Global Mapping of sea ice production and heat/salt flux in ice-covered regions, using satellite passive microwave data

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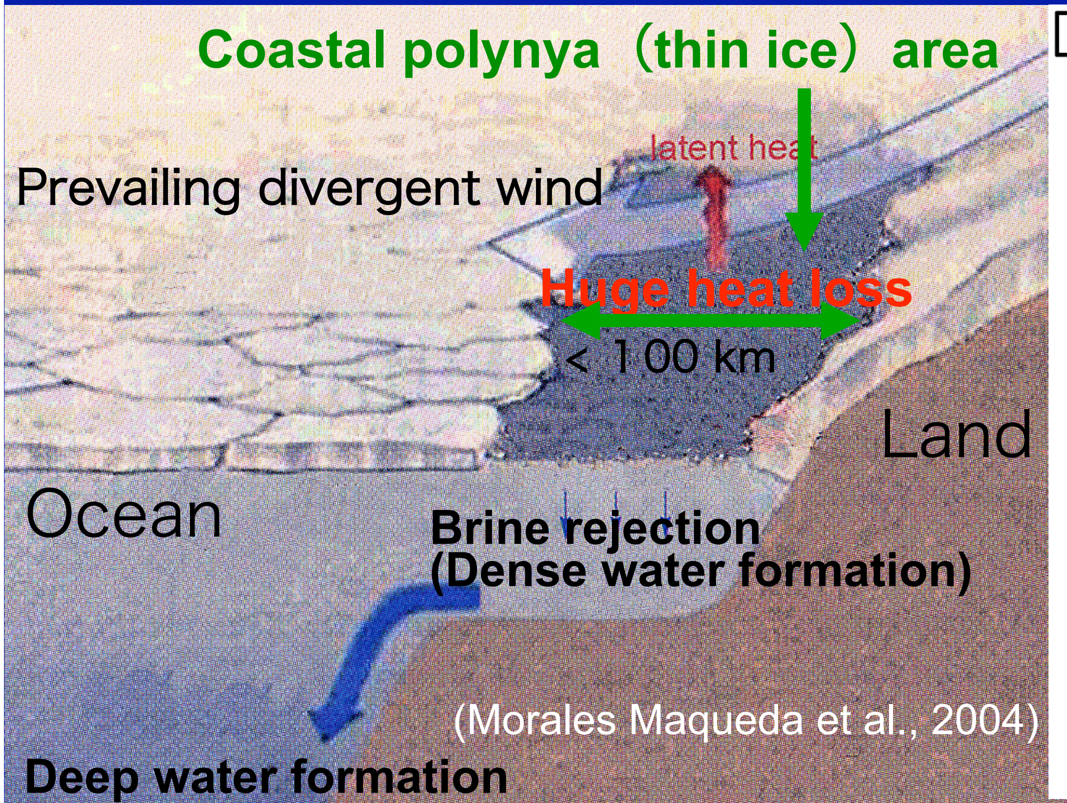
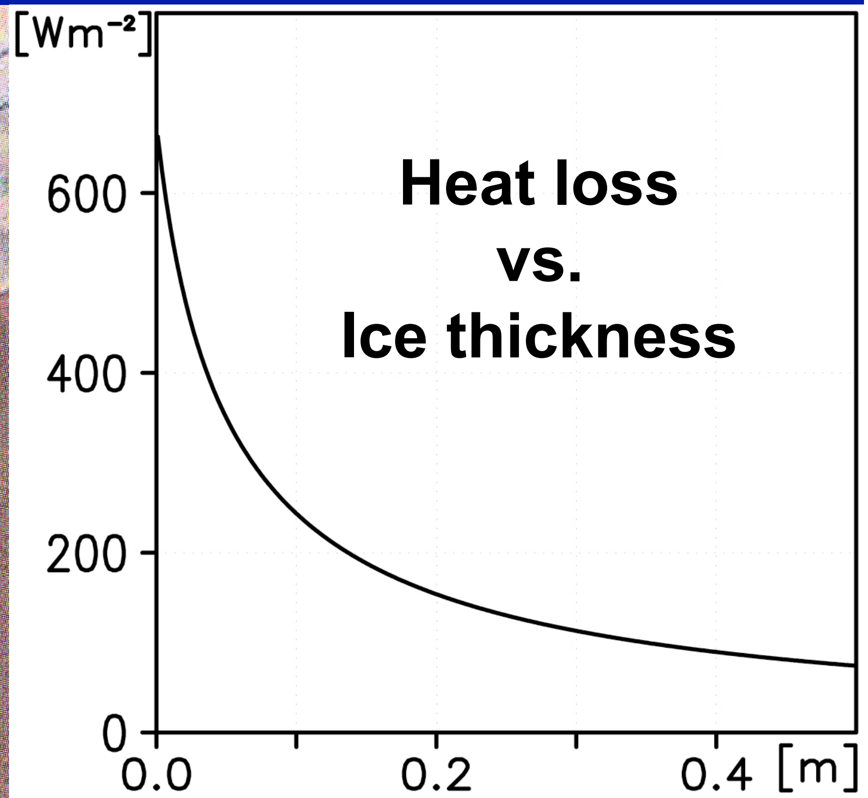
“Predicting the rate and trajectory of polar changes will require new combinations of in situ measurements and satellite remote sensing, and close interaction between observers and modelers “

from introduction in **proposal of this workshop**

Among ambiguities in sea flux in polar regions, existing of coastal polynyas is one of major factors.





Heat flux (and thus ice production and salt flux) is very sensitive to sea ice thickness → Detection of polynya (thin ice) areas and estimation of ice thickness there is cruicial → Use of Microwave

Past Studies

Thin ice detection algorithm (Passive microwave)

Antarctic: Markus and Burns (1995), Tamura et al. (2007)

Arctic : Cavalieri (1994), Martin et al. (2004, 2005)
Sea of Okhotsk : Martin et al. (1998), Nihashi et al.,(2009)

Microwave data + Heat flux calculation → Ice production

Entire Antarctic: Tamura et al. (2008)
Weddell Sea : Markus et al. (1998), Renfrew et al. (2002)
Wilkes Land : Cavalieri and Martin (1985)
Ross Sea : Martin et al. (2007)

Chukchi Sea : Martin et al. (2004, 2005)
Russian Canadian coast: Cavalieri and Martin (1994)
Sea of Okhotsk : Martin et al. (1998), Ohshima et al. (2003)
Nihashi et al. (2009)

Heat Budget Calculation

$$Q_i = (1\text{-}a)SW_i + LW_i + SE_i + LA_i + FC$$

$$Q_w = (1\text{-}a)SW_w + LW_w + SE_w + LA_w$$

a: albedo
SW: shortwave
LW: longwave
SE: sensible heat
LA: latent heat
FC: conductive heat

Ice thickness data : Tamura et al. (2007) algorithm

Meteorological data : ERA-40 (Ta, Td, wind, SLP, cloud)

Sea Ice Production

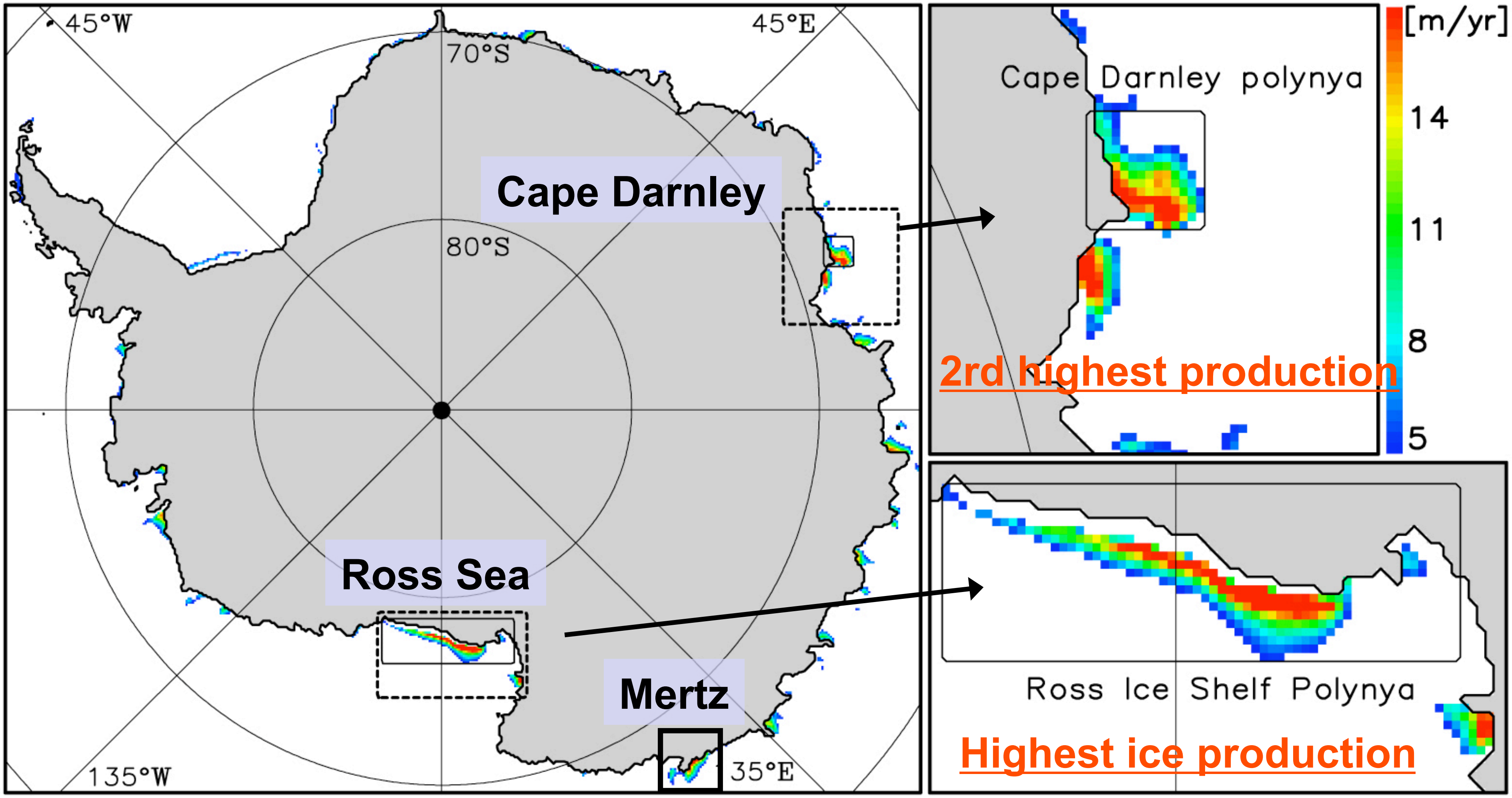
$$V = H / (\rho_i L_f)$$

H : Total heat loss
ρ_i : Ice density
L_f : Latent heat of melting

All heat loss is used for sea ice production

Neglect of upward oceanic heat

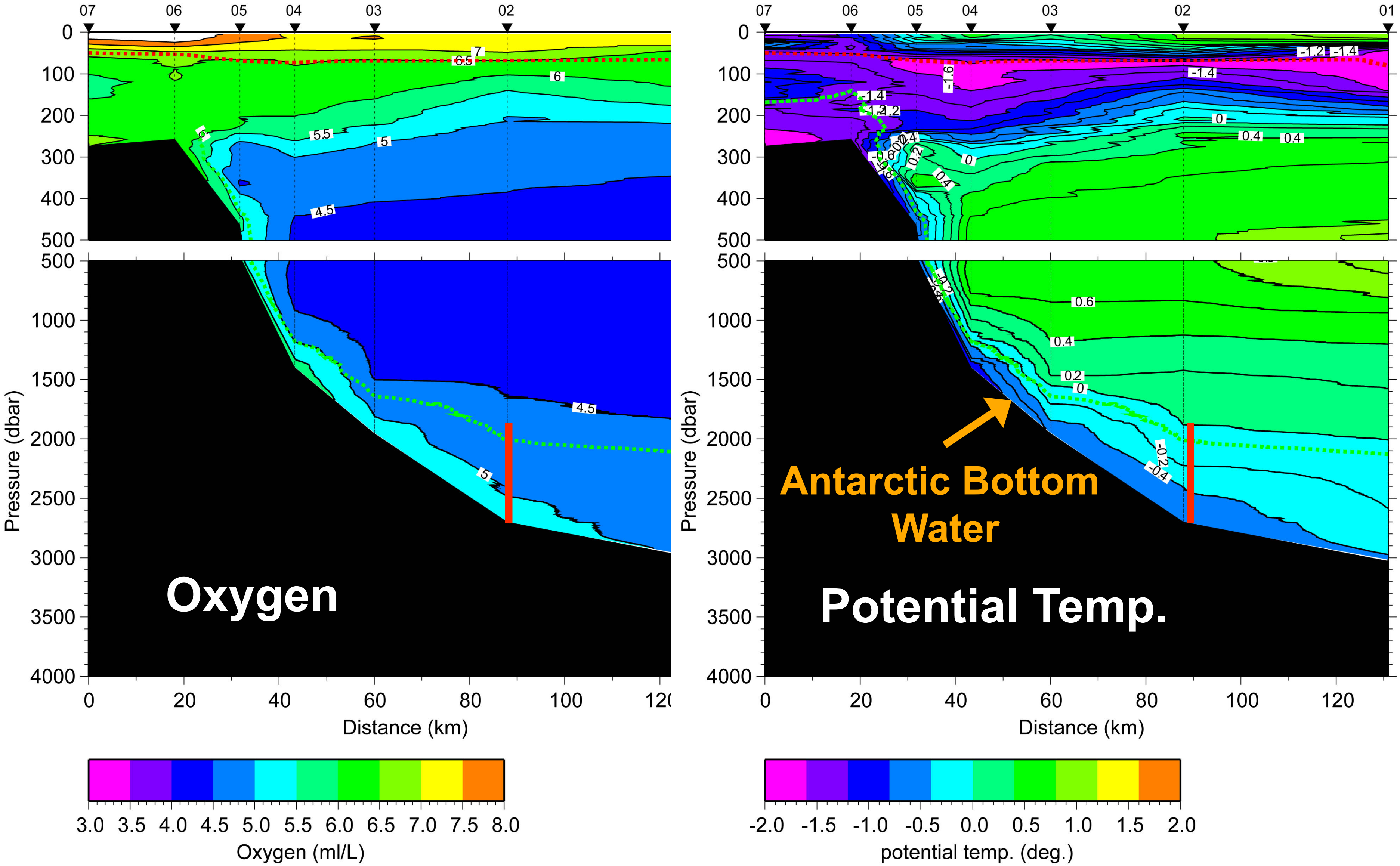
Mapping of annual sea-ice production (1992–2001)



(Tamura, Ohshima and Nihashi, 2008, GRL)

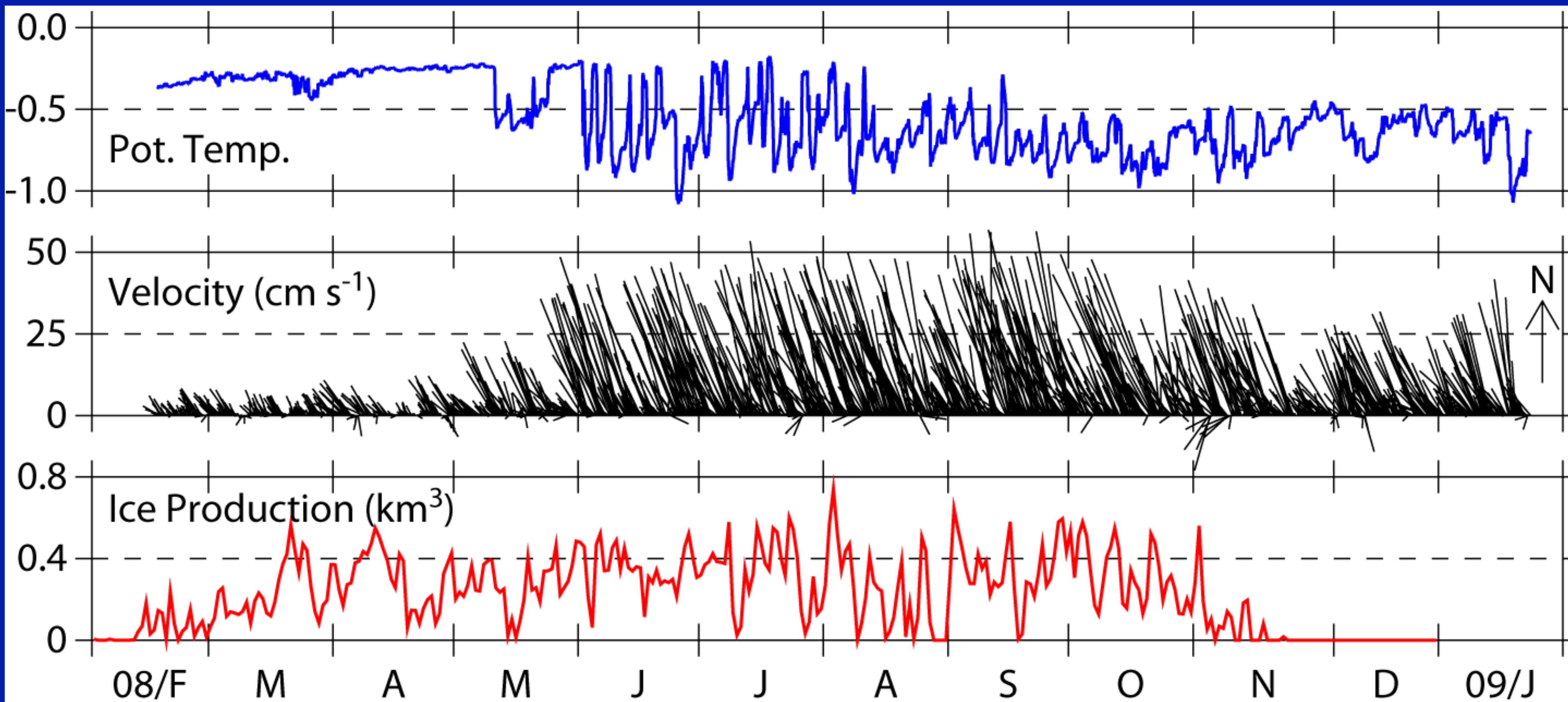
Based on heat flux calculation and SSM/I (passive microwave)

Off Cape Darnley, East Antarctic



Newly-found AABW around Cape Darnley Polynya

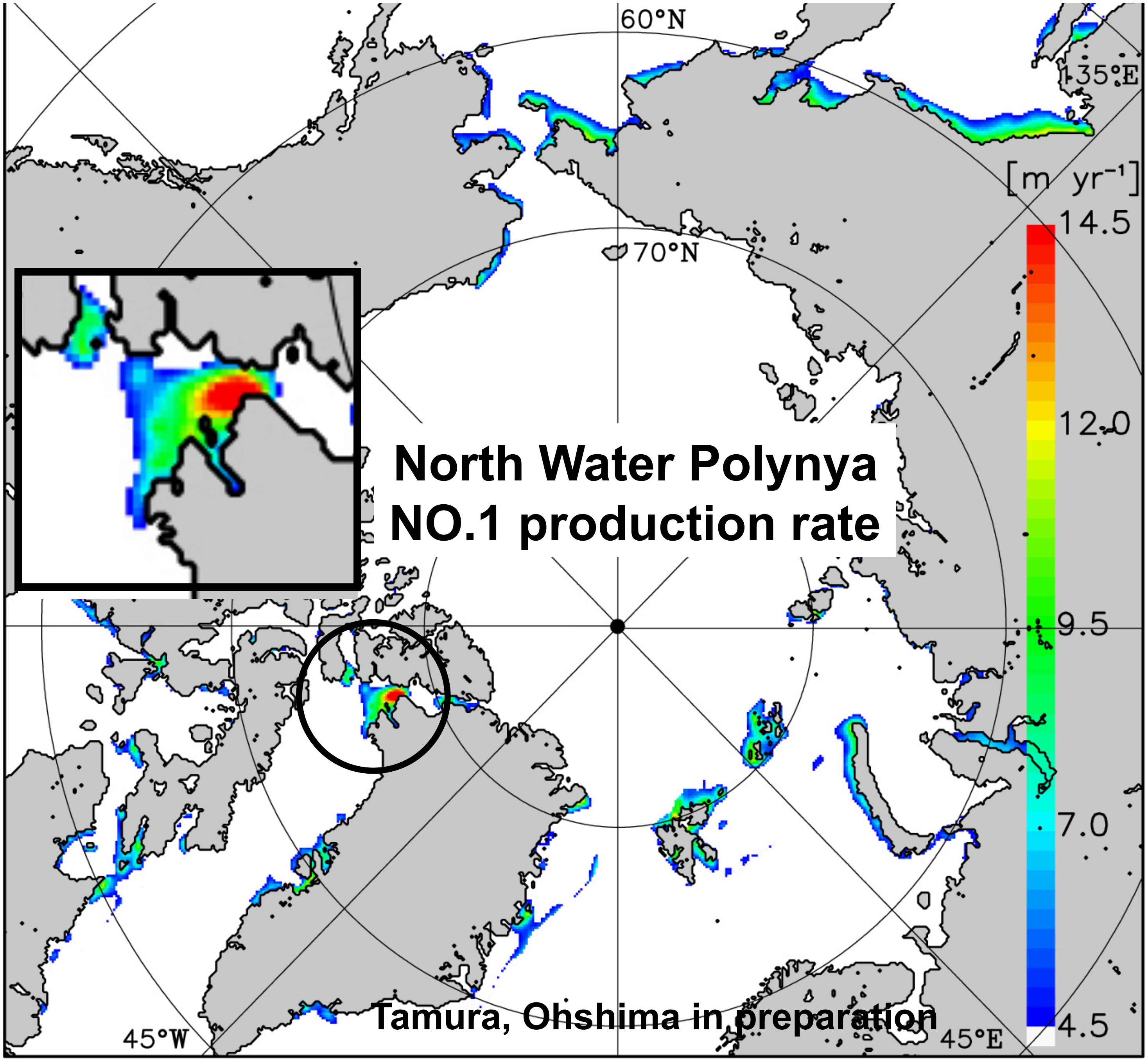
Near-bottom potential temperature and velocity at M3 (Bottom depth: 2659 m)
Ice-production estimate within CDP



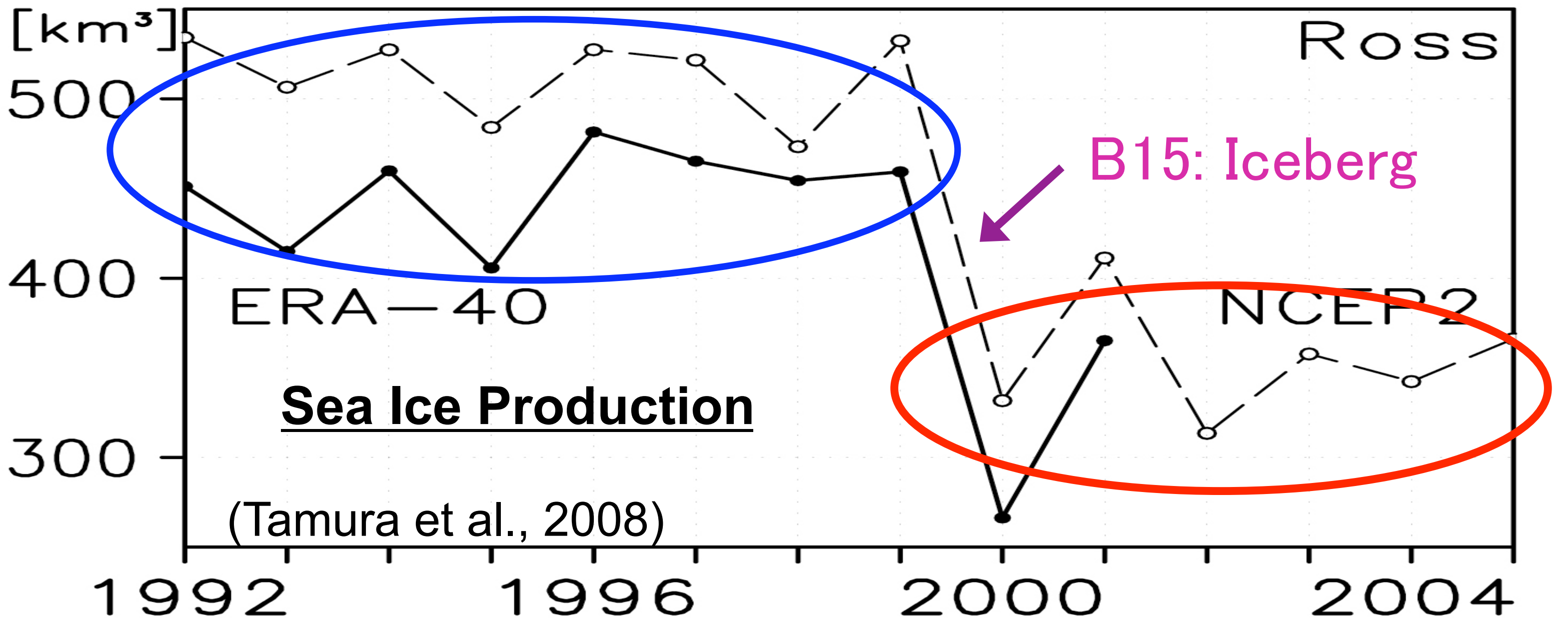
- Cold (dense) signals with strong along-canyon downslope flow after June
- Increase of sea-ice production after March

→ Locally-formed bottom water around Cape Darnley Polynya

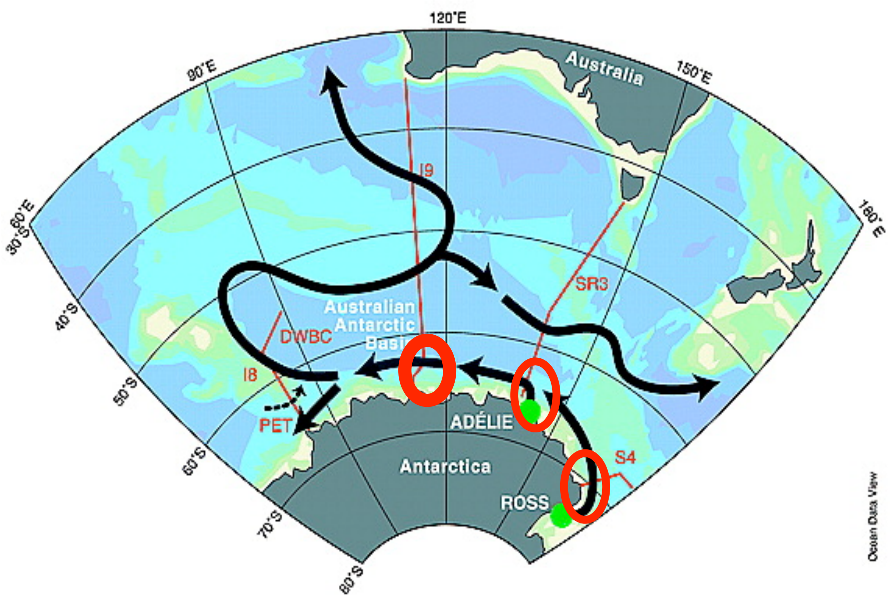
Mapping of sea ice production (1992-2007)

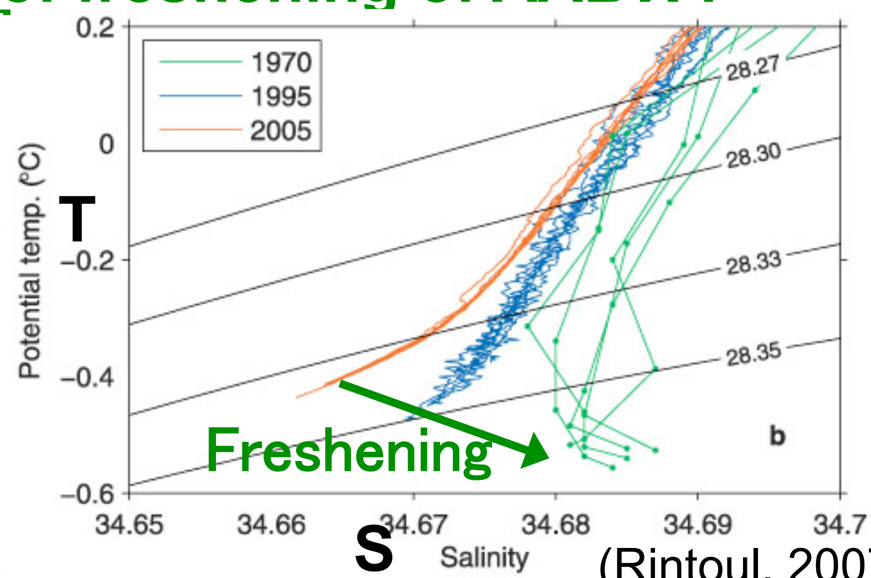


Interannual variability of ice production in Antarctic coastal polynyas



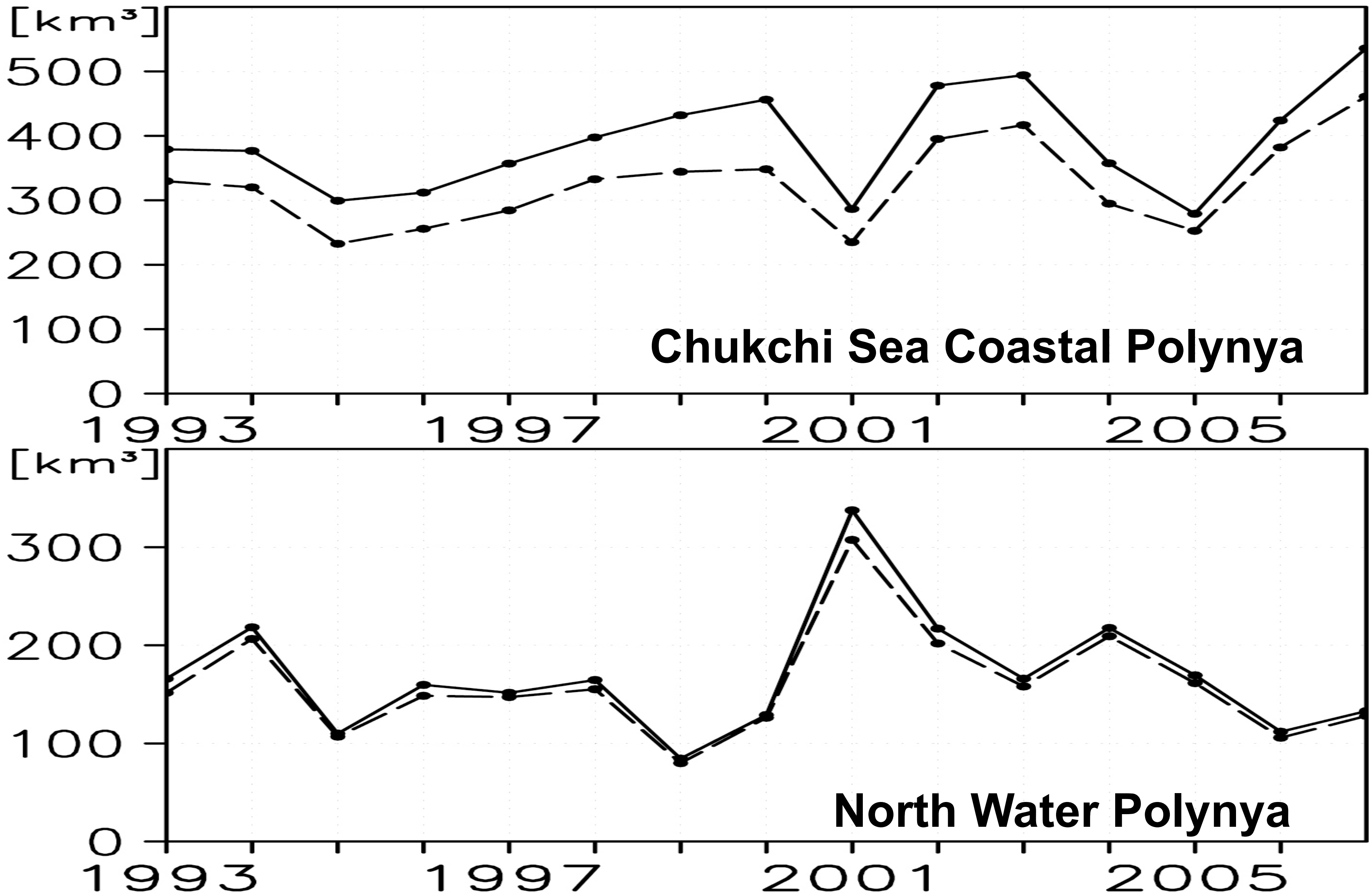
Cause of freshening of AABW?





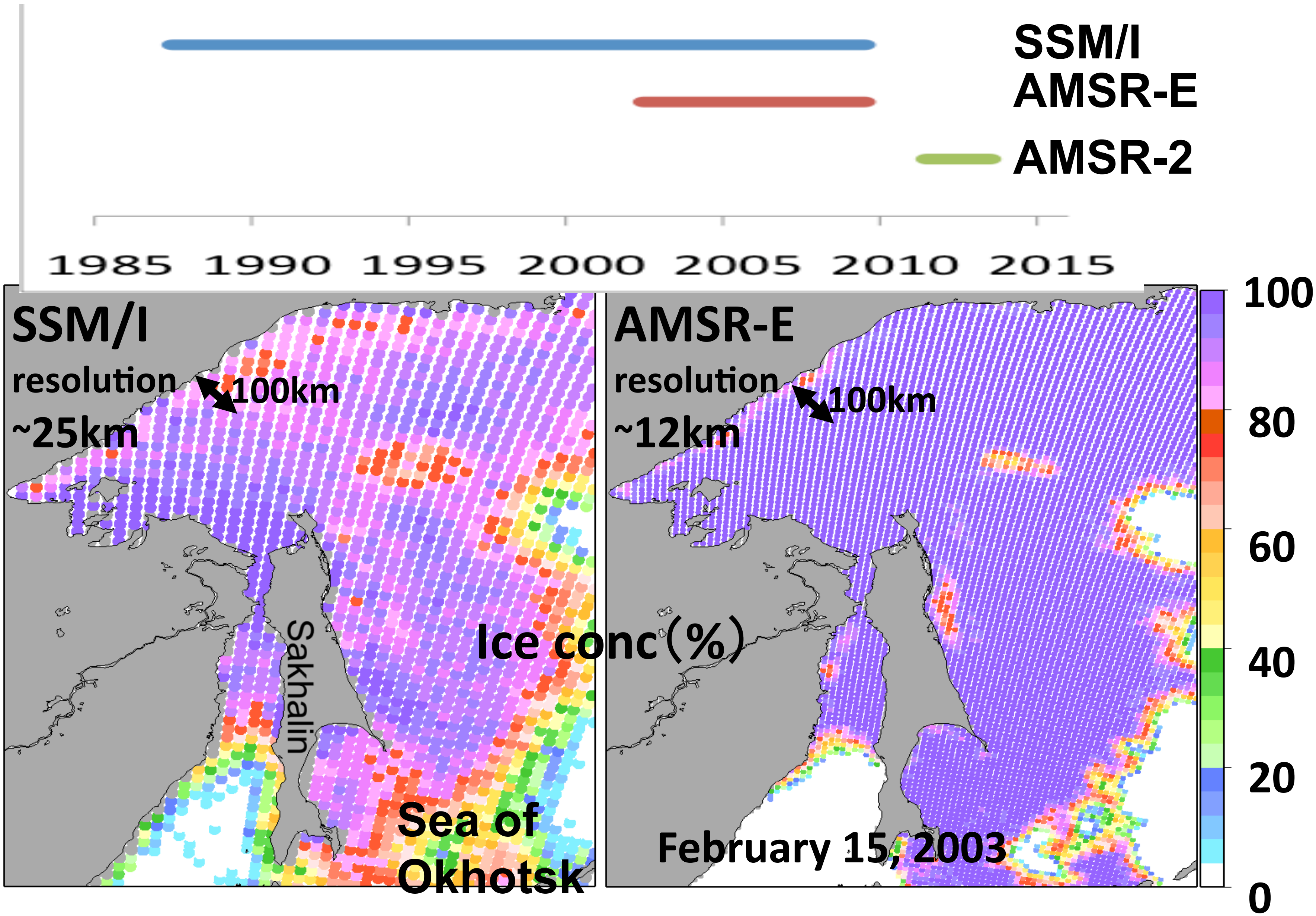
(Rintoul, 2007)

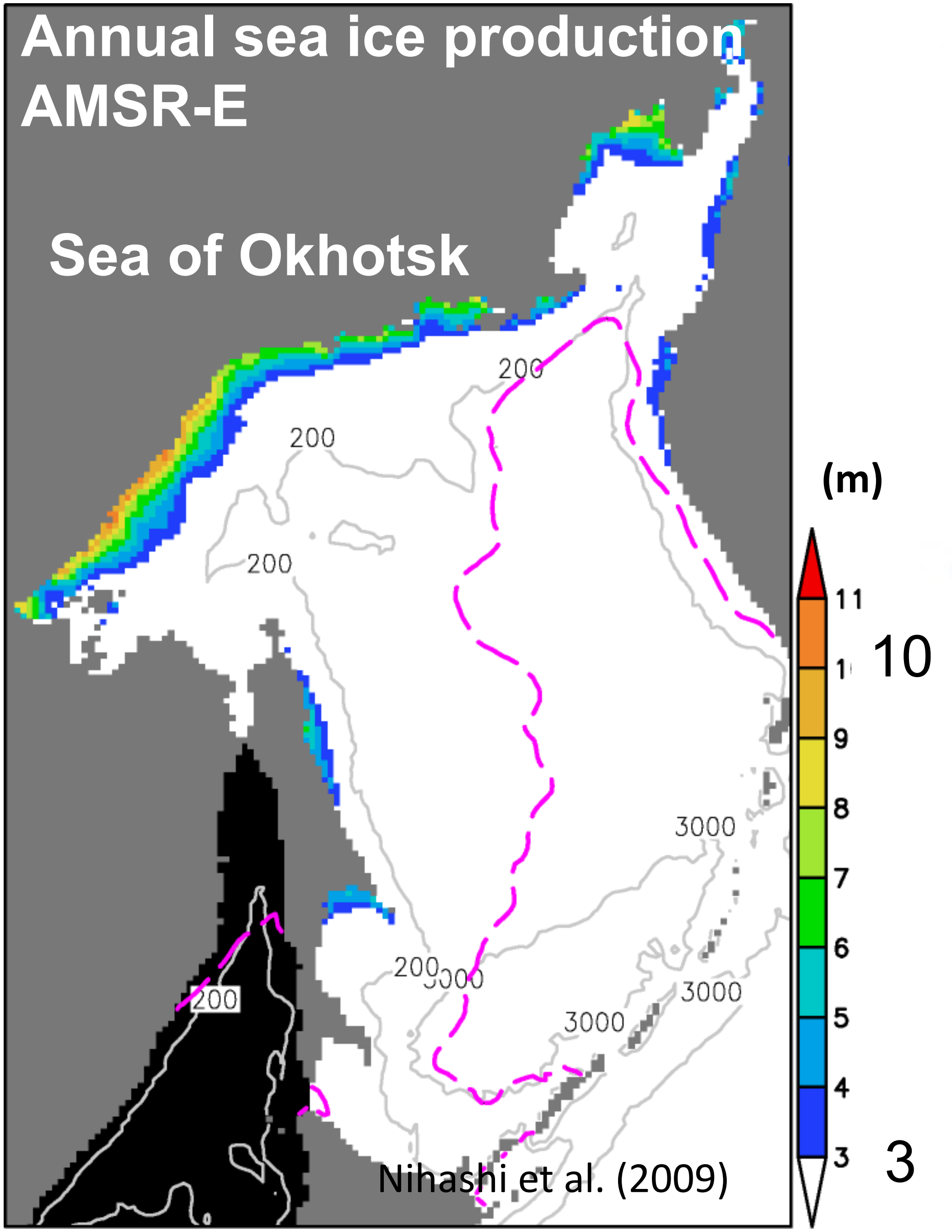
Interannual variability of sea ice production in Arctic ocean

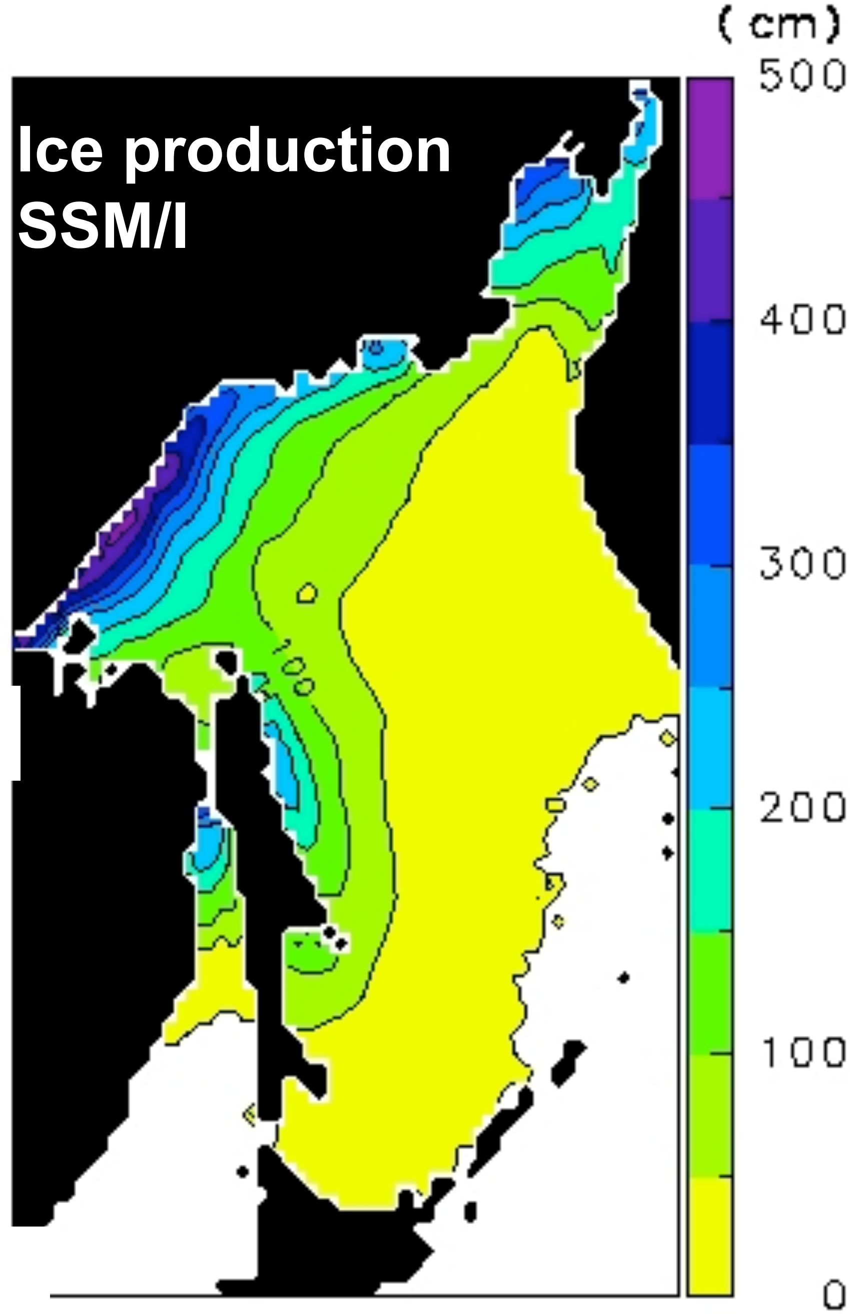


Tamura, Ohshima in preparation

SSM/I 1987-2010 (interannual variations)
AMSR relatively high spatial resolution (12-6 km))



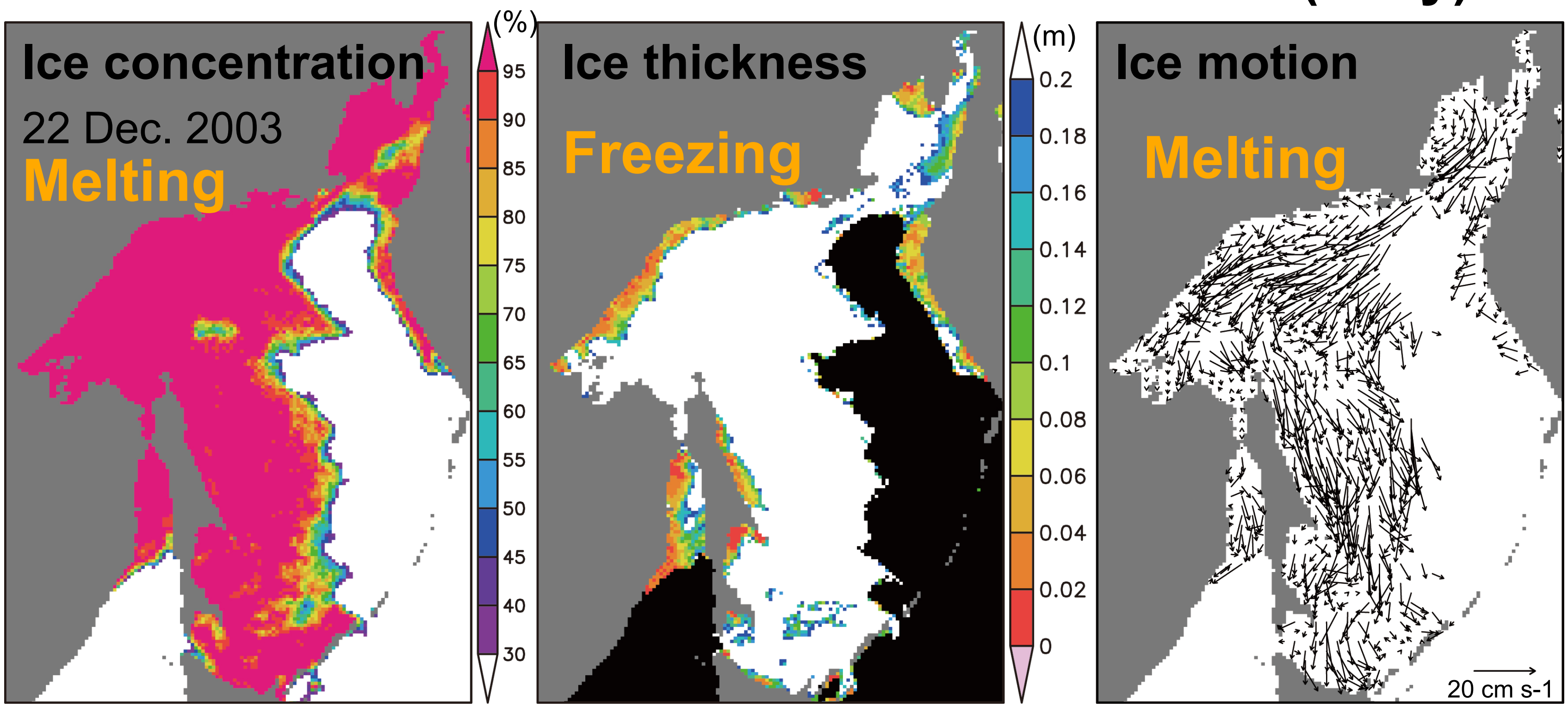




Ohshima et al., 2003

Creation of heat/salt flux data set: case of Okhotsk Sea

Sea ice data are derived from AMSR-E data (daily)



by NT2 algorithm
(Markus and Cavalieri, 2000)

by ice thickness algorithm
(Nihashi et al., 2009)

by maximum correlation method
(Kimura and Wakatsuchi, 2004)

ECMWF: Air temp. Humidity, Wind speed, and SLP (daily)
ISCCP: Cloud (monthly)
HadISST: SST (monthly)

Calculation of salt flux

Salt flux (S)

$$S = \rho_i (s_w - s_i) \frac{dV_i}{dt}$$

Freezing case (Q < 0 W m^{-2})

$$\frac{dV_i}{dt} = \frac{Q}{\rho_i L_f}$$

Melting case (Q > 0 W m-2)

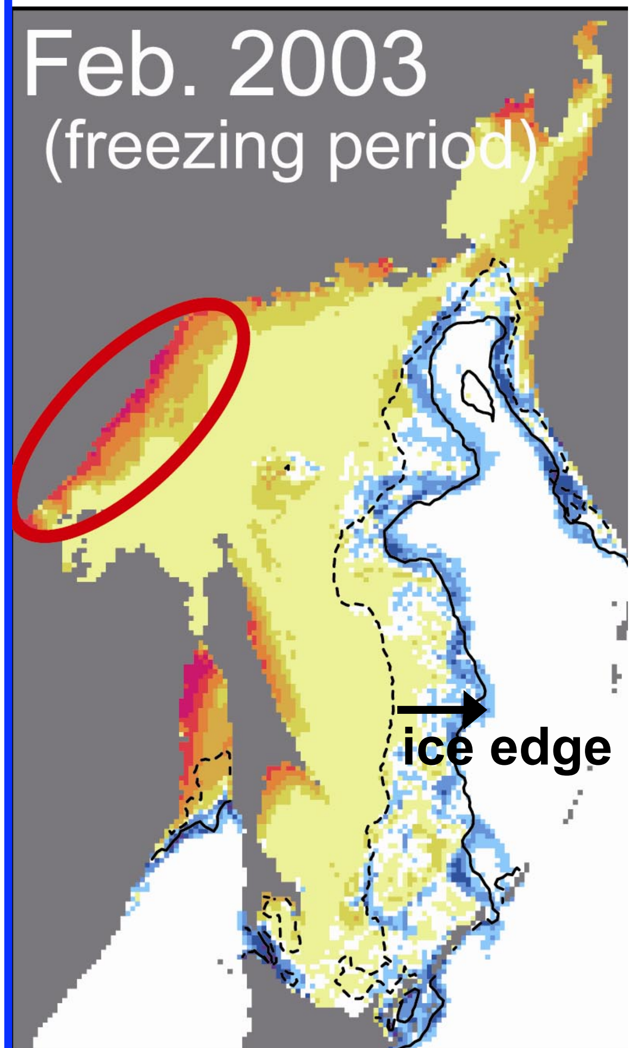
$$\frac{dV_i}{dt} = \overline{h}_i \frac{dA_{melt}}{dt} \qquad \frac{dA_{melt}}{dt} = \frac{dA_{obs}}{dt} - \frac{dA_{adv}}{dt}$$

Q: Net surface heat flux
ρ_i : Density of sea ice
s_w : Water salinity
s_i: Ice salinity
V_i : Ice volume
L_f : Latent heat
h_i : Ice thickness

Advection of sea ice is taken into account

Assumption: constant ice thickness (≒ 0.8 m)
→ the thickness is determined so that the annual salt budget is balanced in the domain

Monthly cumulative freezing and melting

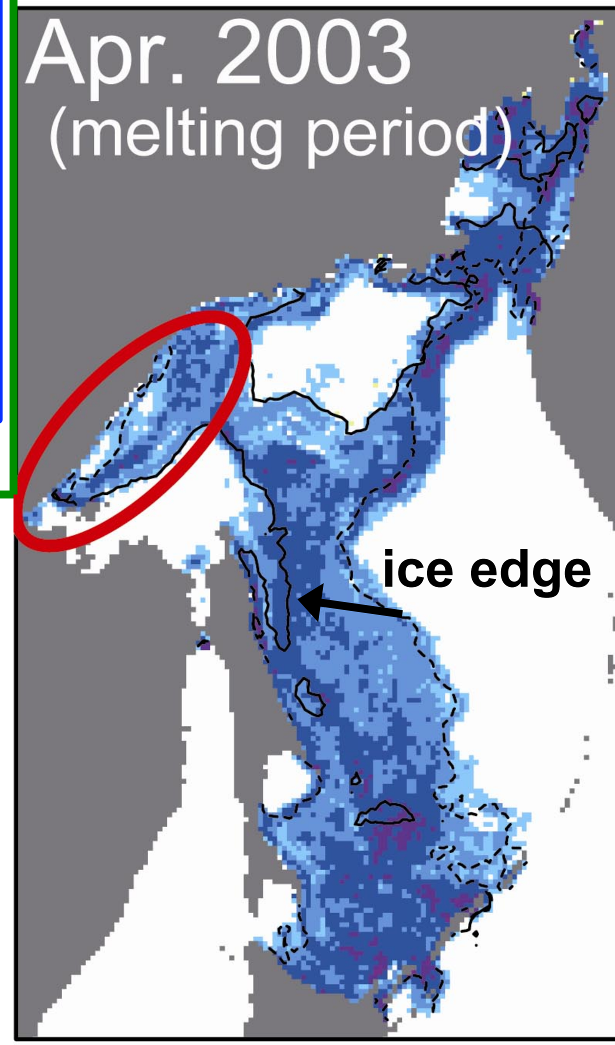


Freezing period

- Active freezing occurs in coastal polynyas

⇒ **Ice production factory**

- Both freezing and meting occur at the ice edge



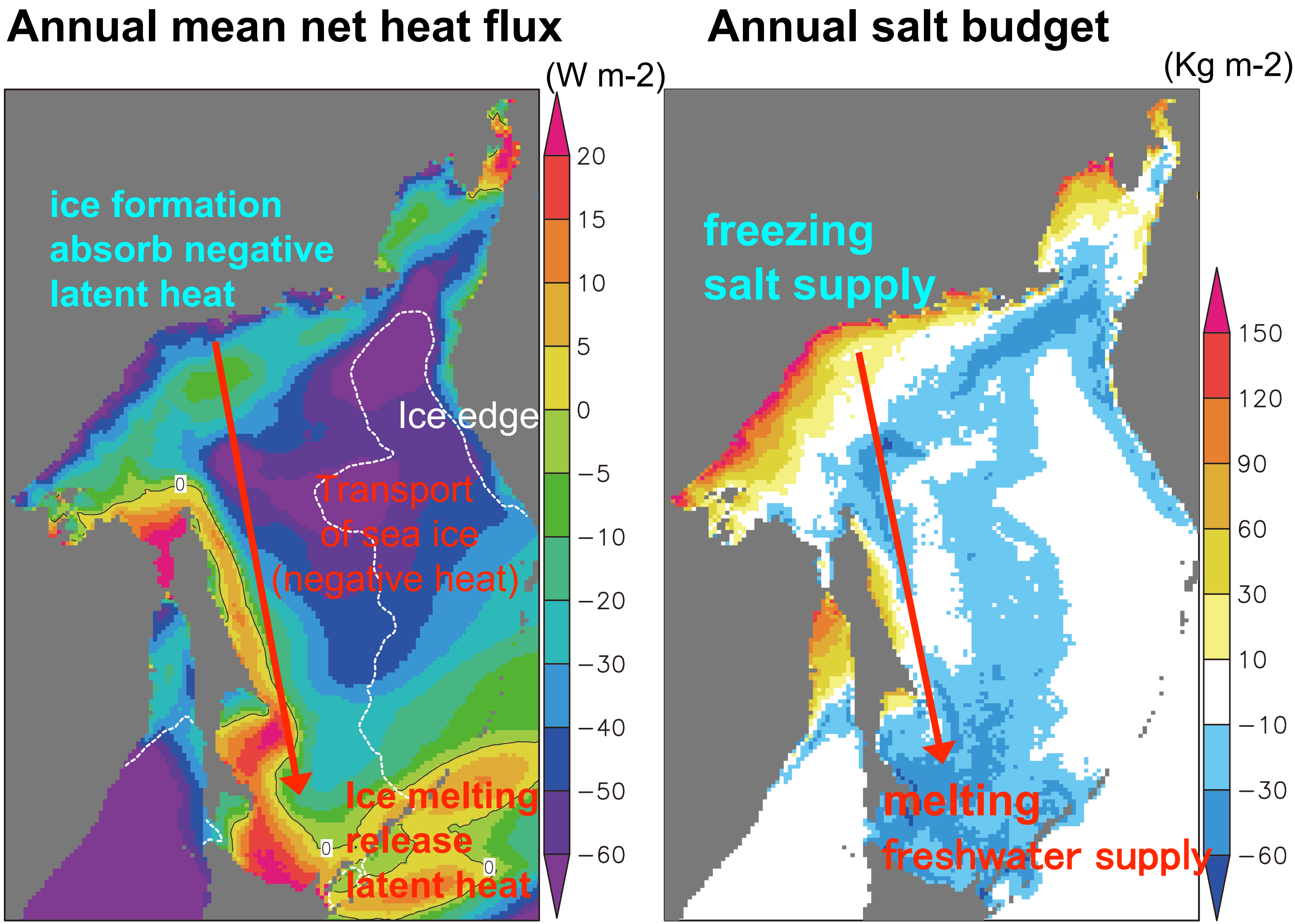
Melting period

- Melting actively occurs in ice edge regons
- Meting is also active at the coastal polynya

⇒ **Ice melting factory**

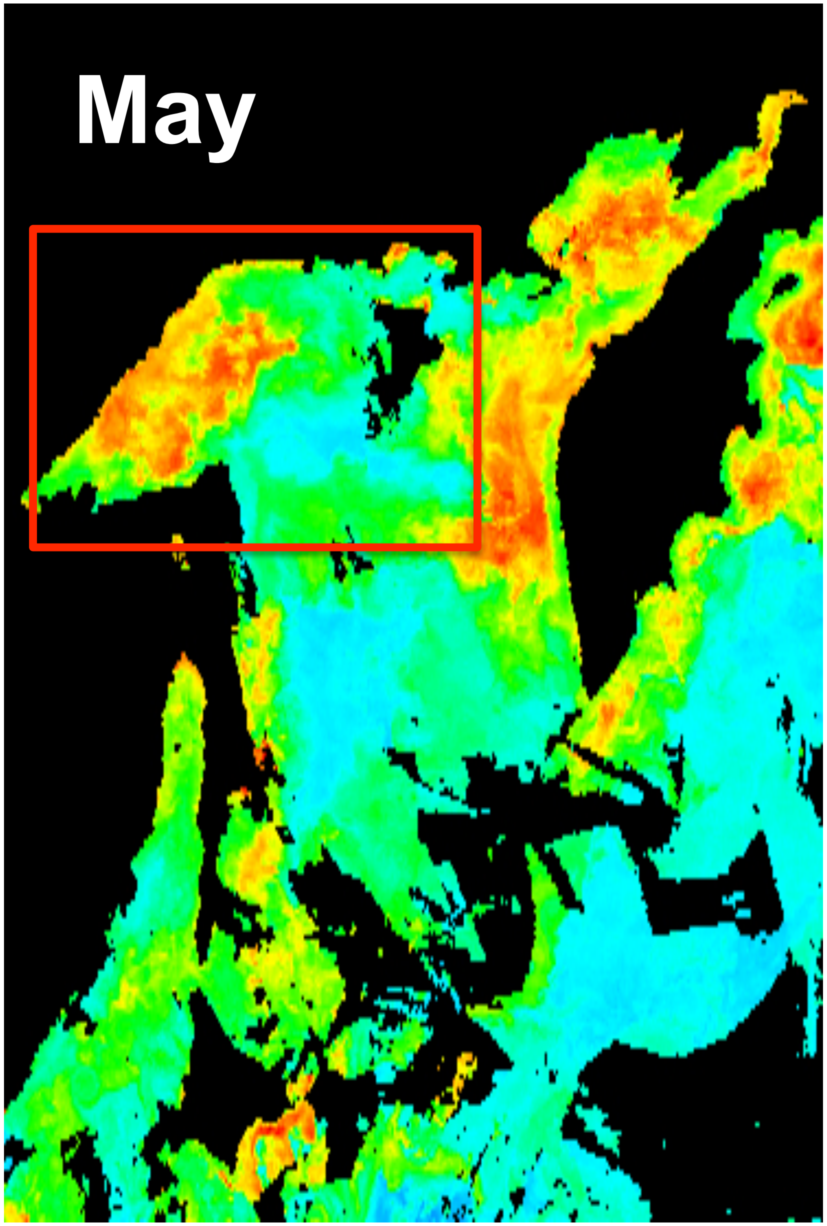
See the poster for the details

Nihashi, Ohshima in preparation

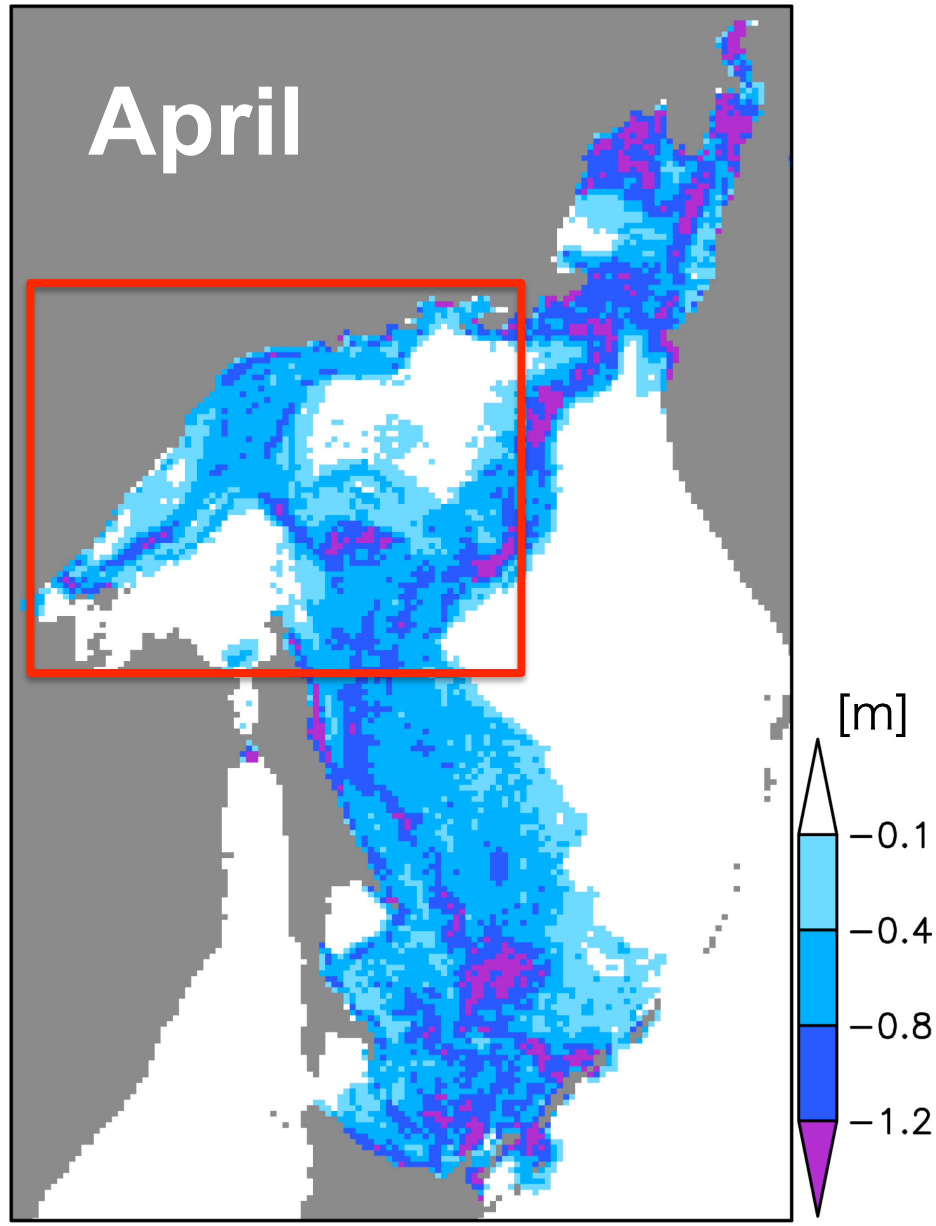

Annual mean net heat flux
(W m-2)
ice formation
absorb negative
latent heat
Ice edge
Transport
of sea ice
(negative heat)
Ice melting
release
latent heat
20
15
10
5
0
−5
−10
−20
−30
−40
−50
−60
Annual salt budget
(Kg m-2)
freezing
salt supply
melting
freshwater supply
150
120
90
60
30
10
−10
−30
−60

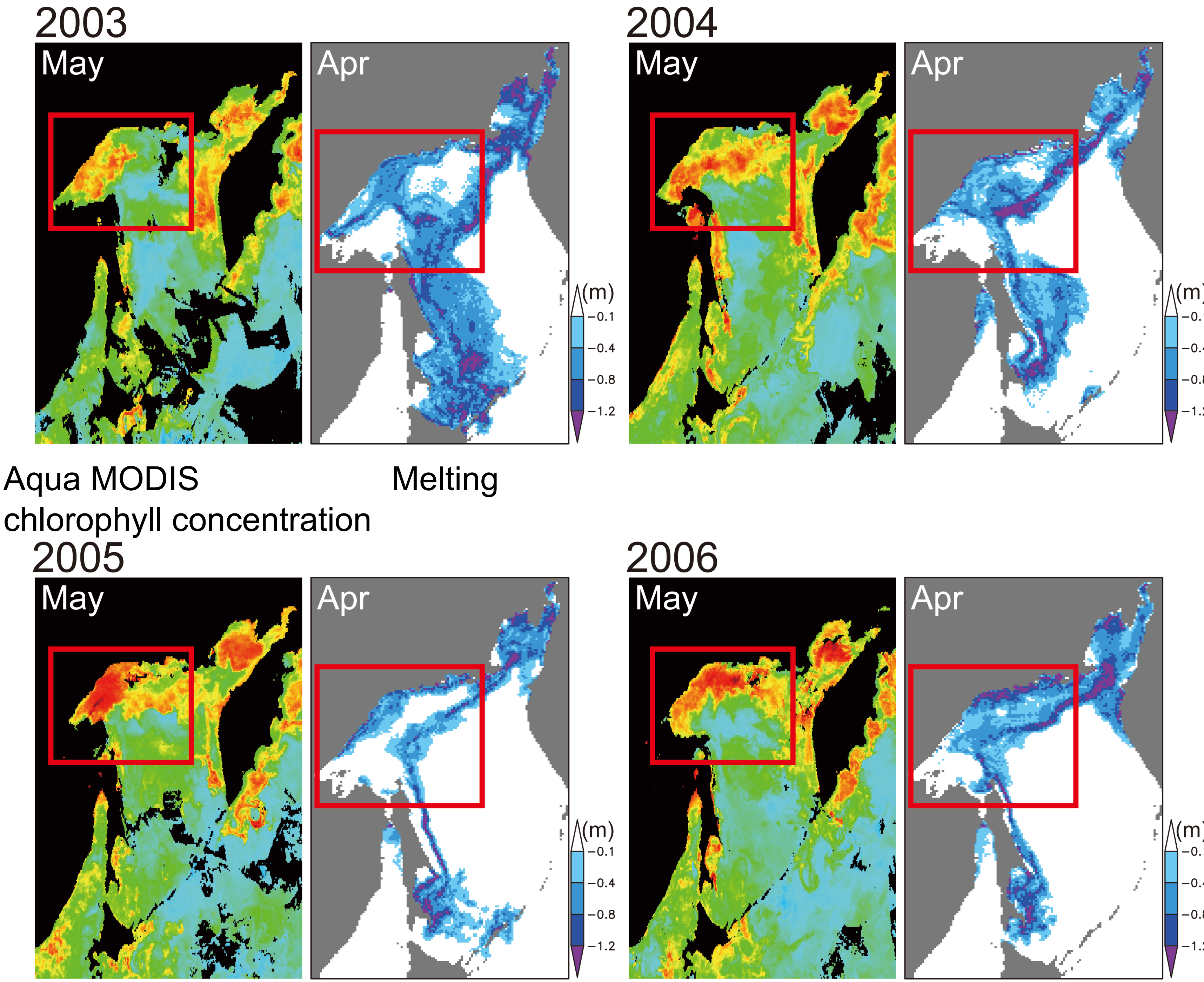
2003

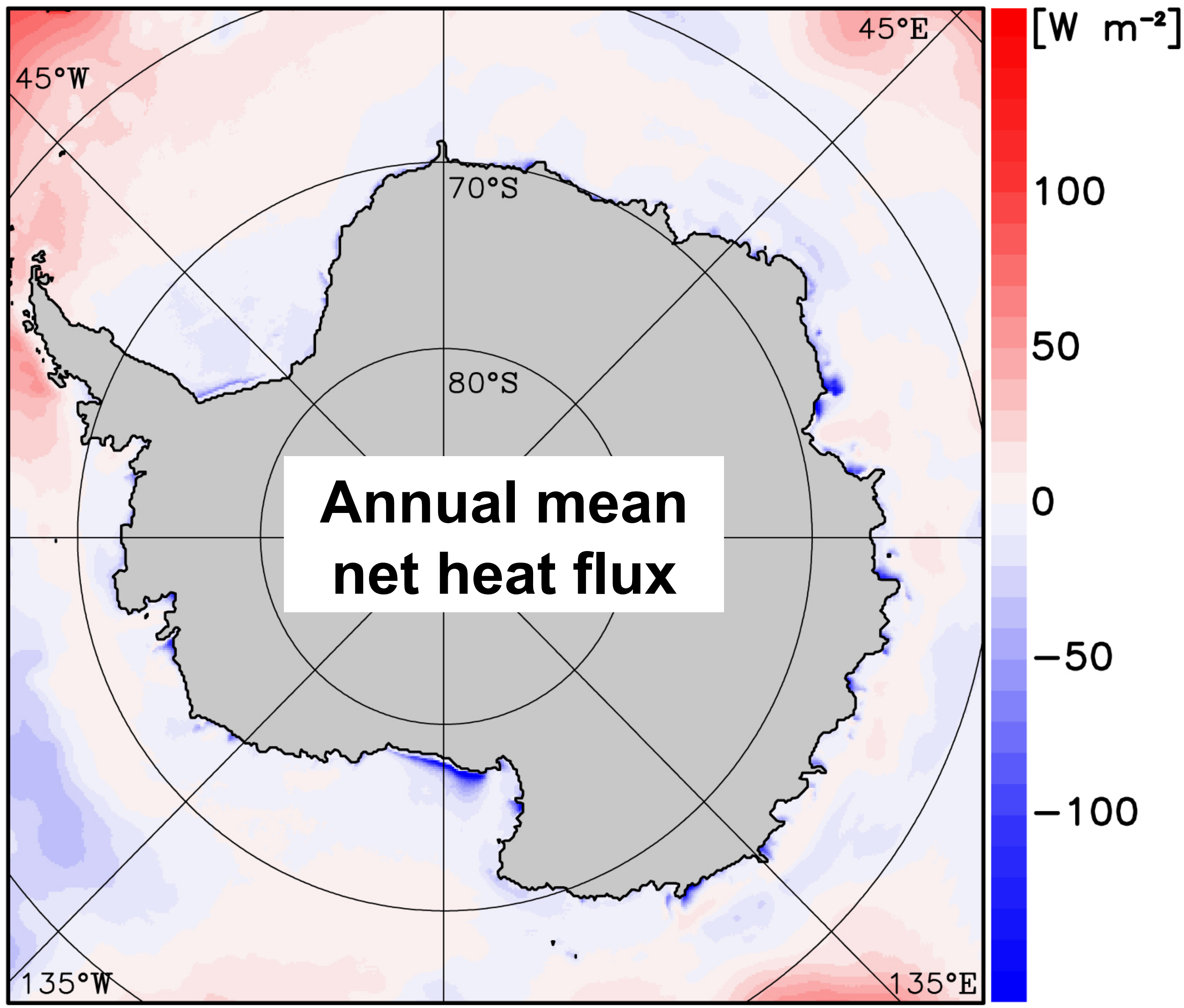
Chlorophyll conc.



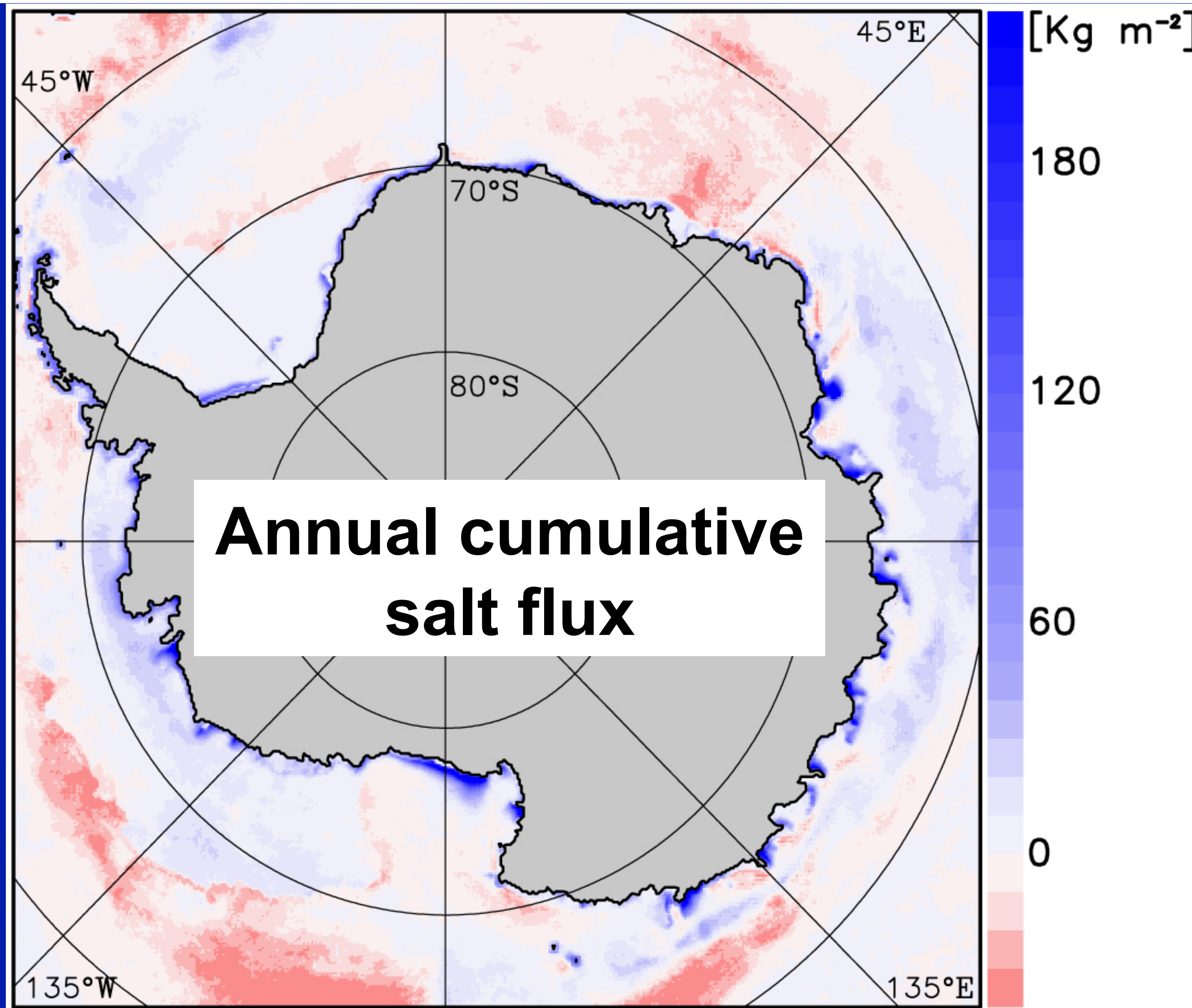
Melting amount of ice




2003
May
Apr
2004
May
Apr
(m)
-0.1
-0.4
-0.8
-1.2
Aqua MODIS
chlorophyll concentration
Melting
2005
May
Apr
2006
May
Apr
(m)
-0.1
-0.4
-0.8
-1.2



Coastal polynya → Hot spot of heat flux



Coastal polynya
Freezing
Salt flux

sea ice
transport

Offshore area
Melting
Freshwater flux

The data set (monthly) is or will be archived on
http://wwwod.lowtem.hokudai.ac.jp/polar-seaflux/ or
http://wwwod.lowtem.hokudai.ac.jp/kaiyodotai-e.html

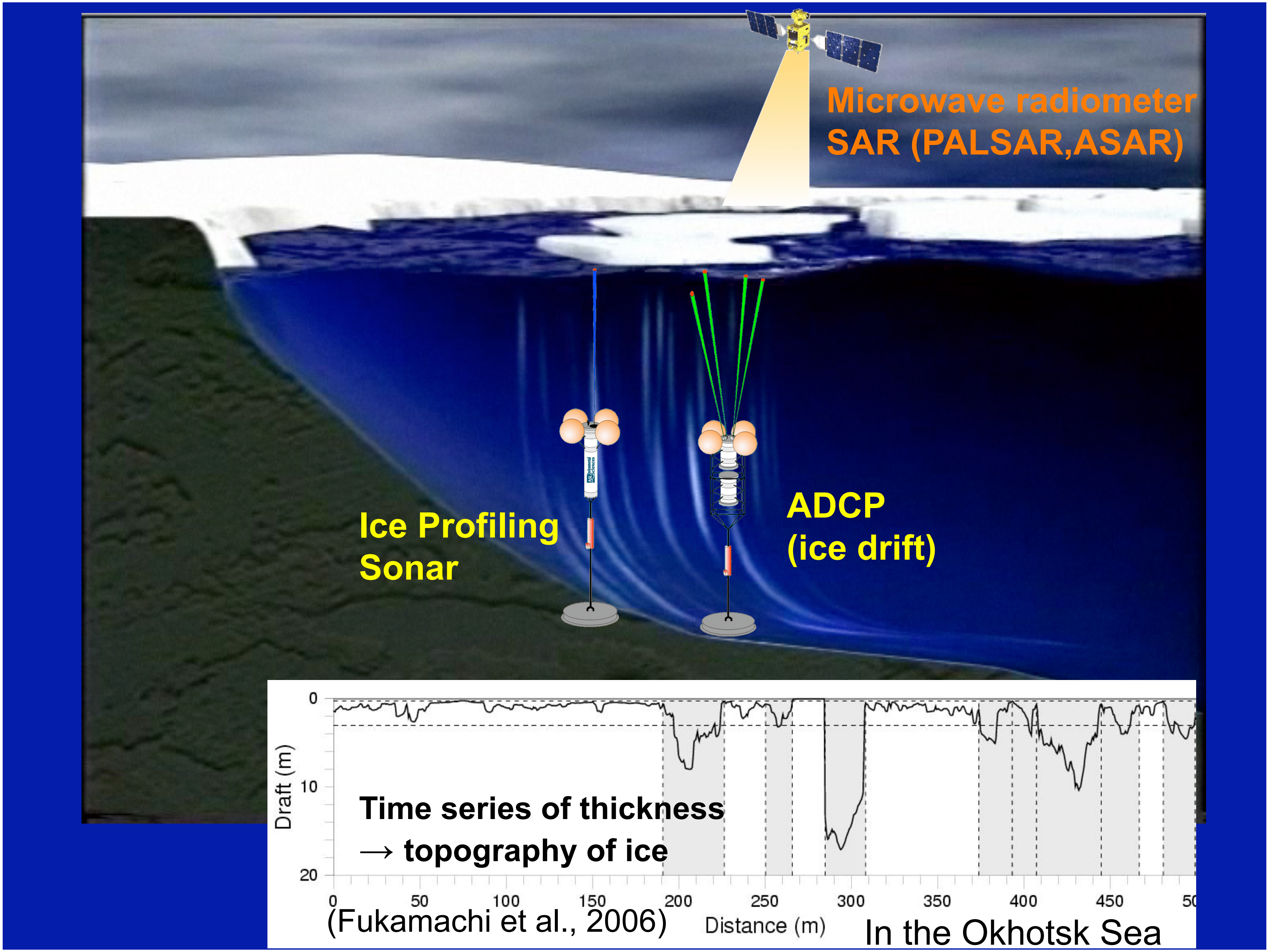
	ice production	heat/salt flux
Southern Ocean	available	2010
Arctic ocean	2011	2011
Sea of Okhotsk	2010	2011

Southern Ocean Data Set has been already used

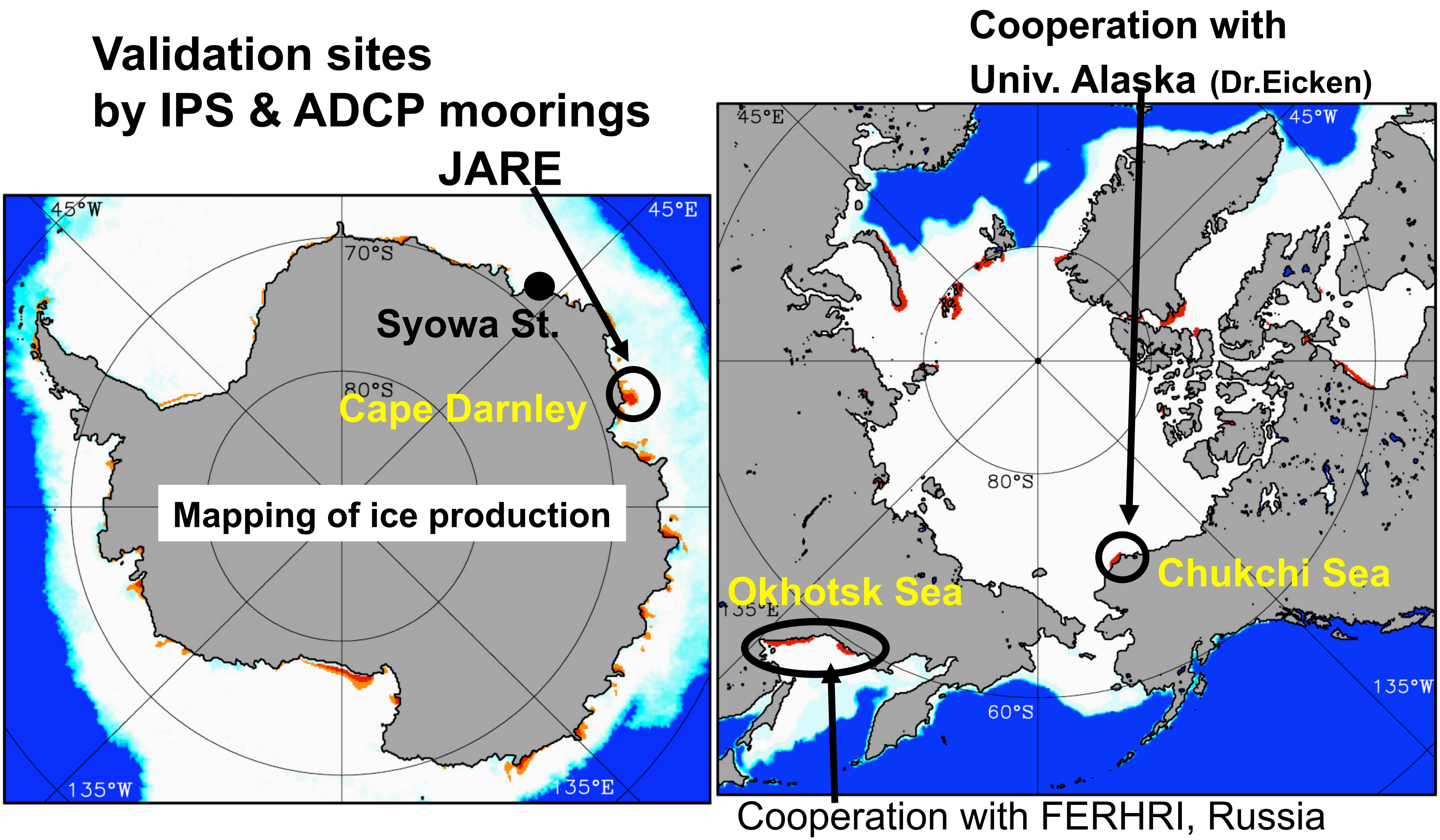
as observational analysis data
in Tamura et al al.(2008,GRL), Williams et al.(2010,JGR) ....

as validation data of model
in CCSR coupled model: Kusahara et al., submitted

as boundary condition data of model
in ACE CRC ice shelf-ocean coupled mode: Galton-Fenzi (ph-D thesis)



Microwave radiometer
SAR (PALSAR,ASAR)
Ice Profiling
Sonar
ADCP
(ice drift)
Draft (m)
0
10
20
Time series of thickness
→ topography of ice
0 50 100 150 200 250 300 350 400 450 50
Distance (m)
(Fukamachi et al., 2006)
In the Okhotsk Sea

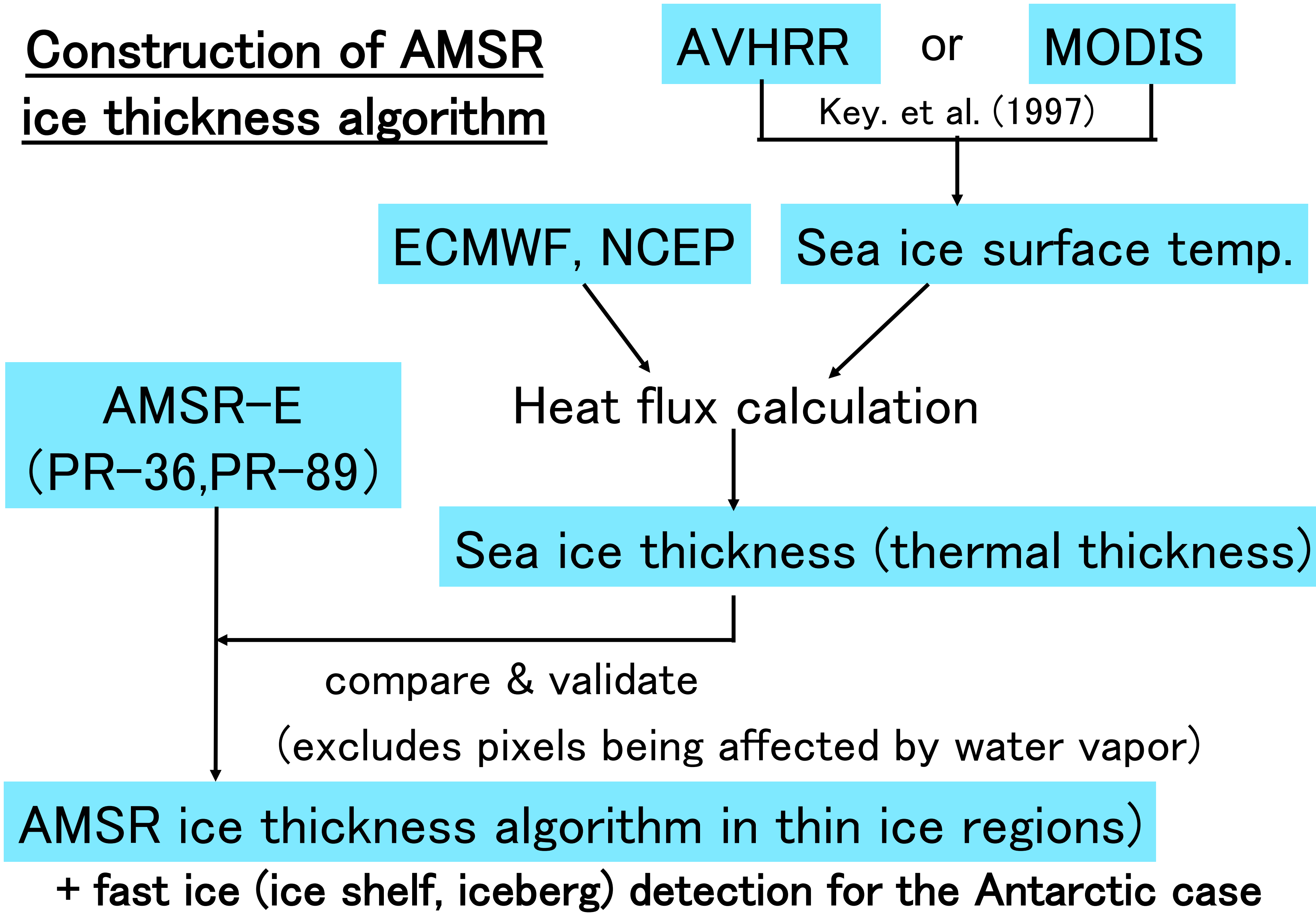


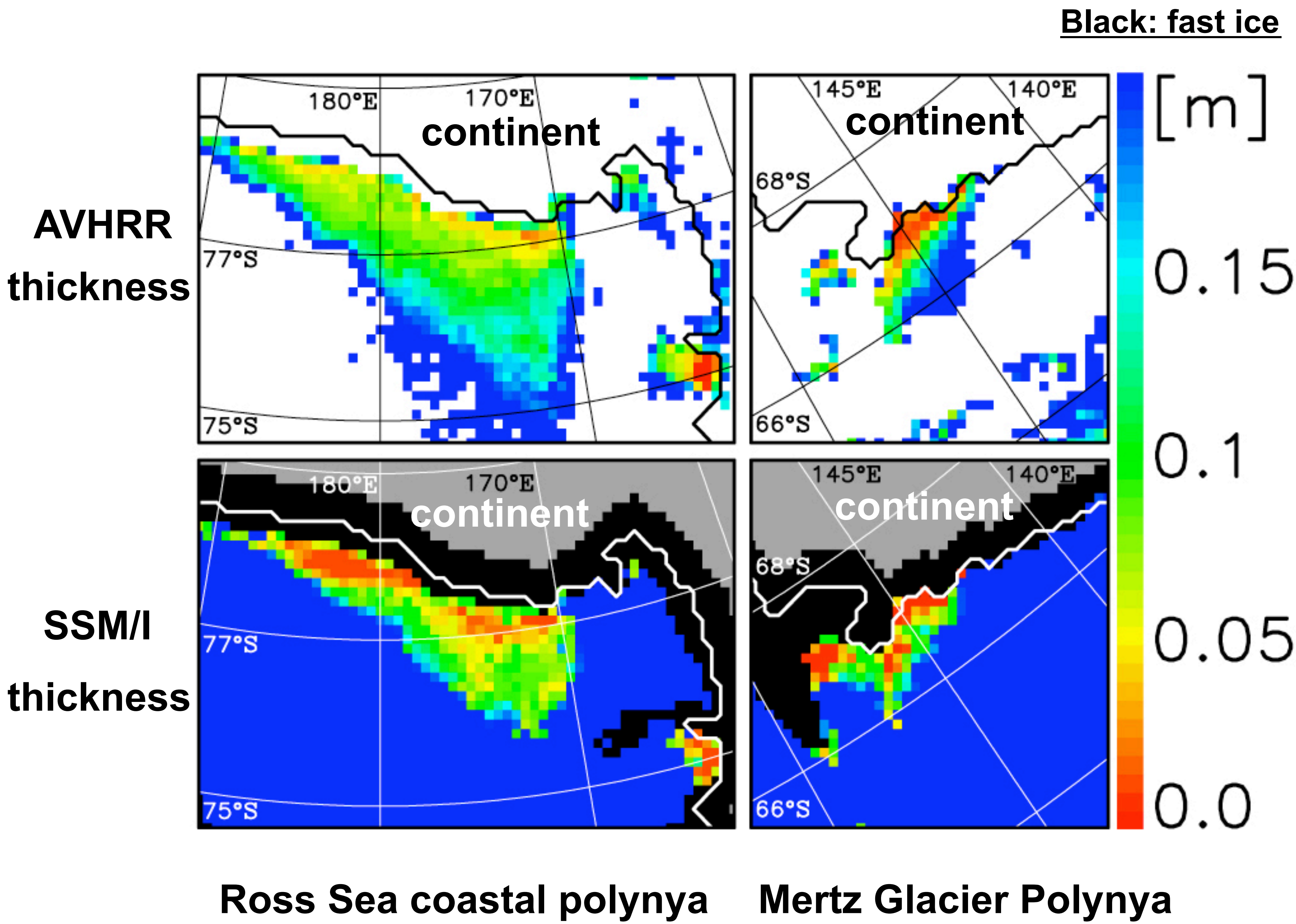
We are now making mooring observations of Ice Profiling Sonar and ADCP in the Antarctic and Arctic polynyas, which will provide very good validation data for the ice thickness and production algorithm.

Thank you !

Method:

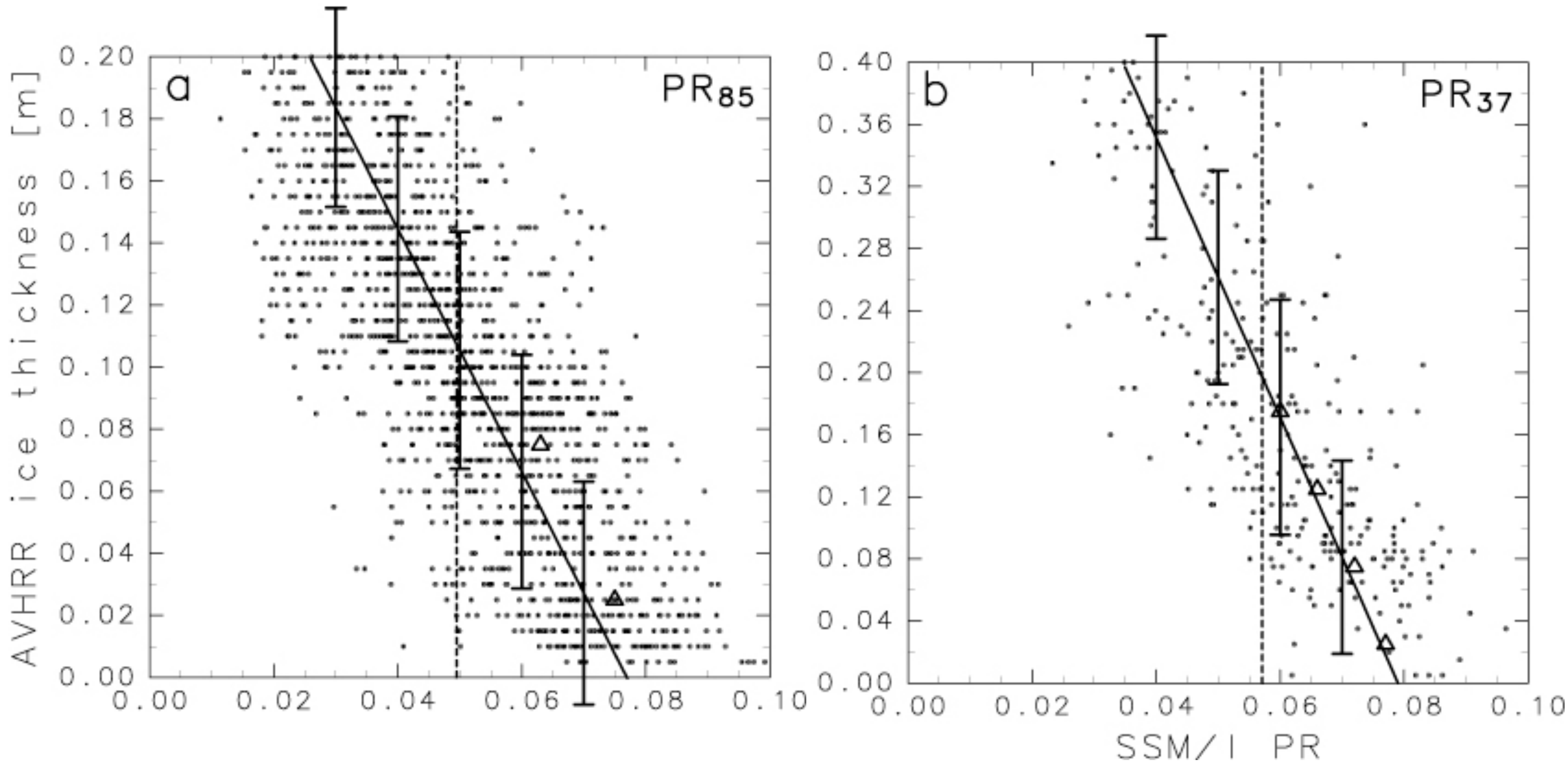
Construction of AMSR ice thickness algorithm





Black: fast ice
AVHRR thickness
SSM/I thickness
continent
continent
continent
continent
180°E
170°E
145°E
140°E
77°S
75°S
68°S
66°S
[m]
0.15
0.1
0.05
0.0
Ross Sea coastal polynya
Mertz Glacier Polynya

Scatterplot of AVHRR ice thickness and SSM/I PR



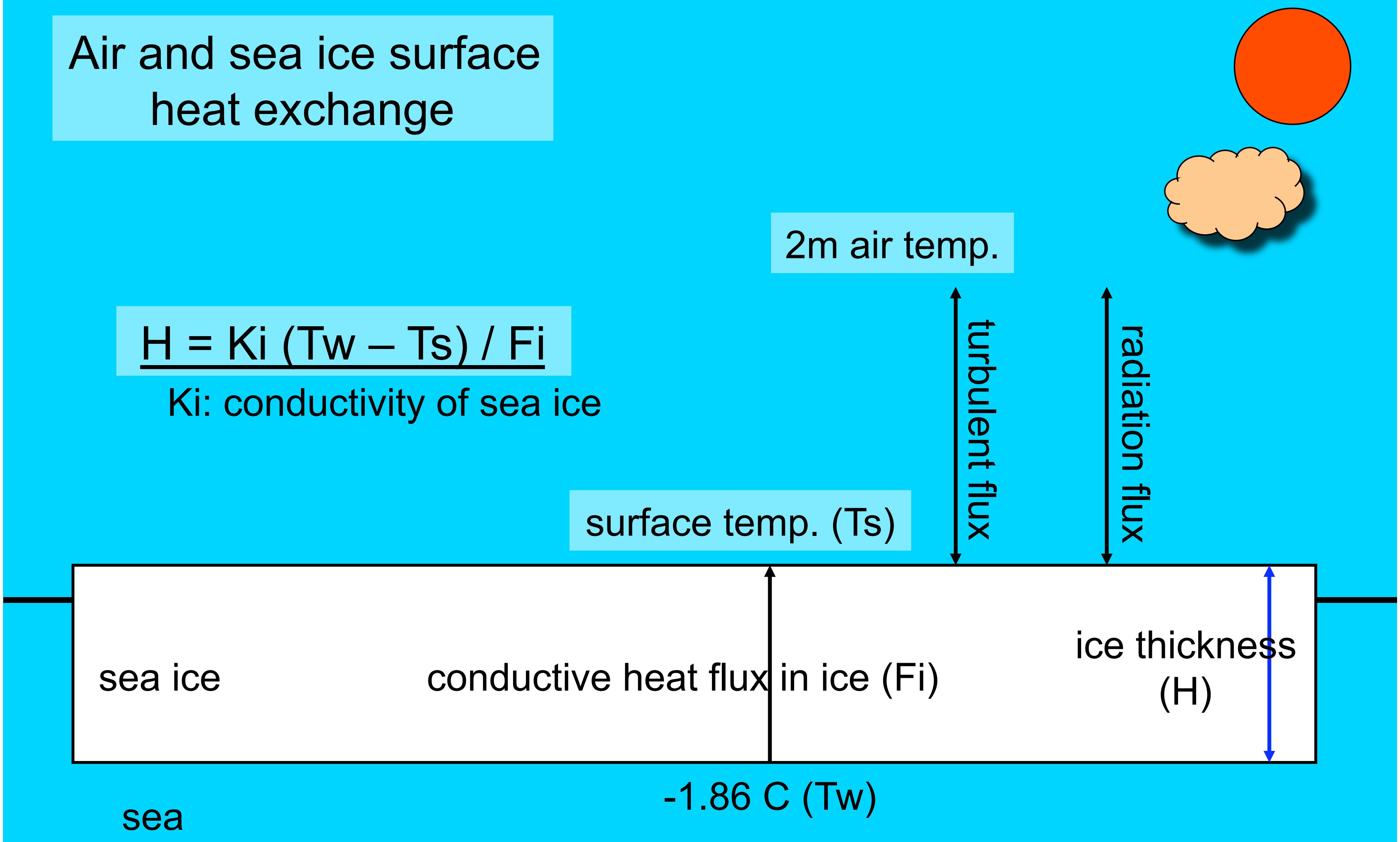
PR-85: 0-0.1 m

PR-37: 0.1-0.2 m

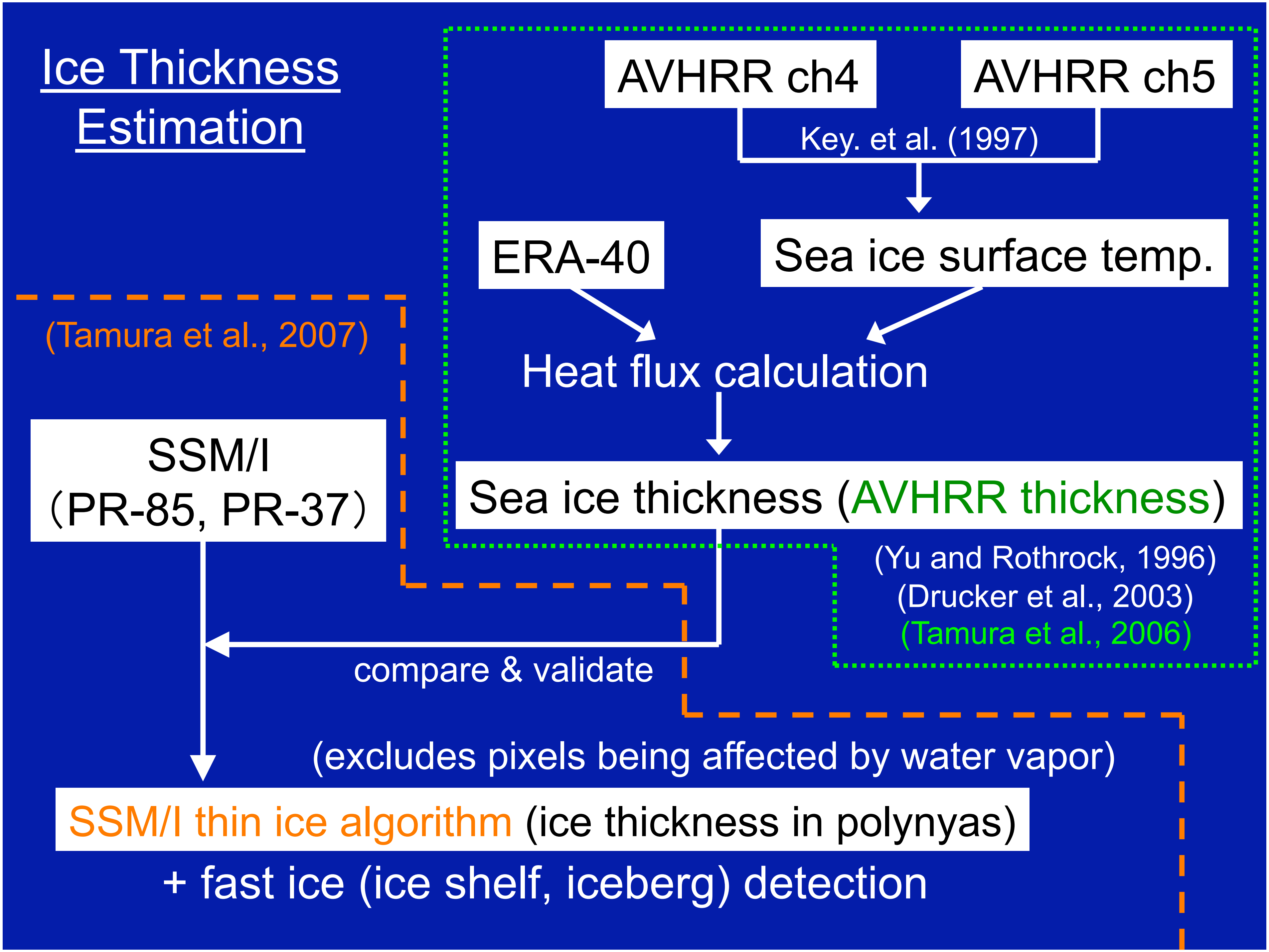
Air and sea ice surface heat exchange

$$H = Ki\,(Tw - Ts) / Fi$$

Ki: conductivity of sea ice

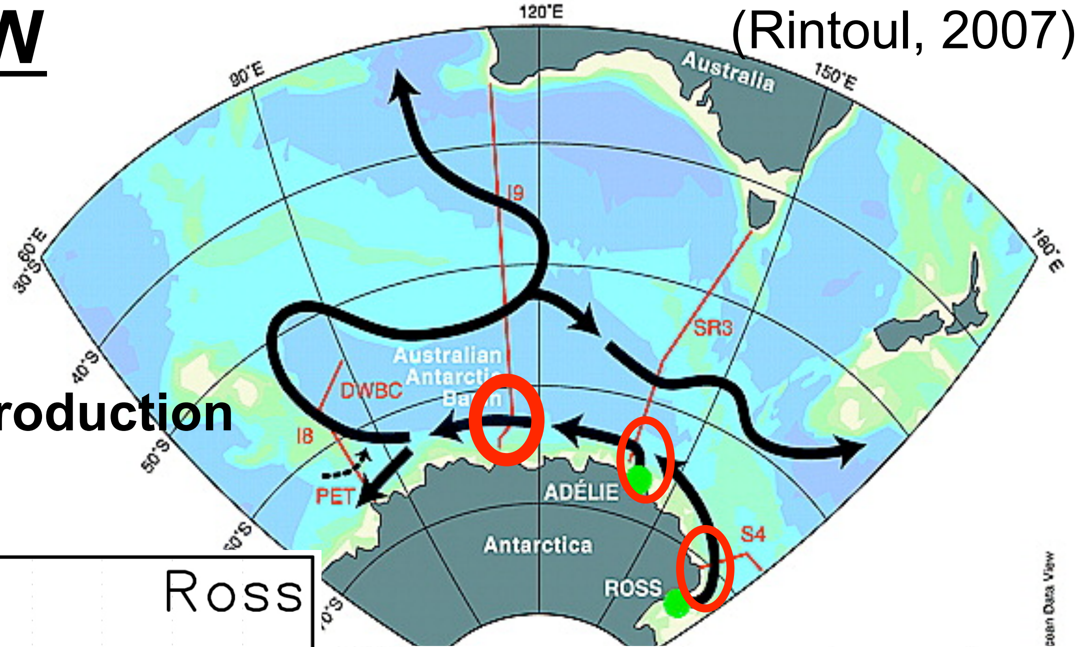


Estimation of sea ice thickness by Yu and Rothrock（1996）


Ice Thickness Estimation
AVHRR ch4
AVHRR ch5
Key. et al. (1997)
ERA-40
Sea ice surface temp.
(Tamura et al., 2007)
Heat flux calculation
SSM/I
(PR-85, PR-37)
Sea ice thickness (AVHRR thickness)
(Yu and Rothrock, 1996)
(Drucker et al., 2003)
(Tamura et al., 2006)
compare & validate
(excludes pixels being affected by water vapor)
SSM/I thin ice algorithm (ice thickness in polynyas)
+ fast ice (ice shelf, iceberg) detection

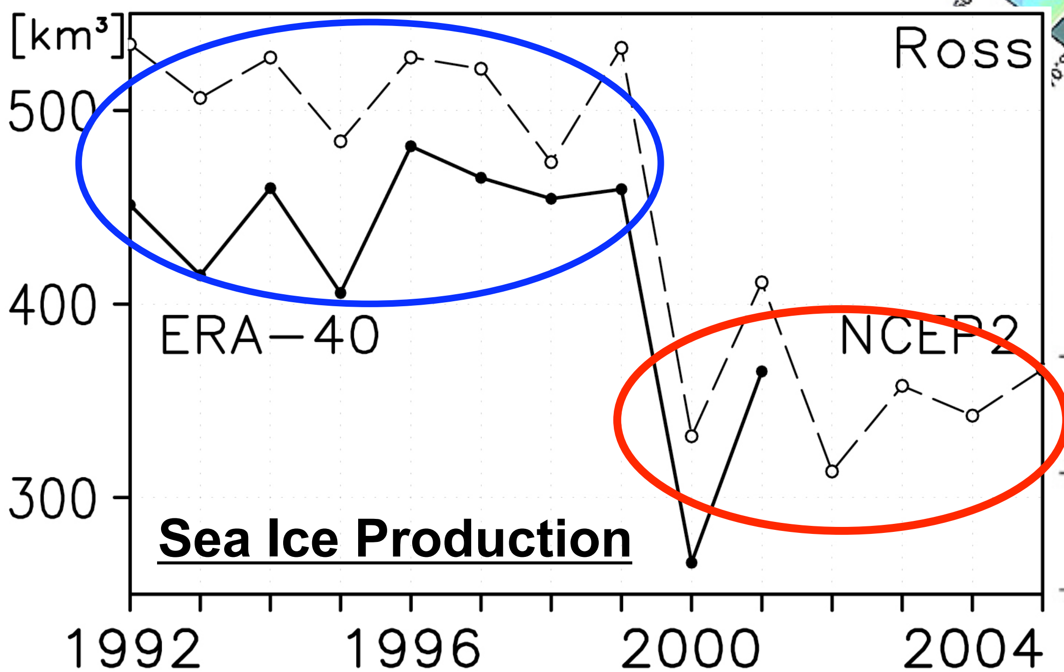
Freshening of AABW

(Rintoul, 2007)

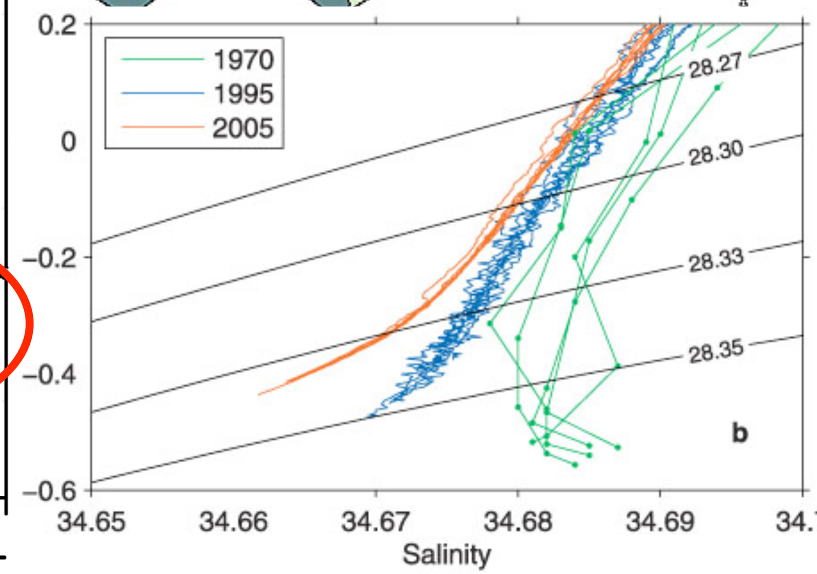


Decrease of Ross Sea Ice Production

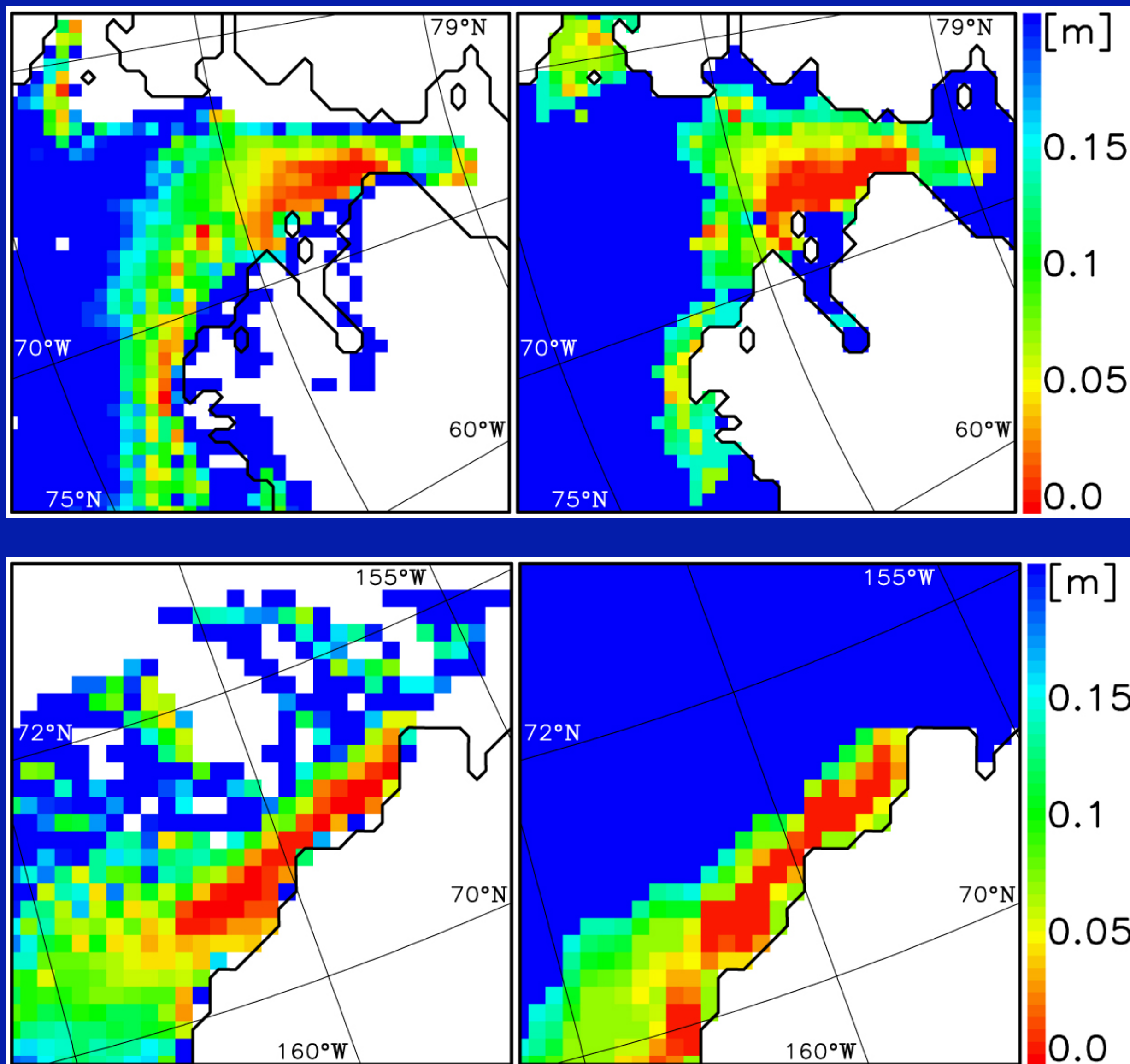
120 km³ = ~70 Gt



(Tamura et al., 2008)



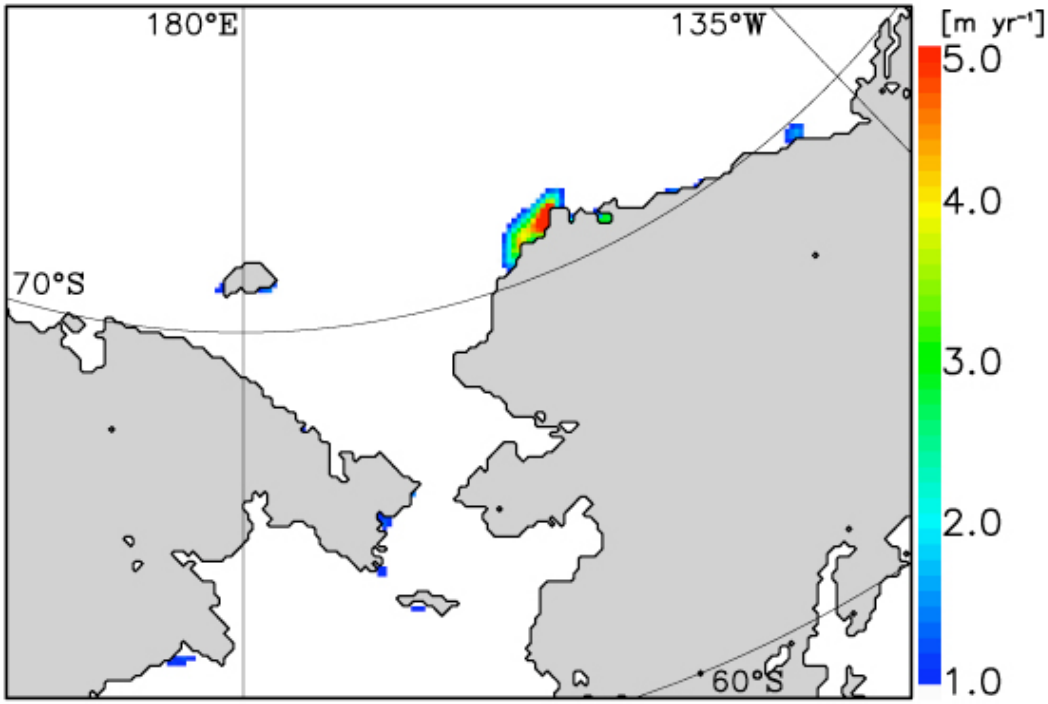
(Rintoul, 2007)



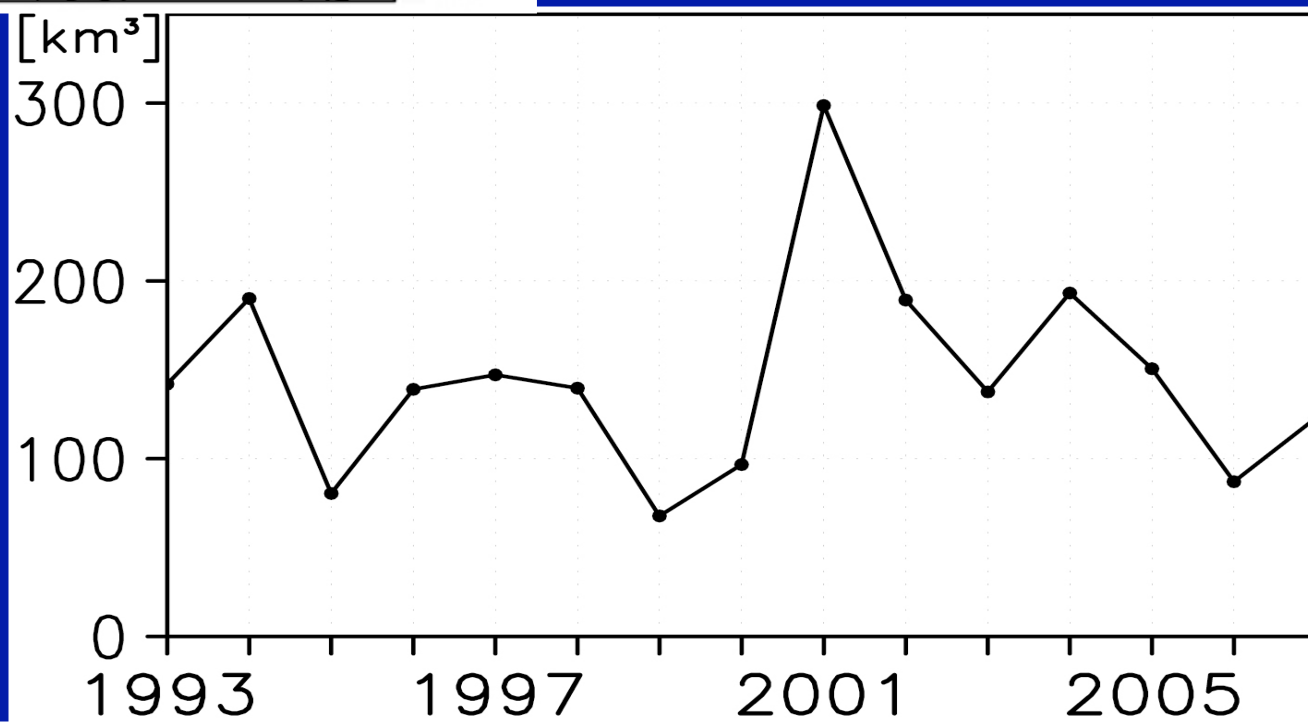
North Water Polynya (Northeast Greenland)

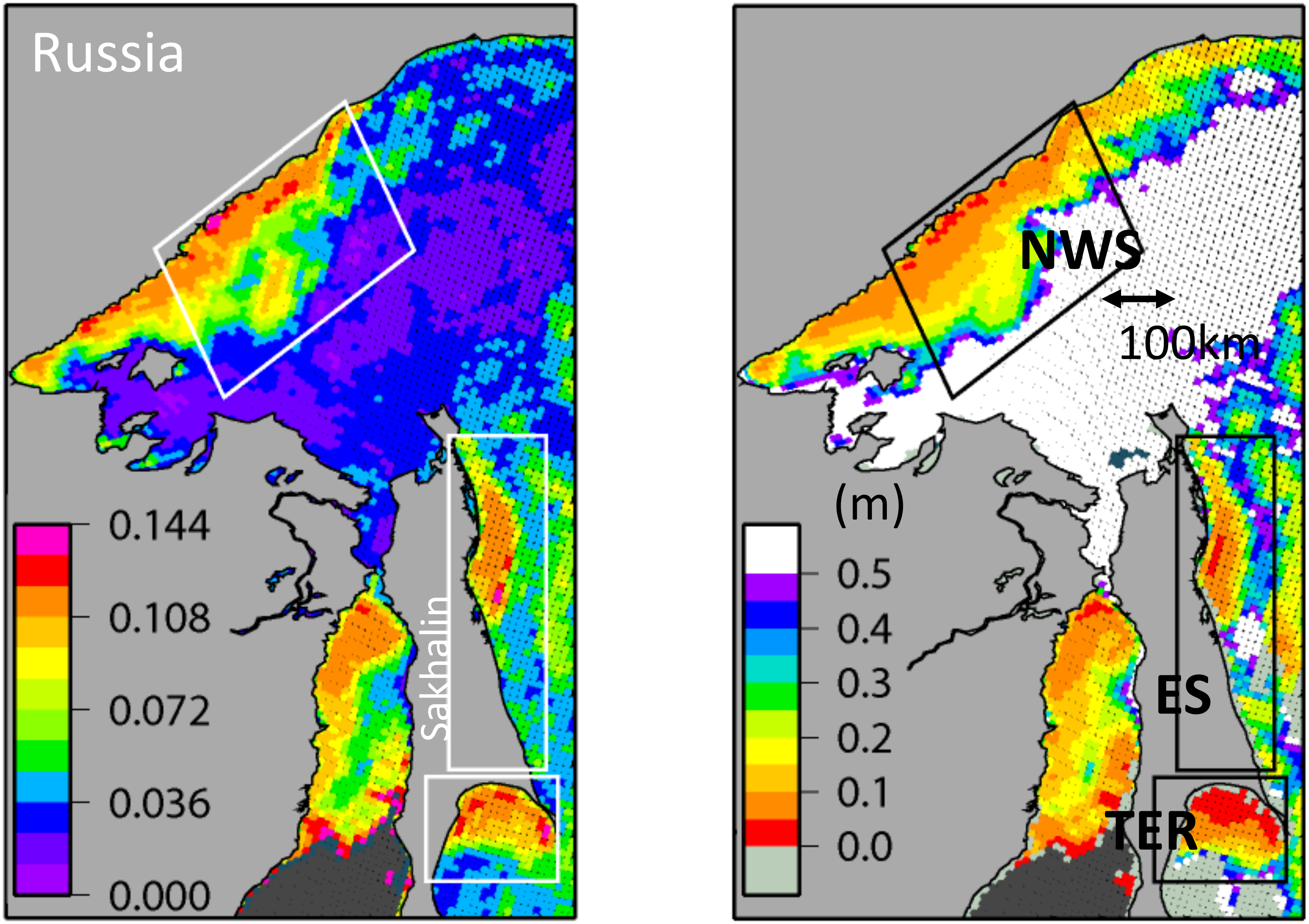
Chukchi Sea coastal polynya

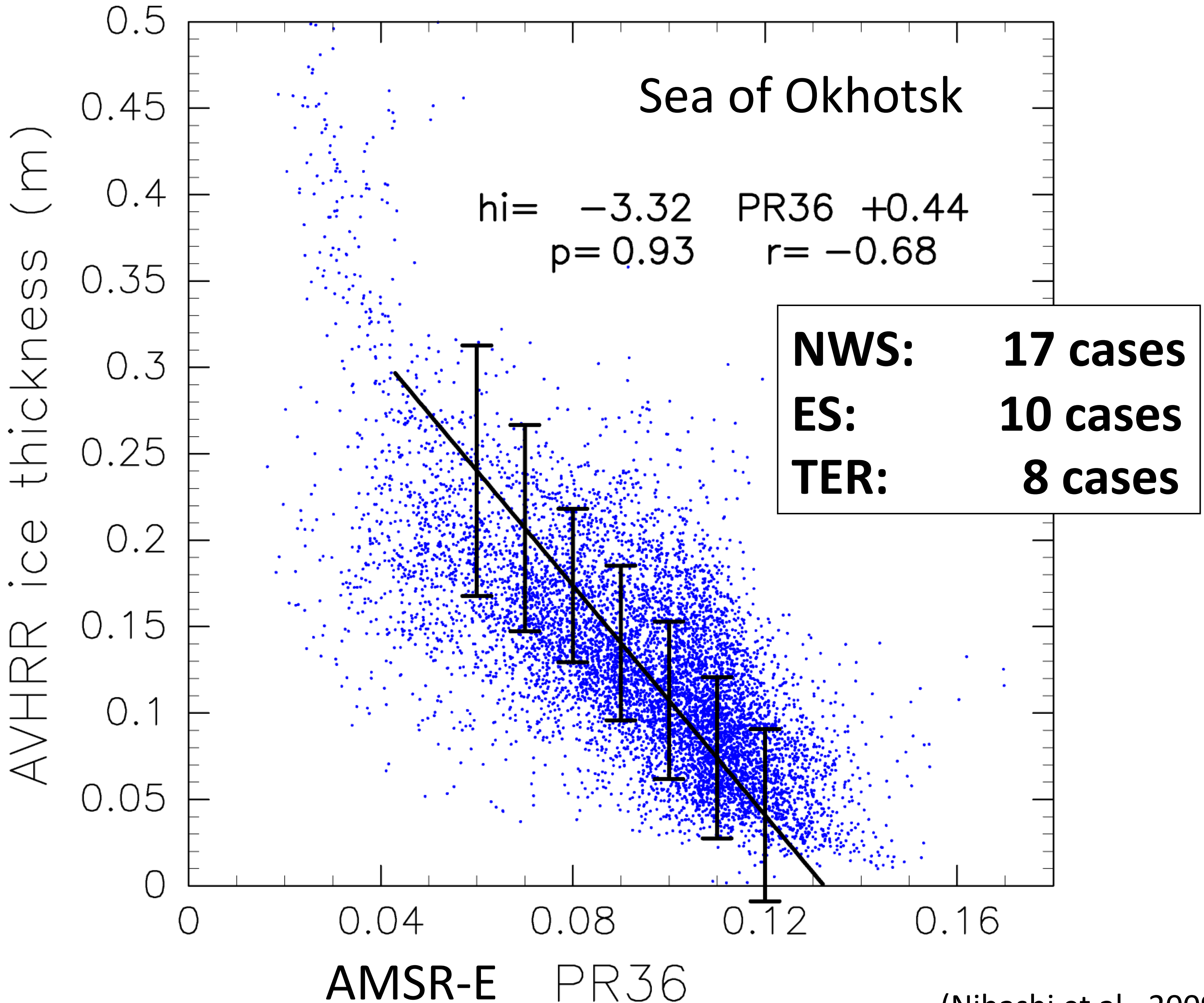
AVHRR thickness **SSM/I thickness**



海氷生産の年変動
（チャクチ海アラスカ沿岸）



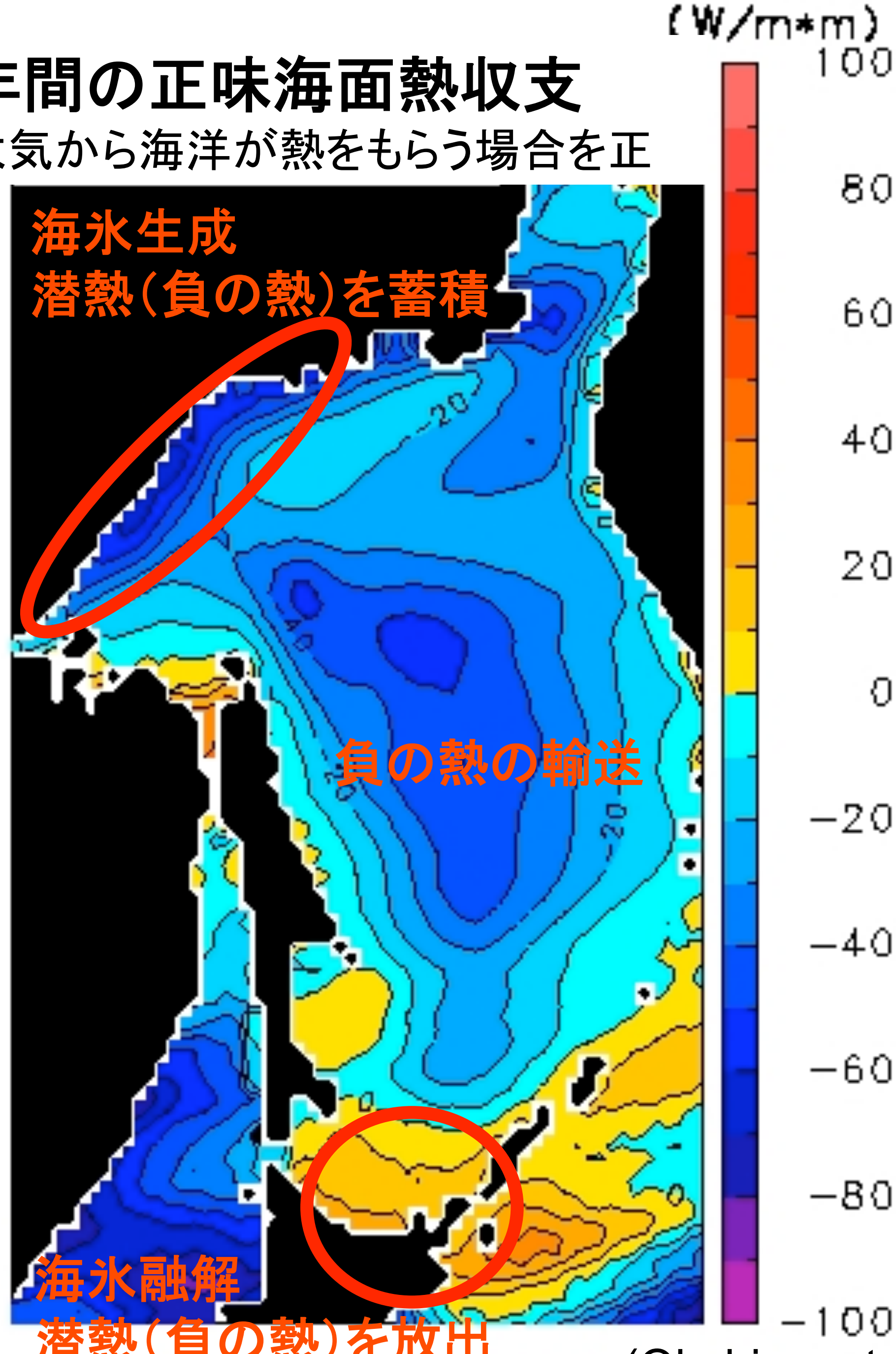

Russia
Sakhalin
0.144
0.108
0.072
0.036
0.000
NWS
100km
(m)
0.5
0.4
0.3
0.2
0.1
0.0
ES
TER



(Nihashi et al., 2009)

年間の正味海面熱収支

大気から海洋が熱をもらう場合を正



(Ohshima et al.,2003)

海氷による気候形成

1mの海氷の融解(潜)熱
＝全大気柱25-30度を昇温

北海道北部・東部域の
寒冷な気候(特に夏季)は、
海氷(+東樺太海流)が
運ぶ負の熱によって形成

Ice Formation

Negative heat flux

Thin ice region (coastal polynyas, MIZ, ice divergence zone)

Freezing period (from March to October)

Ice Melt

Positive heat flux

Sea ice melt is calculated form ice concentration decrease of NT-2 sea ice concentration algorithm

First-year ice thickness is assumed to be 1.2 m

方法

熱フラックス (Q)　(Ohshima et at., 2003)

$$Q = (1 - A)Q_w + AQ_i$$

$$Q_w = (1 - \alpha_w)SW_w + LW_W + SE_w + LA_w$$

$$Q_i = (1 - \alpha_i)SW_i + LW_i + SE_i + LA_i + FC$$

α：アルベド
SW：短波放射
LW：長波放射
A ：海氷密接度
SE：顕熱フラックス
LA：潜熱フラックス
FC：海氷内熱伝導

塩フラックス (S)

$$S = \rho_i(s_w - s_i)\frac{dV_i}{dt}$$

結氷 (Q < 0 W m^{-2})

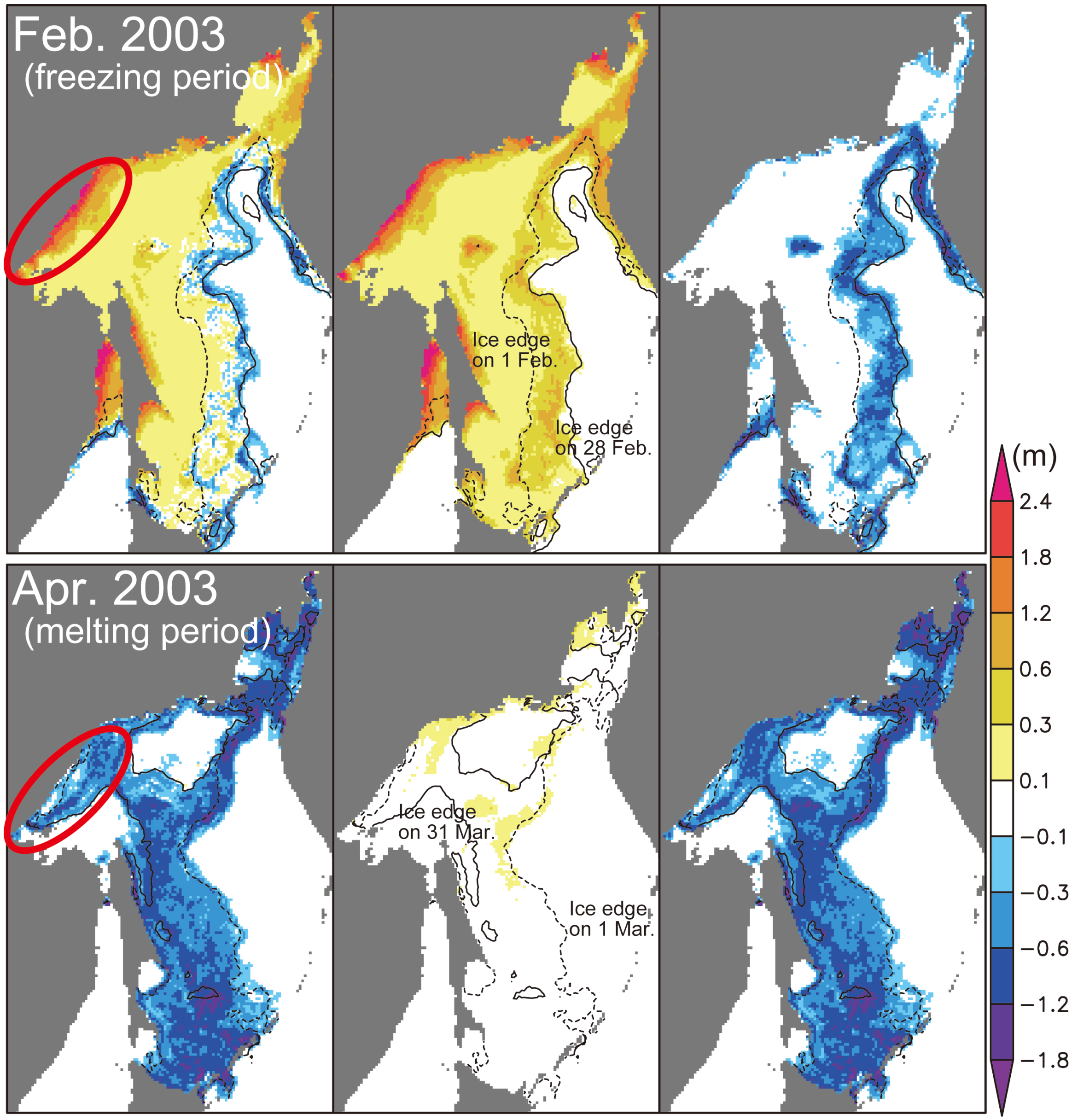
$$\frac{dV_i}{dt} = \frac{Q}{\rho_i L_f}$$

ρ_i：海氷密度
s：塩分
V_i：海氷体積
L_f ：融解潜熱
h_i：平均氷厚

融解に伴う淡水供給

$$\frac{dV_i}{dt} = \overline{h_i}\frac{dA_{melt}}{dt} \qquad \frac{dA_{melt}}{dt} = \frac{dA_{obs}}{dt} - \frac{dA_{adv}}{dt}$$

Monthly cumulative freezing and melting



Freezing + Melting   Freezing   Melting

Freezing period

・Active freezing occurs in coastal polynyas

⇒ **Ice factory**

・Both freezing and meting occur at the ice edge

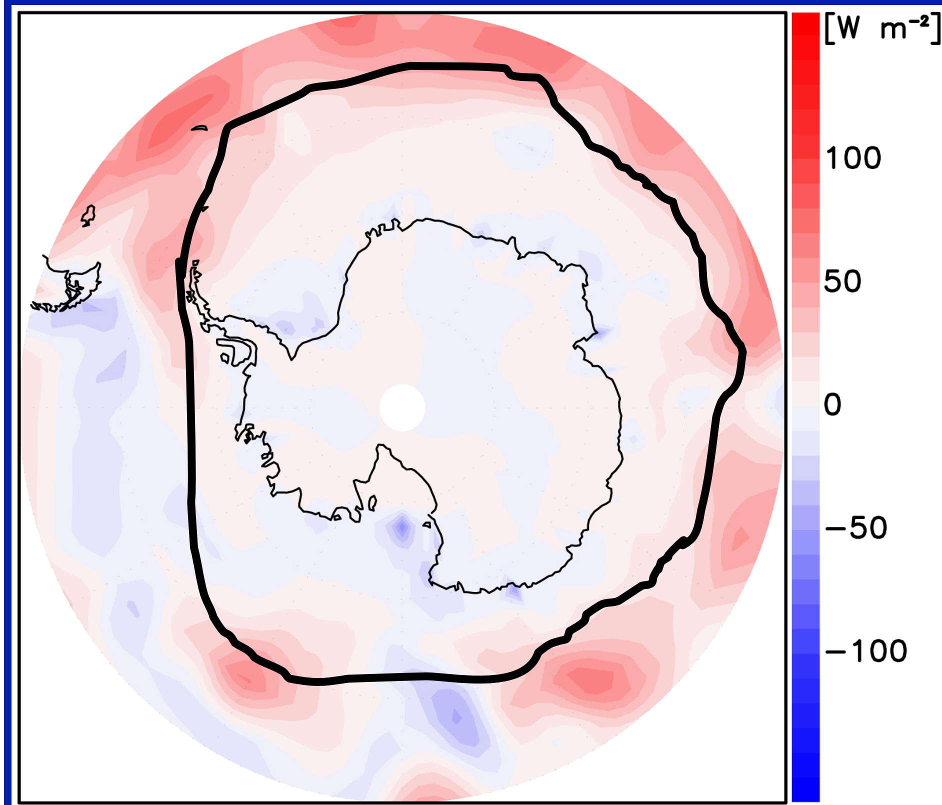
Melting period

・Melting occurs in most of the ice zone

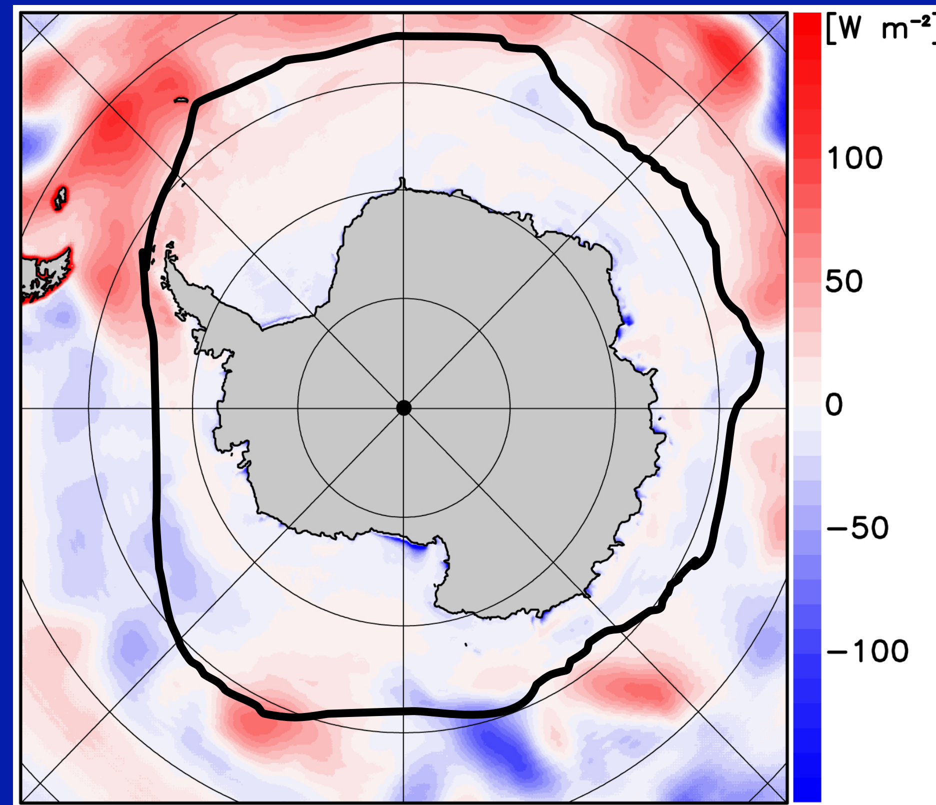
・Remarkable meting is shown at the coastal polynya region

⇒ **Melt water factory**

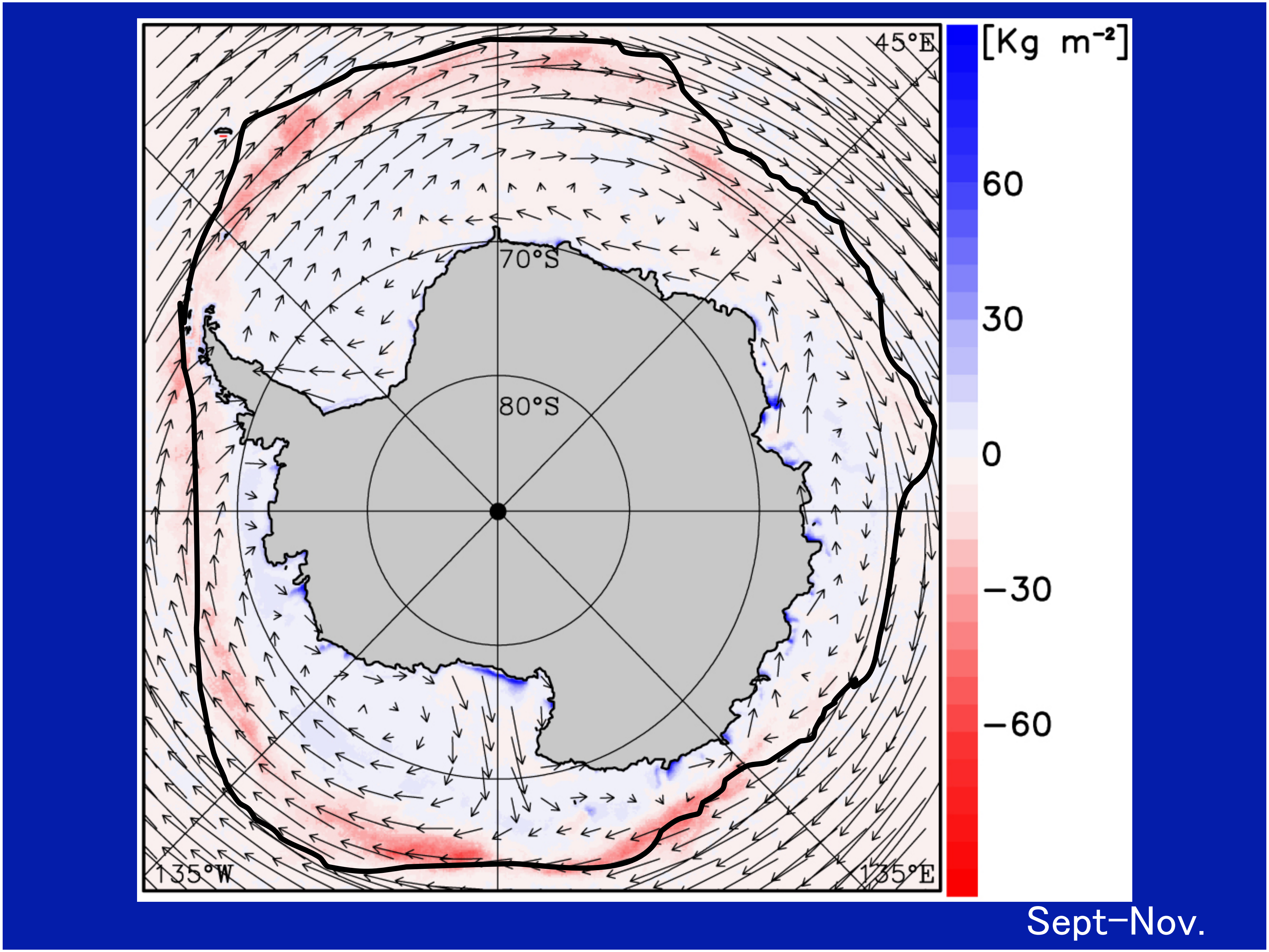
Nihashi, Ohshima in preparation



ERA-40 net heat flux



This study


45°E
70°S
80°S
135°W
135°E
[Kg m⁻²]
60
30
0
−30
−60
Sept−Nov.