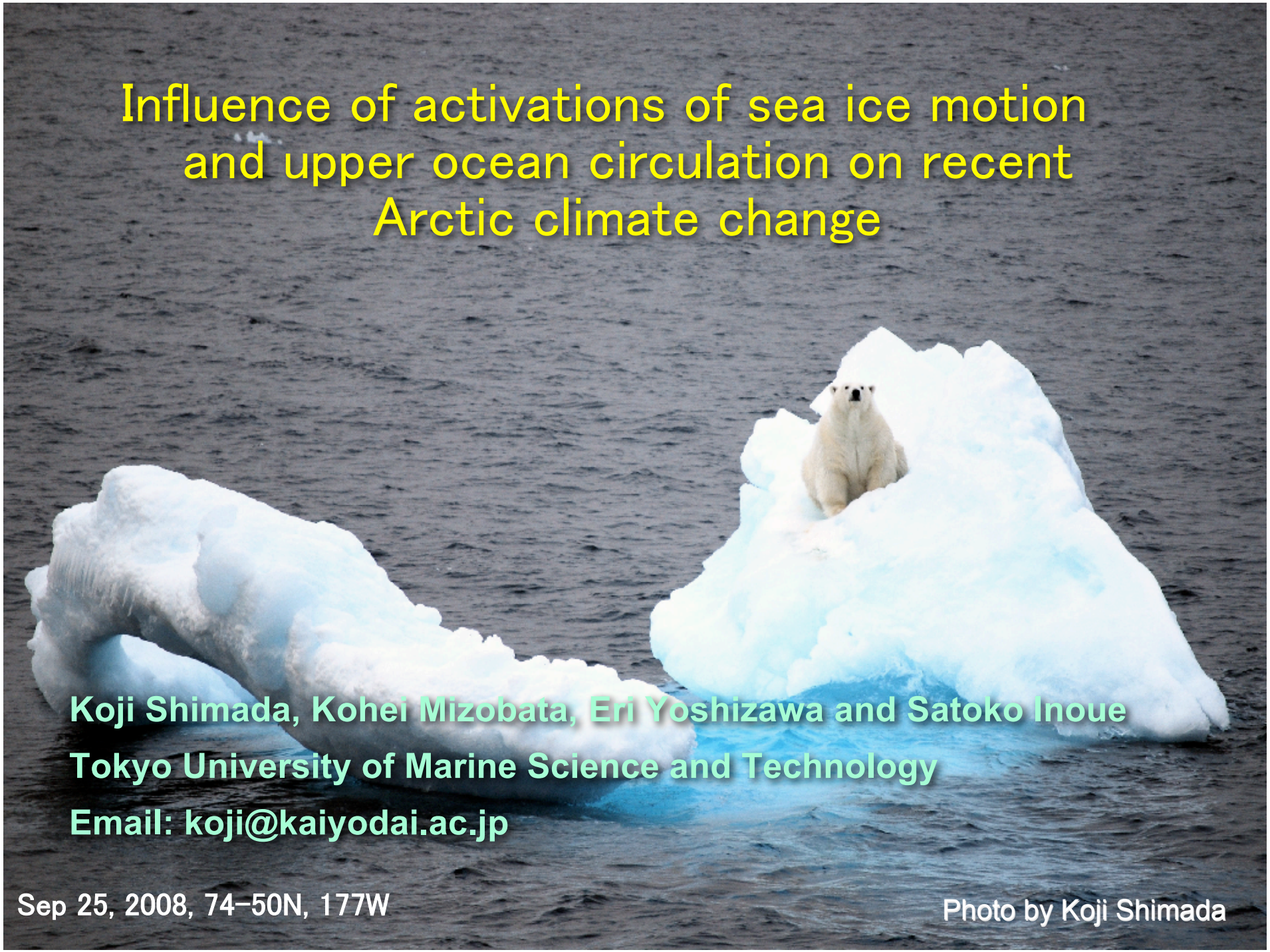


Influence of activations of sea ice motion and upper ocean circulation on recent Arctic climate change

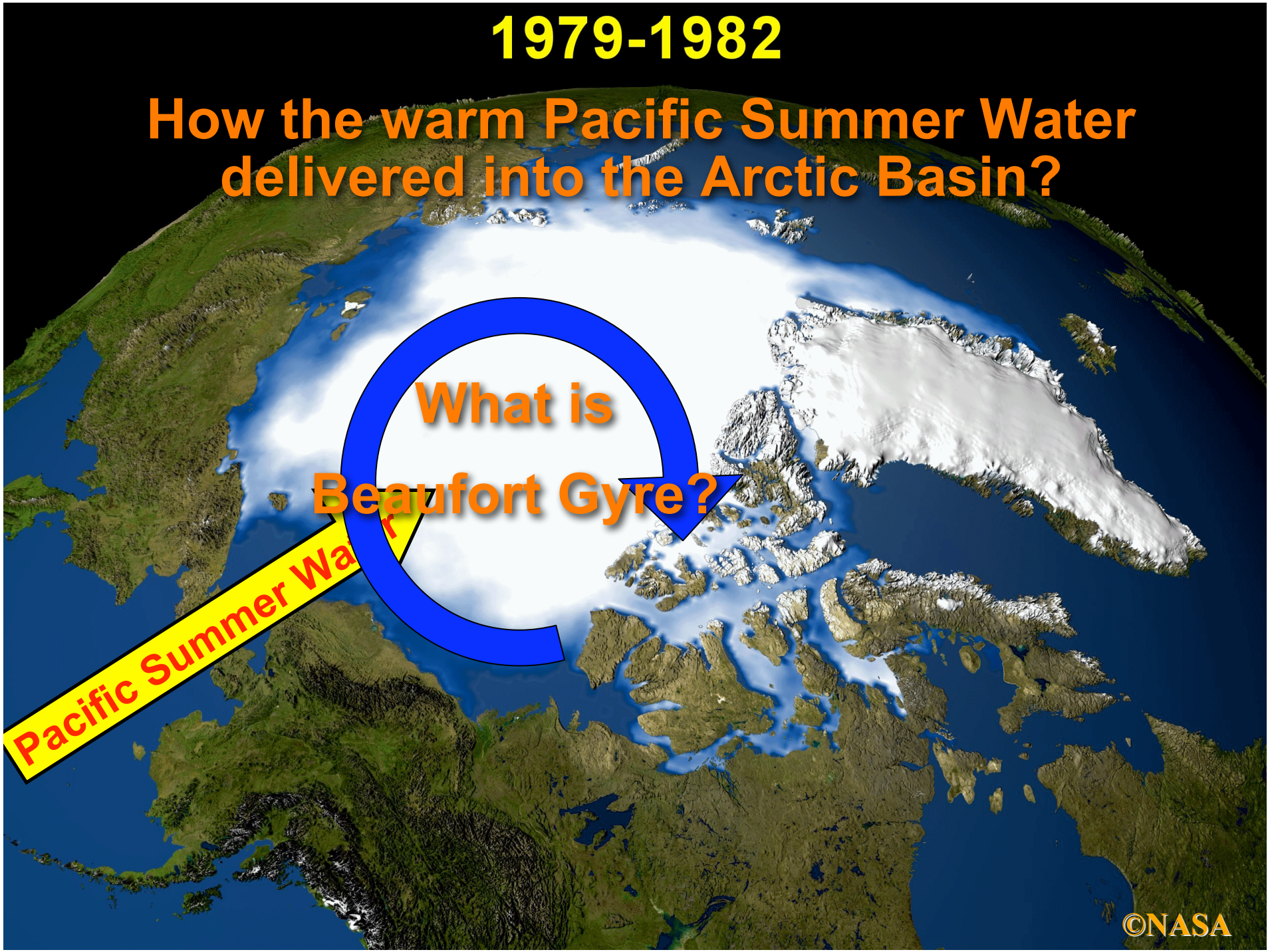
Koji Shimada, Kohei Mizobata, Eri Yoshizawa and Satoko Inoue

Tokyo University of Marine Science and Technology

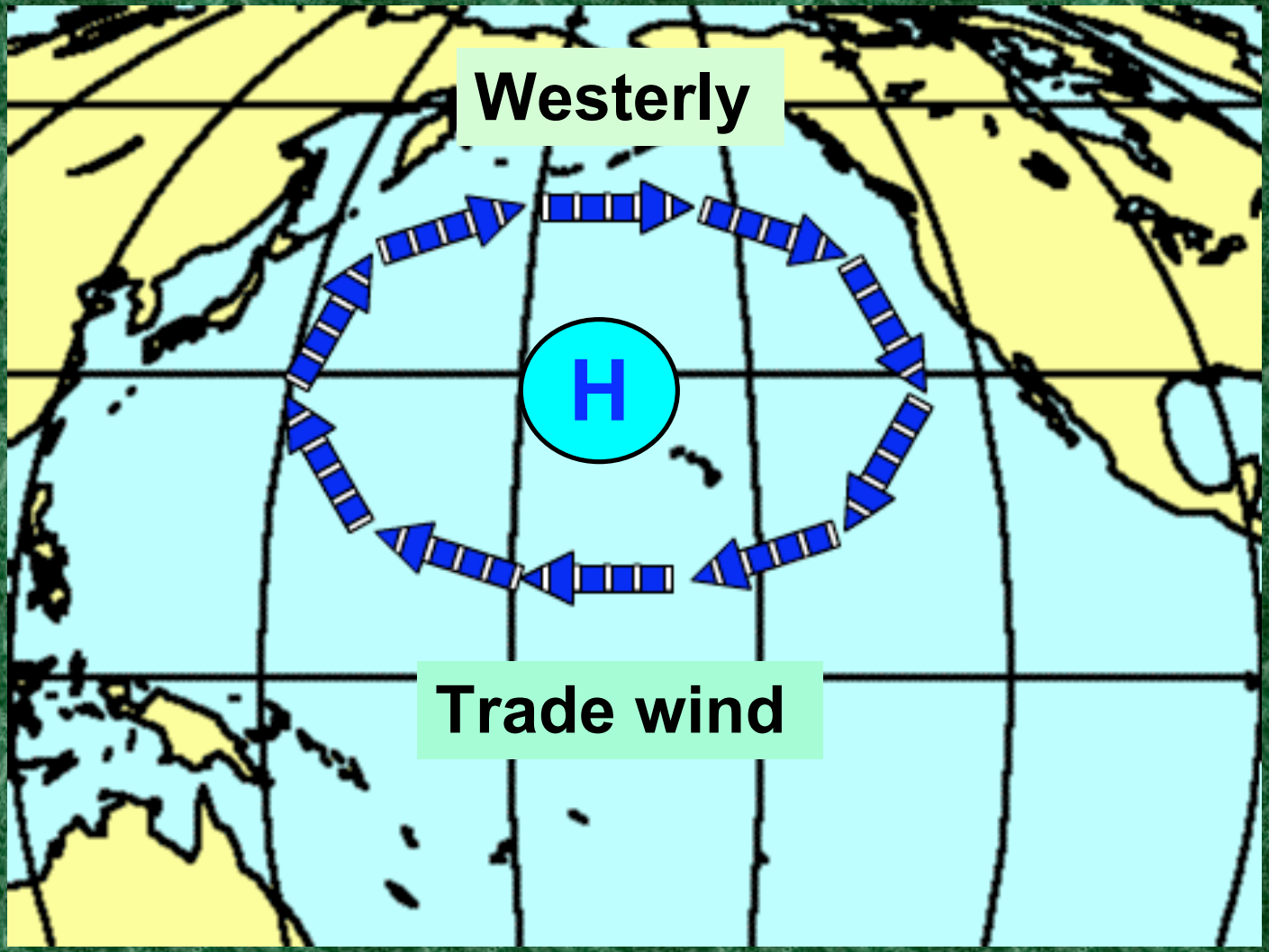
Email: koji@kaiyodai.ac.jp

Sep 25, 2008, 74-50N, 177W

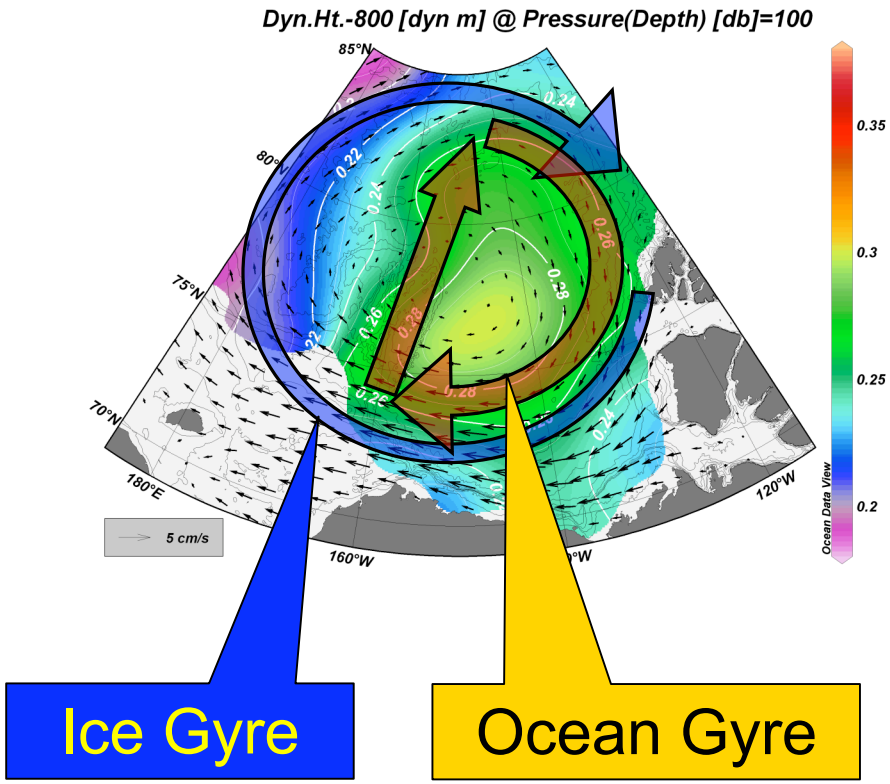
Photo by Koji Shimada

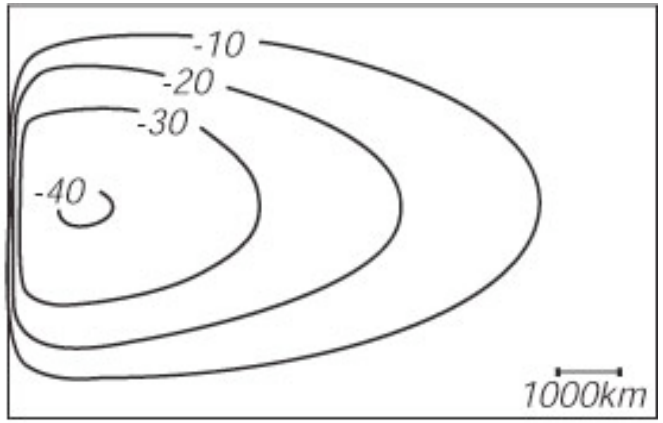

1979-1982
How the warm Pacific Summer Water delivered into the Arctic Basin?
What is
Beaufort Gyre?
Pacific Summer Wa
©NASA

Ekman Pumping only



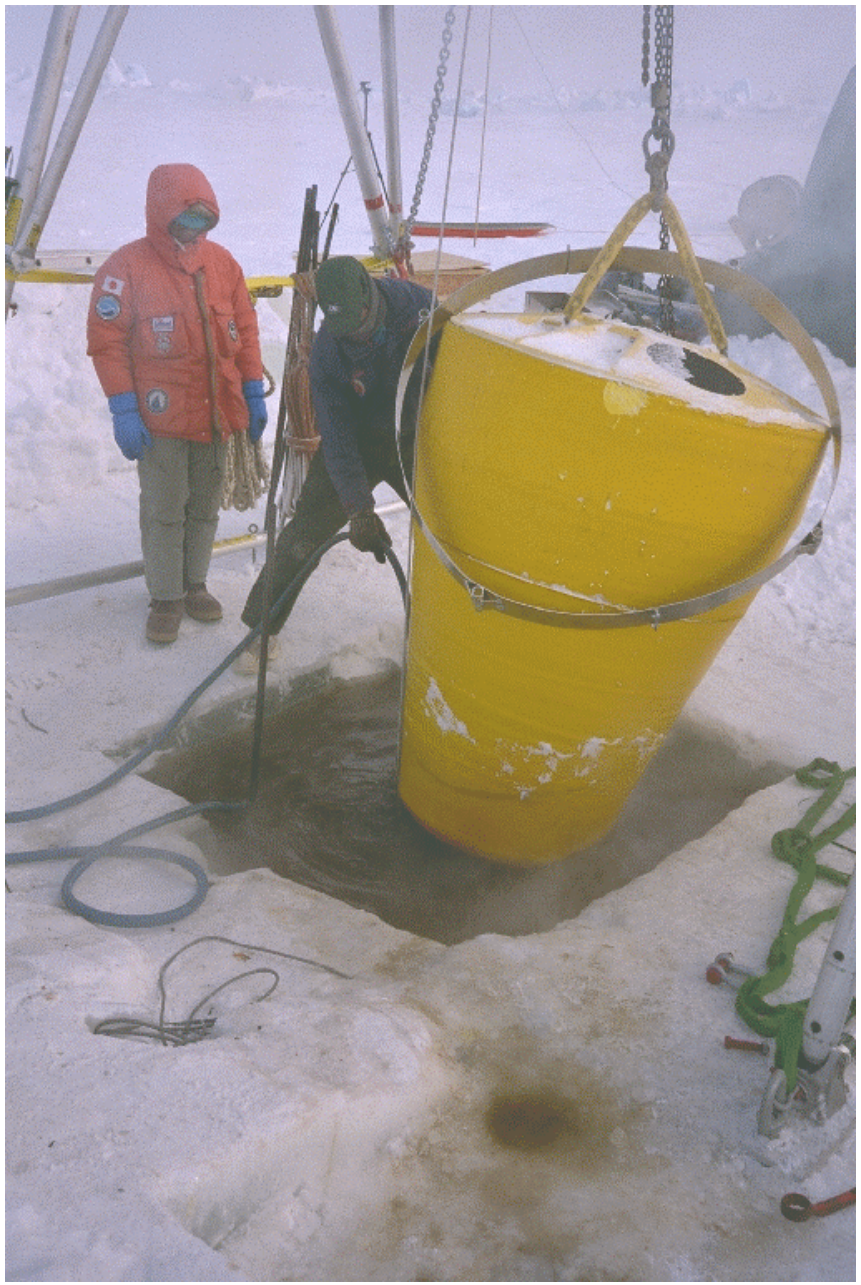
Dennou Club WEB

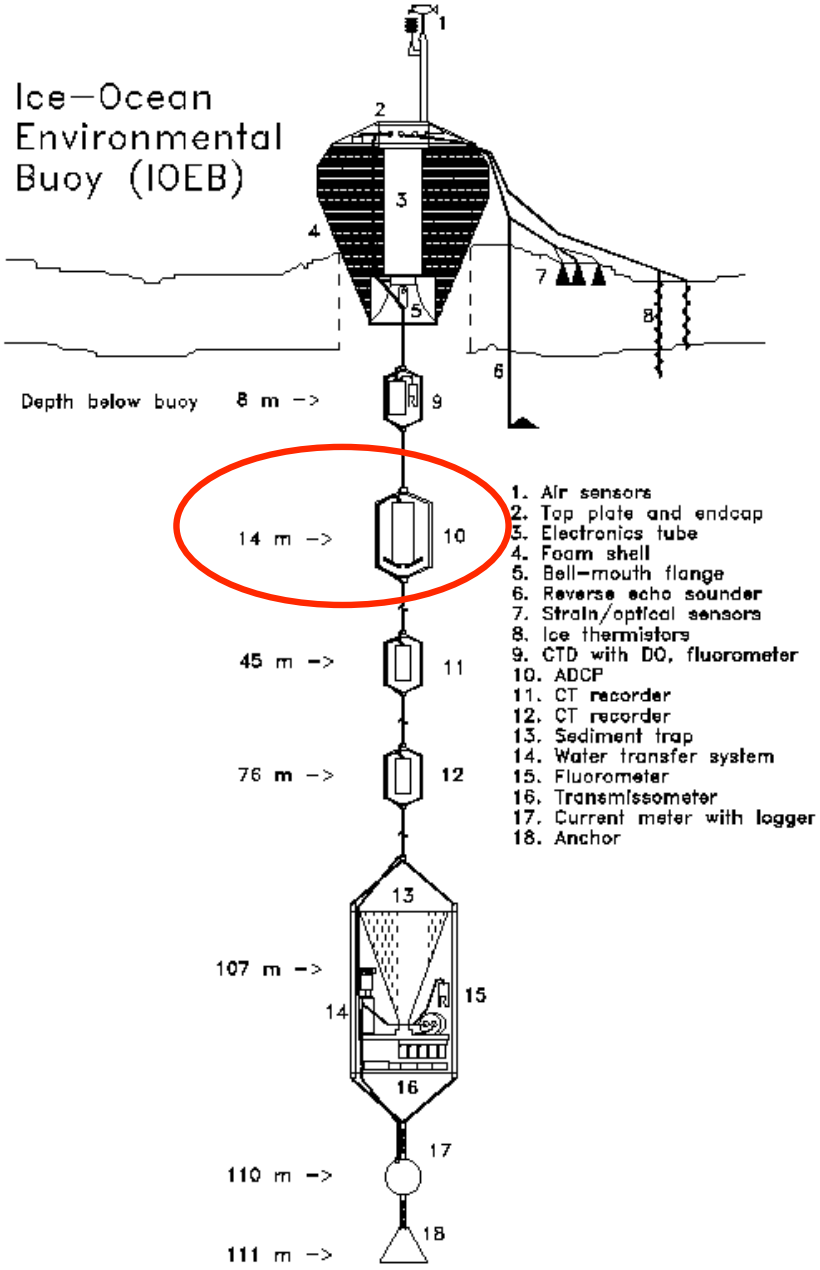


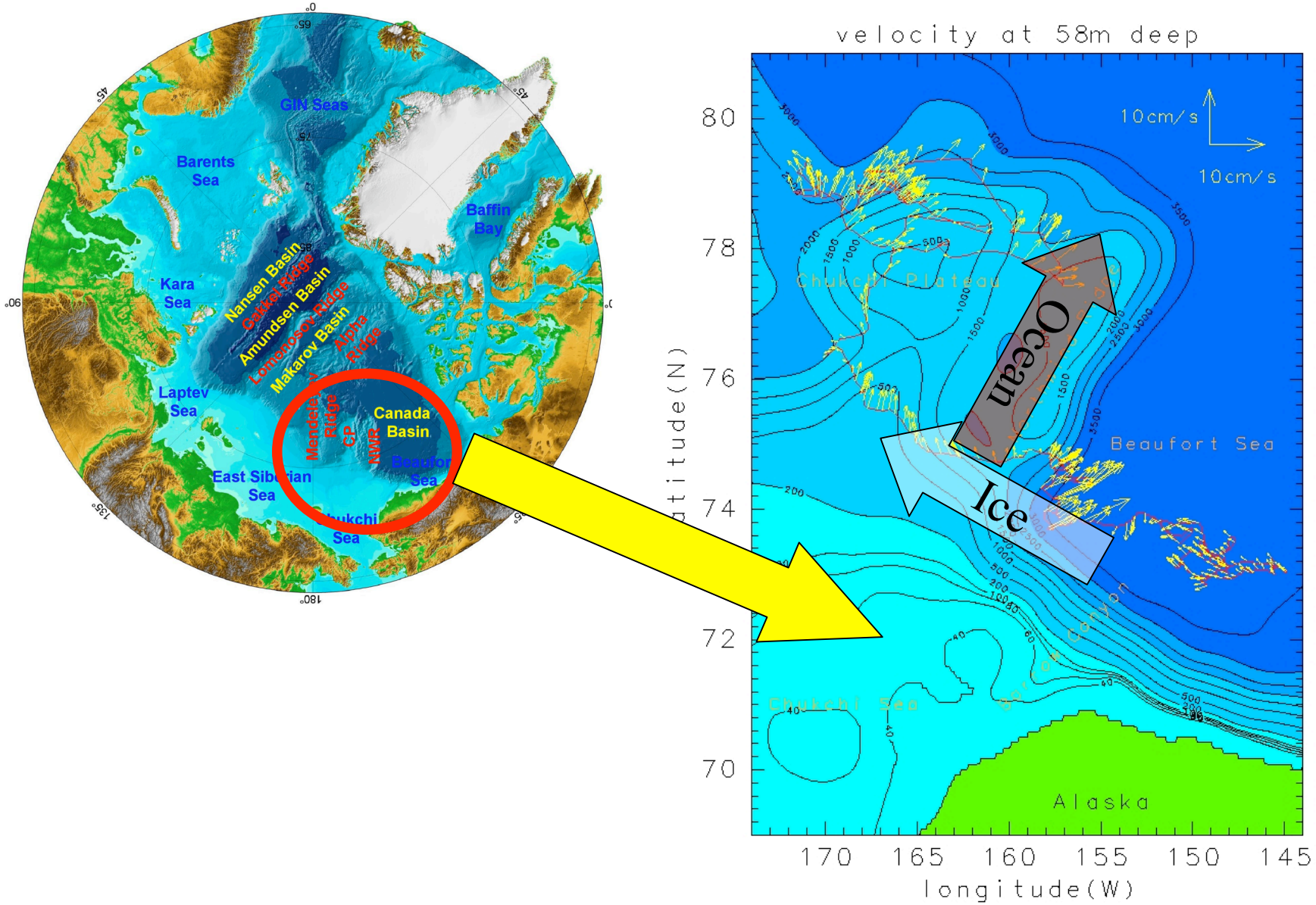


β-plane

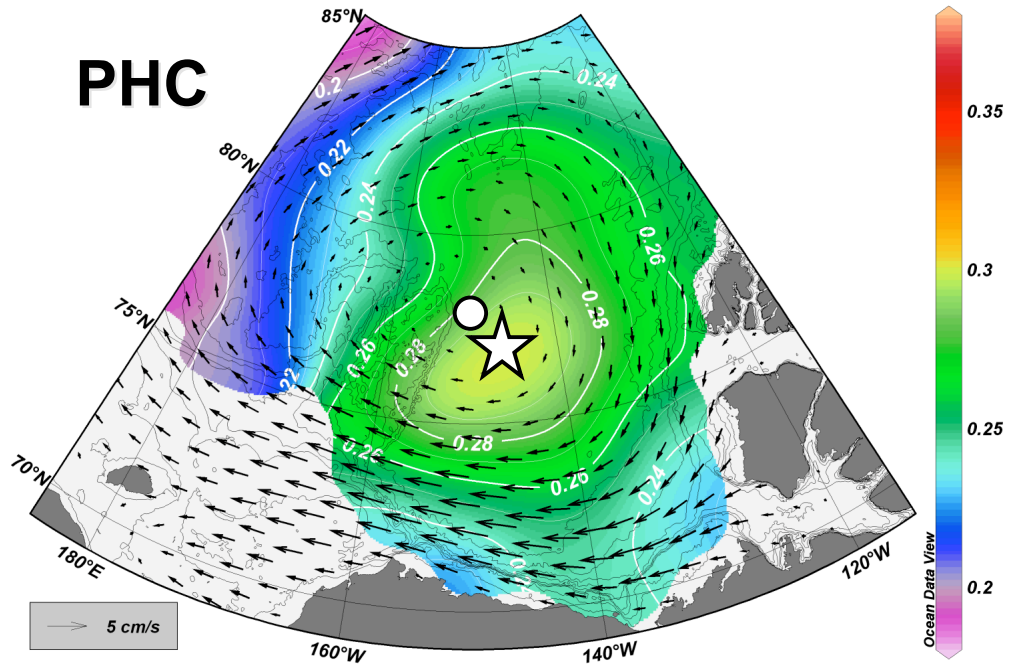
This is principal "Oceanic Beaufort Gyre" established by surface forcing and wave dynamics.
It is different from Beaufort High and Beaufort Ice Gyre.

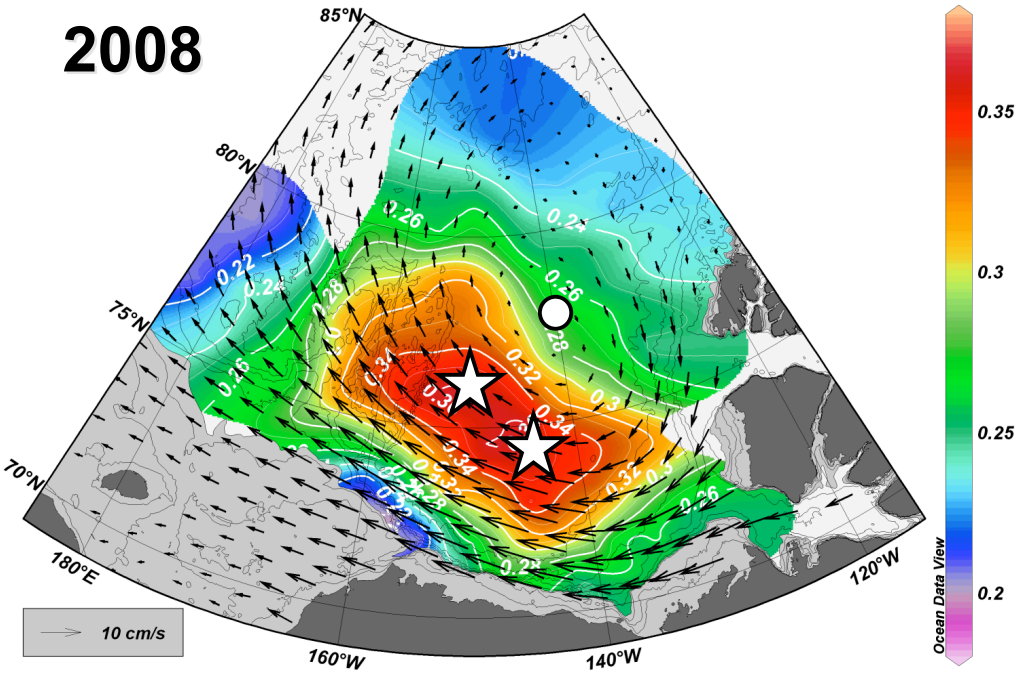



Ice–Ocean
Environmental
Buoy (IOEB)
Depth below buoy
8 m –>
14 m –>
45 m –>
76 m –>
107 m –>
110 m –>
111 m –>
1. Air sensors
2. Top plate and endcap
3. Electronics tube
4. Foam shell
5. Bell–mouth flange
6. Reverse echo sounder
7. Strain/optical sensors
8. Ice thermistors
9. CTD with DO, fluorometer
10. ADCP
11. CT recorder
12. CT recorder
13. Sediment trap
14. Water transfer system
15. Fluorometer
16. Transmissometer
17. Current meter with logger
18. Anchor



Sumata & Shimada (2007)





Ocean circulation field at 100dbar

(dynamic height 100dbar referred to 800dbar)

Key features in 2008:

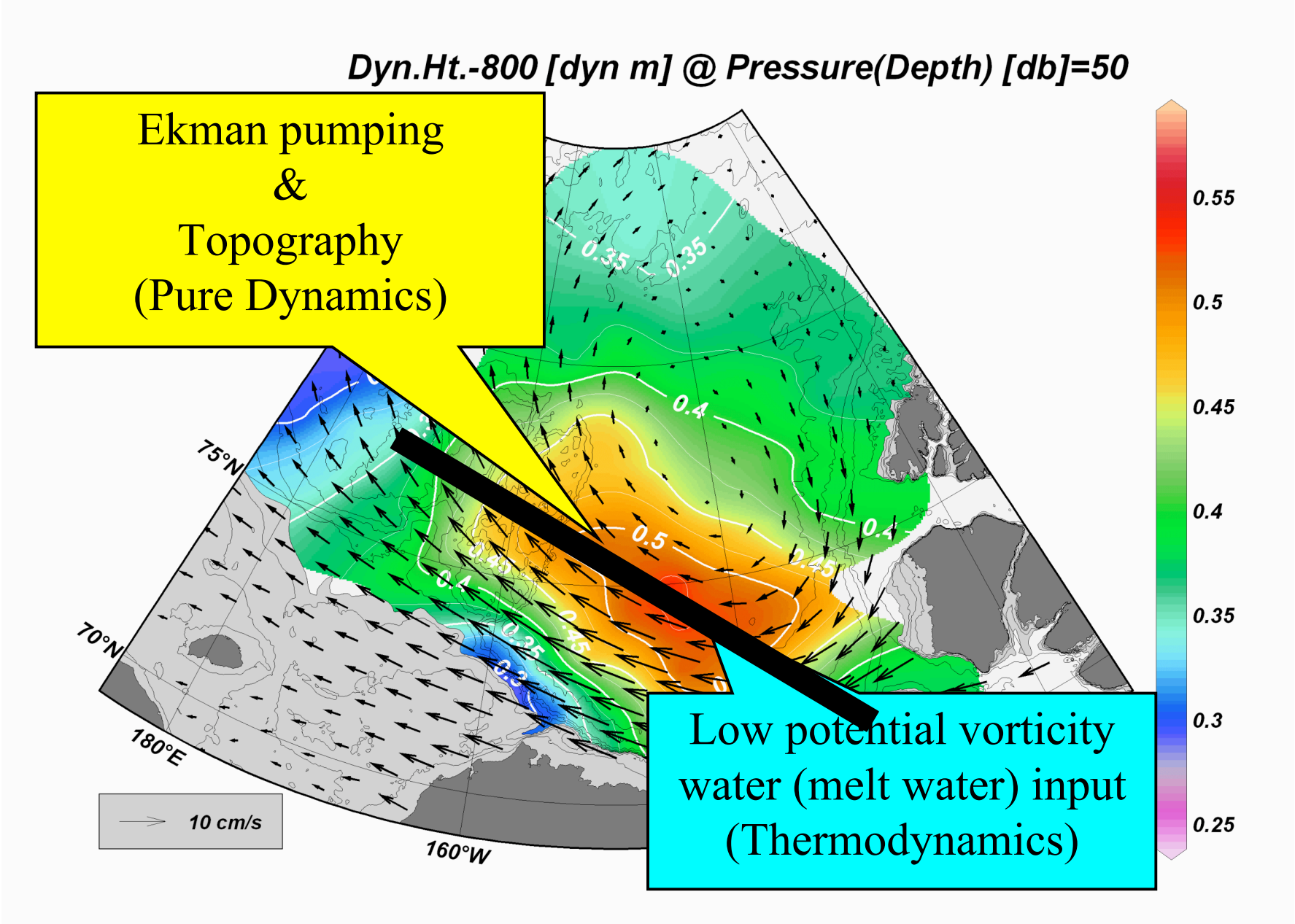
(1) Ocean circulation is strengthened associated with strong sea ice motion

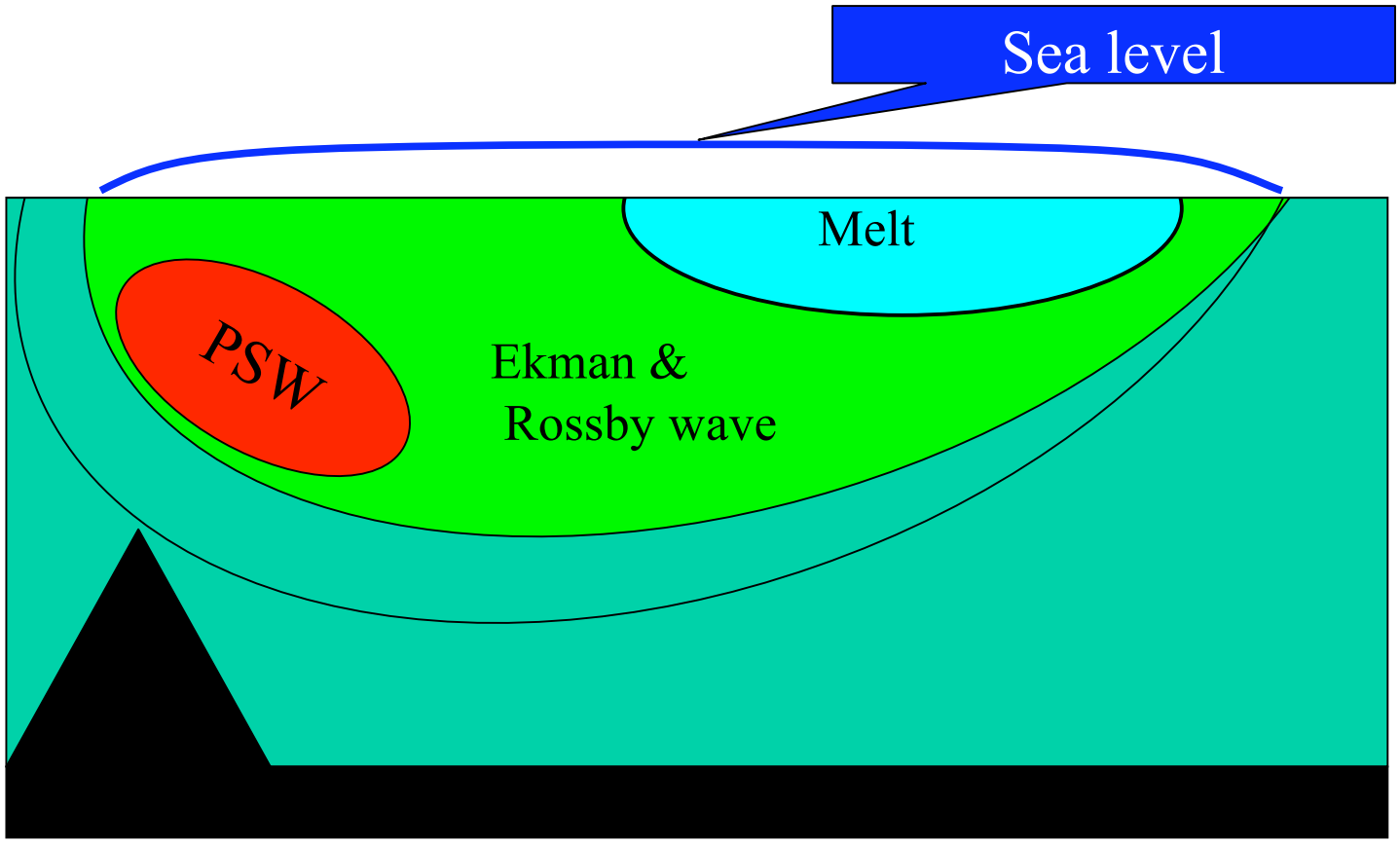
(2) Pattern of ocean circulation is quite different from that of sea ice motion.

(3) There are two centers of oceanic Beaufort Gyre at 100dbar deep.

島田 2010 (気象研究ノート)

Ocean circulation at 50 dbar and 150 dbar

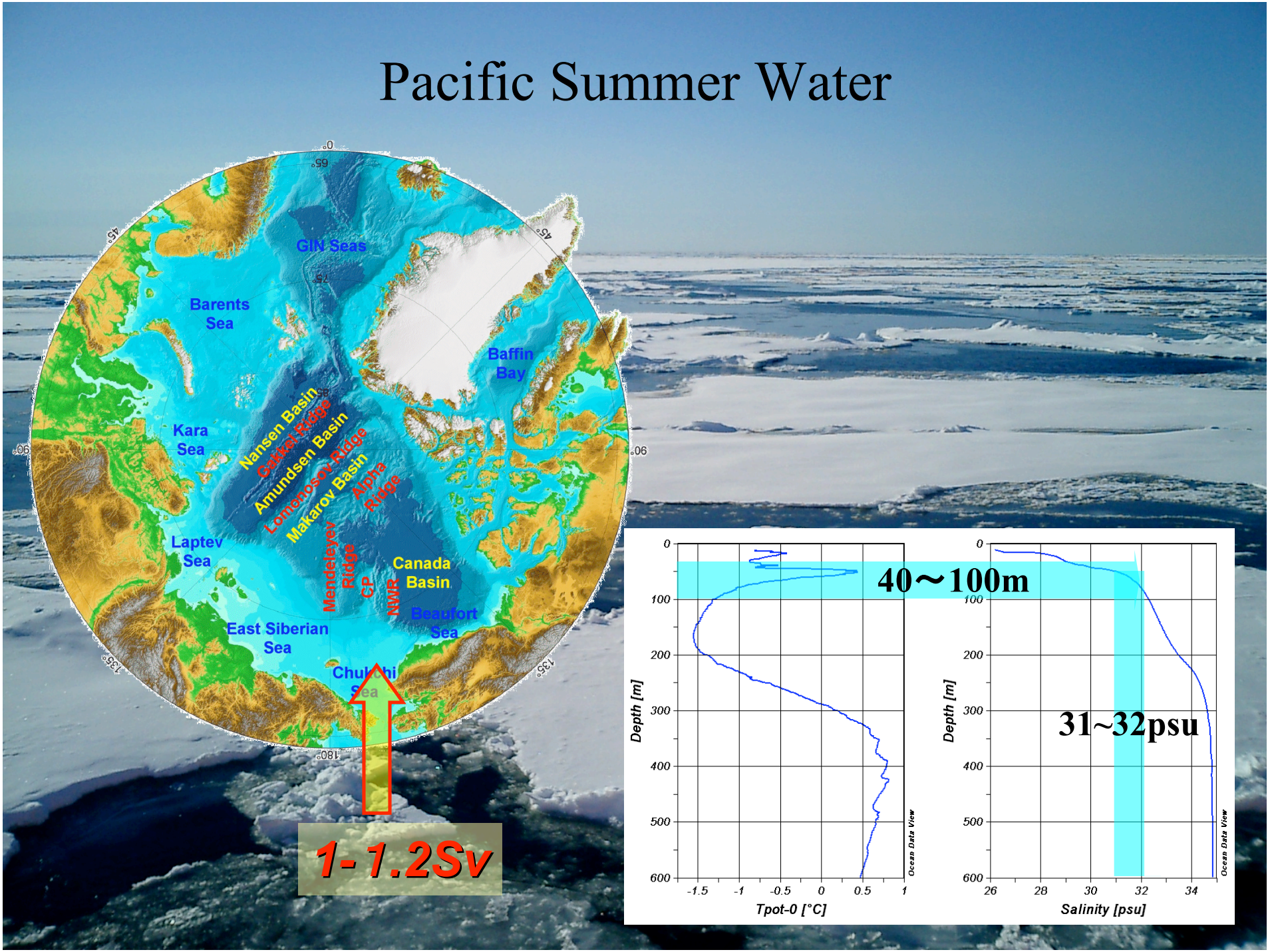




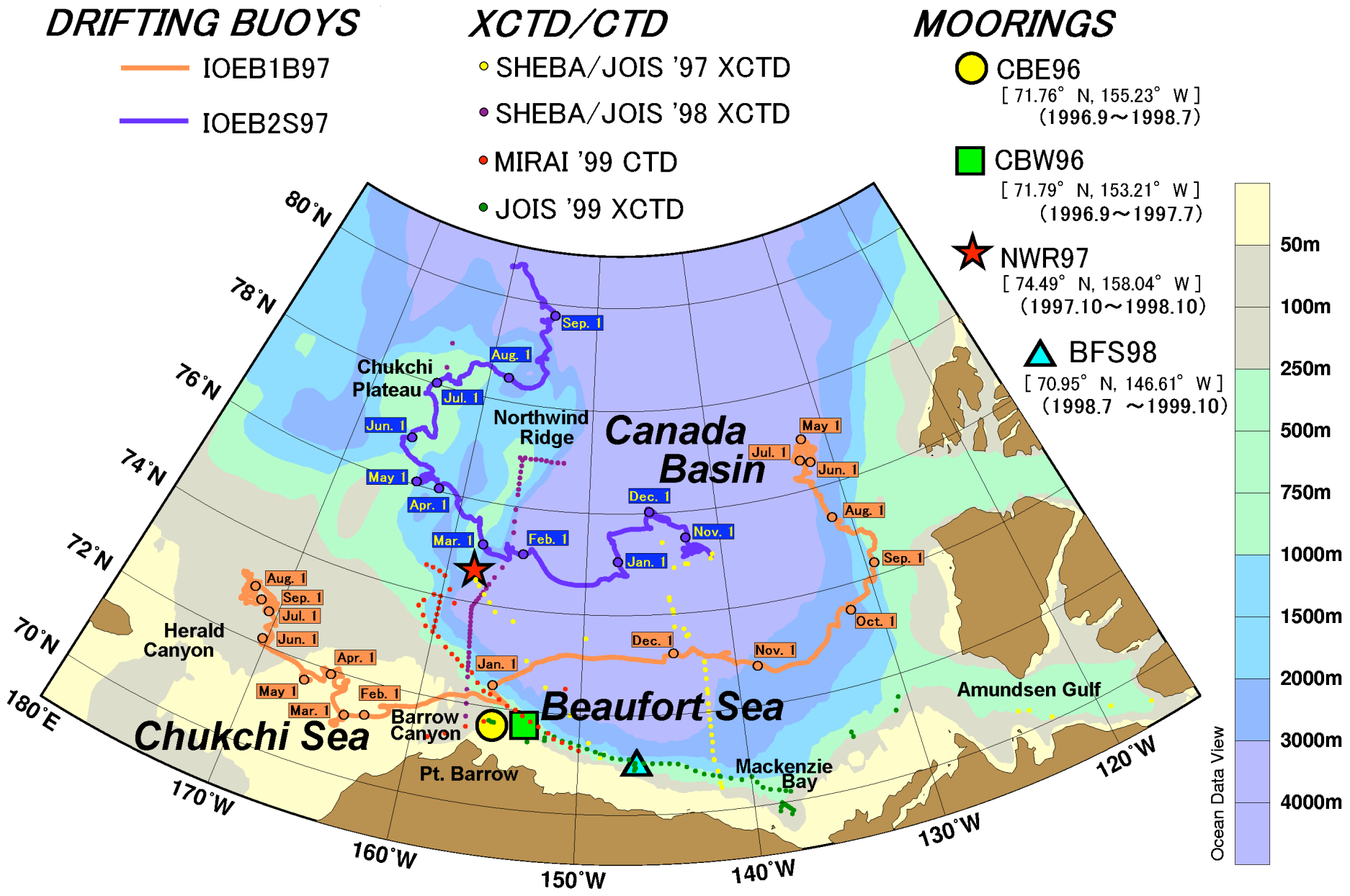
Sea level does not represent real oceanic Beaufort Gyre


1979-1982
First catastrophic reduction of sea ice during SHEBA period 1997-1998.
Pacific Summer Water
©NASA

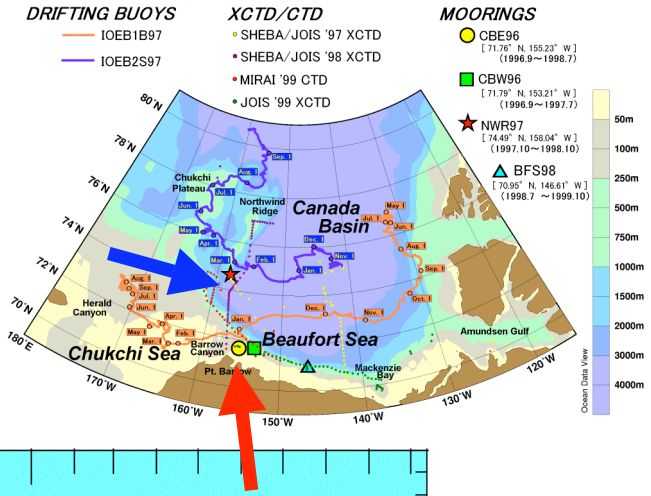
Pacific Summer Water

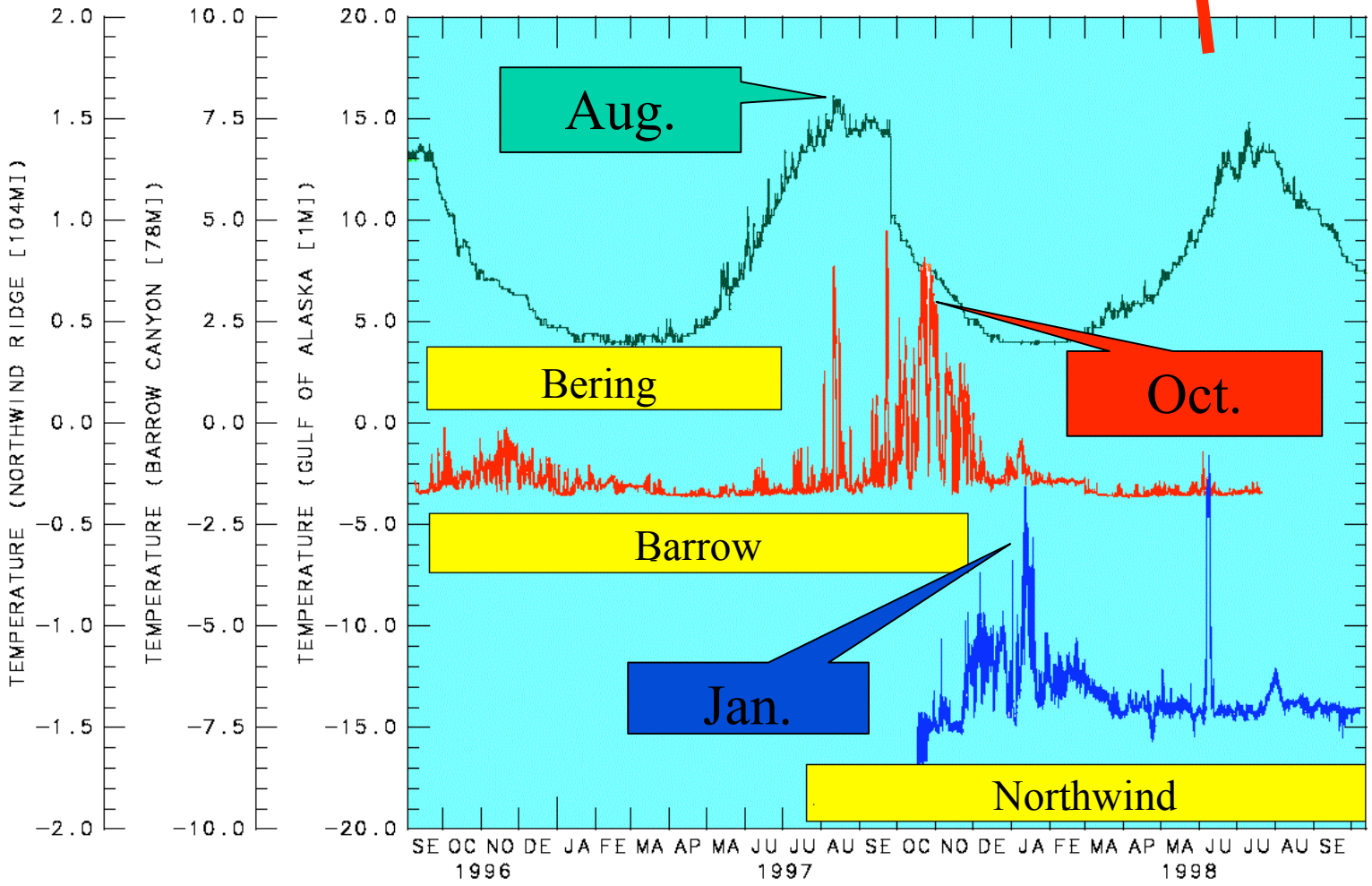


SHEBA

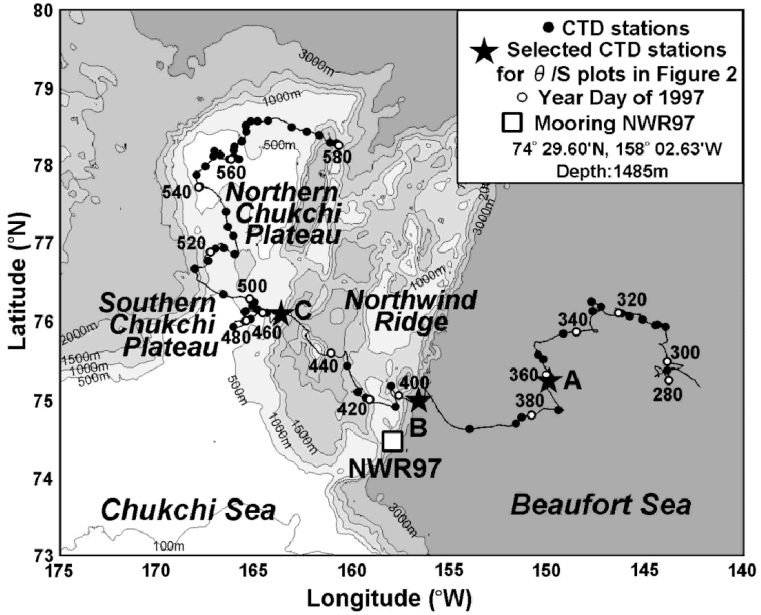

DRIFTING BUOYS
IOEB1B97
IOEB2S97
XCTD/CTD
SHEBA/JOIS '97 XCTD
SHEBA/JOIS '98 XCTD
MIRAI '99 CTD
JOIS '99 XCTD
MOORINGS
CBE96
[71.76° N, 155.23° W]
(1996.9～1998.7)
CBW96
[71.79° N, 153.21° W]
(1996.9～1997.7)
NWR97
[74.49° N, 158.04° W]
(1997.10～1998.10)
BFS98
[70.95° N, 146.61° W]
(1998.7 ～1999.10)
80°N
78°N
76°N
74°N
72°N
70°N
180°E
170°W
160°W
150°W
140°W
130°W
120°W
Chukchi Plateau
Northwind Ridge
Canada Basin
Herald Canyon
Chukchi Sea
Barrow Canyon
Pt. Barrow
Beaufort Sea
Mackenzie Bay
Amundsen Gulf
Sep. 1
Aug. 1
Jul. 1
Jun. 1
May 1
Apr. 1
Mar. 1
Feb. 1
Jan. 1
Dec. 1
Nov. 1
Oct. 1
Ocean Data View
50m
100m
250m
500m
750m
1000m
1500m
2000m
3000m
4000m

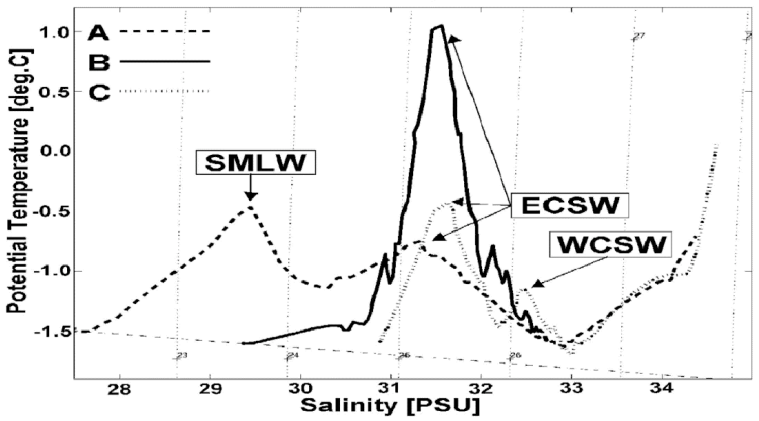
Pacific summer water reaches central Arctic in winter

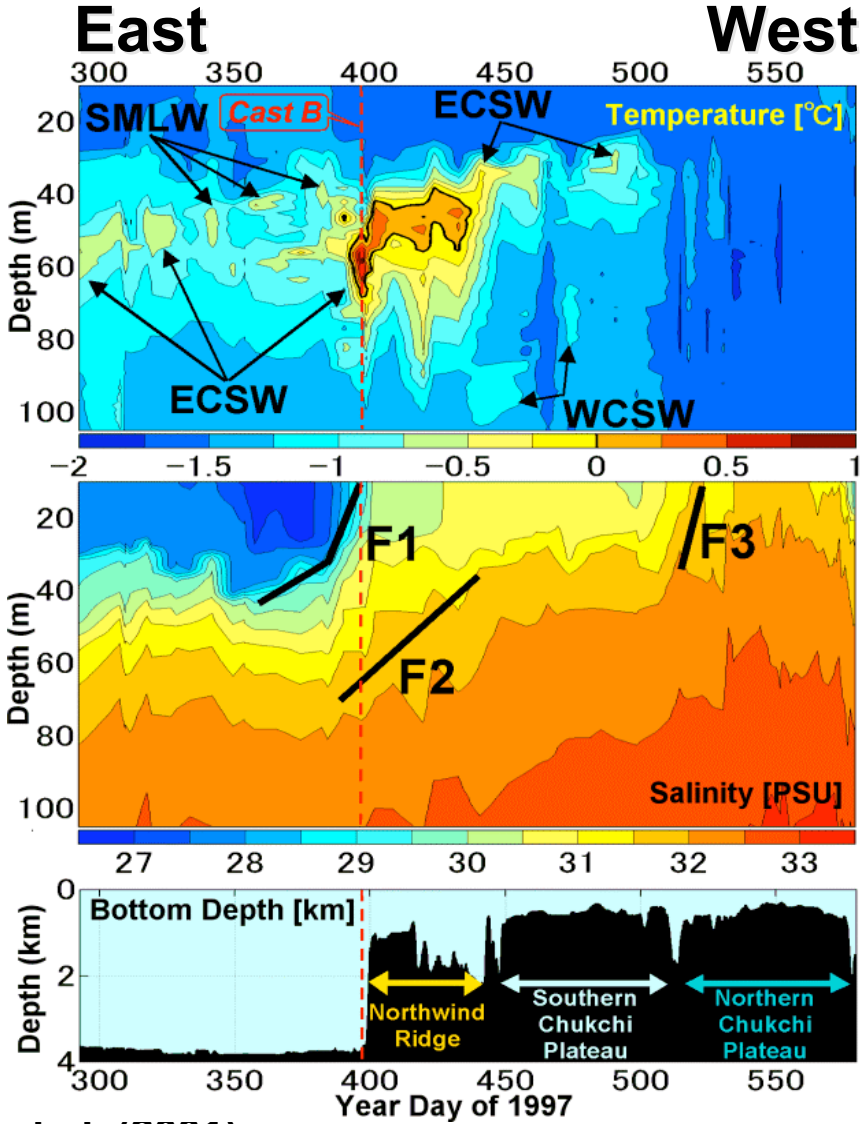




Northward spreading of PSW on the Northwind Ridge (SHEBA1997-1998)

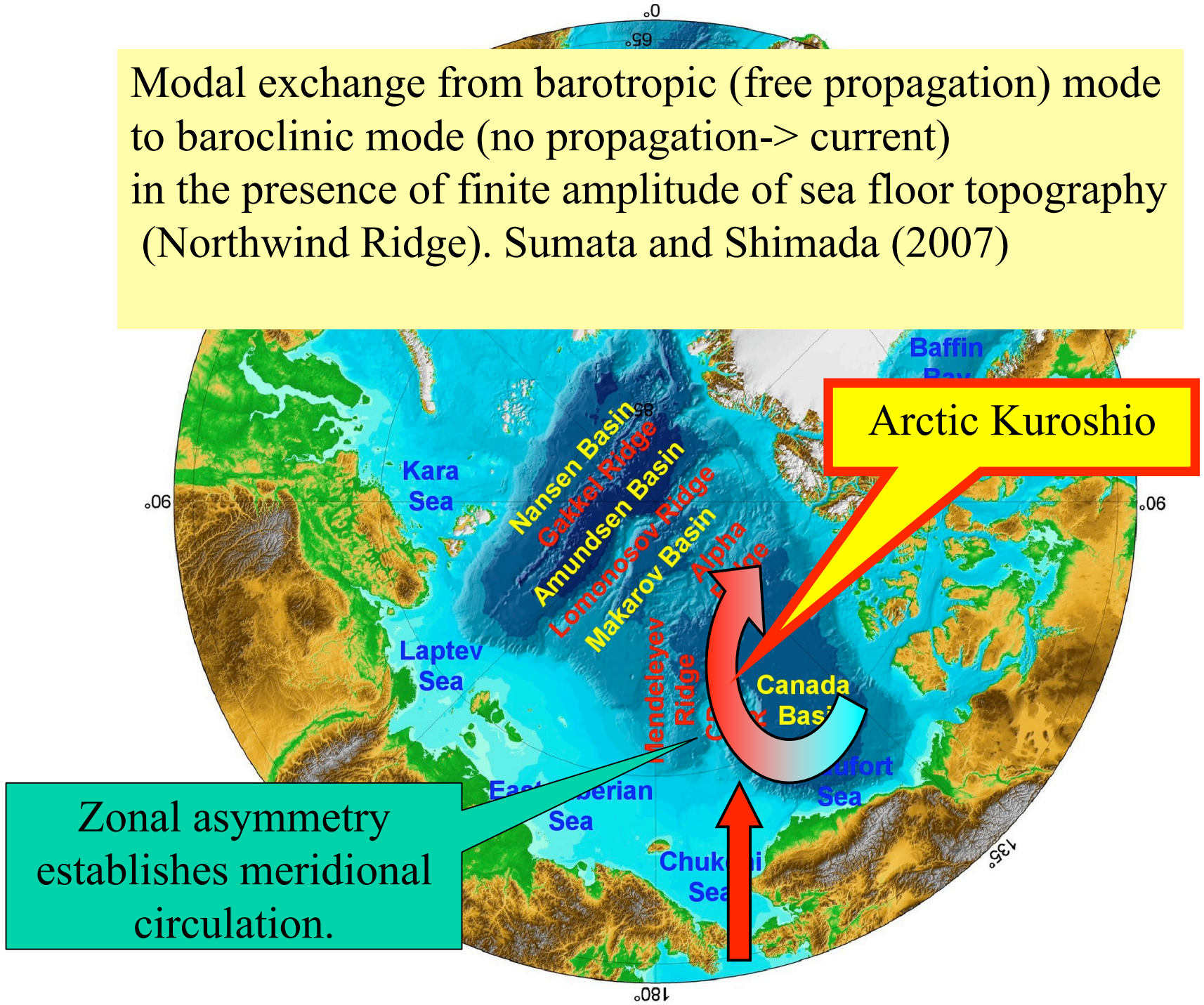


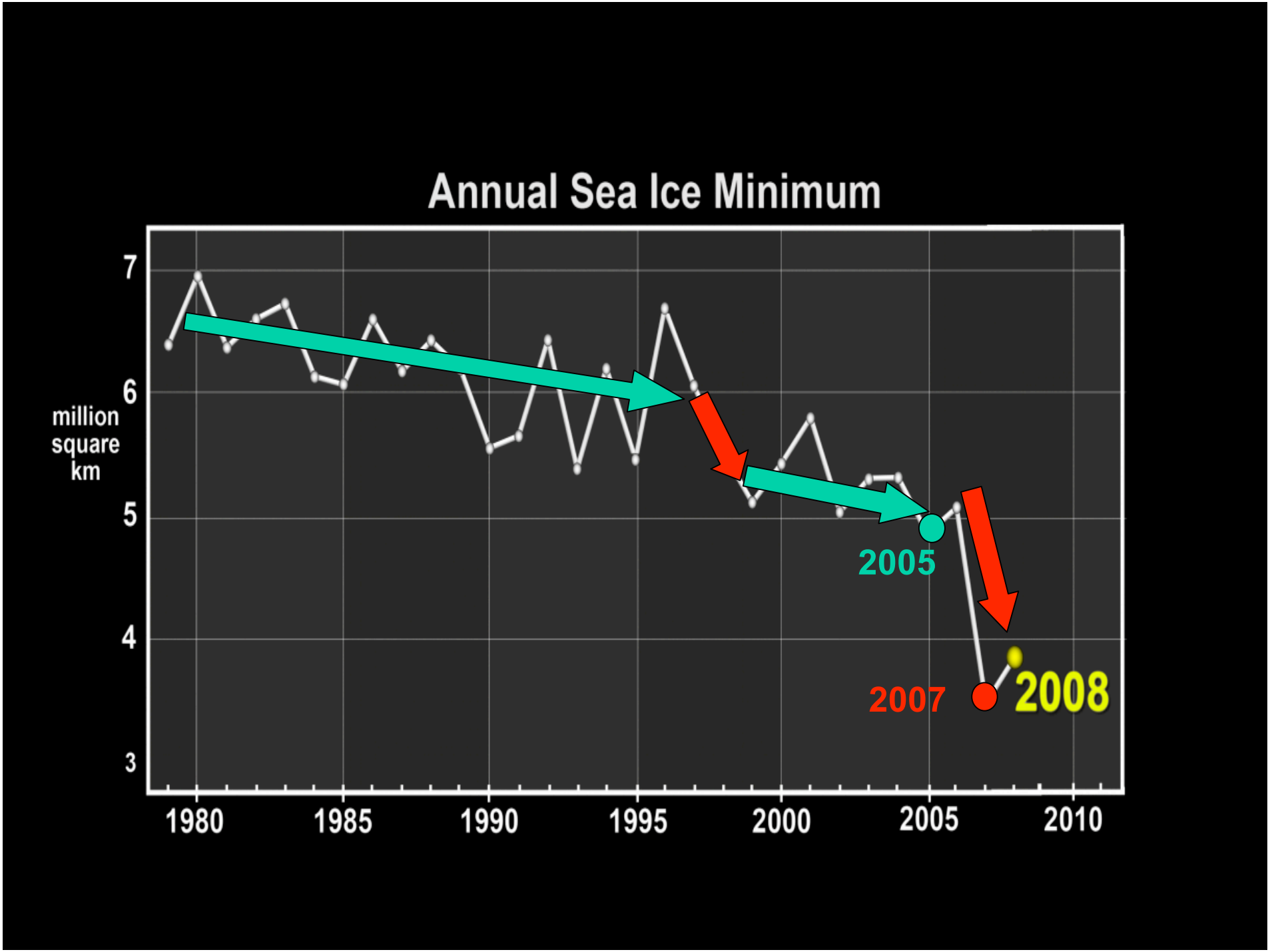


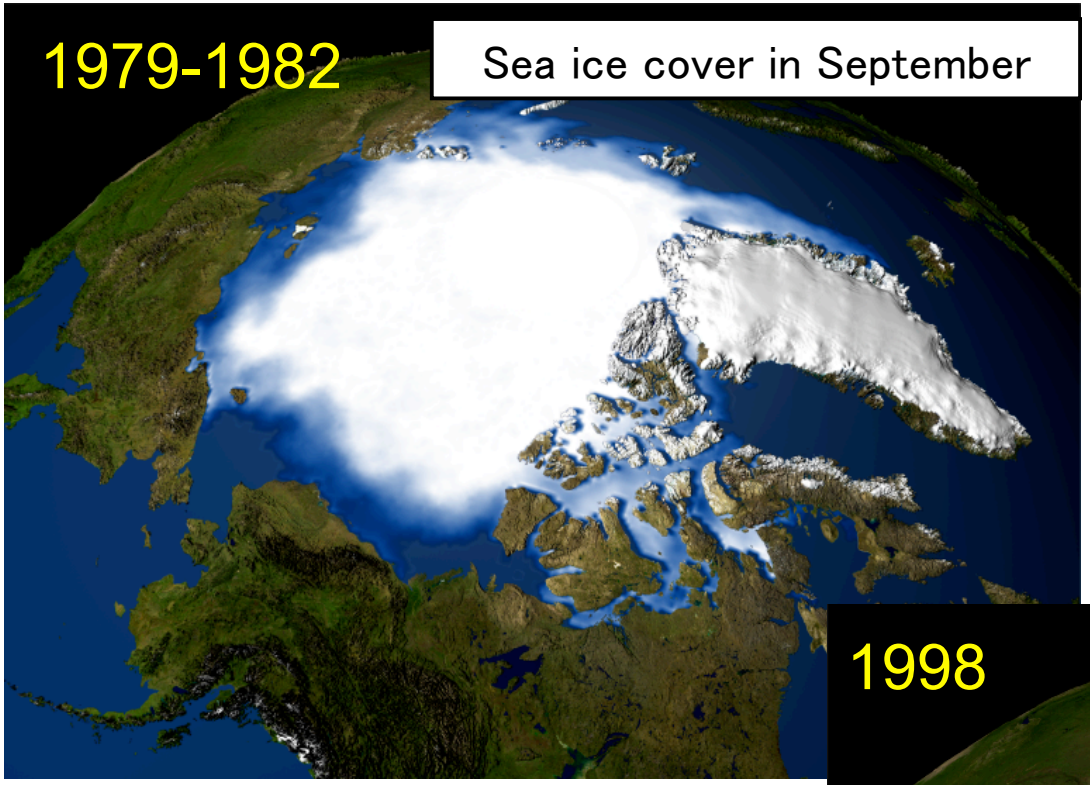


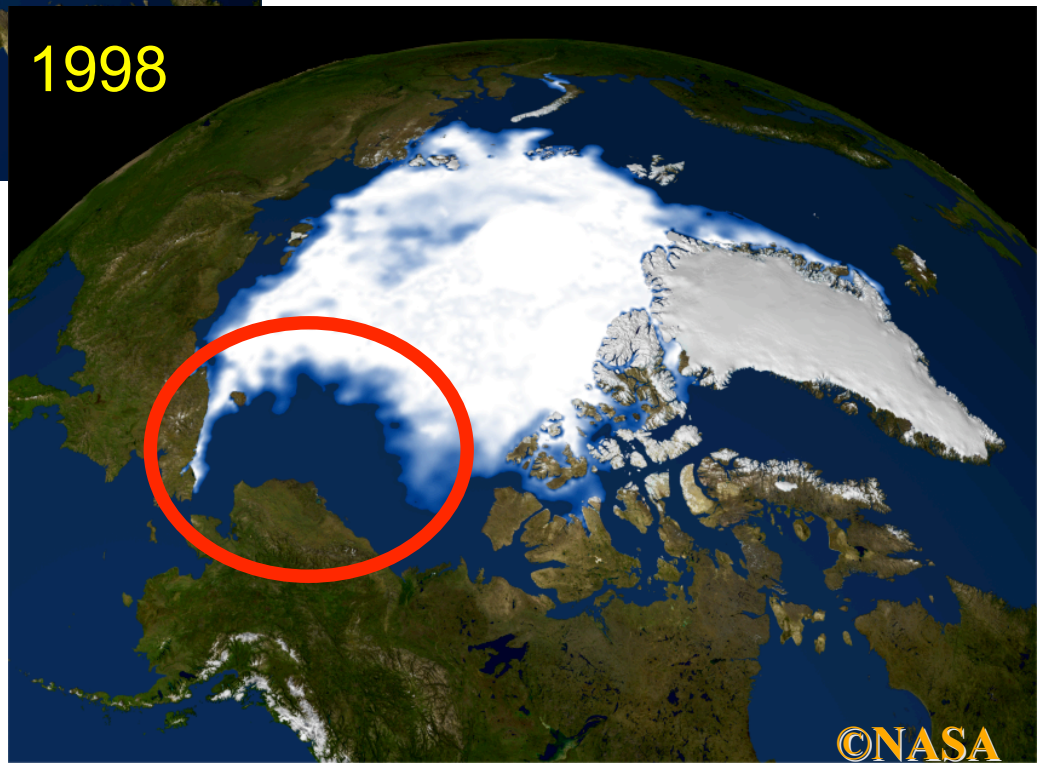
Shimada et al. (2001)

Modal exchange from barotropic (free propagation) mode to baroclinic mode (no propagation-> current)
in the presence of finite amplitude of sea floor topography (Northwind Ridge). Sumata and Shimada (2007)




Annual Sea Ice Minimum
million square km
7
6
5
4
3
1980
1985
1990
1995
2000
2005
2010
2005
2007
2008

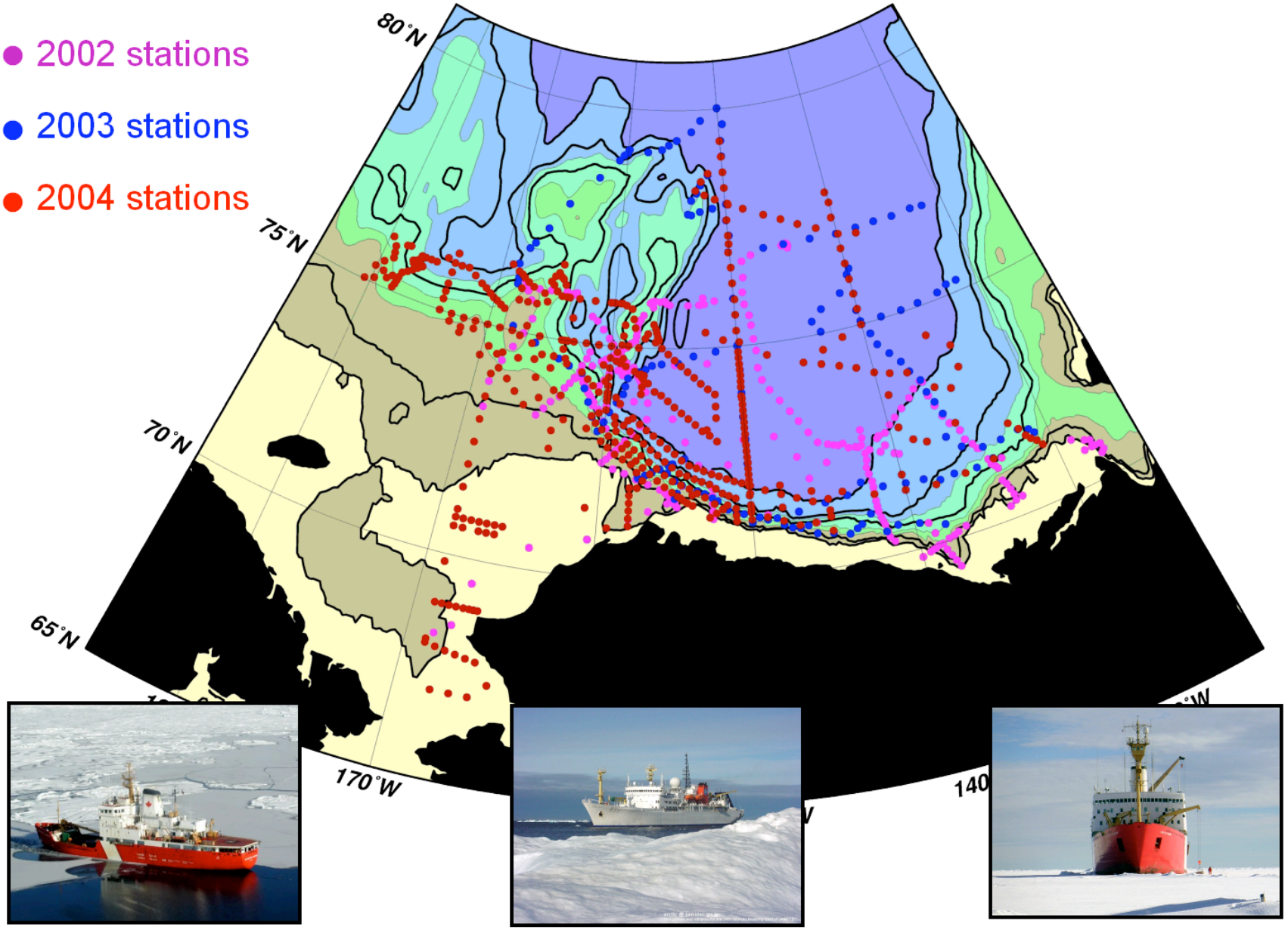




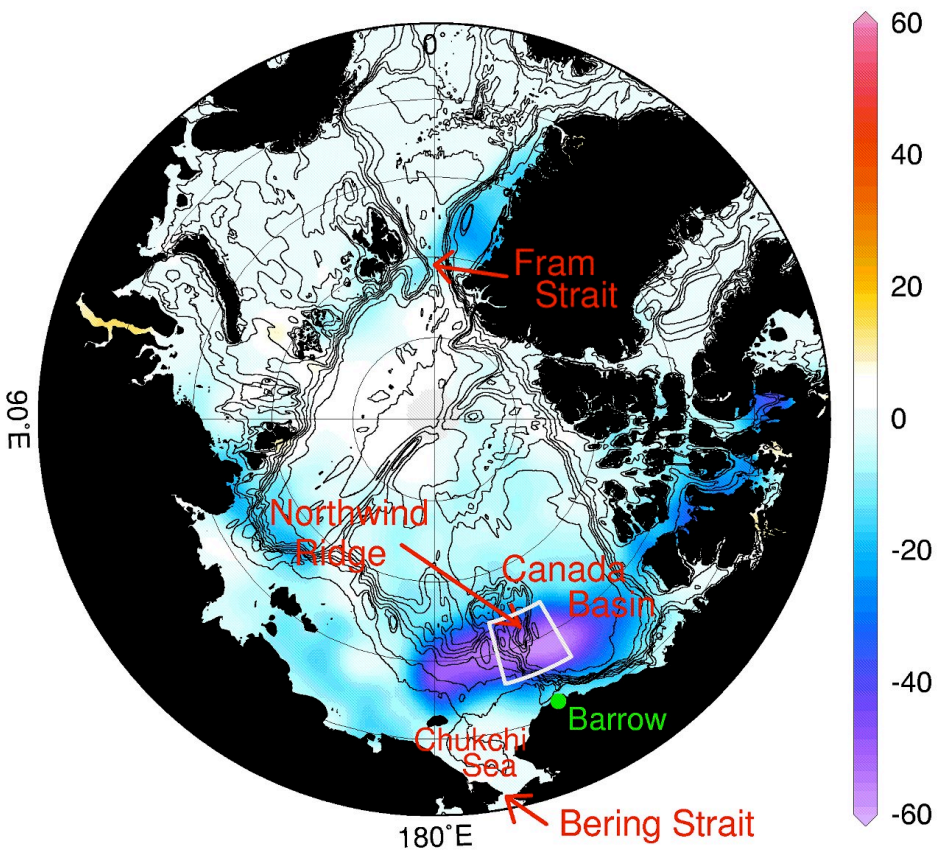
What happened in 1997–1998?

JWACS 2002 - 2004 stations in the Western Arctic

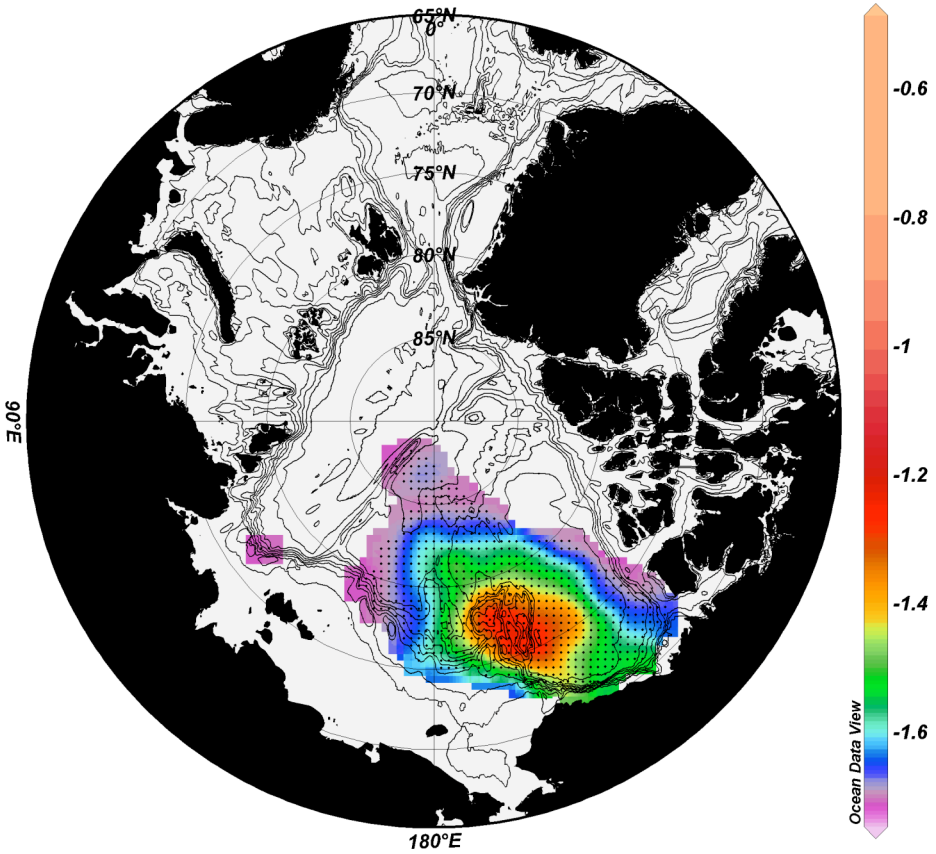
- 2002 stations
- 2003 stations
- 2004 stations

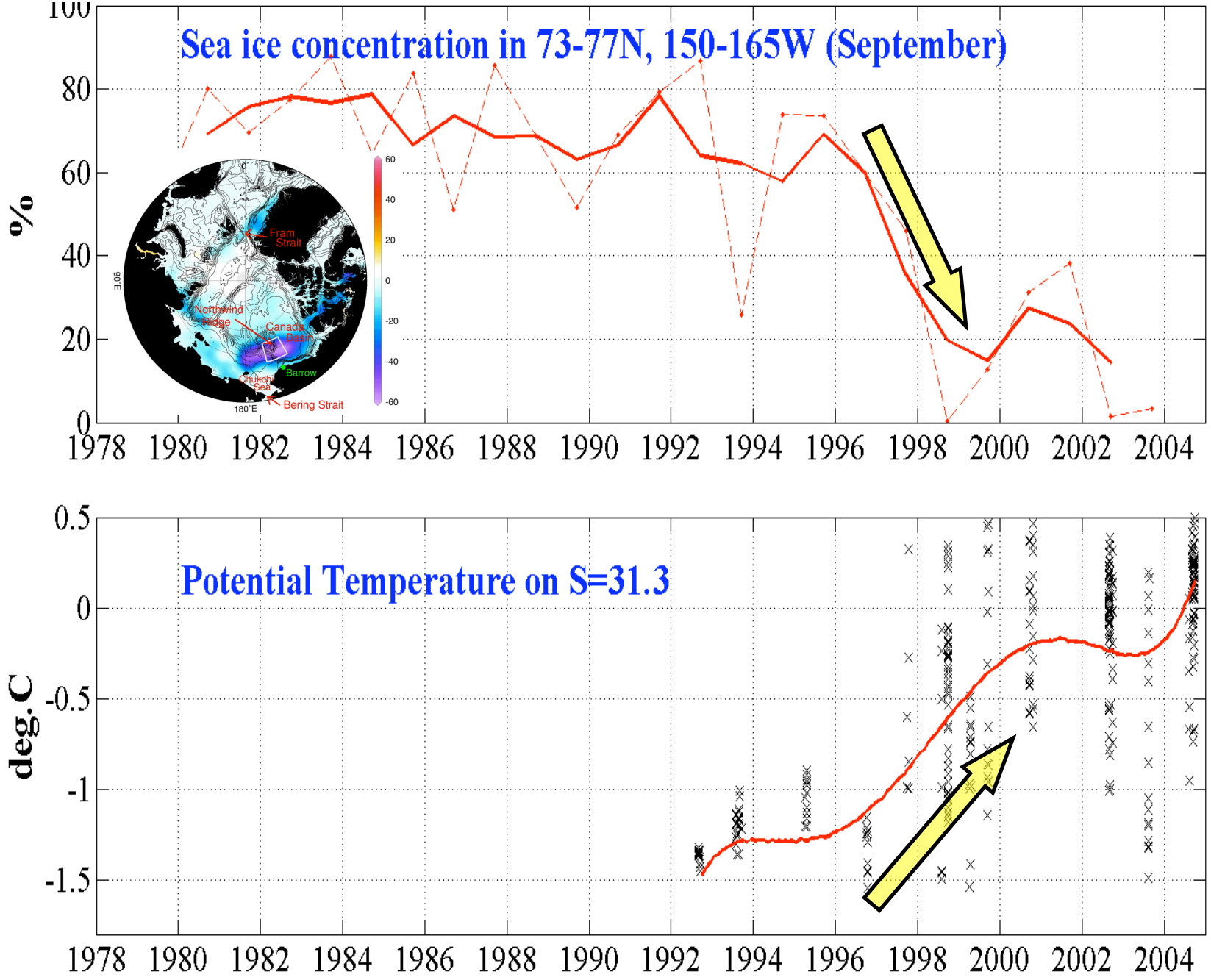


Sea ice concentration anomaly
[1998～2003mean] - [1979-1997mean]



Subsurface ocean temperature
on S=31.5 (Pacific Summer Water)

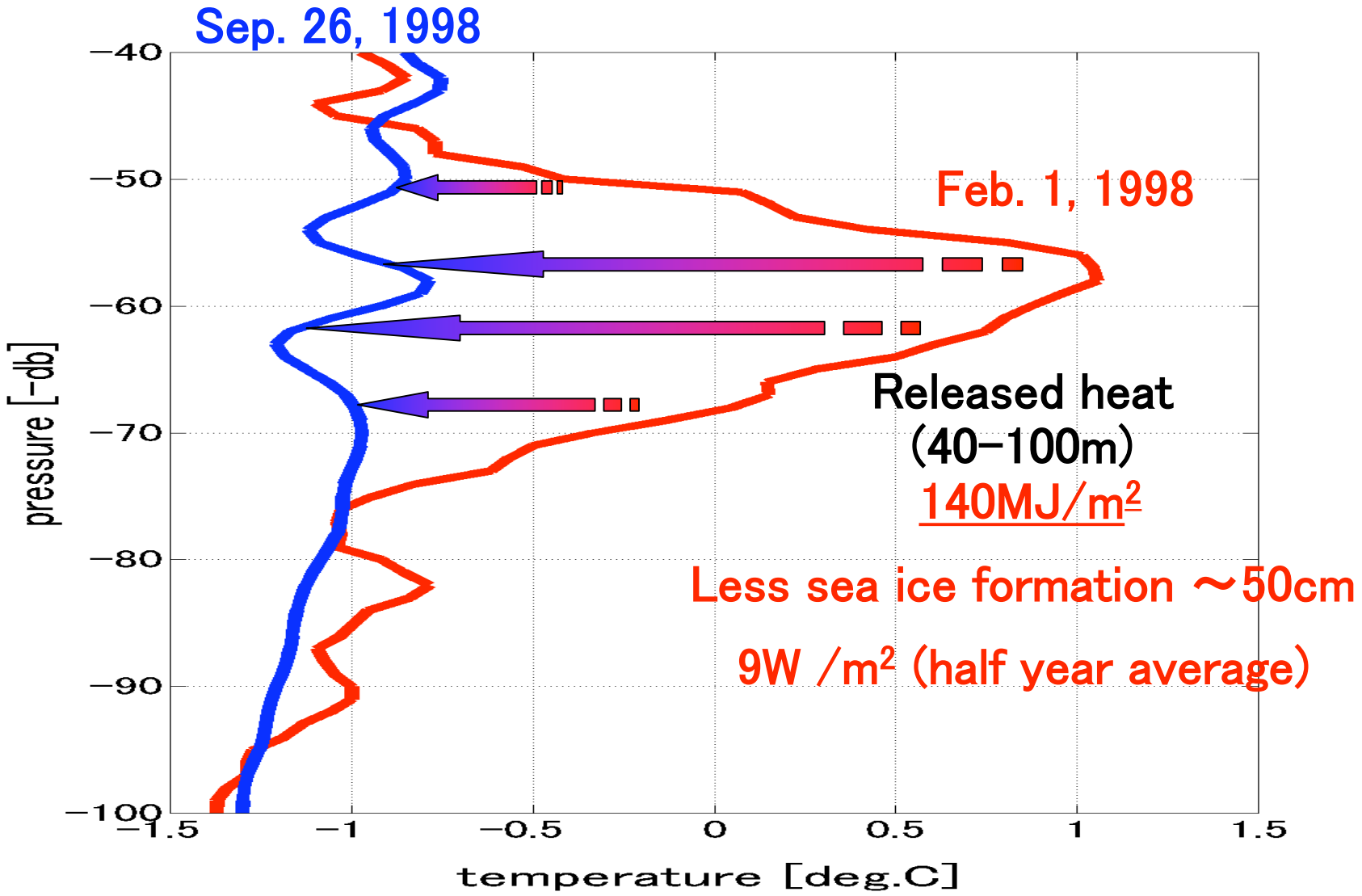


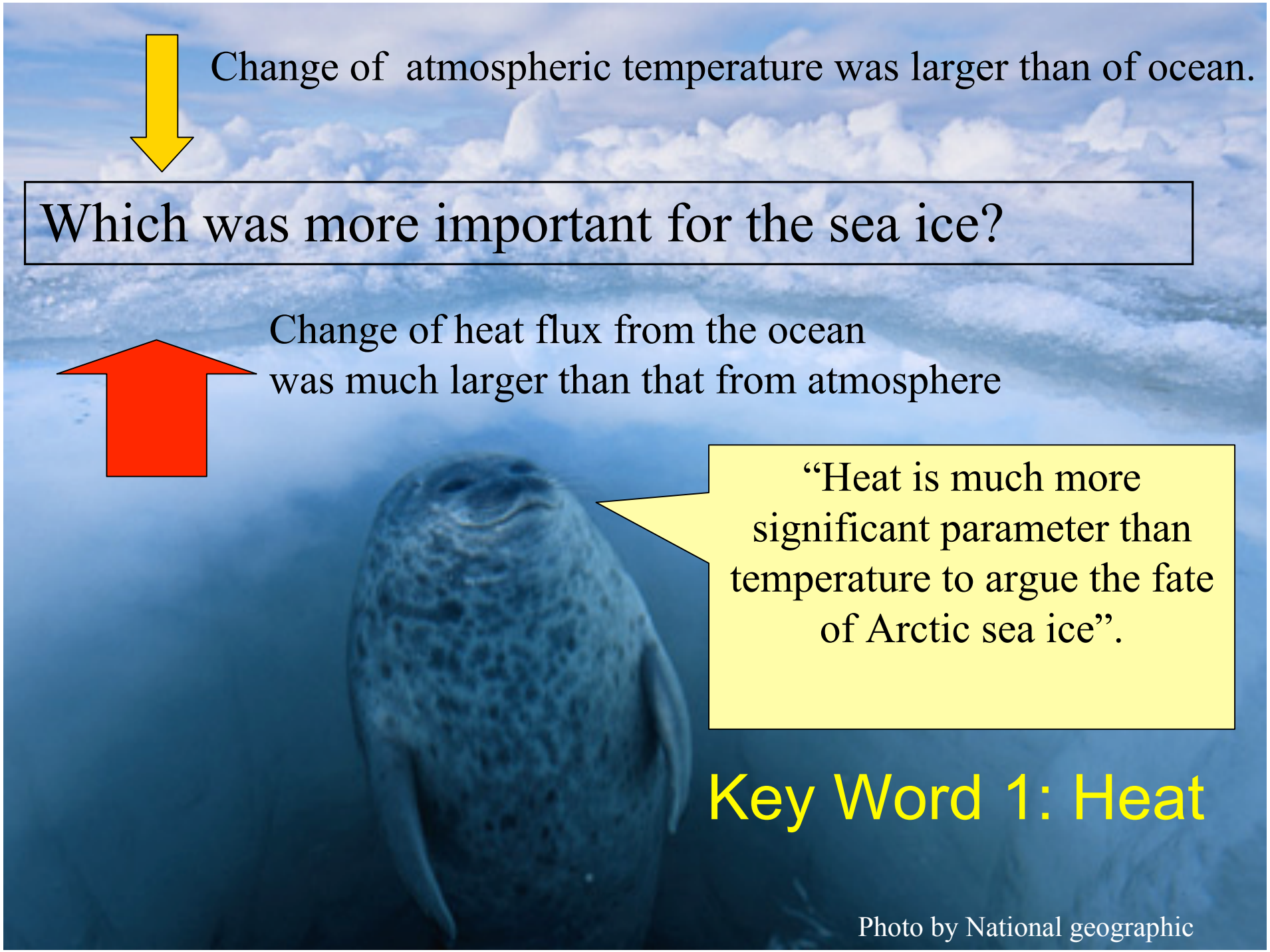


Shimada et al. (2006)

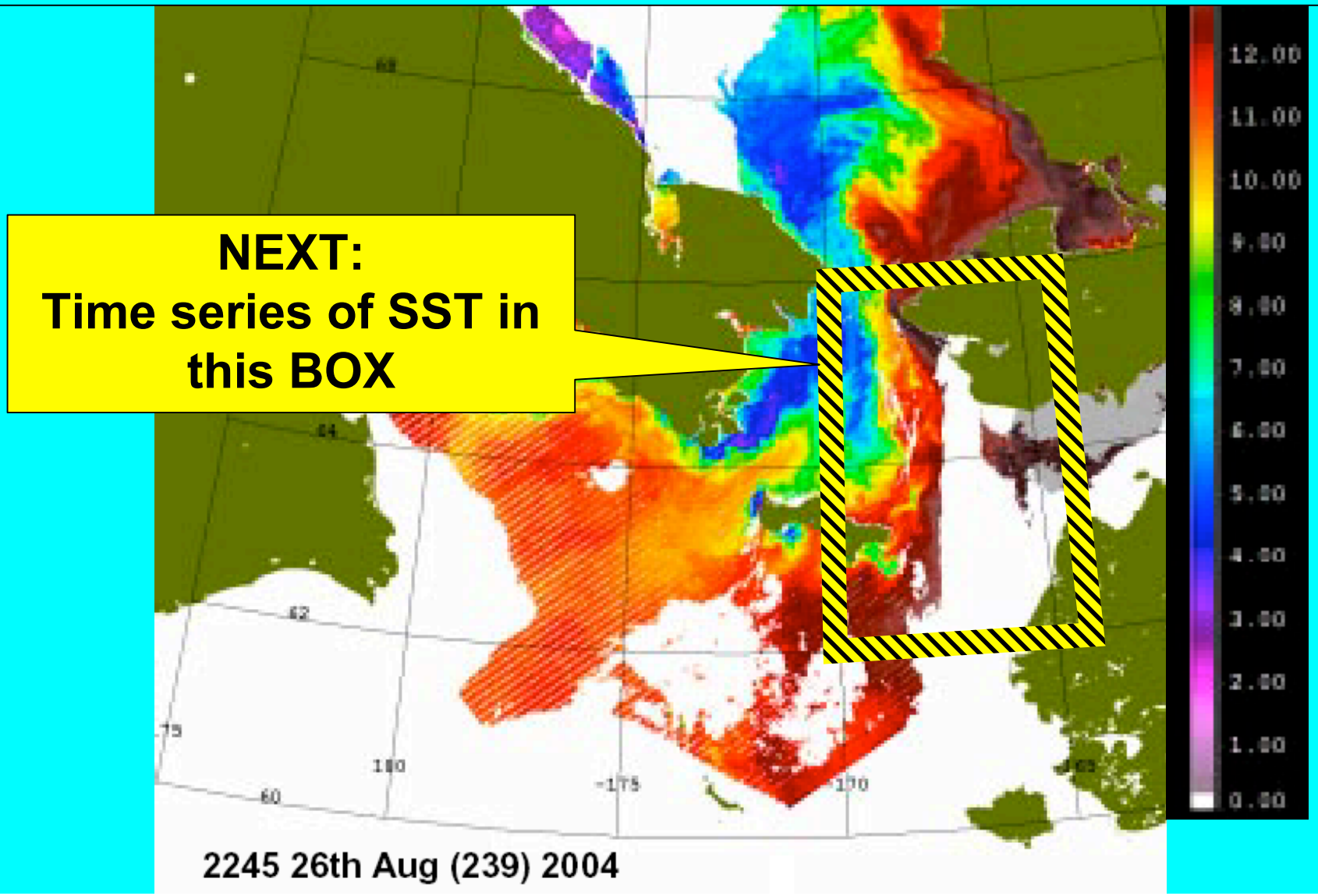

Sea ice reduction
Ice melt
Less ice formation
Outflow through Fram Strait
arctic@jamstec.go.jp

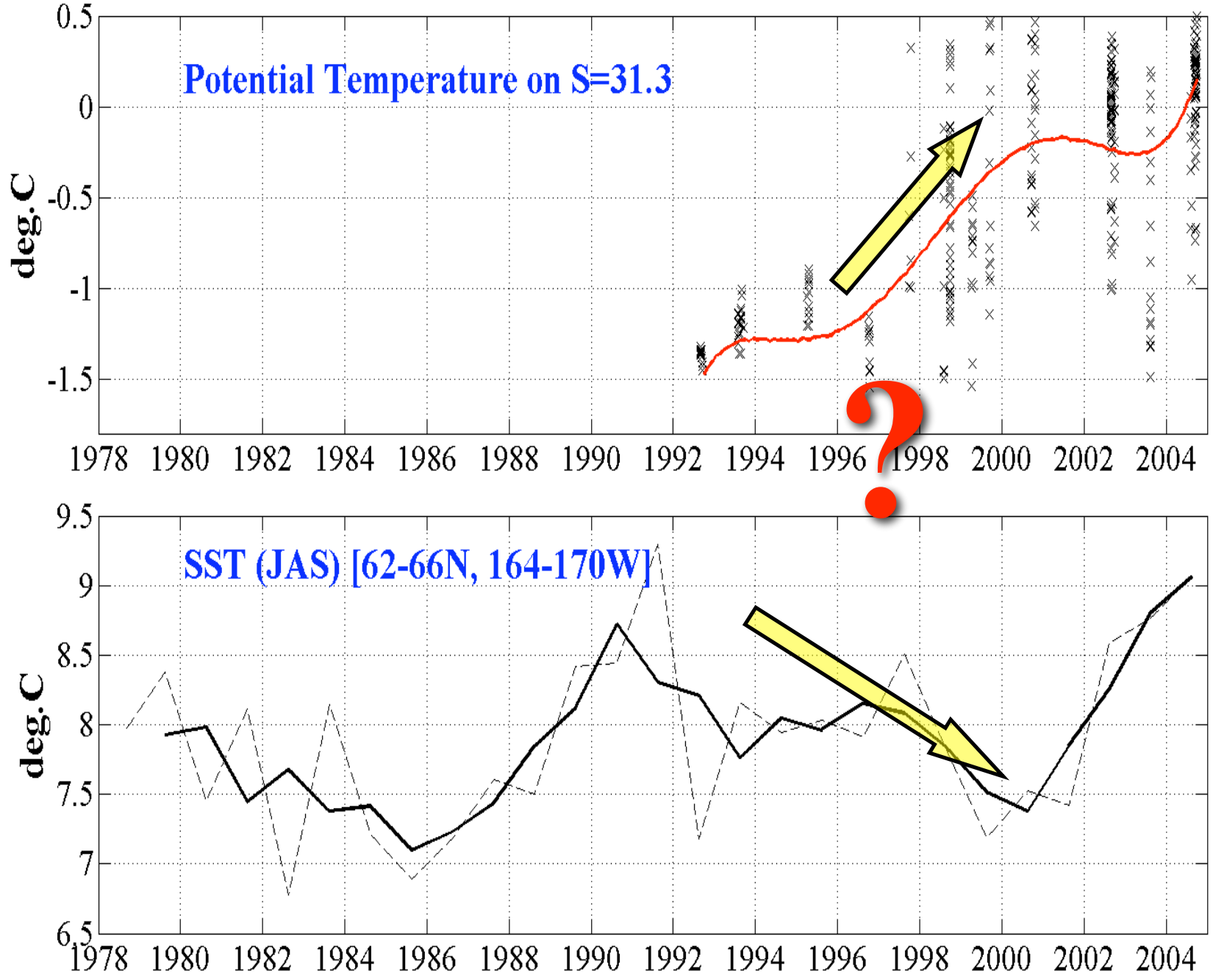
Changes in upper oceanic temperature & stored heat




Change of atmospheric temperature was larger than of ocean.
Which was more important for the sea ice?
Change of heat flux from the ocean
was much larger than that from atmosphere
“Heat is much more significant parameter than temperature to argue the fate of Arctic sea ice”.
Key Word 1: Heat
Photo by National geographic

Is the warming of PSW in the Canada Basin truly caused by changes in the upstream temperature in the northeastern Bering Shelf?





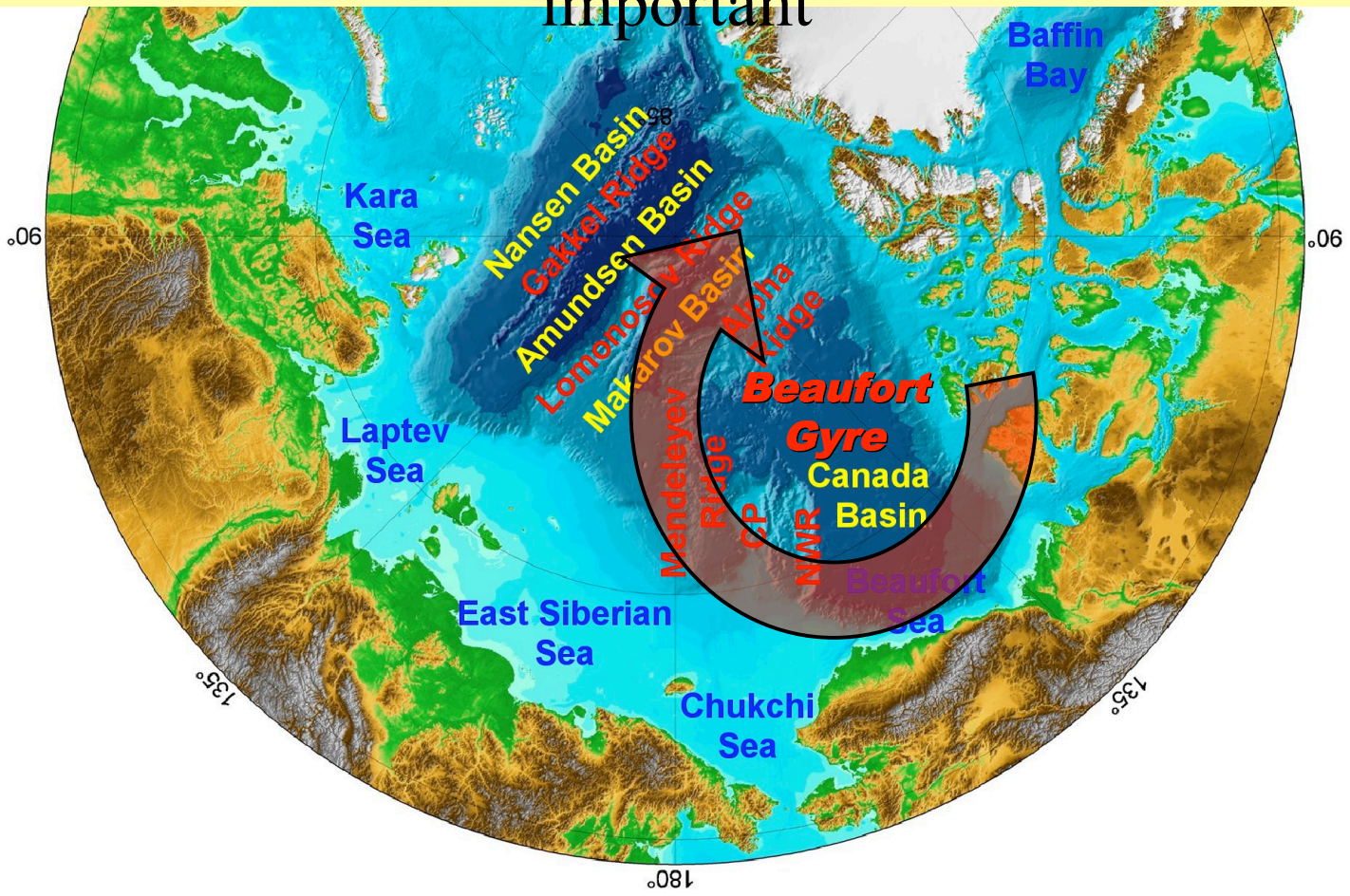
Shimada et al. (2006)

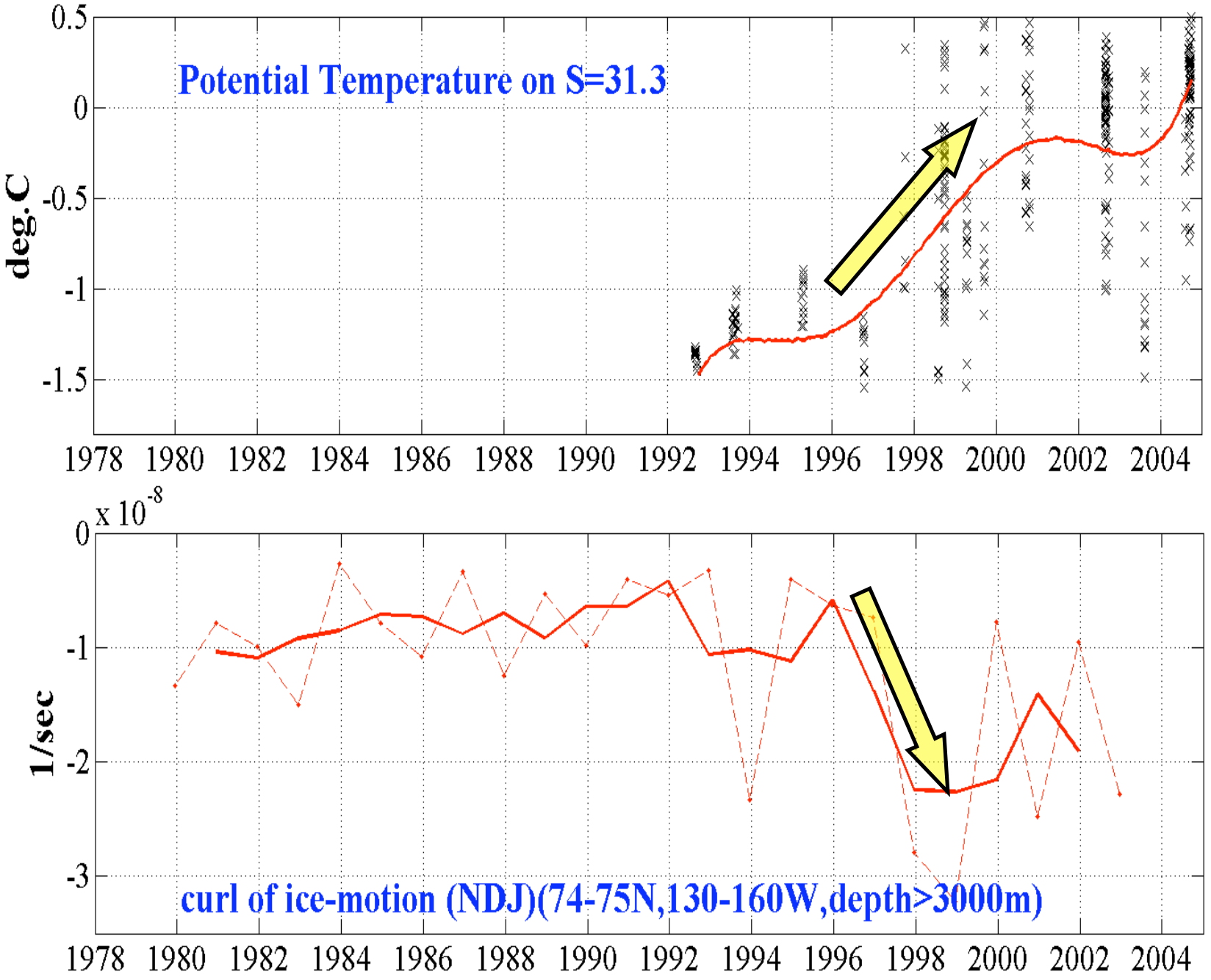
Ocean-Ice feedback mechanism

Upper ocean is not directly driven by wind forcing, but by sea ice motion.

*torque of sea ice motion is important

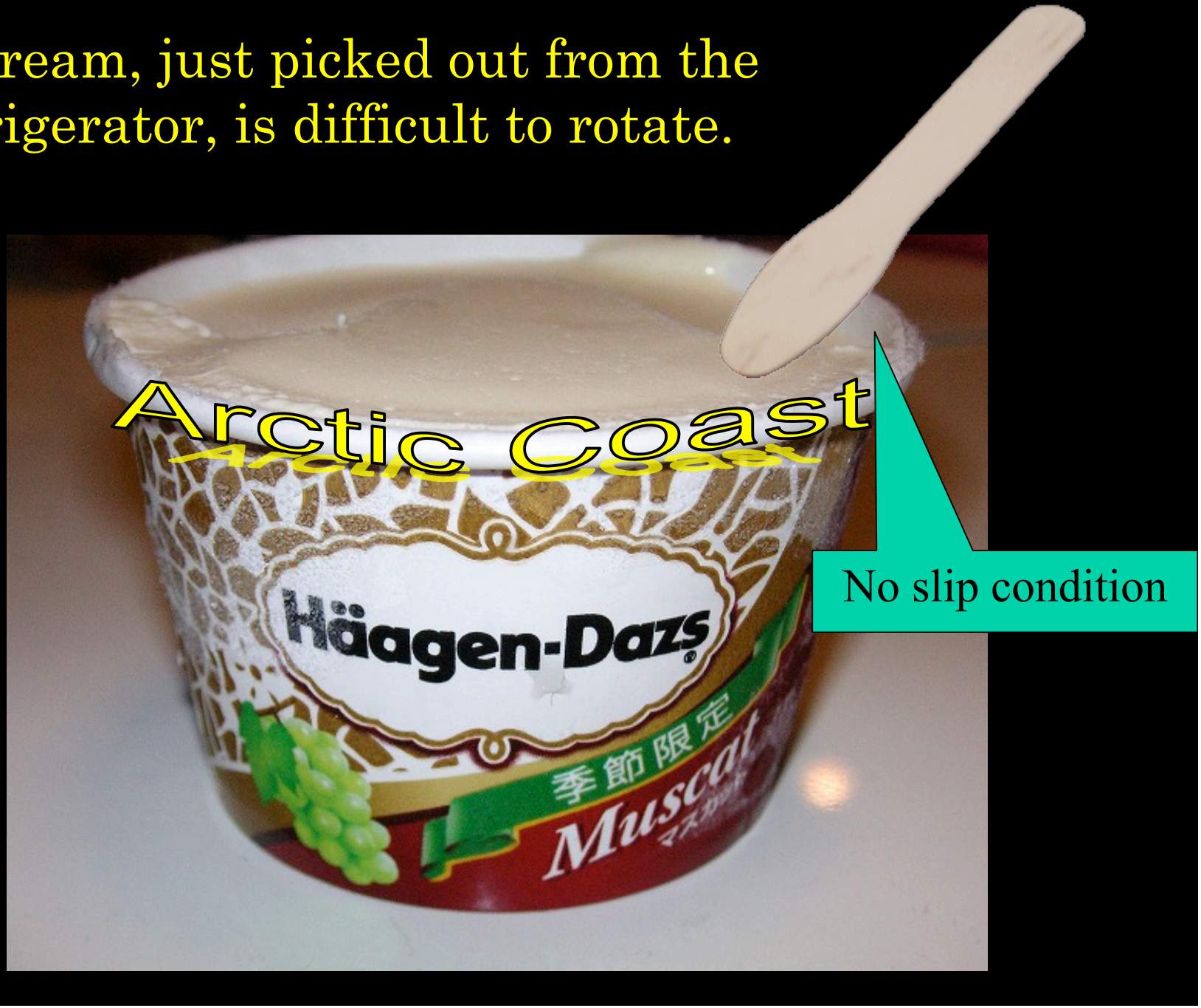
*coastal boundary condition of sea ice motion is important



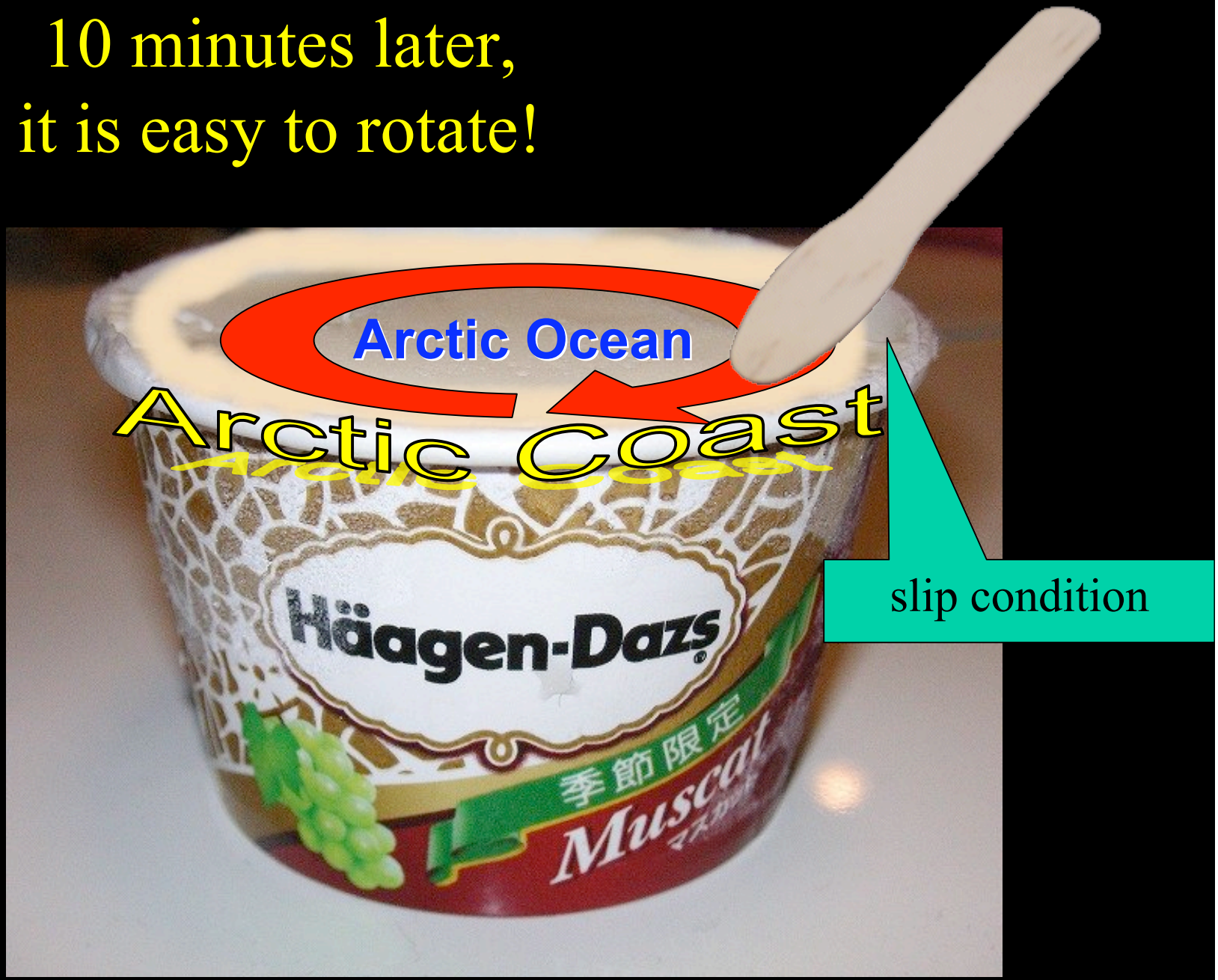


Shimada et al. (2006)

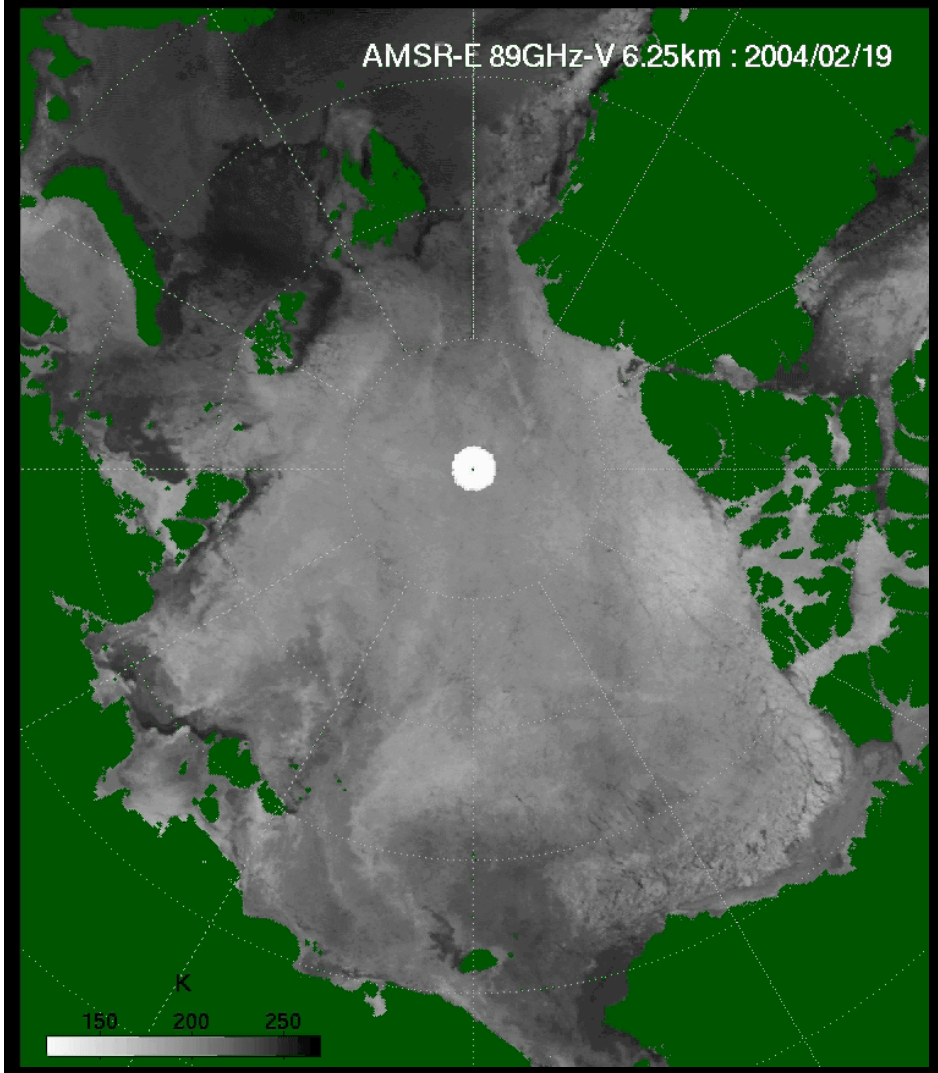
Ice cream, just picked out from the refrigerator, is difficult to rotate.



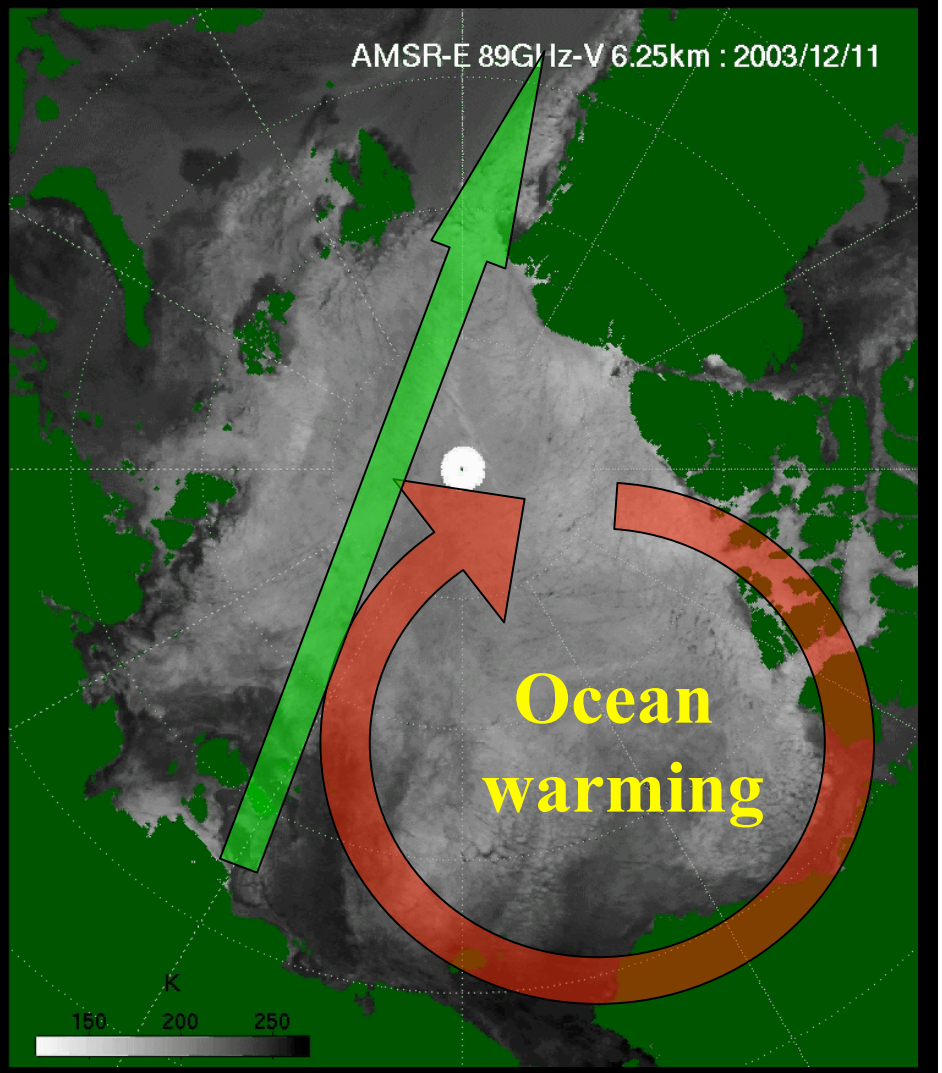
10 minutes later,
it is easy to rotate!

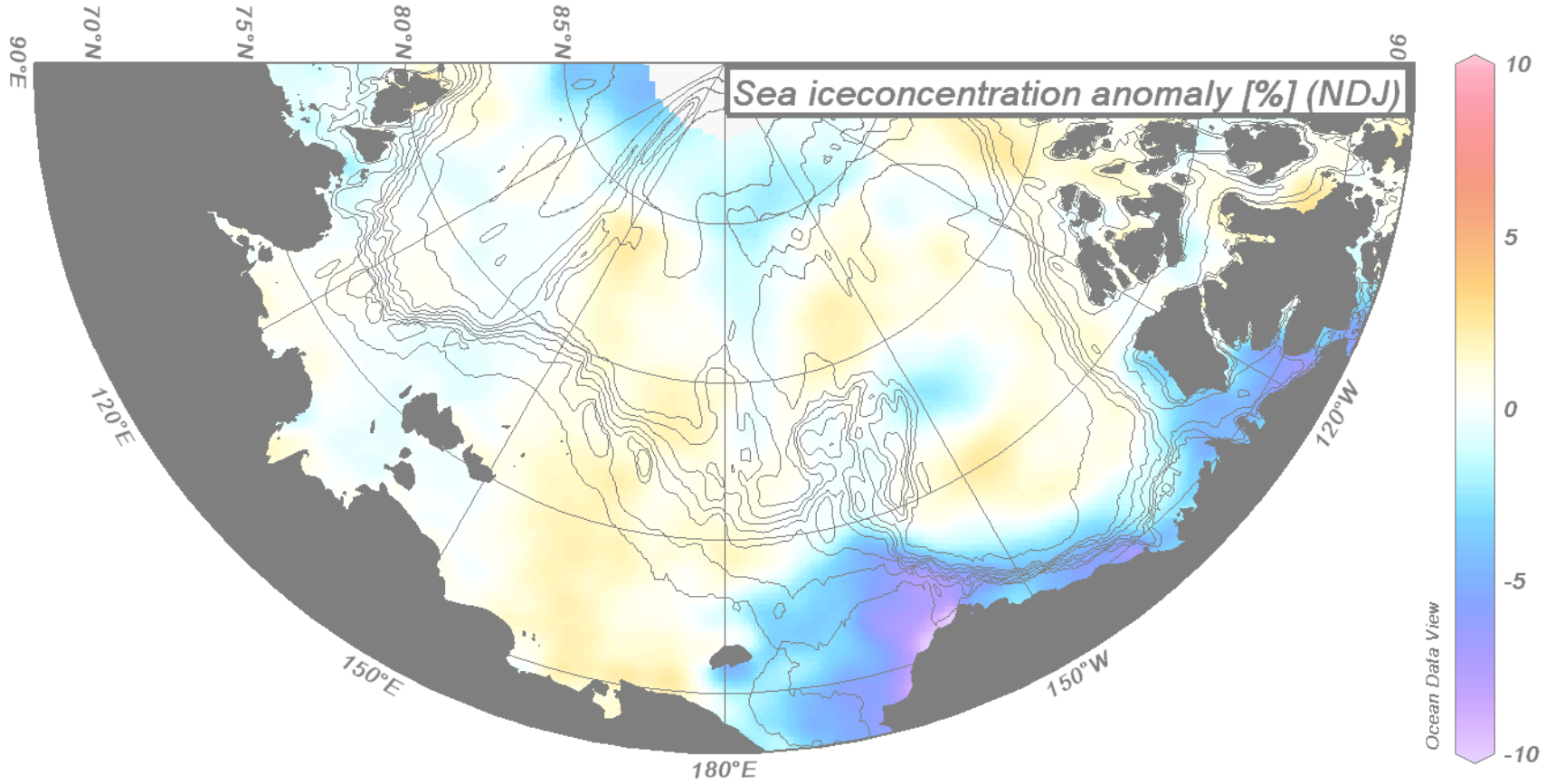


heavy ice condition near Alaskan coast



Less ice condition near Alaskan coast



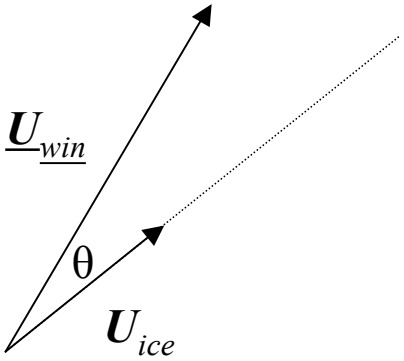


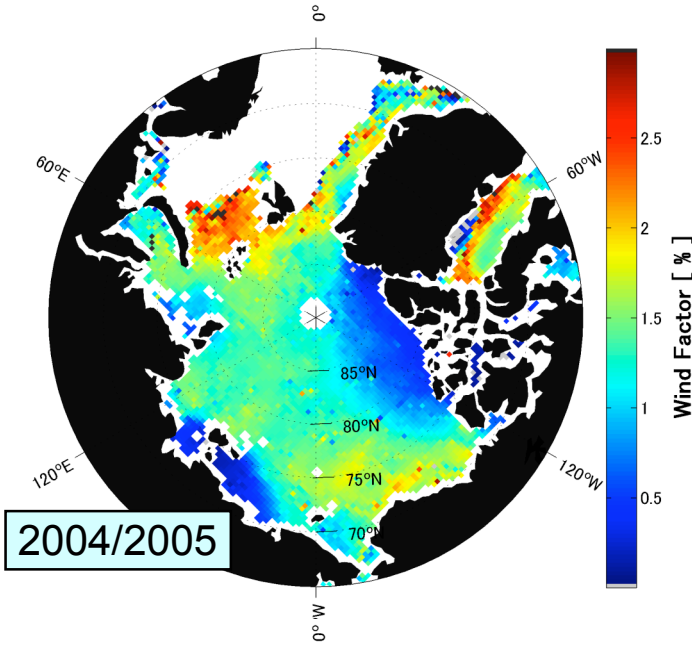
- Sea ice concentration anomaly for November through January [(1997 Nov.~2003 Jan.) – (1979~1997 Jan.)]

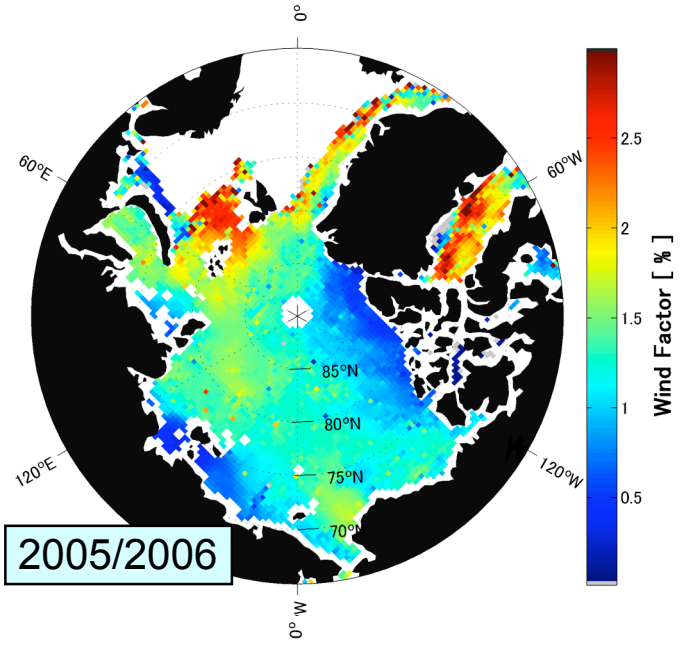
Shimada et al. (2006)

Changes of Wind Factor (Nov.- May)

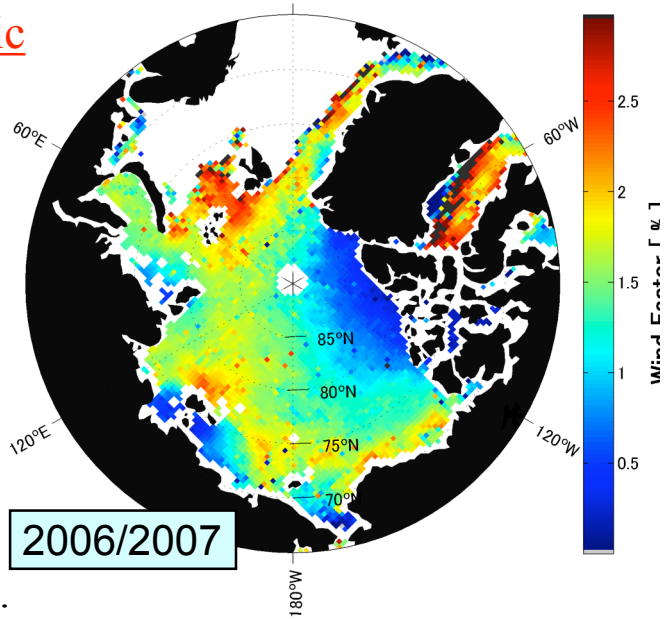
Wind Factor
$=|\boldsymbol{U}_{ice}|/|\underline{\boldsymbol{U}_{wind}}\cos\theta|$

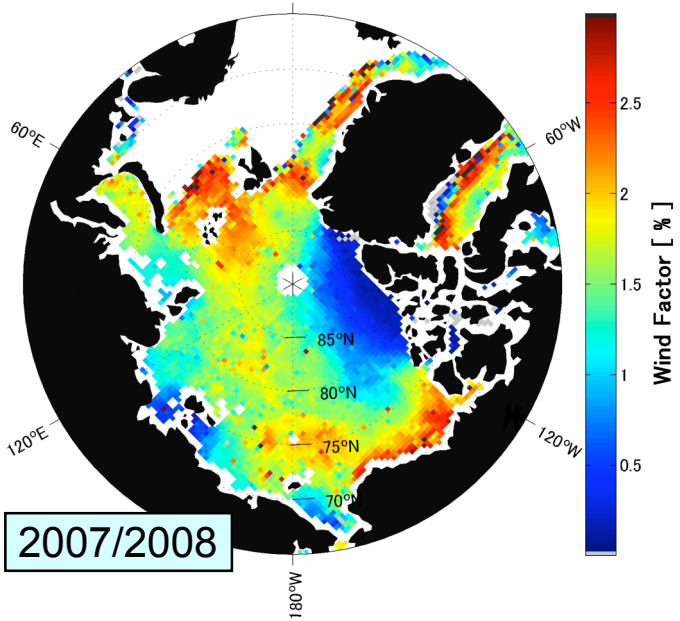






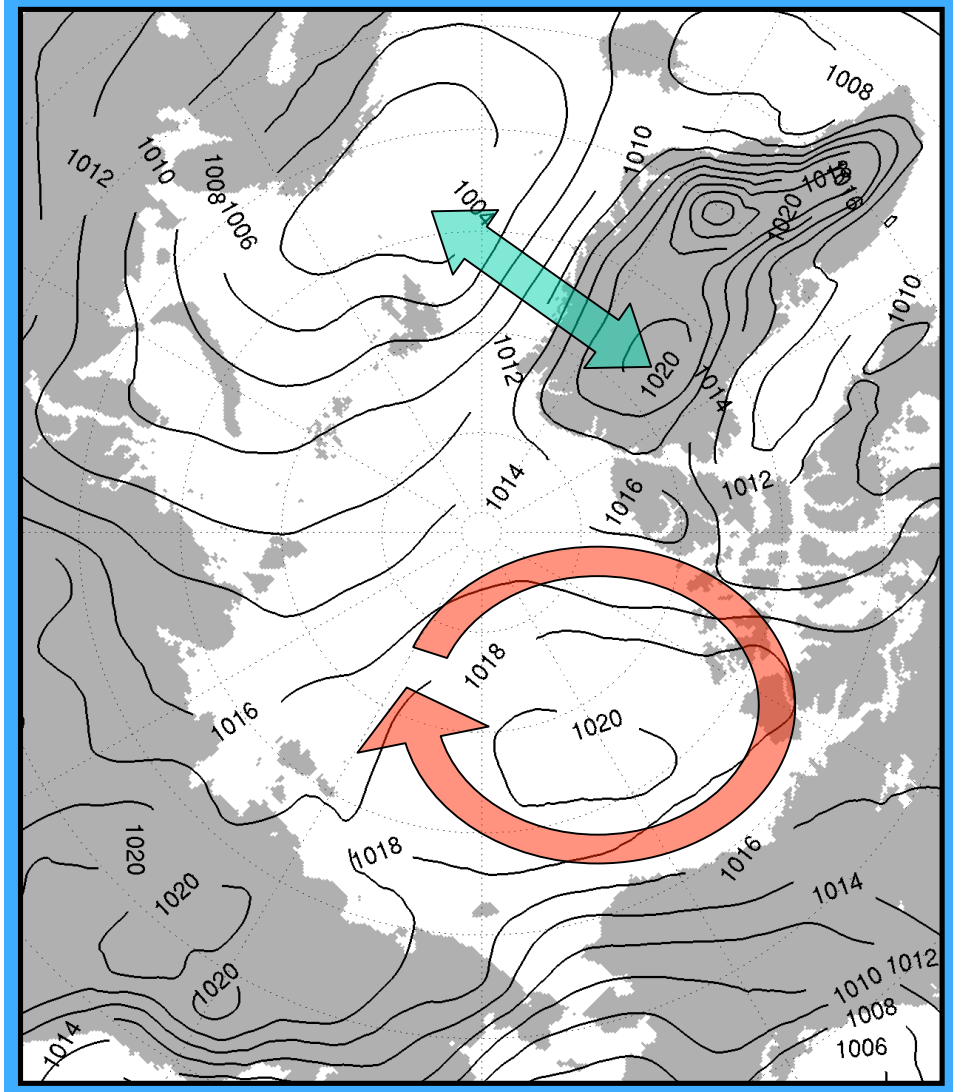
Penetration of atmospheric momentum is increasing.



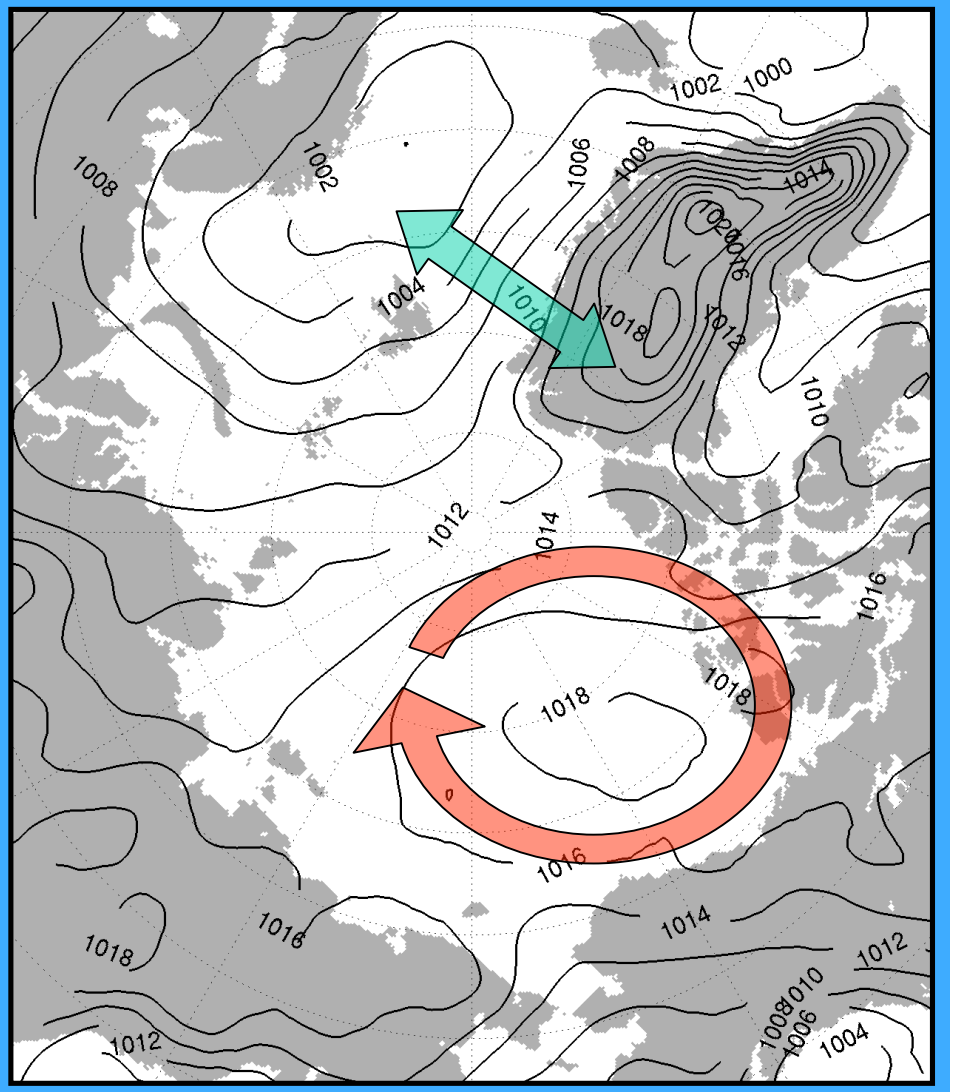


Yoshizawa & Shimada, prep.

Mean SLP
(Oct.1 , 2004 – May. 31, 2005)



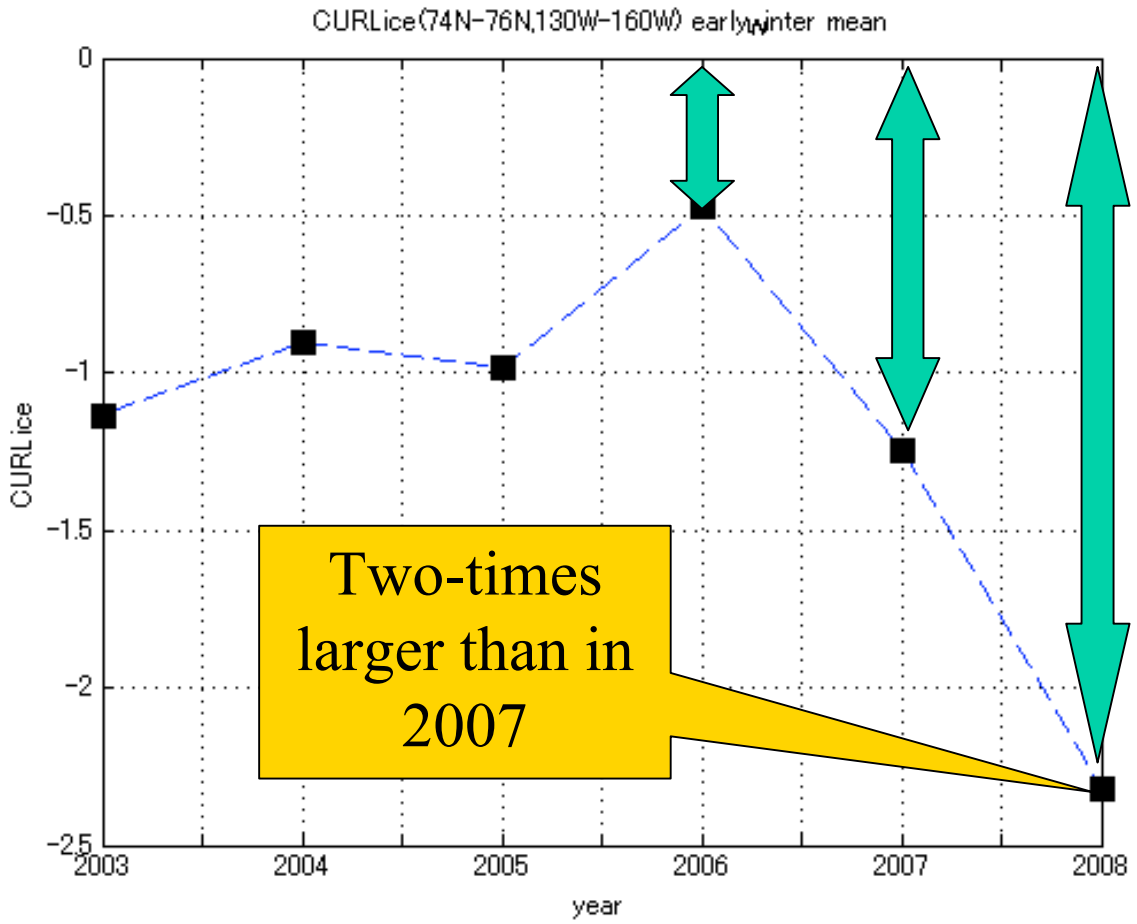
Mean SLP
(Oct.1 , 2006 – May. 31, 2007)

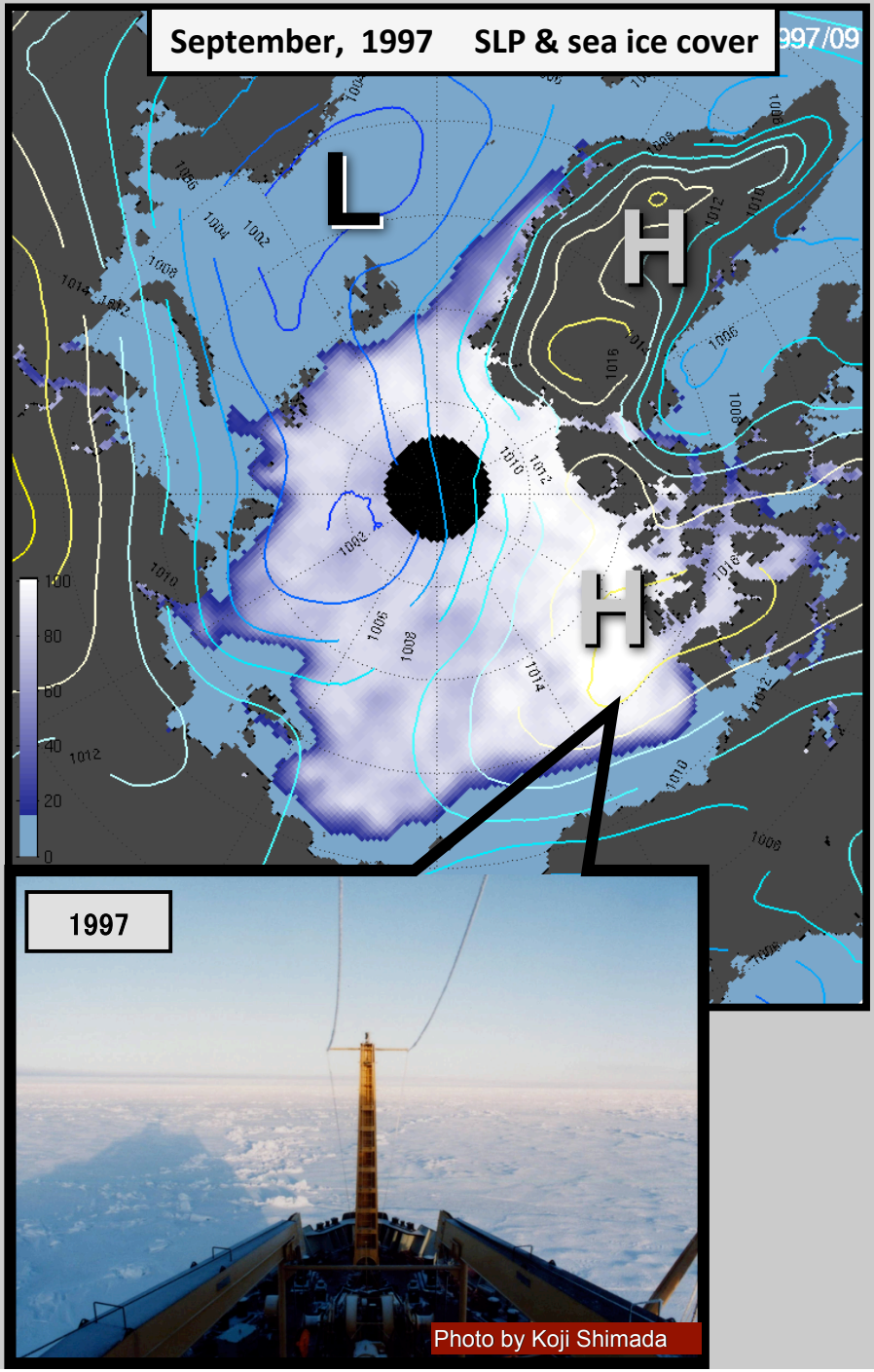


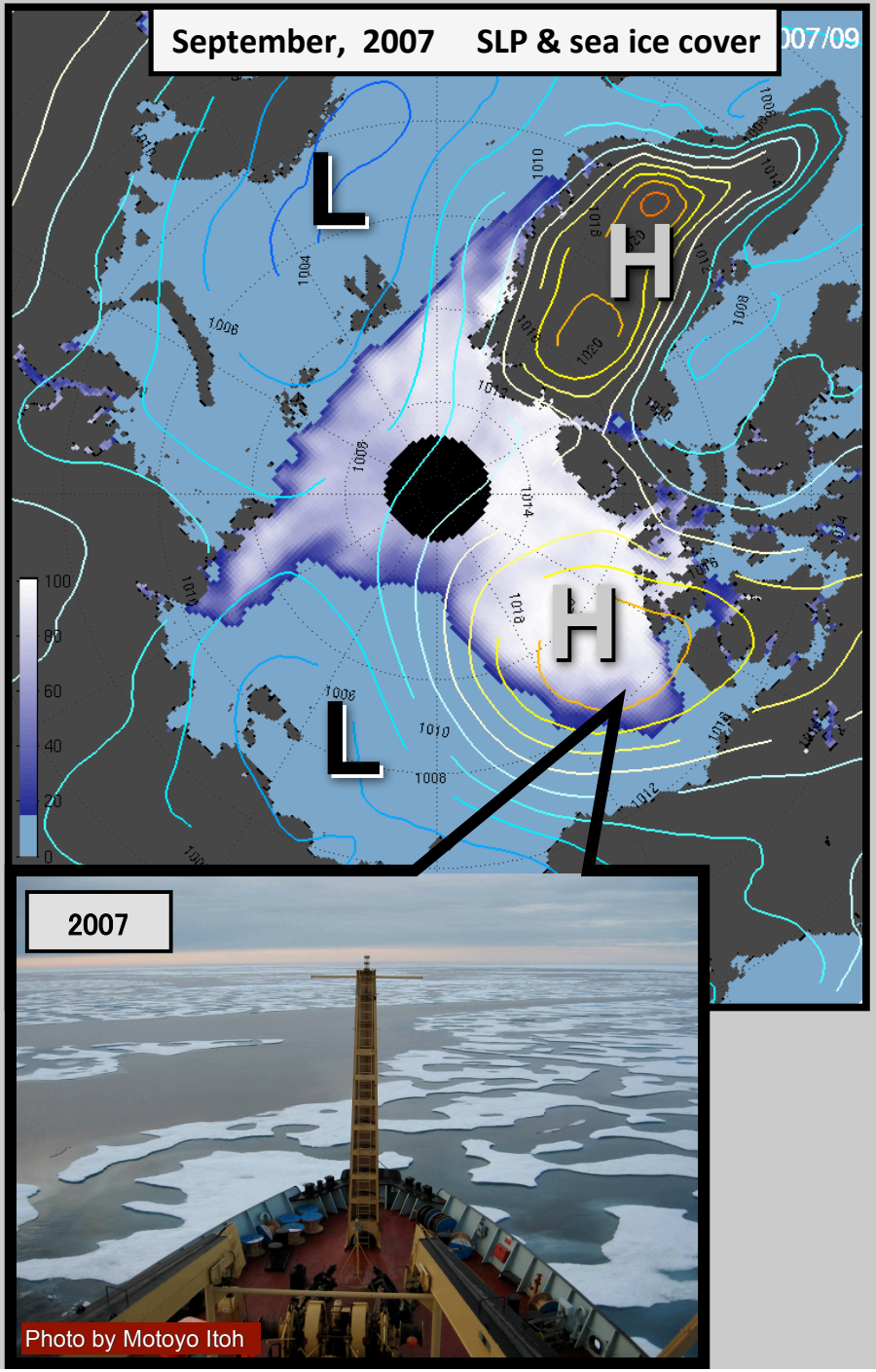
No significant difference in SLP between 2005 and 2007

Rotation of sea ice motion in the Canada Basin

Minus value means clockwise rotation.

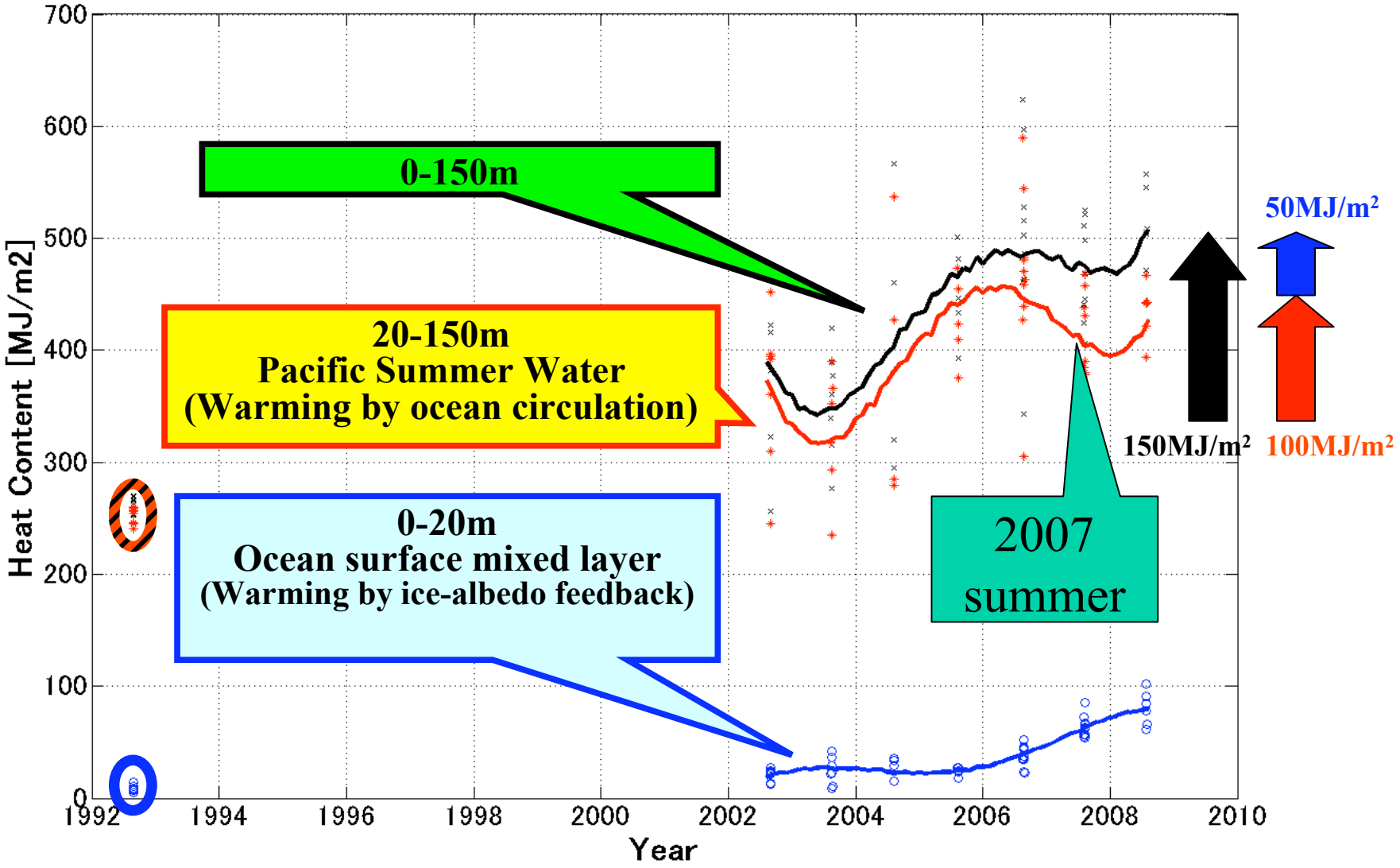



September, 1997 SLP & sea ice cover
L
H
H
1997
Photo by Koji Shimada

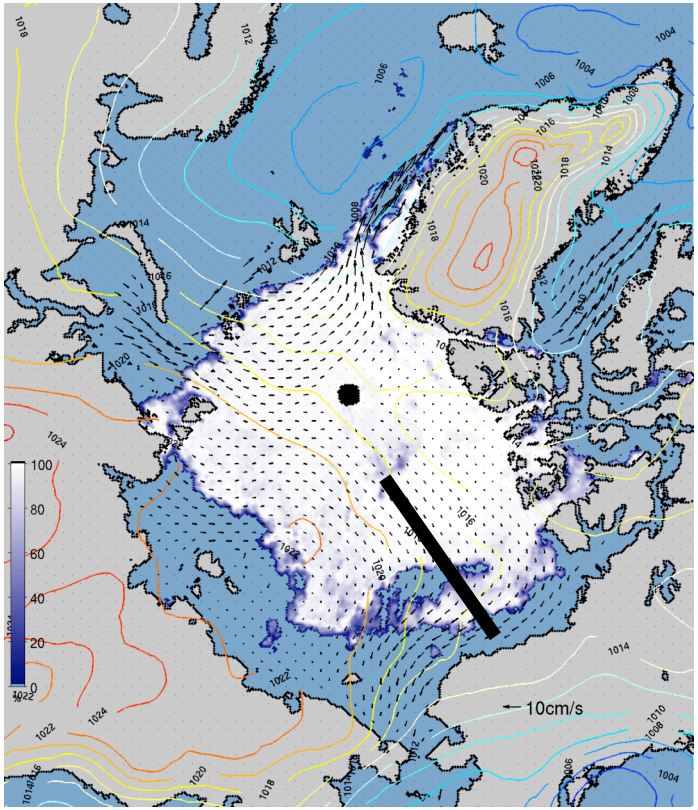

September, 2007 SLP & sea ice cover
L
H
H
L
2007
Photo by Motoyo Itoh

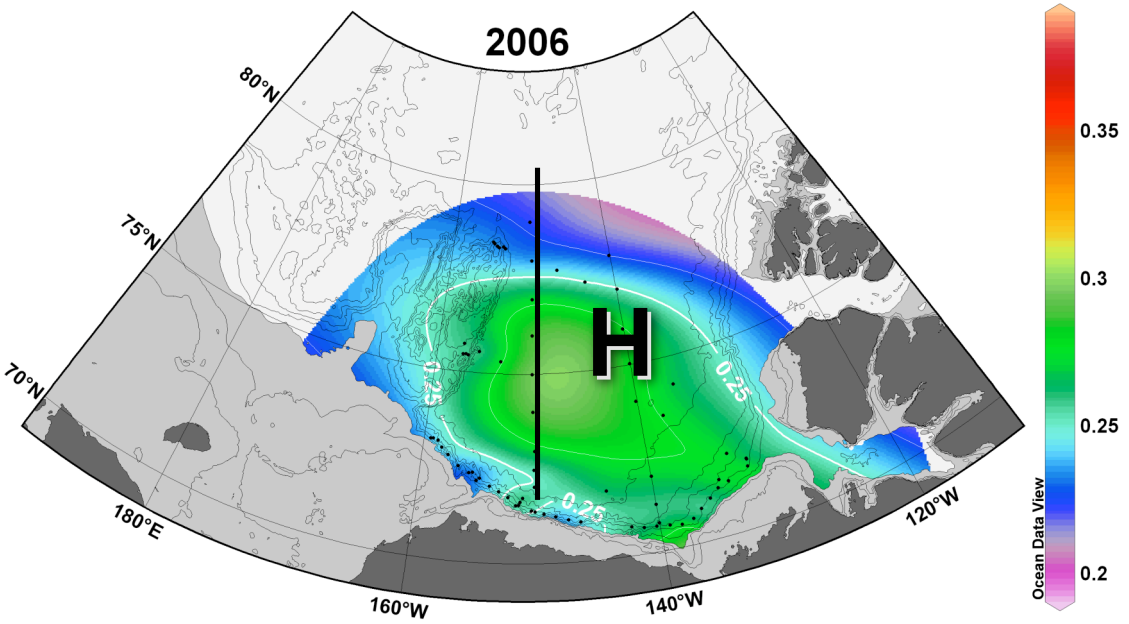

Key word 2: Precondition
Condition for instability, catastrophe
Condition for transition from negative feedback system (oscillation) to positive feedback system (evolution)
Photo by Koji Shimada

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

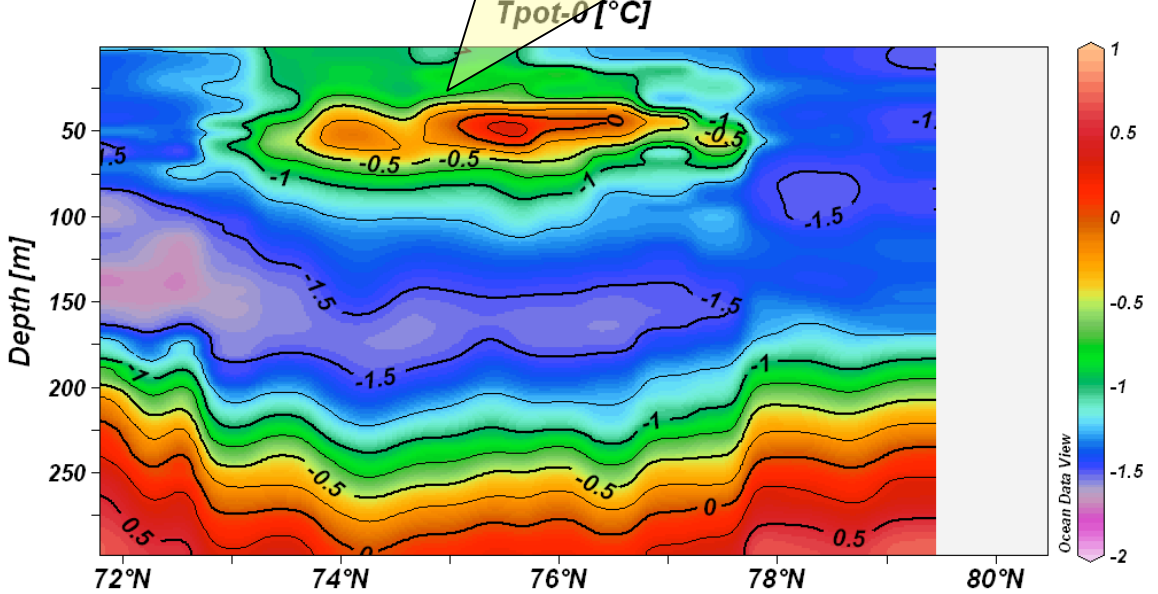


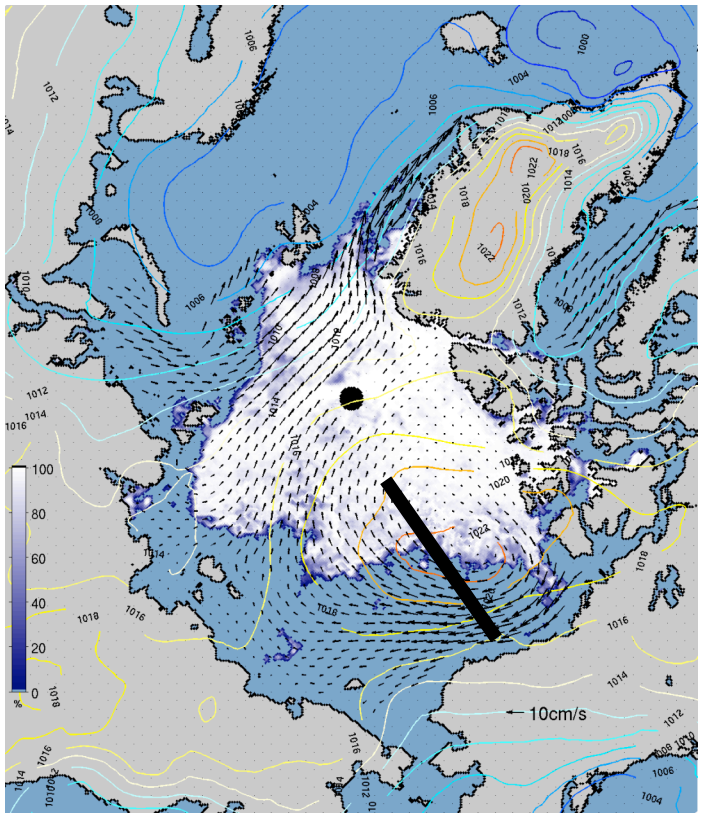
74-76ºN, 150-160ºW (near Northwind Ridge), during July 27- Sep. 1

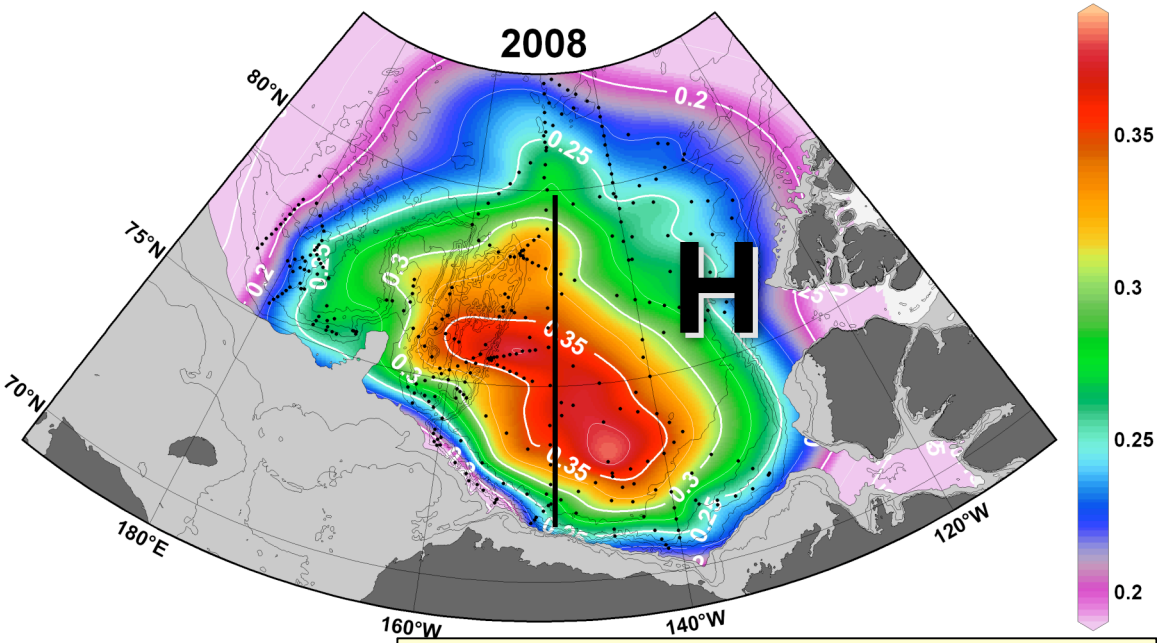




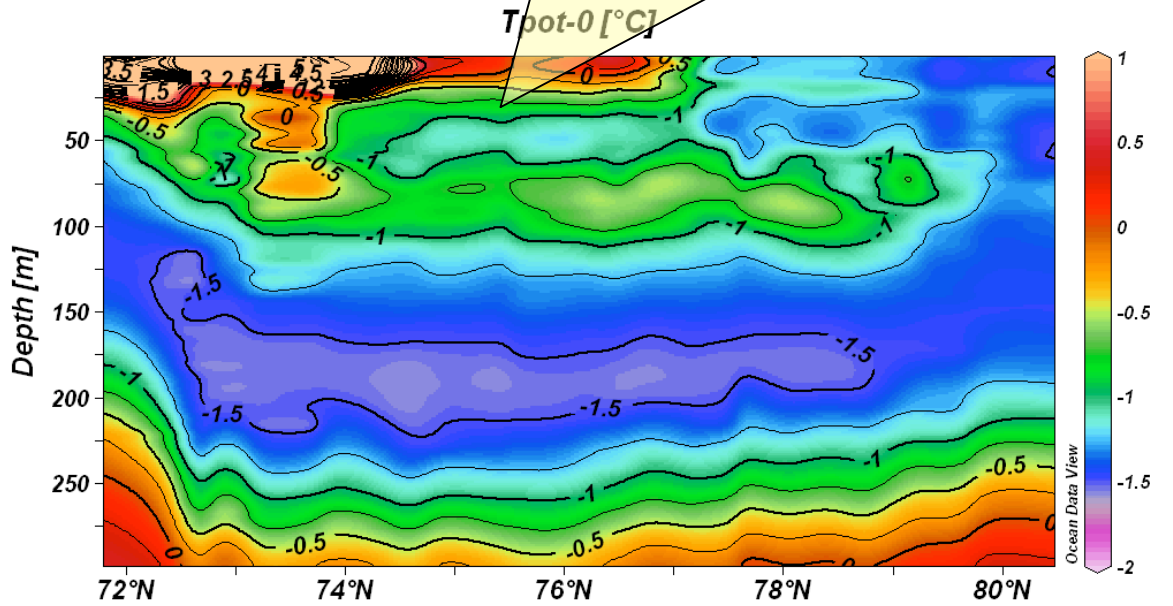
Oceanic heat was released slowly.

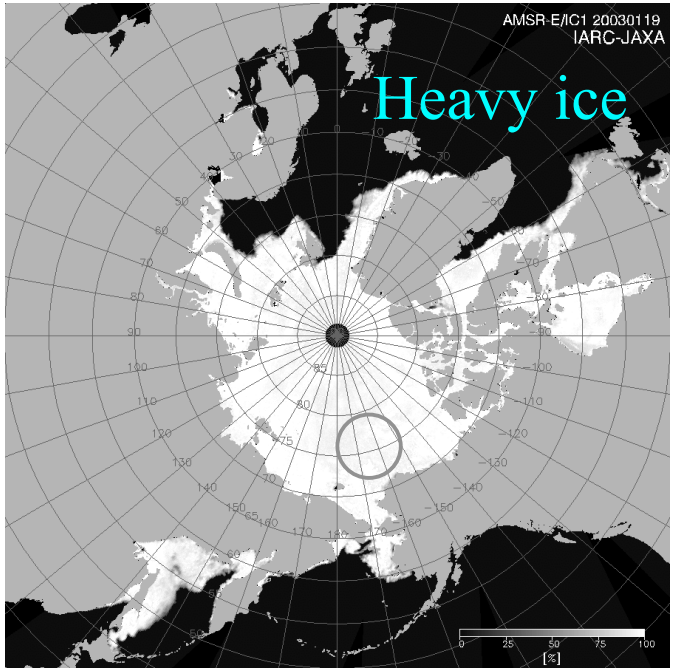


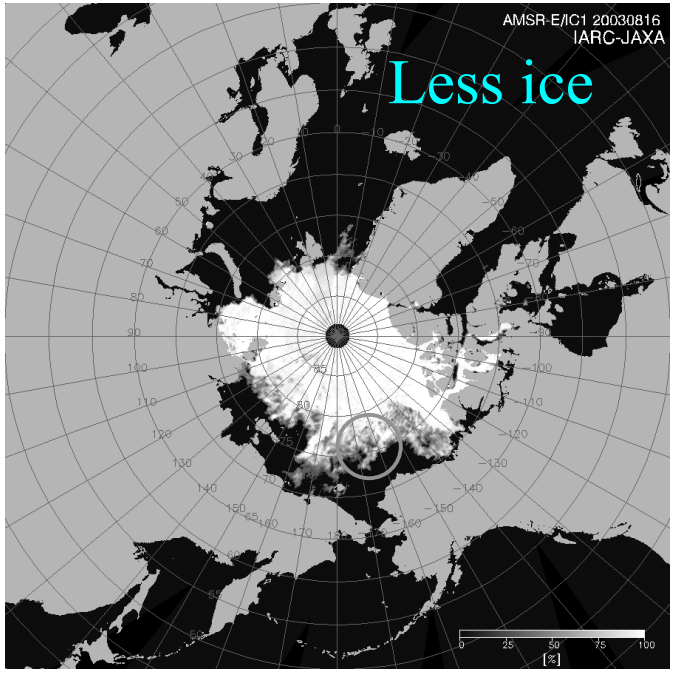


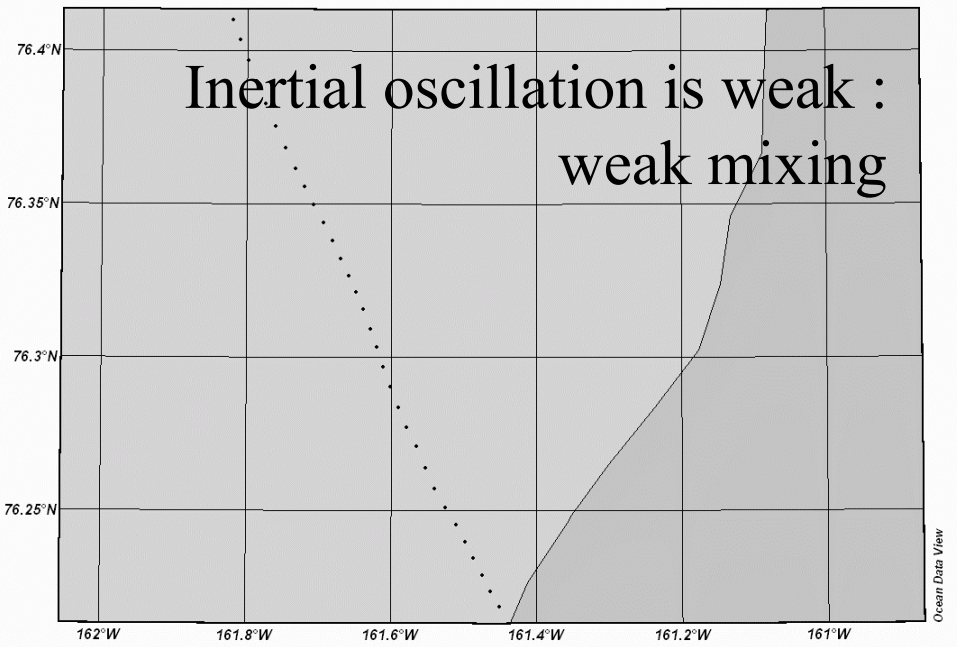


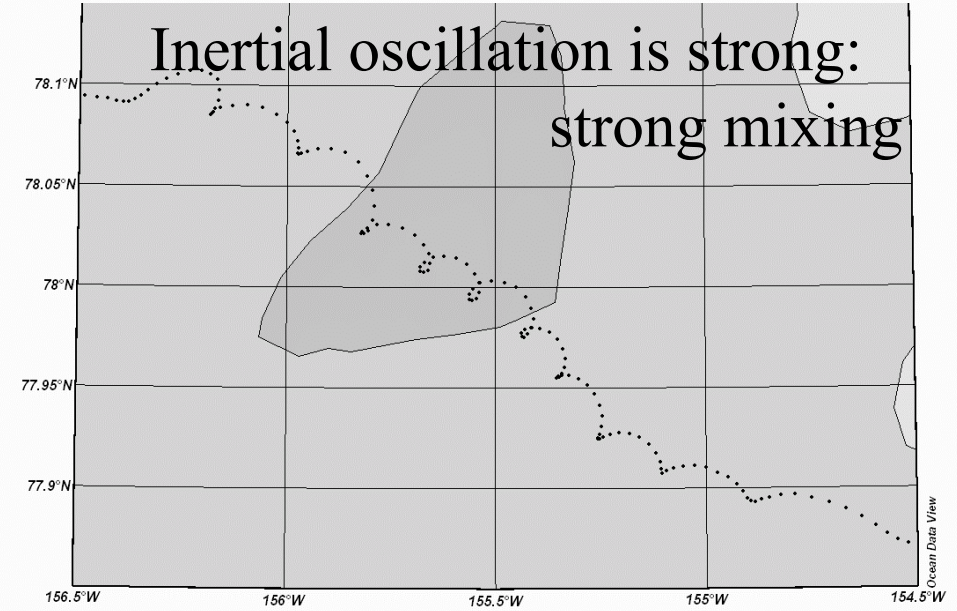
Oceanic heat was released rapidly.
⇒Strong vertical mixing

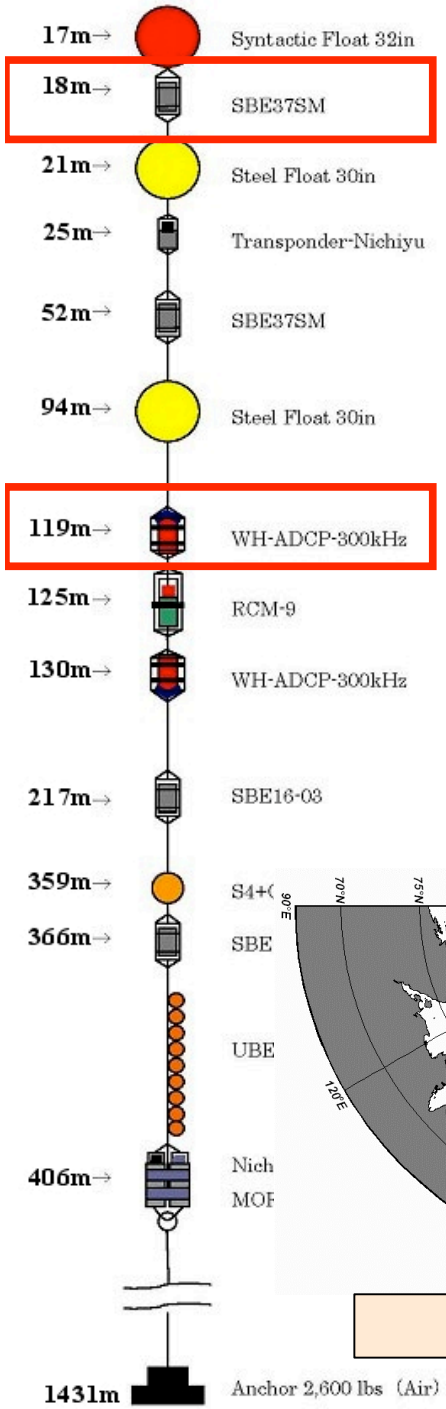



AMSR-E/IC1 20030119
IARC-JAXA
Heavy ice
0 25 50 75 100
[%]


AMSR-E/IC1 20030816
IARC-JAXA
Less ice
0 25 50 75 100
[%]


Inertial oscillation is weak :
weak mixing
76.4°N
76.35°N
76.3°N
76.25°N
162°W
161.8°W
161.6°W
161.4°W
161.2°W
161°W
Ocean Data View


Inertial oscillation is strong:
strong mixing
78.1°N
78.05°N
78°N
77.95°N
77.9°N
156.5°W
156°W
155.5°W
155°W
154.5°W
Ocean Data View



Mooring: NWR03

Position: 74° 29.65′ N
158° 02.58′ W

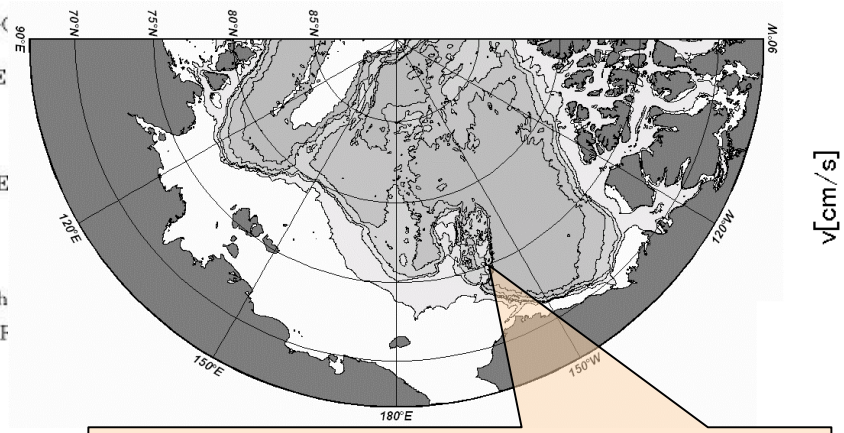
Depth: 1,459m

Current meter:
RCM-9: 1
WH-ADCP-300kHz: 2
S4+CT: 1

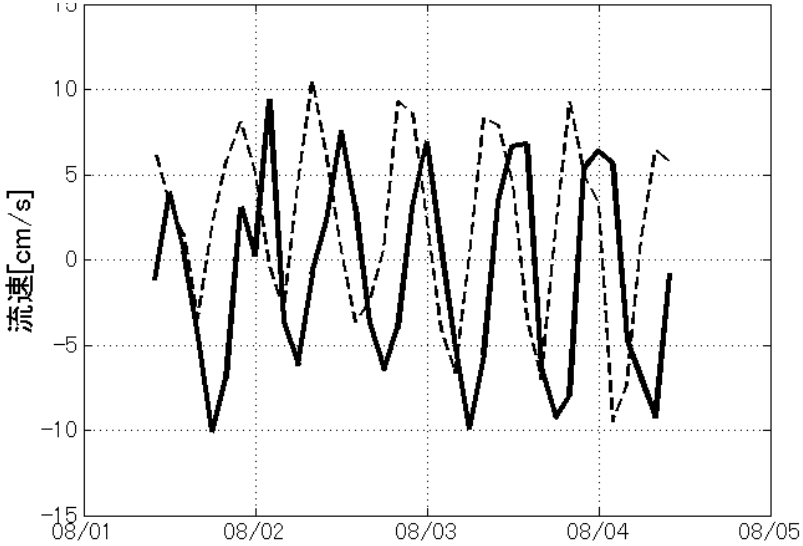
CTD:
SBE37SM: 2
SBE16-03: 1
SBE16-04: 1

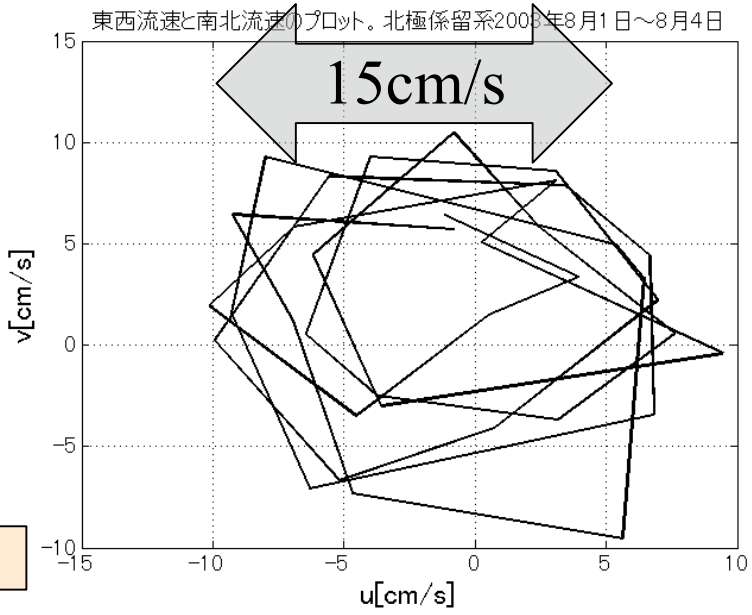
Nichiyu-TL-T: 1

Acoustic release:
Nichiyu-LTi:
OCEANO AR861B2S:

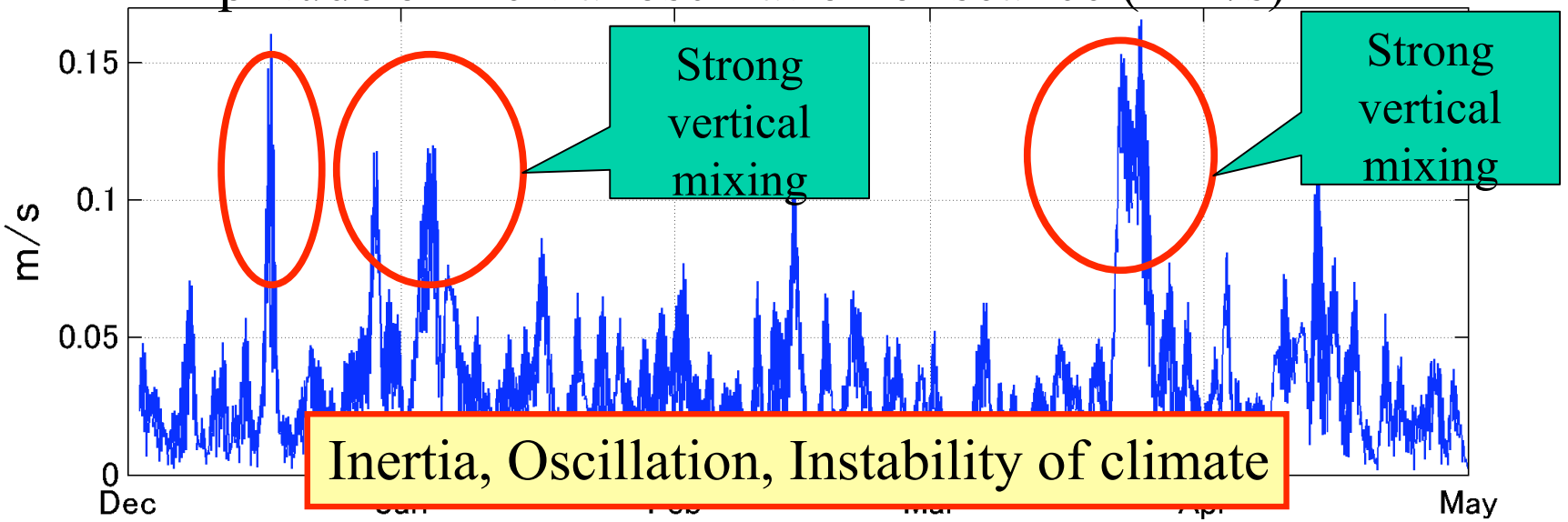


u(eastward velocity): solid
v(northward velocity):dashed

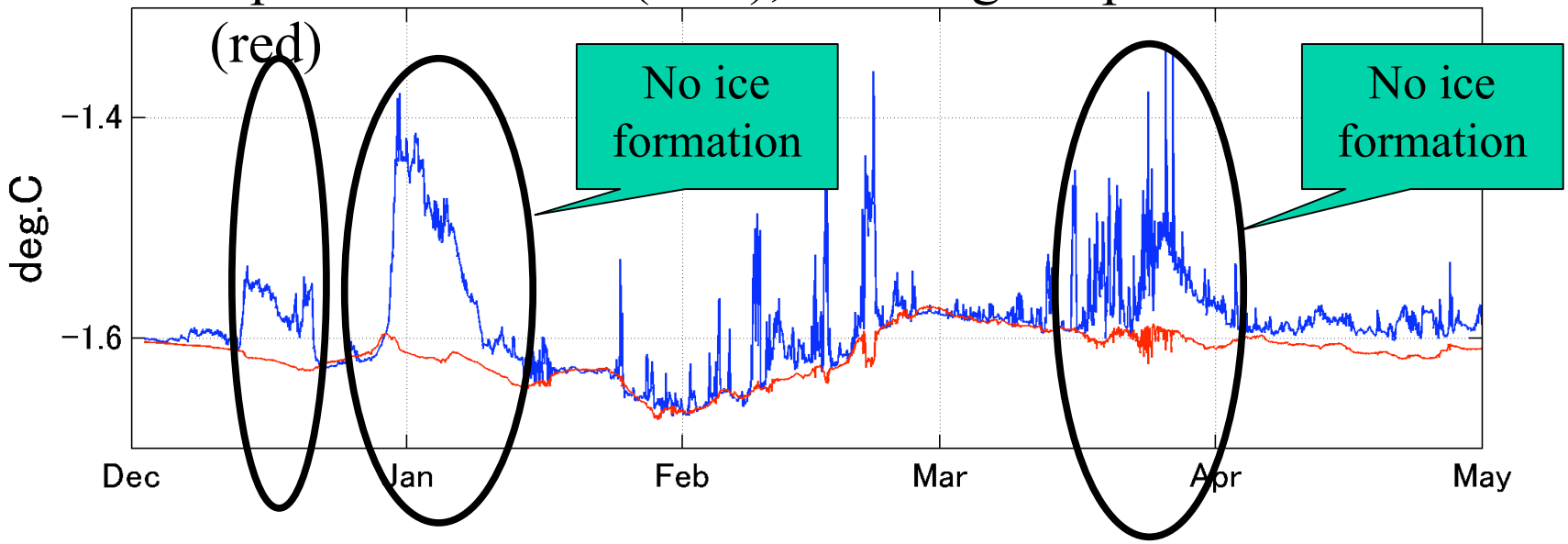




Amplitude of inertial oscillation of sea ice (mm/s)

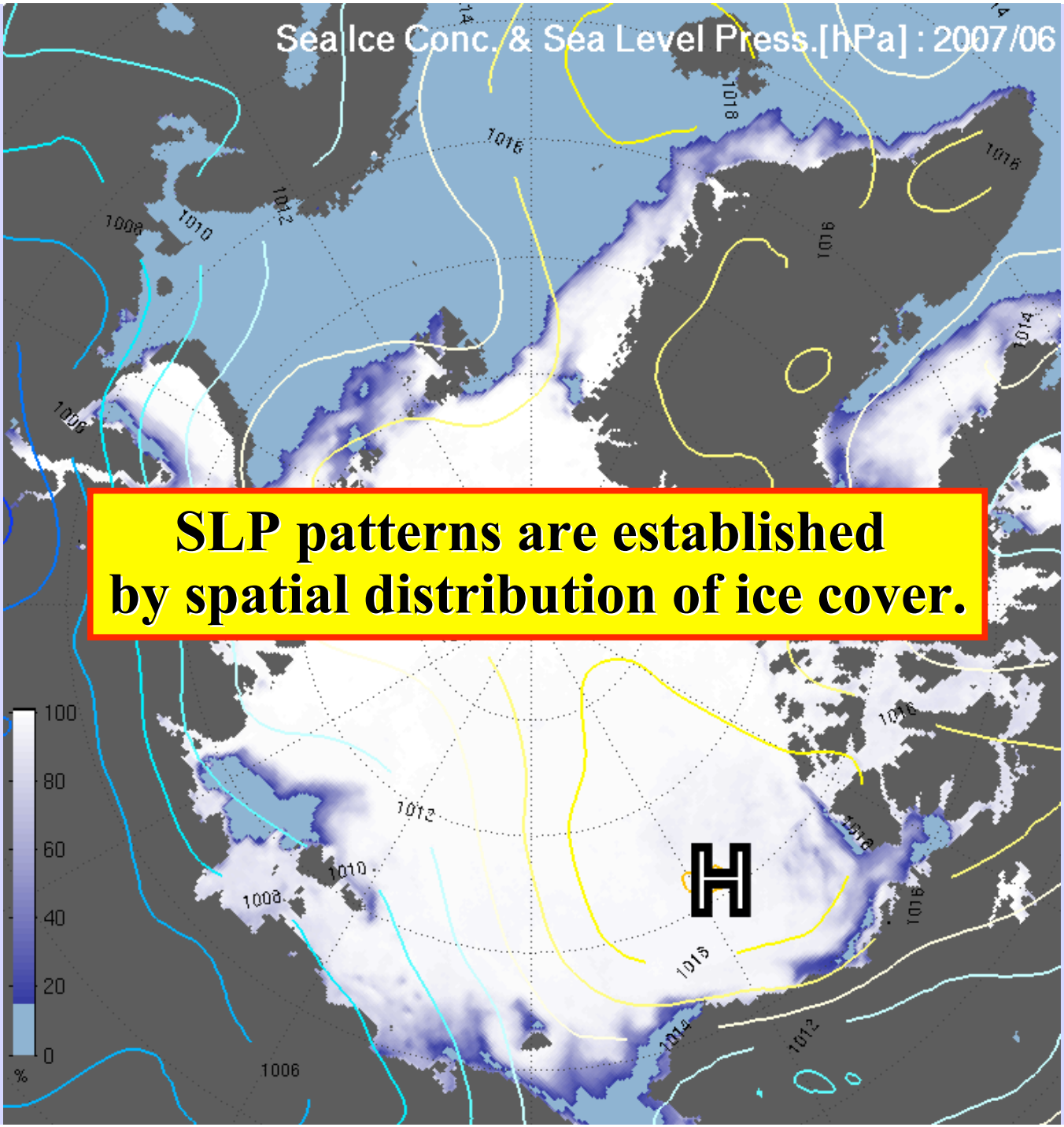


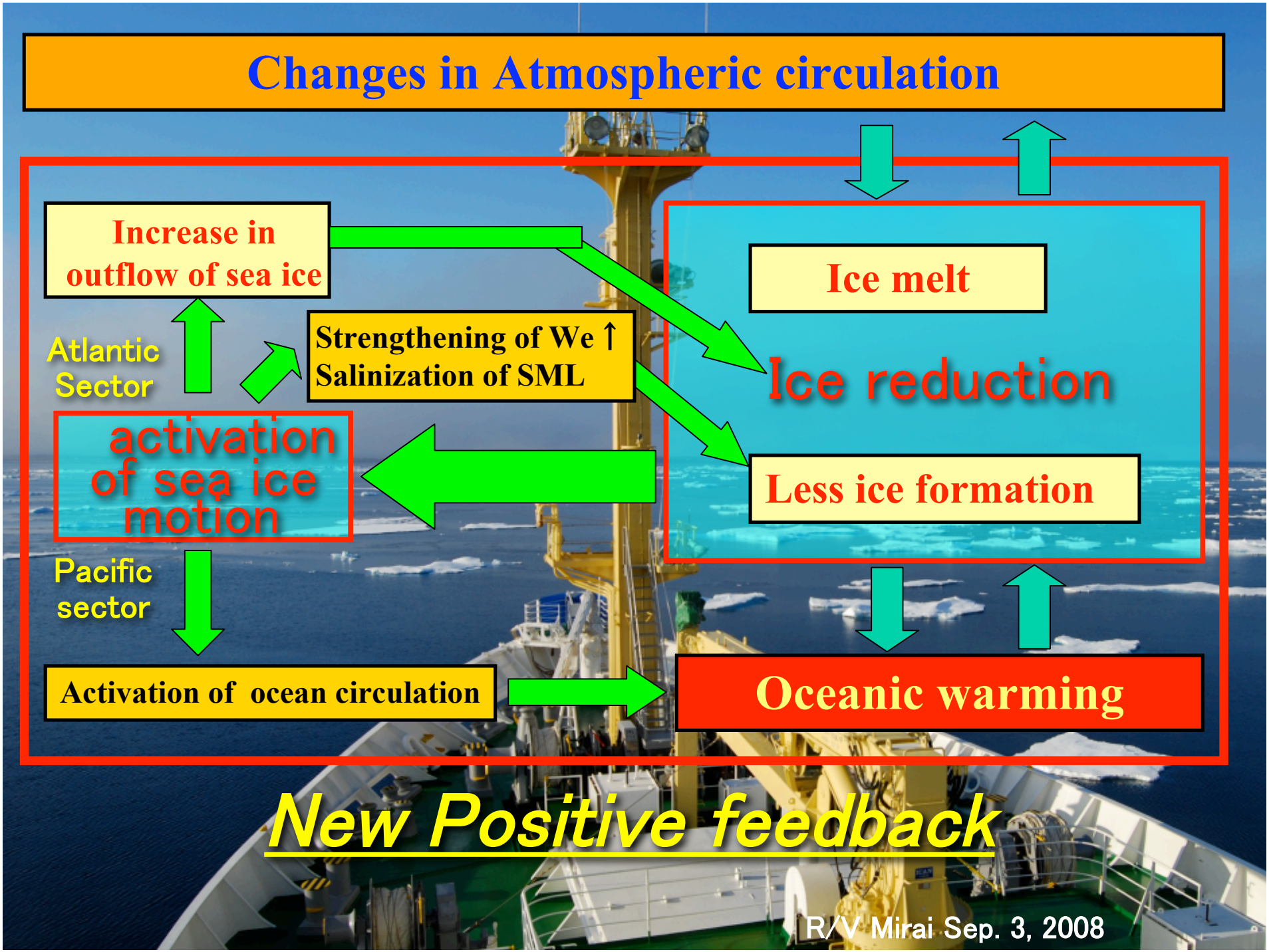
Temperature at 18m (blue), Freezing temperature at 18m (red)



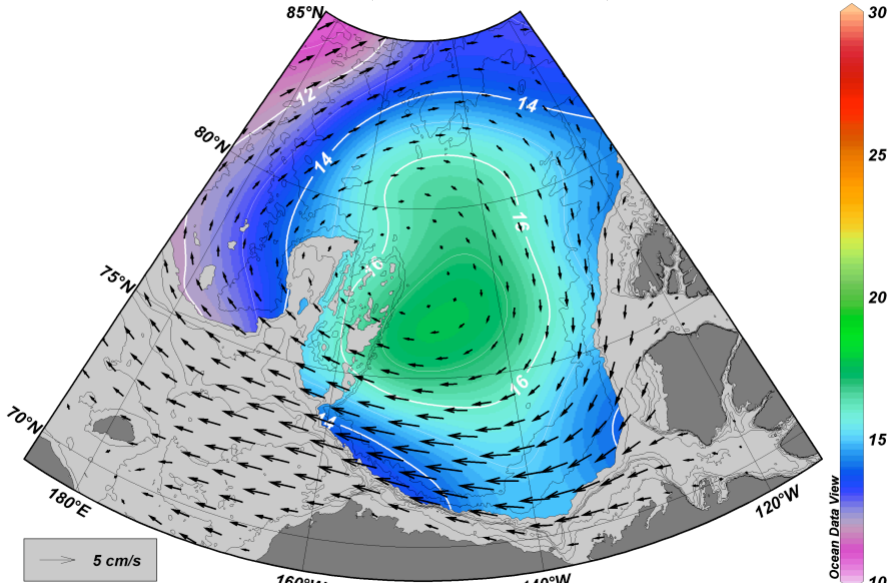
Shimada & Inoue (prep.)

Key word 3: Order

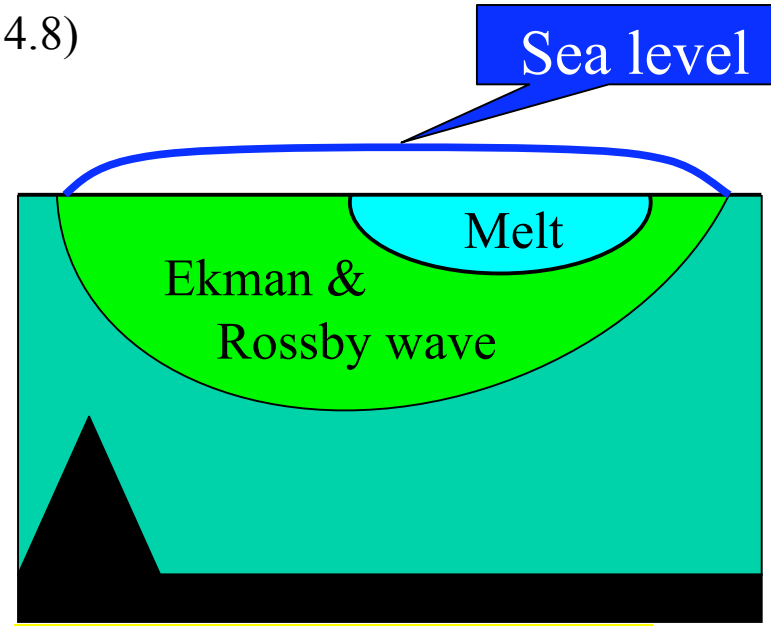

Sea Ice Conc. & Sea Level Press.[hPa] : 2007/06
SLP patterns are established
by spatial distribution of ice cover.
100
80
60
40
20
0
%
H
1006
1008
1010
1012
1014
1016
1018


Changes in Atmospheric circulation
Increase in outflow of sea ice
Ice melt
Atlantic Sector
Strengthening of We ↑
Salinization of SML
Ice reduction
activation of sea ice motion
Less ice formation
Pacific sector
Activation of ocean circulation
Oceanic warming
New Positive feedback
R/V Mirai Sep. 3, 2008

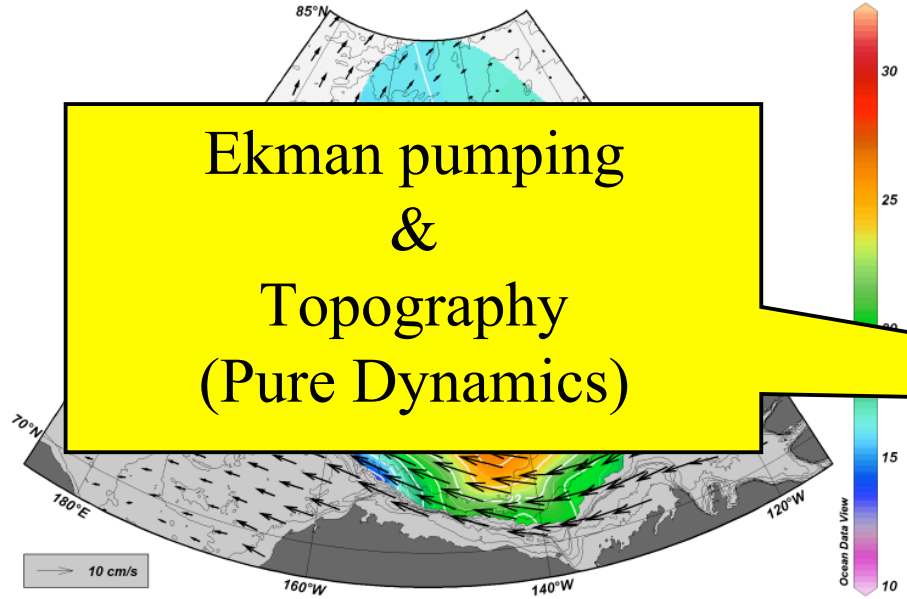
Freshwater storage [m]0-1000m (Reference Salinity 34.8)
& Sea ice velocities (NDJFMAM)



FW: PHC (Aug.-Sep.), Ice vel.: 1987-2007

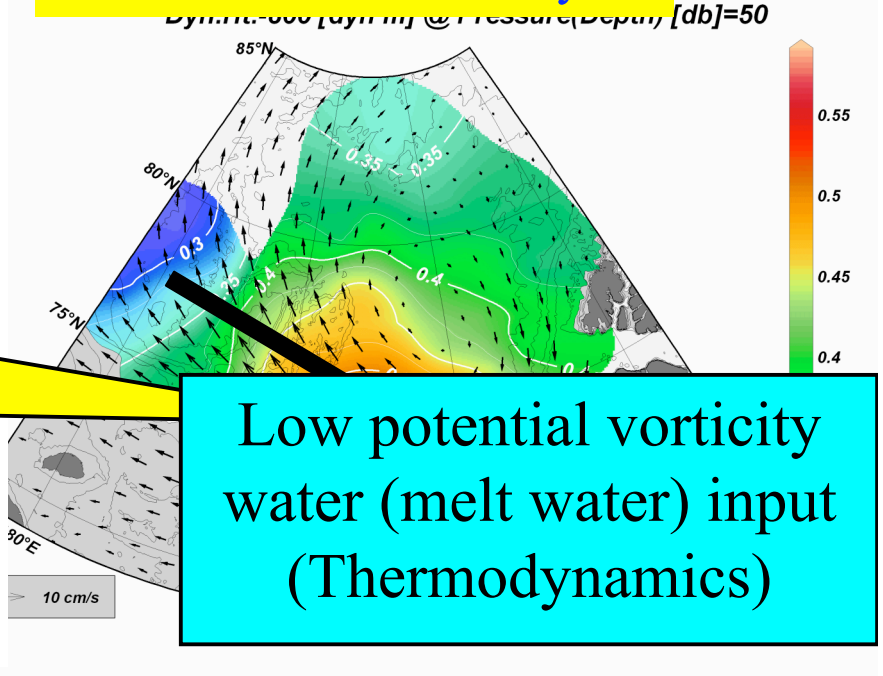


Sea level does not represent real oceanic Beaufort Gyre



FW: 2008 (Aug.-Sep.), Ice vel.: 2007/2008

Ekman pumping
&
Topography
(Pure Dynamics)



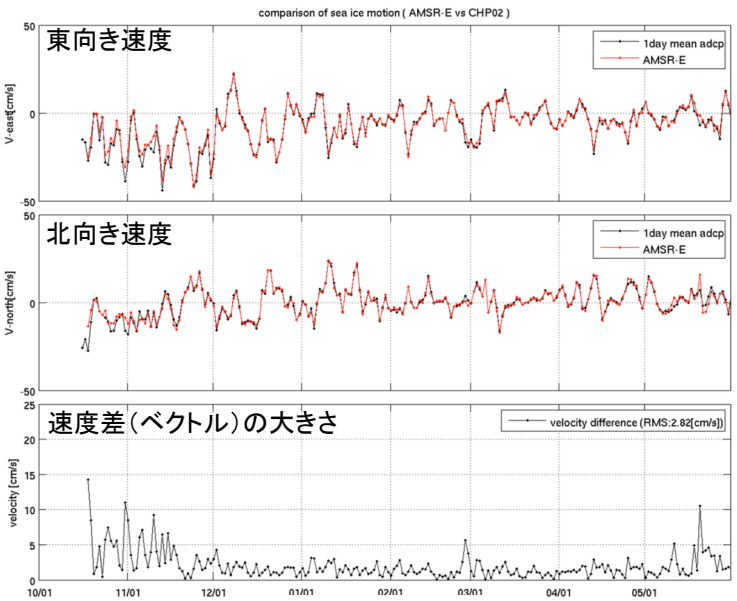
Low potential vorticity water (melt water) input (Thermodynamics)

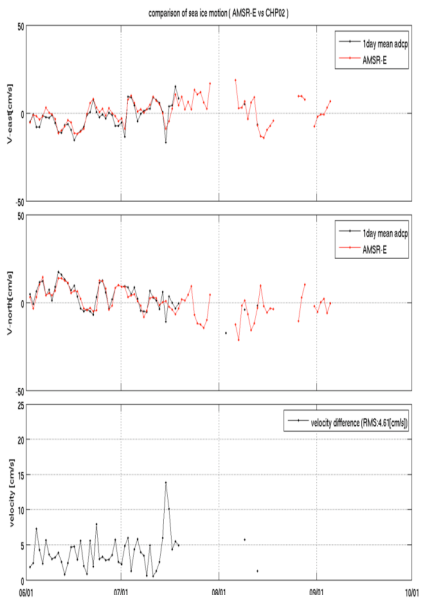
Performance of our ice velocity data

WINTER

SUMMER

Our AMSR-E
v.s
ADCP-CHP02





2002/10/1 ～ 5/31

2003/6/1 ～ 9/30

NSIDC
v.s
ADCP-CHP02