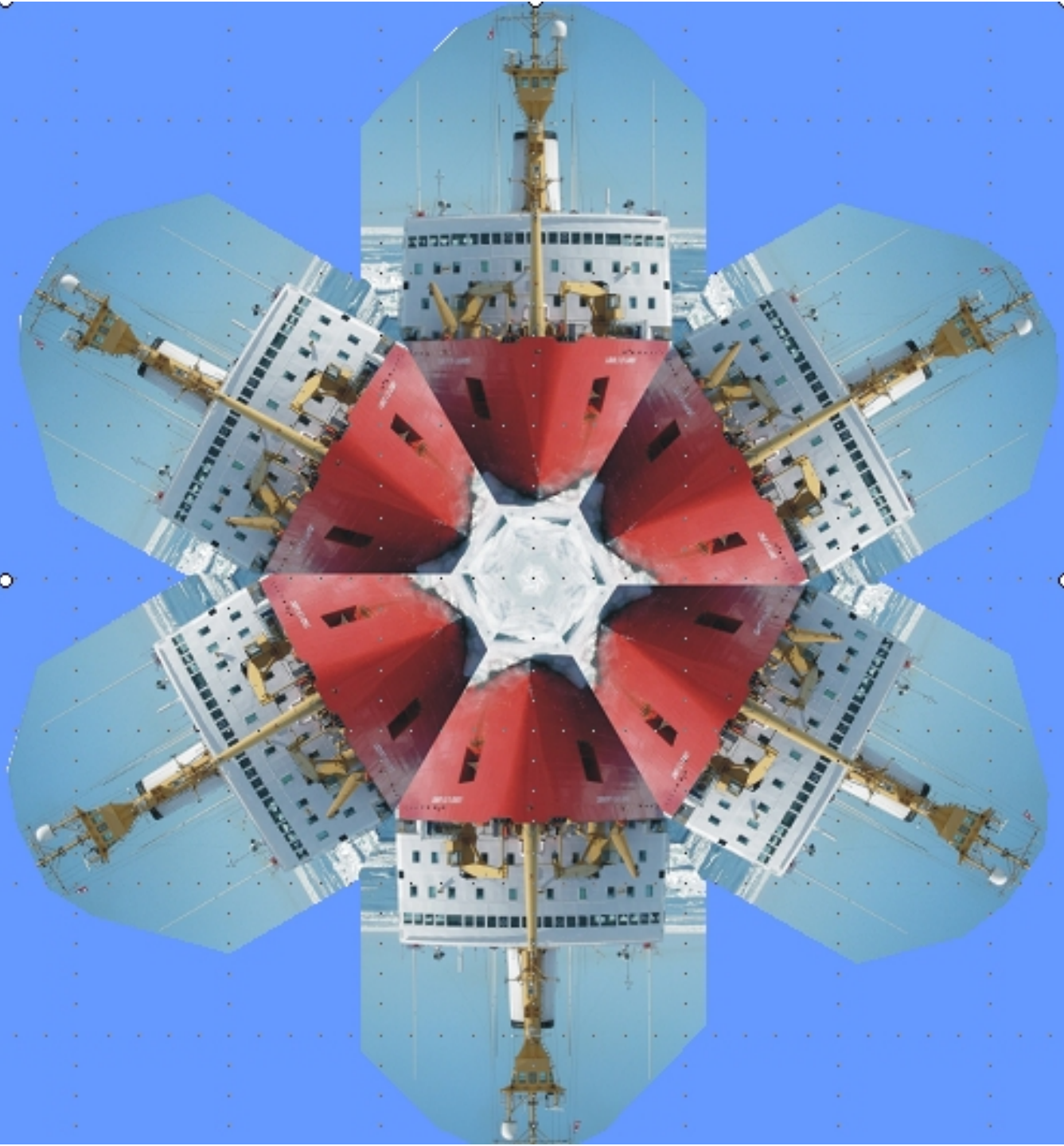
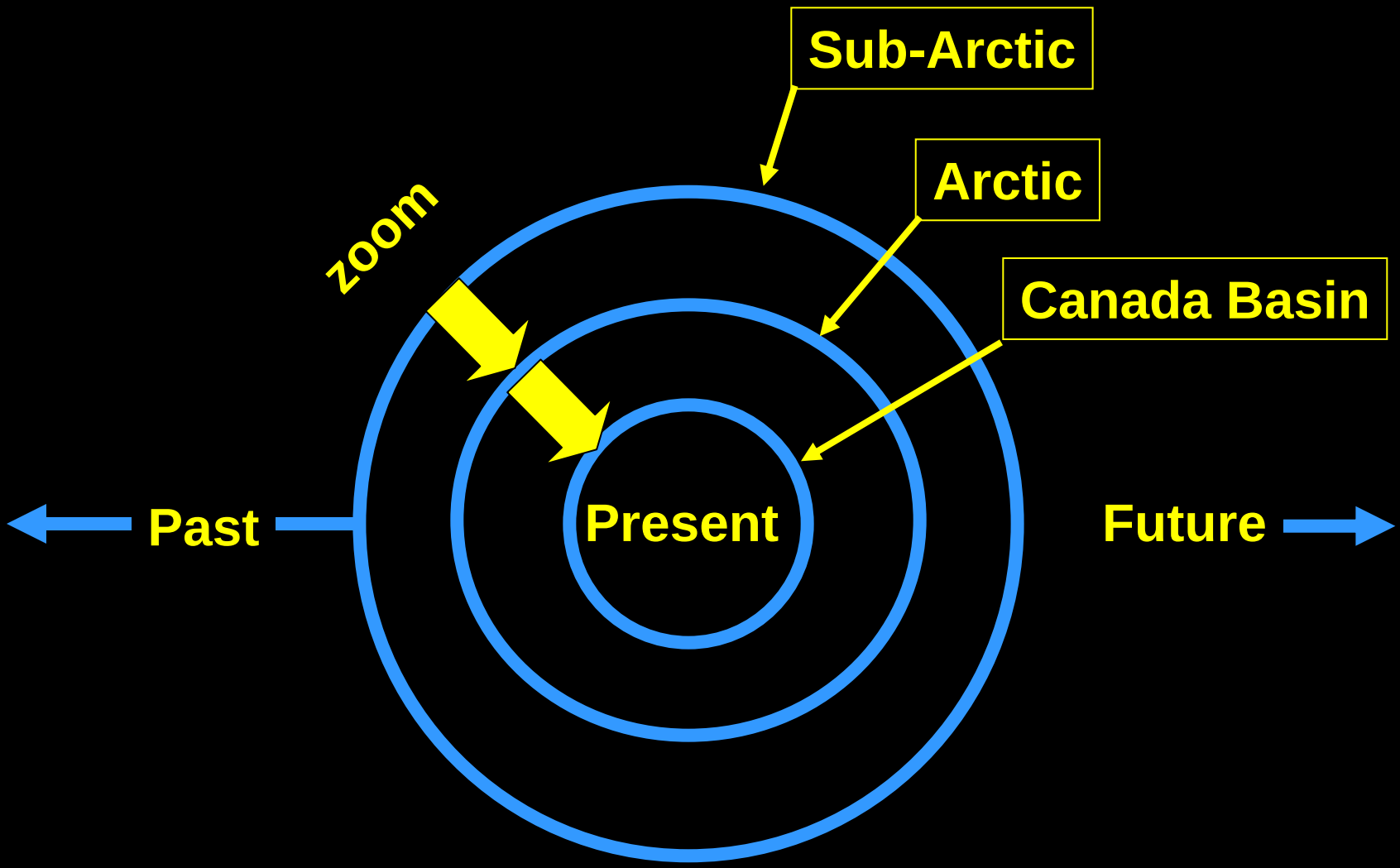


One Changing Ocean: A Northern Perspective

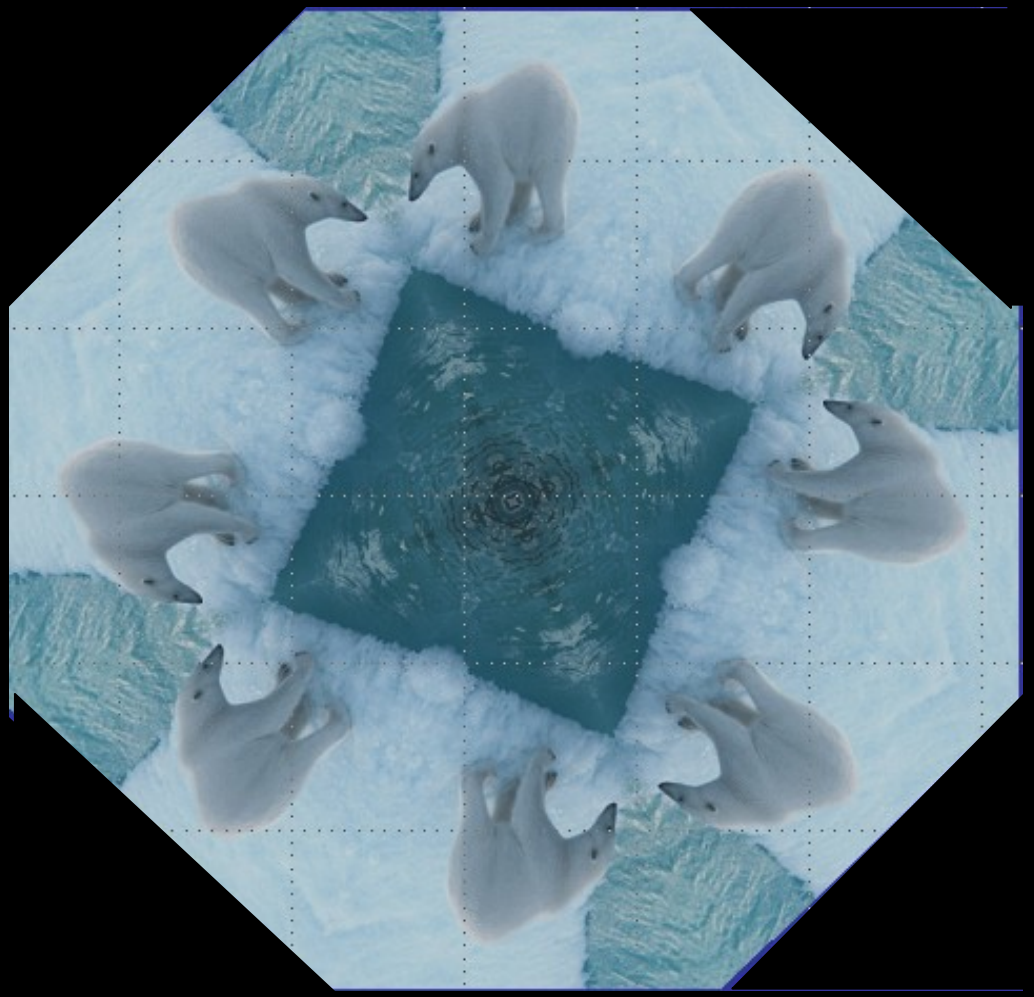
EDDY CARMACK

Fiona McLaughlin, Bill Williams, Koji Shimada, Michiyo Yamamoto-Kawai, Motoyo Itoh, Andrey Proshutinsky, Richard Krishfield, Jackie Grebmeier, Robie Macdonald, Waldek Walczowski, Sarah Zimmermann, and more ….

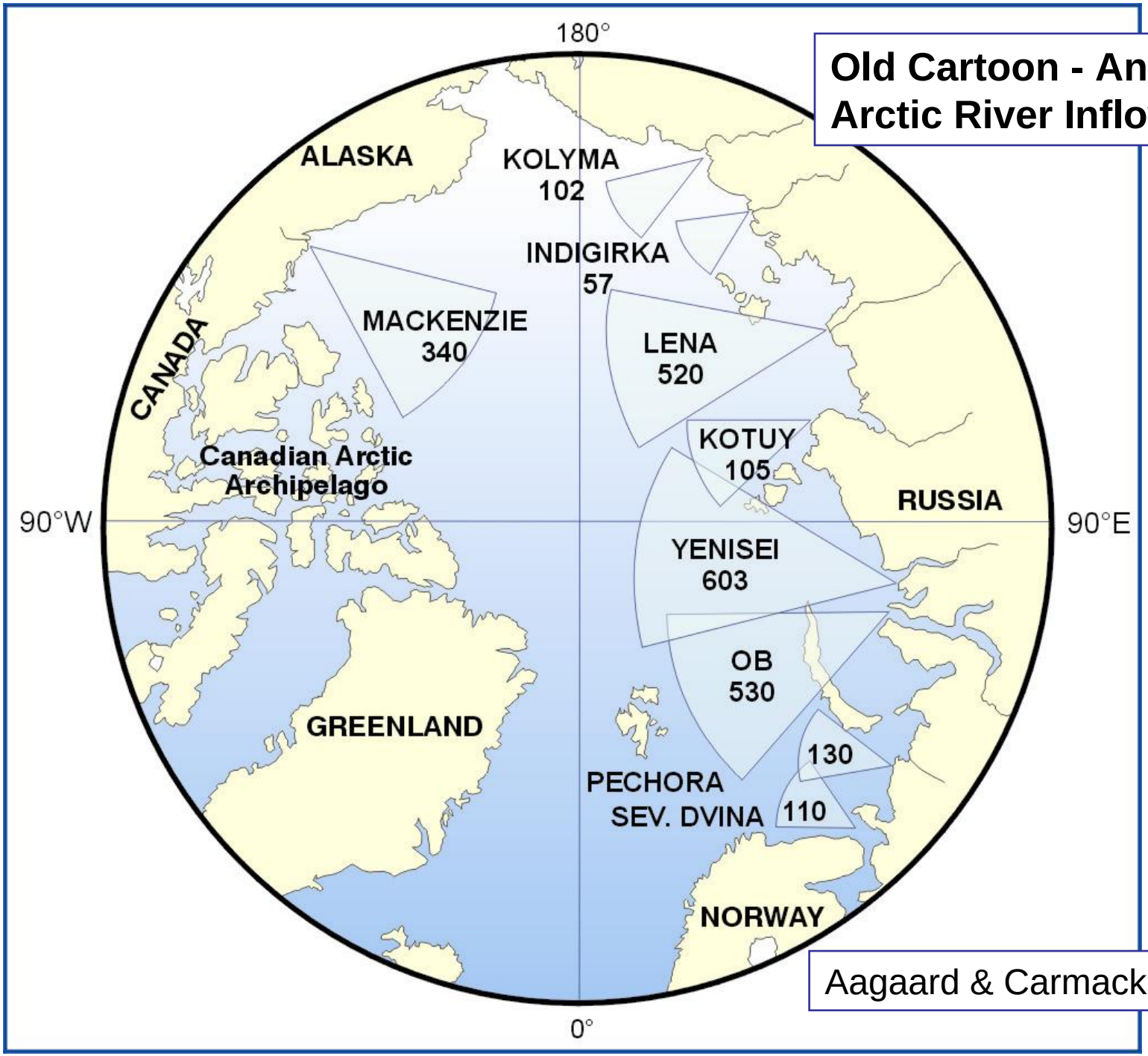


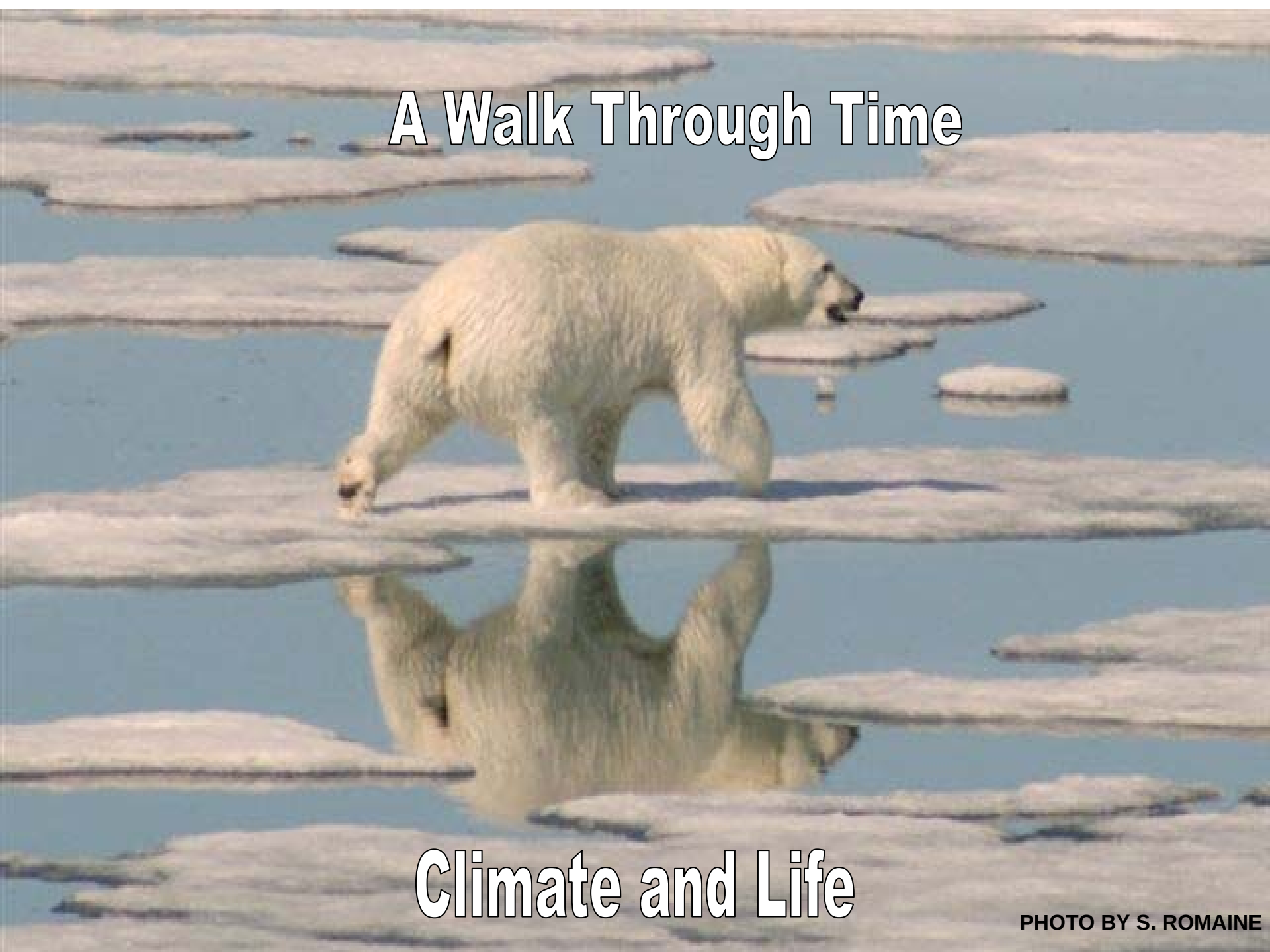
ΔPhysics = ΔBiology

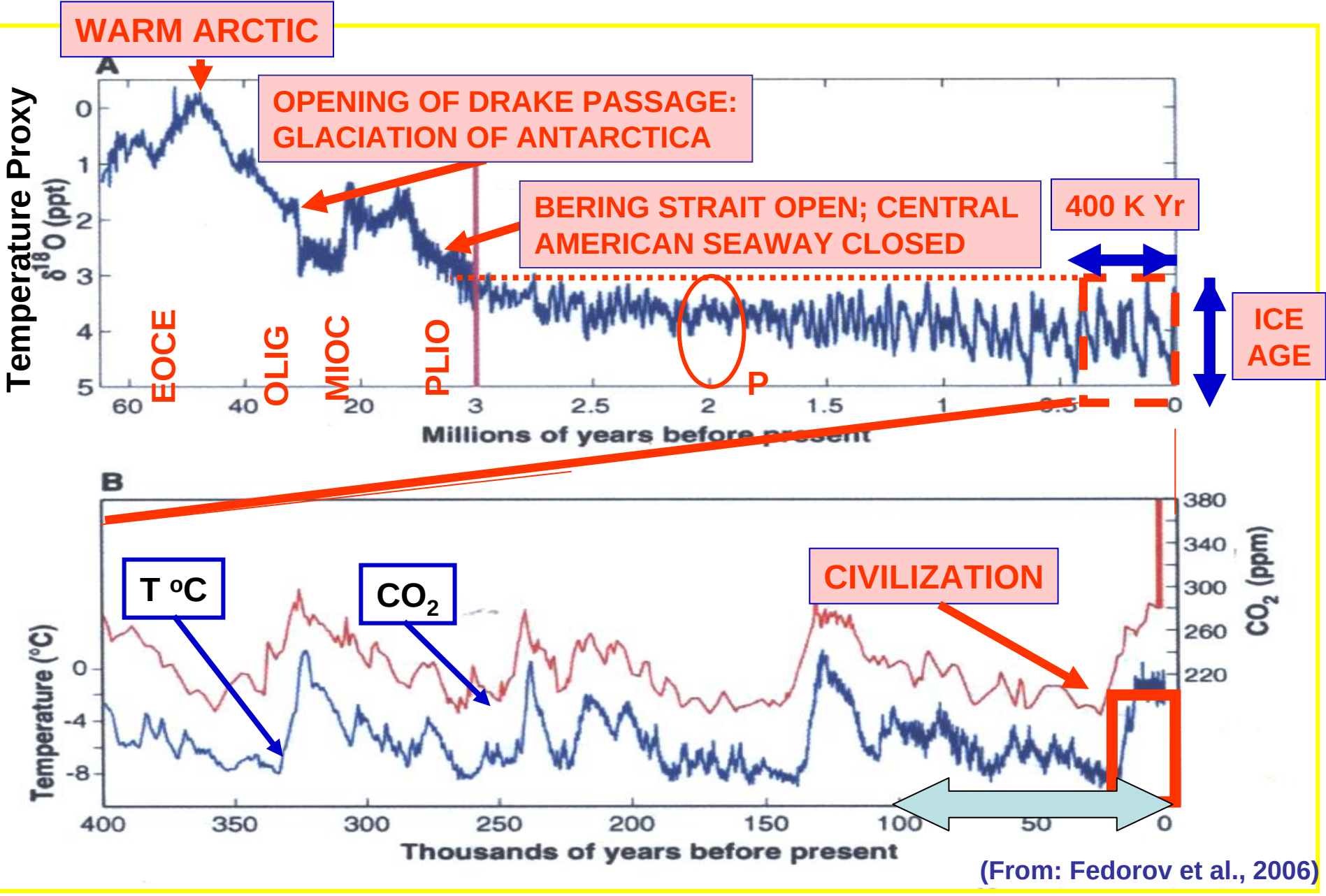
I. Climate, THC and the Hydrological Cycle



The Great Metaphor

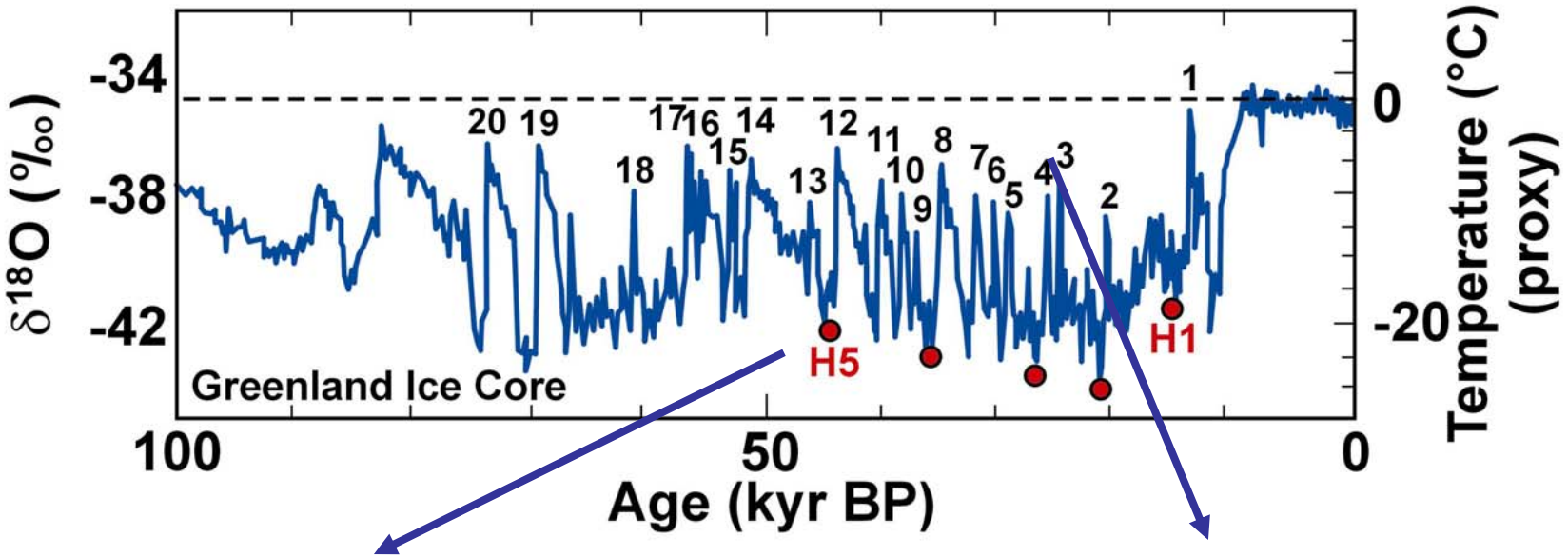

Old Cartoon - Annual Arctic River Inflows
180°
90°W
90°E
0°
ALASKA
CANADA
KOLYMA
102
INDIGIRKA
57
MACKENZIE
340
LENA
520
KOTUY
105
Canadian Arctic Archipelago
RUSSIA
YENISEI
603
OB
530
GREENLAND
130
PECHORA
SEV. DVINA
110
NORWAY
Aagaard & Carmack 1989

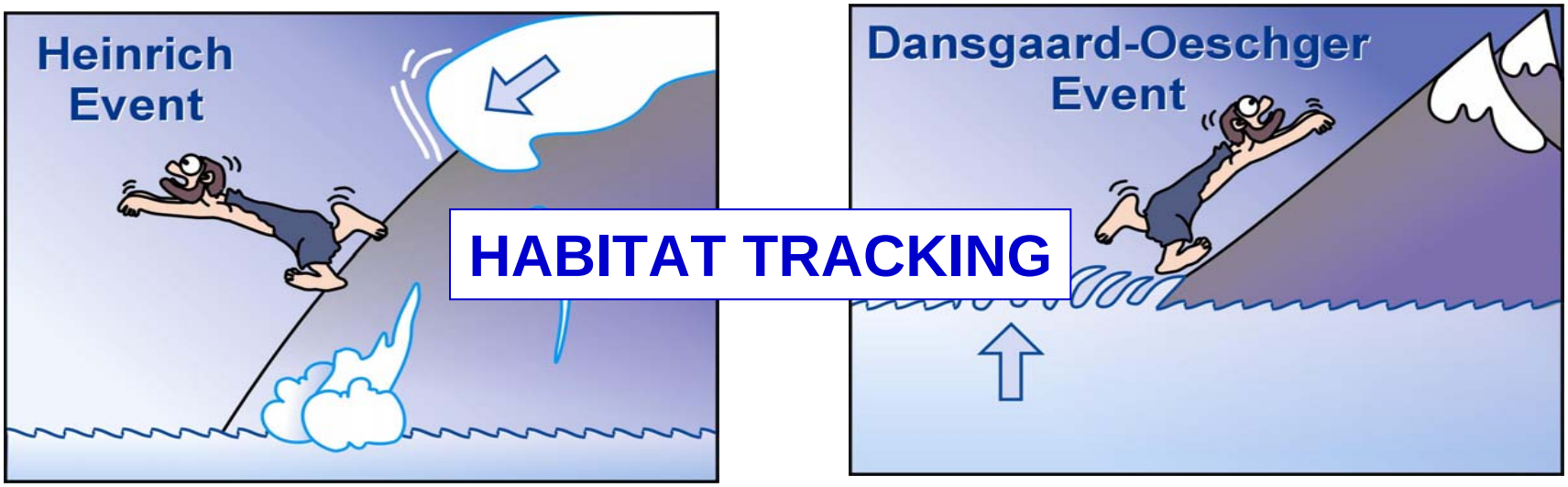

A Walk Through Time
Climate and Life
PHOTO BY S. ROMAINE



(From: Fedorov et al., 2006)

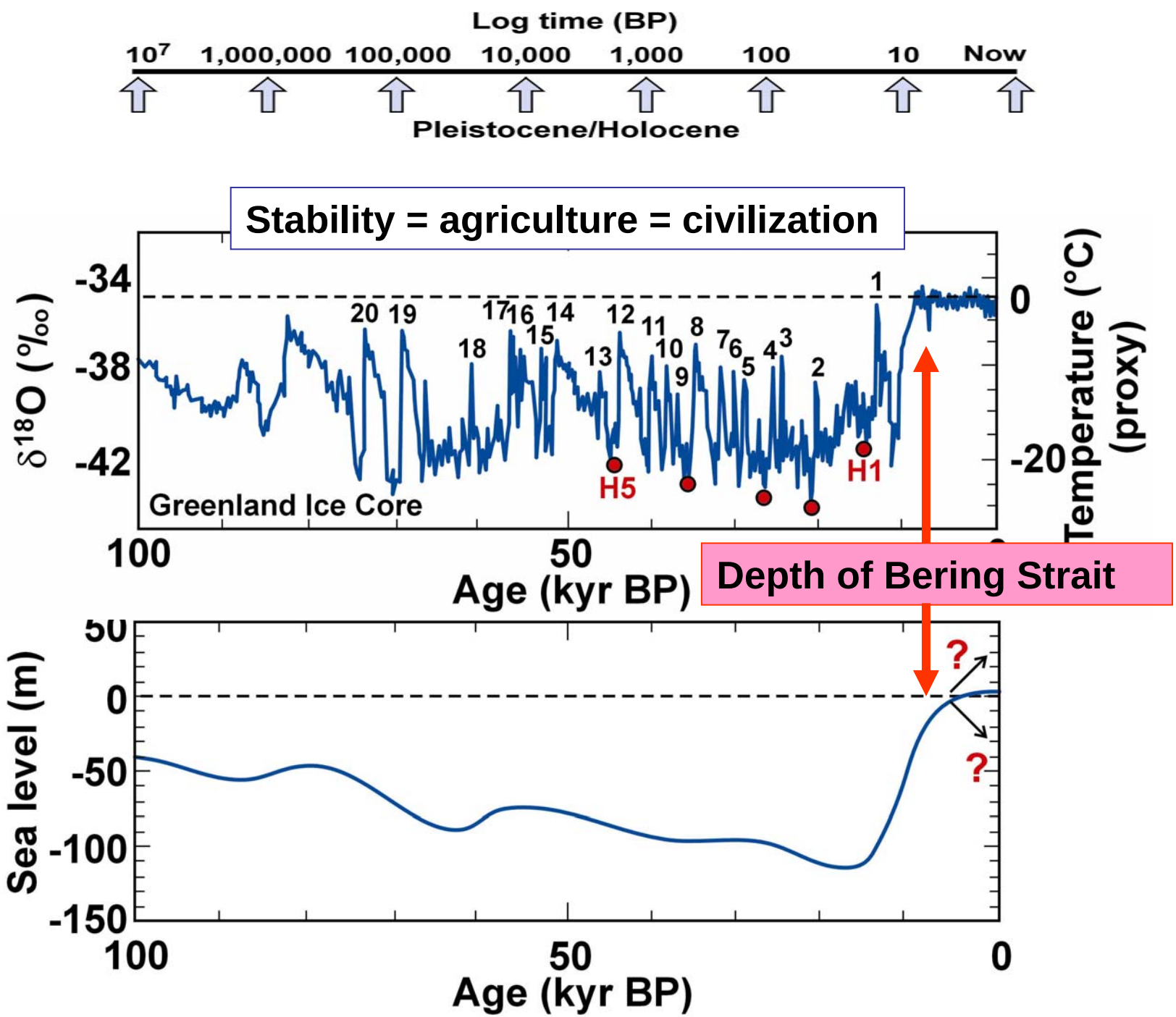
Premise: Large-scales shifts in climate alter the ecological landscape which give faunal or speciation pressures leading to genetic selection (deMenocal, 2004).

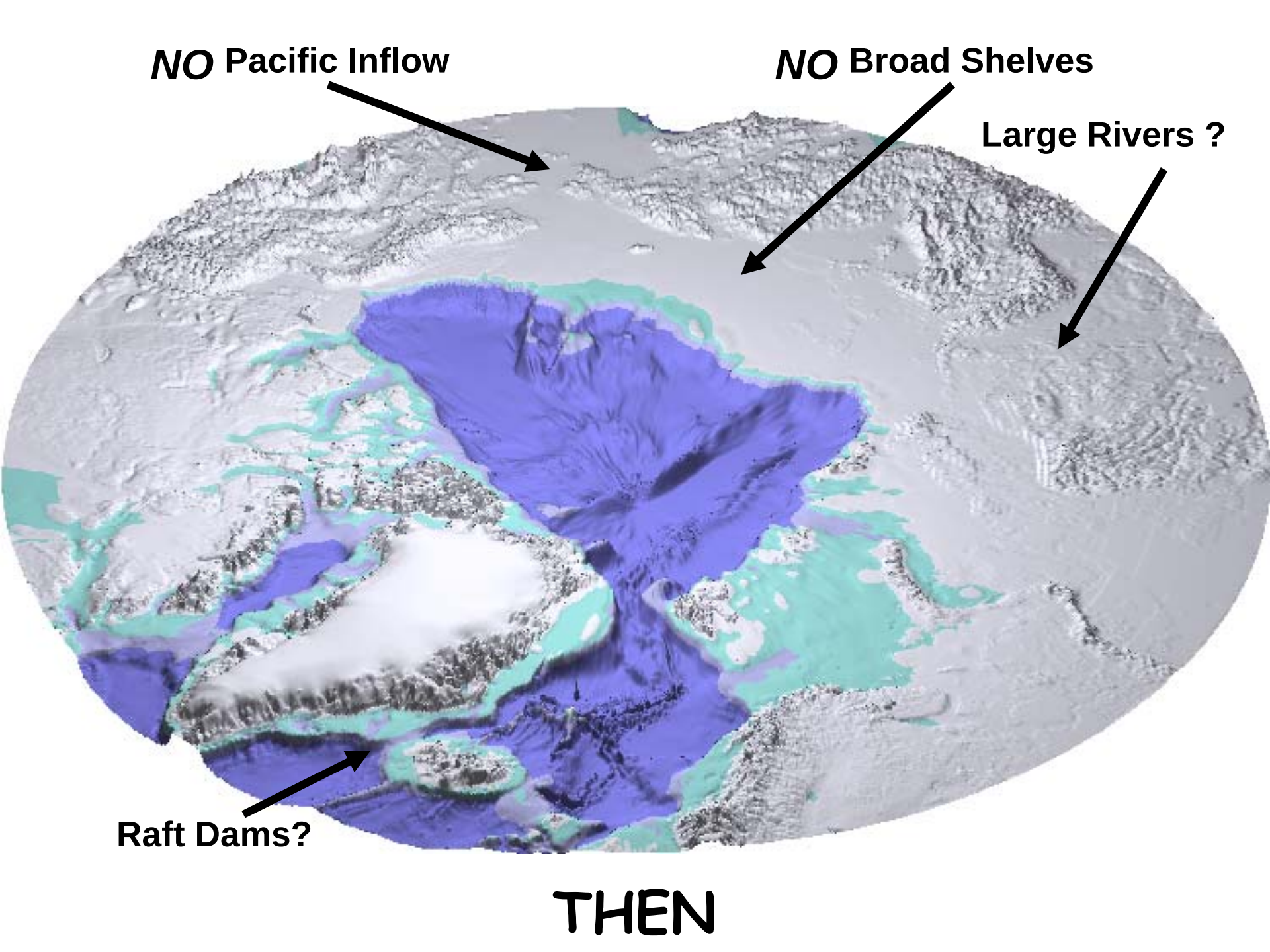


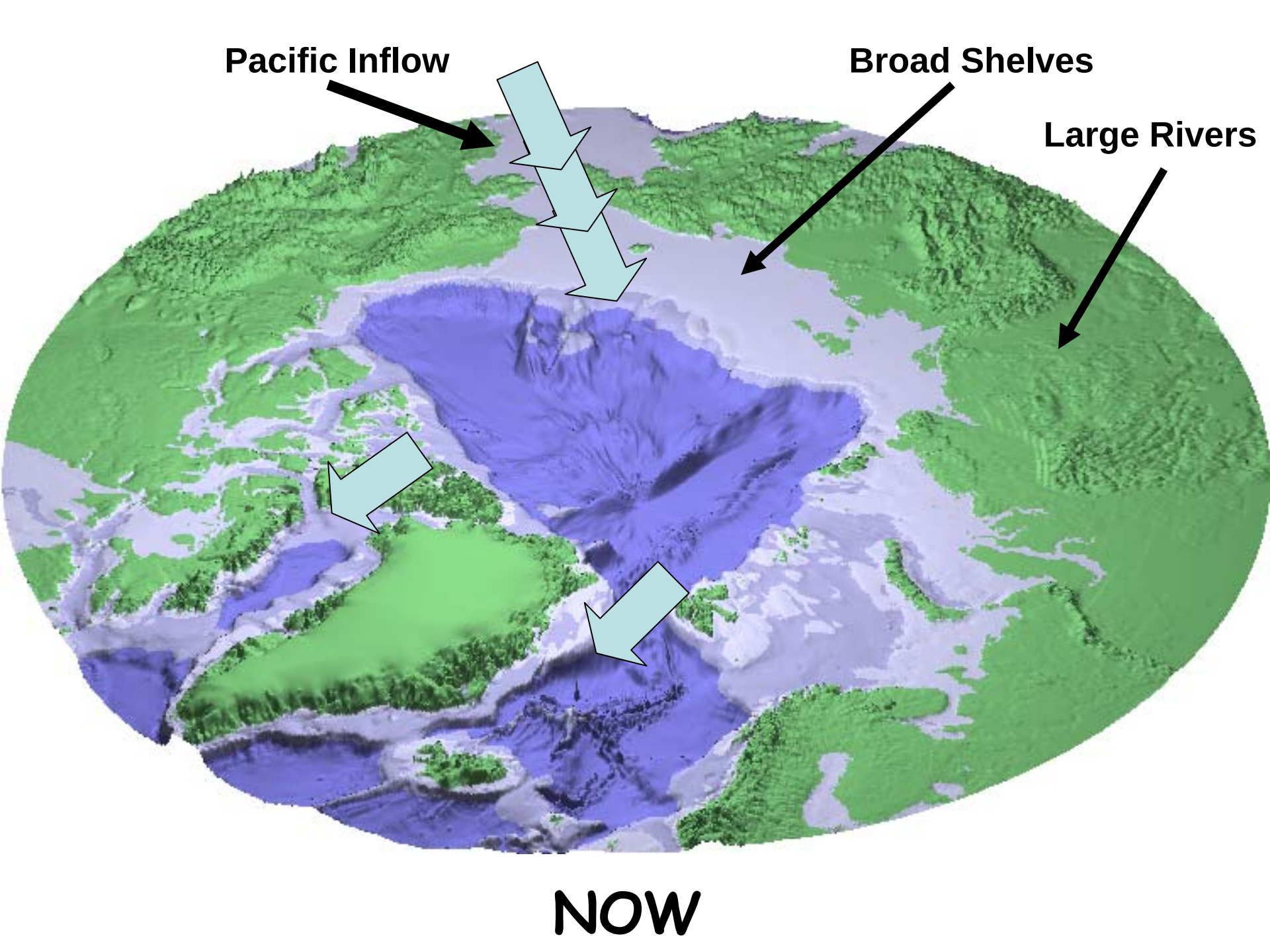


According to Michael Cook (A Brief History of the Human Race, 2004) This was a time when genus *Homo* developed

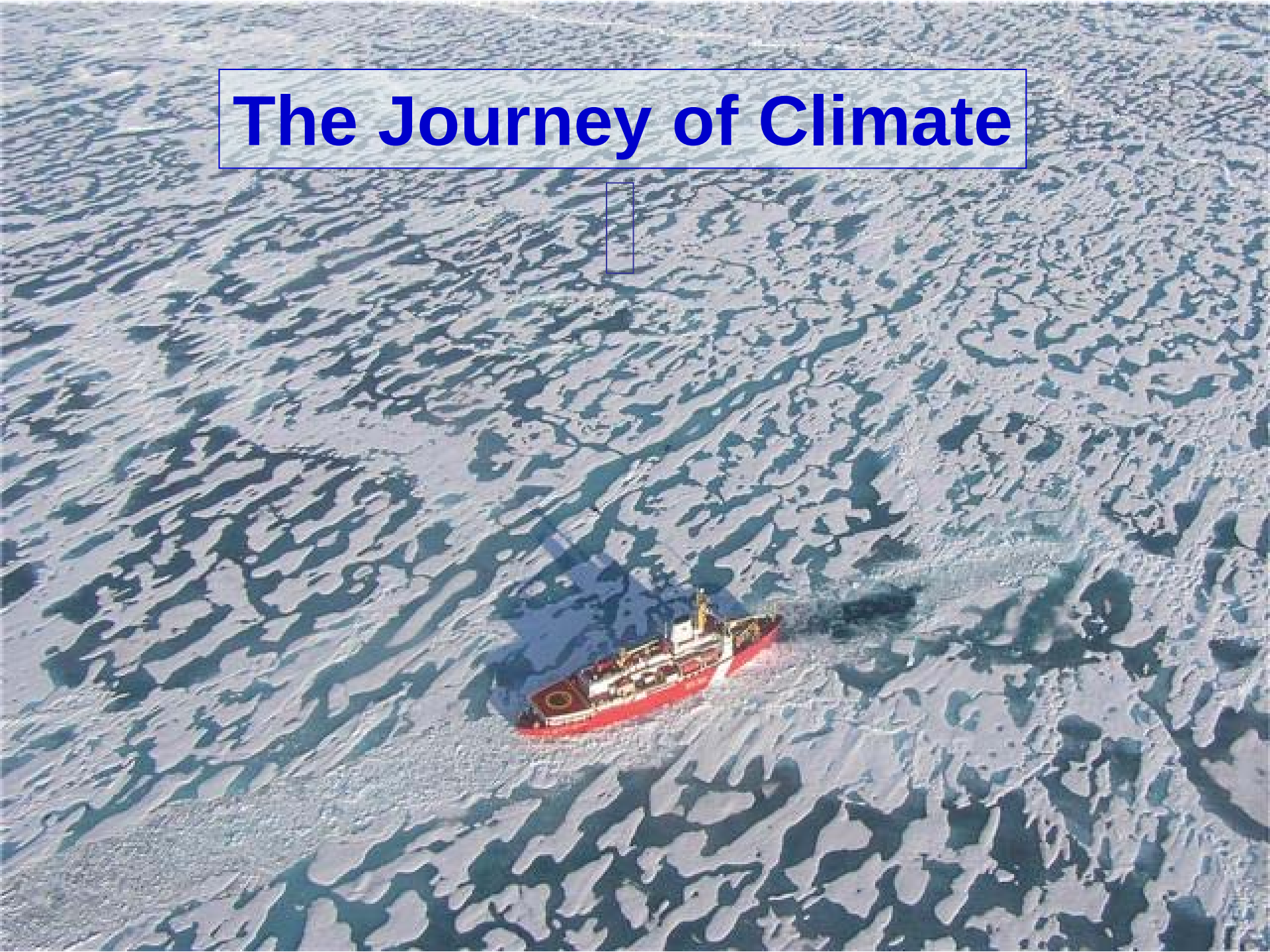
…… "cultural agility" ……

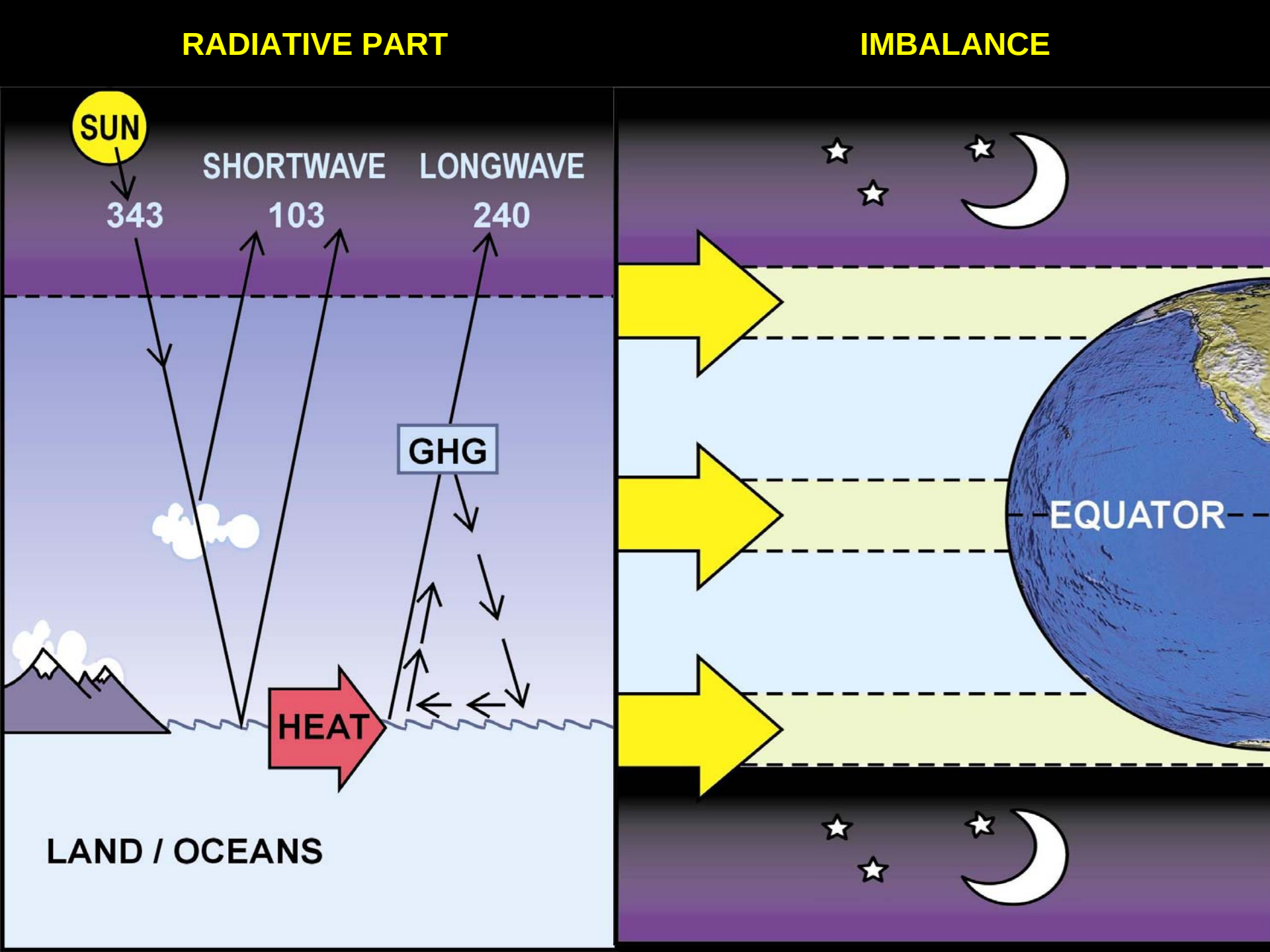

Log time (BP)
10^7
1,000,000
100,000
10,000
1,000
100
10
Now
Pleistocene/Holocene
Stability = agriculture = civilization
δ18O (‰)
-34
-38
-42
20 19
18
17 16 15 14
13
12
11 10 9
8
7 6 5
4 3
2
1
H5
H1
Greenland Ice Core
0
-20
Temperature (°C)
(proxy)
100
50
Age (kyr BP)
Depth of Bering Strait
Sea level (m)
50
0
-50
-100
-150
?
?
100
50
0
Age (kyr BP)

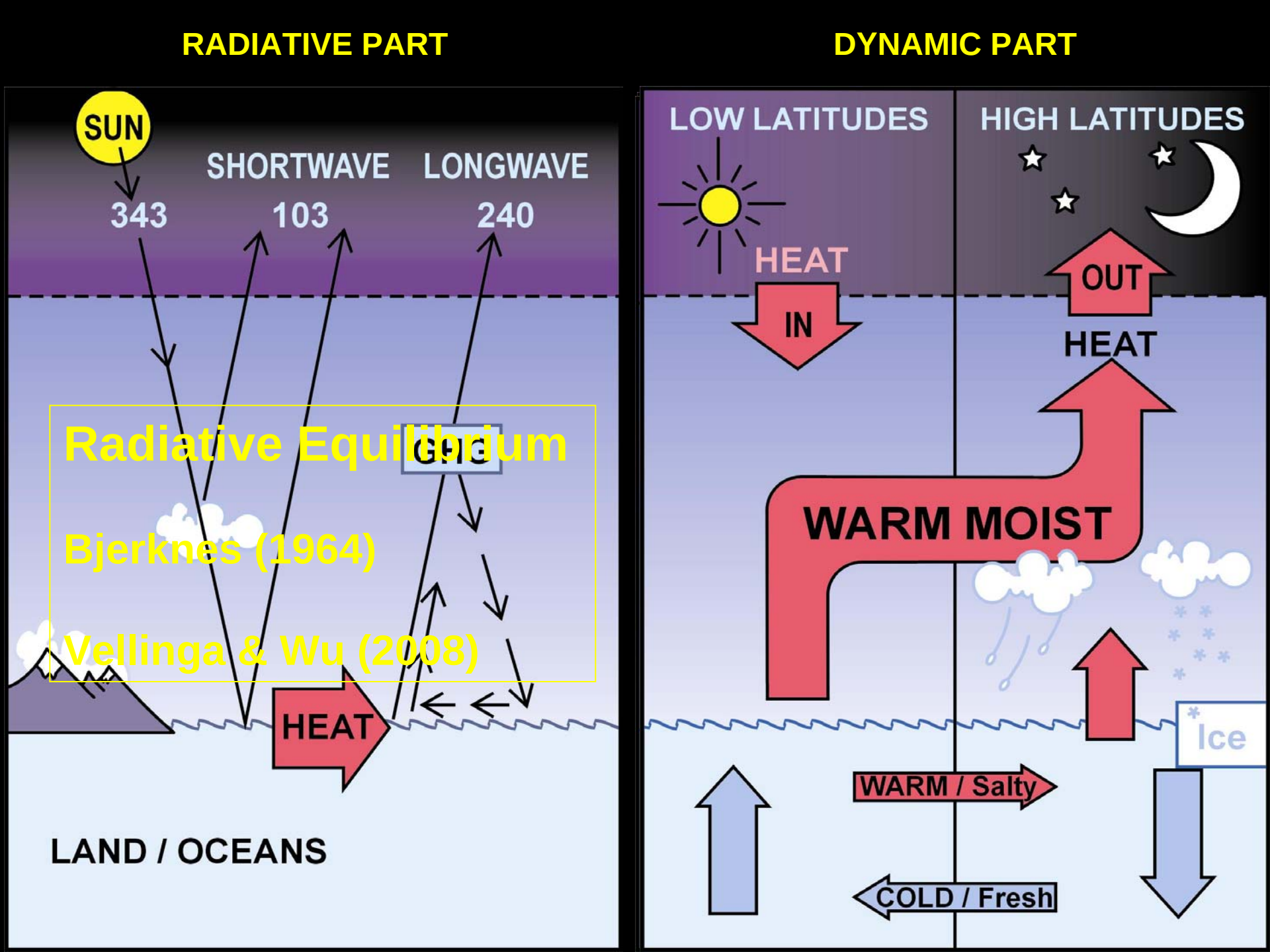

NO Pacific Inflow
NO Broad Shelves
Large Rivers ?
Raft Dams?
THEN


Pacific Inflow
Broad Shelves
Large Rivers
NOW

The Journey of Climate




RADIATIVE PART
IMBALANCE
SUN
SHORTWAVE
LONGWAVE
343
103
240
GHG
HEAT
LAND / OCEANS
EQUATOR


RADIATIVE PART
DYNAMIC PART
SUN
343
SHORTWAVE
103
LONGWAVE
240
GHG
HEAT
LAND / OCEANS
Radiative Equilibrium
Bjerknes (1964)
Vellinga & Wu (2008)
LOW LATITUDES
HIGH LATITUDES
HEAT
IN
OUT
HEAT
WARM MOIST
Ice
WARM / Salty
COLD / Fresh

JOB DONE!

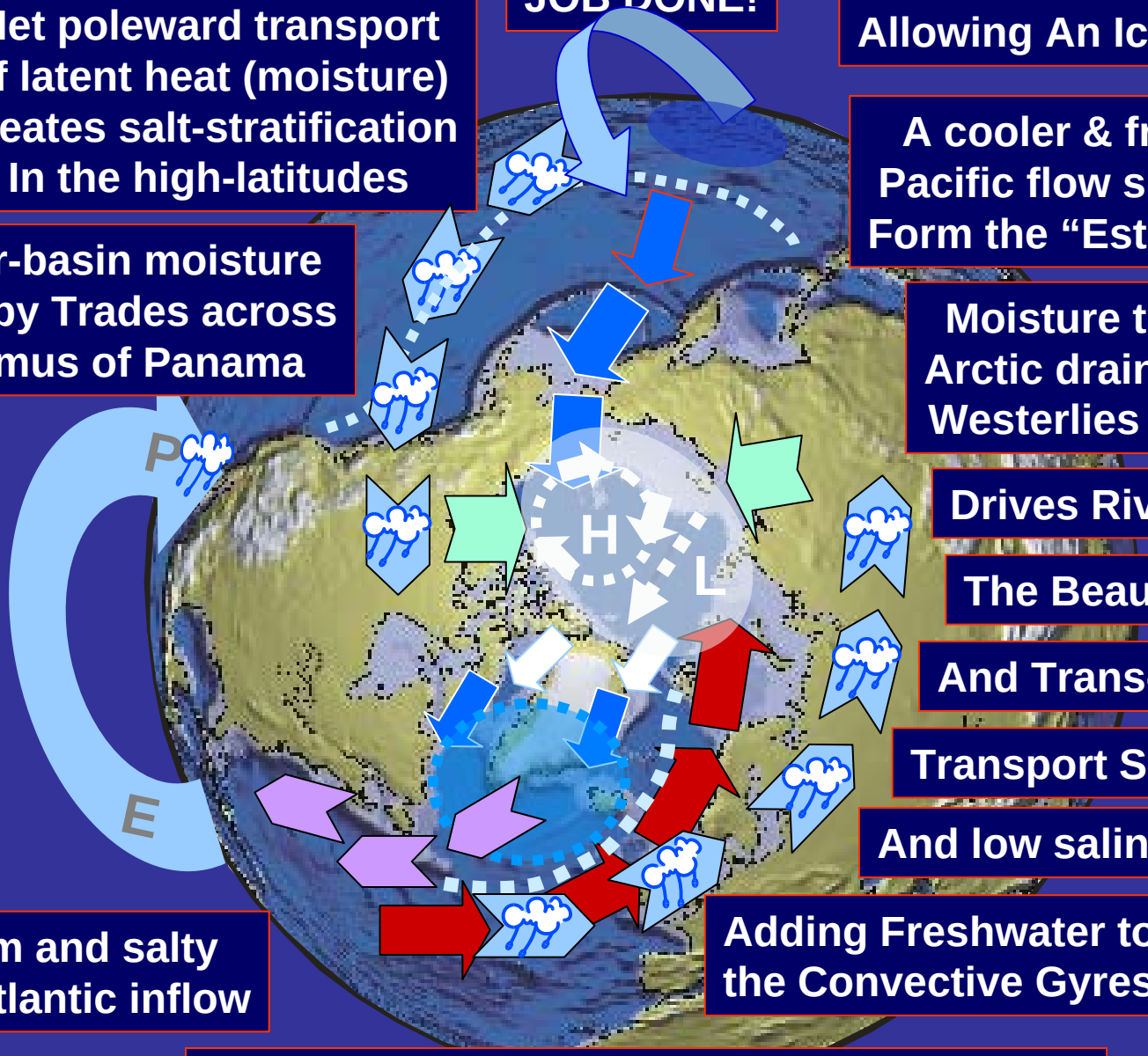
Net poleward transport of latent heat (moisture) creates salt-stratification In the high-latitudes

Allowing An Ice Cover

A cooler & fresher North Pacific flow s ‘downhill’ to Form the “Estuarine Arctic”

Net inter-basin moisture transfer by Trades across the Isthmus of Panama

Moisture transfer to the Arctic drainage basins by Westerlies (storm tracks)



Drives River Discharge

The Beaufort Gyre

And Trans-Polar Drift

Transport Sea Ice

And low salinity water

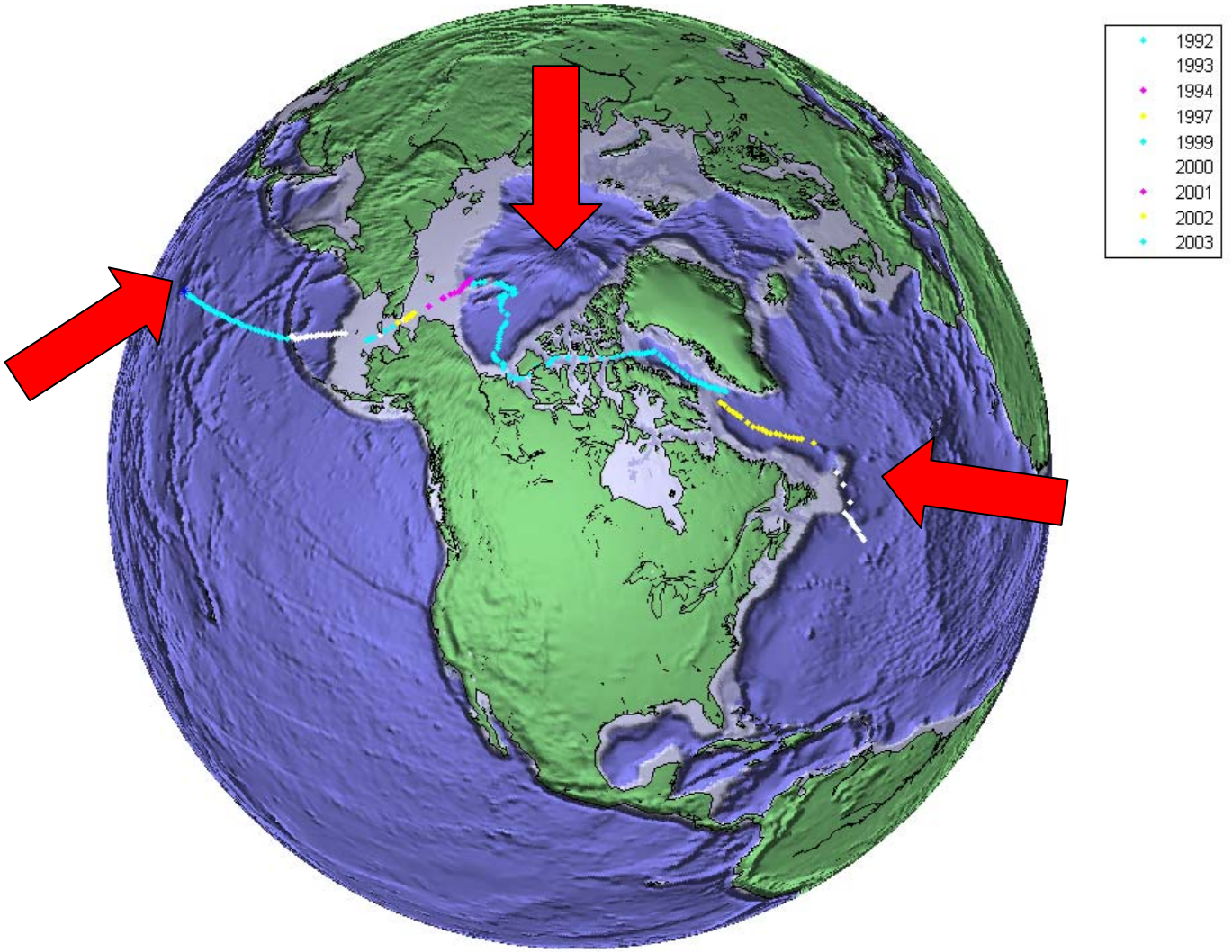
A warm and salty North Atlantic inflow

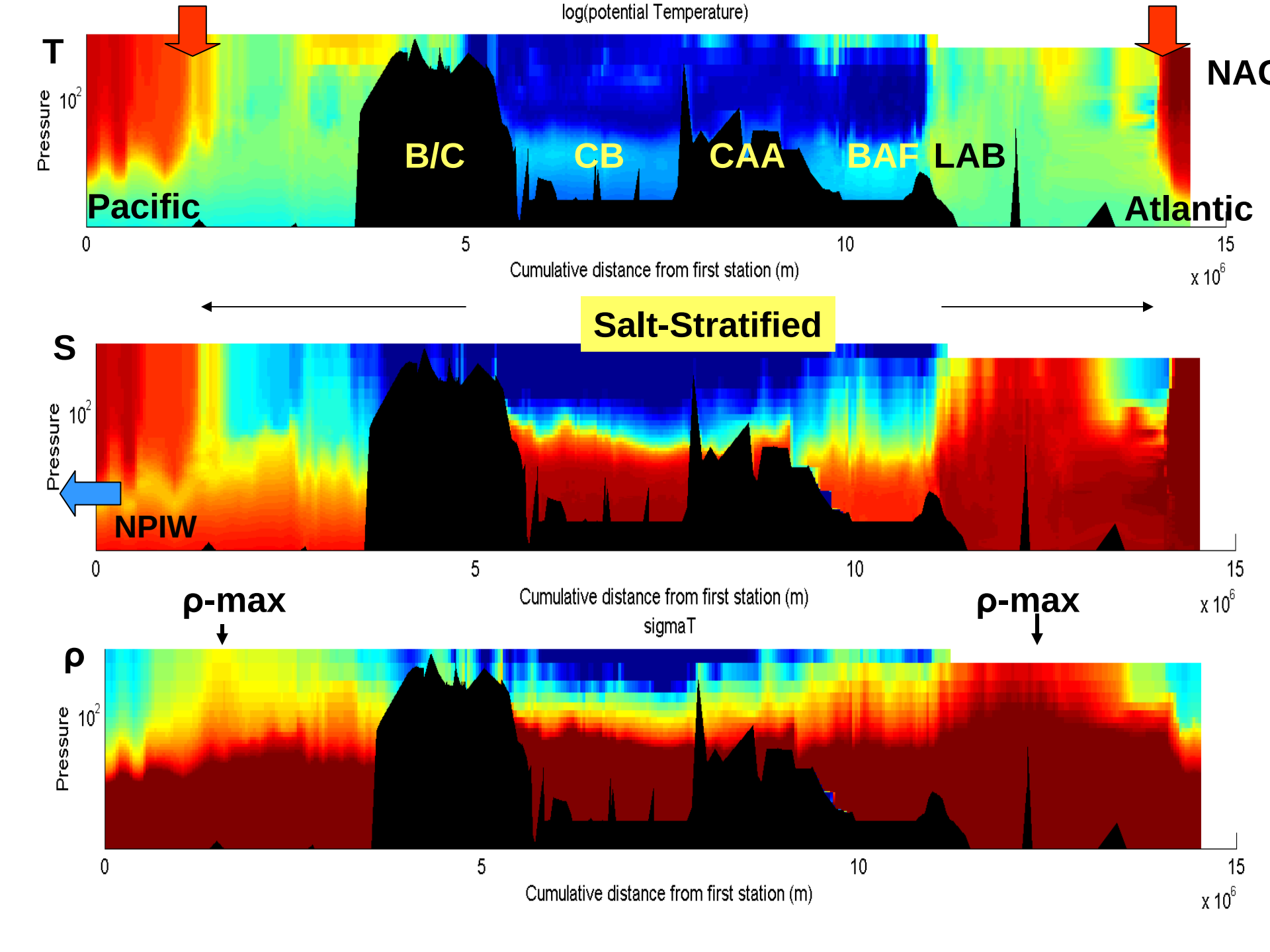
Adding Freshwater to the Convective Gyres …

Thus affecting the Thermohaline Circulation

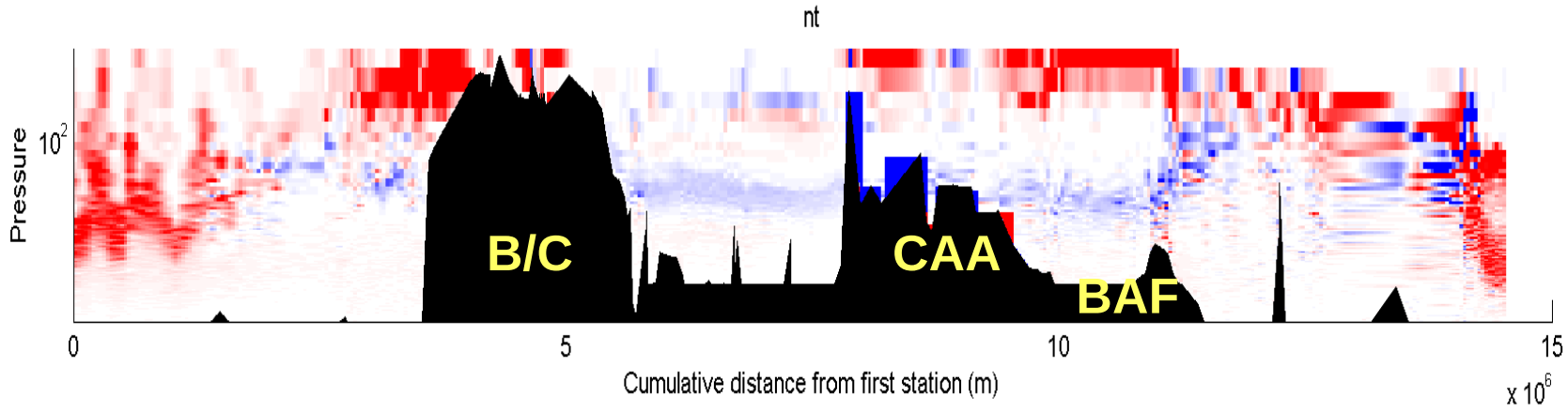
THE JOB: TO GET HEAT FROM THE LOW TO THE HIGH LATITUDES

Around Canada

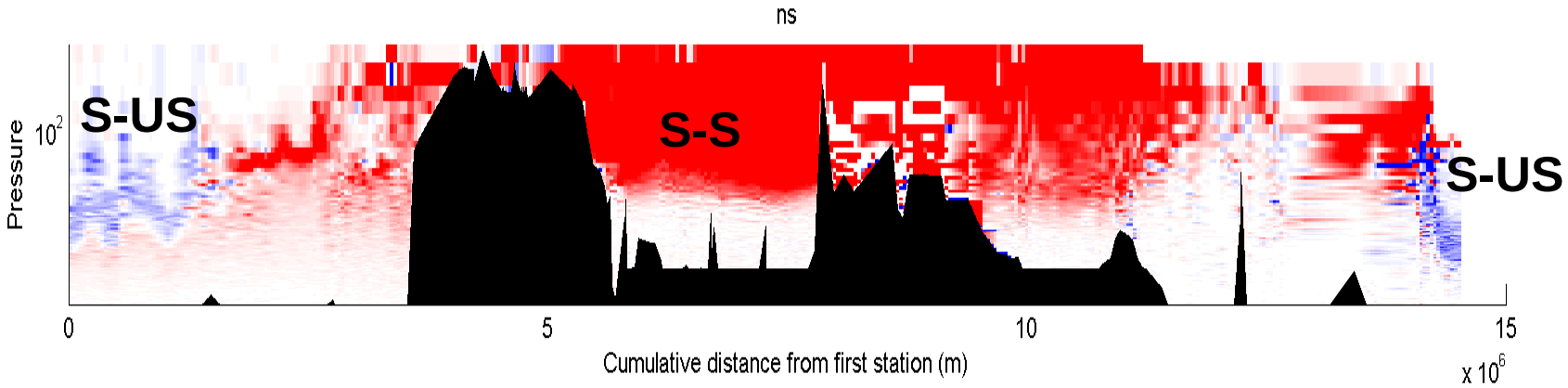



log(potential Temperature)
T
Pressure
10^2
B/C
CB
CAA
BAF
LAB
Pacific
Atlantic
NAC
0
5
10
15
Cumulative distance from first station (m)
x 10^6
Salt-Stratified
S
Pressure
10^2
NPIW
0
5
10
15
Cumulative distance from first station (m)
x 10^6
ρ-max
ρ-max
sigmaT
ρ
Pressure
10^2
0
5
10
15
Cumulative distance from first station (m)
x 10^6

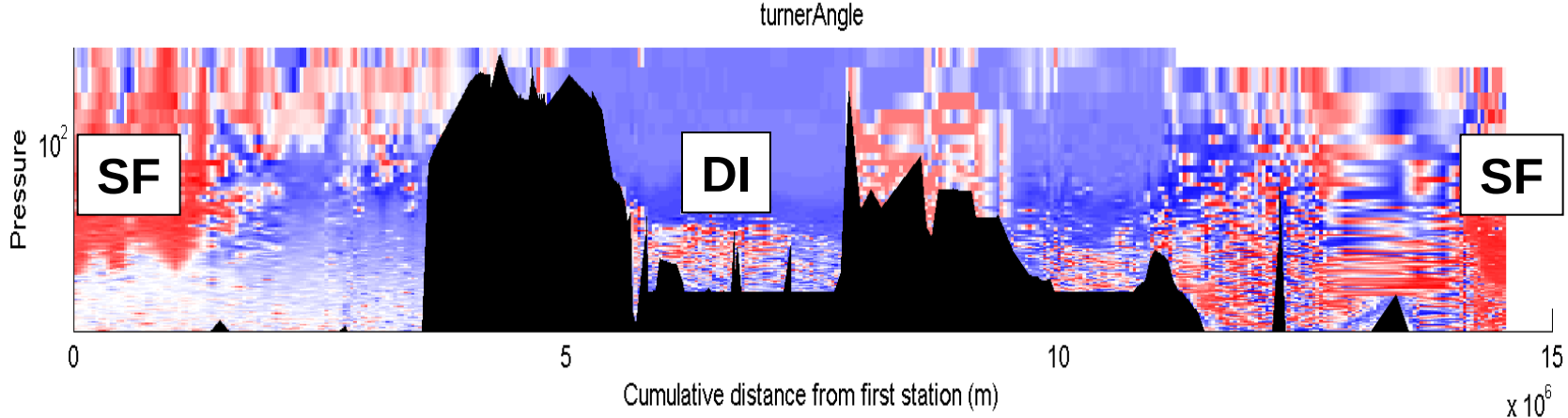
N_T^2

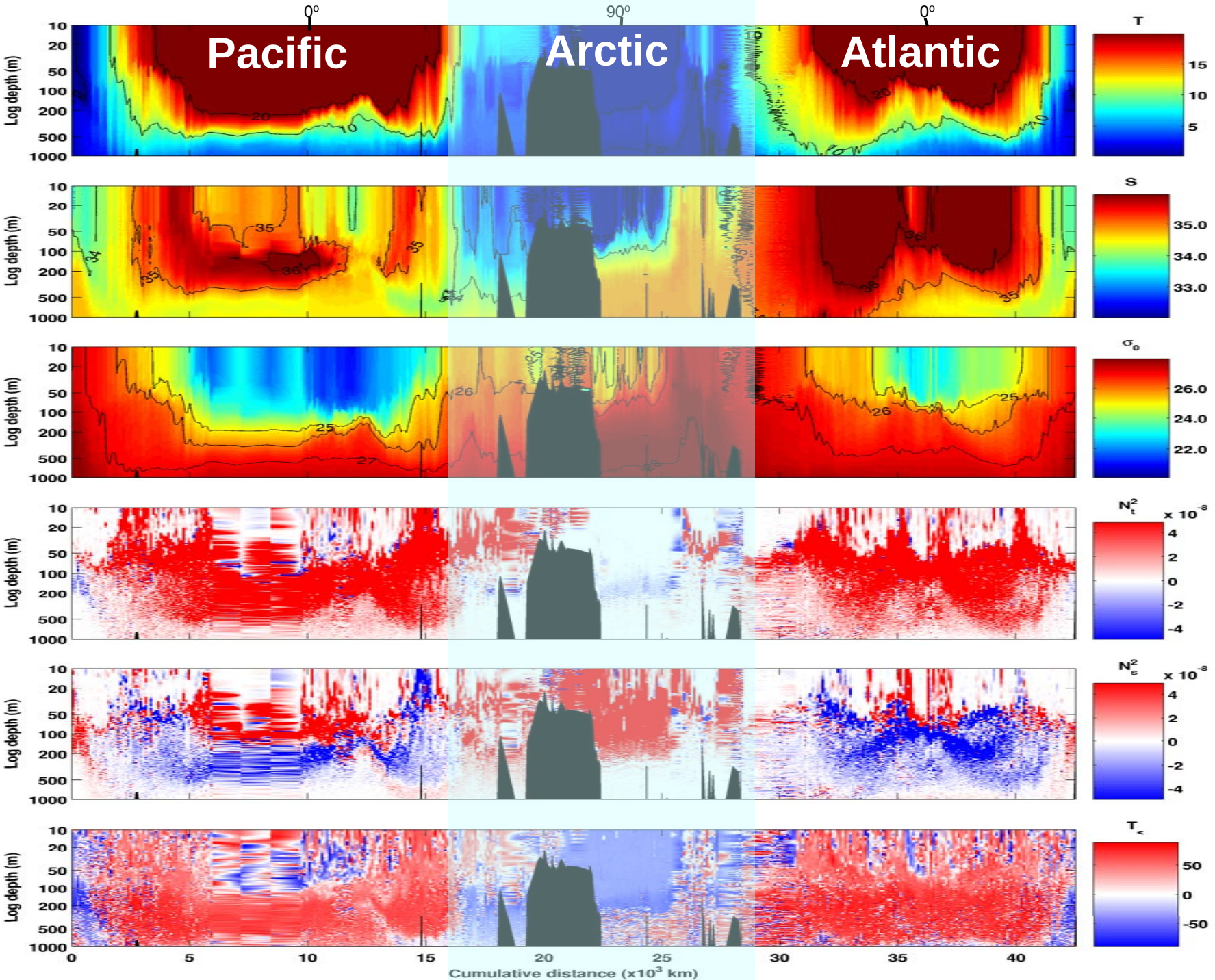

nt
Pressure
10^2
B/C
CAA
BAF
0
5
10
15
Cumulative distance from first station (m)
x 10^6

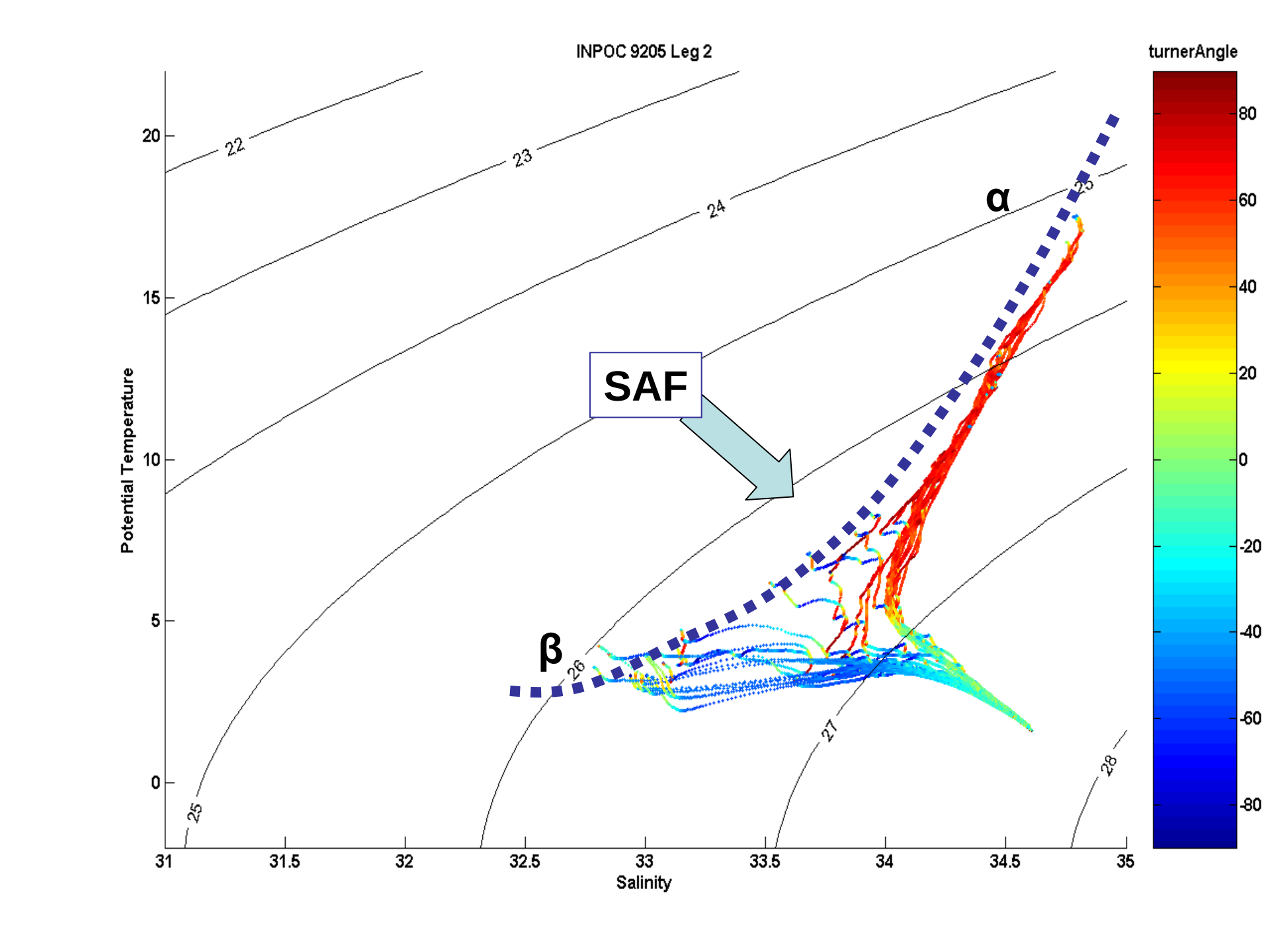
N_S^2

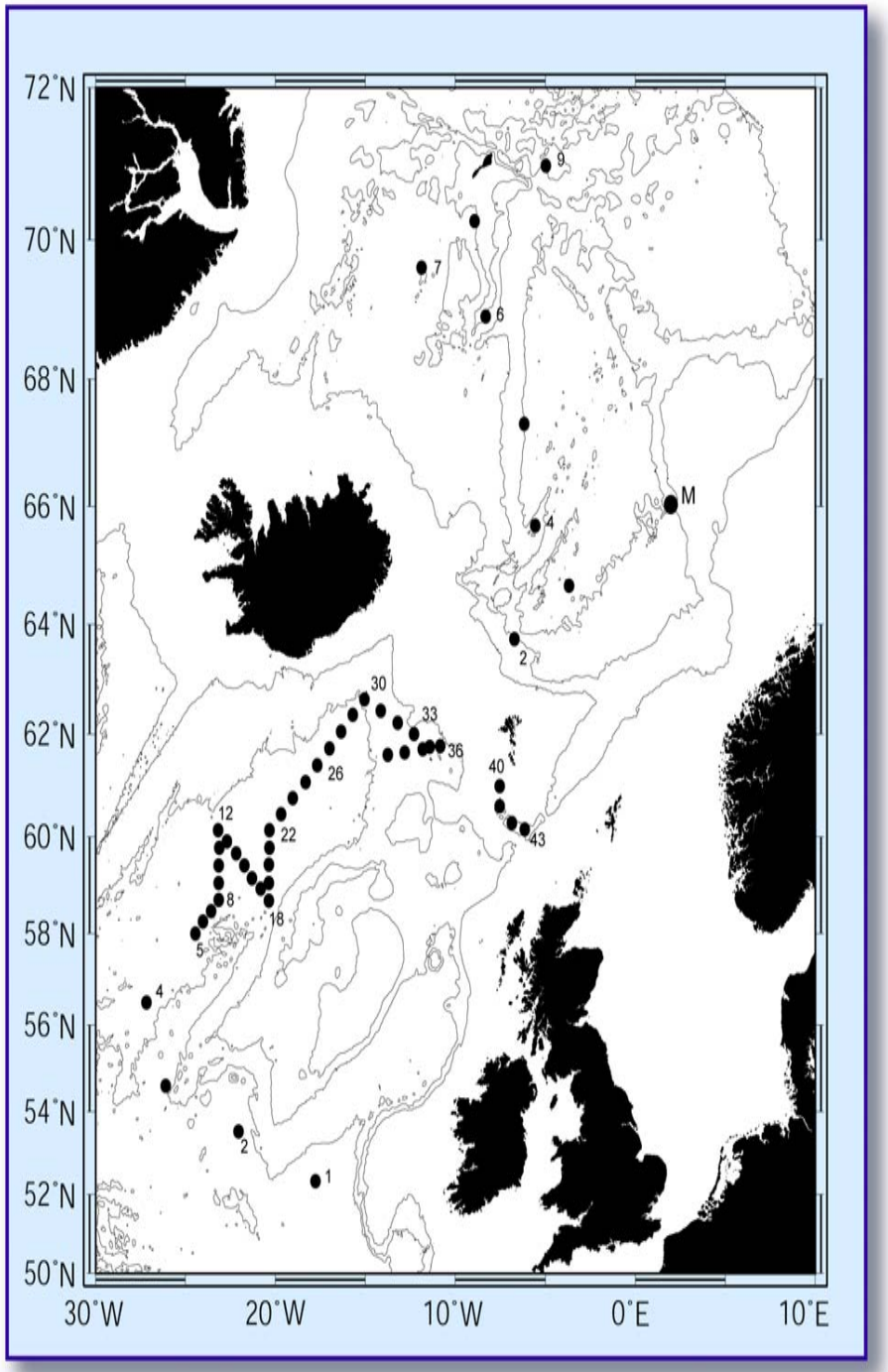

ns
Pressure
10^2
S-US
S-S
S-US
0
5
10
15
Cumulative distance from first station (m)
x 10^6

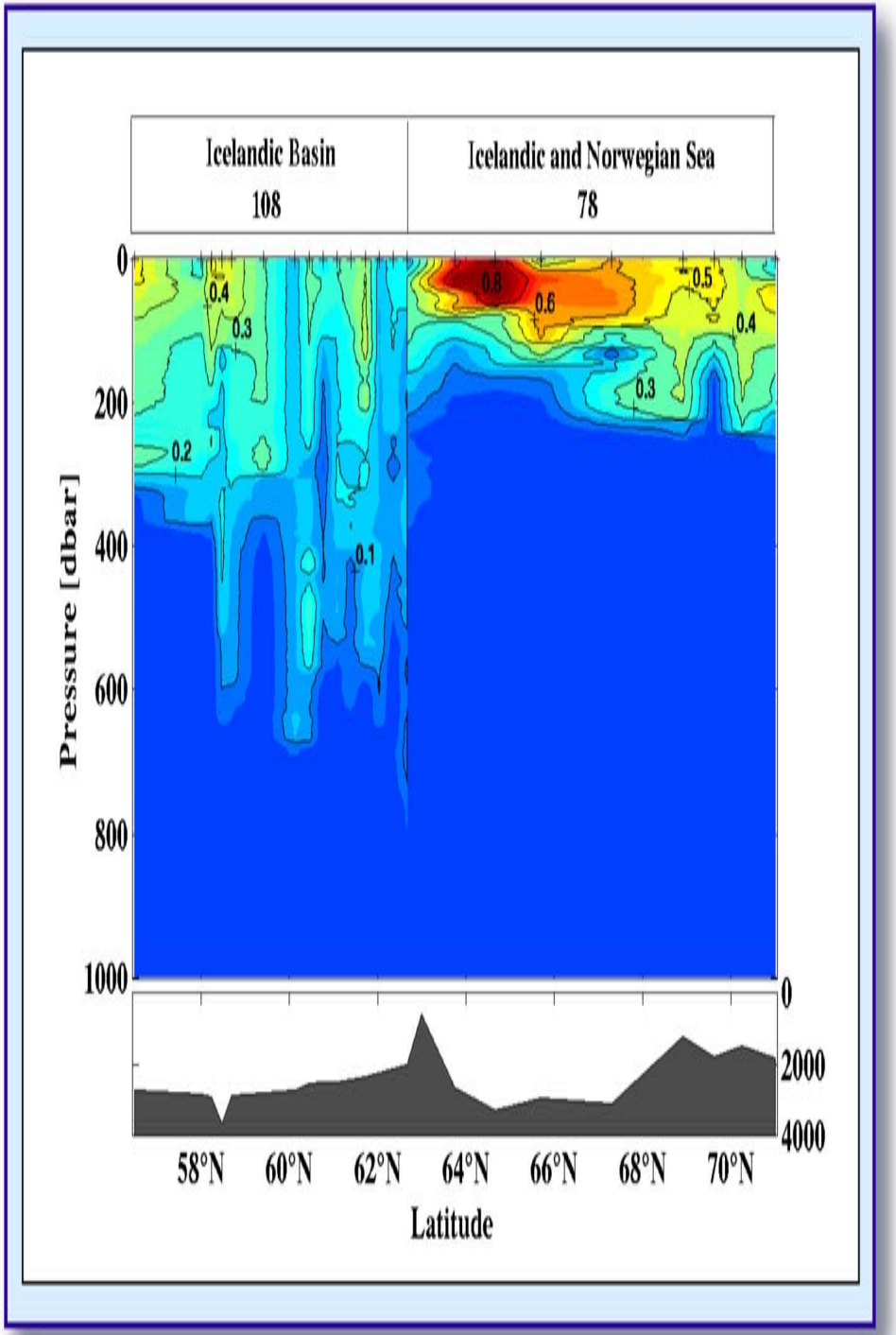
Tu

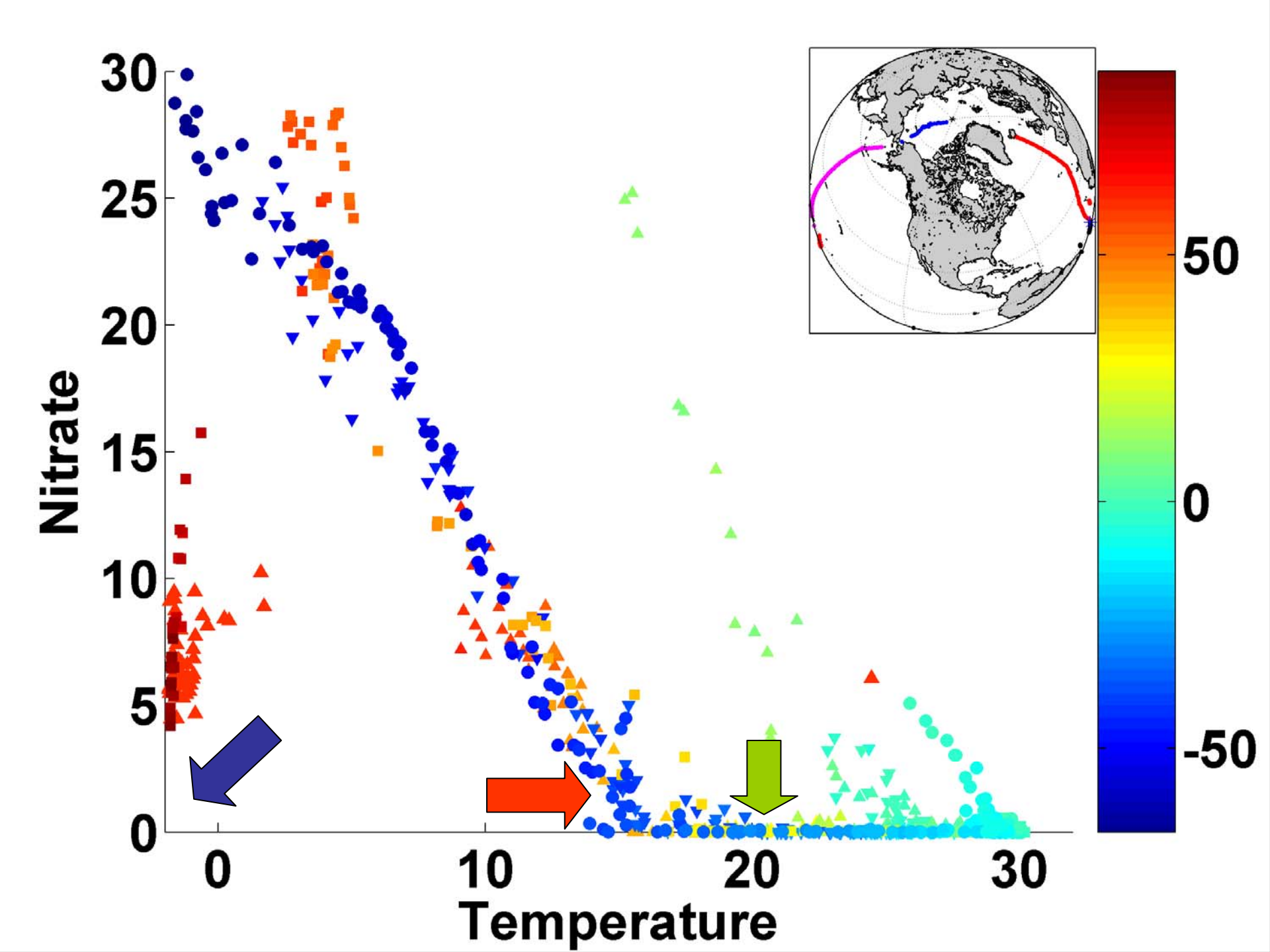

turnerAngle
Pressure
10^2
SF
DI
SF
0
5
10
15
Cumulative distance from first station (m)
x 10^6

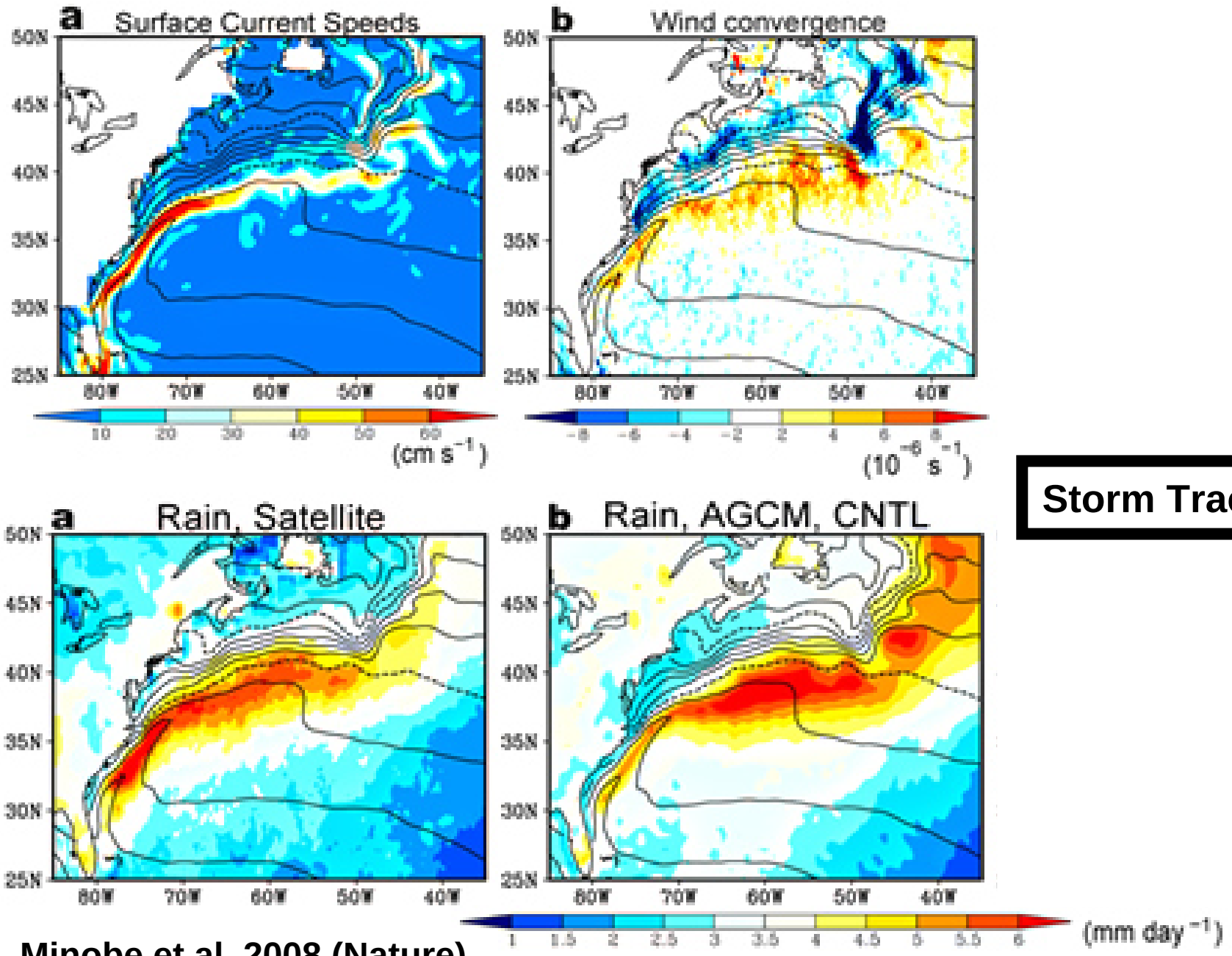

0°
90°
0°
Pacific
Arctic
Atlantic
Log depth (m)
10
20
50
100
200
500
1000
T
S
σ_0
N_t^2
N_s^2
$T_<$
x 10^{-8}
Cumulative distance (x10^3 km)
0
5
10
15
20
25
30
35
40


INPOC 9205 Leg 2
turnerAngle
Potential Temperature
Salinity
SAF
α
β
22
23
24
25
26
27
28
20
15
10
5
0
31
31.5
32
32.5
33
33.5
34
34.5
35
80
60
40
20
0
-20
-40
-60
-80


72°N
70°N
68°N
66°N
64°N
62°N
60°N
58°N
56°N
54°N
52°N
50°N
30°W
20°W
10°W
0°E
10°E
M

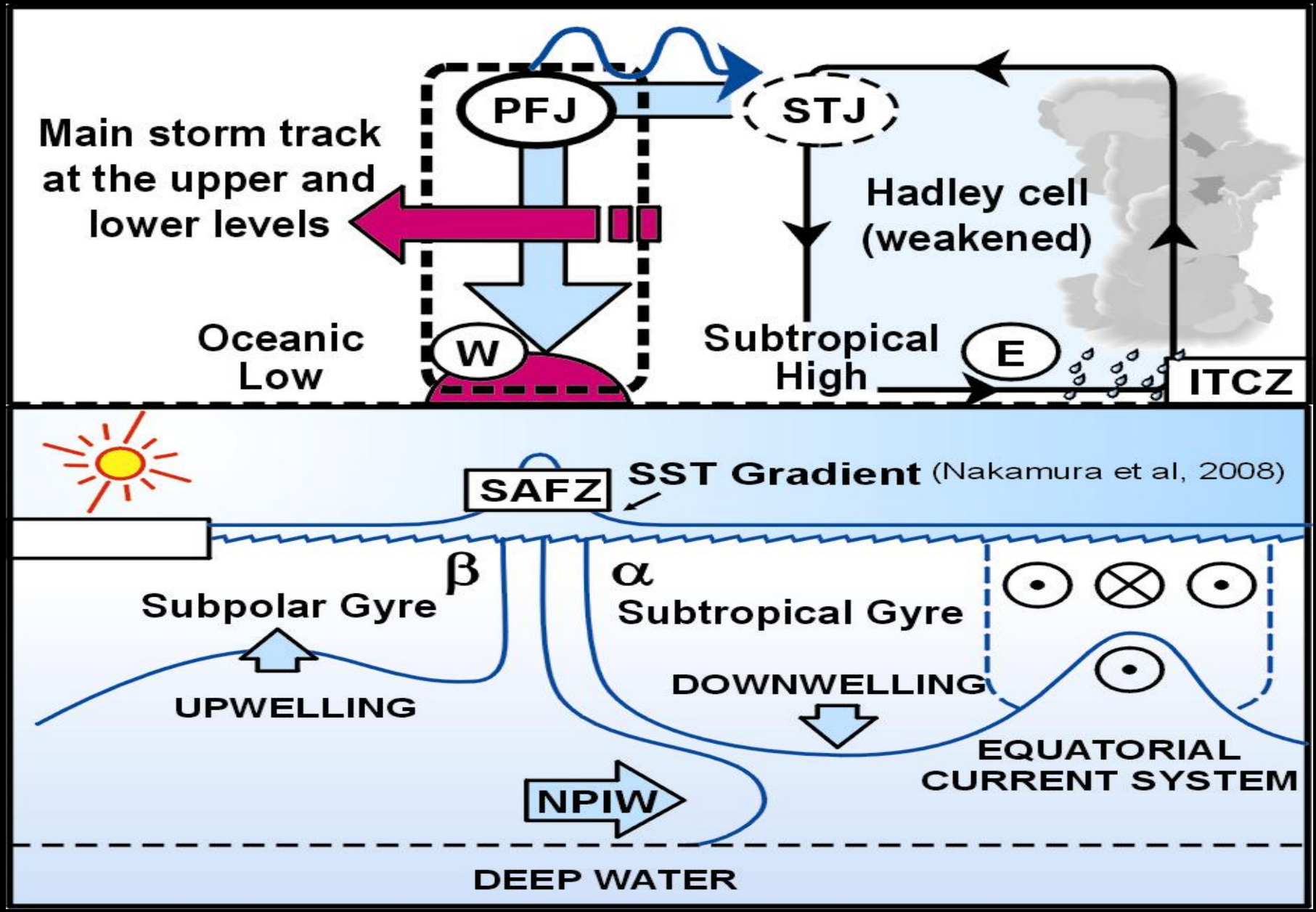

Icelandic Basin
108
Icelandic and Norwegian Sea
78
Pressure [dbar]
0
200
400
600
800
1000
0.8
0.6
0.5
0.4
0.3
0.2
0.1
0
2000
4000
58°N
60°N
62°N
64°N
66°N
68°N
70°N
Latitude


30
25
20
15
10
5
0
Nitrate
0
10
20
30
Temperature
50
0
-50

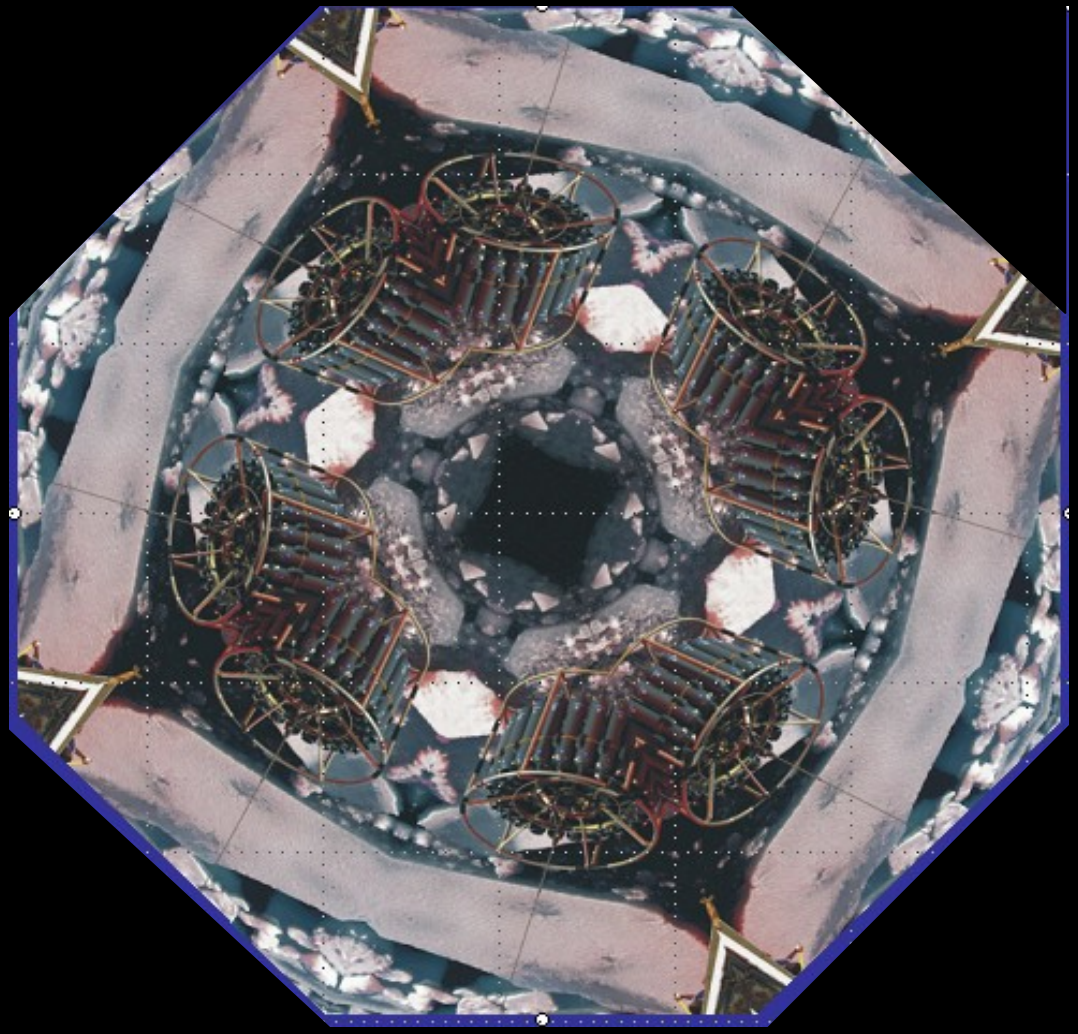


Storm Tracks

Minobe et al. 2008 (Nature)

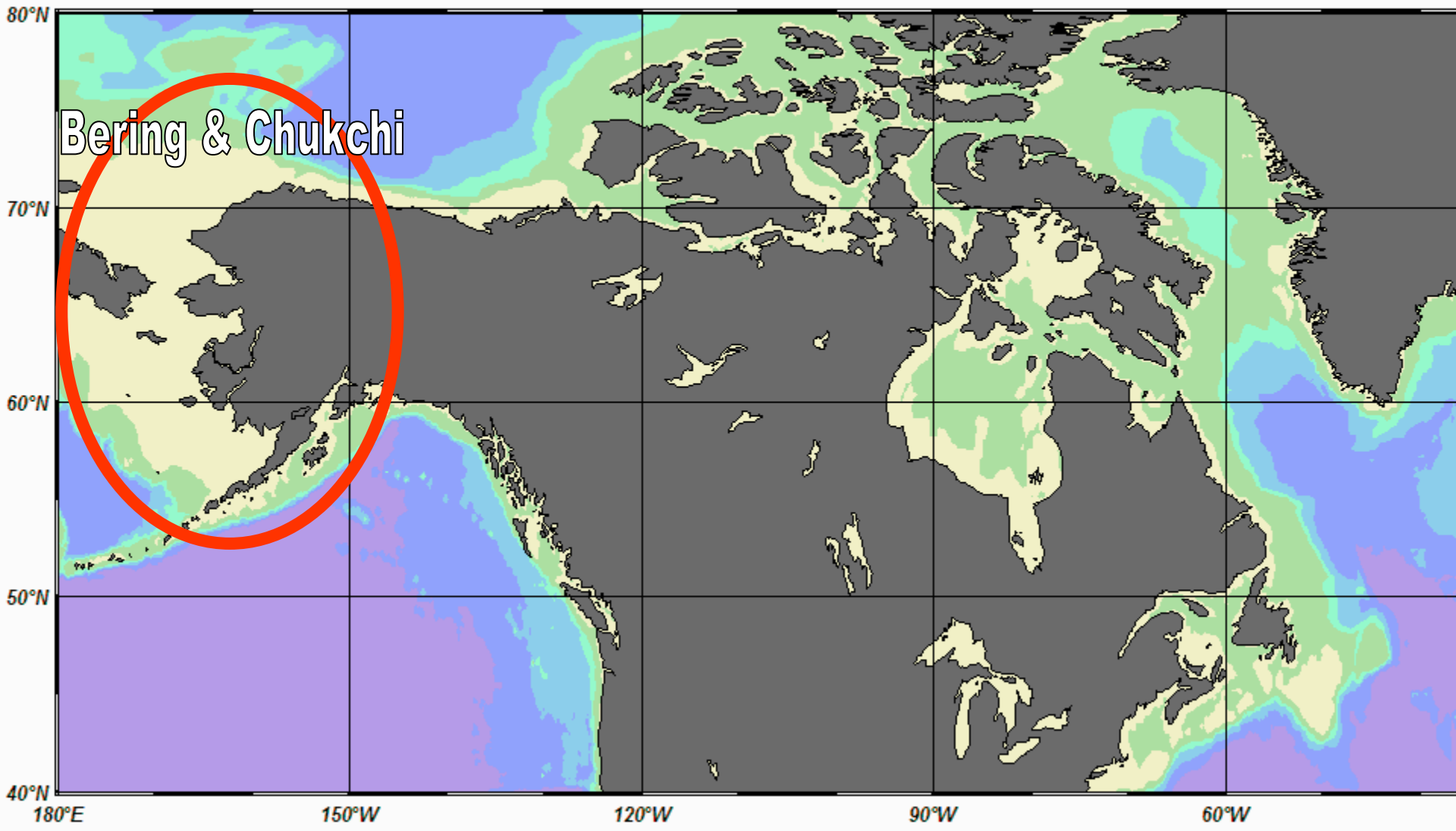

PFJ
STJ
Main storm track
at the upper and
lower levels
Hadley cell
(weakened)
Oceanic
Low
W
Subtropical
High
E
ITCZ
SAFZ
SST Gradient (Nakamura et al, 2008)
β
Subpolar Gyre
α
Subtropical Gyre
UPWELLING
DOWNWELLING
EQUATORIAL
CURRENT SYSTEM
NPIW
DEEP WATER

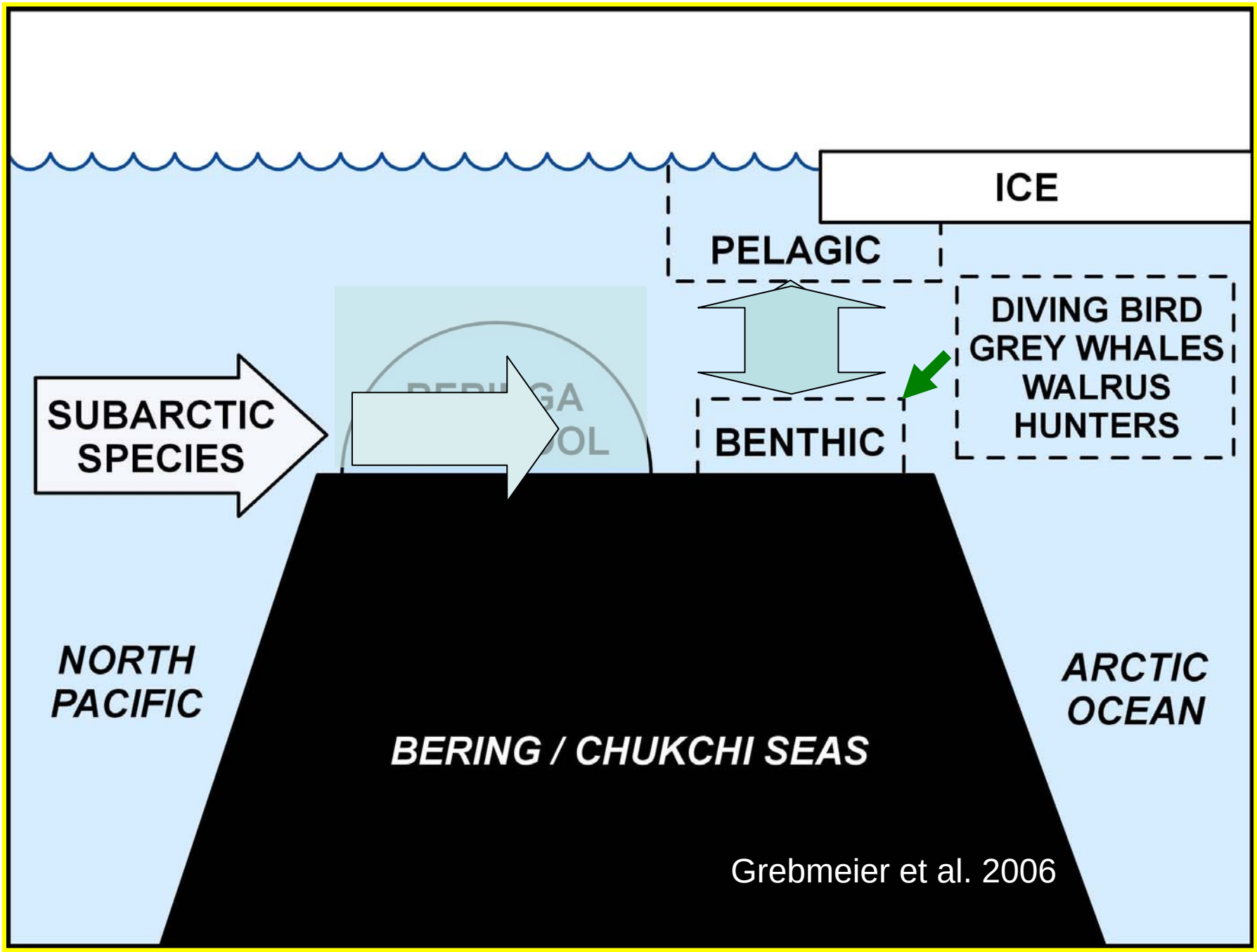
II. Changing Arctic: Water, Ice & Biota



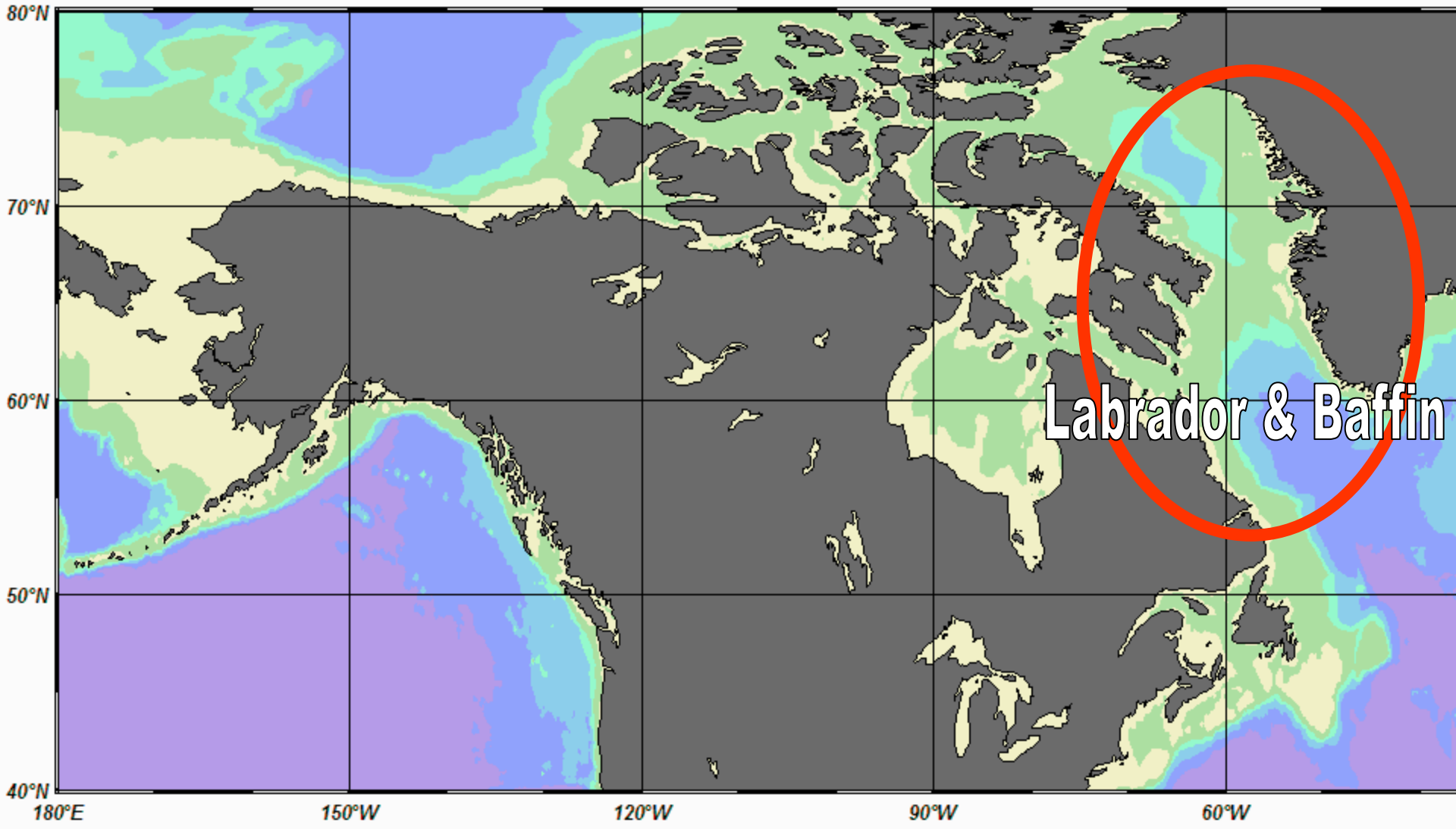

CLICK

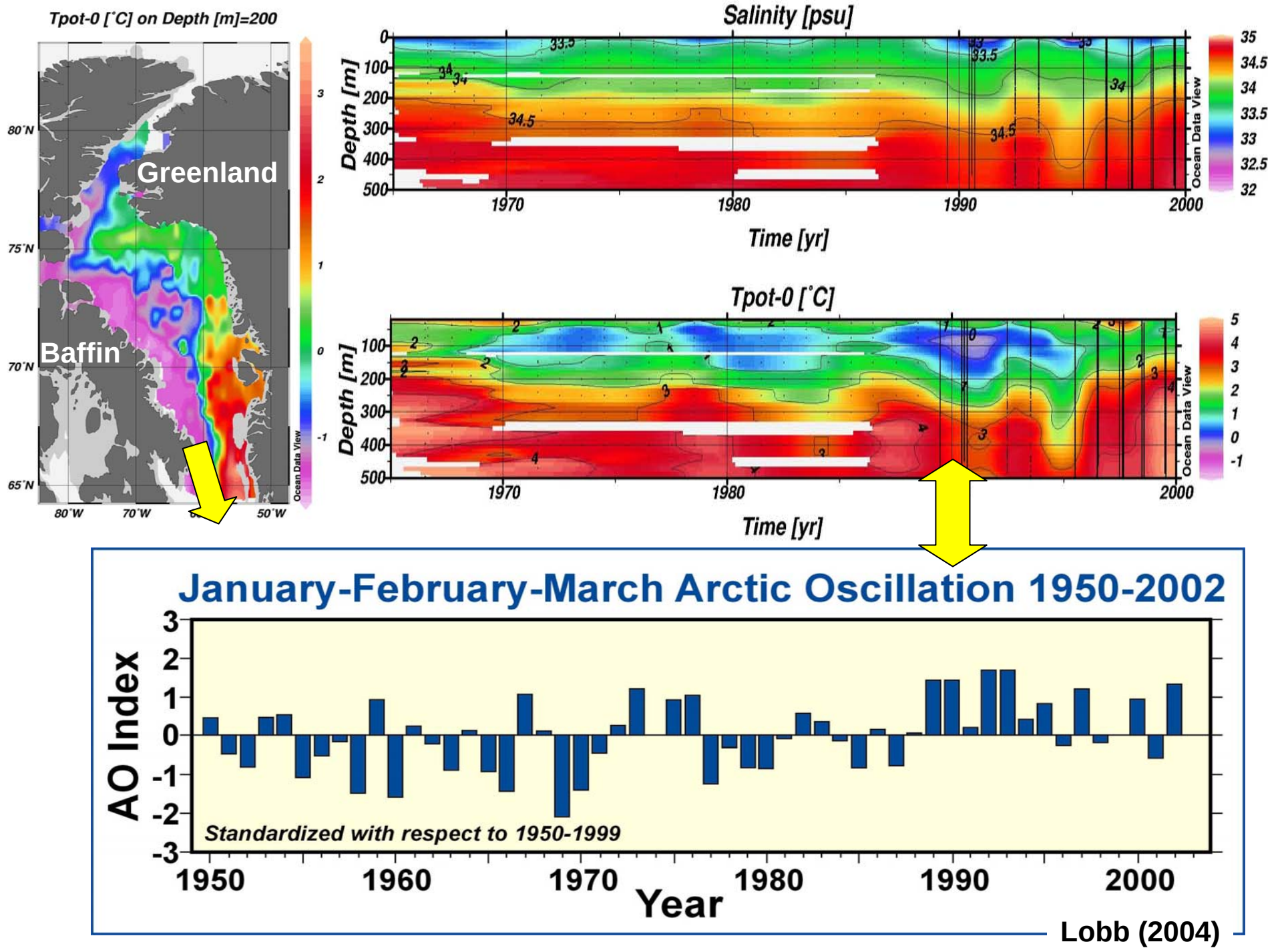

lechampiondumonde.com
OBSERVED CHANGE
BERING SEA
LABRADOR/BAFFIN
ARCTIC OCEAN
ATLANTIC WATERS
PACIFIC WATERS
SEA ICE
pH

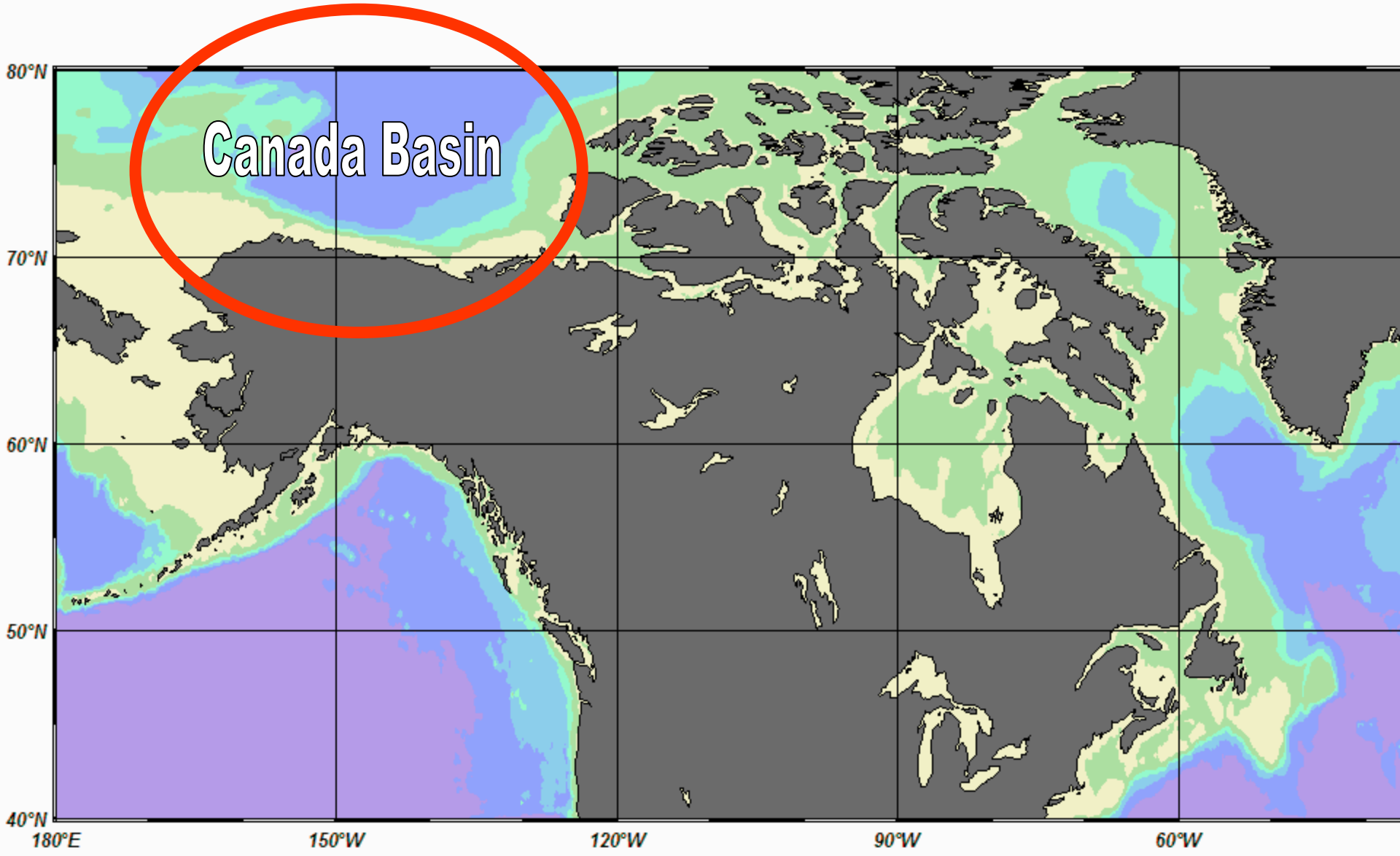

Bering & Chukchi
80°N
70°N
60°N
50°N
40°N
180°E
150°W
120°W
90°W
60°W



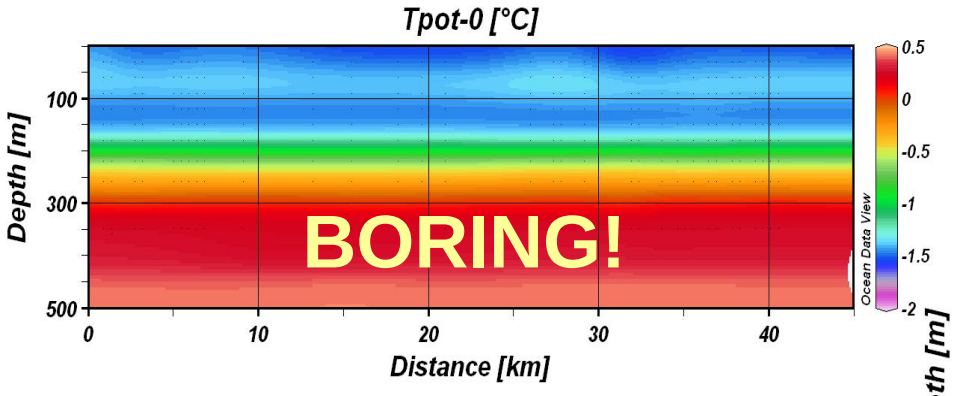
Grebmeier et al. 2006

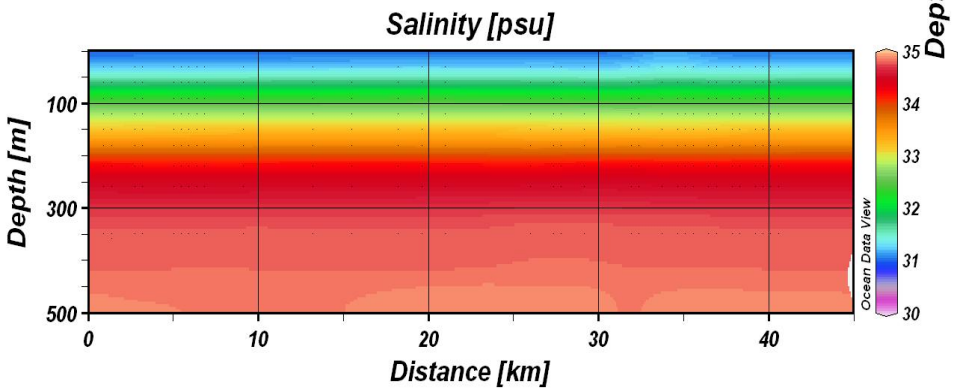

80°N
70°N
60°N
50°N
40°N
180°E
150°W
120°W
90°W
60°W
Labrador & Baffin

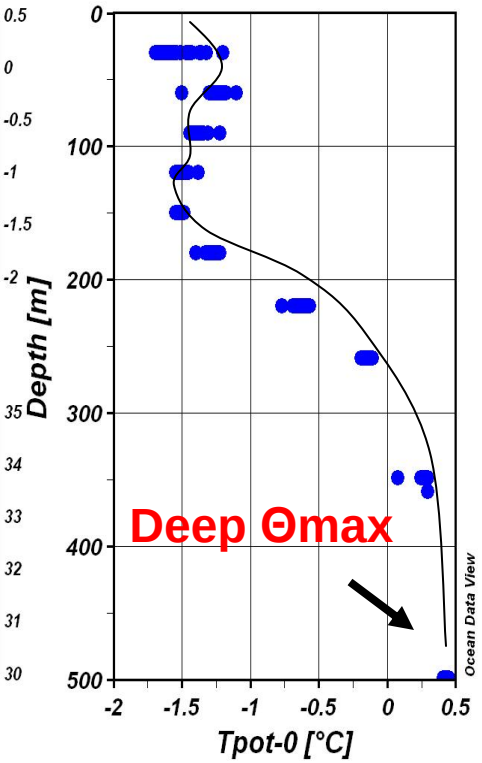

Tpot-0 [˚C] on Depth [m]=200
Greenland
Baffin
80˚N
75˚N
70˚N
65˚N
80˚W
70˚W
50˚W
Ocean Data View
Salinity [psu]
Depth [m]
Time [yr]
1970
1980
1990
2000
Tpot-0 [˚C]
January-February-March Arctic Oscillation 1950-2002
AO Index
Standardized with respect to 1950-1999
Year
1950
1960
1970
1980
1990
2000
Lobb (2004)

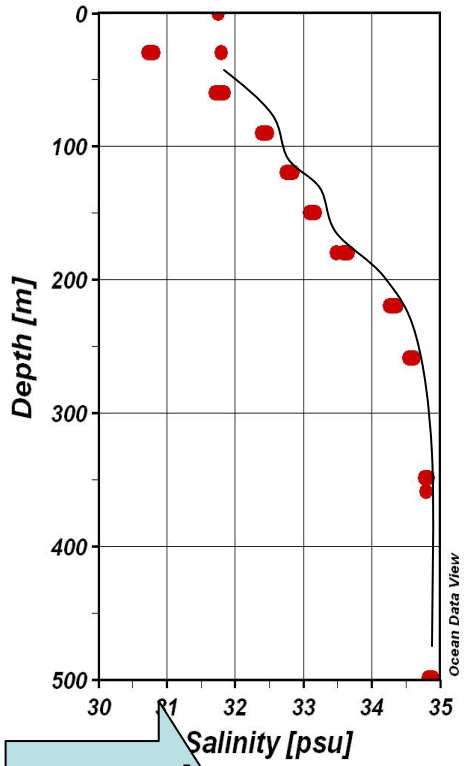

Canada Basin
80°N
70°N
60°N
50°N
40°N
180°E
150°W
120°W
90°W
60°W

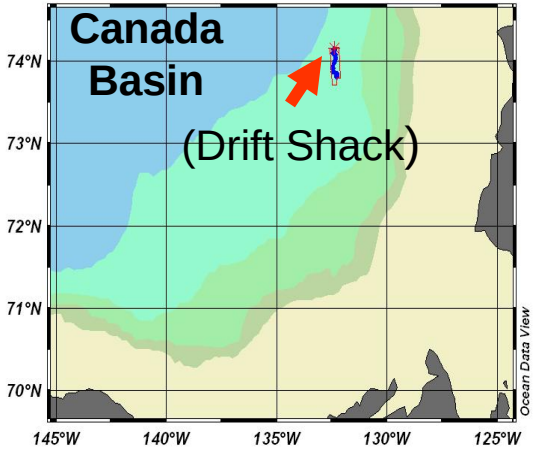
CANADA BASIN: PRE-INVASION DAYS



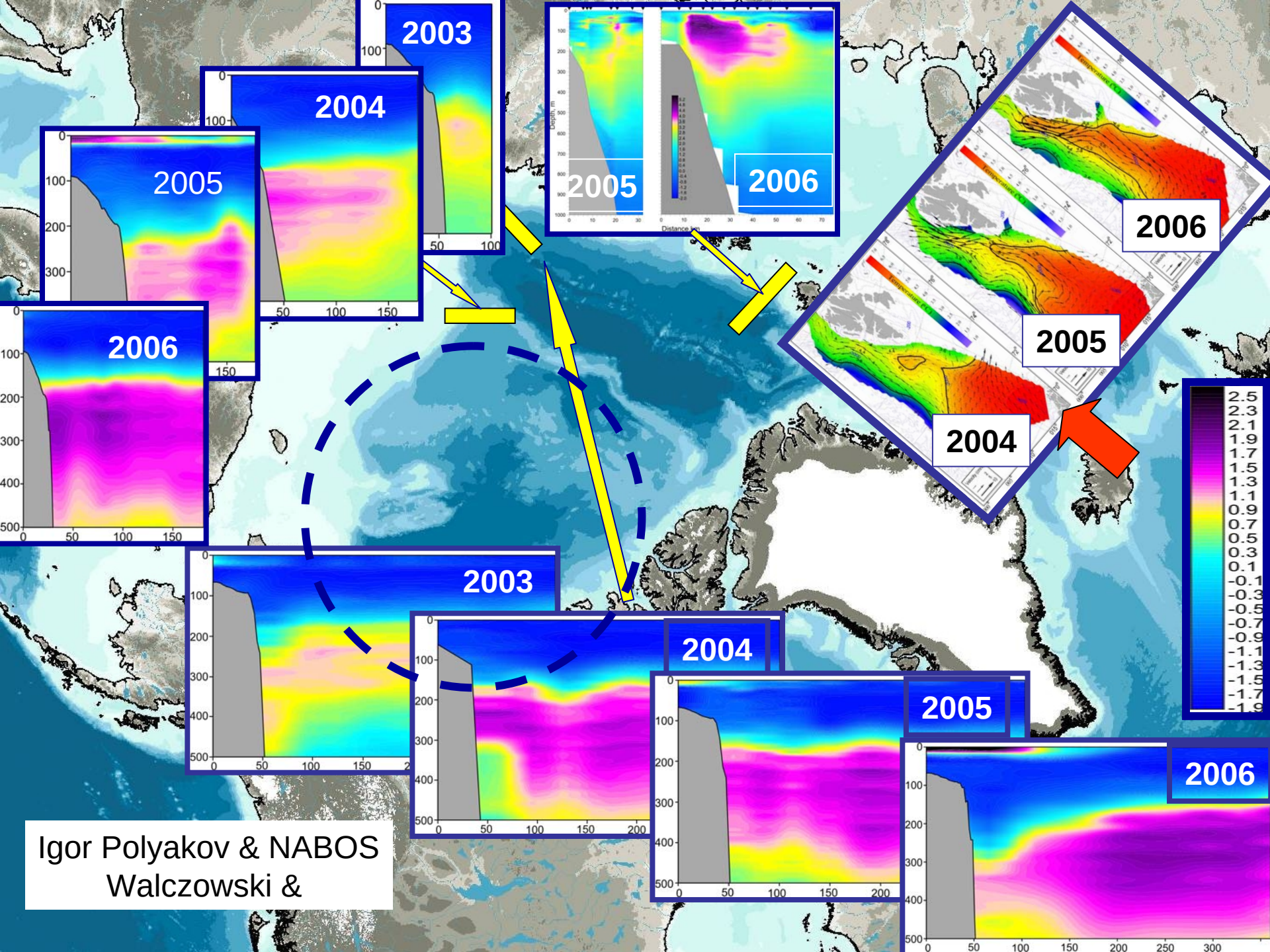


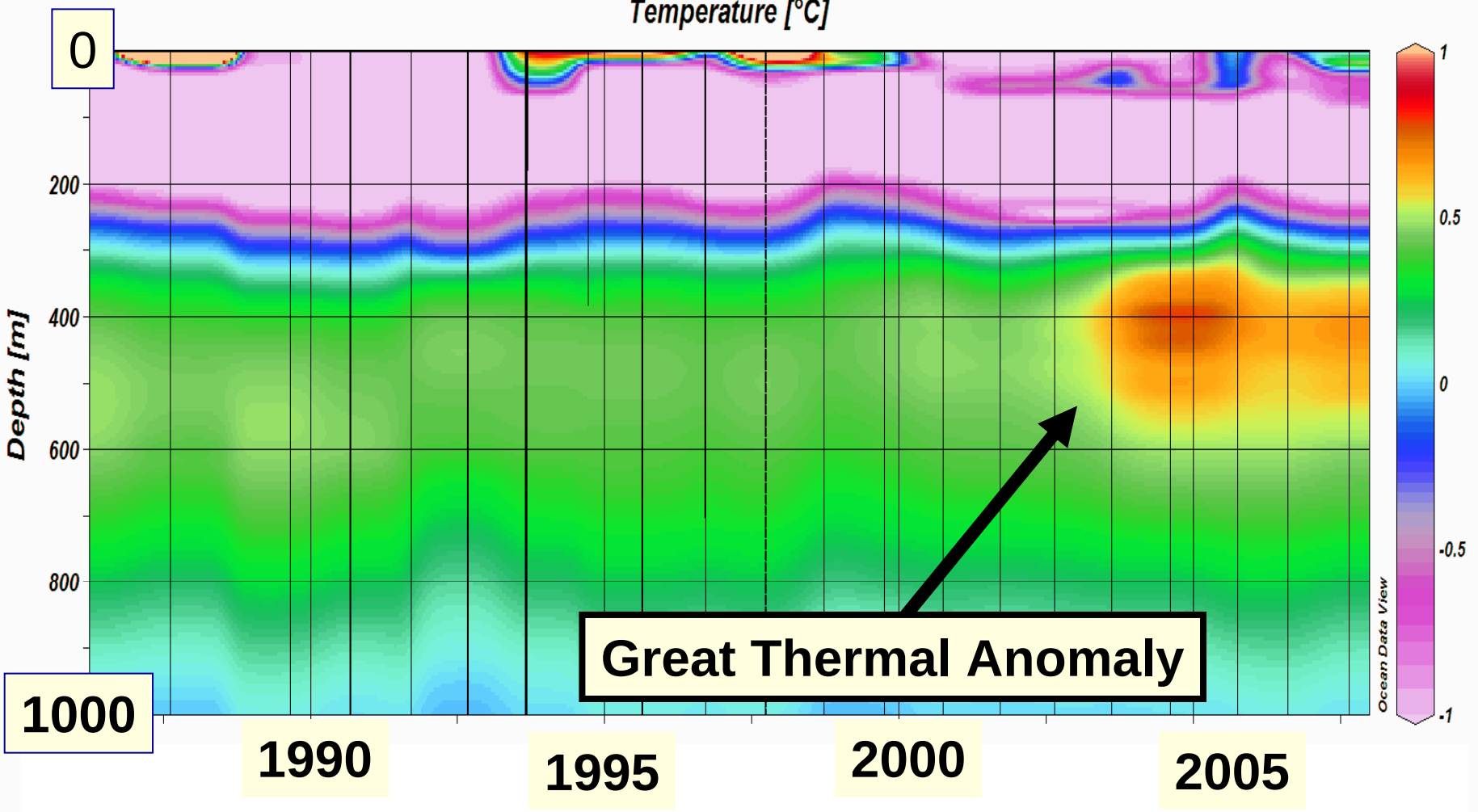






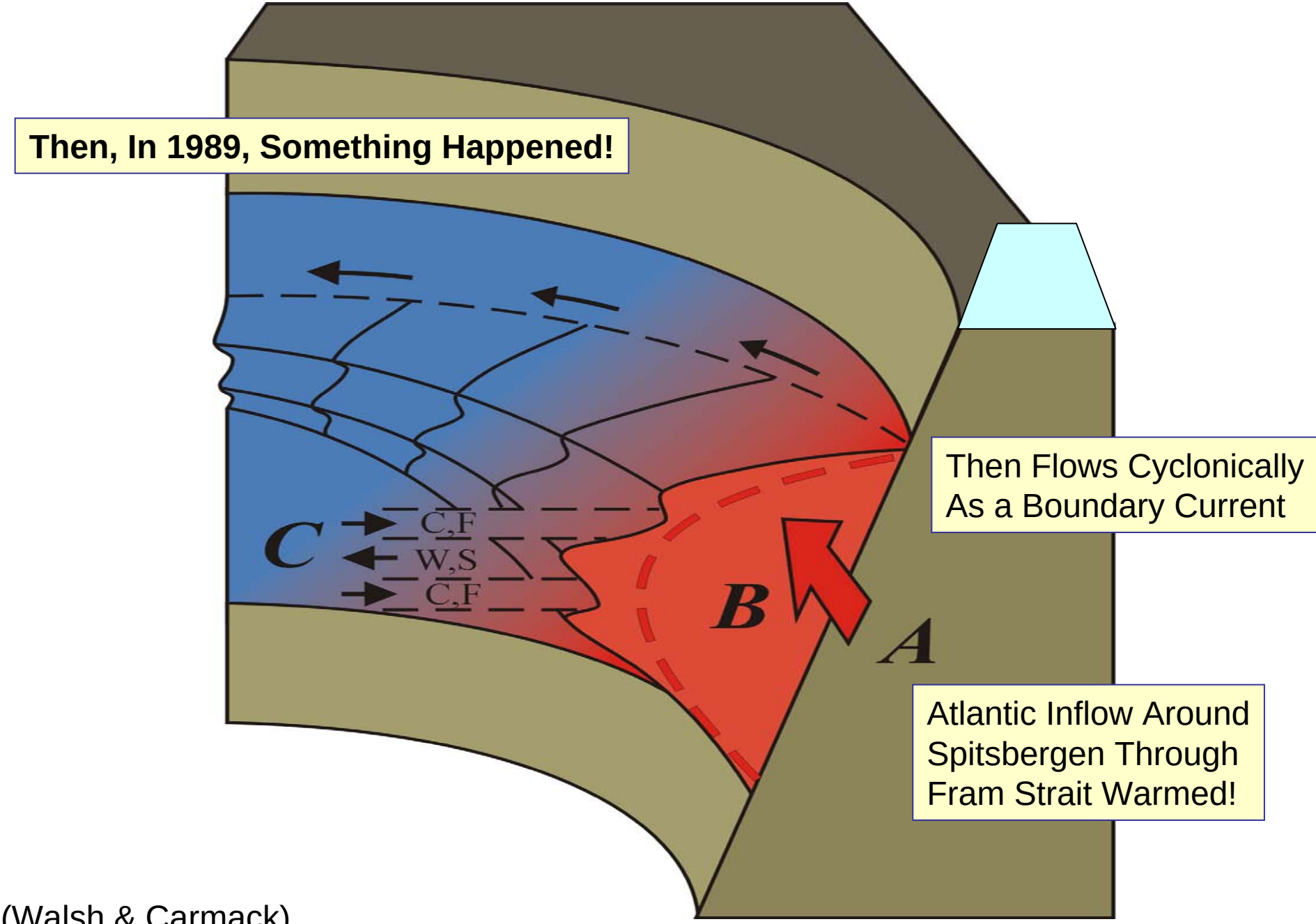
Canada Basin 1971


2003
2004
2005
2006
2005
2006
2006
2005
2004
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
-1.3
-1.5
-1.7
2003
2004
2005
2006
Igor Polyakov & NABOS
Walczowski &

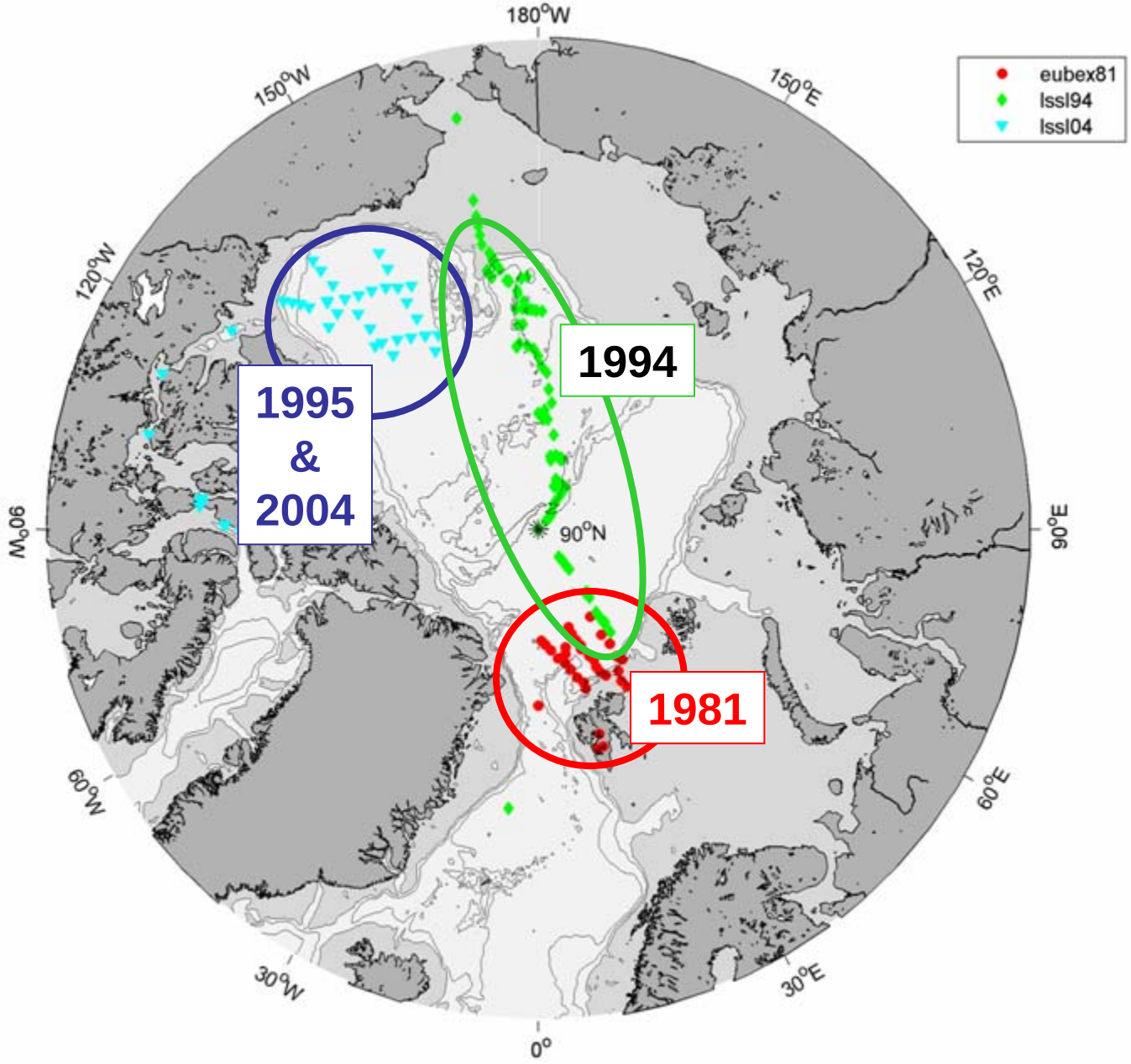


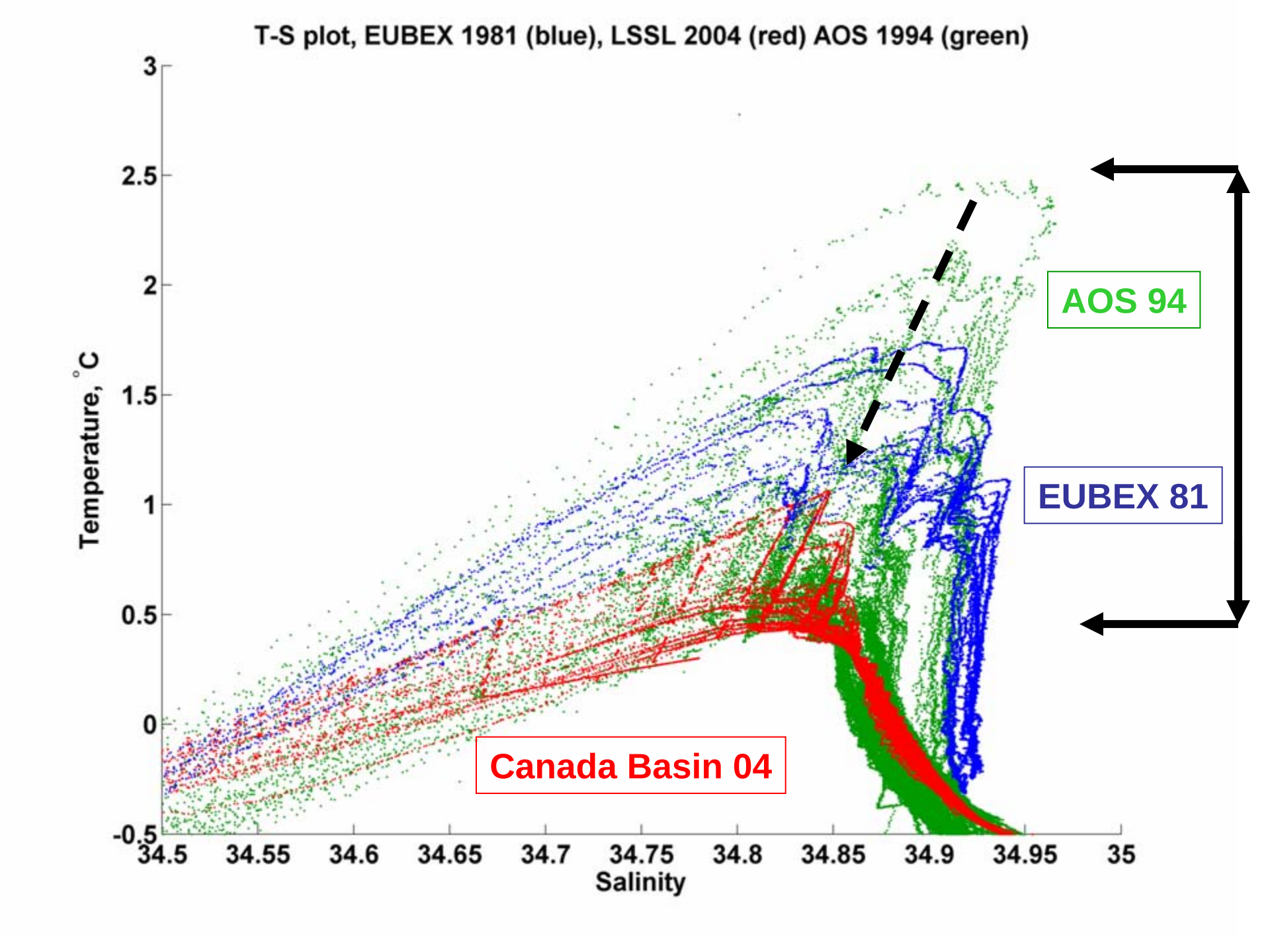
Atlantic Waters

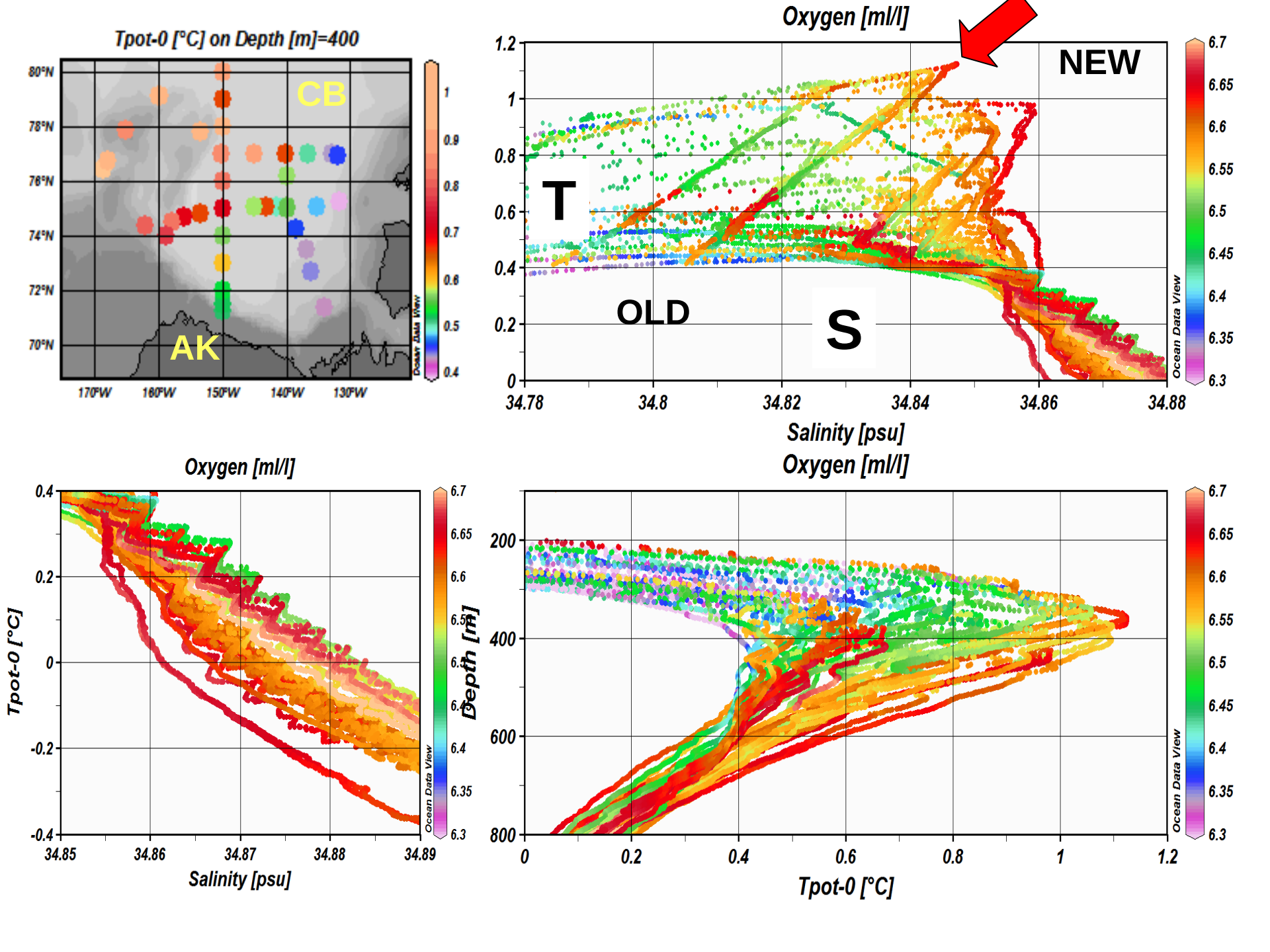
(The ‘End of the Line” for the Gulf Stream!)



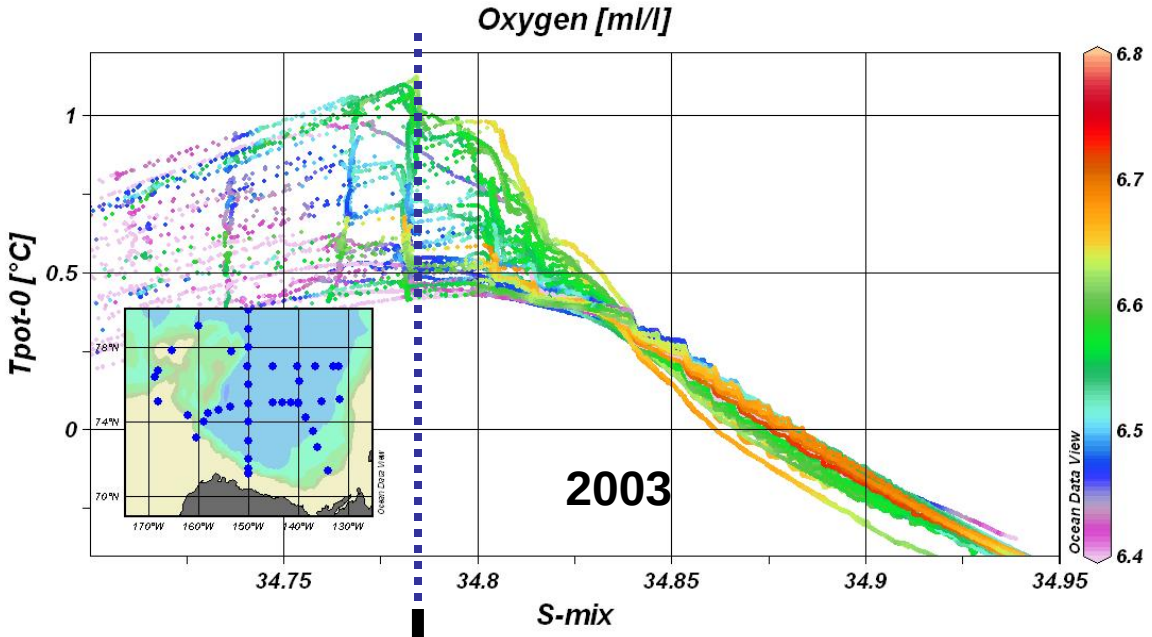
(Walsh & Carmack)

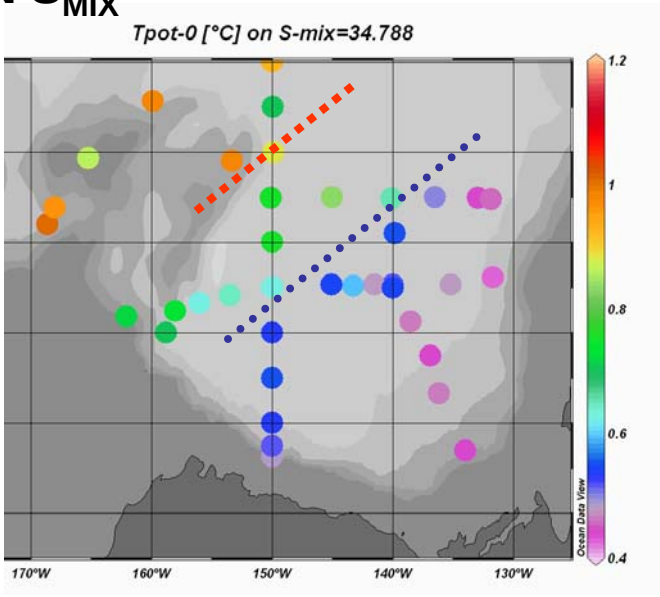

180°W
150°W
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
30°E
0°
90°N
eubex81
lssl94
lssl04
1994
1995
&
2004
1981

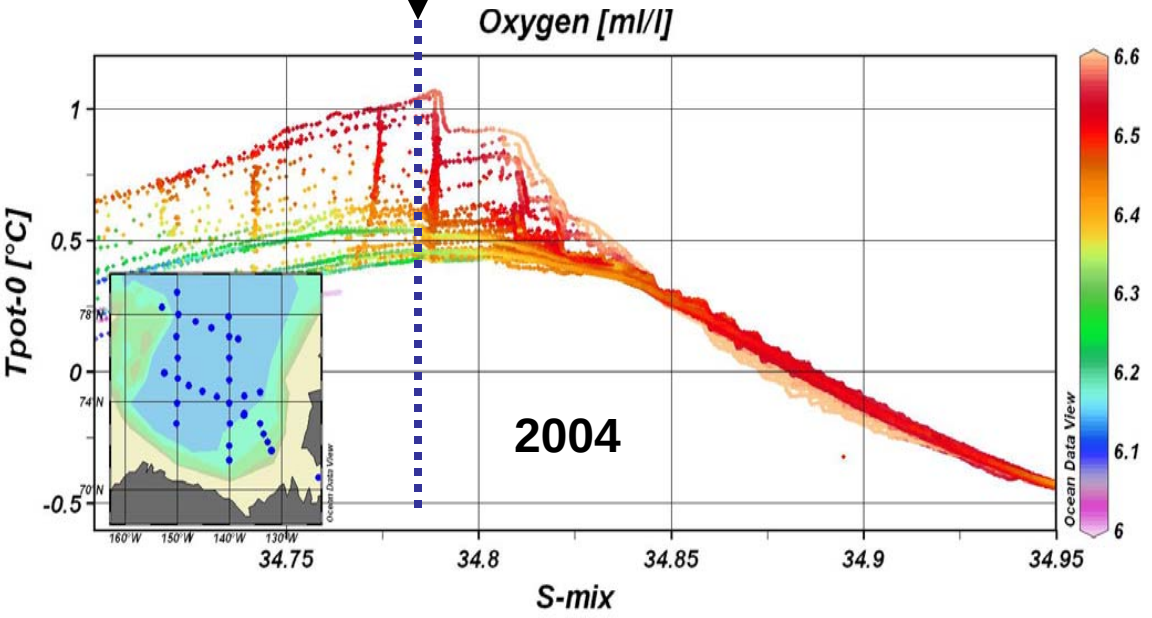

T-S plot, EUBEX 1981 (blue), LSSL 2004 (red) AOS 1994 (green)
Temperature, °C
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
34.5
34.55
34.6
34.65
34.7
34.75
34.8
34.85
34.9
34.95
35
AOS 94
EUBEX 81
Canada Basin 04

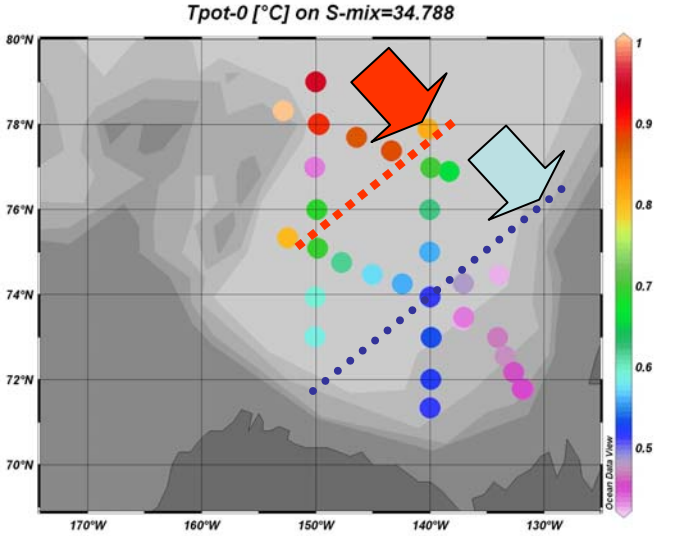

Tpot-0 [°C] on Depth [m]=400
80°N
78°N
76°N
74°N
72°N
70°N
170°W
160°W
150°W
140°W
130°W
CB
AK
1
0.9
0.8
0.7
0.6
0.5
0.4
Ocean Data View
Oxygen [ml/l]
NEW
T
OLD
S
1.2
1
0.8
0.6
0.4
0.2
0
34.78
34.8
34.82
34.84
34.86
34.88
Salinity [psu]
6.7
6.65
6.6
6.55
6.5
6.45
6.4
6.35
6.3
Oxygen [ml/l]
Tpot-0 [°C]
0.4
0.2
0
-0.2
-0.4
34.85
34.86
34.87
34.88
34.89
Salinity [psu]
Oxygen [ml/l]
Depth [m]
200
400
600
800
0
0.2
0.4
0.6
0.8
1
1.2
Tpot-0 [°C]

POTENTIAL TEMPERATURE ON S_{MIX}

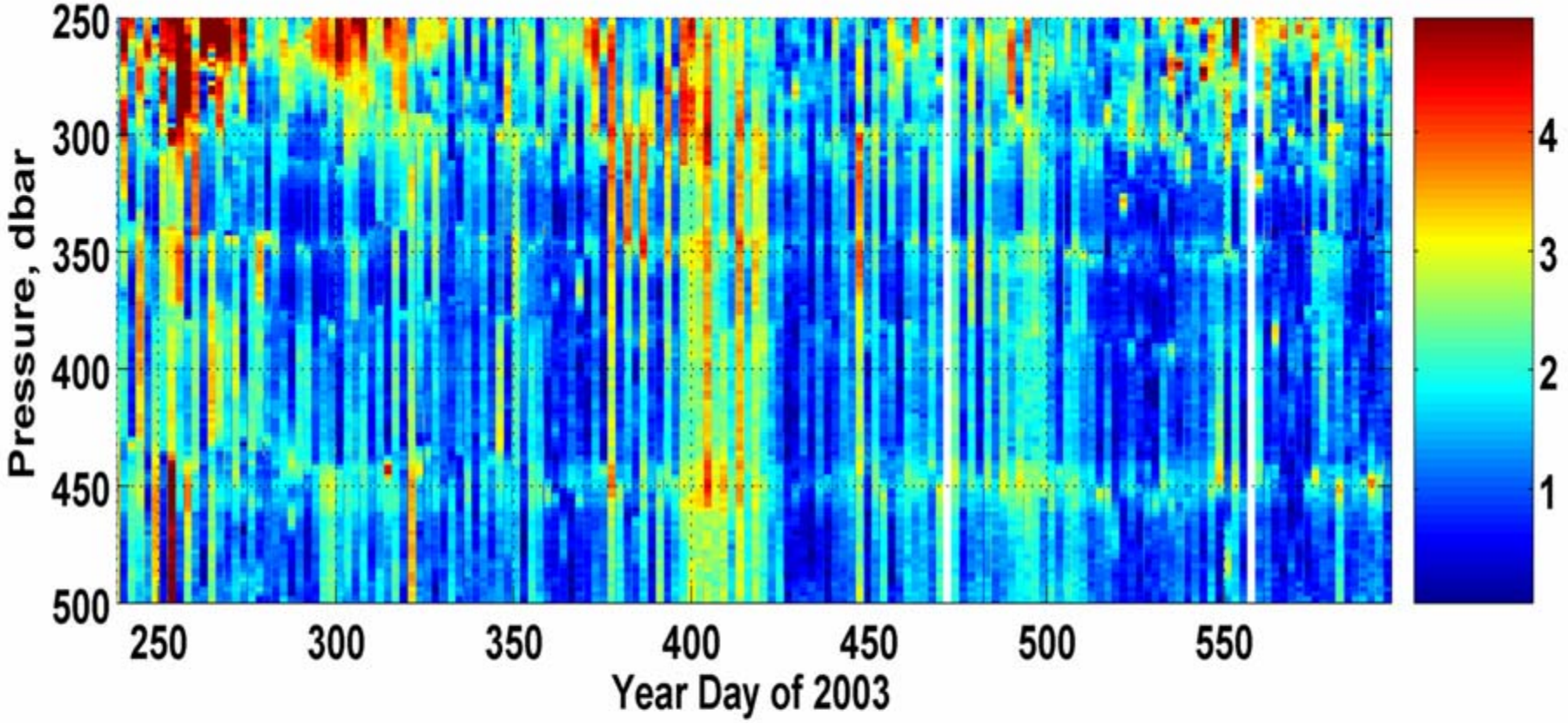






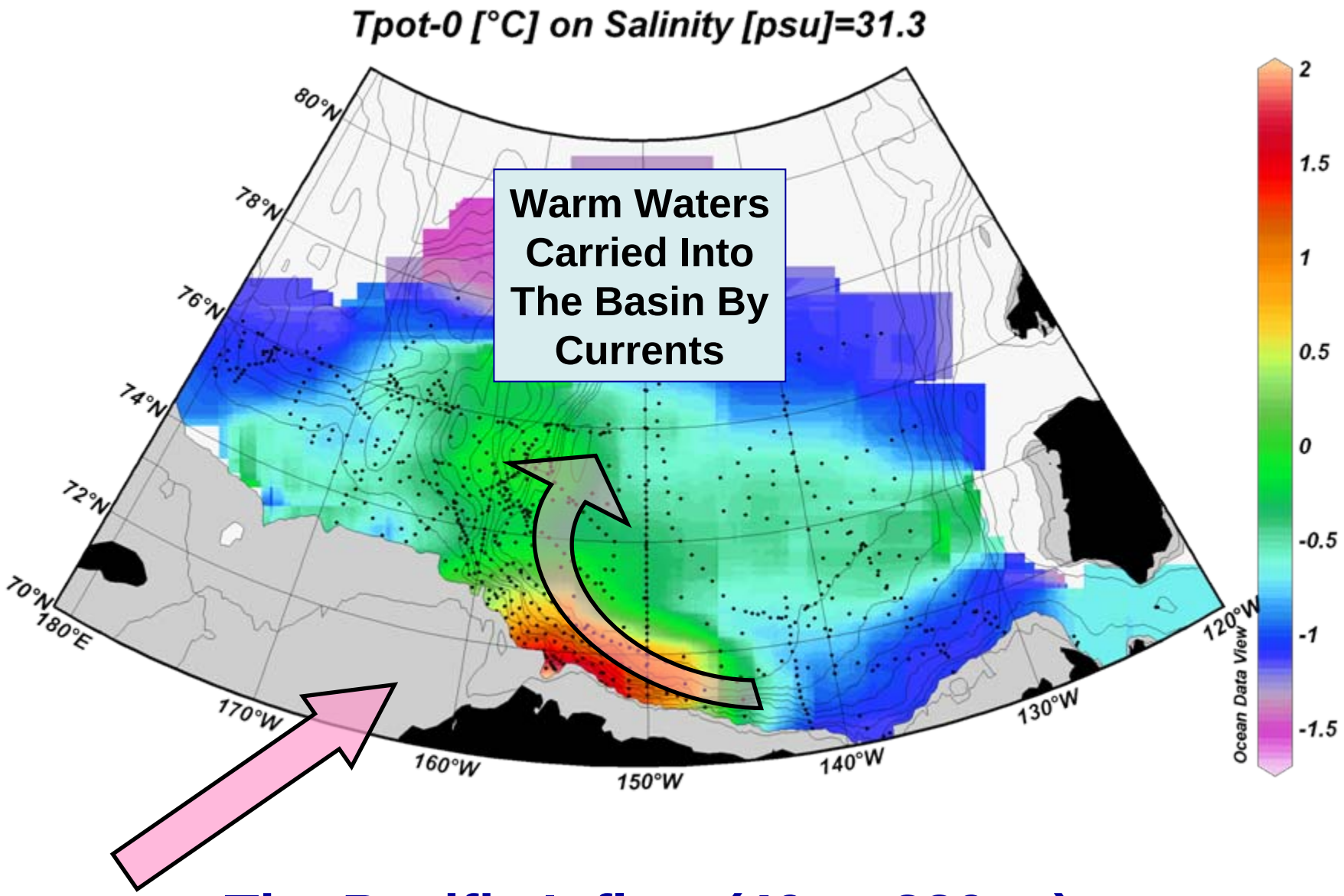


BGEP Mooring C – 77N 140 W



Self-Propelled?

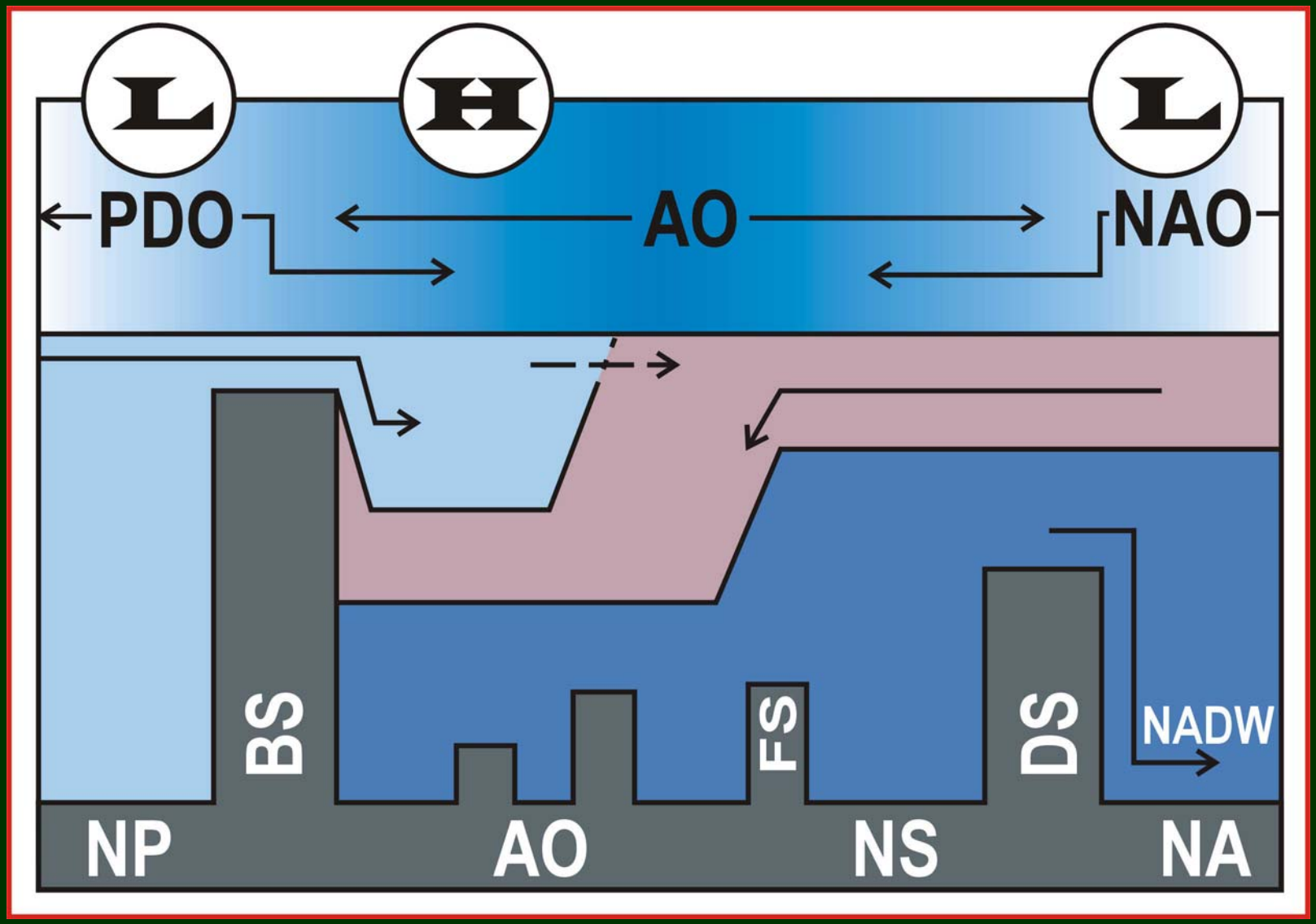
Williams, et al.

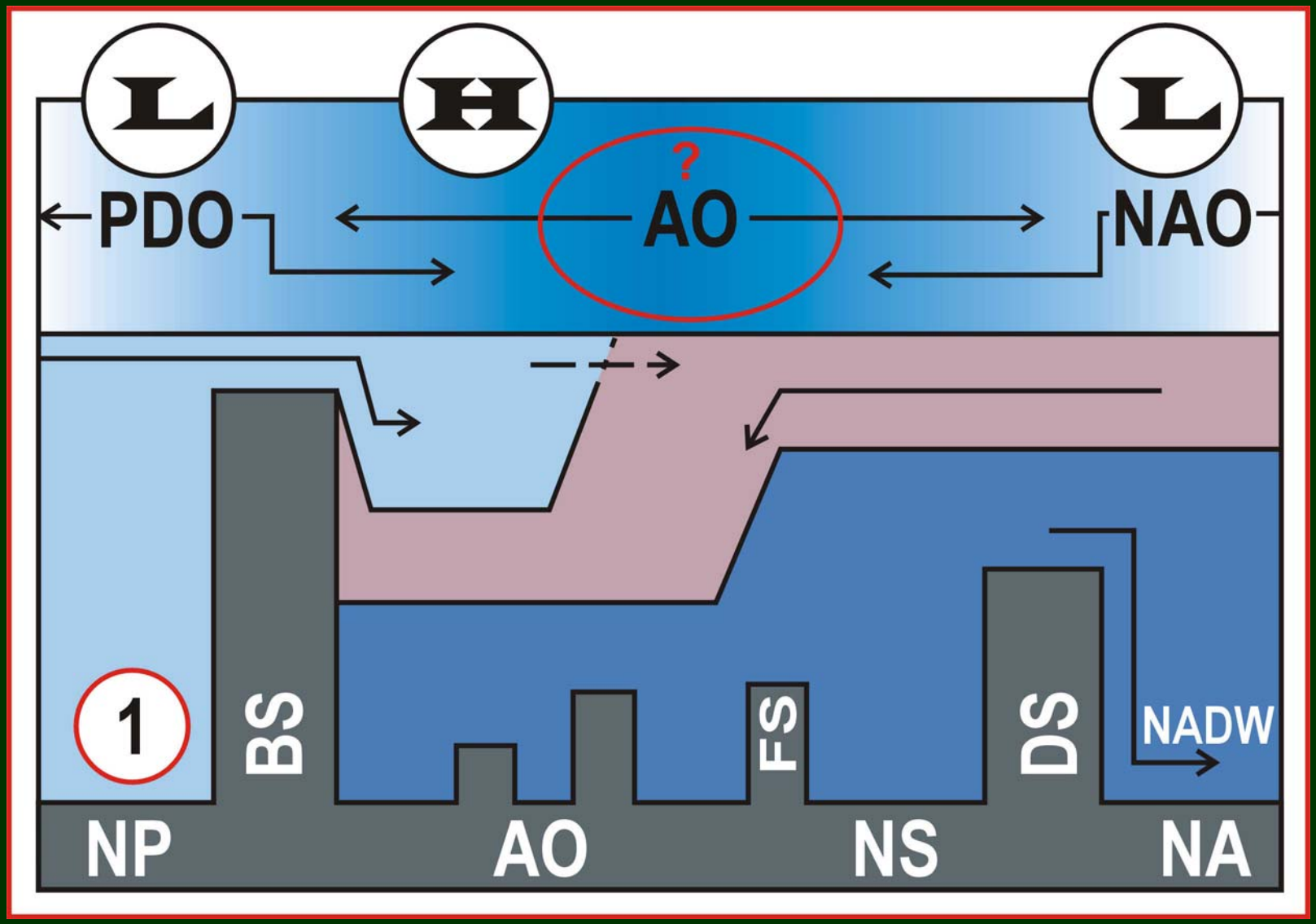


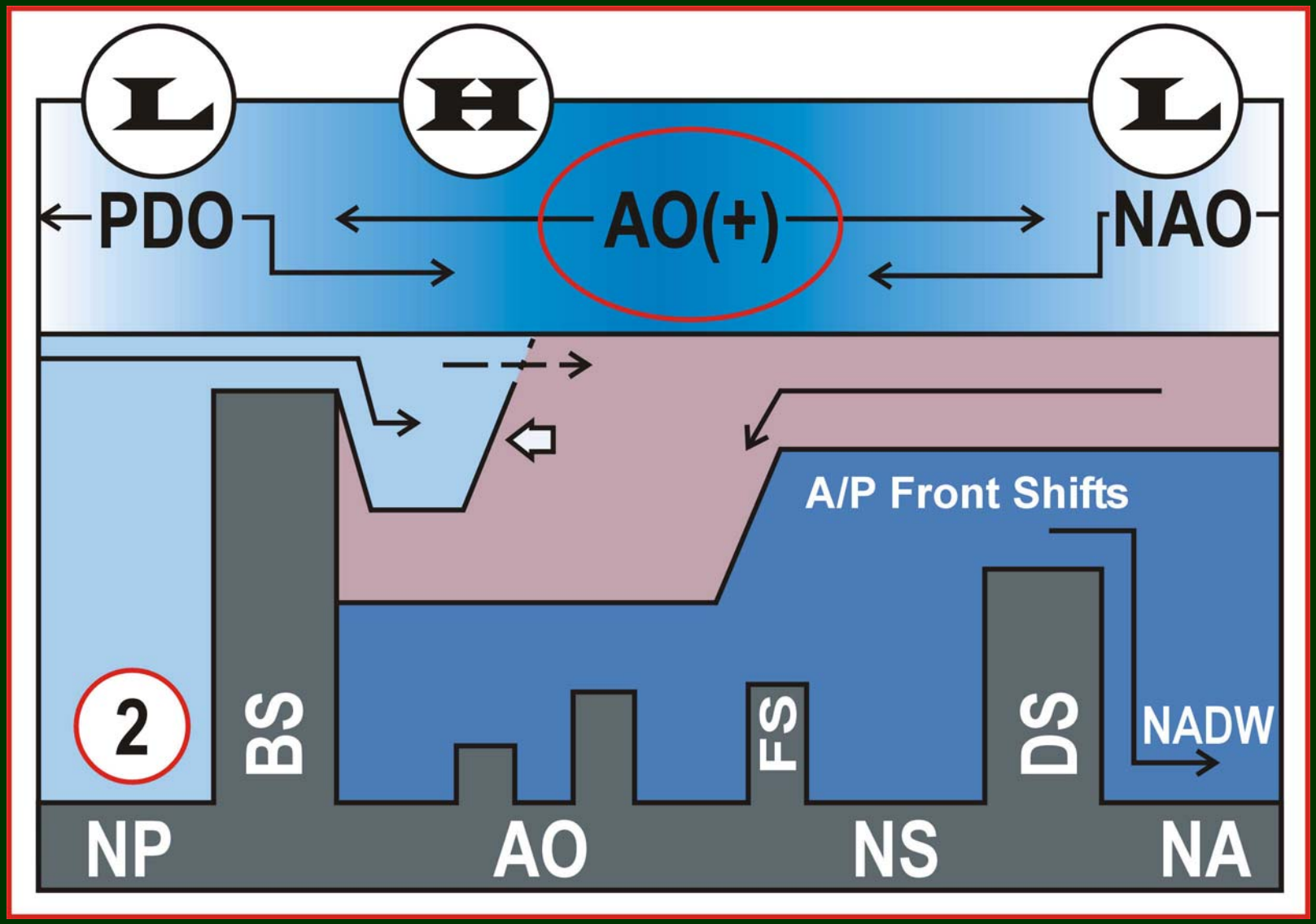
The Pacific Inflow (40 to 220 m)

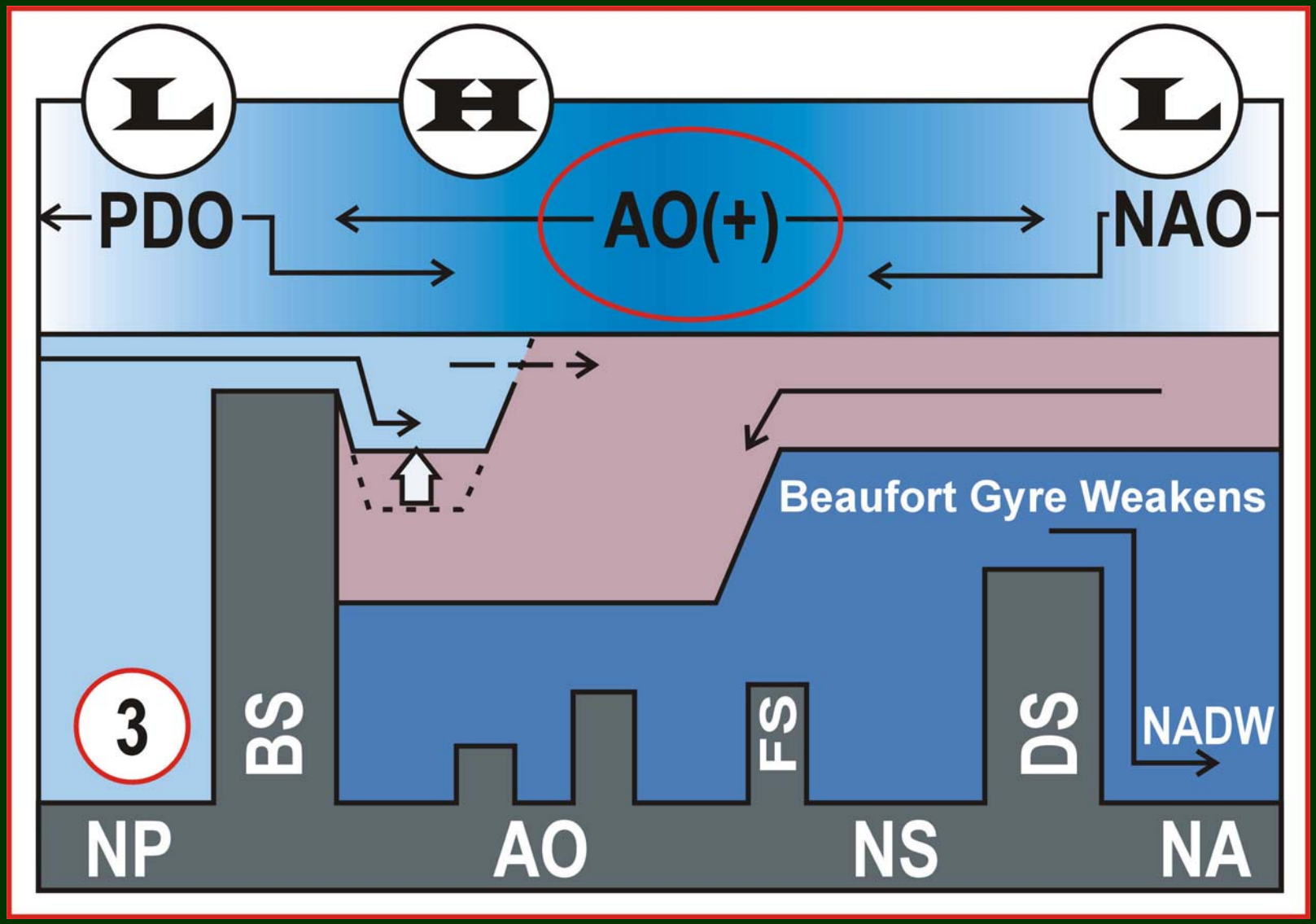
Summary of the Pacific/Atlantic Showdown (1989-2006)

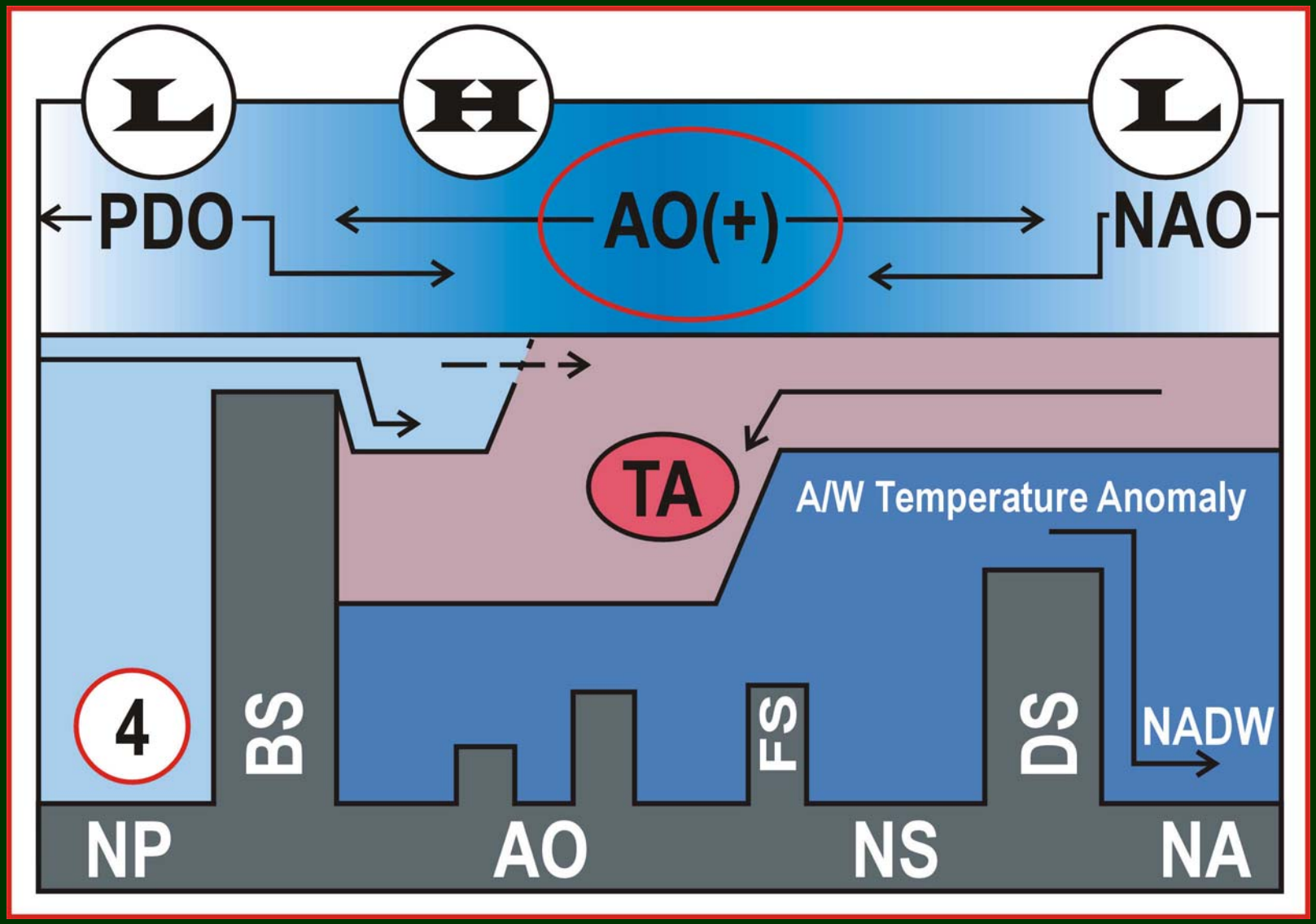
R. HOPCROFT

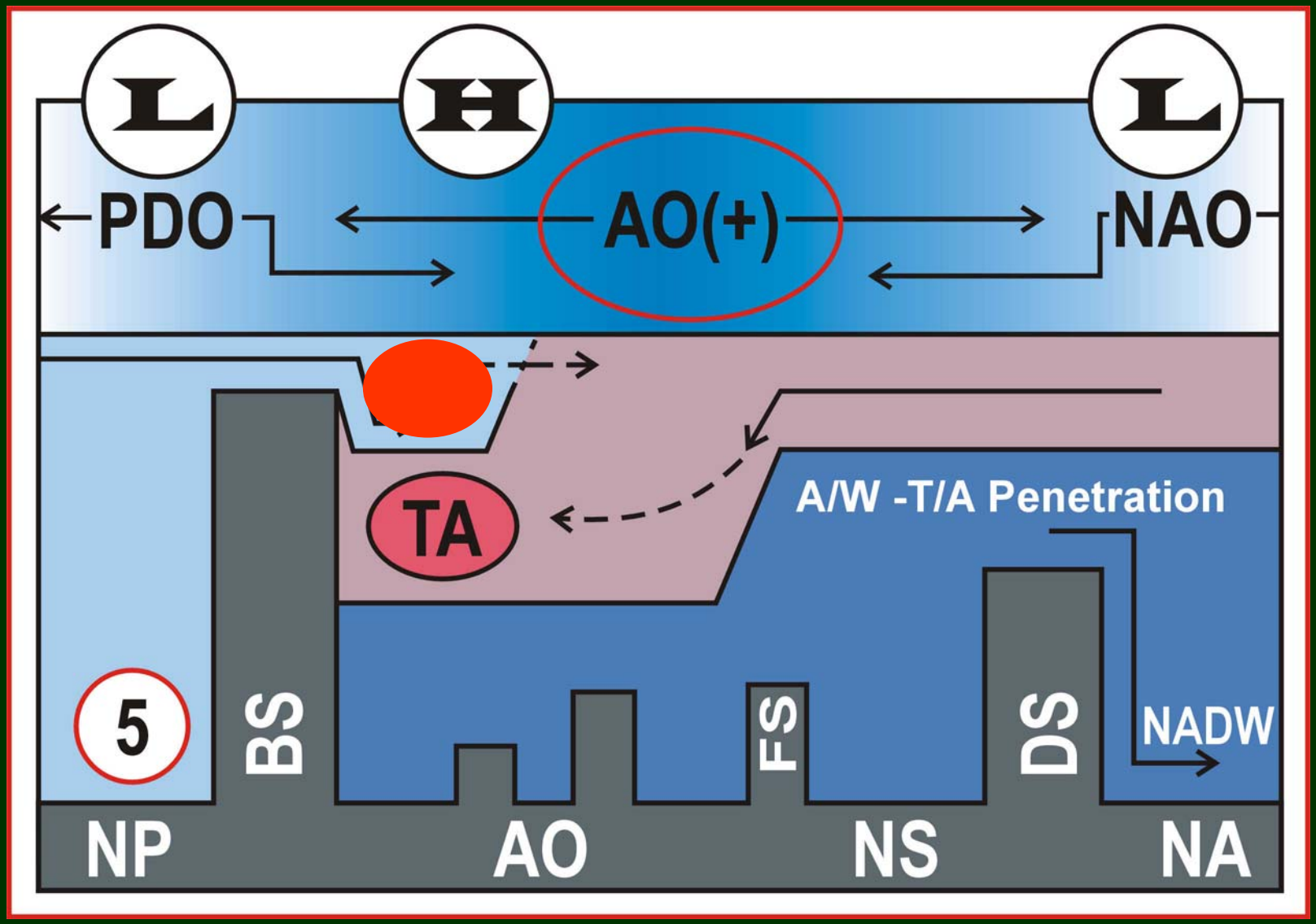

L
H
L
PDO
AO
NAO
BS
FS
DS
NADW
NP
AO
NS
NA


L
H
L
?
PDO
AO
NAO
1
BS
FS
DS
NADW
NP
AO
NS
NA


L
H
L
PDO
AO(+)
NAO
A/P Front Shifts
2
BS
FS
DS
NADW
NP
AO
NS
NA

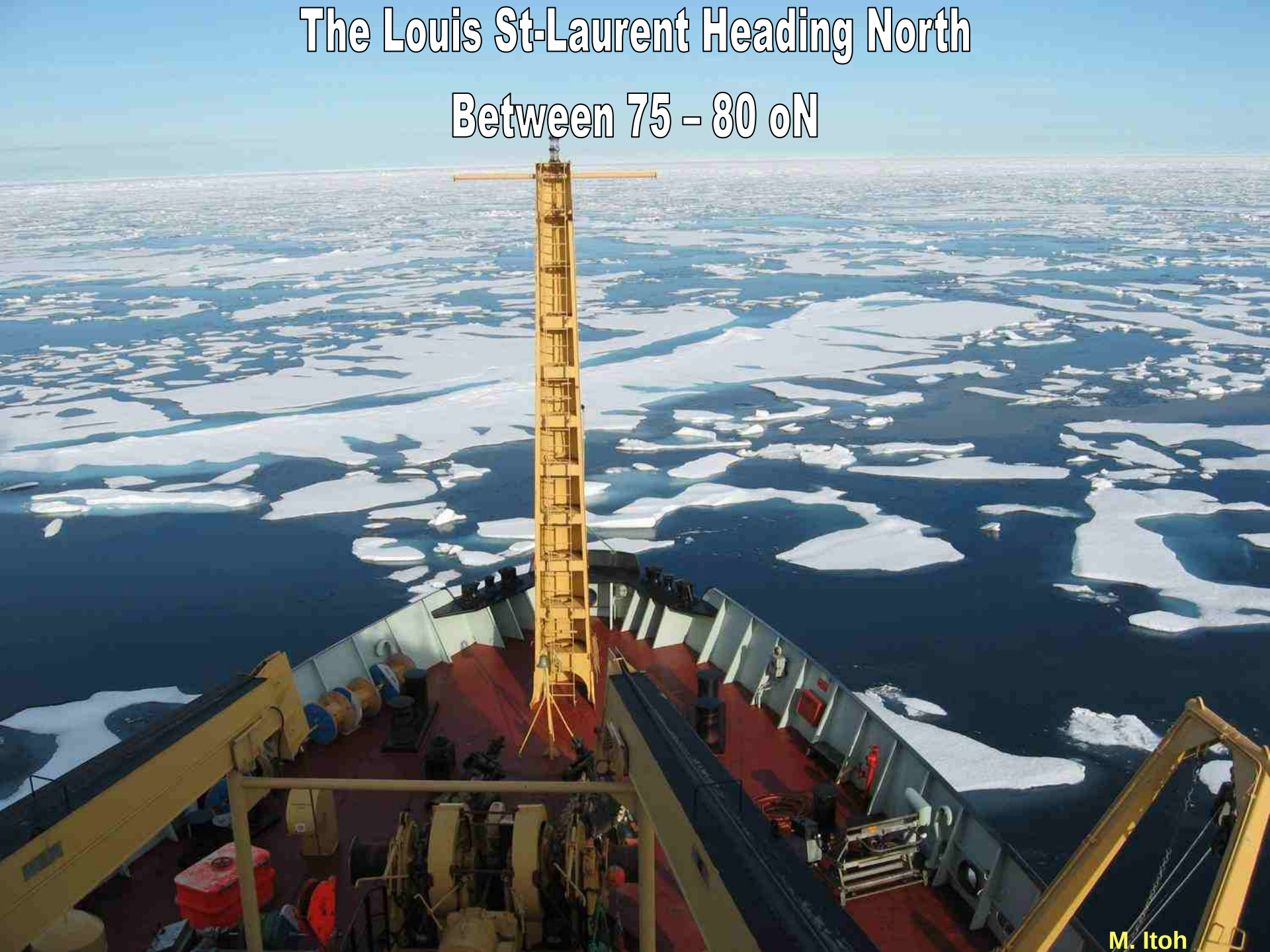

L
H
L
PDO
AO(+)
NAO
Beaufort Gyre Weakens
3
BS
FS
DS
NADW
NP
AO
NS
NA


L
H
L
PDO
AO(+)
NAO
TA
A/W Temperature Anomaly
4
BS
FS
DS
NADW
NP
AO
NS
NA

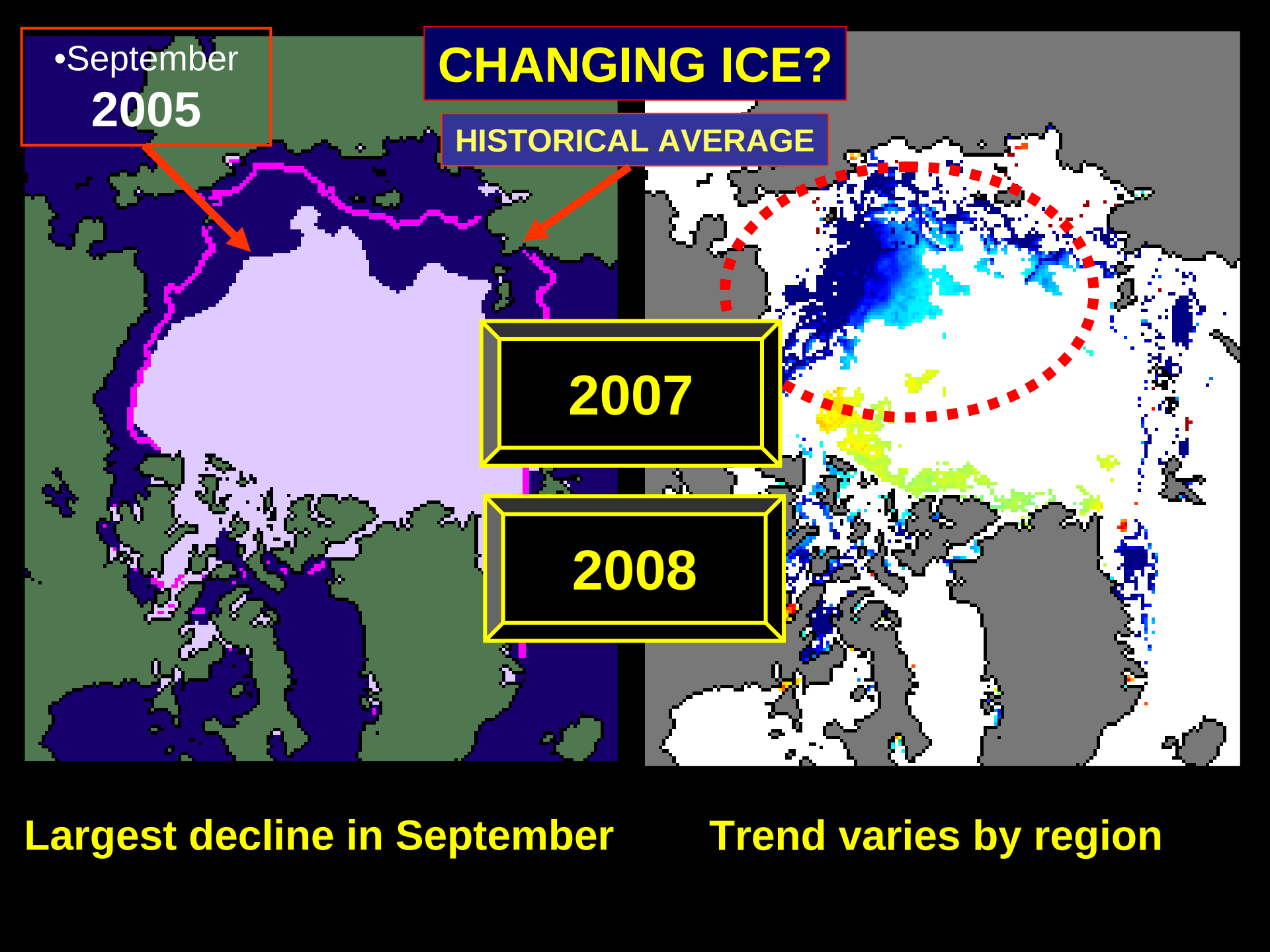

L
H
L
PDO
AO(+)
NAO
TA
A/W -T/A Penetration
5
BS
FS
DS
NADW
NP
AO
NS
NA

The Louis St-Laurent Heading North

Between 75 – 80 oN

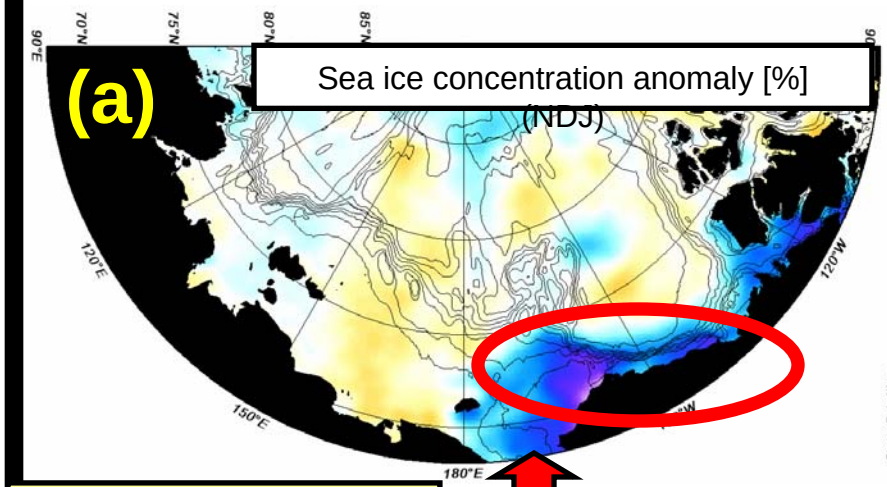


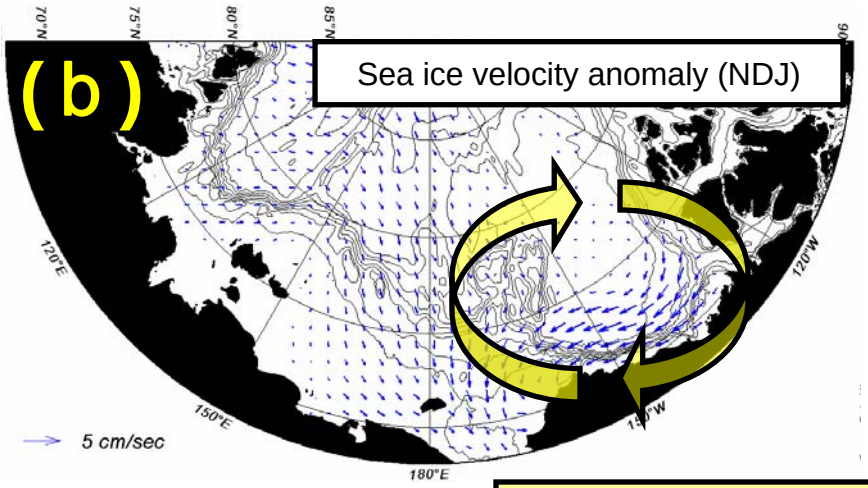
M. Itoh


•September
2005
CHANGING ICE?
HISTORICAL AVERAGE
2007
2008
Largest decline in September
Trend varies by region

① change in lateral boundary condition for sea ice motion

② strengthening of sea ice motion and upper ocean circulation

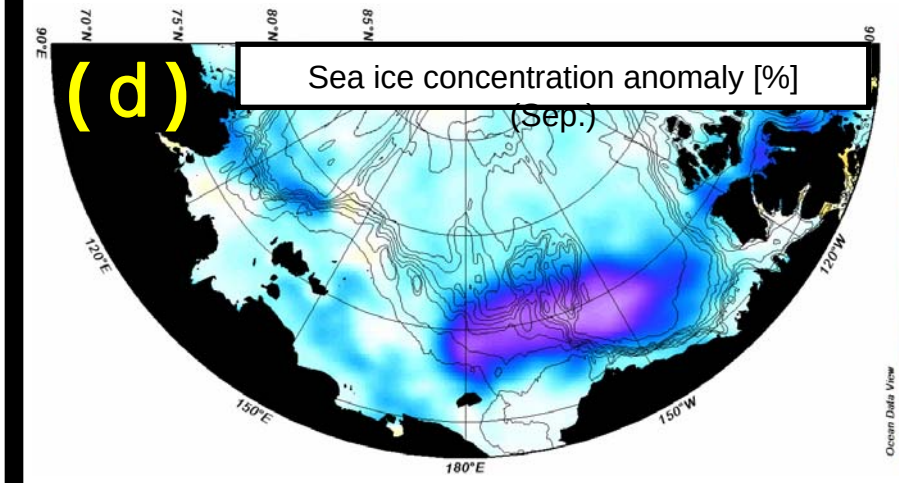


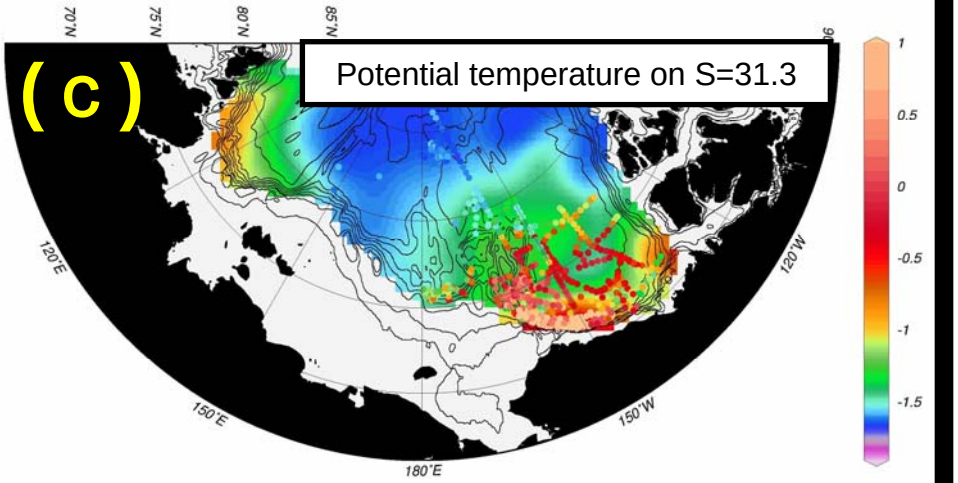


Warm Pacific Summer Water inflow

⑥ retarding of sea ice formation near coast

③ increase in oceanic heat transport



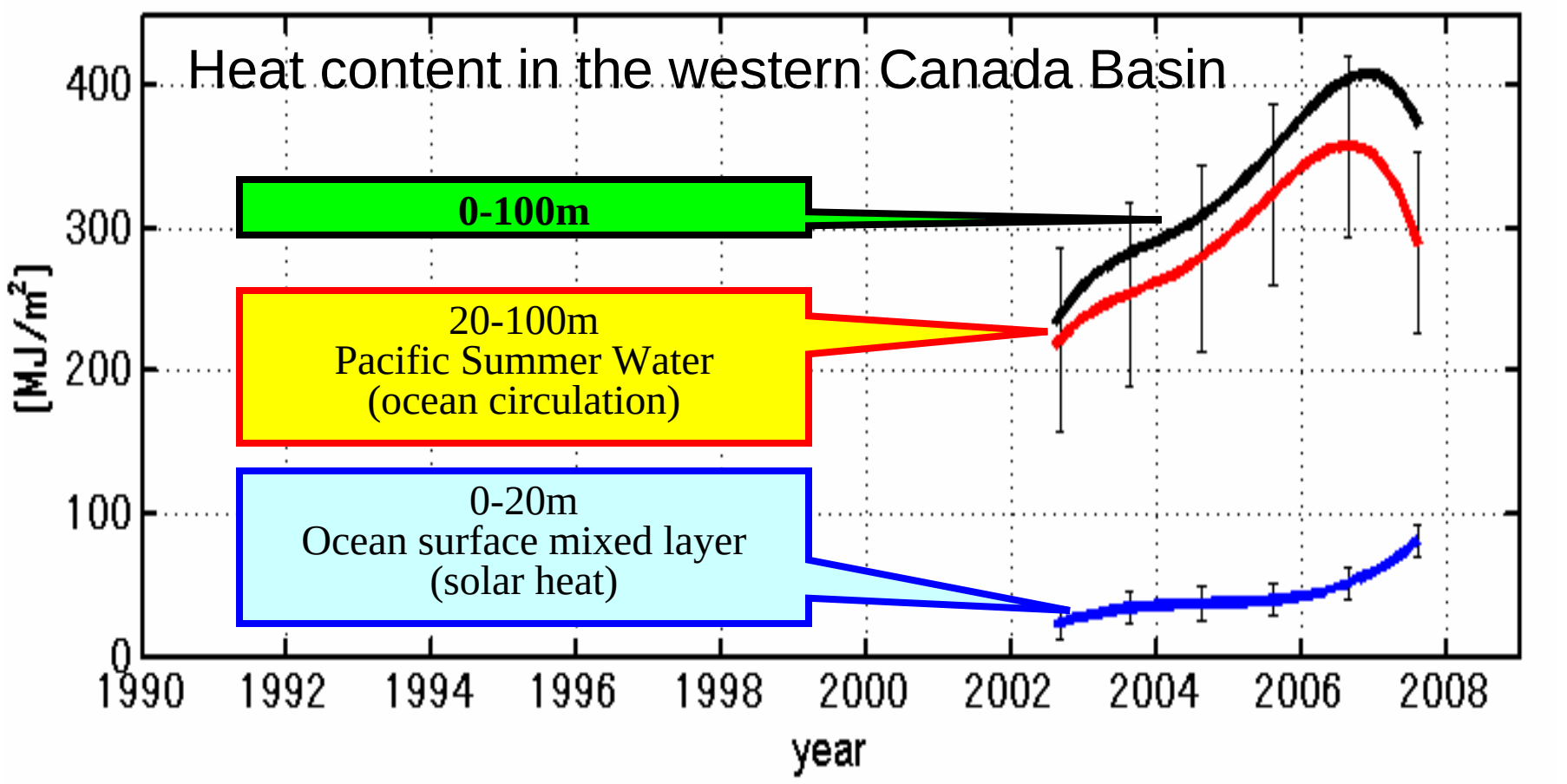


⑤ice reduction

④warming of the upper ocean

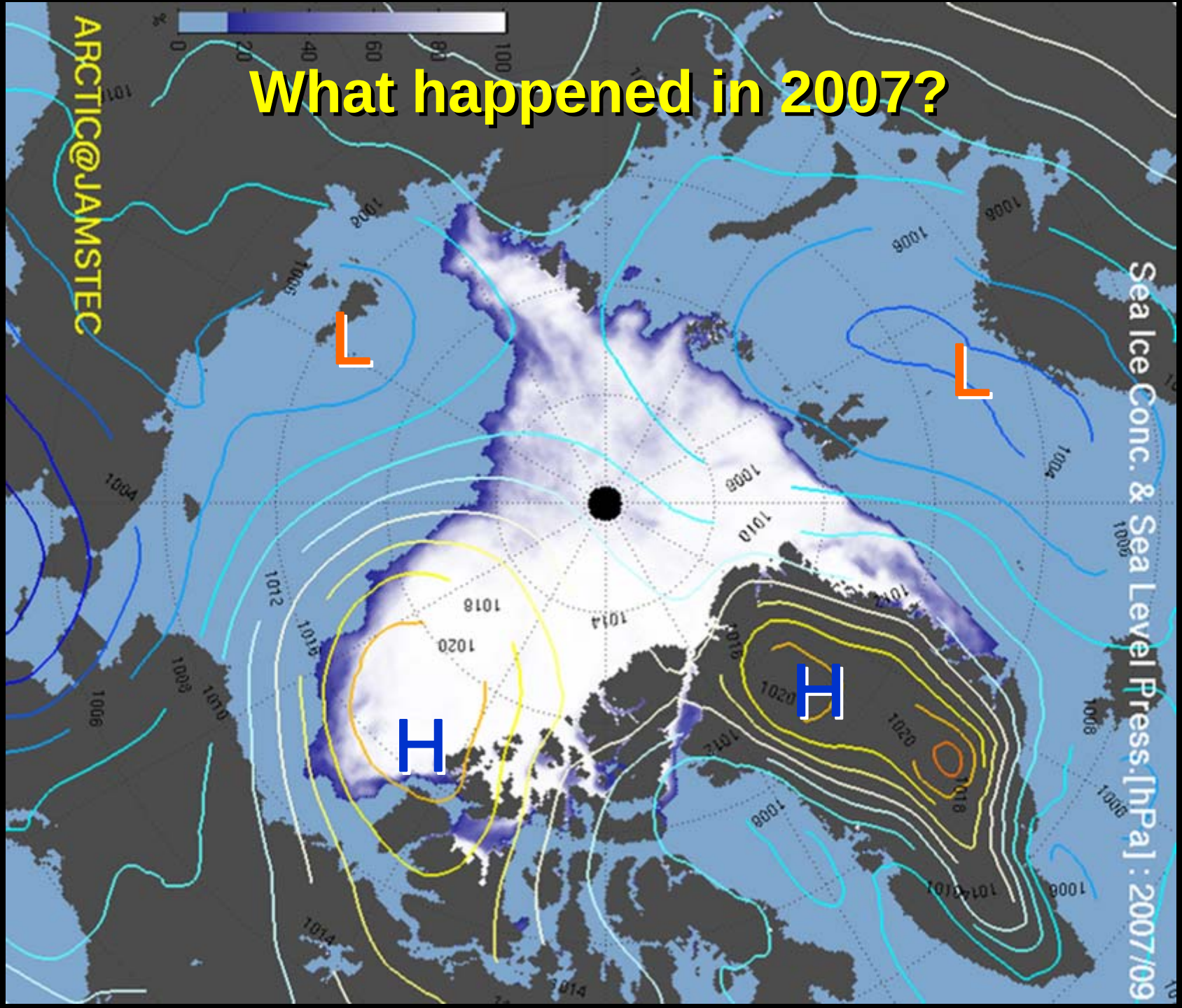
Ocean warming was sustained

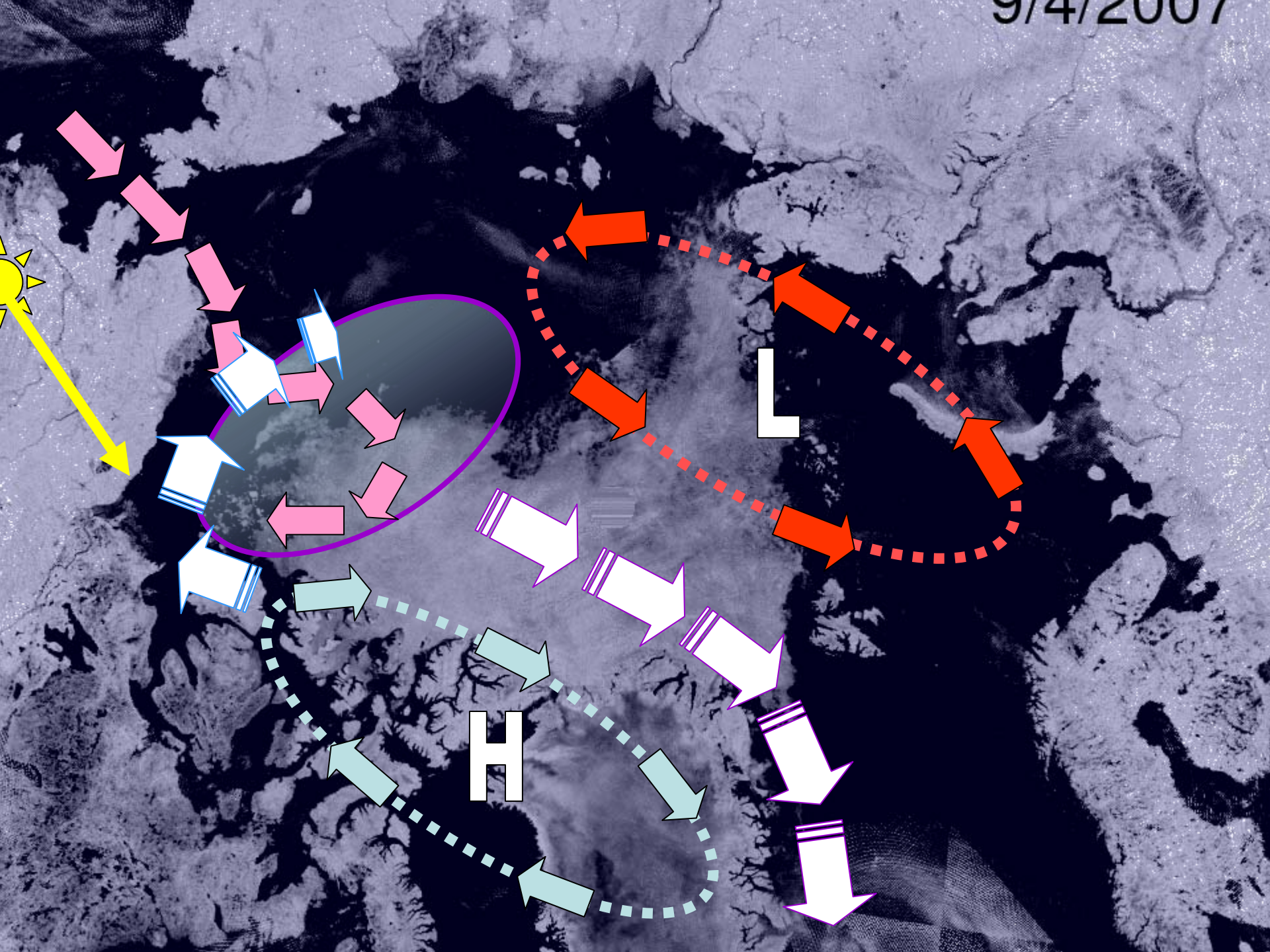
ocean-ice feedback > ice-albedo feedback



Area: 74-76°N, 150-160°W

Koji Shimada


What happened in 2007?
ARCTIC@JAMSTEC
Sea Ice Conc. & Sea Level Press.[hPa] : 2007/09
L
L
H
H


9/4/2007
L
H

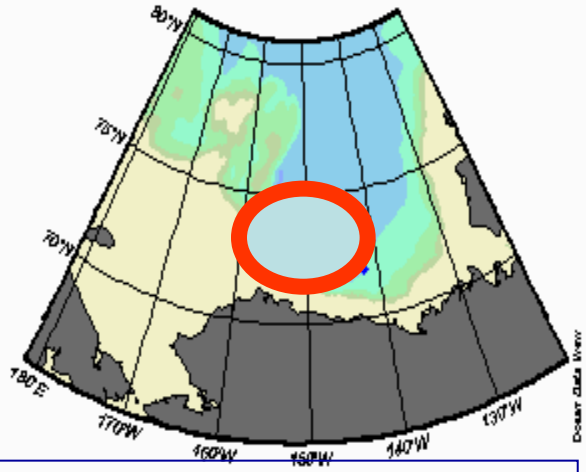
Canada Basin (0 - 100m) Time Series: 1987-2007

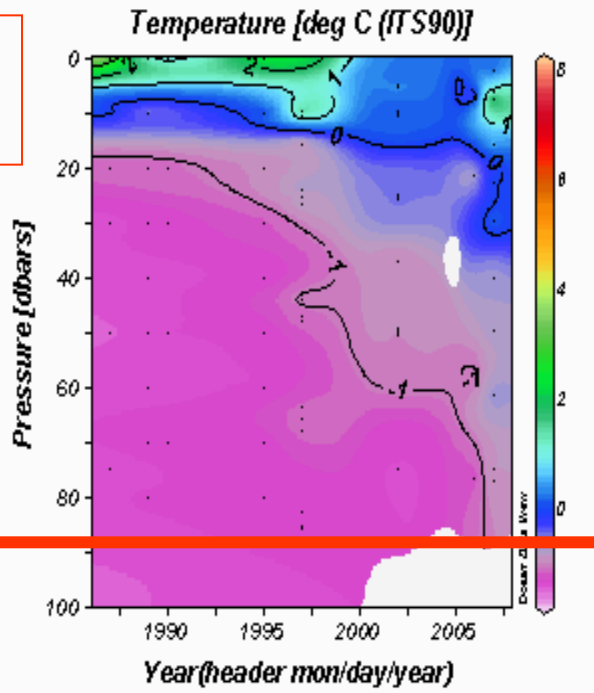
Using 18-O ratio to find freshwater compositions

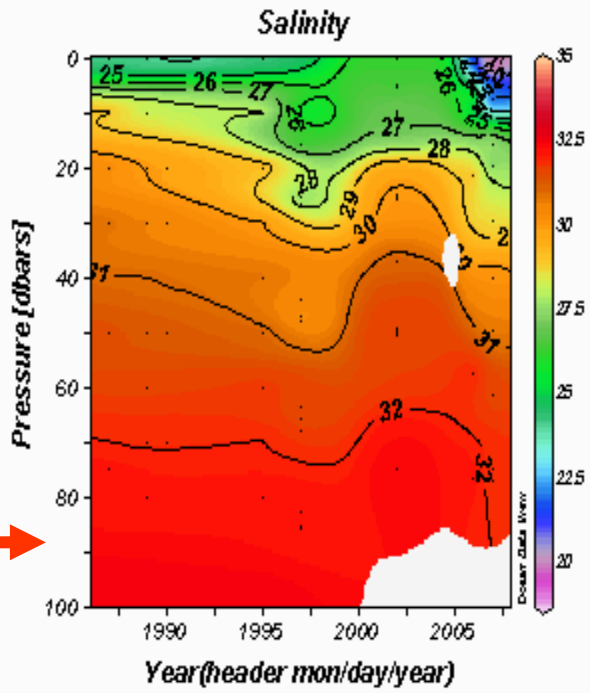
1. Warmer

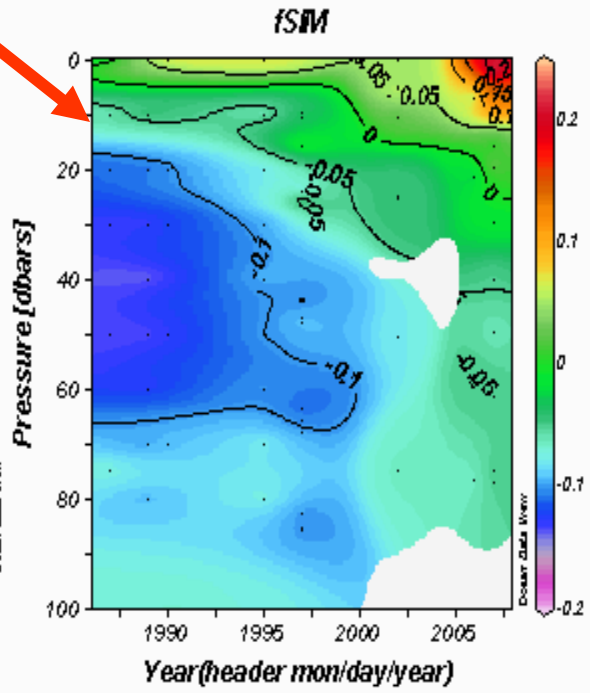
2. Fresher

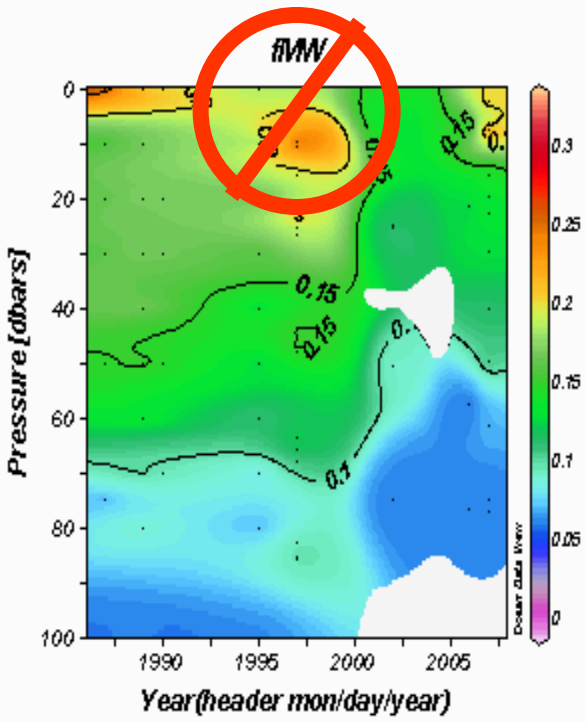
3. More Sea Ice Melt





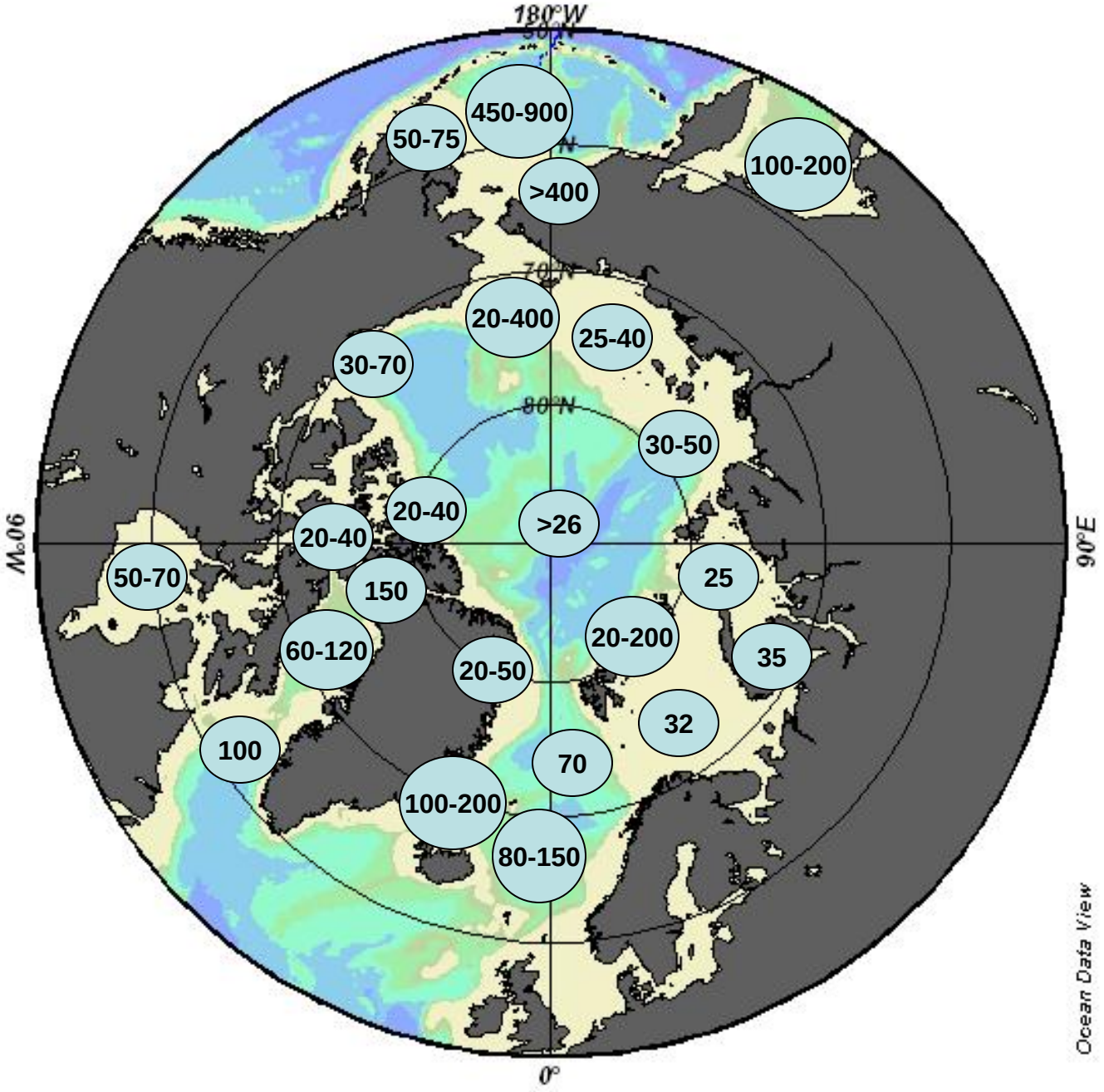


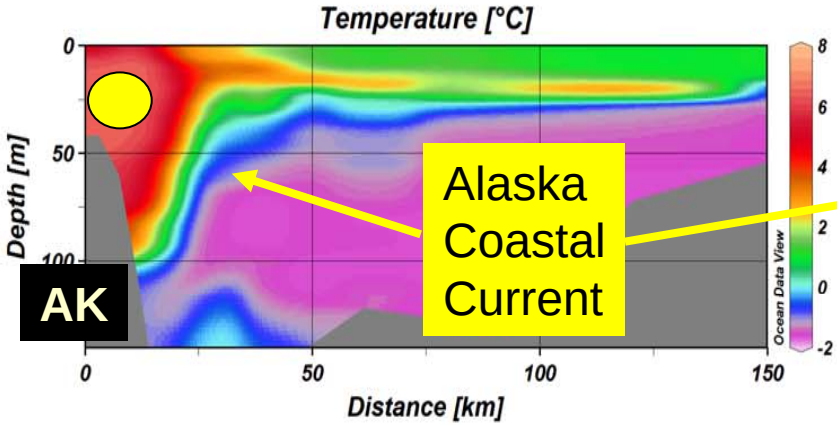


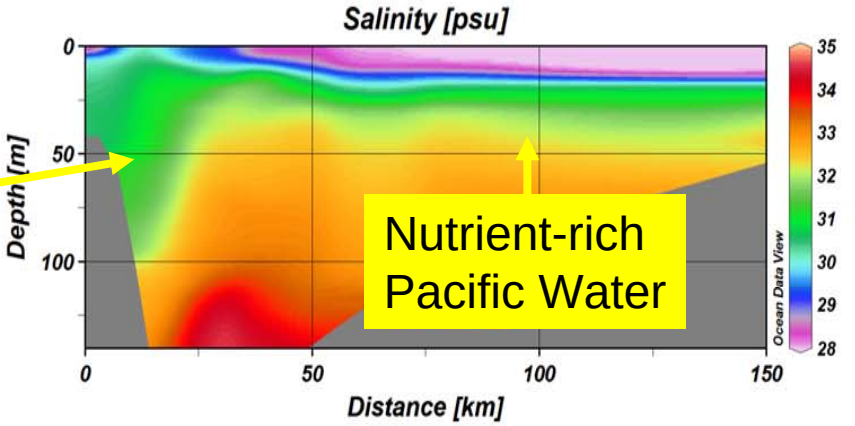


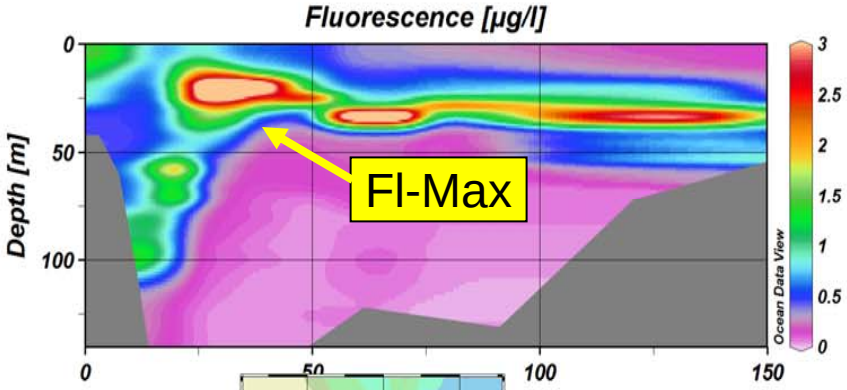
Yamamoto-Kawai

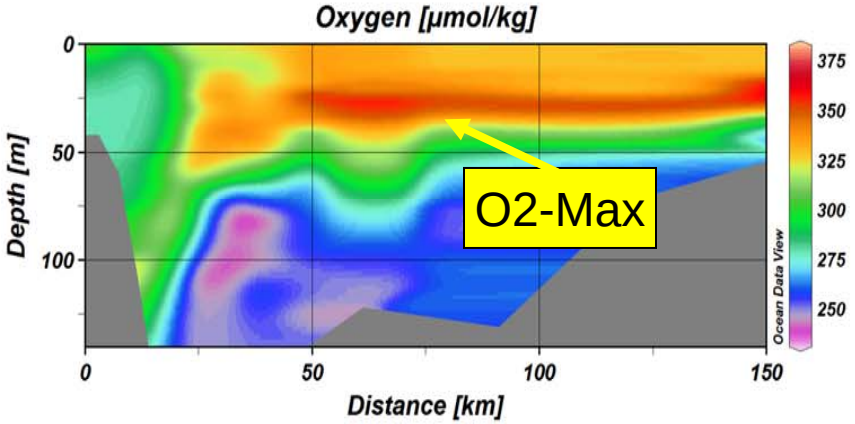

What
About Me?
B. Van Hardenberg

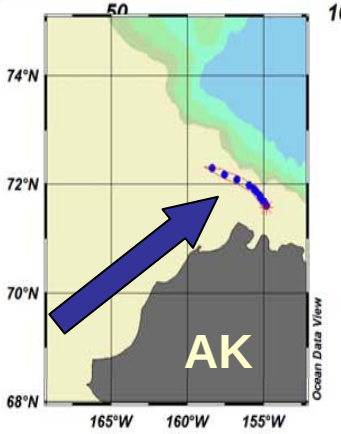

180°W
90°W
90°E
0°
450-900
50-75
100-200
>400
20-400
25-40
30-70
30-50
20-40
20-40
>26
50-70
150
25
60-120
20-200
35
20-50
32
100
70
100-200
80-150
Ocean Data View

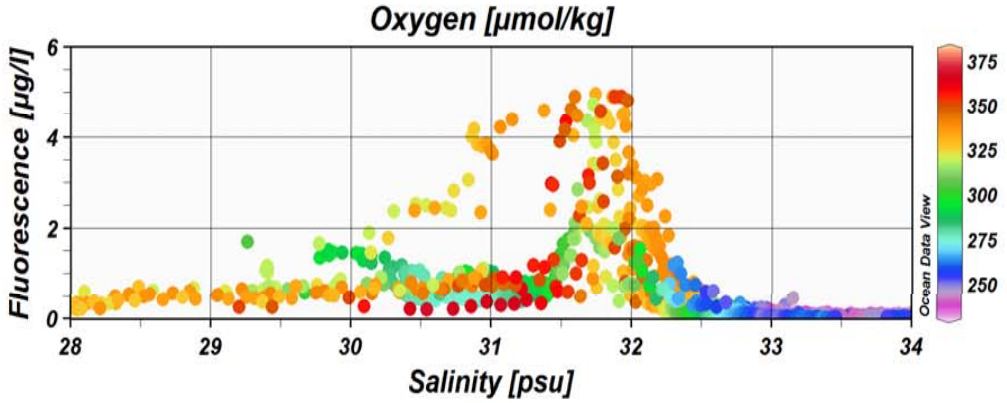

Temperature [°C]
Depth [m]
Distance [km]
AK
Alaska
Coastal
Current
Ocean Data View


Salinity [psu]
Depth [m]
Distance [km]
Nutrient-rich
Pacific Water
Ocean Data View

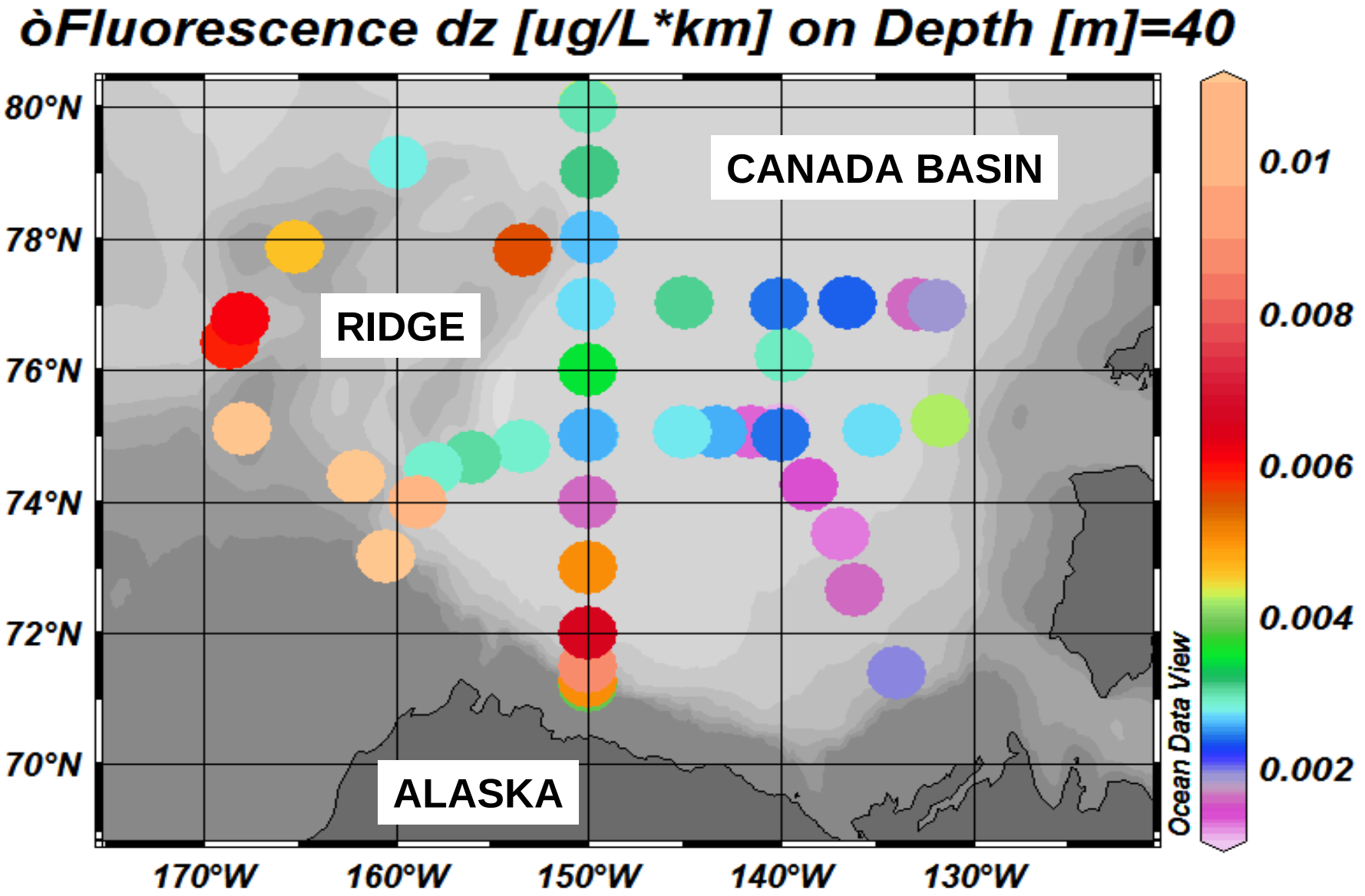

Fluorescence [µg/l]
Depth [m]
Fl-Max
Ocean Data View


Oxygen [µmol/kg]
Depth [m]
Distance [km]
O2-Max
Ocean Data View


74°N
72°N
70°N
68°N
165°W
160°W
155°W
AK
Ocean Data View


Oxygen [µmol/kg]
Fluorescence [µg/l]
Salinity [psu]
Ocean Data View

PACIFIC PASTURES



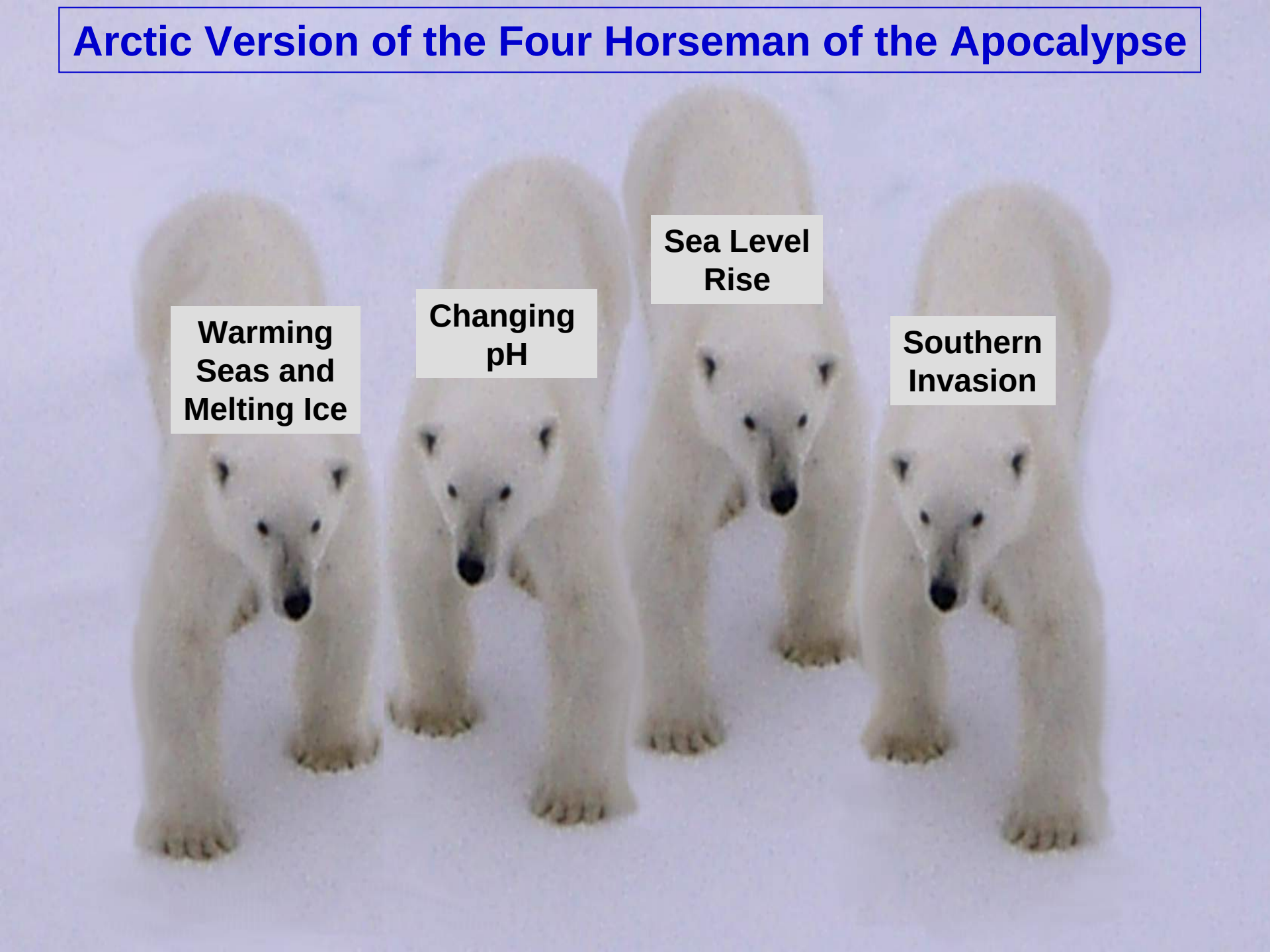

Retreat of Sea Ice
Shelf-break Upwelling
Wind-Generated Mixing
Increase Light

Changing pH ?

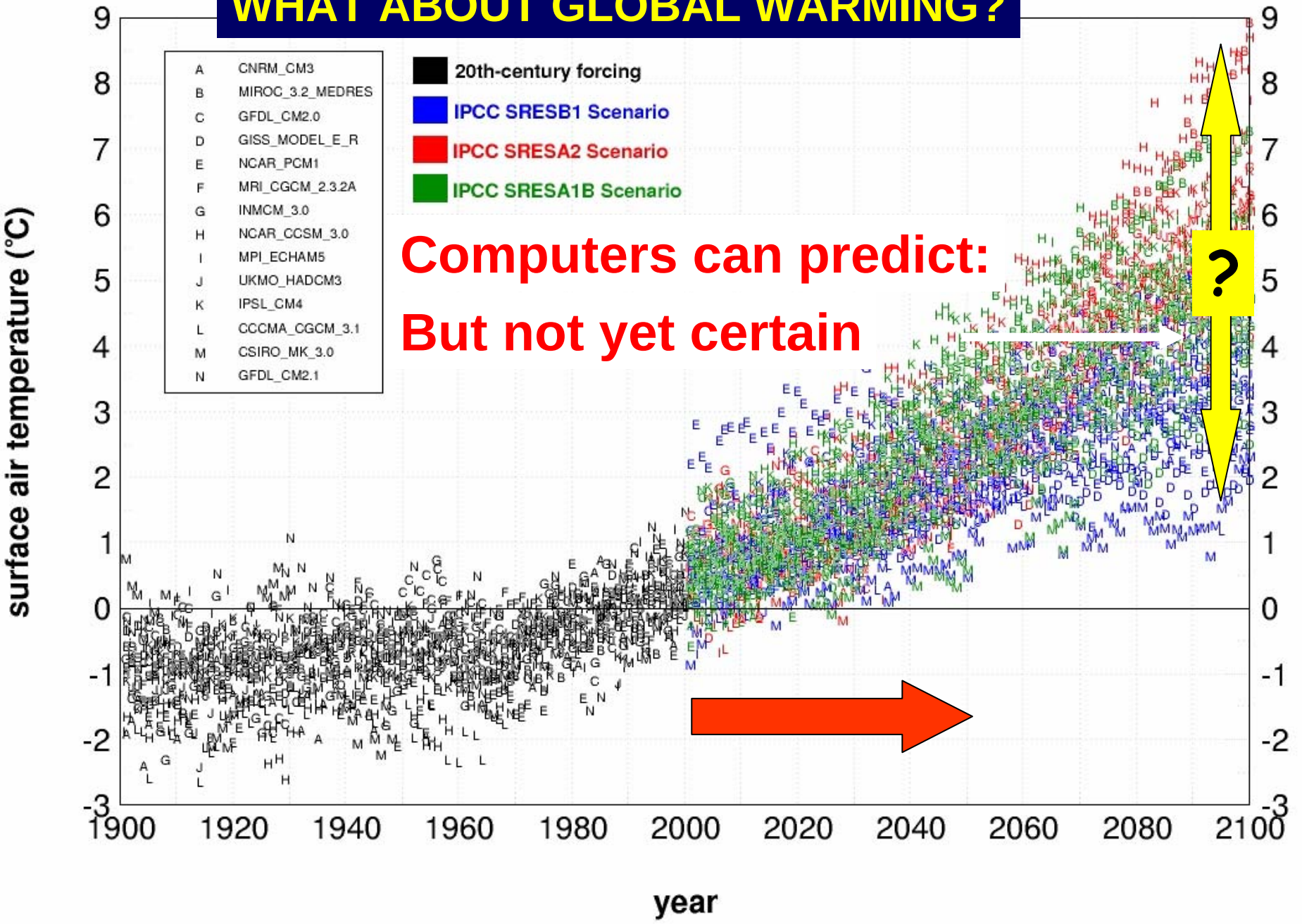
R. Hopcroft


Sea Level Rise?

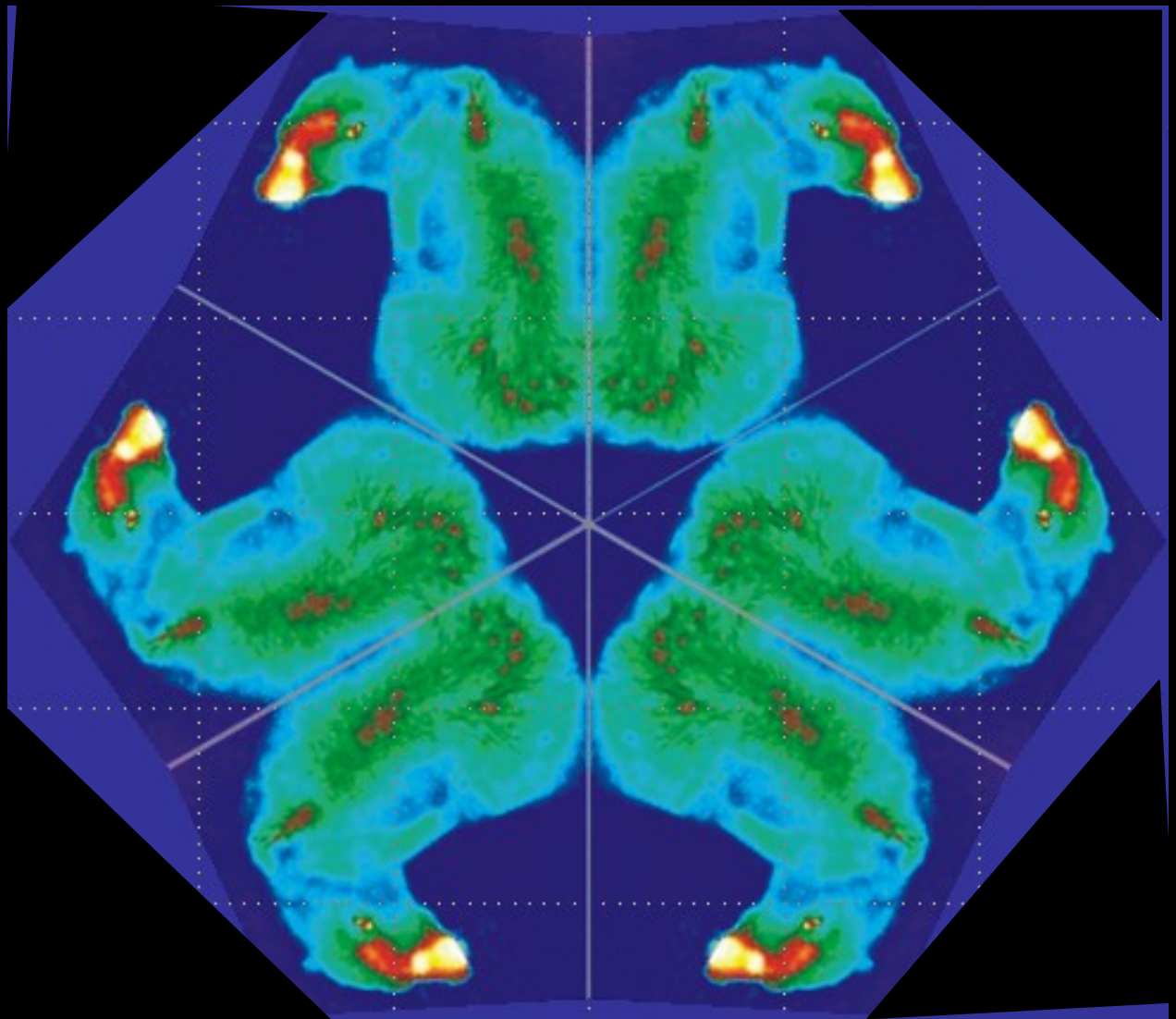
Arctic Version of the Four Horseman of the Apocalypse



WHAT ABOUT GLOBAL WARMING?



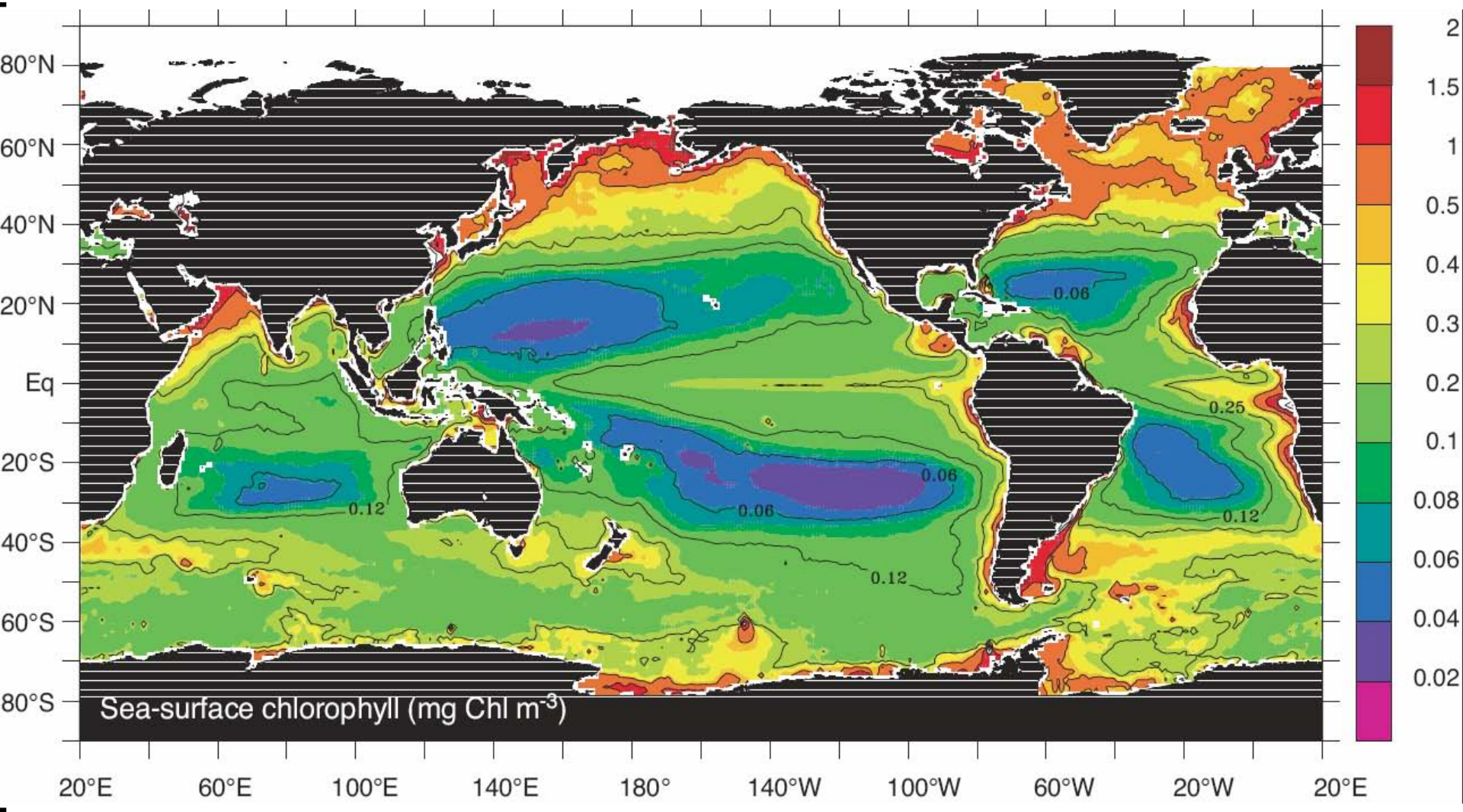
III. Observing the Northern Ocean (Strategy)



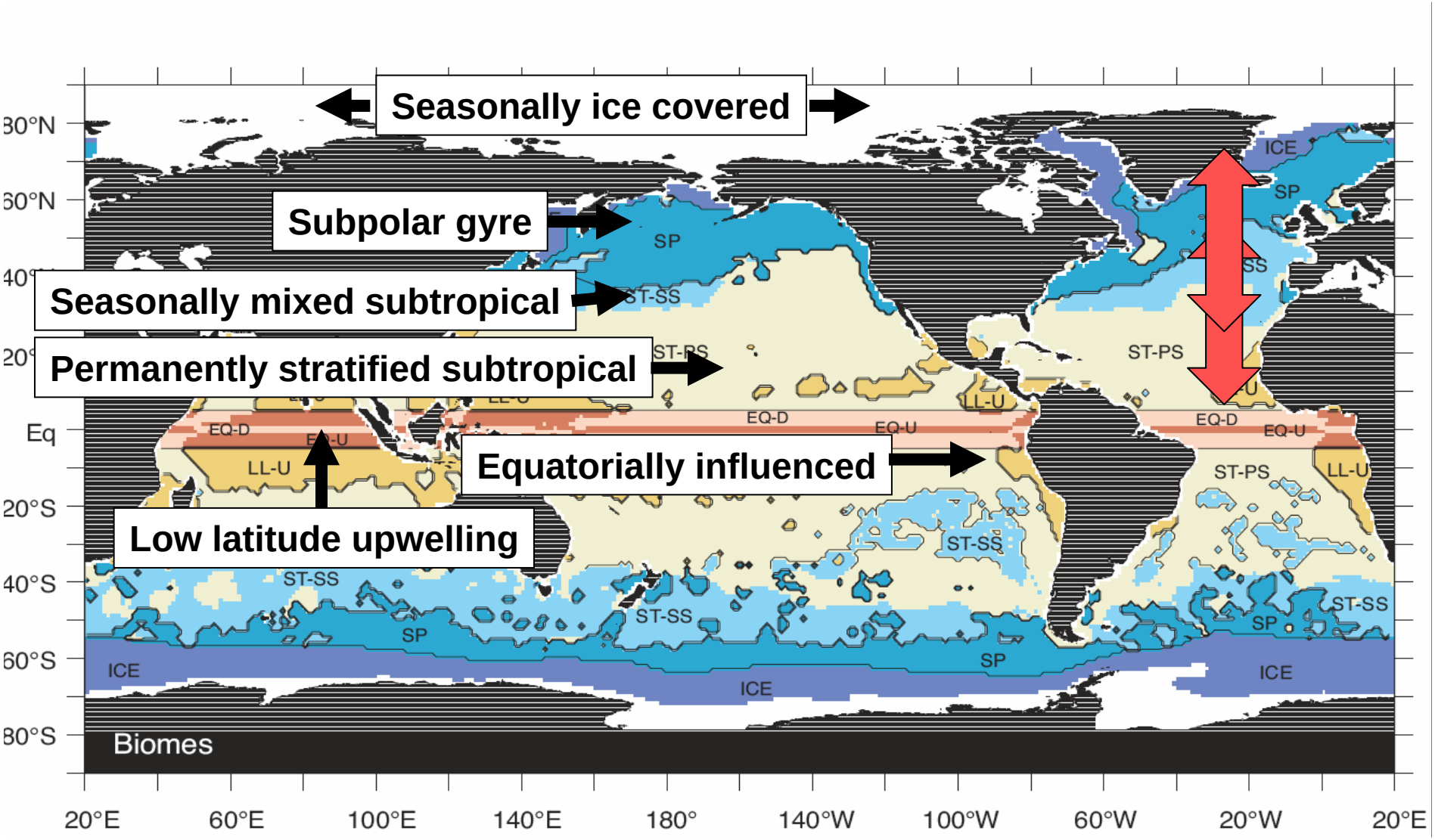
Biome definitions

(From Sarmiento et al., 2004)

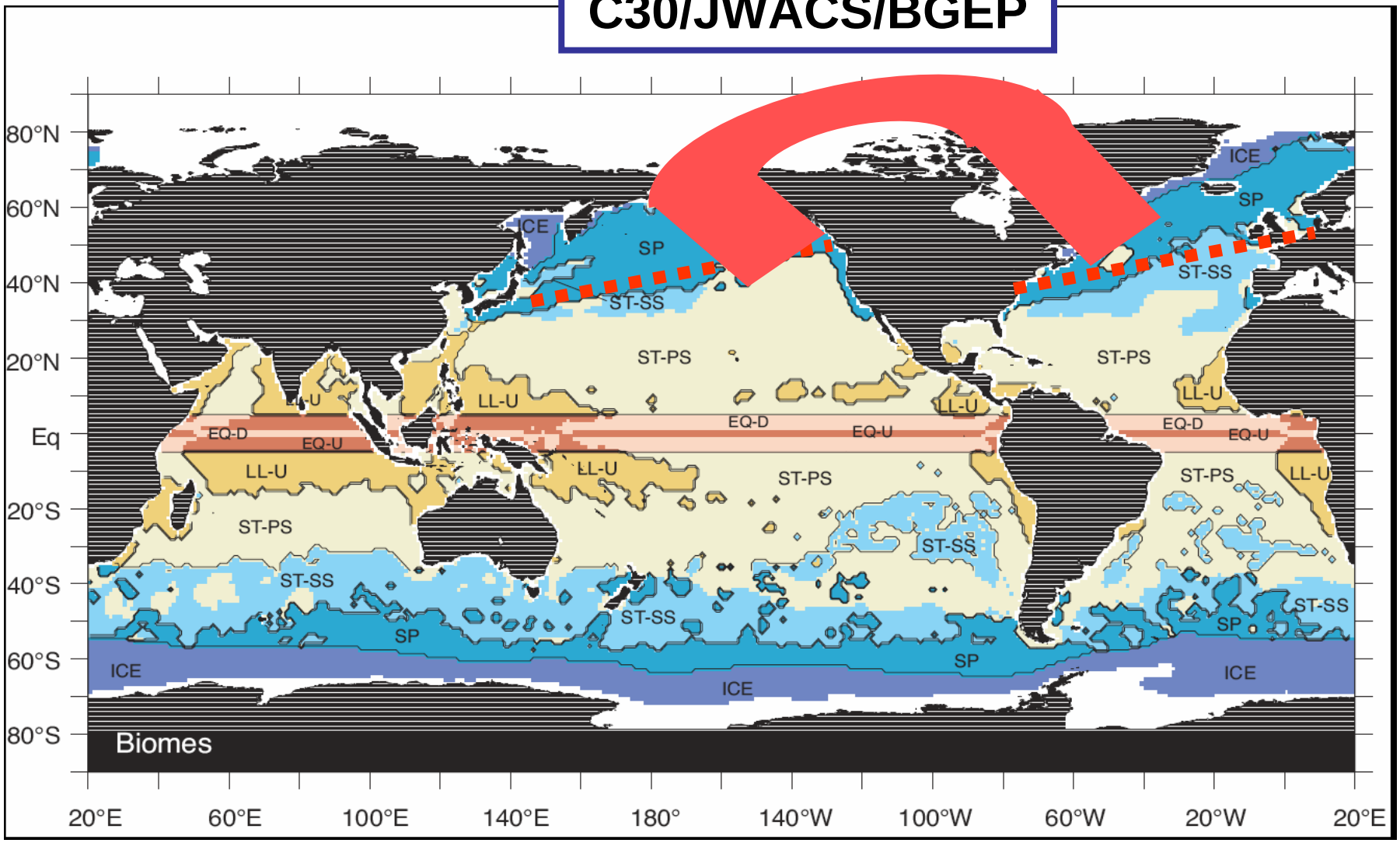
The chlorophyll distribution and ocean physics motivate breaking the world up into six “biomes”



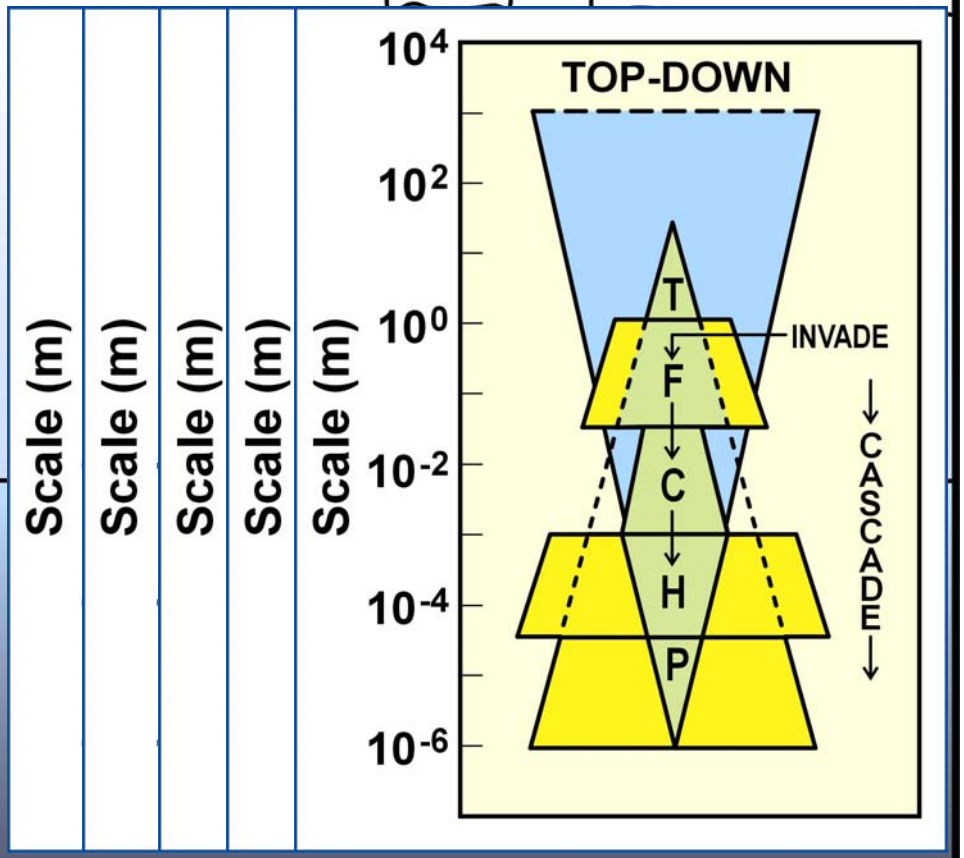
DIAGNOSTICS

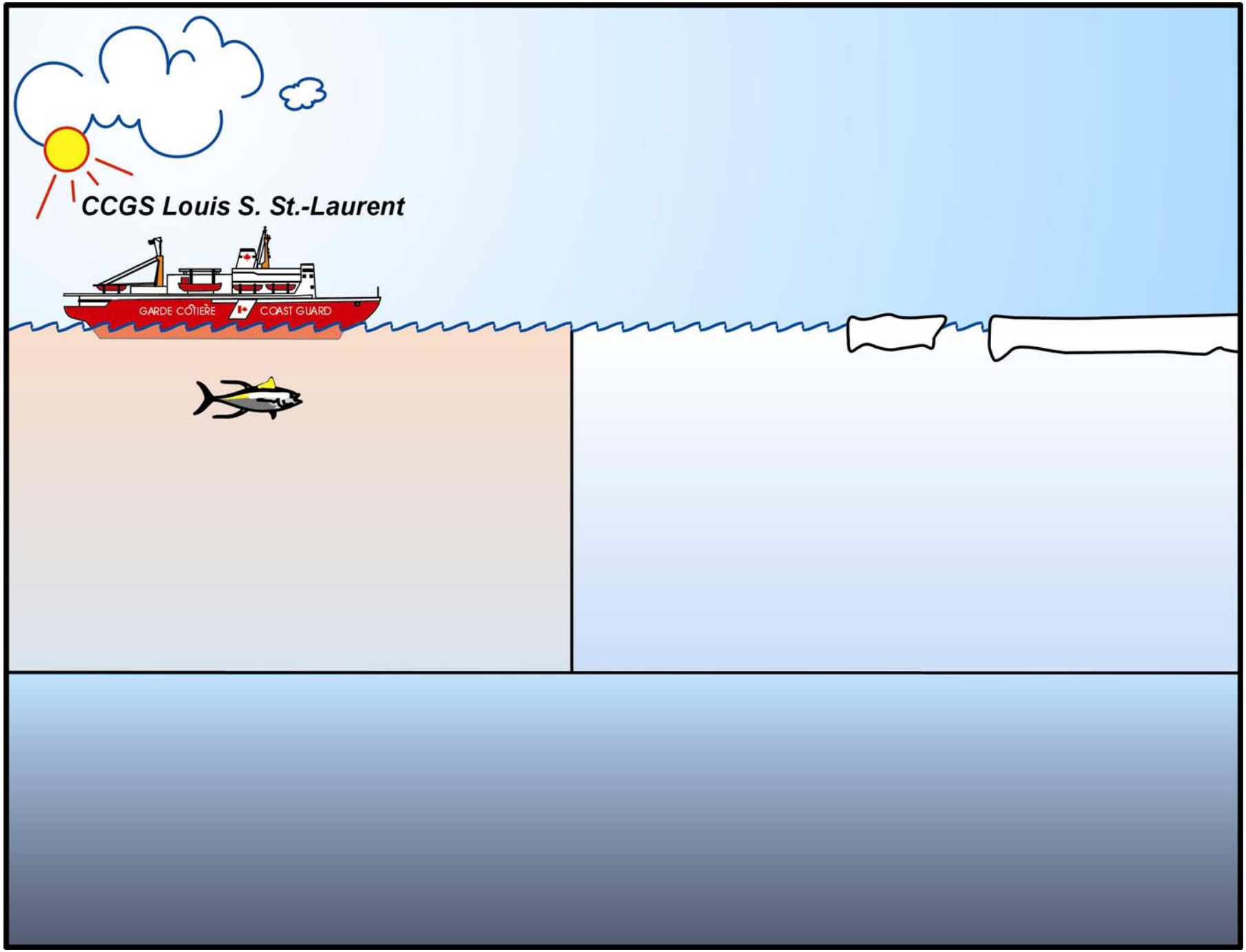


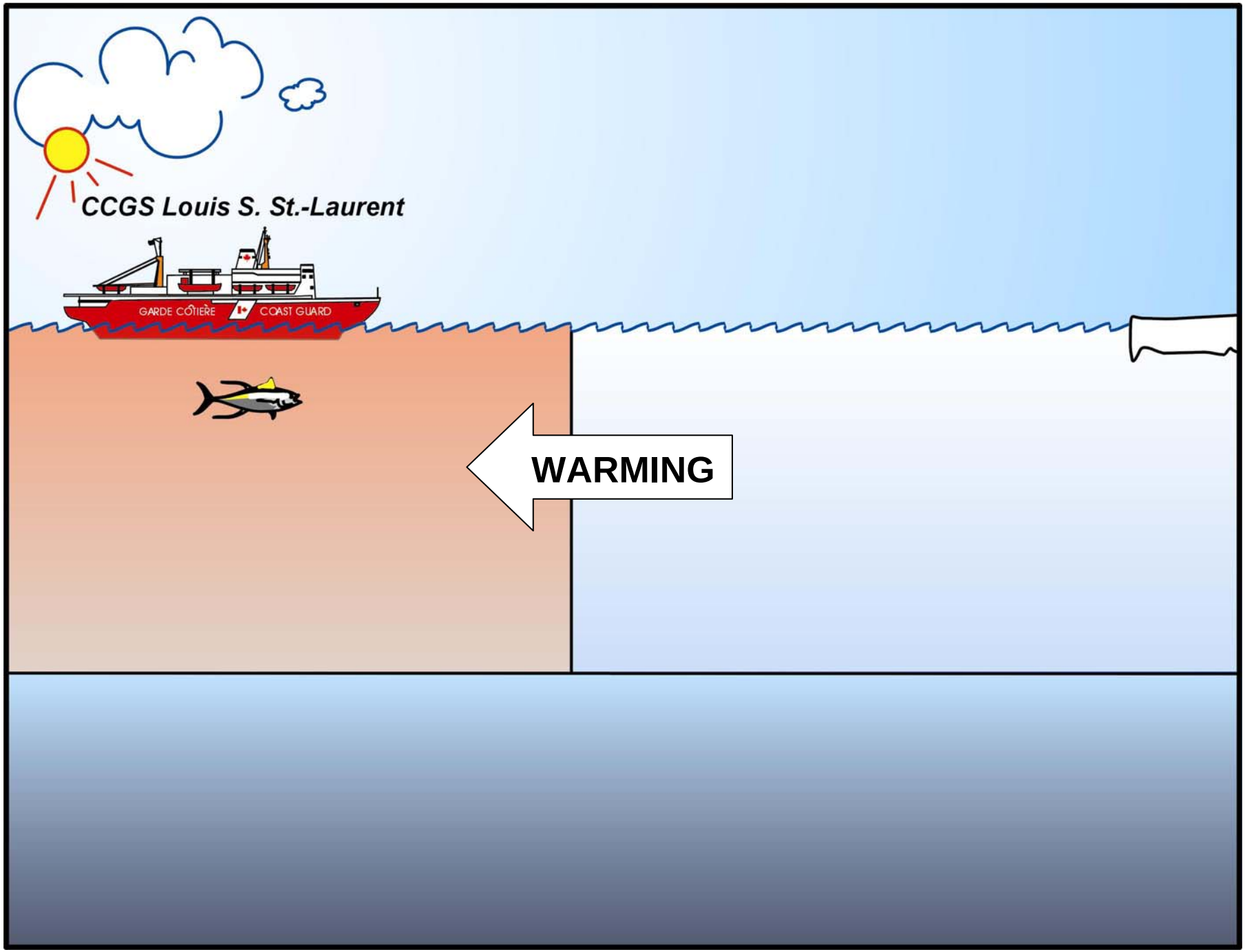
Canada/Japan/USA
C30/JWACS/BGEP

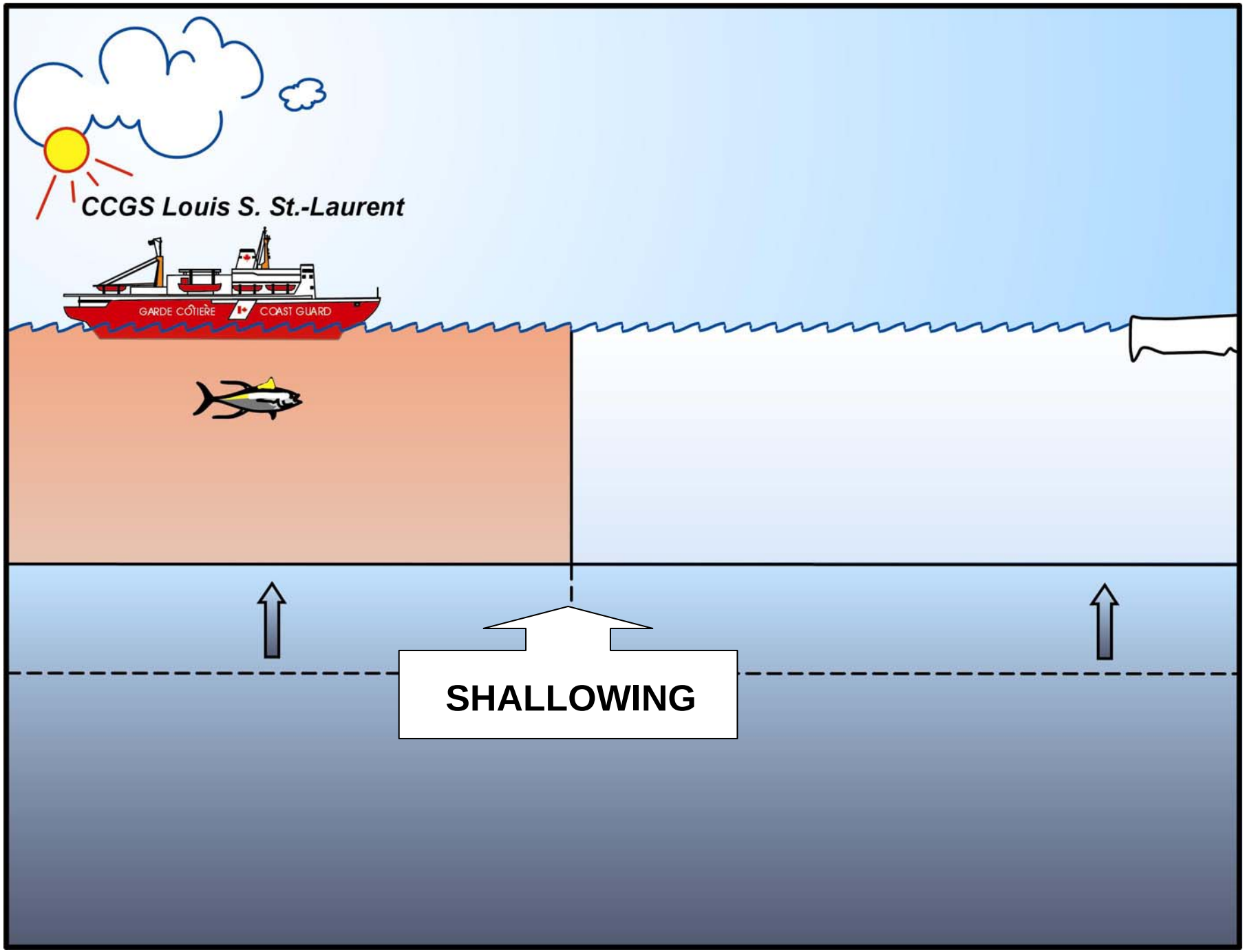


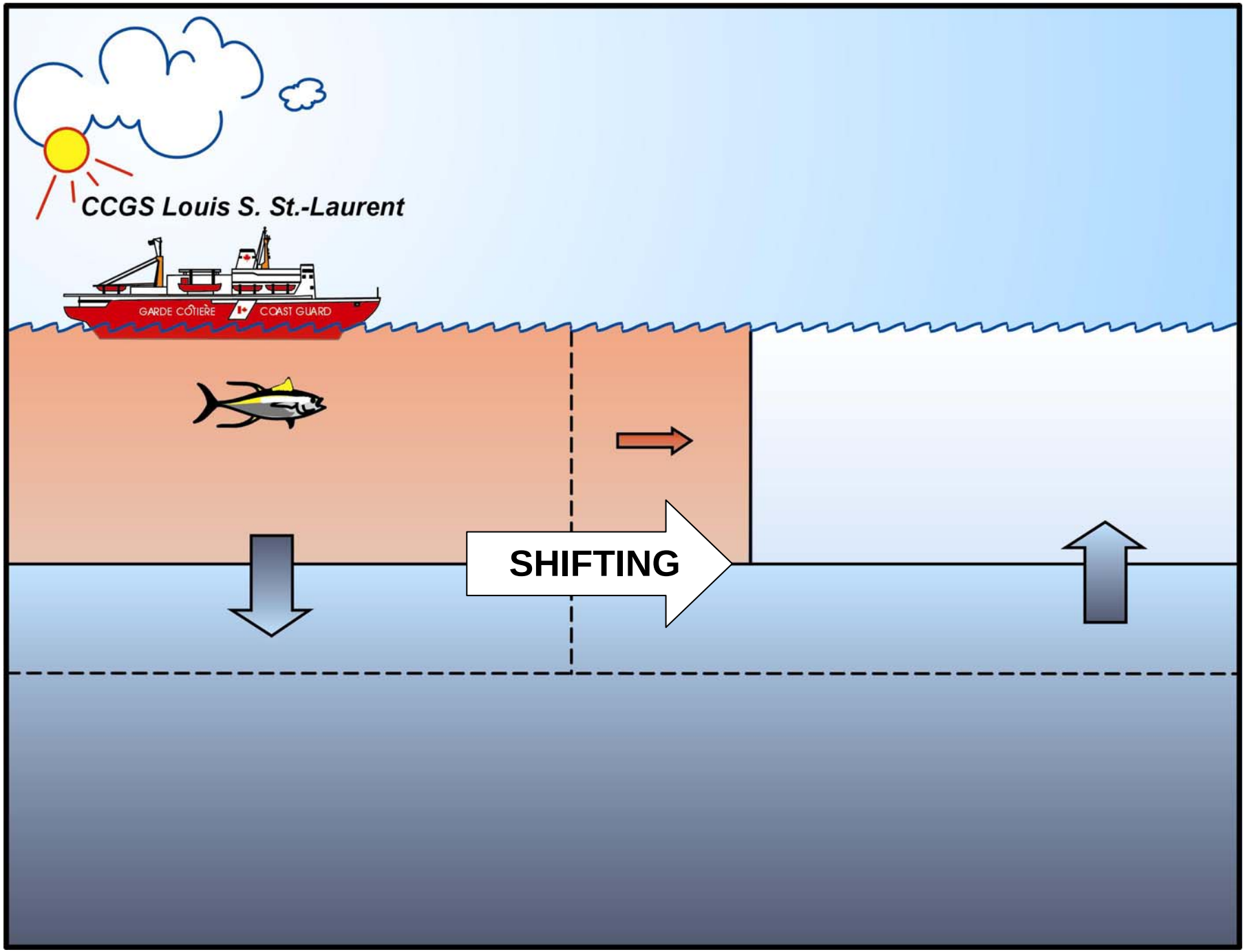
CONSIDER FOODWEBS

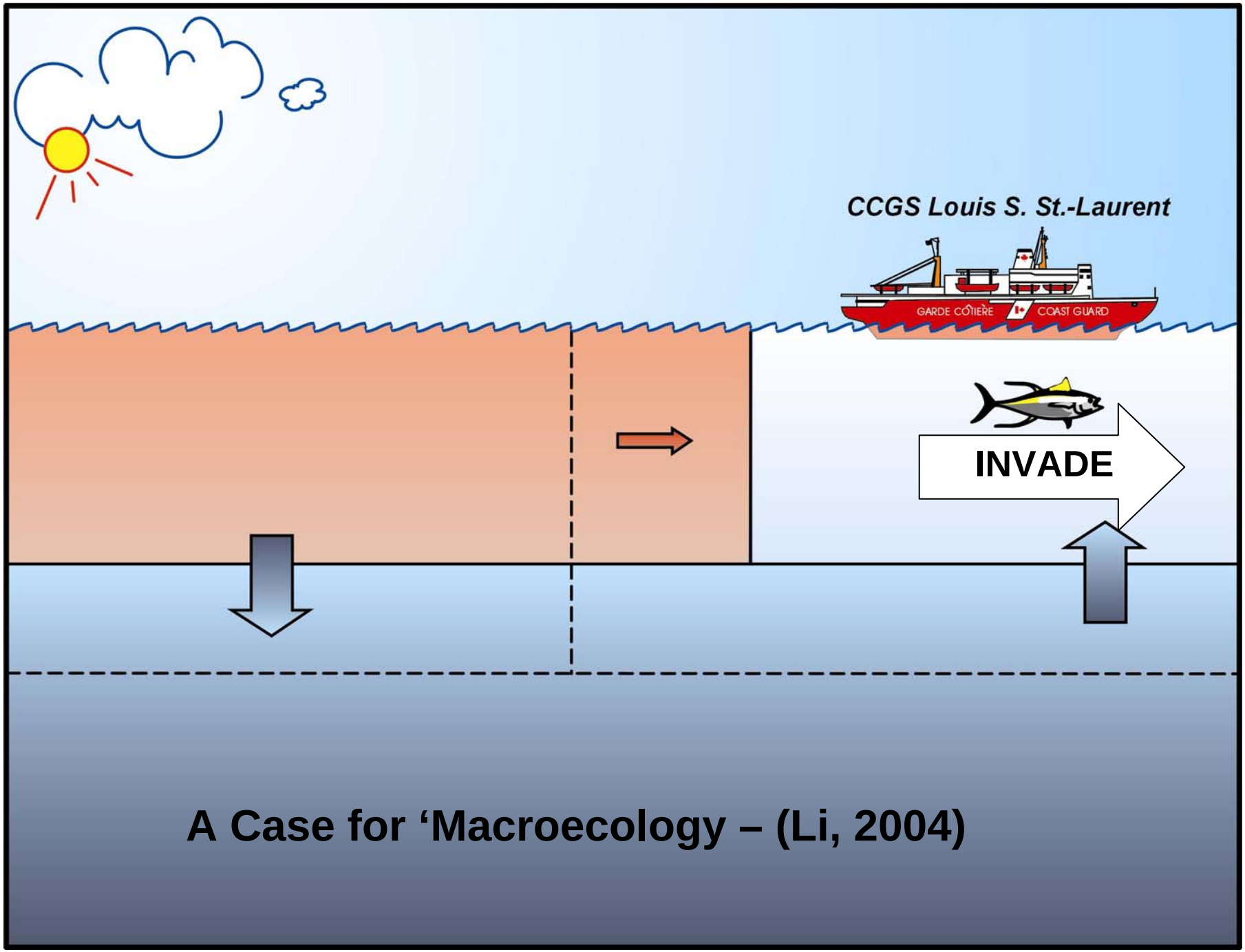



CCGS Louis S. St.-Laurent
GARDE CÔTIÈRE
COAST GUARD


CCGS Louis S. St.-Laurent
GARDE CÔTIÈRE
COAST GUARD
WARMING


CCGS Louis S. St.-Laurent
GARDE CÔTIÈRE
COAST GUARD
SHALLOWING


CCGS Louis S. St.-Laurent
GARDE CÔTIÈRE
COAST GUARD
SHIFTING

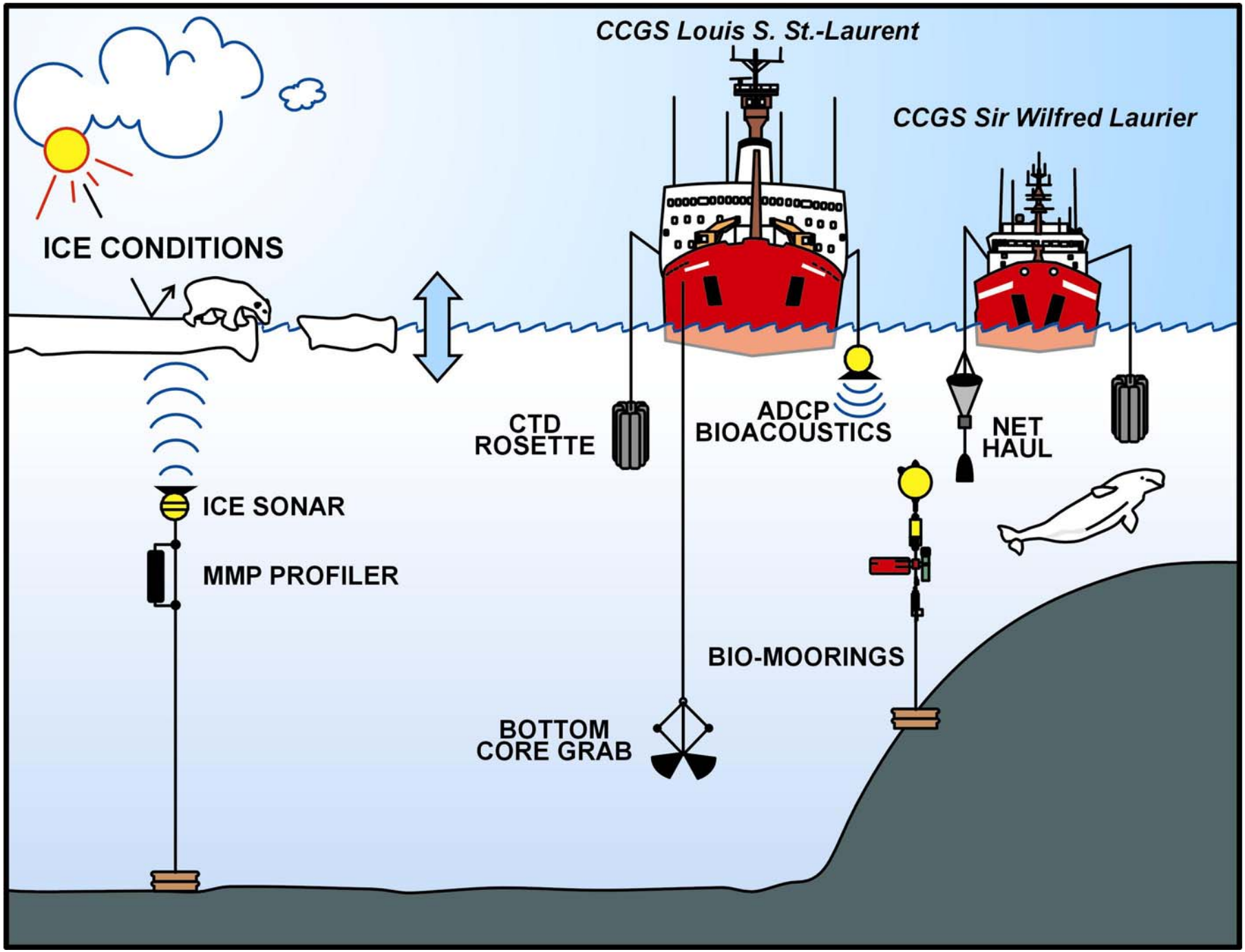


A Case for 'Macroecology – (Li, 2004)

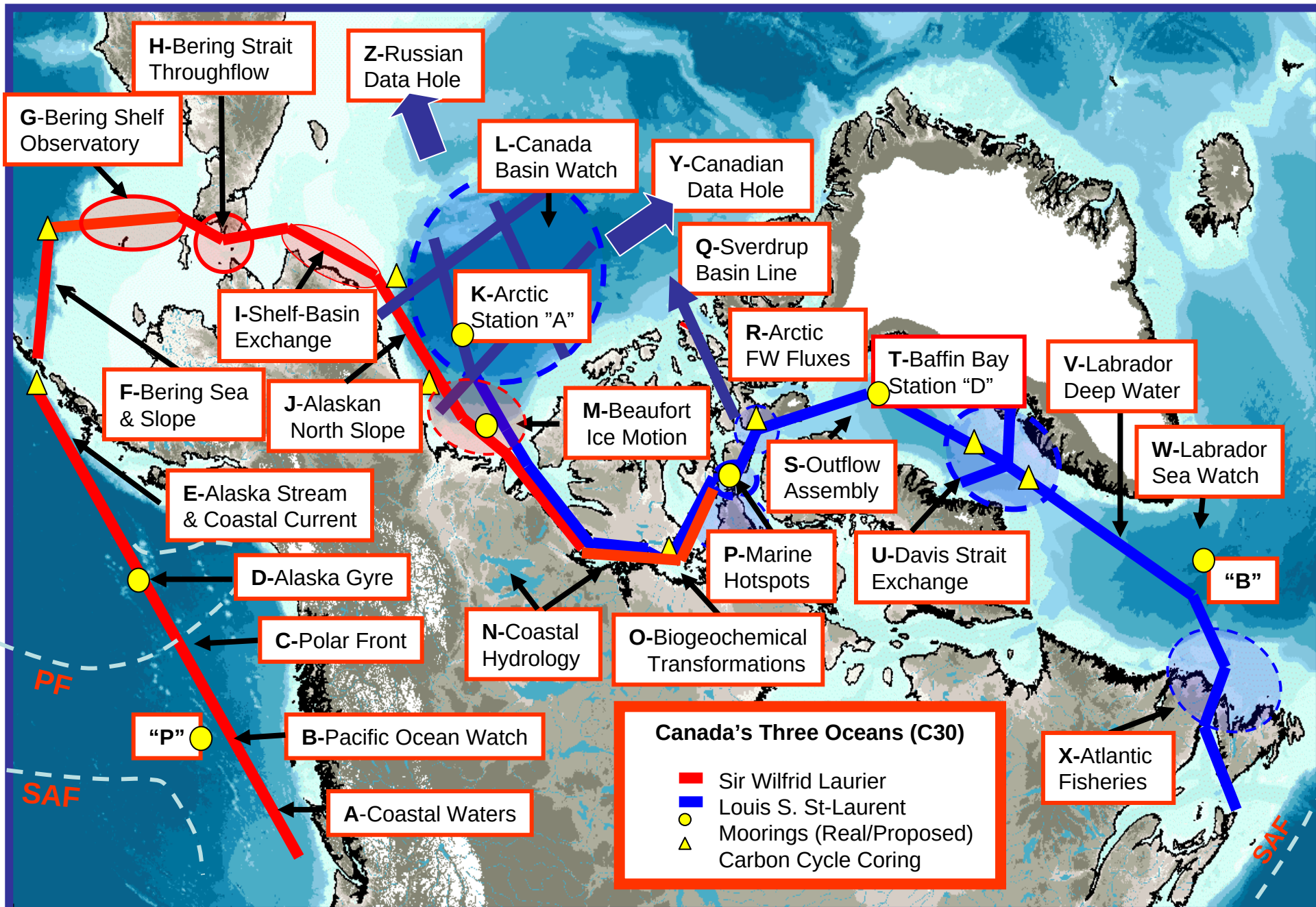
The International Polar Year

The Canada's 3 Oceans Project

C3O Requirements…


CCGS Louis S. St.-Laurent
CCGS Sir Wilfred Laurier
ICE CONDITIONS
CTD
ROSETTE
ADCP
BIOACOUSTICS
NET
HAUL
ICE SONAR
MMP PROFILER
BIO-MOORINGS
BOTTOM
CORE GRAB

Marine Canada Eh to Zed: 26 Regional Foci for Biogeographical Monitoring



Ship Work

Moorings

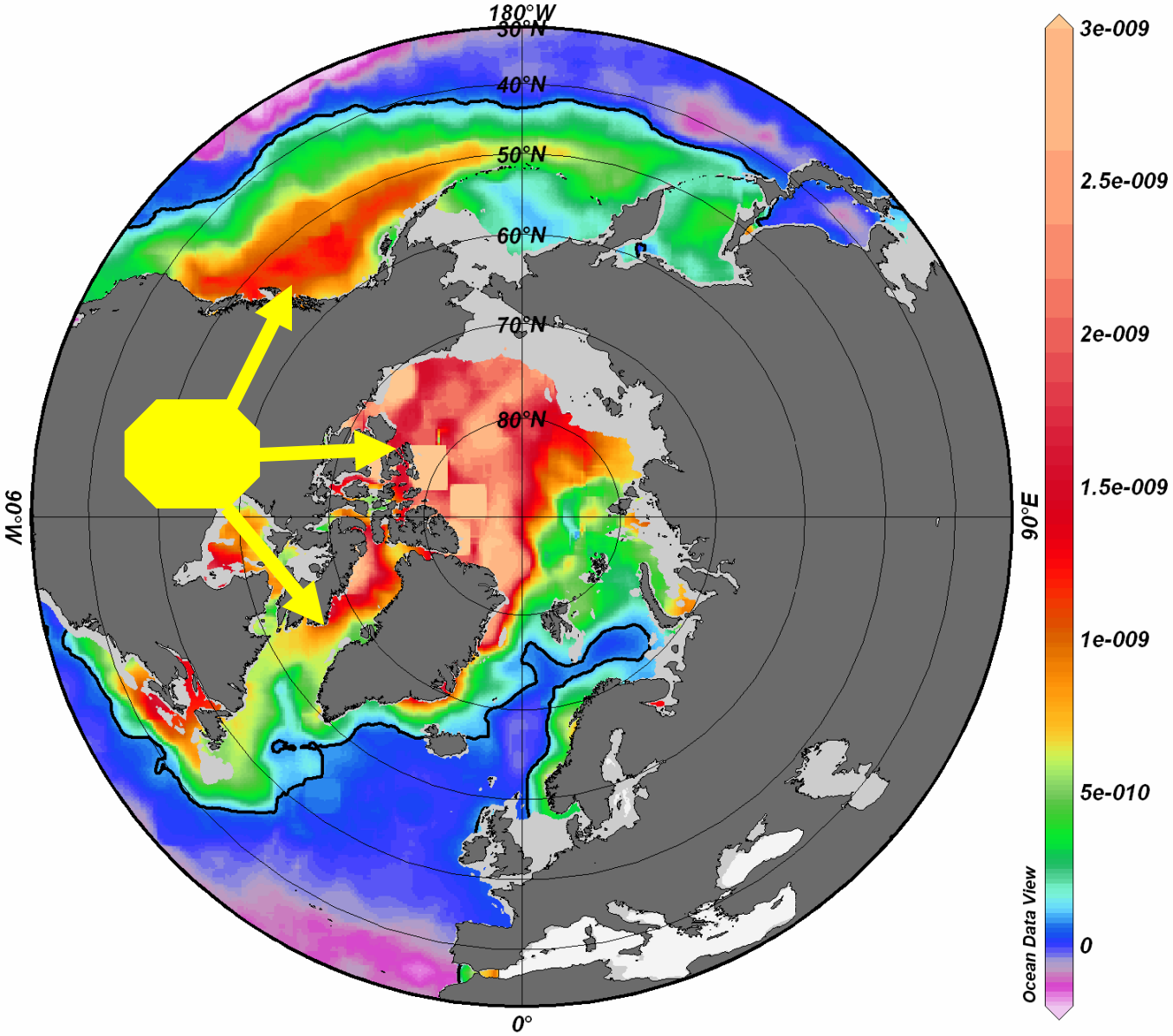
WATER SAMPLING

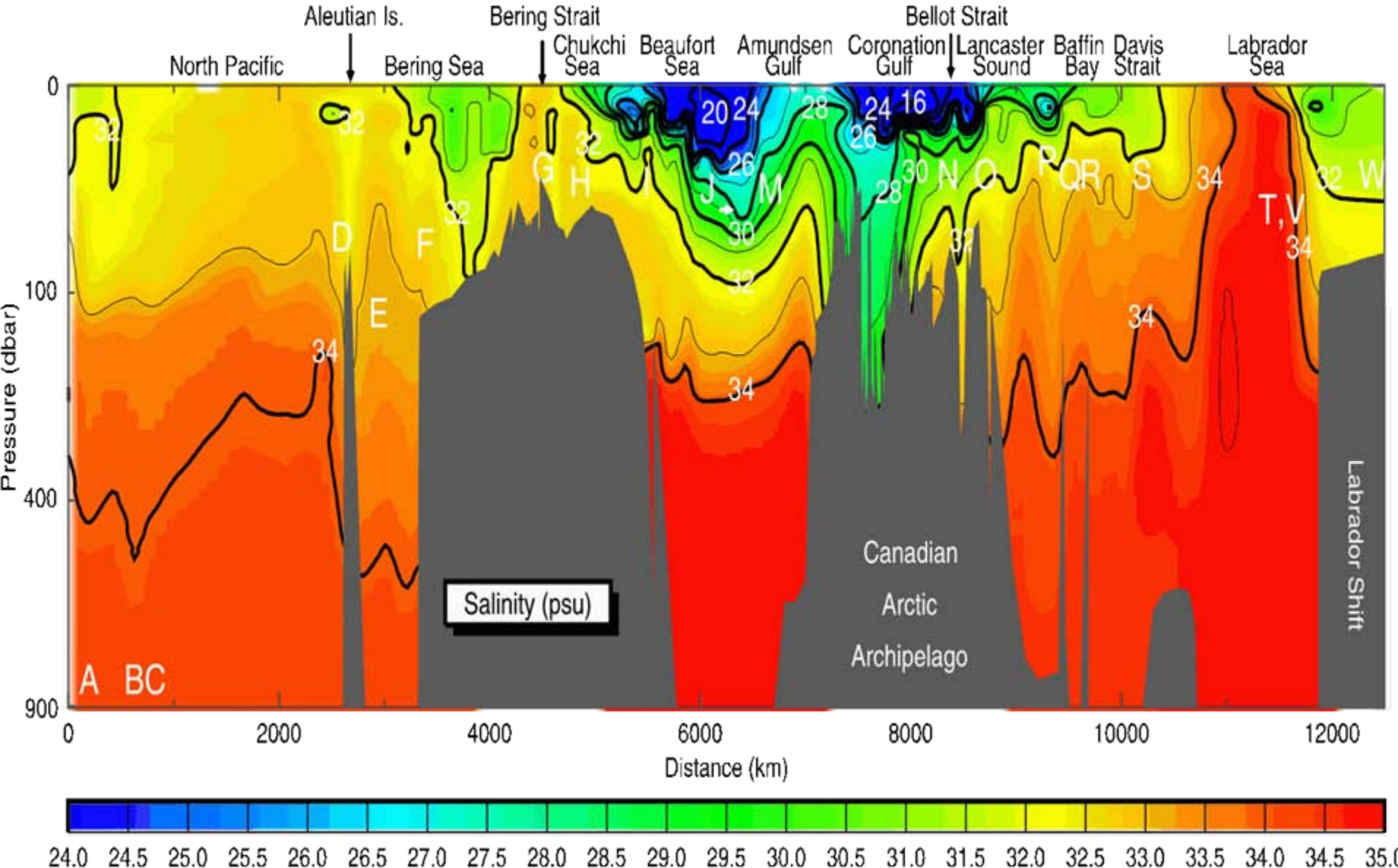
PLANKTON SAMPLING

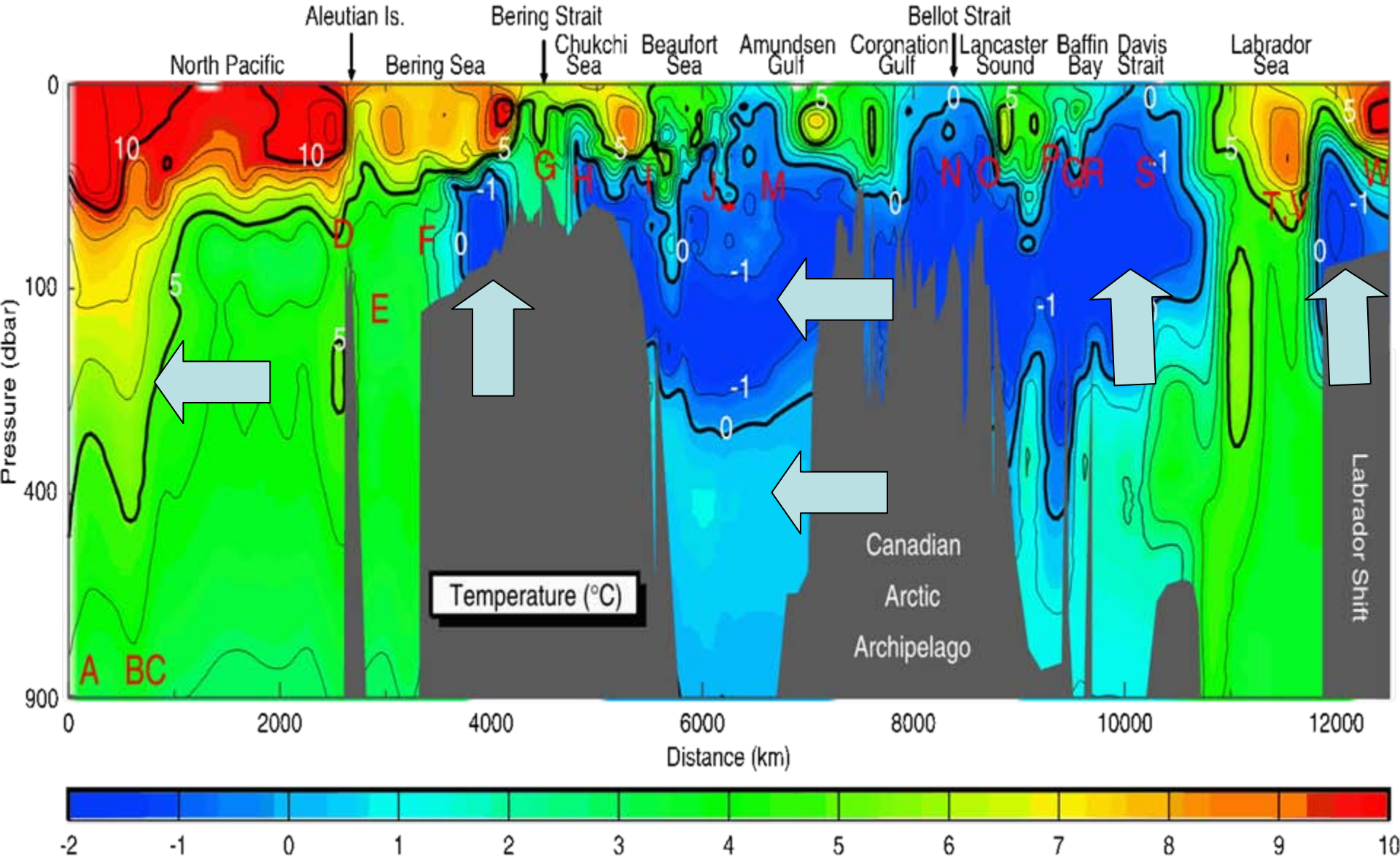
LAB WORK

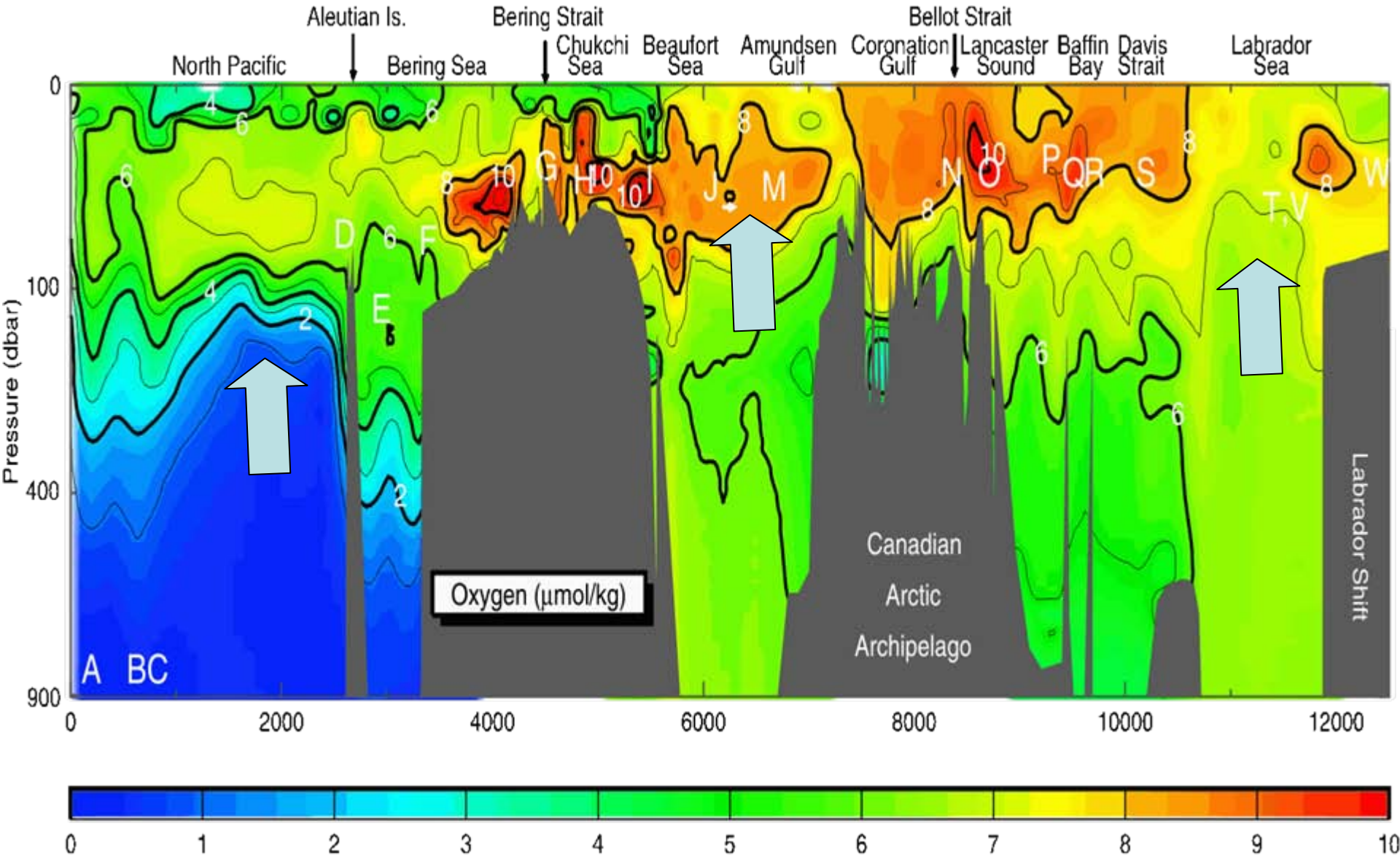
ICE WORK

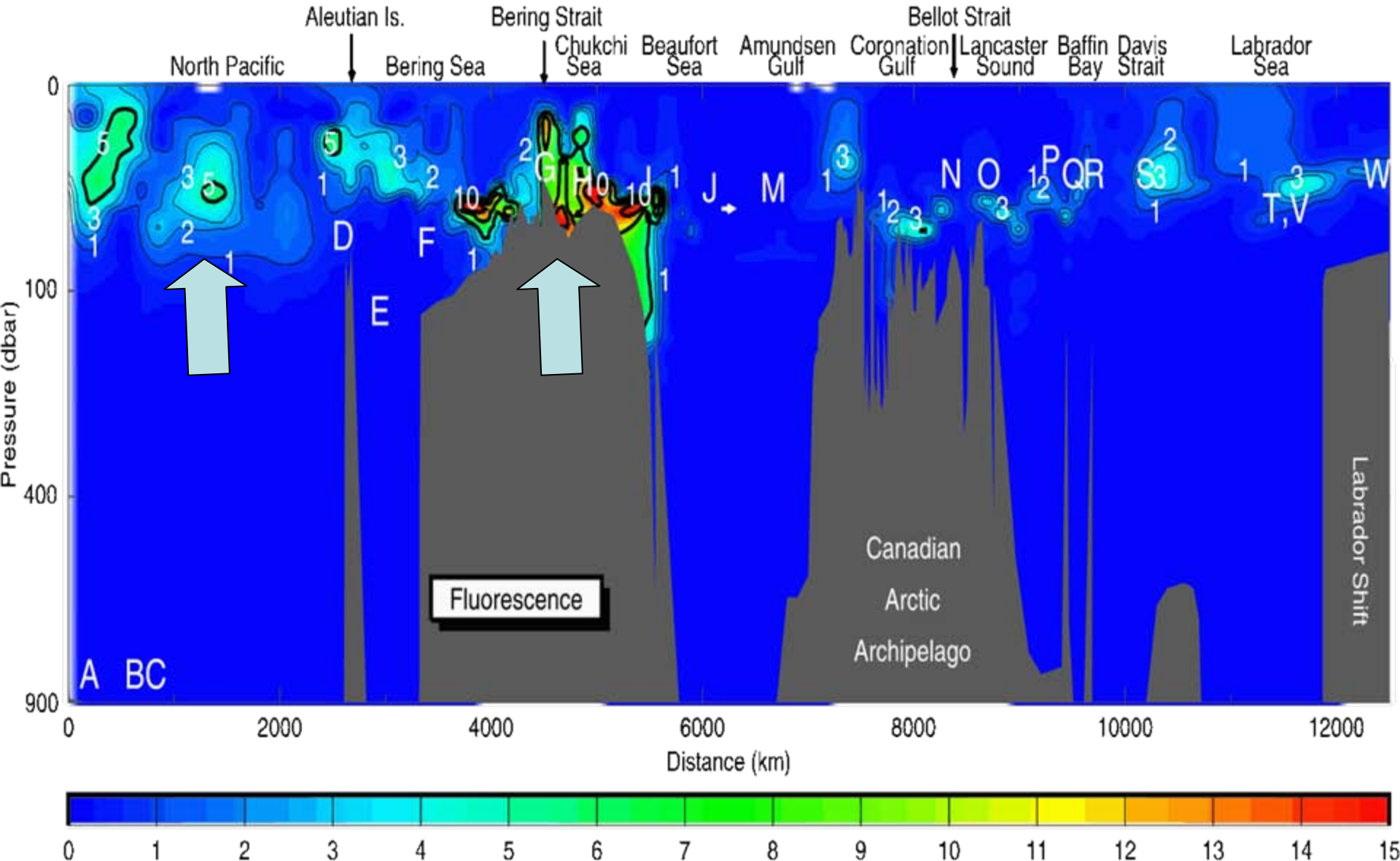
Zooming-in … Hot Spots


pvs on pressure=100
180°W
30°N
40°N
50°N
60°N
70°N
80°N
90°E
0°
M06
3e-009
2.5e-009
2e-009
1.5e-009
1e-009
5e-010
0
Ocean Data View


Aleutian Is.
Bering Strait
Bellot Strait
North Pacific
Bering Sea
Chukchi Sea
Beaufort Sea
Amundsen Gulf
Coronation Gulf
Lancaster Sound
Baffin Bay
Davis Strait
Labrador Sea
Pressure (dbar)
0
100
400
900
0
2000
4000
6000
8000
10000
12000
Distance (km)
Salinity (psu)
Canadian Arctic Archipelago
Labrador Shift
A
BC
D
E
F
G
H
I
J
M
N
O
P
QR
S
T,V
W
24.0 24.5 25.0 25.5 26.0 26.5 27.0 27.5 28.0 28.5 29.0 29.5 30.0 30.5 31.0 31.5 32.0 32.5 33.0 33.5 34.0 34.5 35.0


Aleutian Is.
Bering Strait
Bellot Strait
North Pacific
Bering Sea
Chukchi Sea
Beaufort Sea
Amundsen Gulf
Coronation Gulf
Lancaster Sound
Baffin Bay
Davis Strait
Labrador Sea
Pressure (dbar)
0
100
400
900
A
BC
D
E
F
G
H
I
J
M
N
O
P
R
S
T
U
W
Temperature (°C)
Canadian Arctic Archipelago
Labrador Shift
0
2000
4000
6000
8000
10000
12000
Distance (km)
-2
-1
0
1
2
3
4
5
6
7
8
9
10


Aleutian Is.
Bering Strait
Bellot Strait
North Pacific
Bering Sea
Chukchi Sea
Beaufort Sea
Amundsen Gulf
Coronation Gulf
Lancaster Sound
Baffin Bay
Davis Strait
Labrador Sea
Pressure (dbar)
0
100
400
900
0
2000
4000
6000
8000
10000
12000
A
BC
D
E
F
G
H
I
J
M
N
O
P
Q
R
S
T
V
W
Oxygen (µmol/kg)
Canadian Arctic Archipelago
Labrador Shift
0
1
2
3
4
5
6
7
8
9
10


Aleutian Is.
Bering Strait
Bellot Strait
North Pacific
Bering Sea
Chukchi Sea
Beaufort Sea
Amundsen Gulf
Coronation Gulf
Lancaster Sound
Baffin Bay
Davis Strait
Labrador Sea
Pressure (dbar)
0
100
400
900
0
2000
4000
6000
8000
10000
12000
Distance (km)
Fluorescence
Canadian Arctic Archipelago
Labrador Shift
A
BC
D
E
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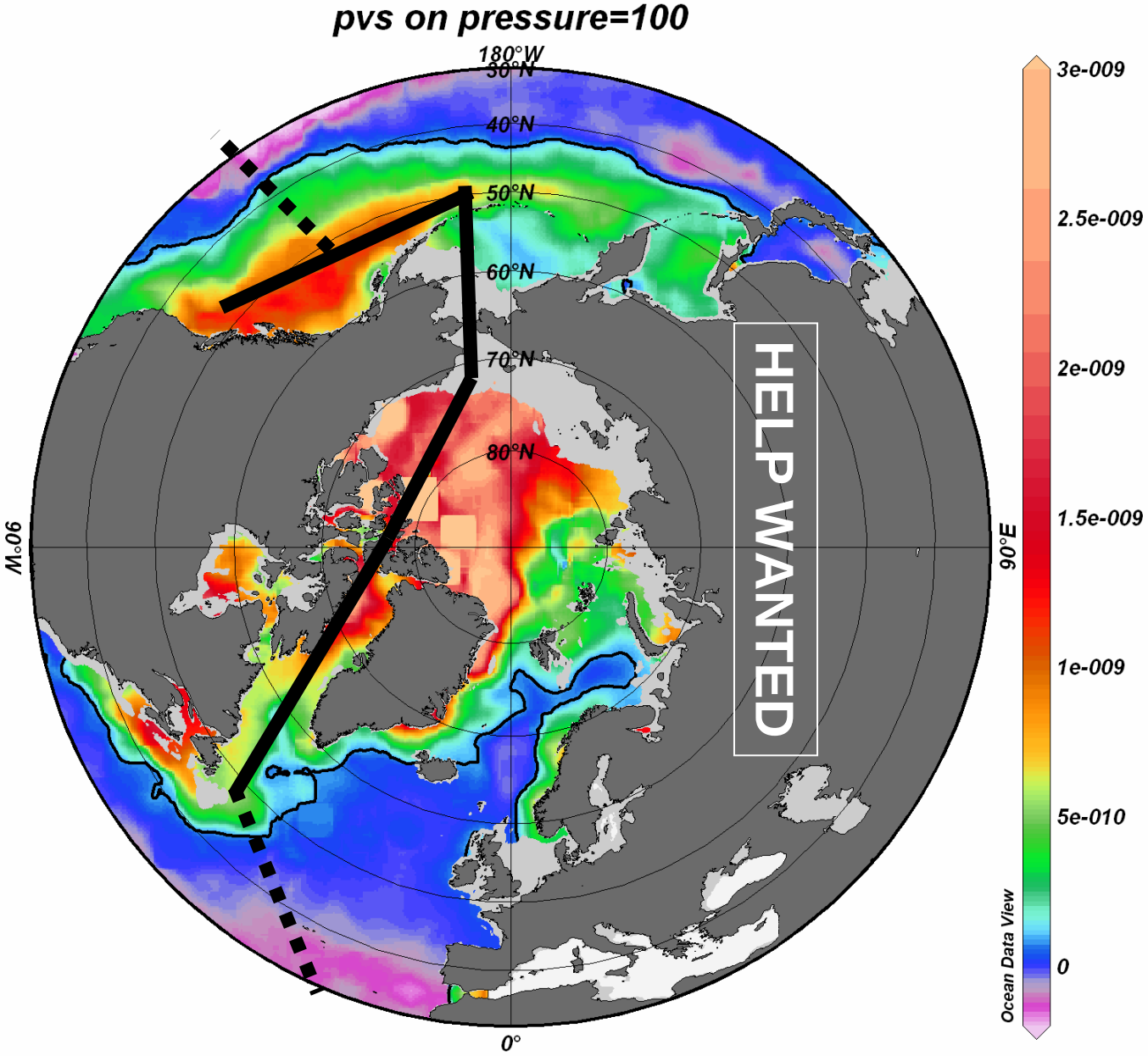
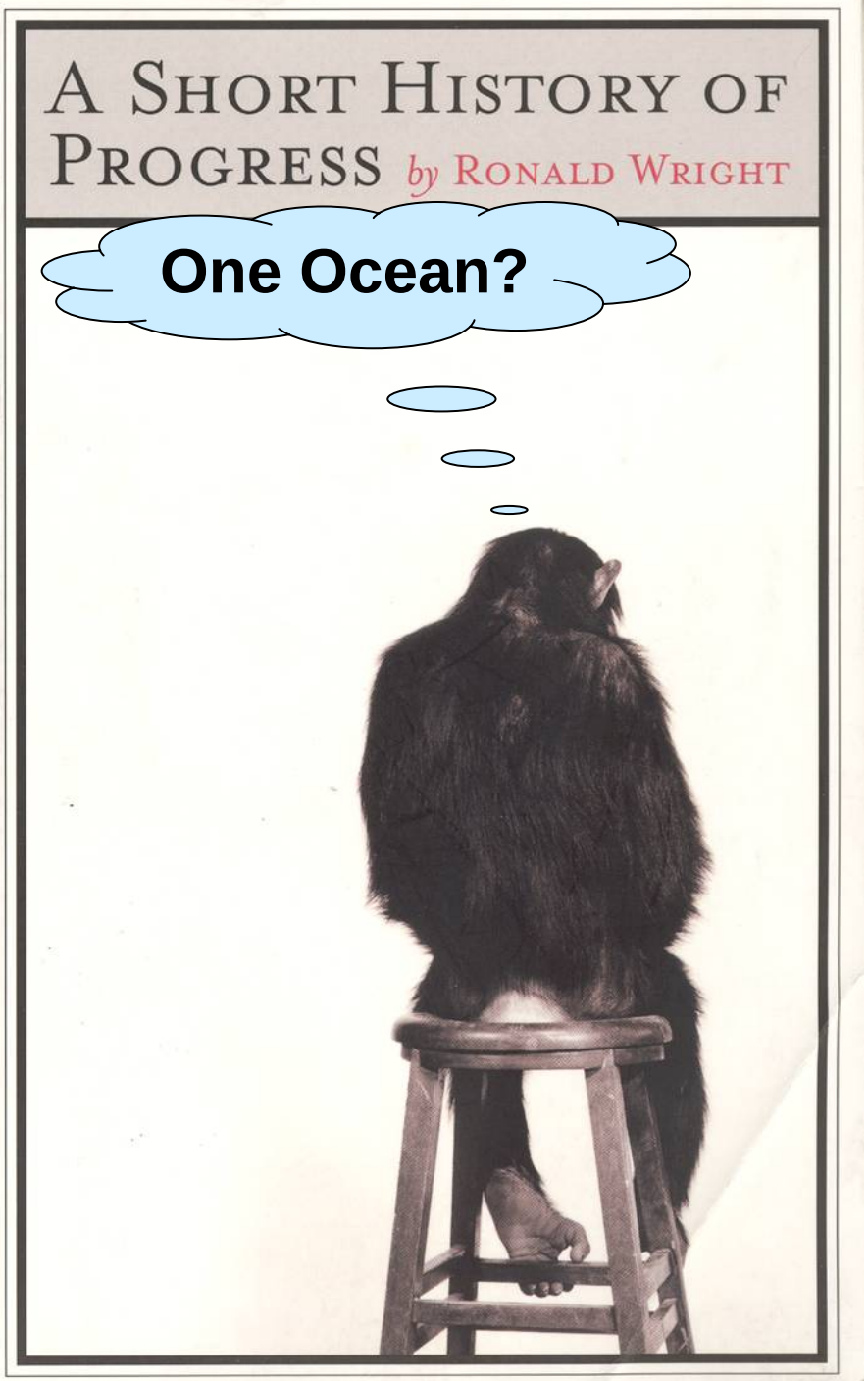
13
14
15


pvs on pressure=100
180°W
30°N
40°N
50°N
60°N
70°N
80°N
90°W
90°E
0°
HELP WANTED
3e-009
2.5e-009
2e-009
1.5e-009
1e-009
5e-010
0
Ocean Data View



Fact: Science must take its social obligation seriously

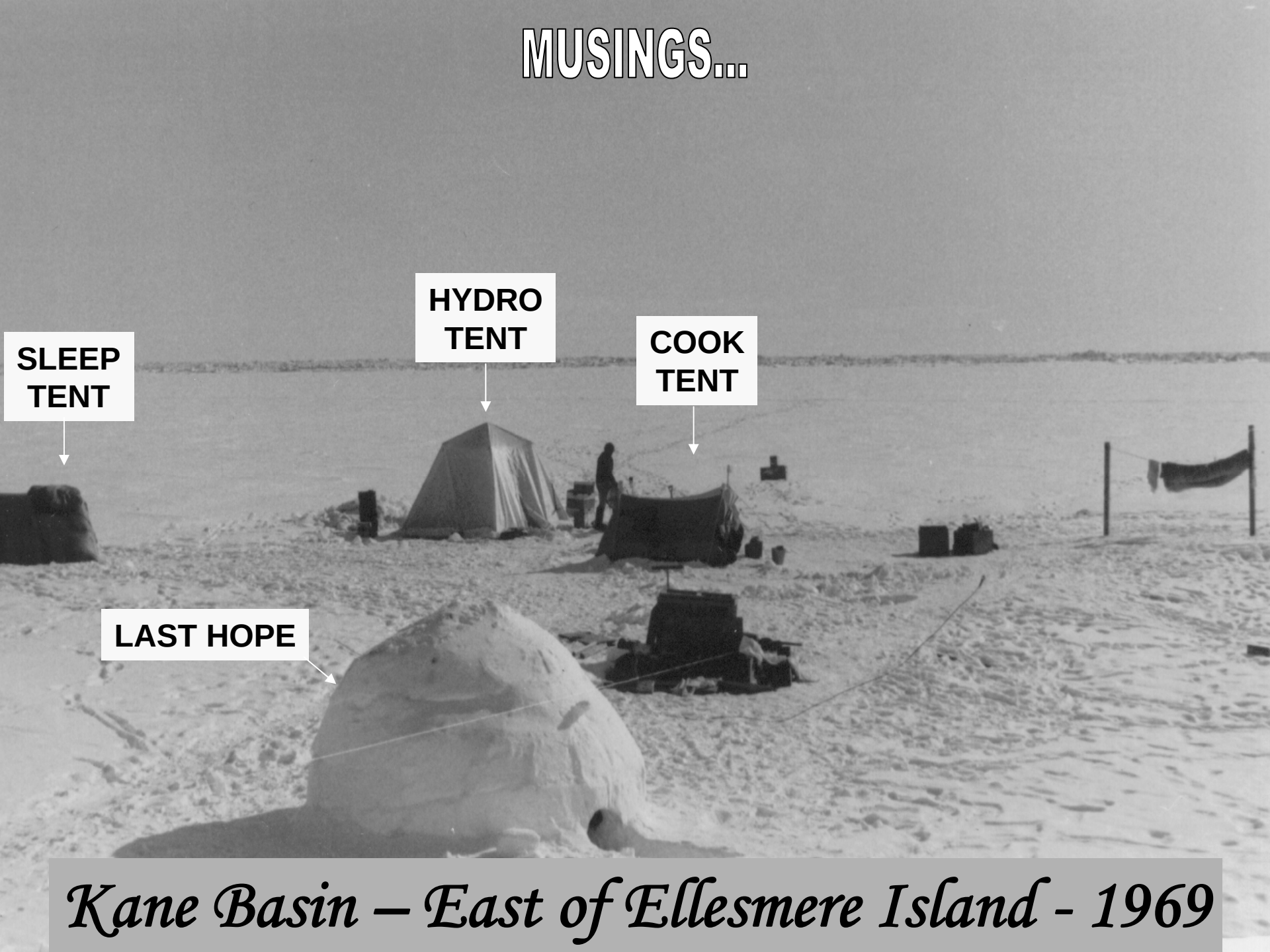
Two Points from the 2004 Massey Lectures …

Ronald Wright

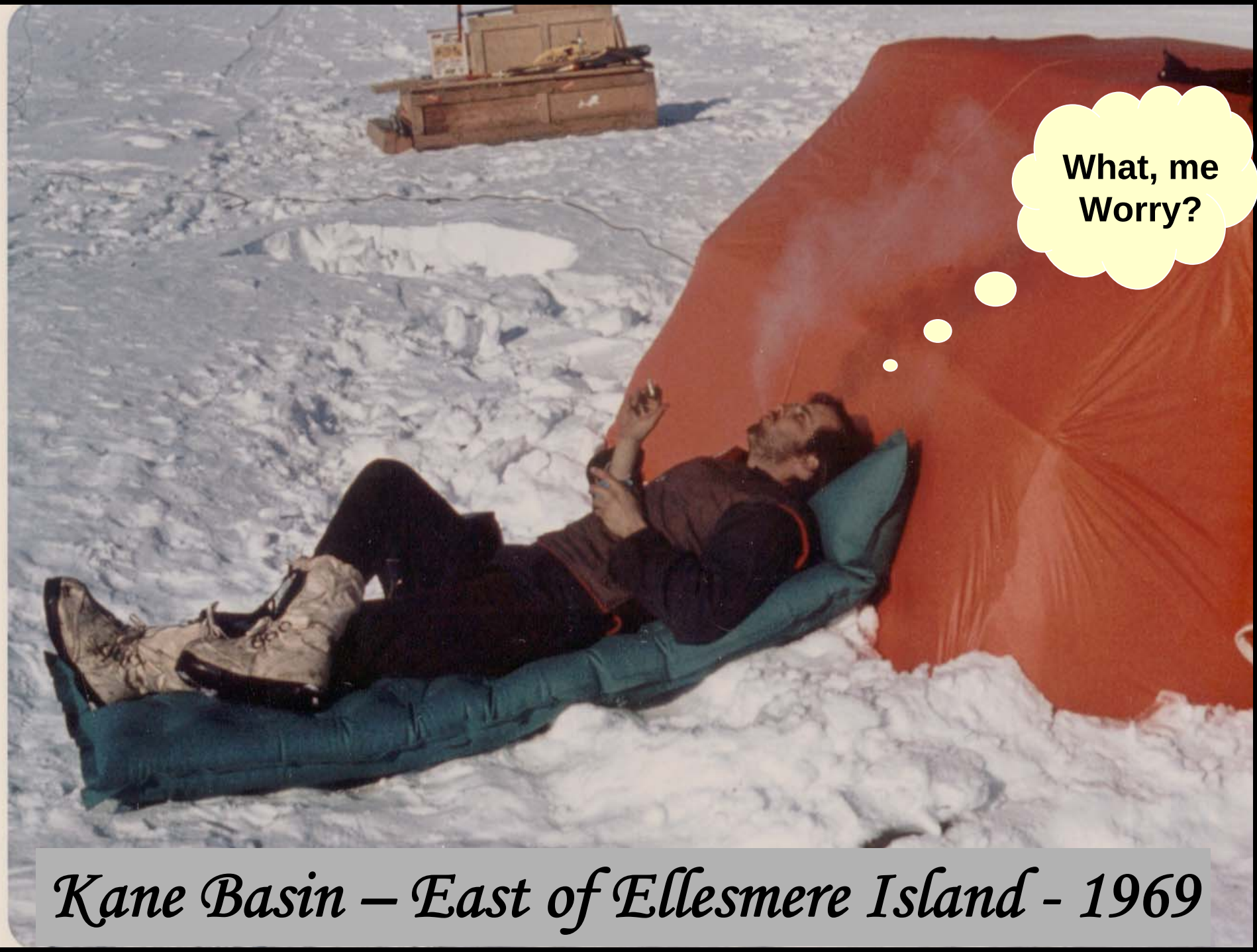
- The pattern of cultural progress, followed by over-consumption & societal collapse, has been repeated time and time again by societies that failed to look ahead and adjust accordingly

- When cultures finally enter the last stages of social collapse, the young of that final generation harbour deep anger towards the former generations that fouled the nest, and they thus behave as such.

MUSINGS...

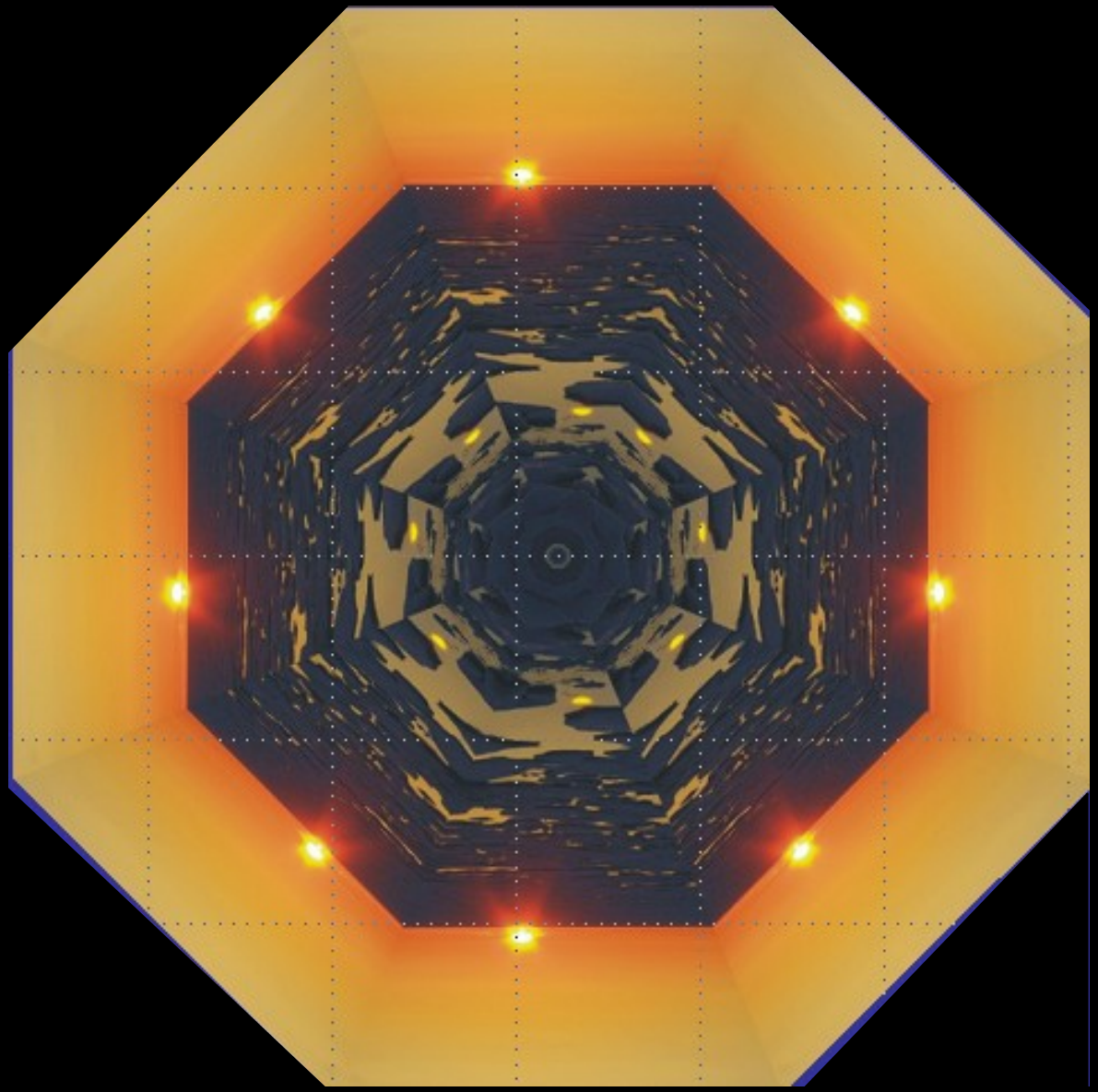


Kane Basin – East of Ellesmere Island - 1969



Kane Basin – East of Ellesmere Island - 1969

CONCLUSIONS



The Arctic Ocean is fully connected to the Global Ocean System; and must be studied accordingly

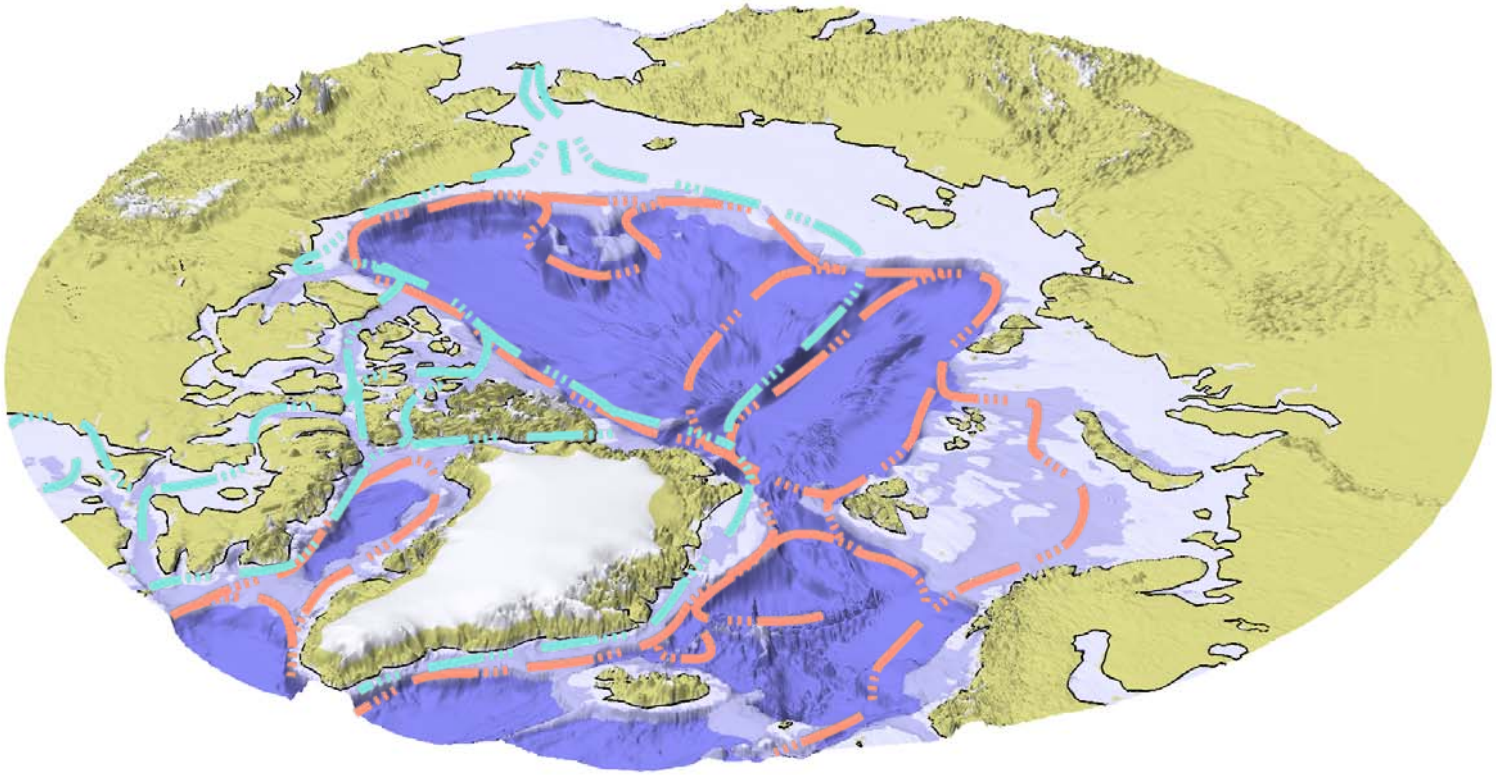
The High-Latitudes are Changing Fast; We Must Prepare; We Must Observe

Biogeography deserves Our Most Serious Attention

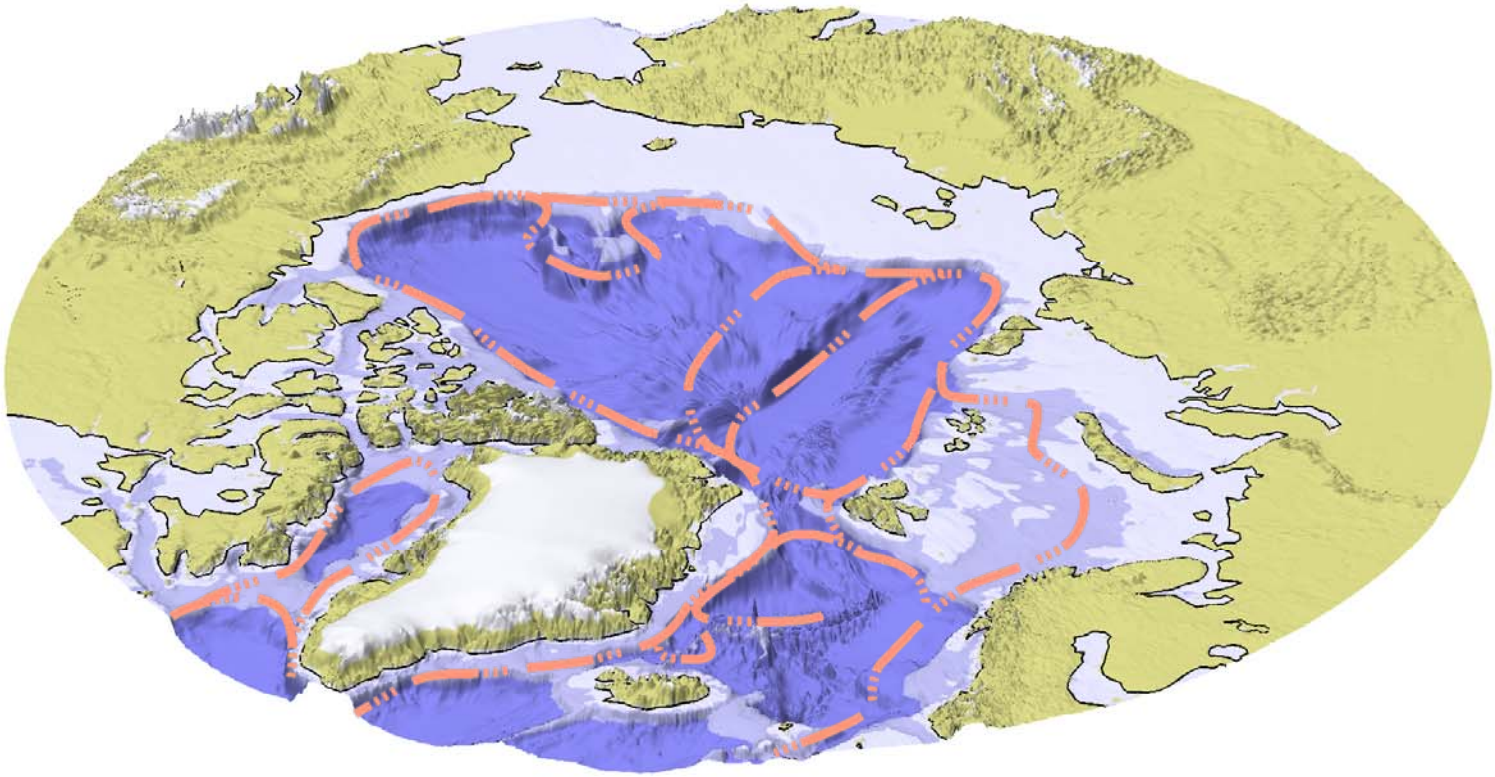

In Other Words…
THE ARCTIC IS A TREASURE
CLIMATE IS FOR KEEPS
THANK YOU

QUESTIONS

ARCTIC BASIN CIRCULATION



Atlantic Water Circulation

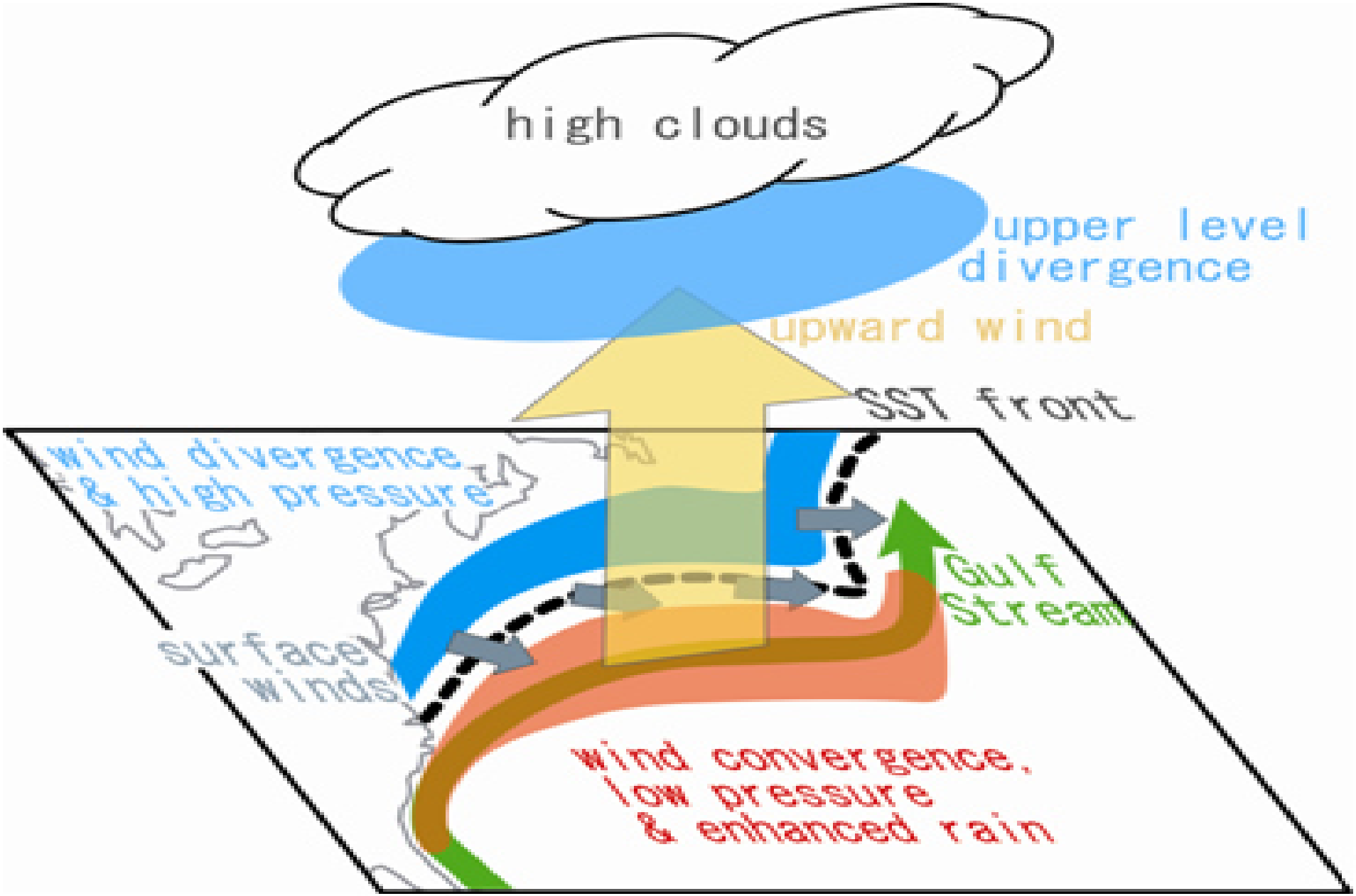


LESSONS FROM THE PAST

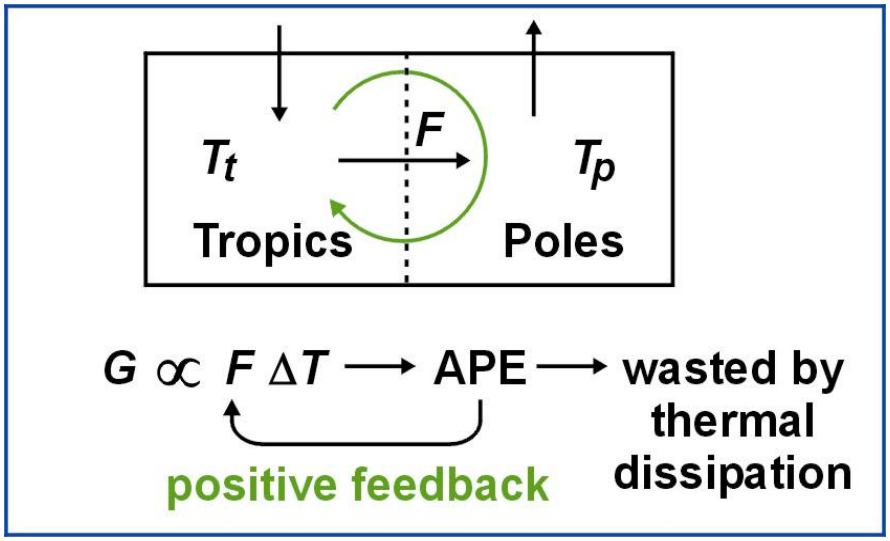
THE NEED FOR FLEXIBILITY

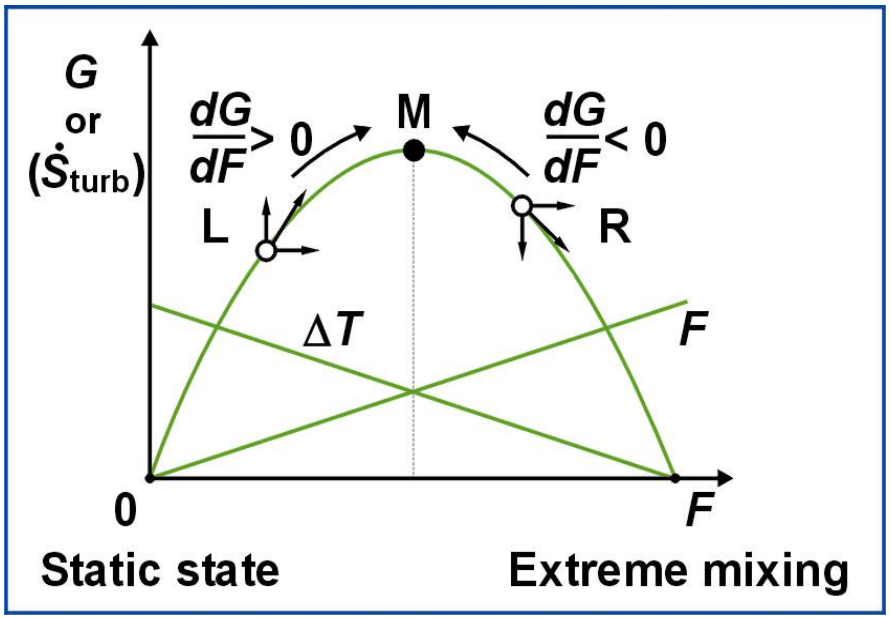
SO – IF EVEN “NATURAL” VARIBILITY CAN BRING DOWN KINGDOMS …

MAYBE IT’S TIME TO WAKE UP …

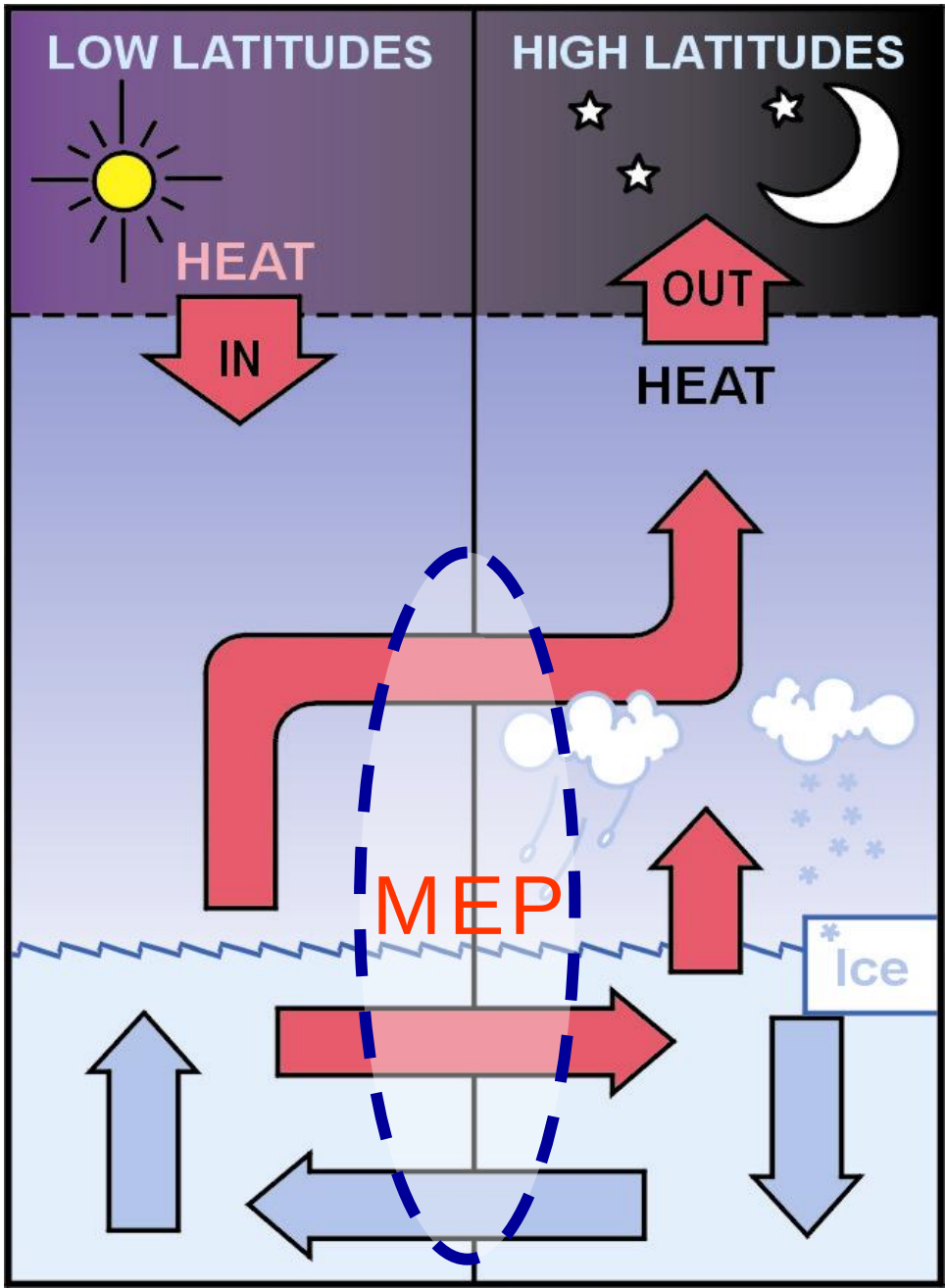


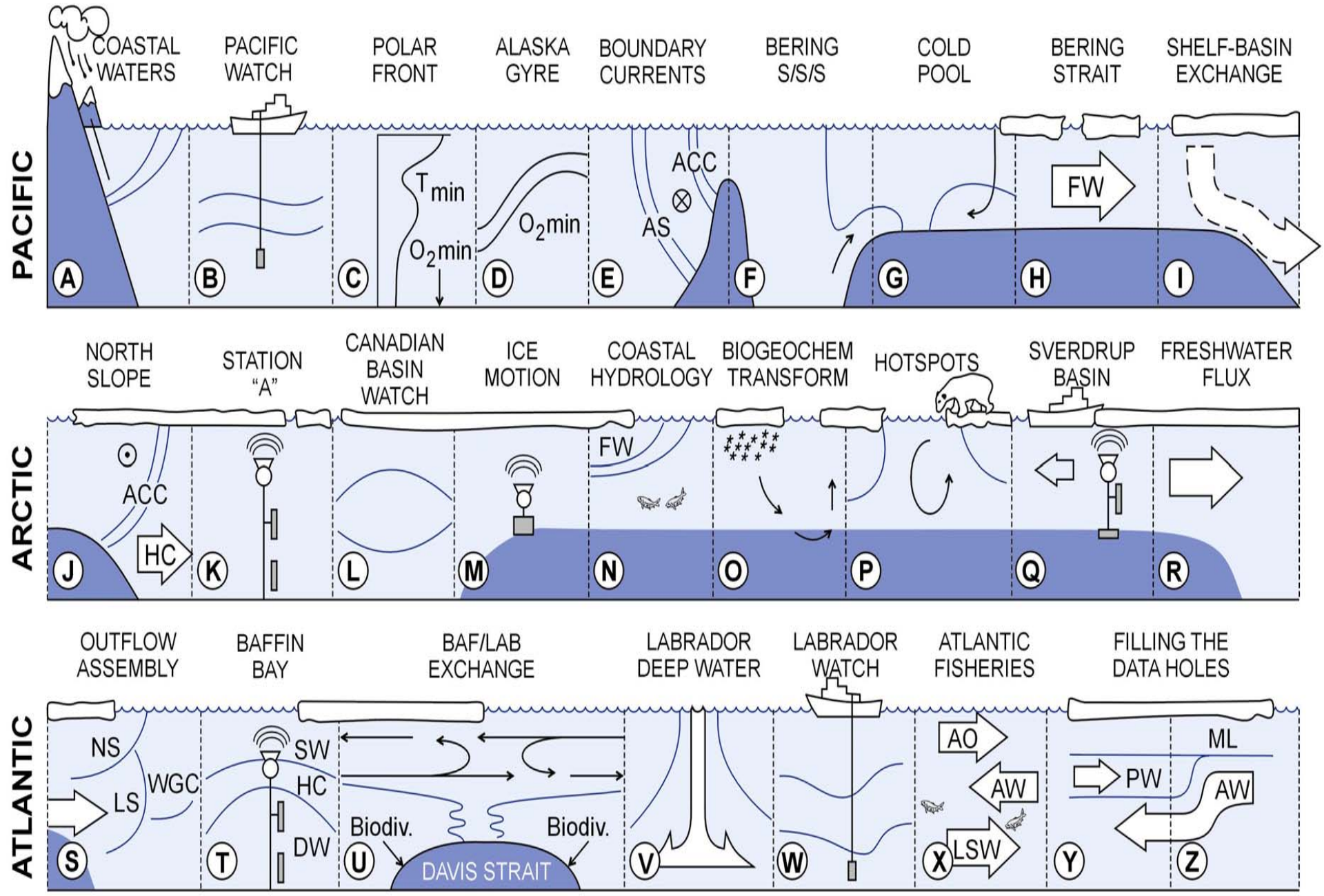
JAMSTEC Press Release (2008)





Shimokawa & Ozawaa (2007)




PACIFIC
COASTAL WATERS
PACIFIC WATCH
POLAR FRONT
ALASKA GYRE
BOUNDARY CURRENTS
BERING S/S/S
COLD POOL
BERING STRAIT
SHELF-BASIN EXCHANGE
T min
O2min
O2min
ACC
AS
FW
A
B
C
D
E
F
G
H
I
ARCTIC
NORTH SLOPE
STATION "A"
CANADIAN BASIN WATCH
ICE MOTION
COASTAL HYDROLOGY
BIOGEOCHEM TRANSFORM
HOTSPOTS
SVERDRUP BASIN
FRESHWATER FLUX
ACC
HC
FW
J
K
L
M
N
O
P
Q
R
ATLANTIC
OUTFLOW ASSEMBLY
BAFFIN BAY
BAF/LAB EXCHANGE
LABRADOR DEEP WATER
LABRADOR WATCH
ATLANTIC FISHERIES
FILLING THE DATA HOLES
NS
LS
WGC
SW
HC
DW
Biodiv.
Biodiv.
DAVIS STRAIT
AO
AW
LSW
ML
PW
AW
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U
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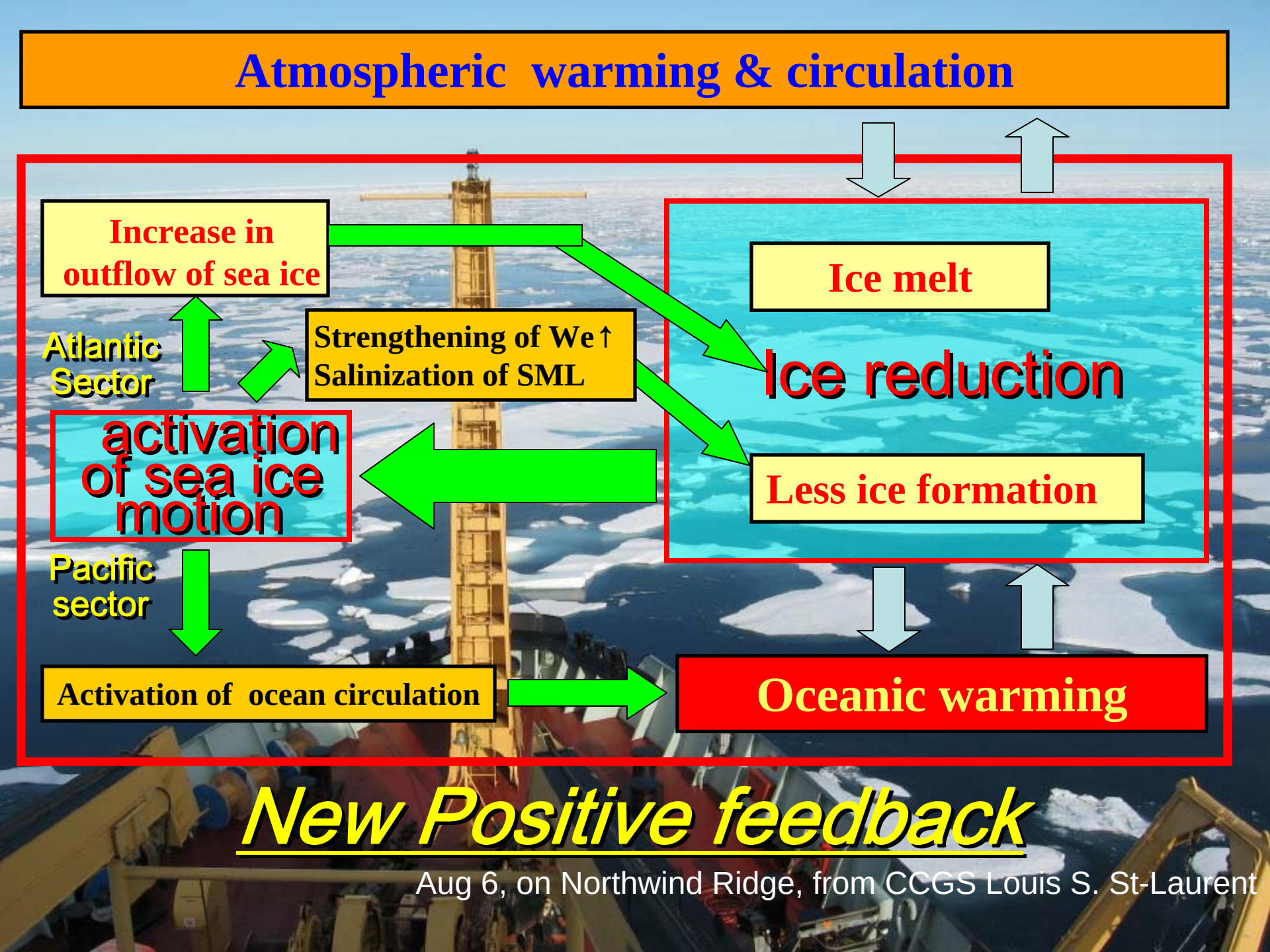
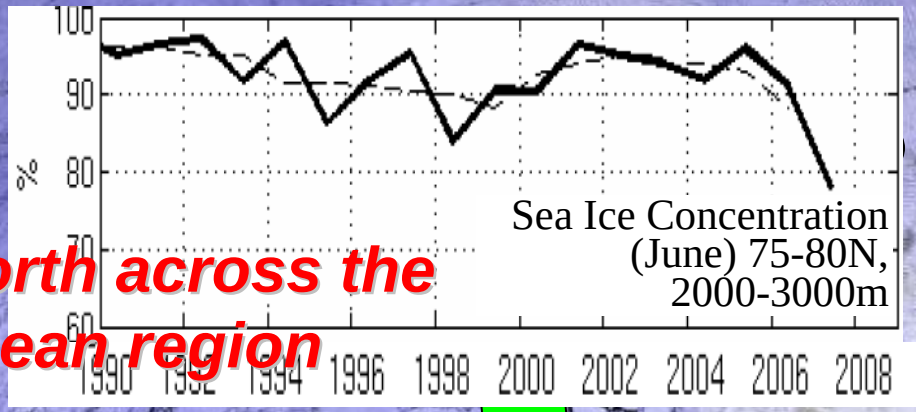

Atmospheric warming & circulation
Increase in outflow of sea ice
Atlantic Sector
Strengthening of We↑
Salinization of SML
activation of sea ice motion
Pacific sector
Activation of ocean circulation
Ice melt
Ice reduction
Less ice formation
Oceanic warming
New Positive feedback
Aug 6, on Northwind Ridge, from CCGS Louis S. St-Laurent



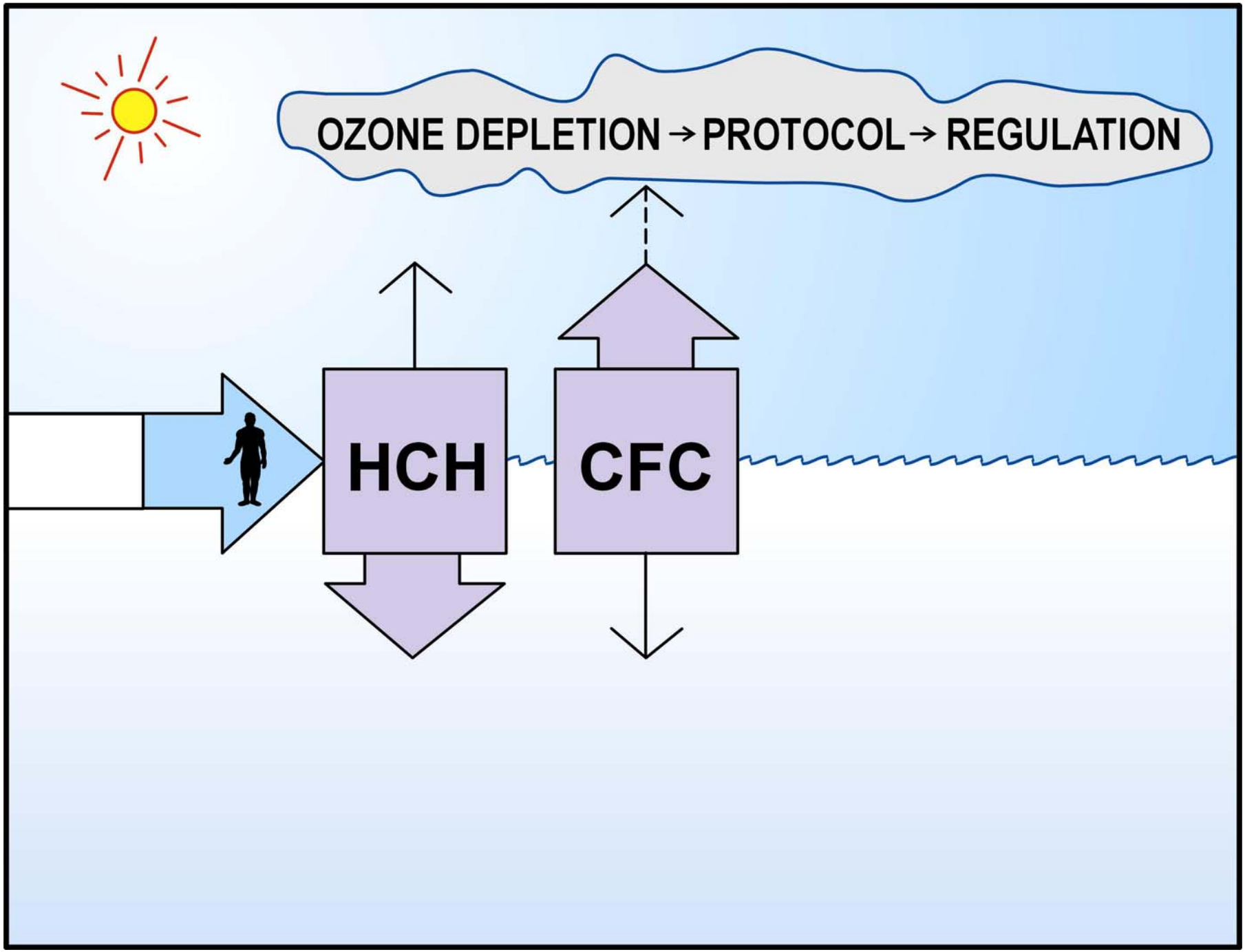
New ice toward north across the warmest upper ocean region

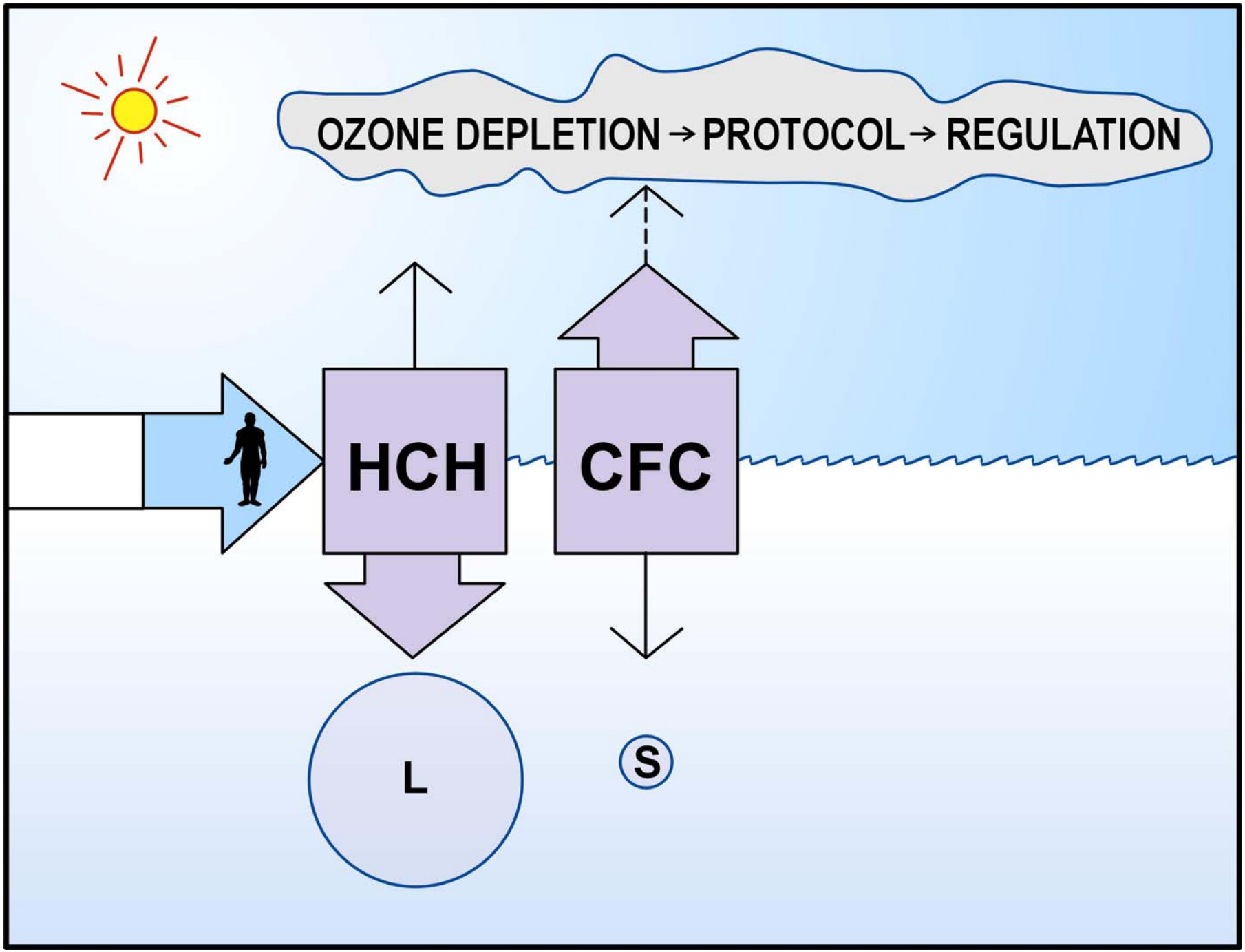
Further acceleration of sea ice reduction

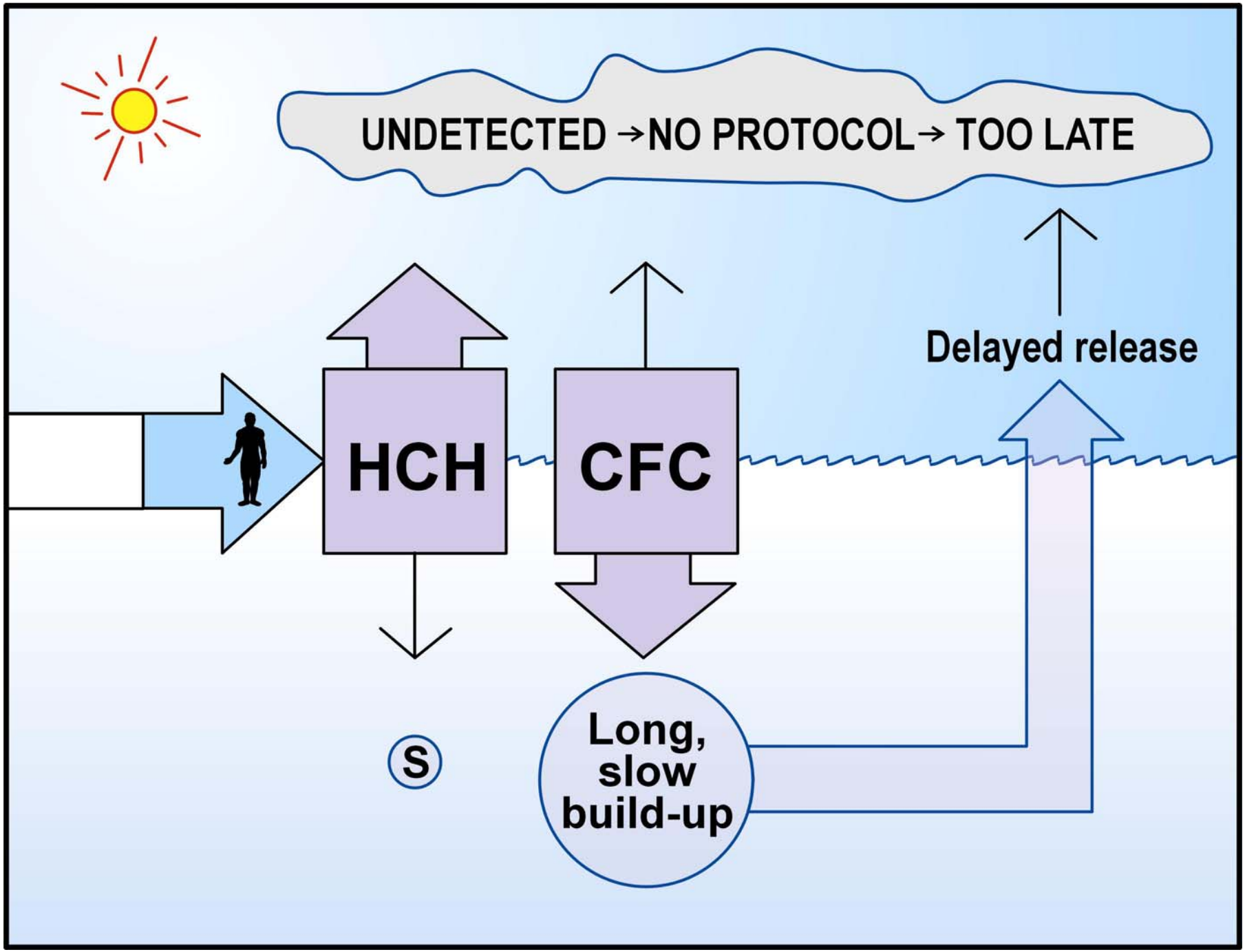
Rapid movement of heavy ice toward warm southern Beaufort Sea

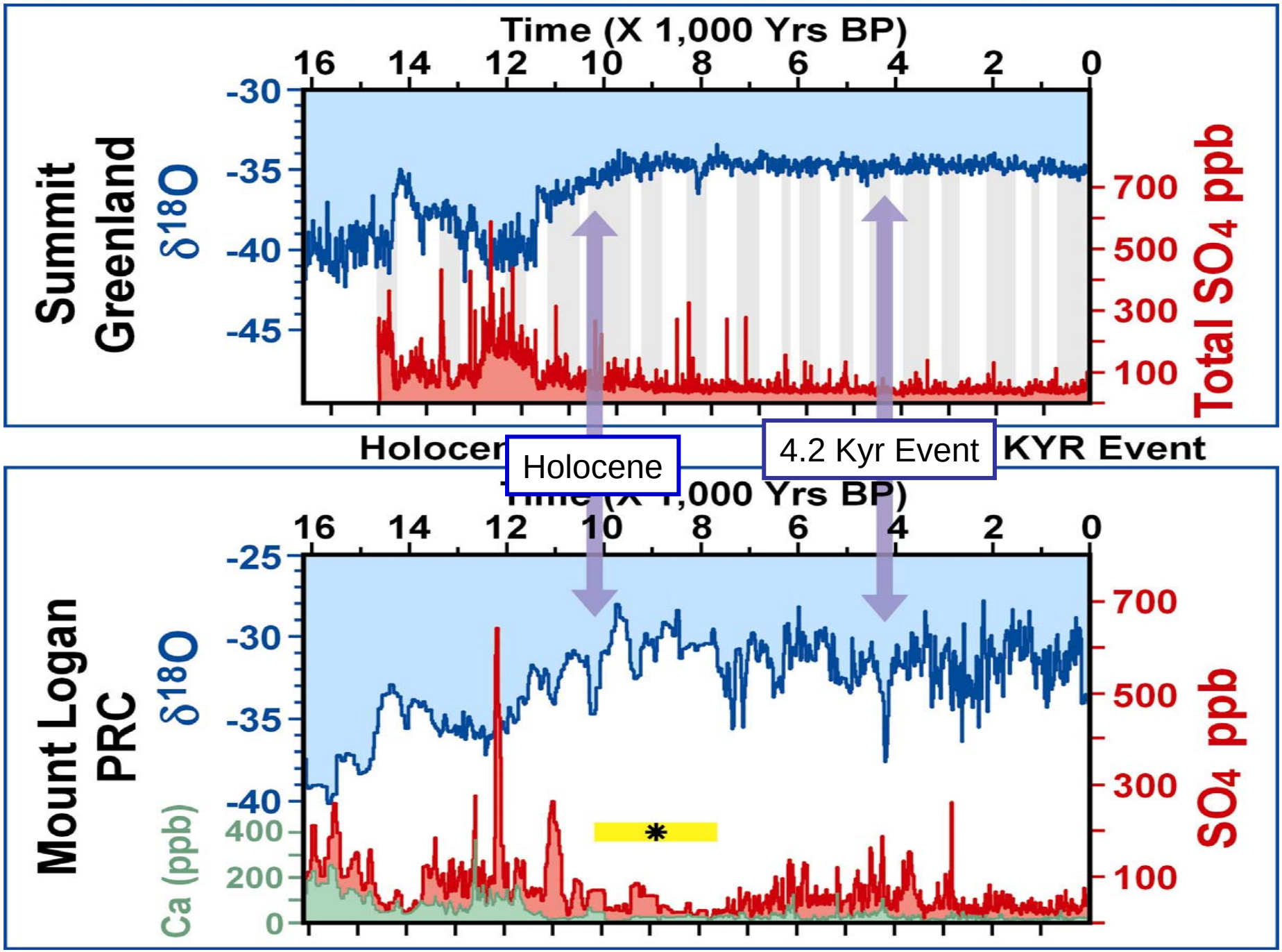
Warmest water under the ice in the Canada Basin

June 9, 2007

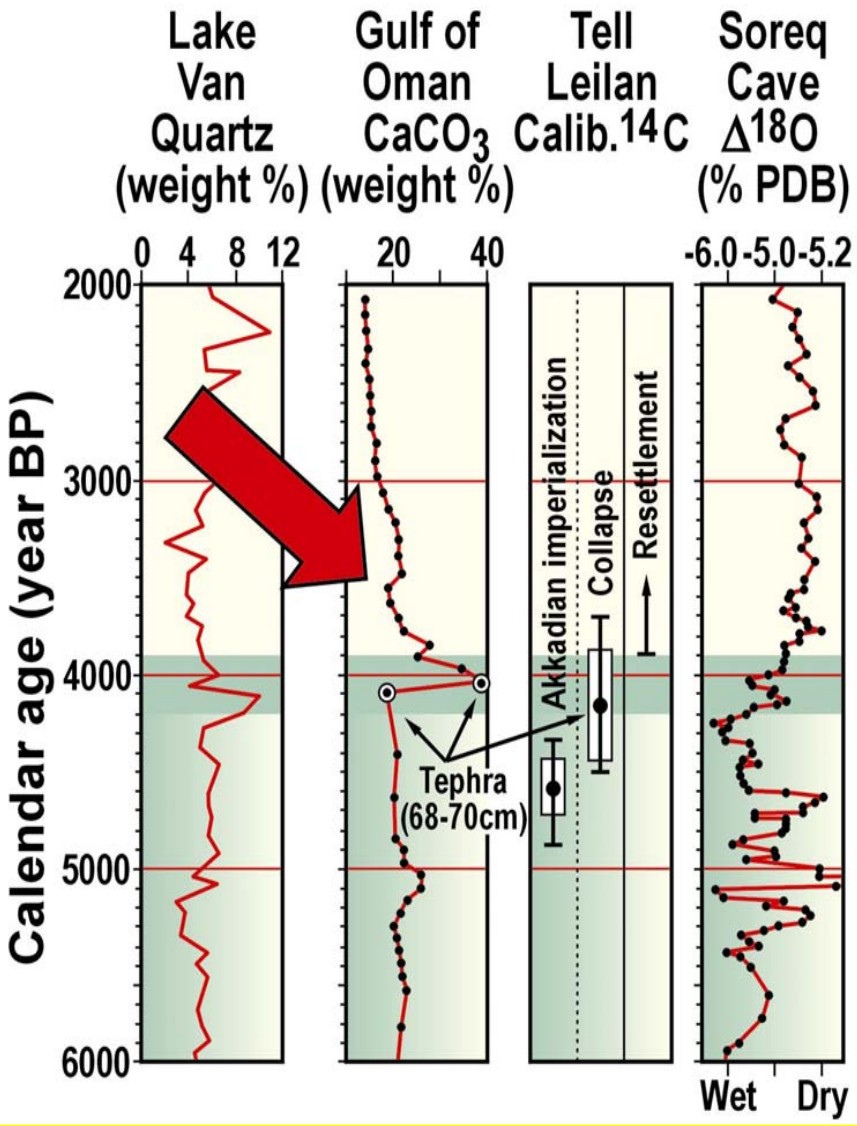

OZONE DEPLETION → PROTOCOL → REGULATION
HCH
CFC

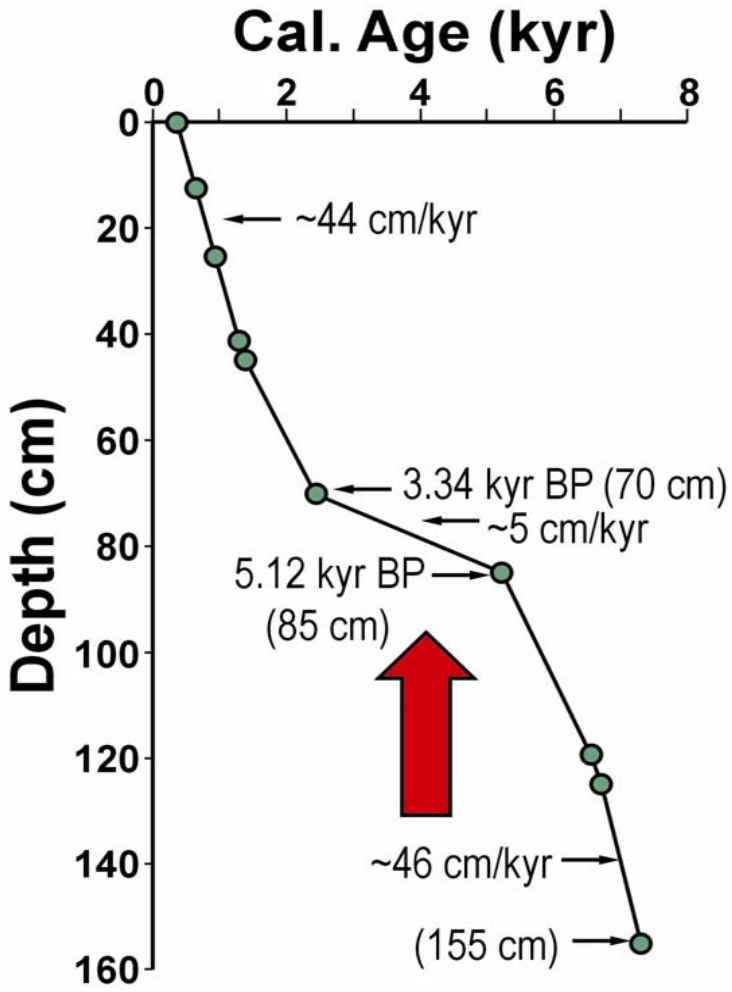

OZONE DEPLETION → PROTOCOL → REGULATION
HCH
CFC
L
S


UNDETECTED →NO PROTOCOL→ TOO LATE
Delayed release
HCH
CFC
S
Long, slow build-up


Time (X 1,000 Yrs BP)
16
14
12
10
8
6
4
2
0
Summit Greenland
δ18O
-30
-35
-40
-45
Total SO4 ppb
700
500
300
100
Holocene
4.2 Kyr Event
KYR Event
Mount Logan PRC
δ18O
-25
-30
-35
-40
Ca (ppb)
400
200
0
SO4 ppb
700
500
300
100

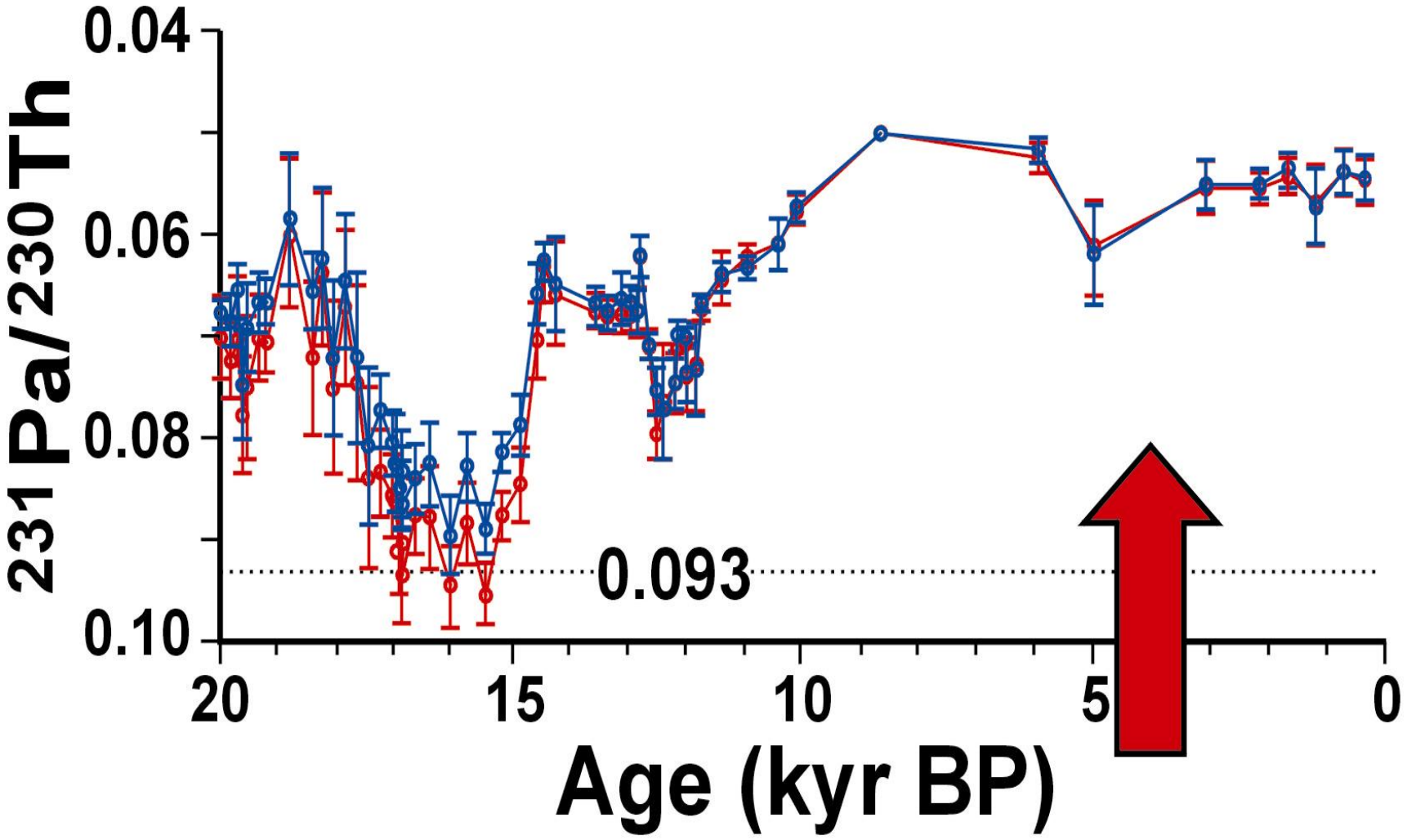
Weiss & Bradley, Science, 2001: collapse of the Akkadian Empire was due to widespread drought between 3-5 kyr BP.





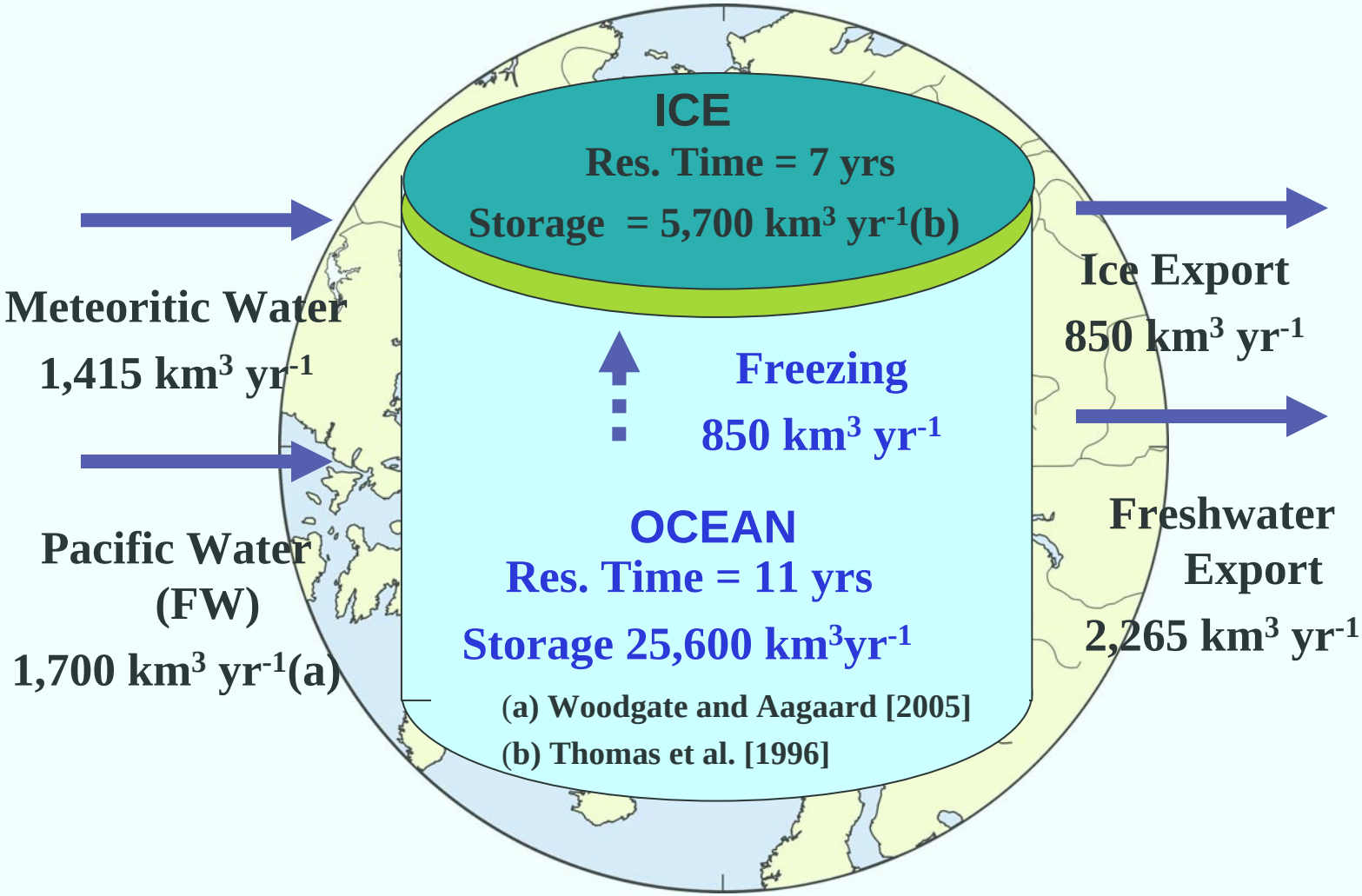
Darby & Bischof (2004): 6-8 fold decrease in sedimentation in the Beaufort; perhaps a shift towards more ice export to NA.

Under +AO the Transpolar Drift increases; so Ice Export increases; perhaps the THC slows

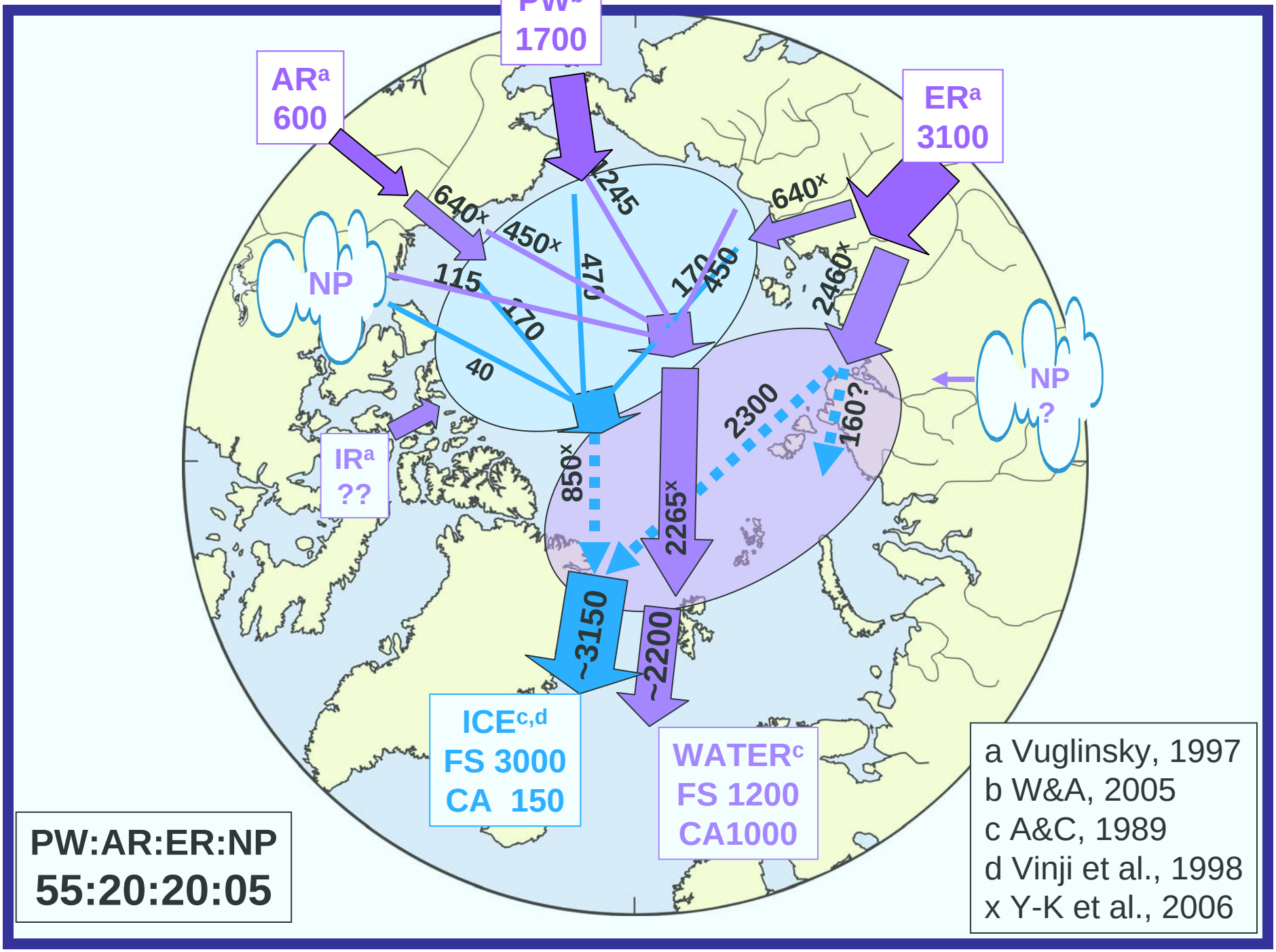


Francois (2004): using decay of Uranium daughter products, examined MOC rate.

Canada Basin



Yamamoto-Kawai et al. submitted


PW[b]
1700
AR[a]
600
ER[a]
3100
NP
NP
?
IR[a]
??
640x
450x
1245
640x
115
170
470
170
450
2460x
40
2300
160?
850x
2265x
~3150
~2200
ICE[c,d]
FS 3000
CA 150
WATER[c]
FS 1200
CA1000
PW:AR:ER:NP
55:20:20:05
a Vuglinsky, 1997
b W&A, 2005
c A&C, 1989
d Vinji et al., 1998
x Y-K et al., 2006