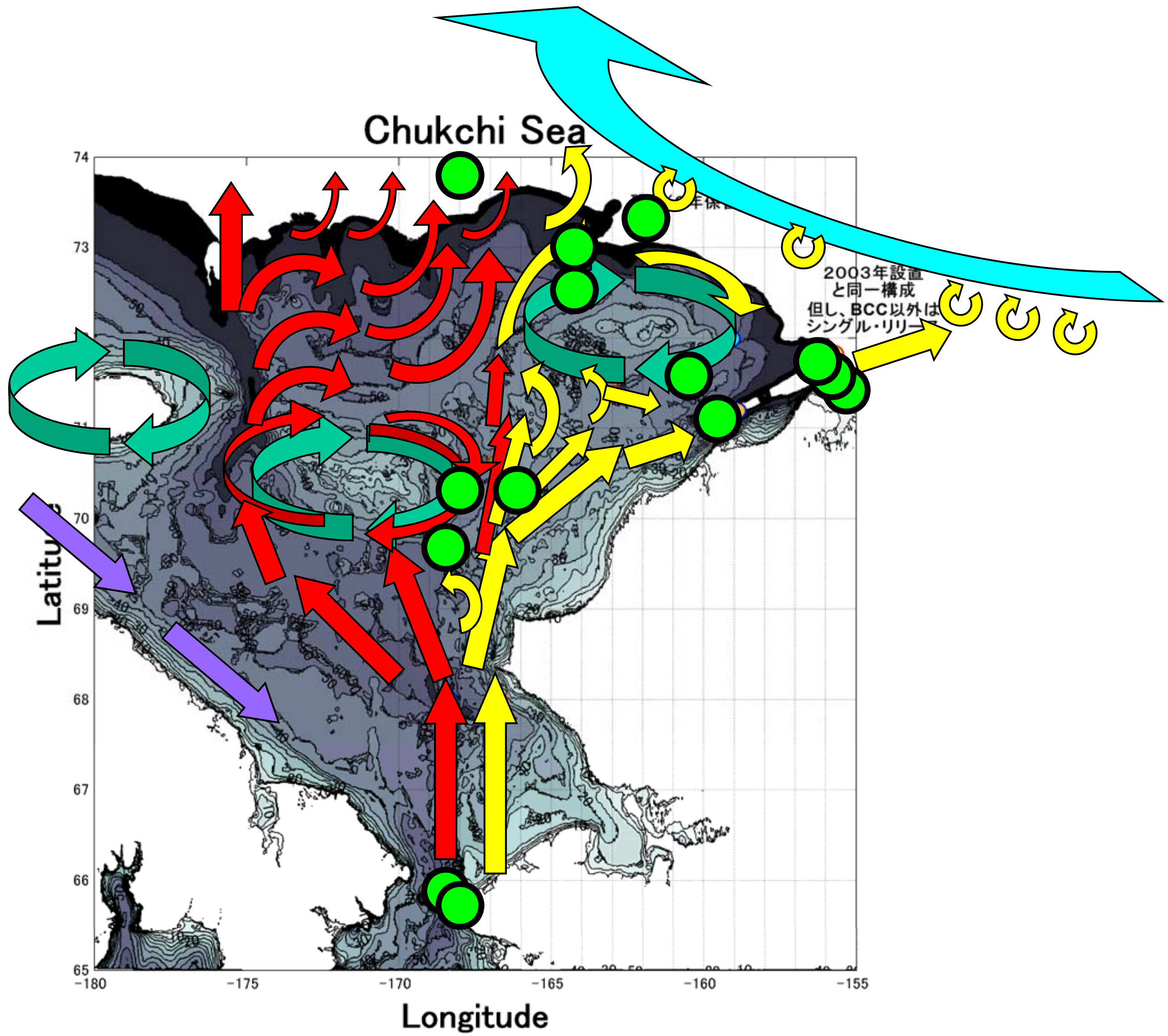


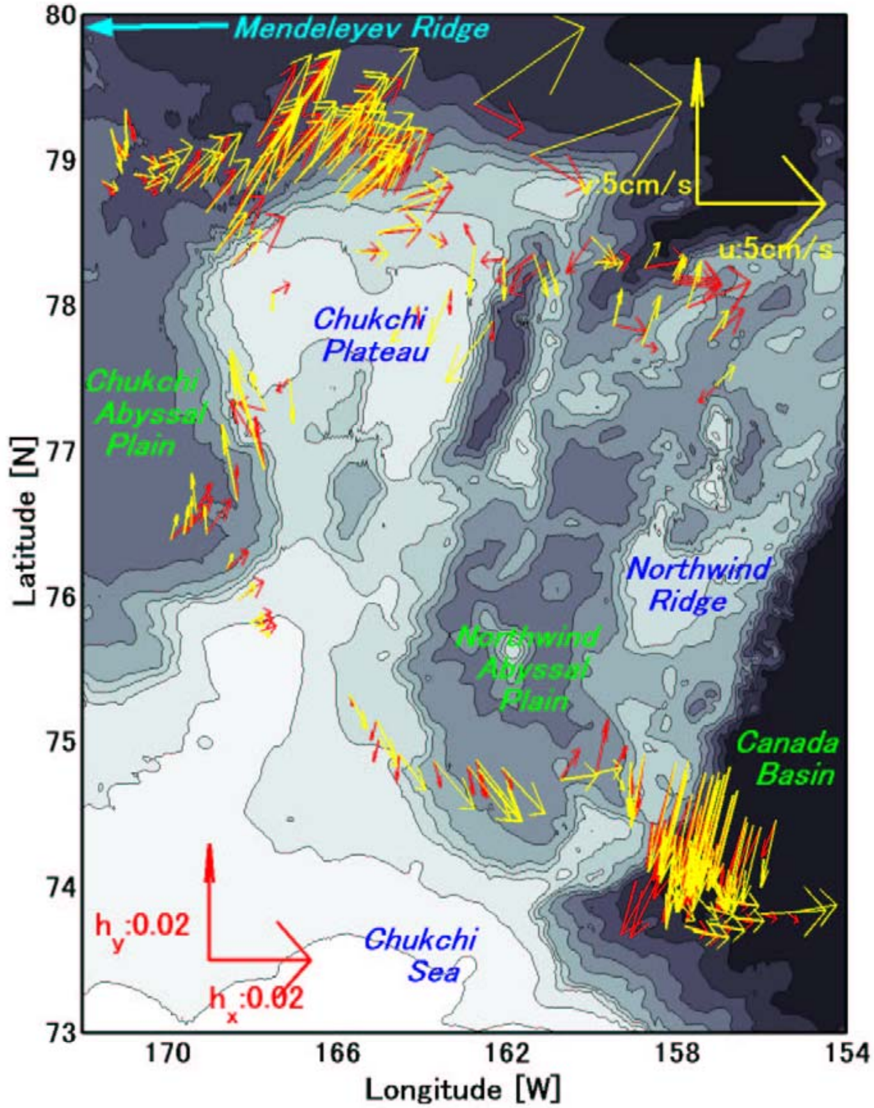
Tpot-0 [°C] @ Salinity [psu]=31.3
80°N
75°N
70°N
65°N
160°E
180°E
160°W
140°W
120°W
CTD&XCTD
(2001-2005)
1.1Sv
1.1Sv
Summer
2
1.5
1
0.5
0
-0.5
-1
-1.5
Ocean Data View



Tpot-0 [°C] @ Salinity [psu]=33.1
75°N
70°N
65°N
160°E
180°E
160°W
140°W
120°W
CTD&XCTD
(2001-2005)
0.3Sv
0.2Sv
0.5Sv
Winter
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
Ocean Data View

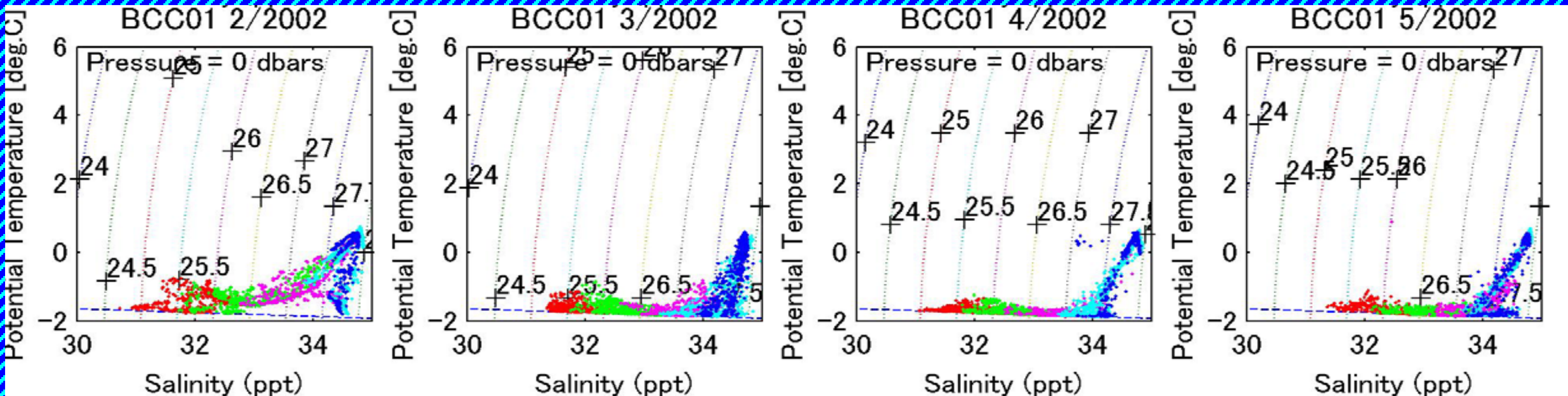
JWACS 2004 mooring stations





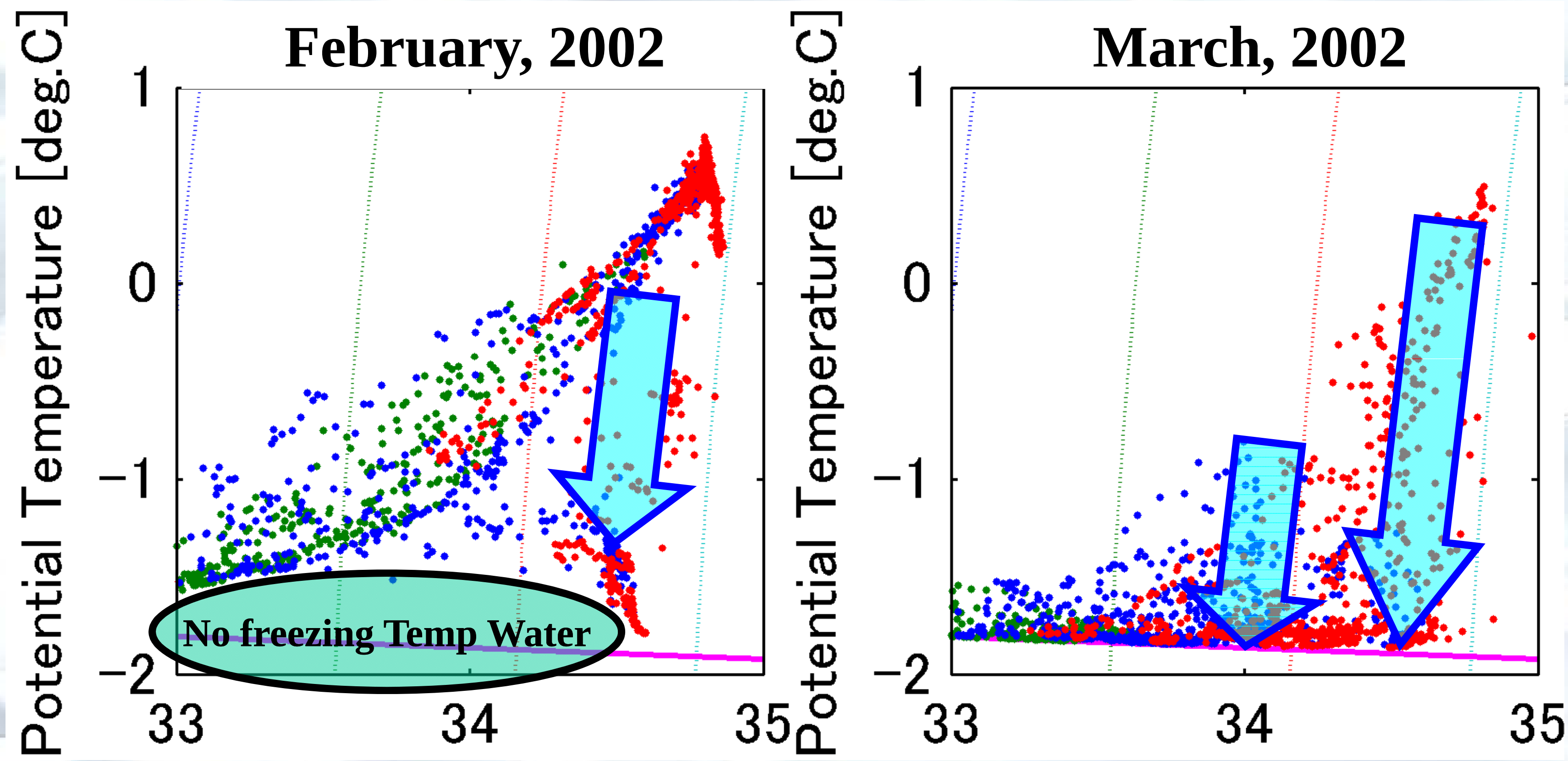
Mendeleyev Ridge
v:5cm/s
u:5cm/s
Chukchi Plateau
Chukchi Abyssal Plain
Northwind Ridge
Northwind Abyssal Plain
Canada Basin
Chukchi Sea
h_y:0.02
h_x:0.02
Latitude [N]
Longitude [W]
80
79
78
77
76
75
74
73
170
166
162
158
154

Timeseries of TS scatter plot at the mouth of the Barrow Canyon



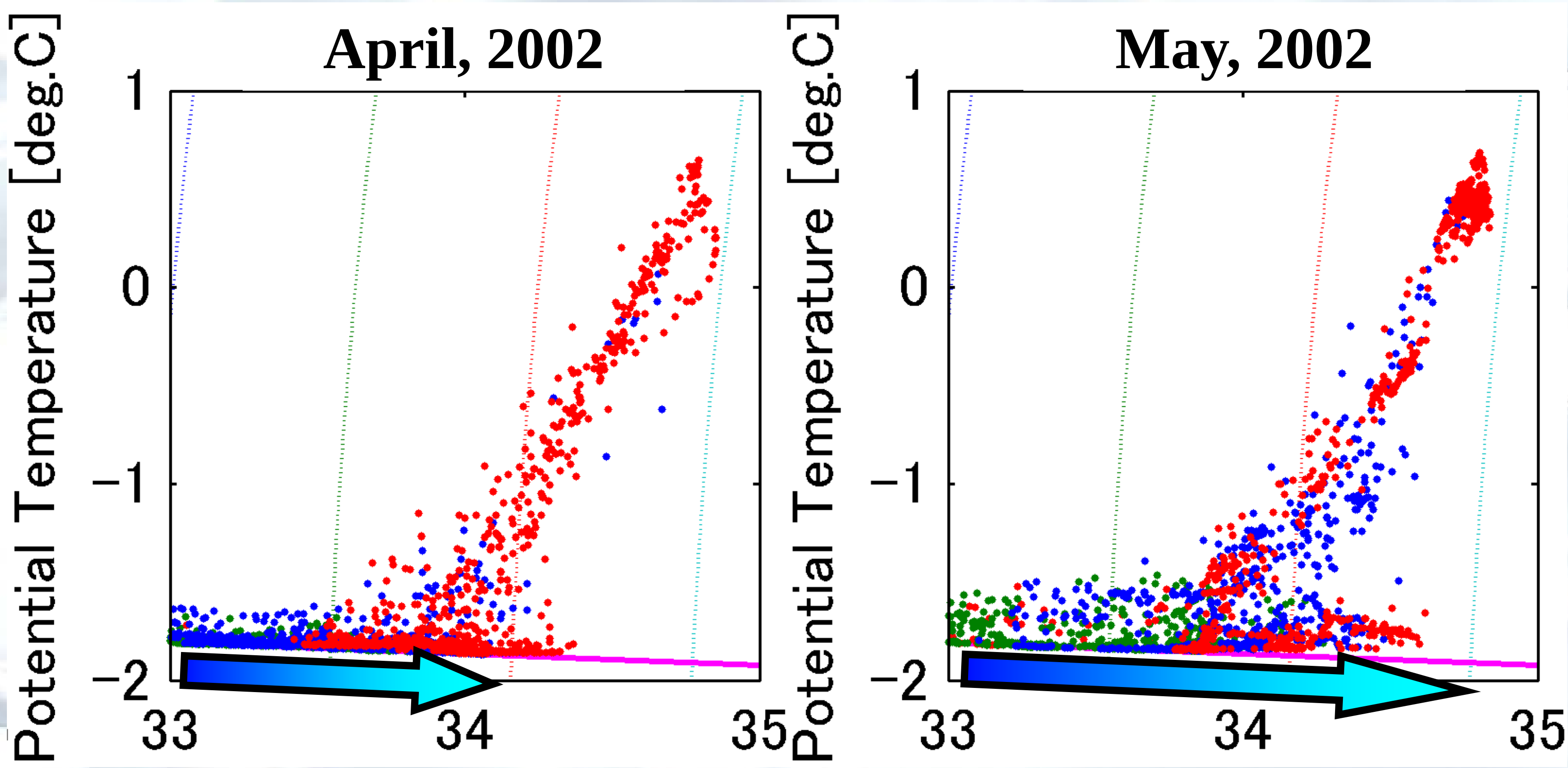
Dense water formation

AW upwelling & cooling

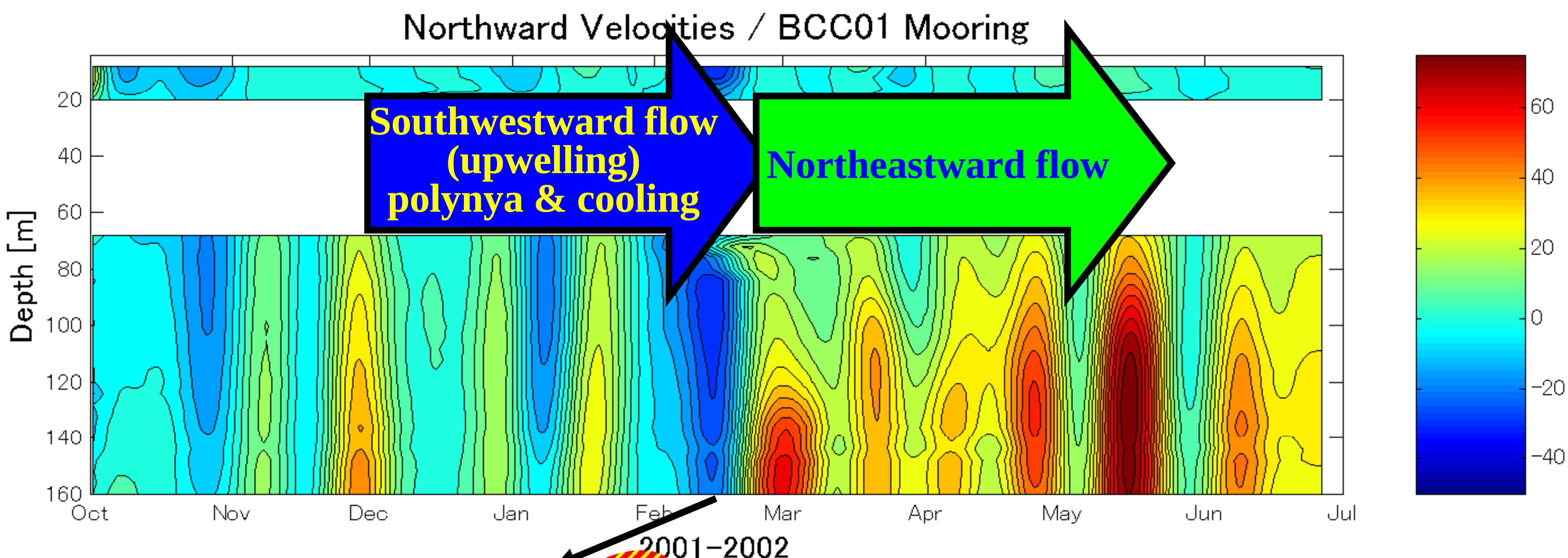


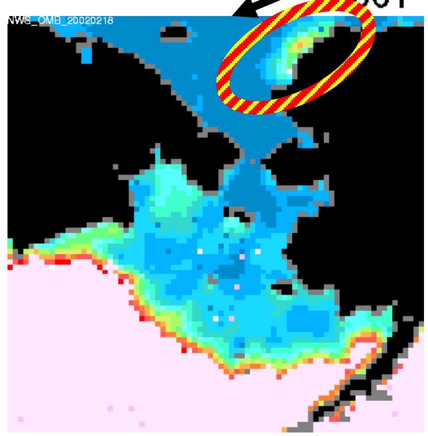
Dense water formation

Brine ejection



Velocity field in the Barrow Canyon

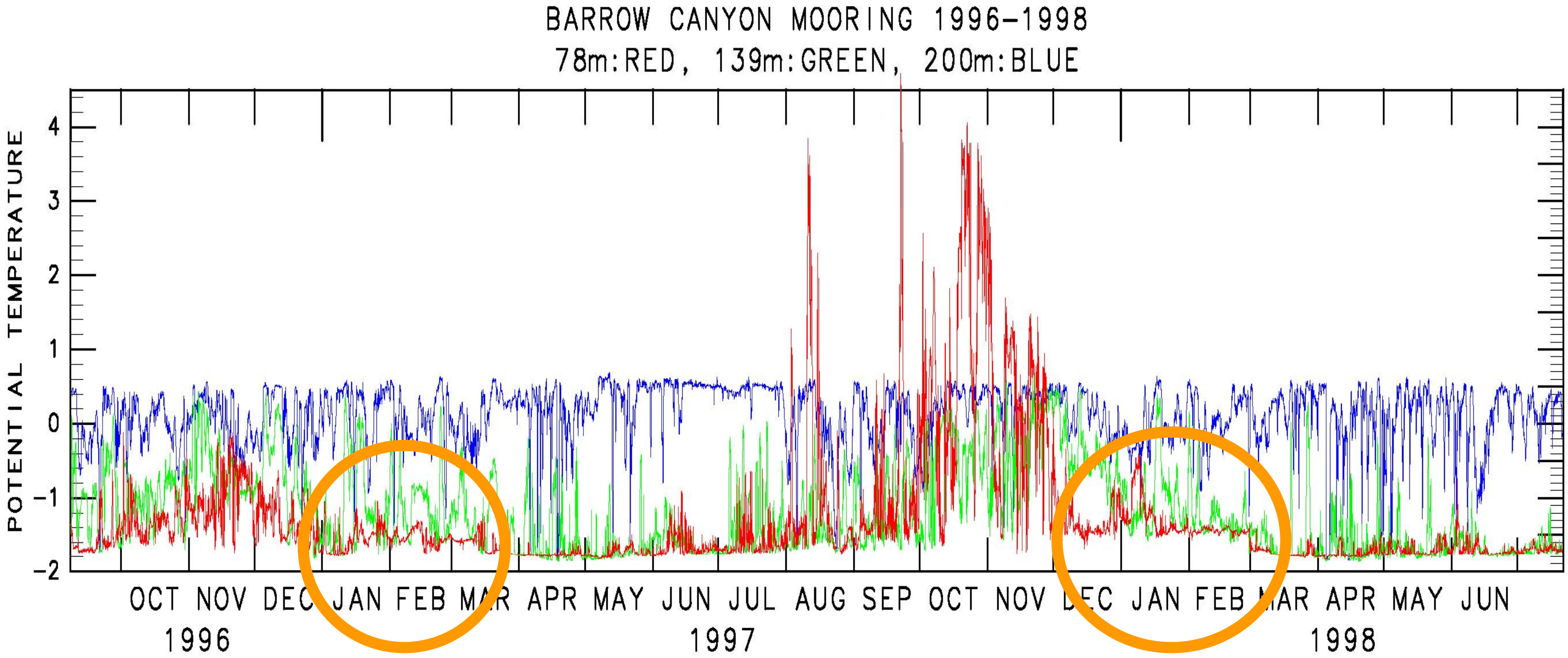




Winter Water switchyard is expected

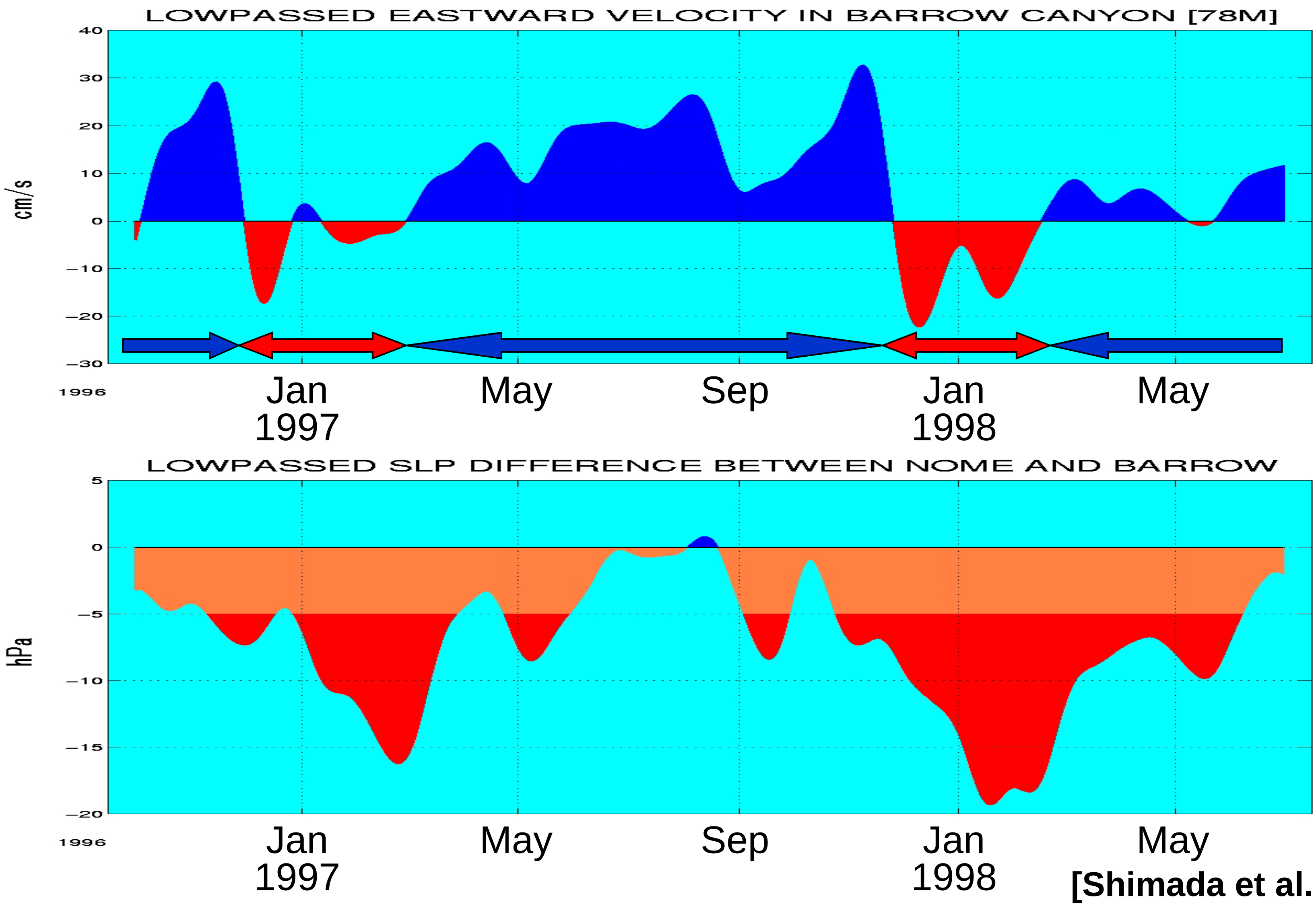
Another temperature maximum in early winter

- Temperature maximum appears not only in late autumn but also early winter
  → Flow reversal during winter on North Slope



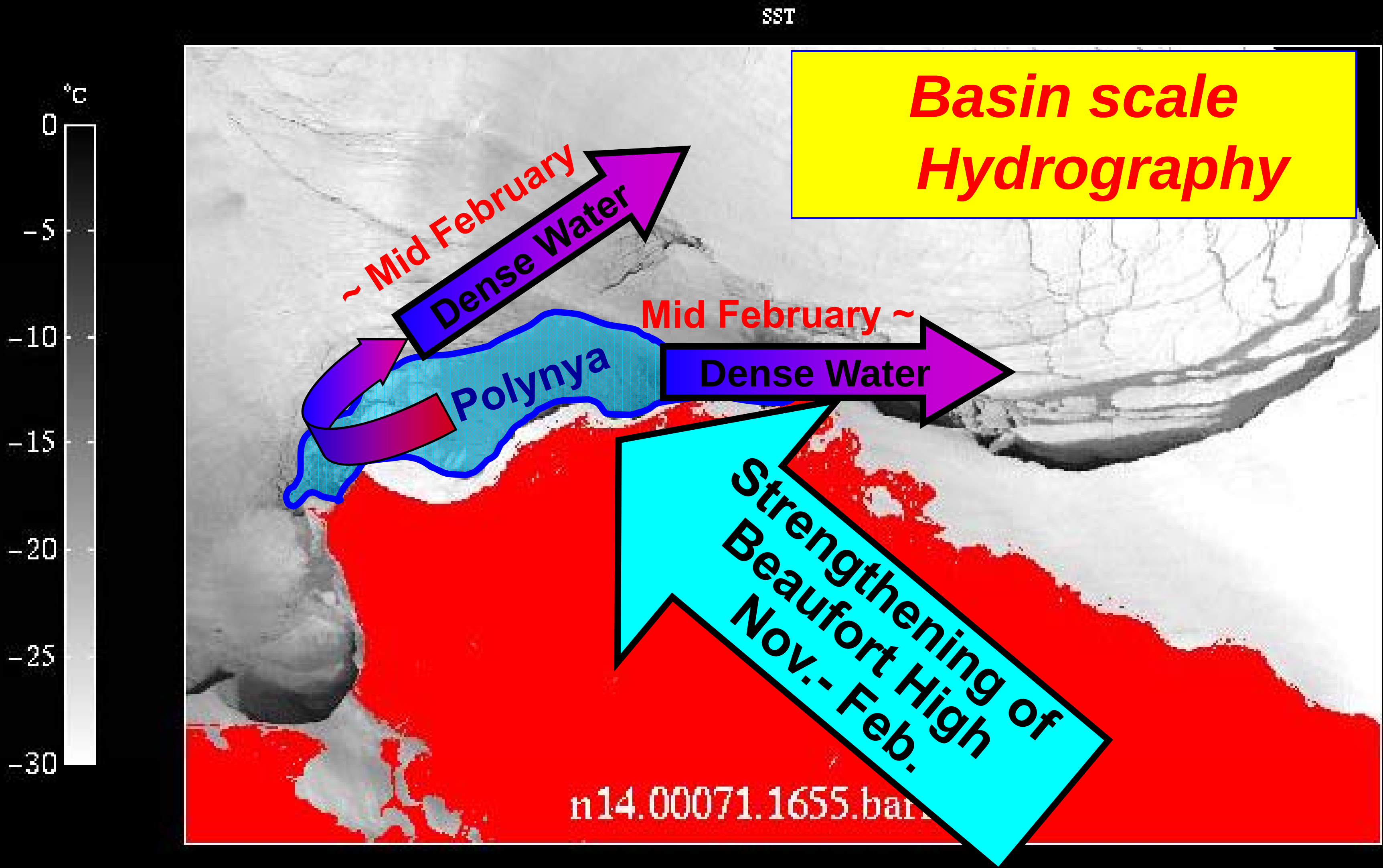
Advection of ECSW on the shelf break

Advective direction of ECSW depends on seasonal wind



[Shimada et al. (2000)]

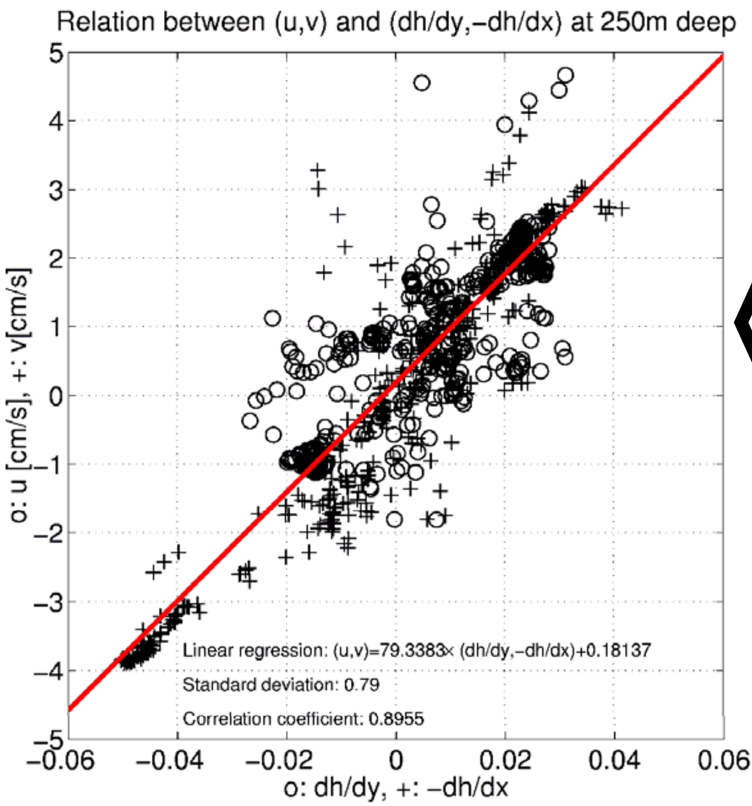
Winter Water Formation



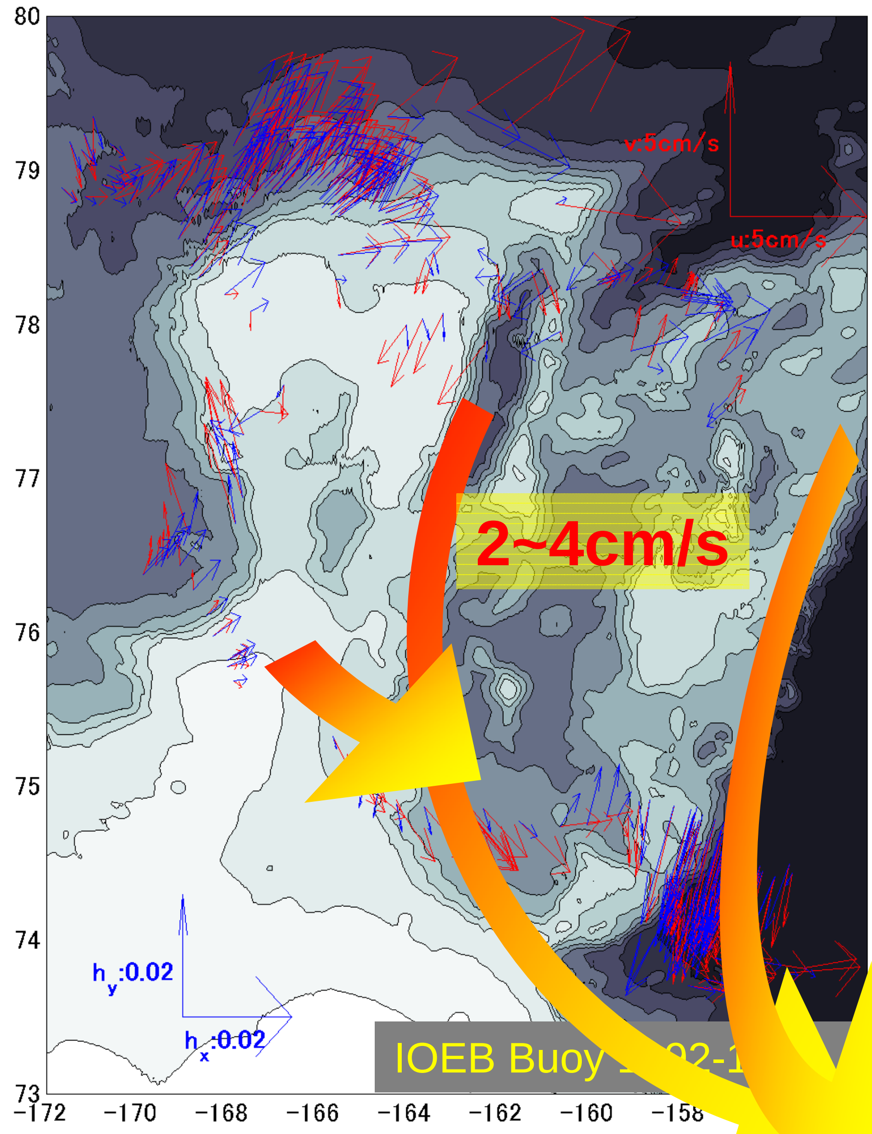
AVHRR image/ Courtesy: Seelye Martin

Atlantic Water Circulation on the Chukchi Borderland

Weak Beaufort High



(u,v)=79.3×(dh/dy,-dh/dx)+0.18

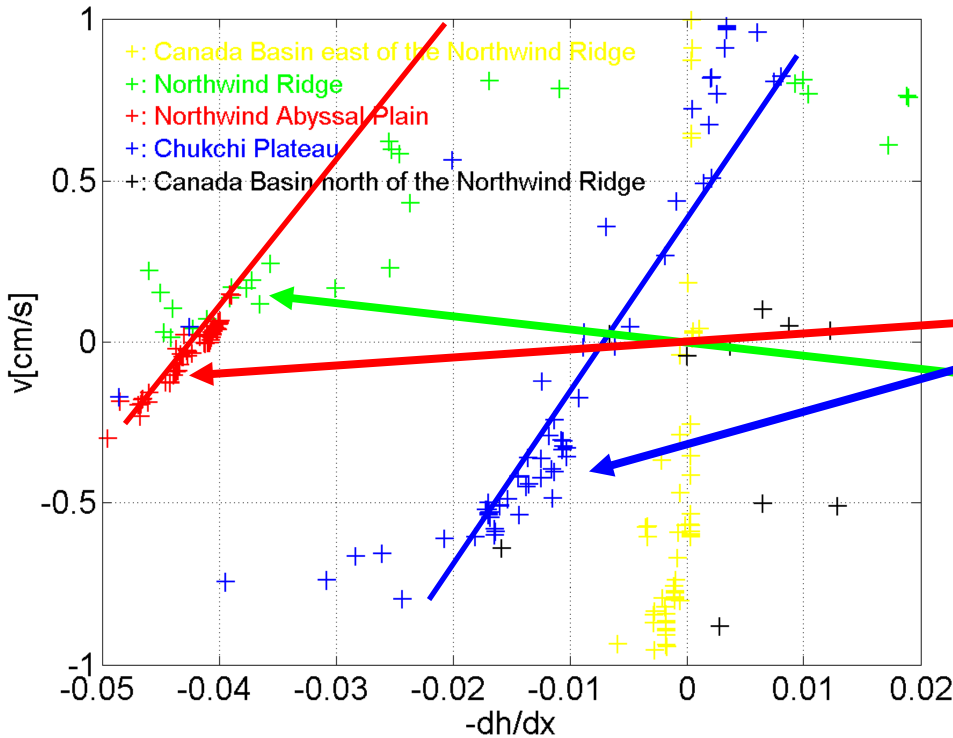


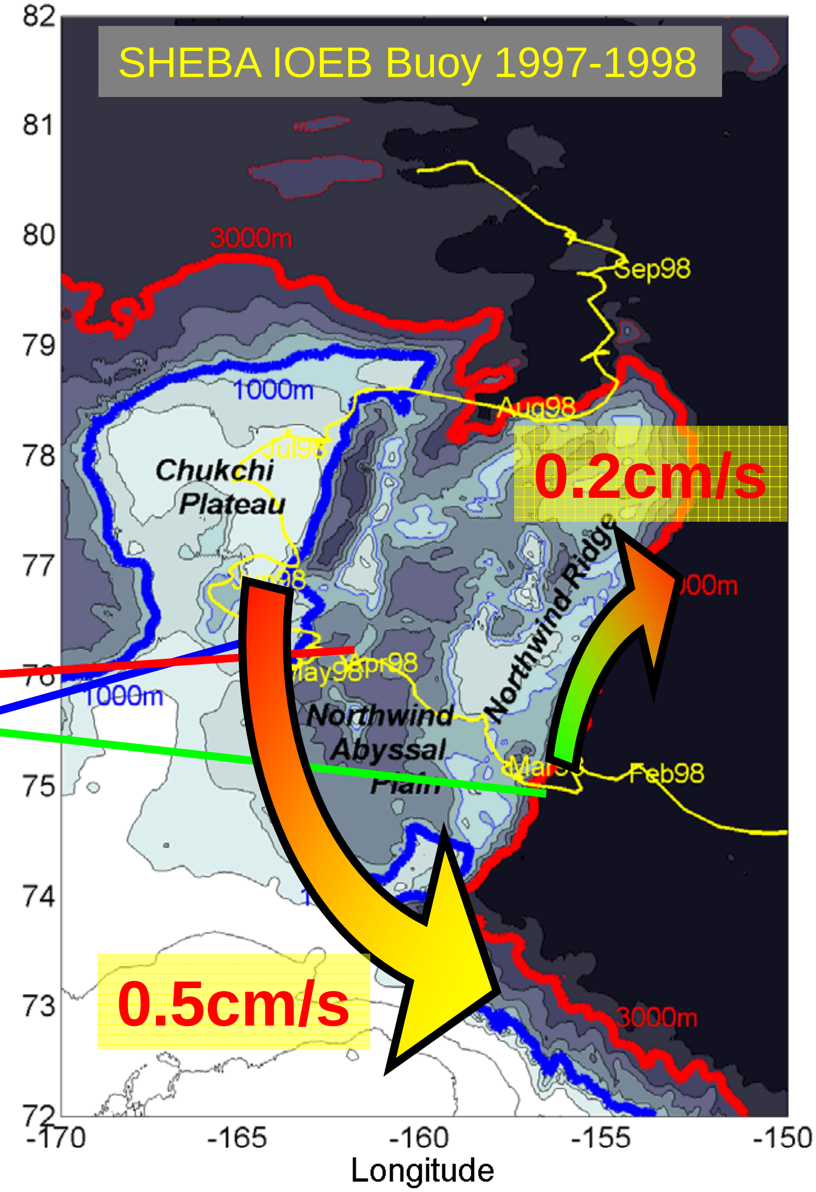
Horizontal velocity (*u,v*) at 250m deep (red vectors)

Topography vectors (*dh/dy, -dh/dx*) (blue vector).

Atlantic Water Circulation on the Chukchi Borderland

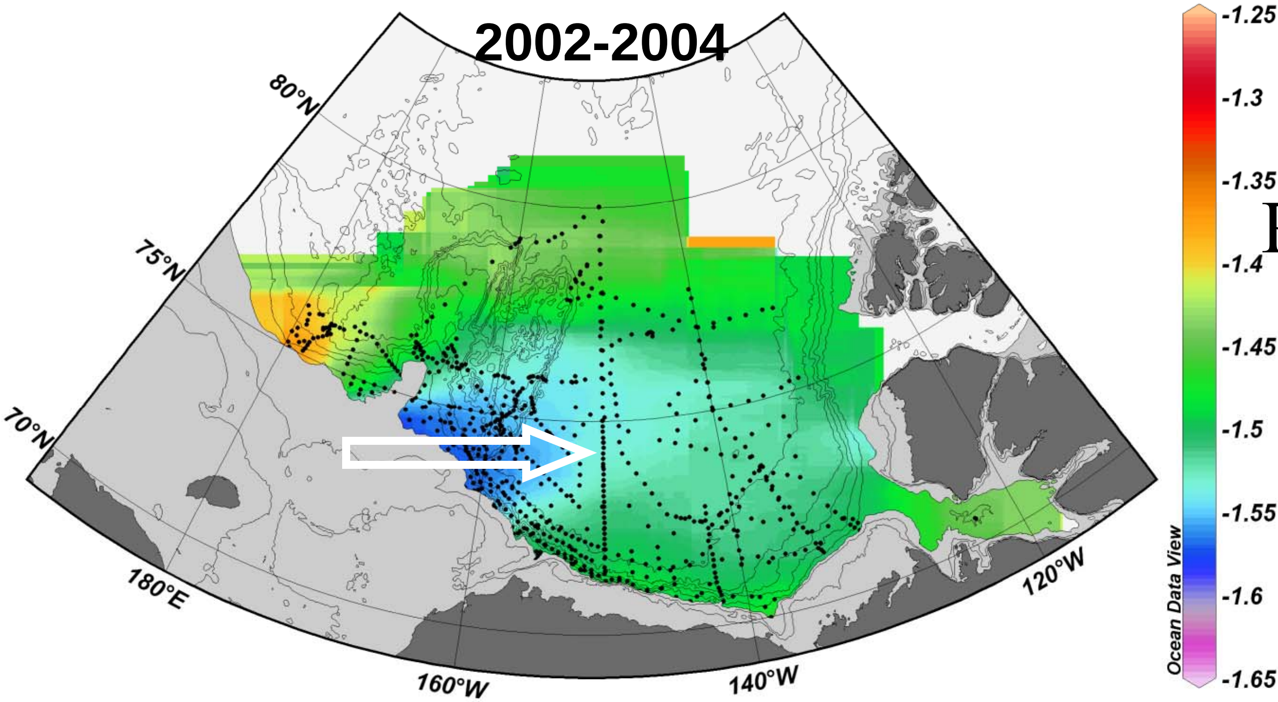
Strong Beaufort High



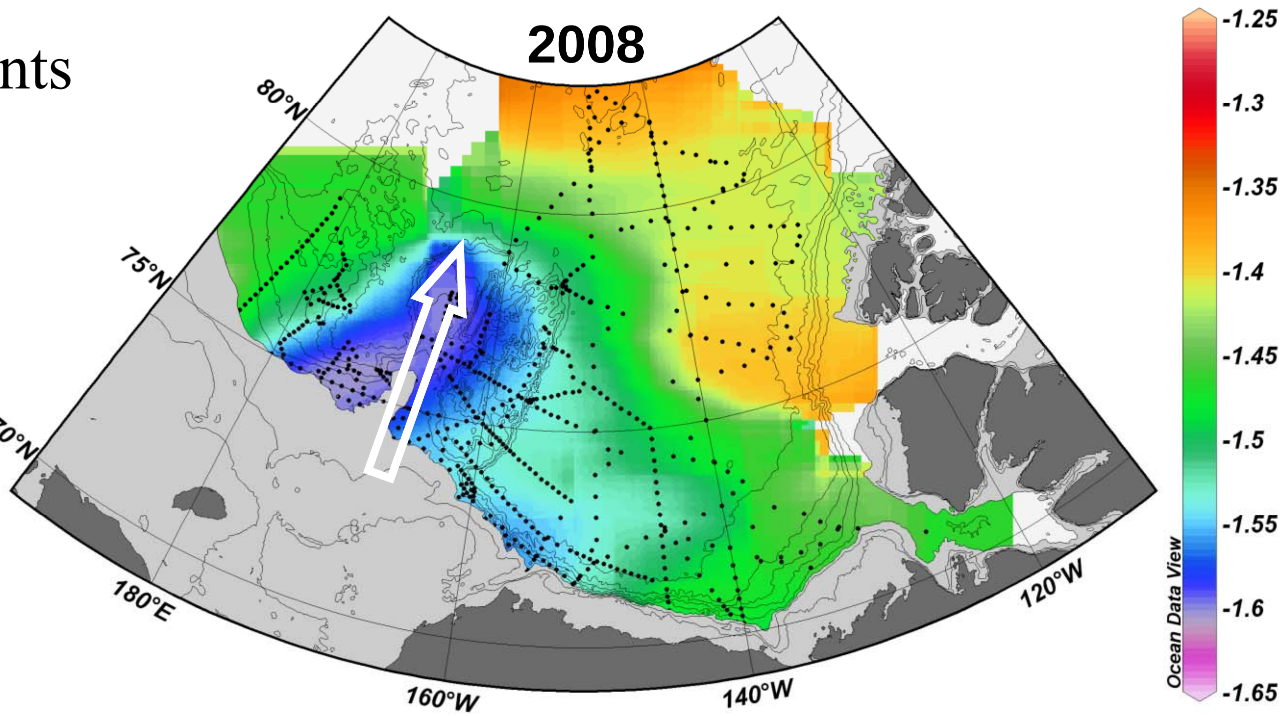


Eastern flank

Spreading of Pacific Winter Water

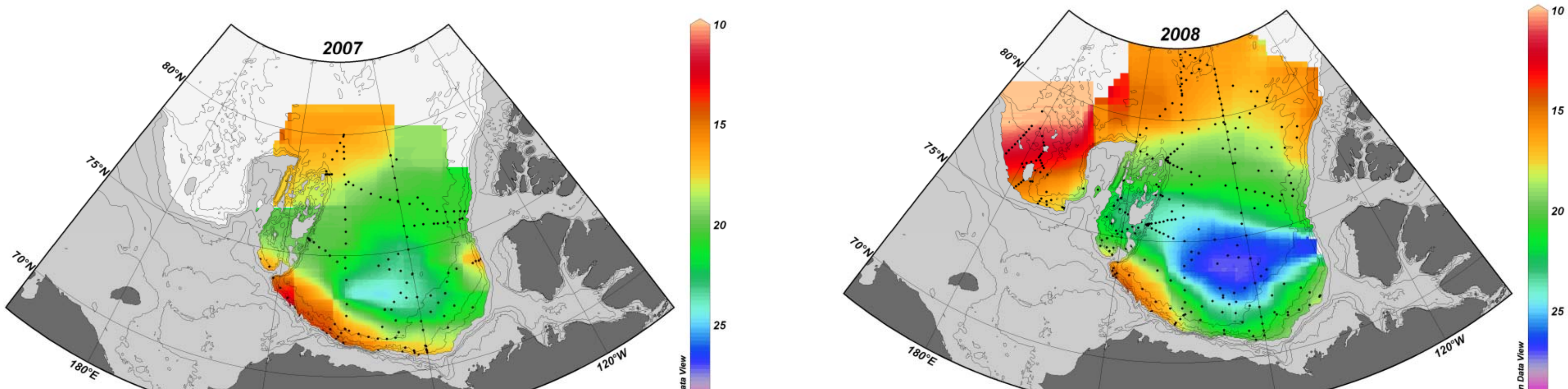


buoyancy driven currents dominates

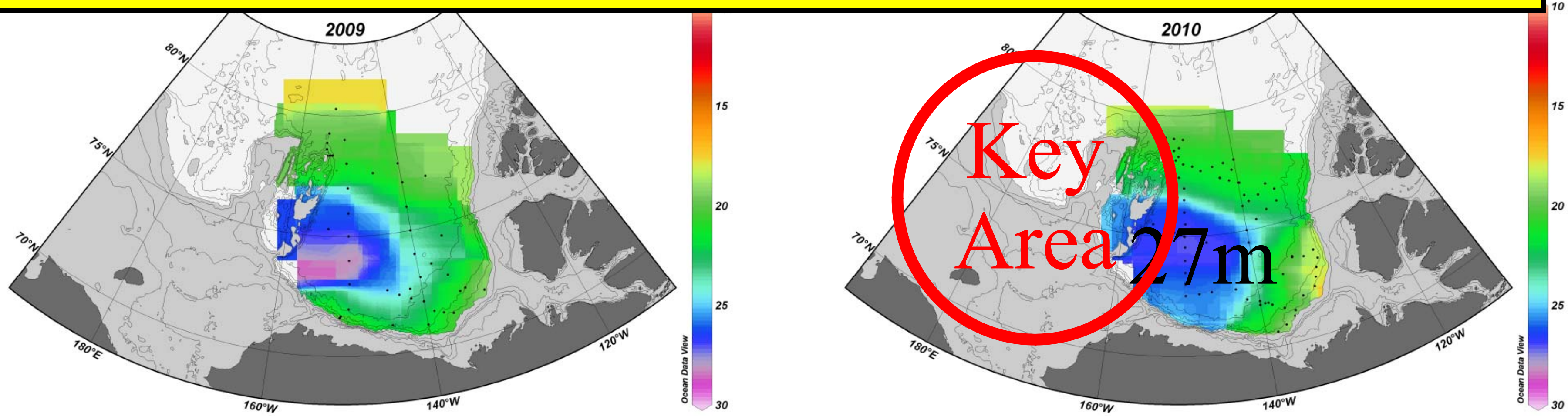


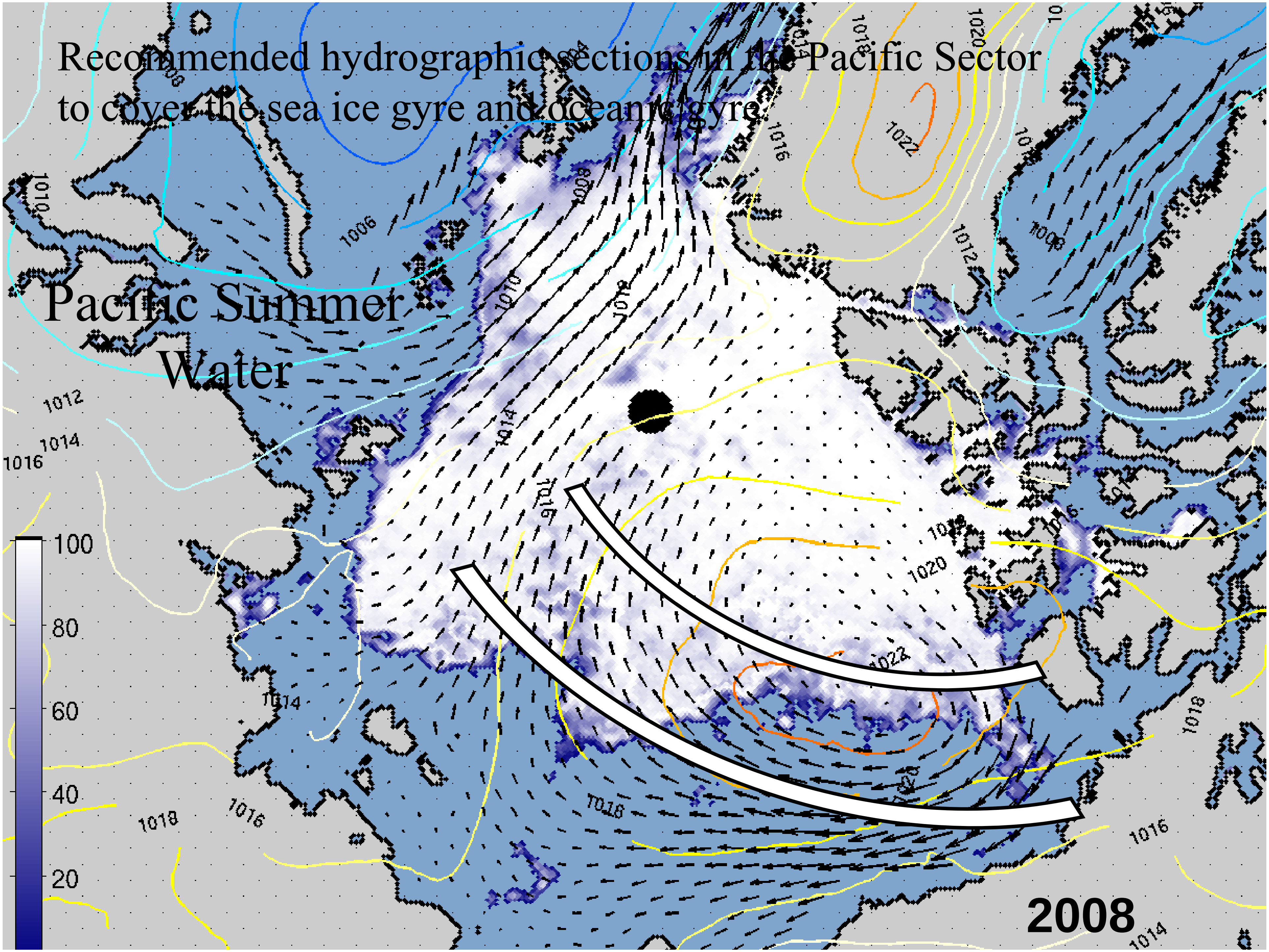
Wind driven currents overcome buoyancy driven currents

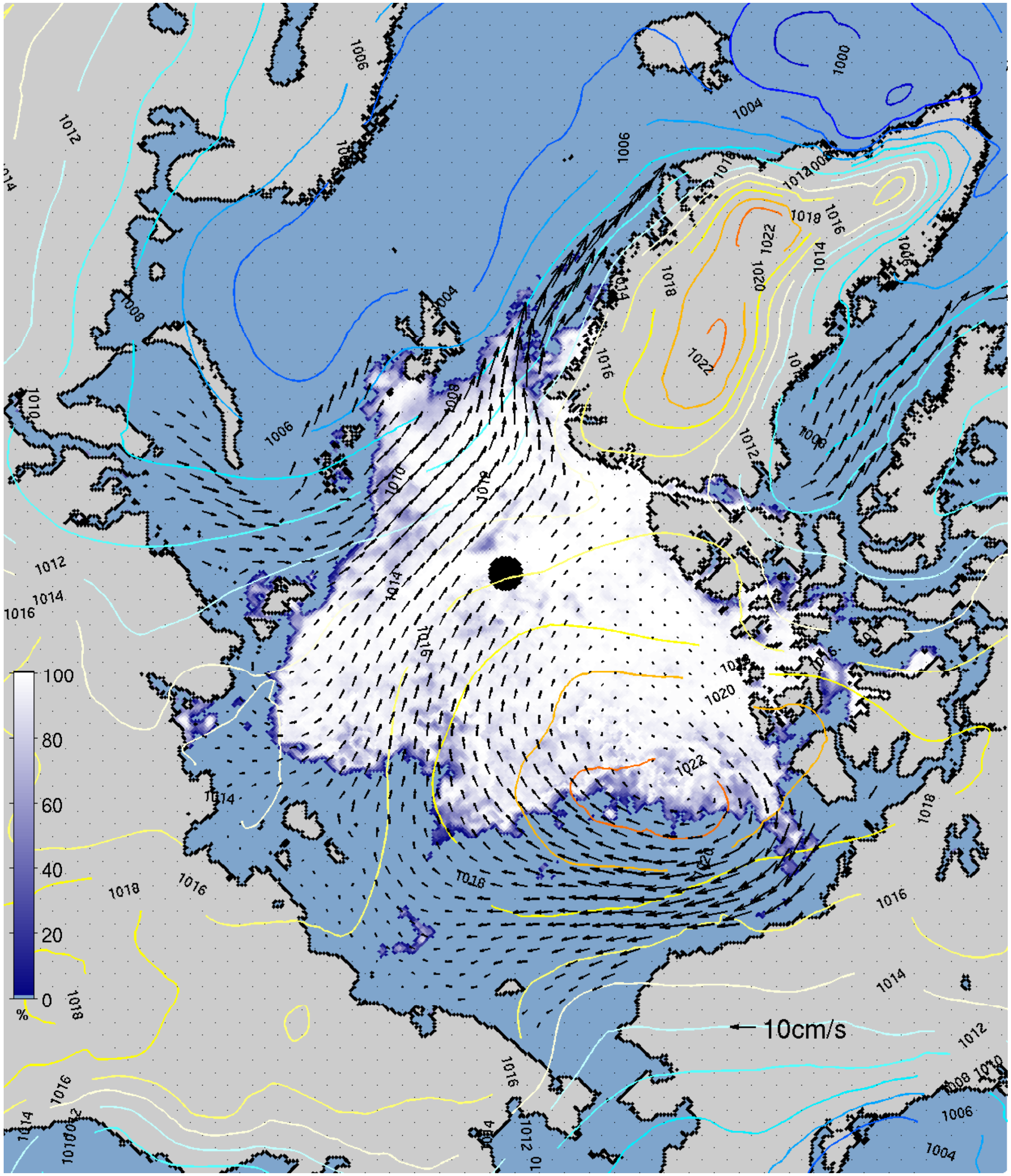
Great salinity anomaly is assumed to be located in the Chukchi Borderland area (Northwind Ridge and Chukchi Plateau). Significant changes in ocean circulation and biogeochemical environment would occur in this area.

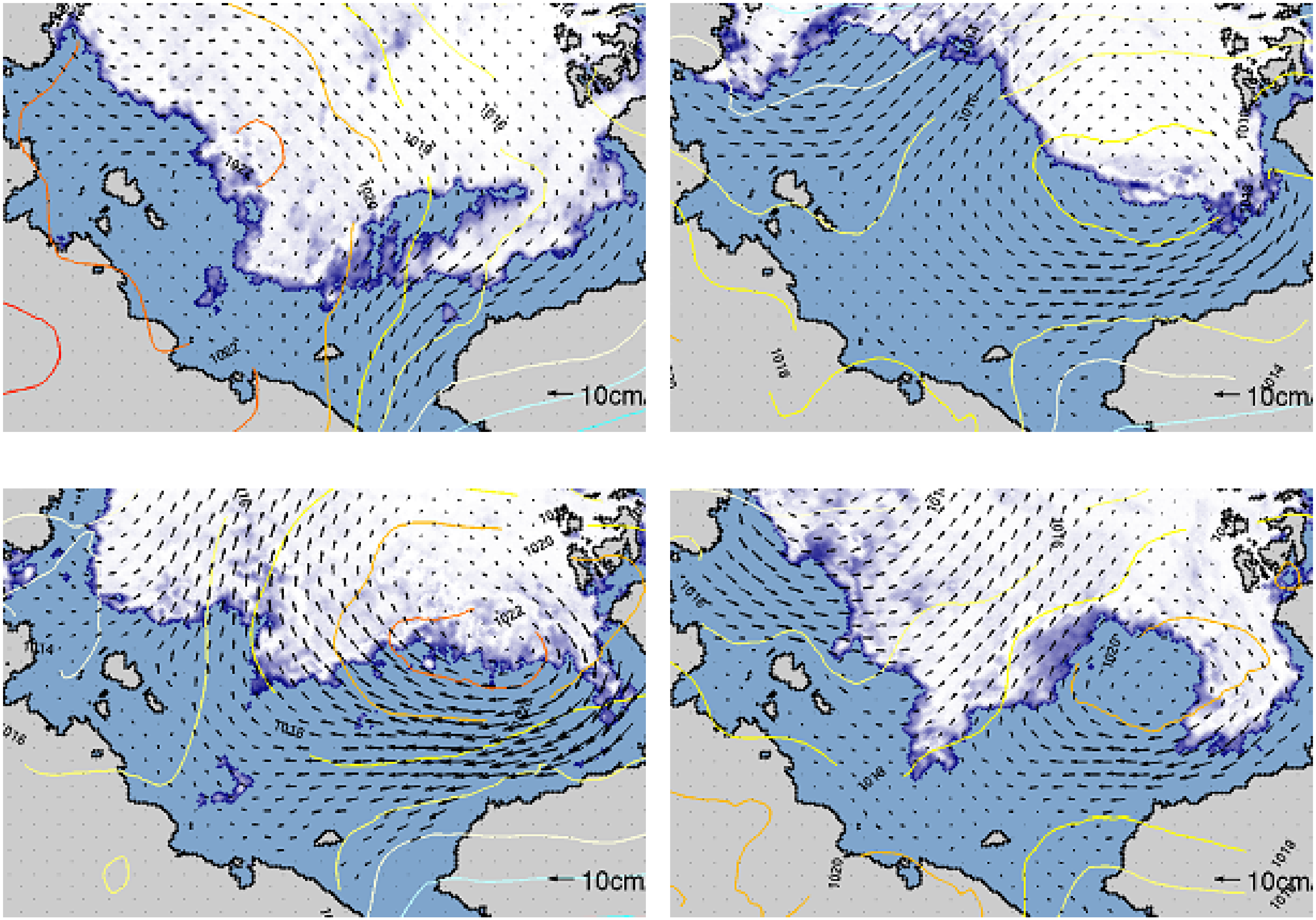


Great salinity anomaly is now propagating




Recommended hydrographic sections in the Pacific Sector
to cover the sea ice gyre and oceanic gyre.
Pacific Summer
Water
2008
100
80
60
40
20
1006
1008
1010
1012
1014
1016
1018
1020
1022


100
80
60
40
20
0
%
10cm/s



10cm
10cm
10cm
10cm

Climate

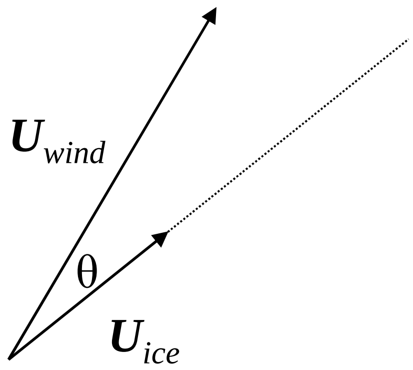
Ecosystem

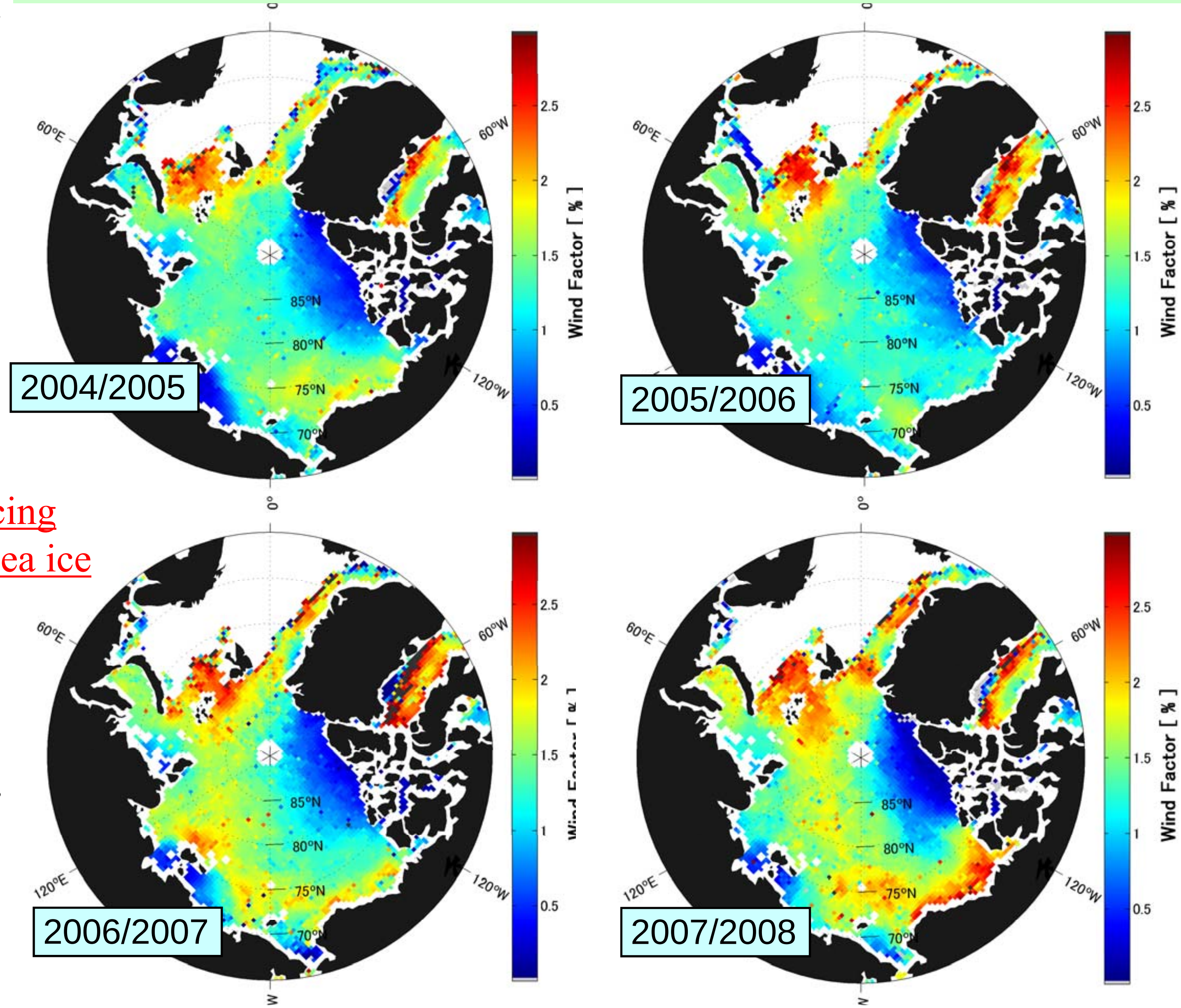
Changes in Wind Factor (Nov.- May) :

A control parameter for penetration of momentum from atmosphere into ocean through sea ice cover.

Wind Factor

$= |\boldsymbol{U}_{ice}| / |\boldsymbol{U}_{wind} \cos\theta|$

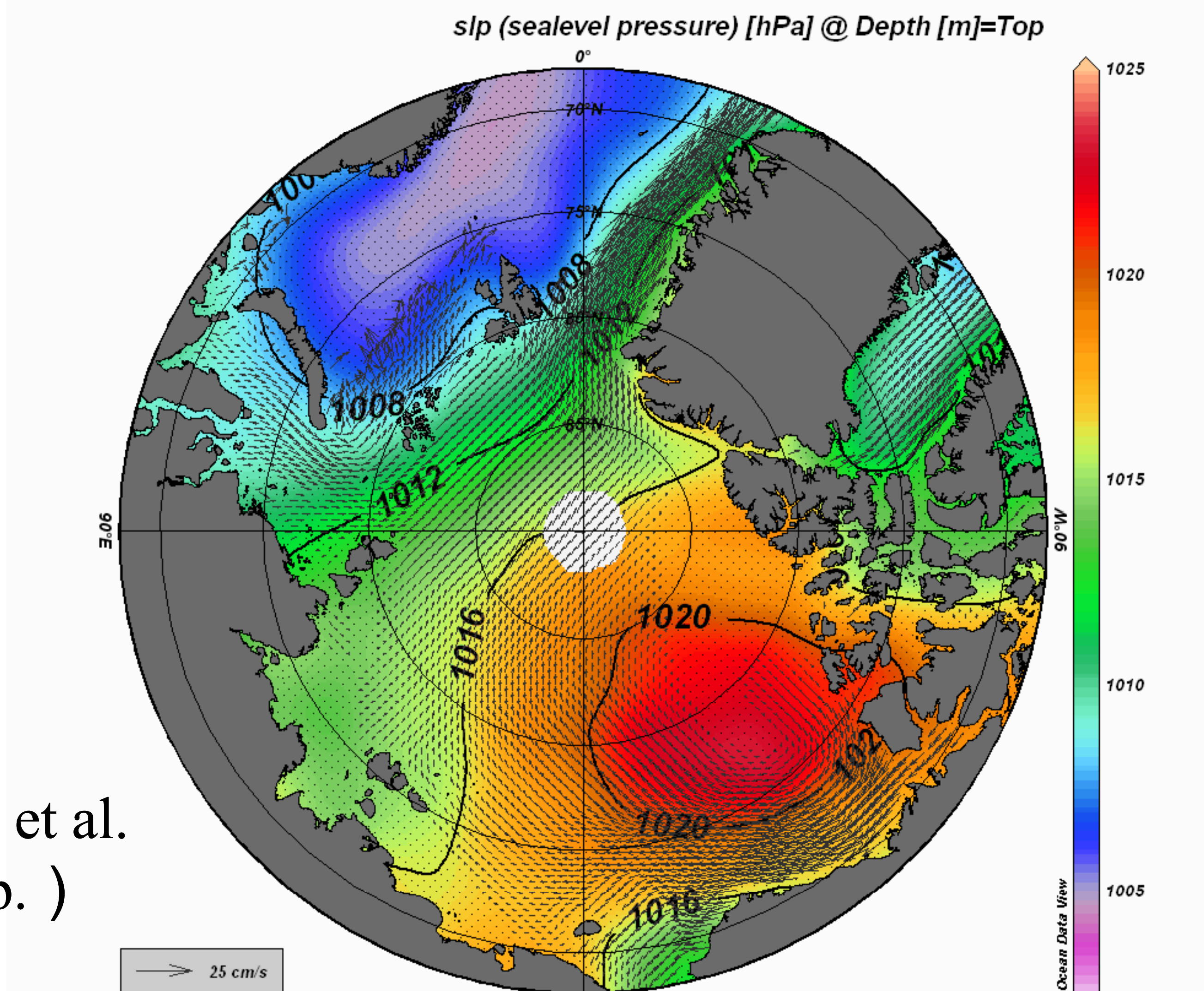




<u>Penetration of wind forcing into the ocean through sea ice substantially increased.</u>

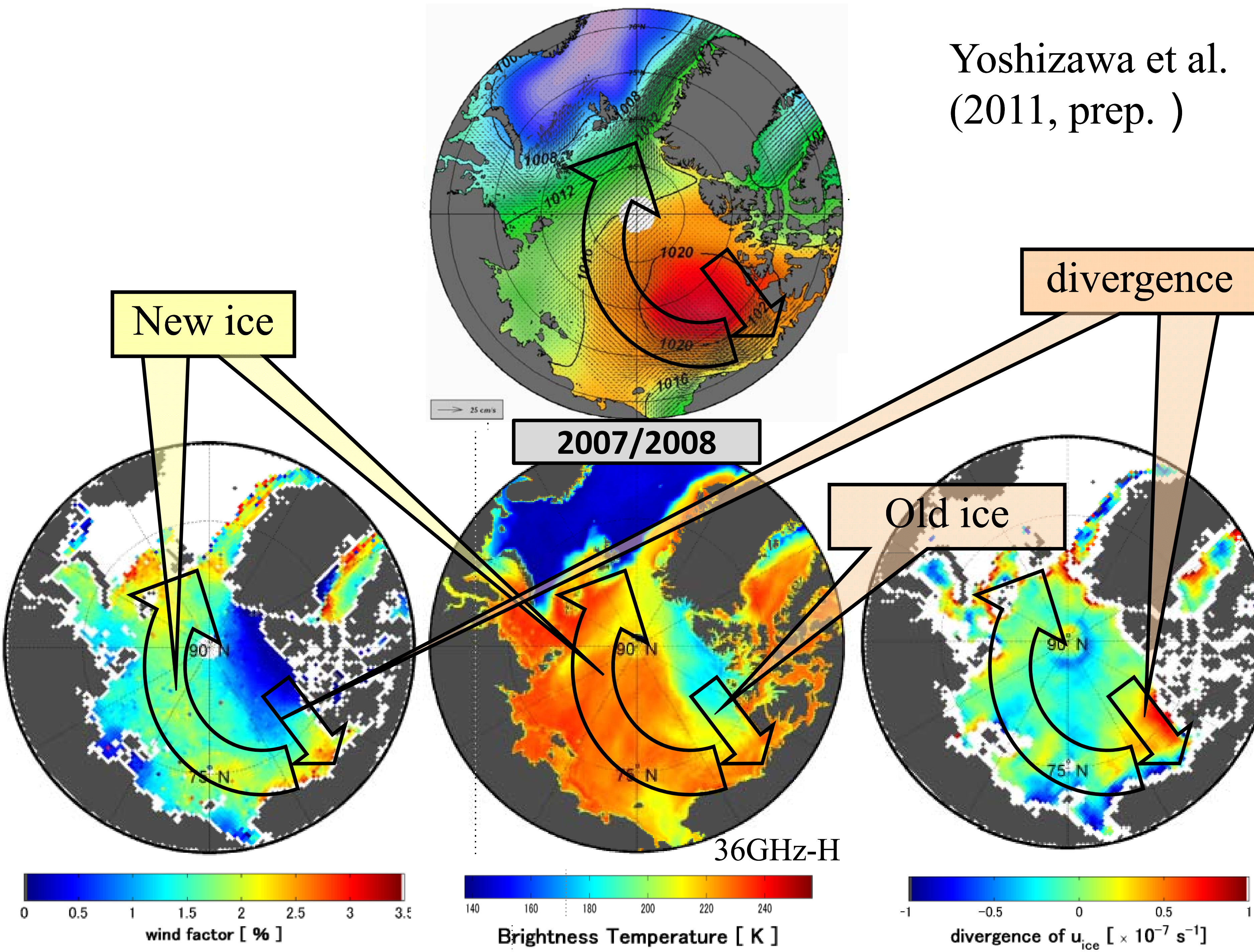
Yoshizawa et al. (2011, prep.)

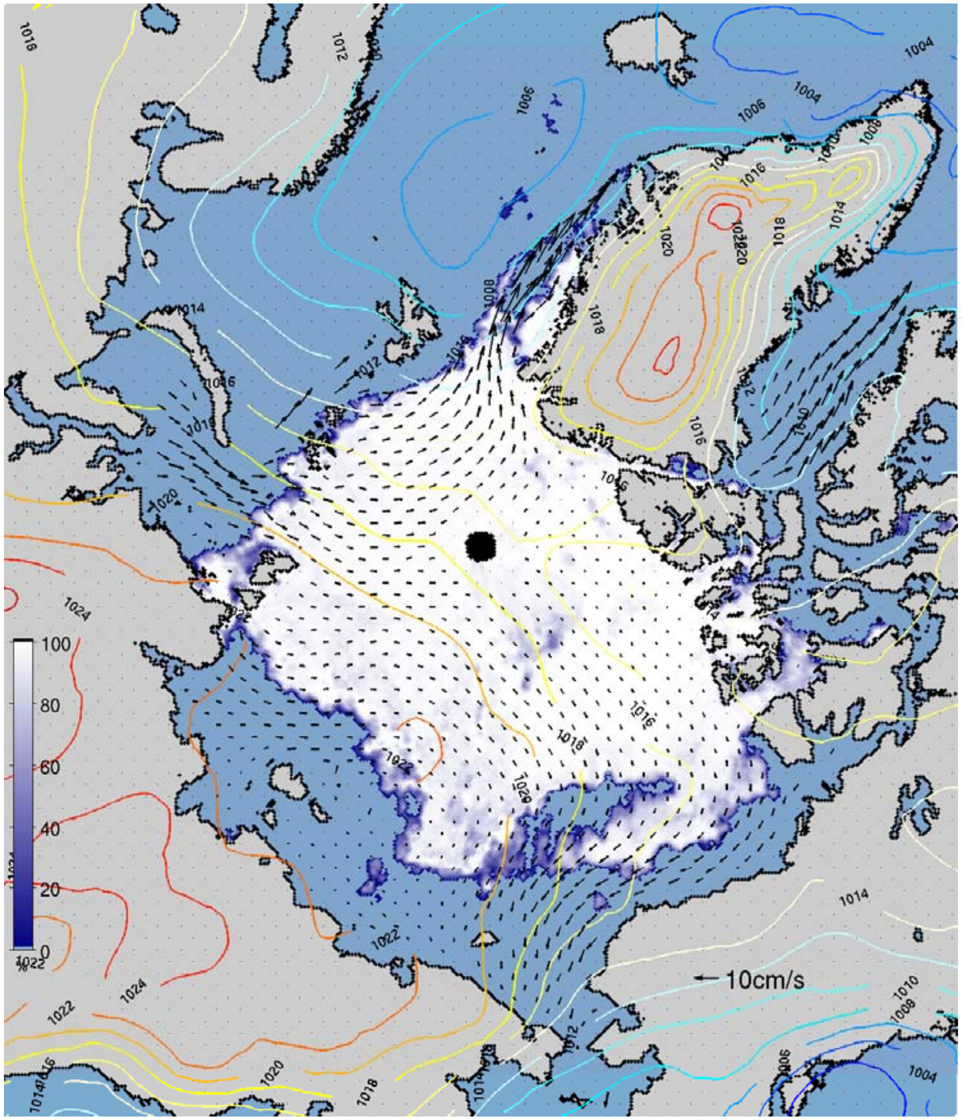
Why wind factor is getting larger?

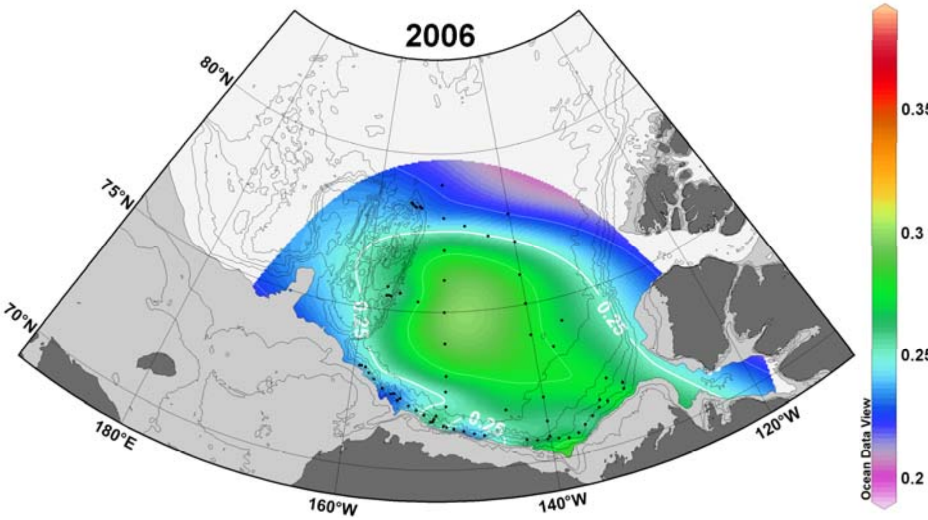


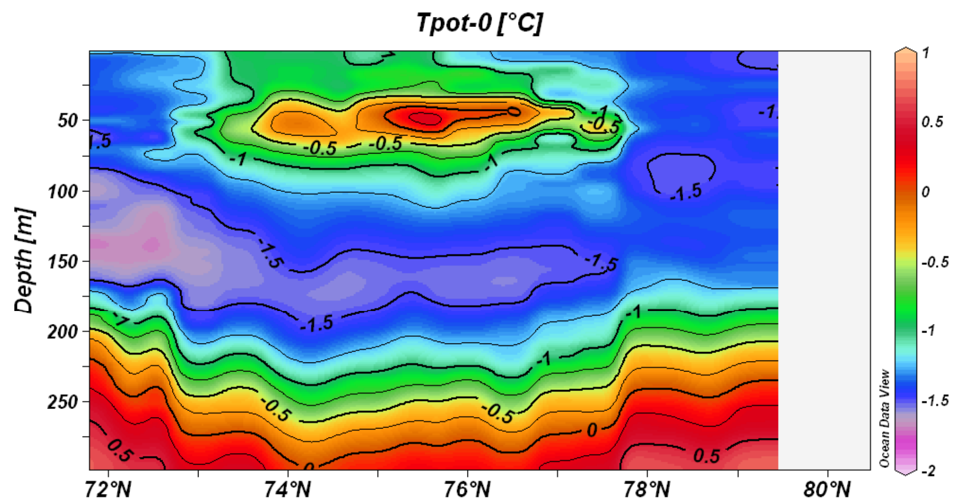
Yoshizawa et al.
(2011, prep.)

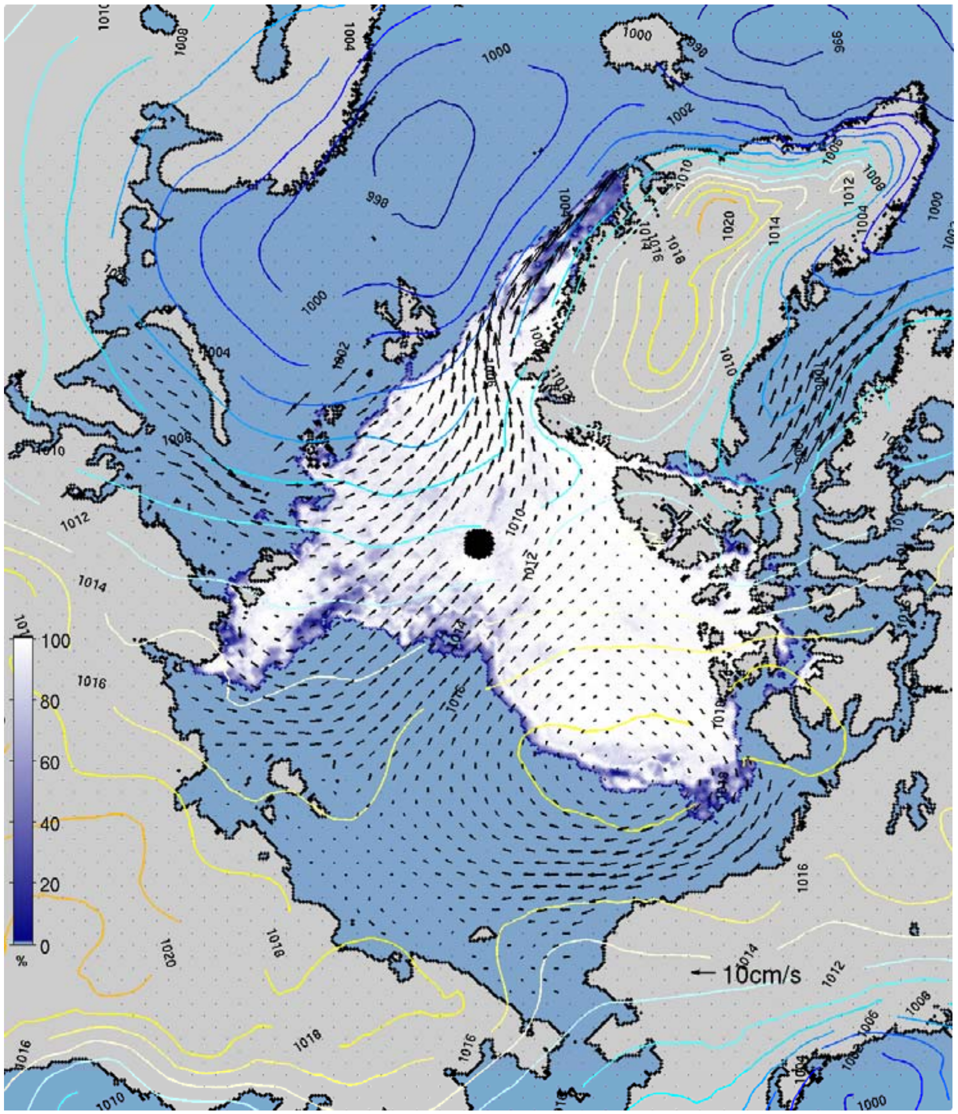
Winter (Nov – May) mean sea level pressure [hPa] and sea ice motion in 2007/2008.

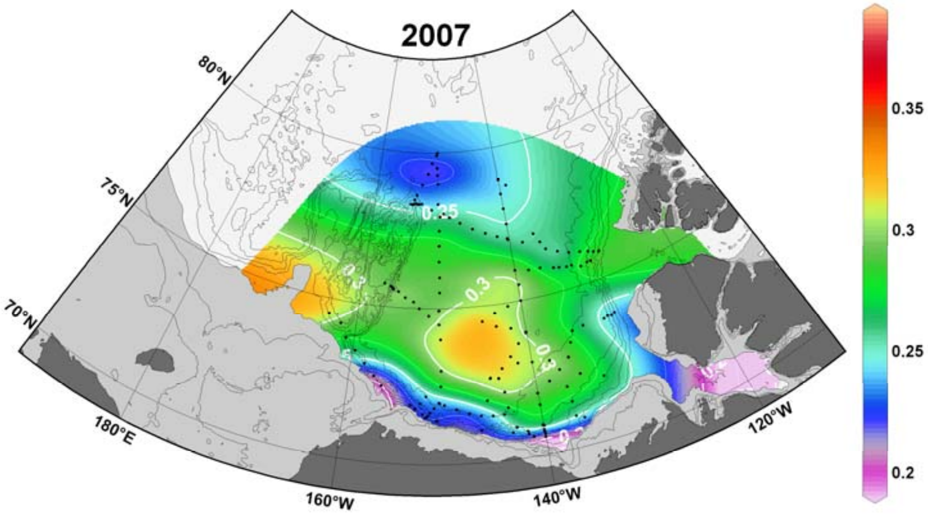

Yoshizawa et al.
(2011, prep.)
divergence
New ice
Old ice
2007/2008
36GHz-H
1008
1012
1016
1020
90° N
75° N
0 0.5 1 1.5 2 2.5 3 3.5
wind factor [%]
140 160 180 200 220 240
Brightness Temperature [K]
-1 -0.5 0 0.5 1
divergence of u_ice [× 10^-7 s^-1]

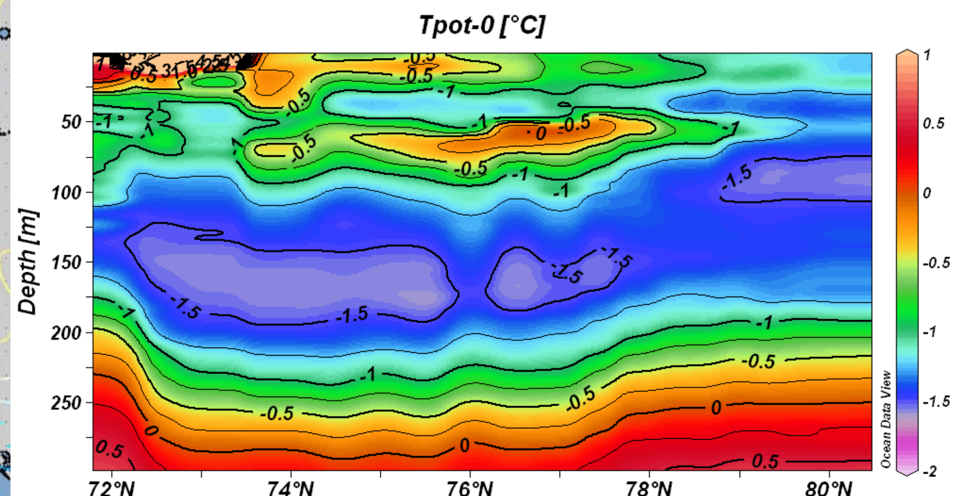

100
80
60
40
20
0
10cm/s
1004
1006
1008
1012
1014
1016
1018
1020
1022
1024

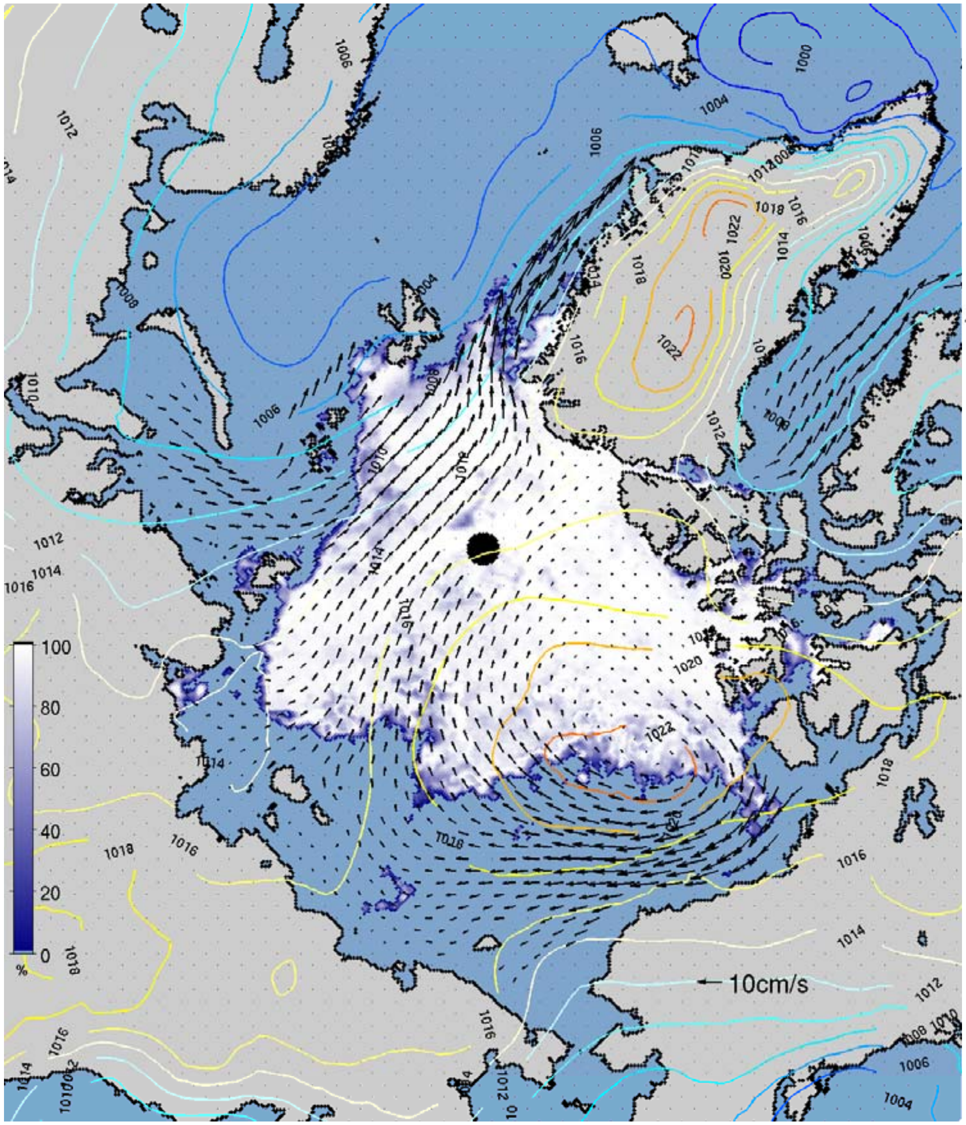

2006
80°N
75°N
70°N
180°E
160°W
140°W
120°W
0.25
0.35
0.3
0.25
0.2
Ocean Data View

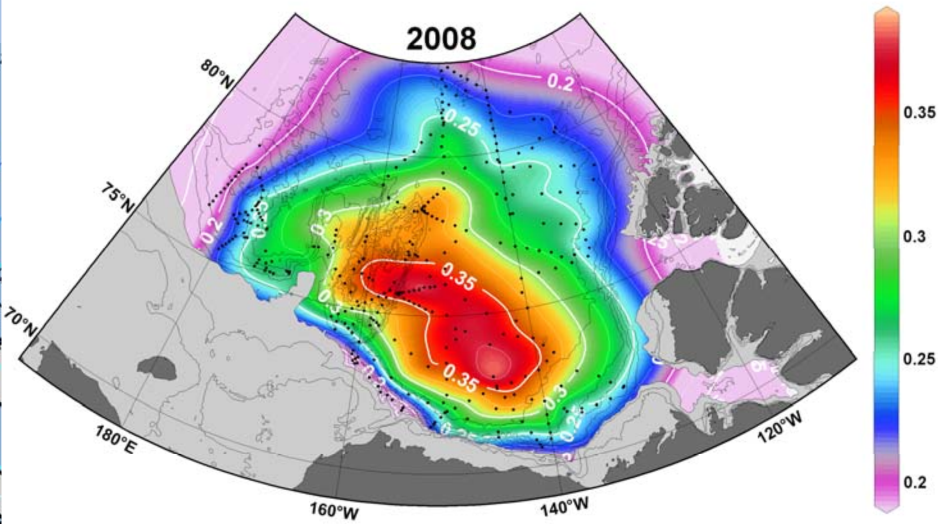

Tpot-0 [°C]
Depth [m]
50
100
150
200
250
72°N
74°N
76°N
78°N
80°N
-0.5
-1
-1.5
0
0.5
1
-2
Ocean Data View

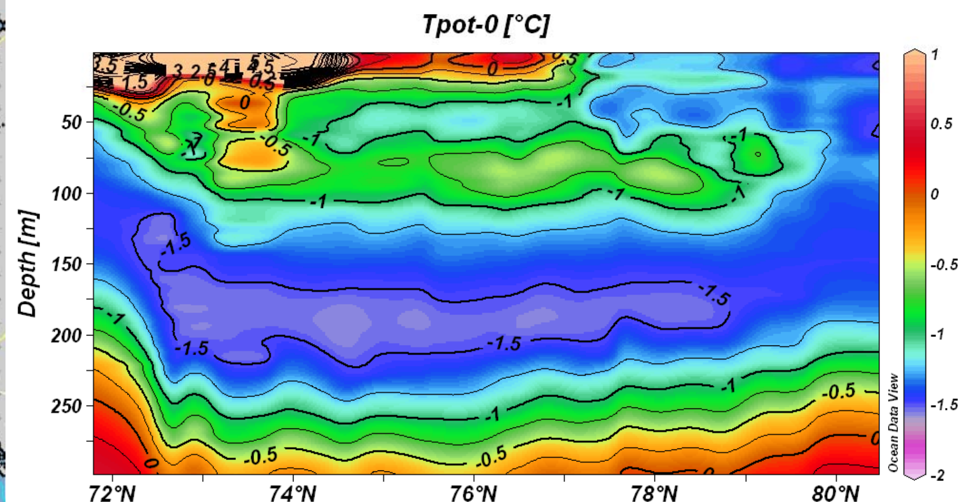

100
80
60
40
20
0
%
10cm/s

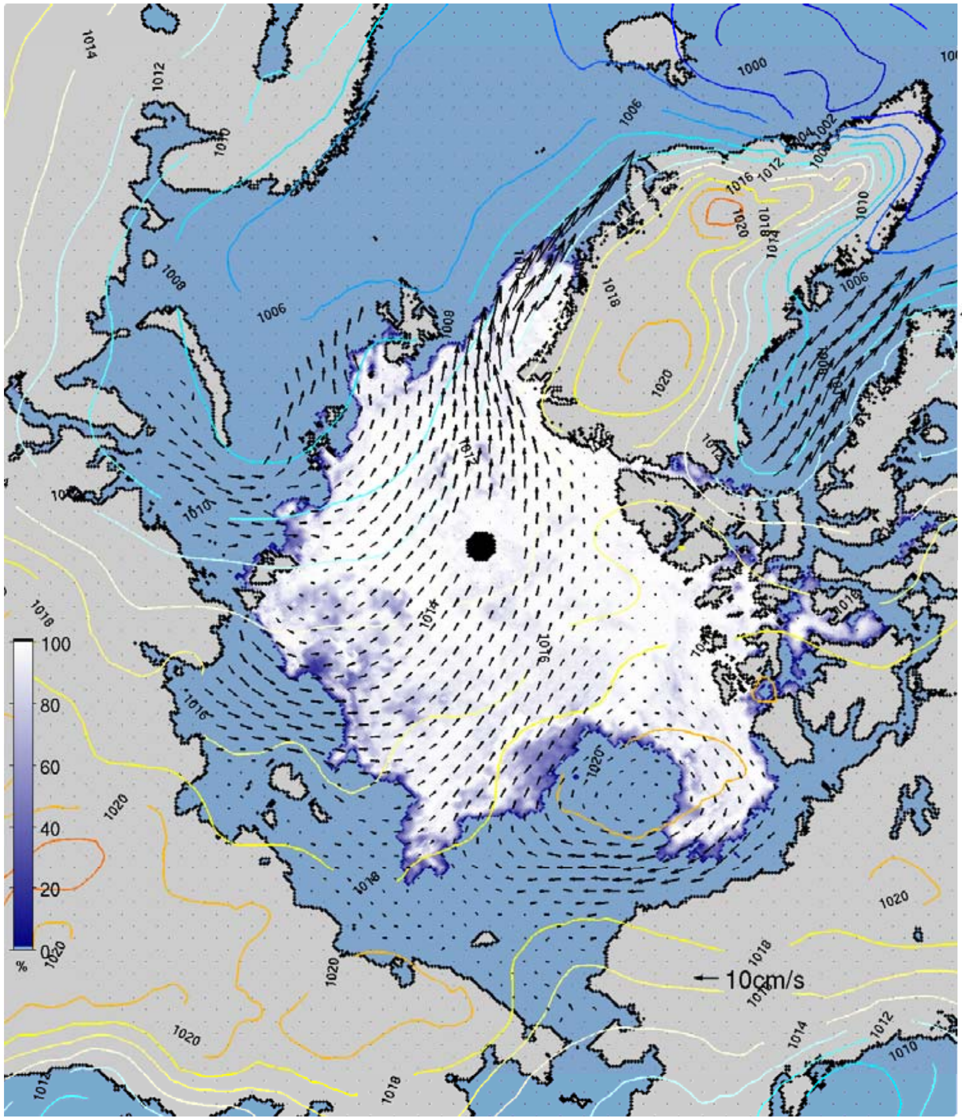

2007
80°N
75°N
70°N
180°E
160°W
140°W
120°W
0.35
0.3
0.25
0.2


Tpot-0 [°C]
Depth [m]
50
100
150
200
250
72°N
74°N
76°N
78°N
80°N
1
0.5
0
-0.5
-1
-1.5
-2
Ocean Data View

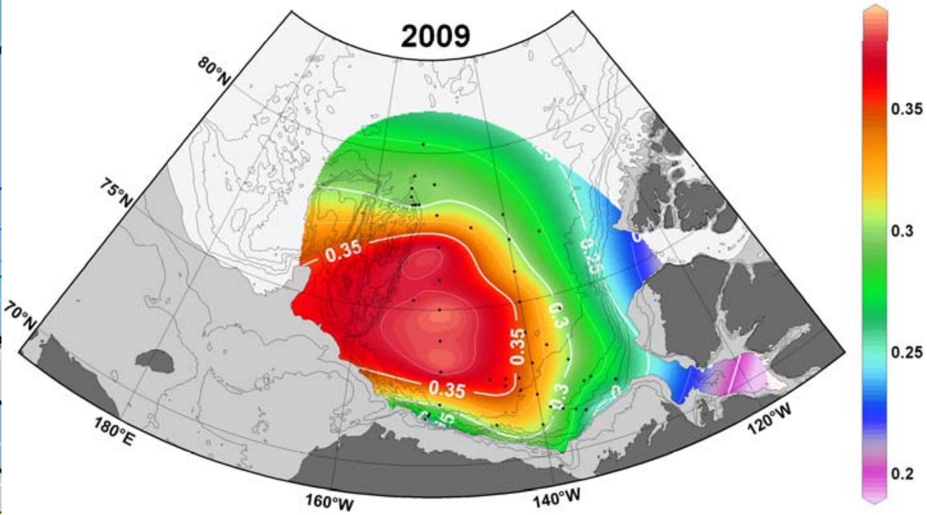

100
80
60
40
20
0
%
10cm/s


2008
80°N
75°N
70°N
180°E
160°W
140°W
120°W
0.2
0.25
0.3
0.35

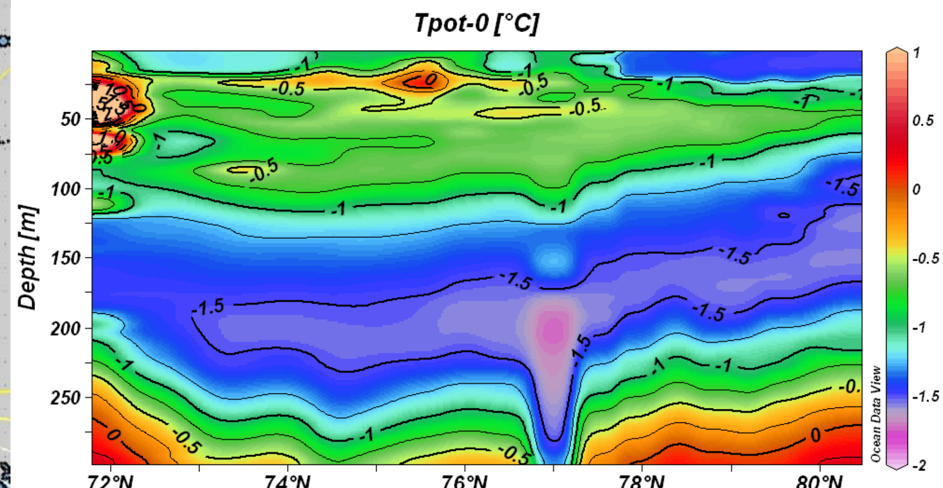

Tpot-0 [°C]
Depth [m]
50
100
150
200
250
72°N
74°N
76°N
78°N
80°N
1
0.5
0
-0.5
-1
-1.5
-2
Ocean Data View



100
80
60
40
20
0
%
10cm/s

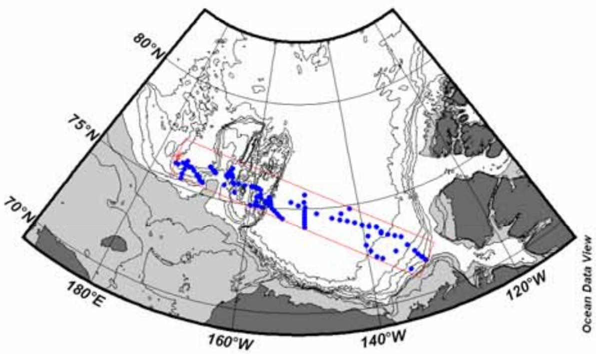


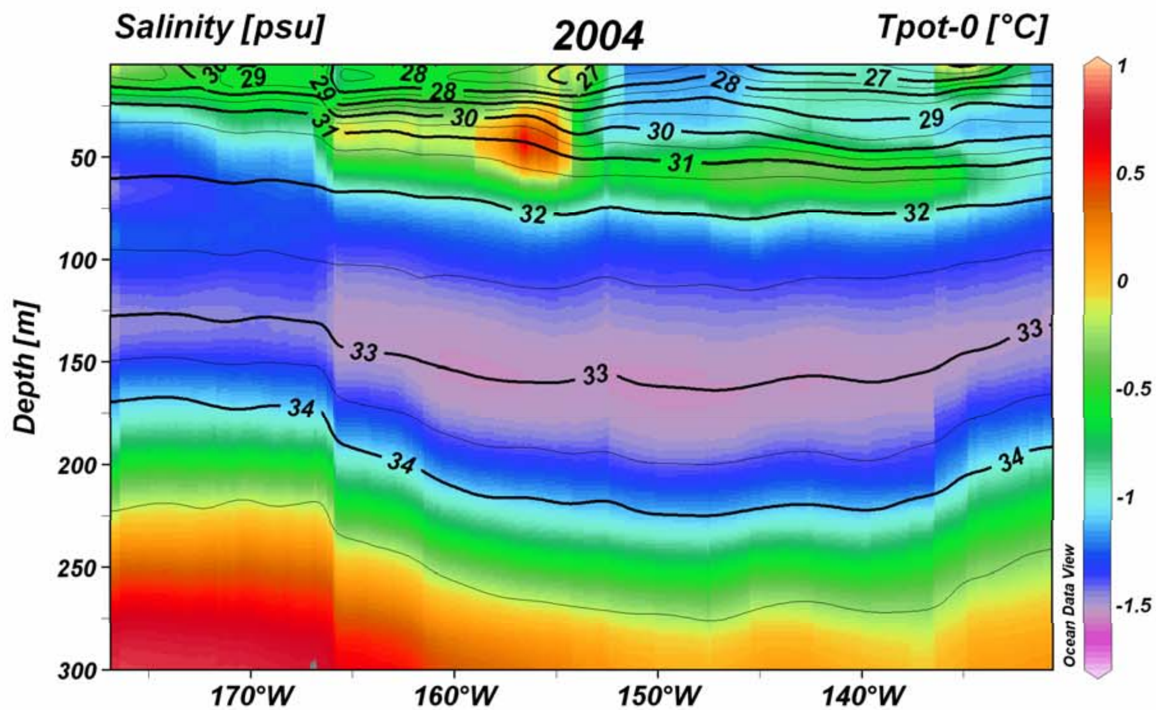
2009
80°N
75°N
70°N
180°E
160°W
140°W
120°W
0.35
0.3
0.25
0.35
0.3
0.25
0.2

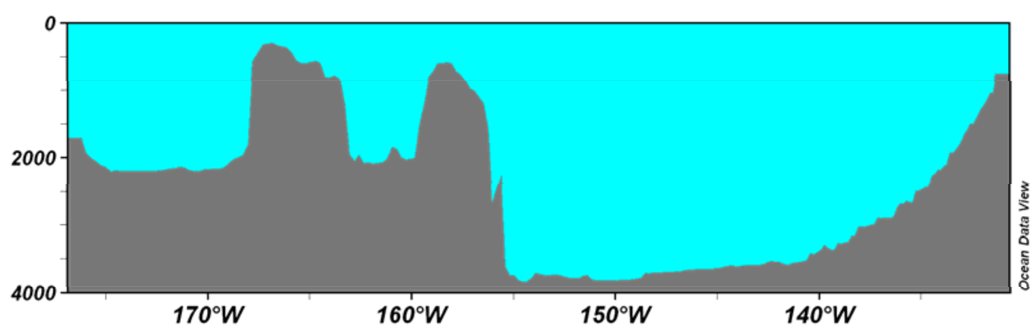


Tpot-0 [°C]
Depth [m]
50
100
150
200
250
72°N
74°N
76°N
78°N
80°N
Ocean Data View
1
0.5
0
-0.5
-1
-1.5
-2

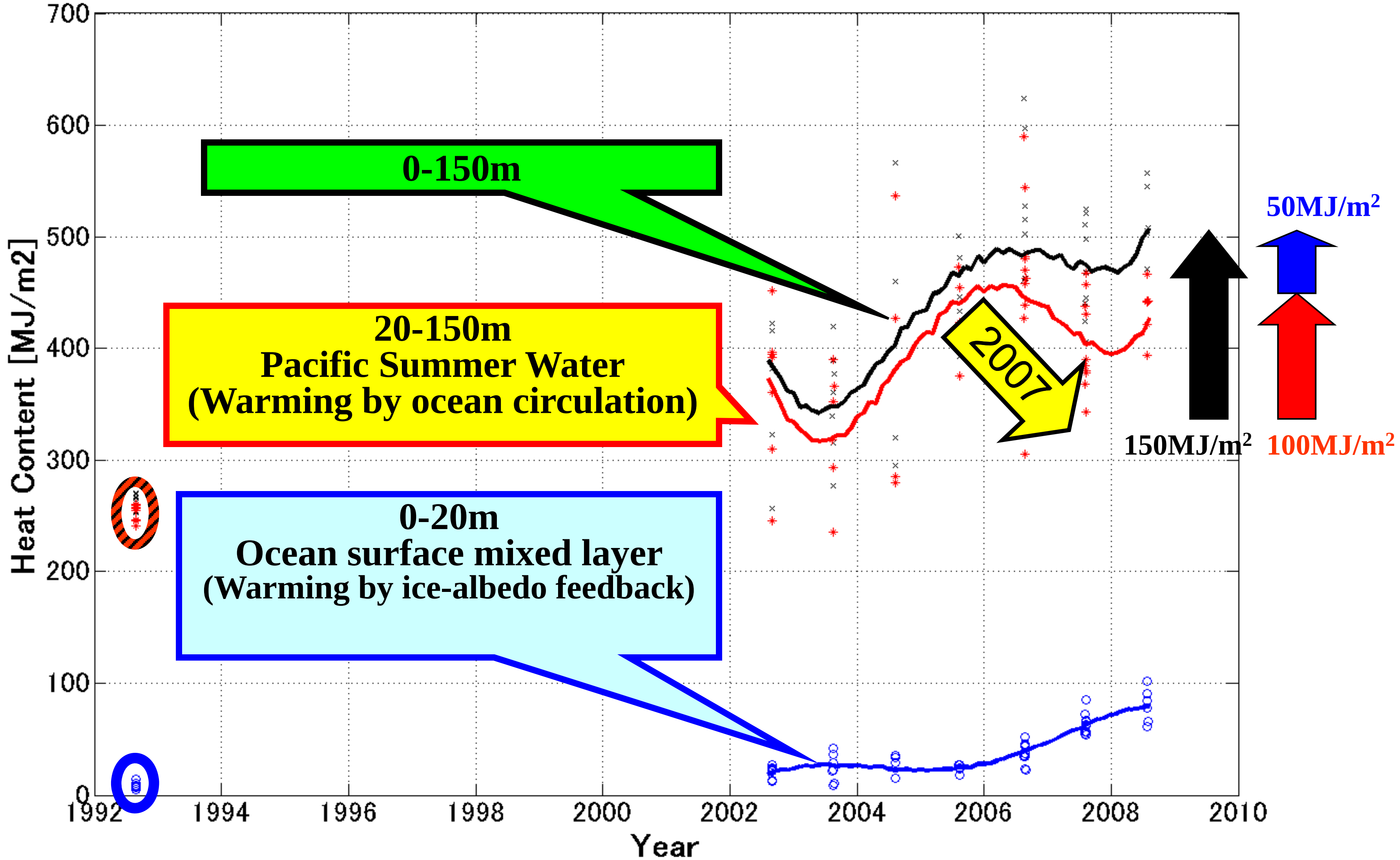
Changes in spreading pathway of Pacific Water into the Canada Basin







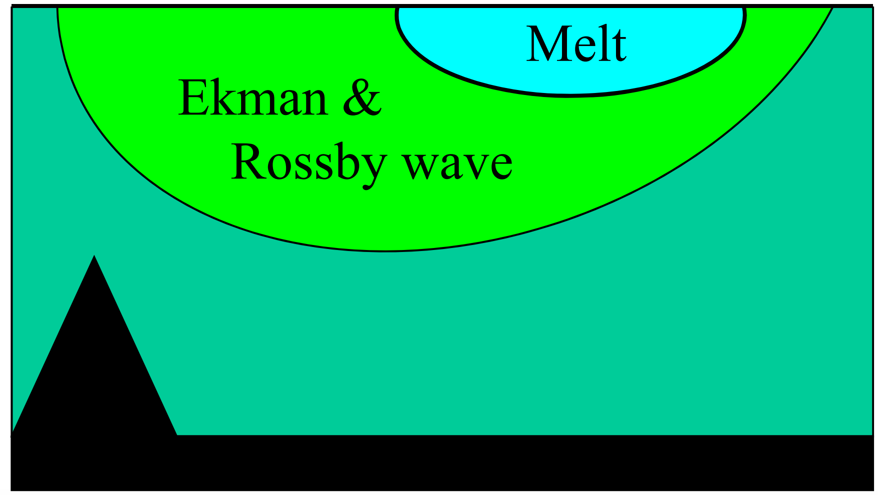
Warming by the strengthening ocean circulation led the warming by ice-albedo feedback

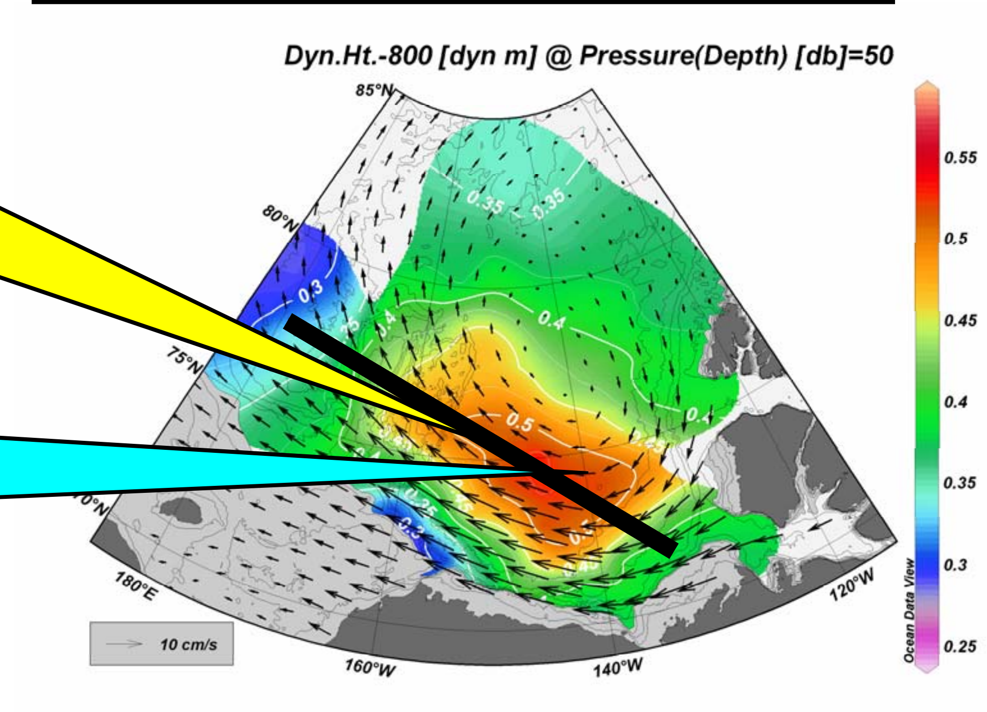


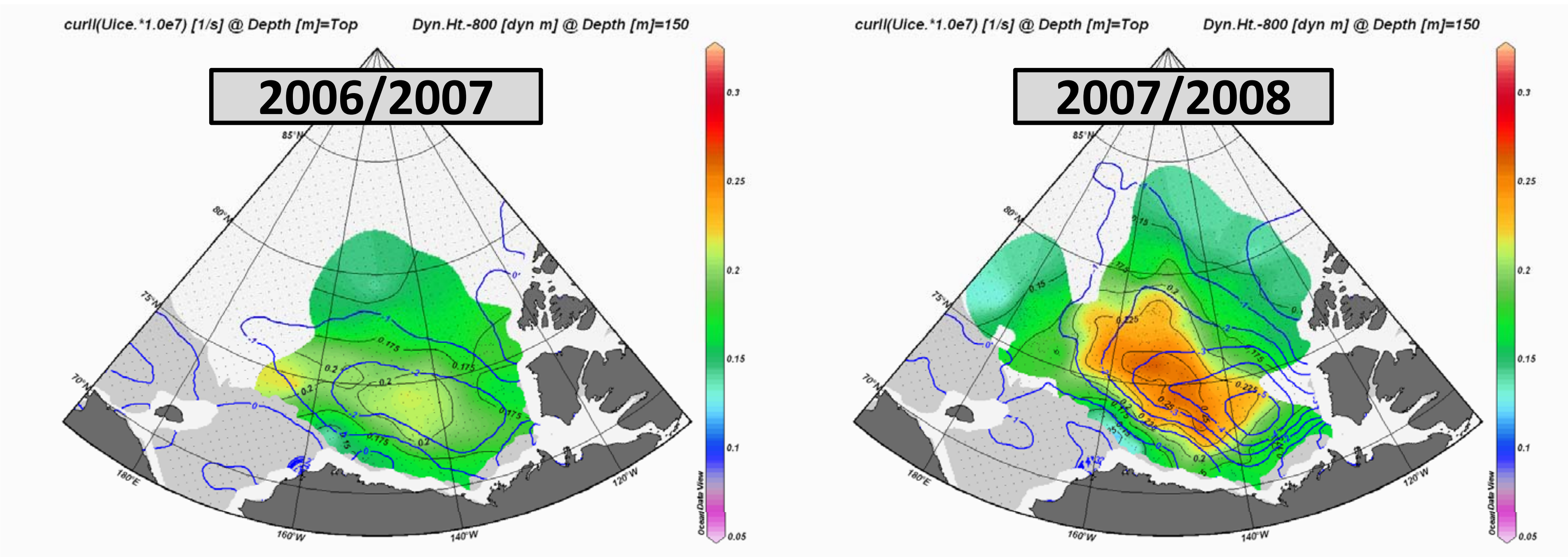
<u>74-76°N, 150-160°W (near Northwind Ridge), during July 27- Sep. 1</u>

Ekman pumping
&
Topography
(Pure Dynamics)

Low potential vorticity
water (melt water) input
(Thermodynamics)





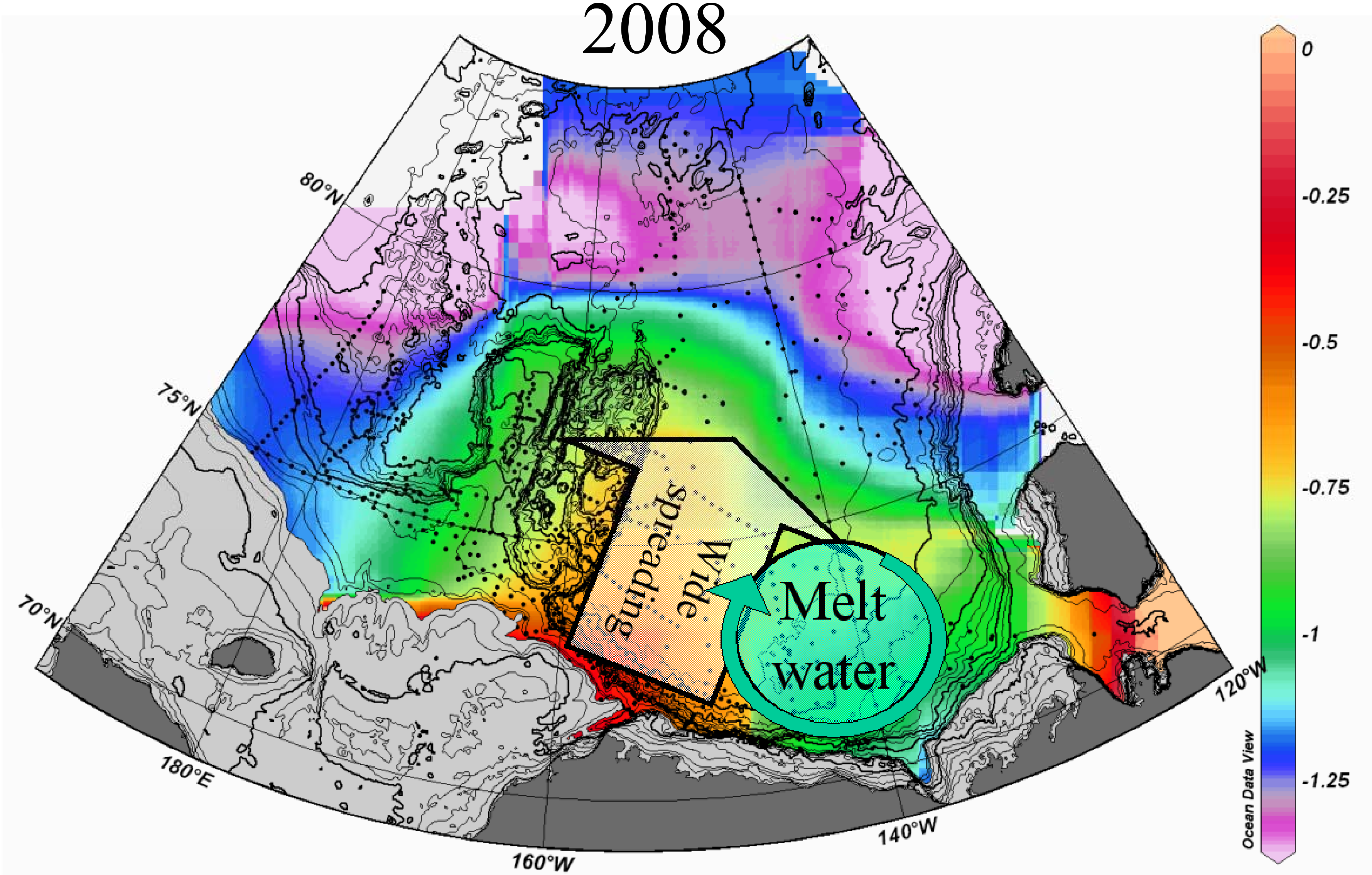


Ocean dynamic height (colors) & curl of sea ice motion (contours)

★ Strength of upper ocean circulation does not linearly respond to strength of Ekman Pumping caused by sea ice motion driven by wind.

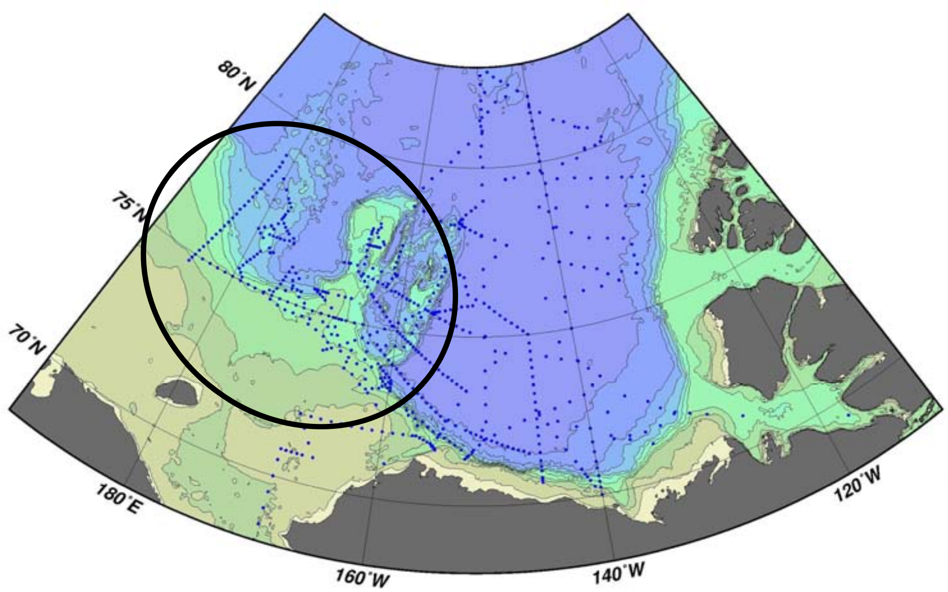
★ We should recall basic dynamics toward precise understanding and responding.

2008

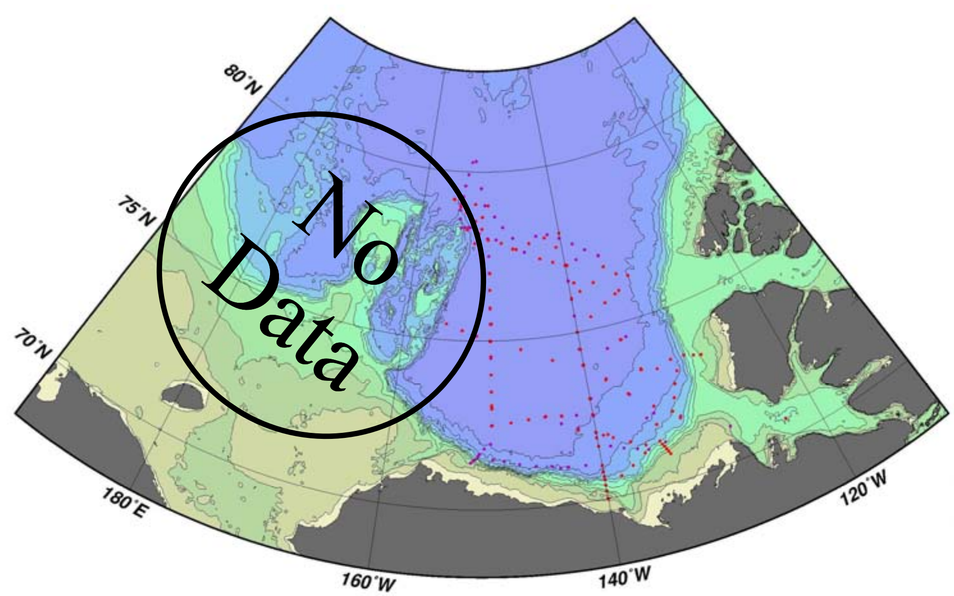


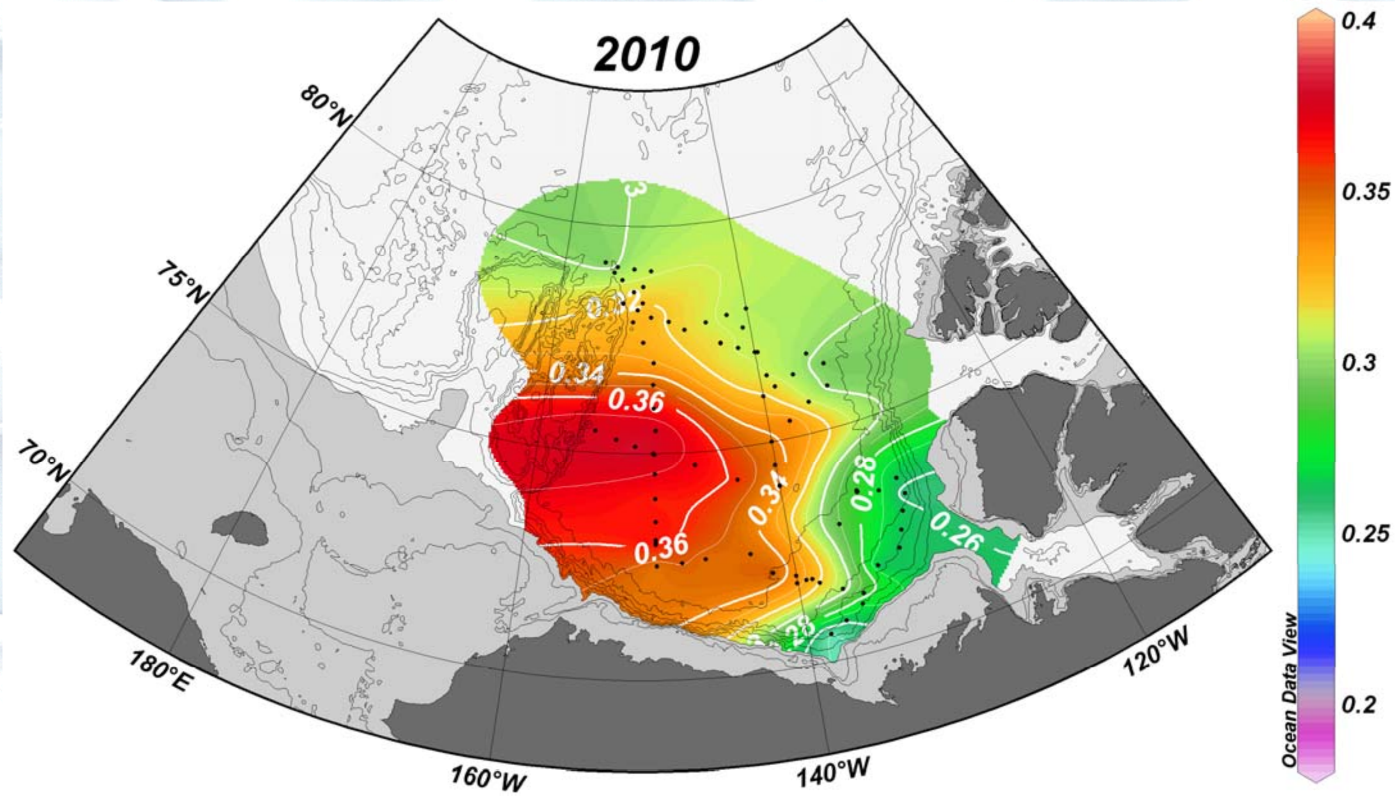
80°N
75°N
70°N
180°E
160°W
140°W
120°W
Wide spreading
Melt water
0
-0.25
-0.5
-0.75
-1
-1.25
Ocean Data View

Best distribution of hydrographic to understand changes in 2008



Important area, but no observation in 2009 and 2010.





- The dynamic height is still high value in 2010.
- 5cm sea level rise occurred within 5 years in the western Canada Basin.
- Features of ocean circulation have completely changed after IPY.

Ice motion is fast, but ocean circulation is tardy.
Huge accumulation of melt water was occurred in the southwestern Canada Basin (biologically hot spot).