

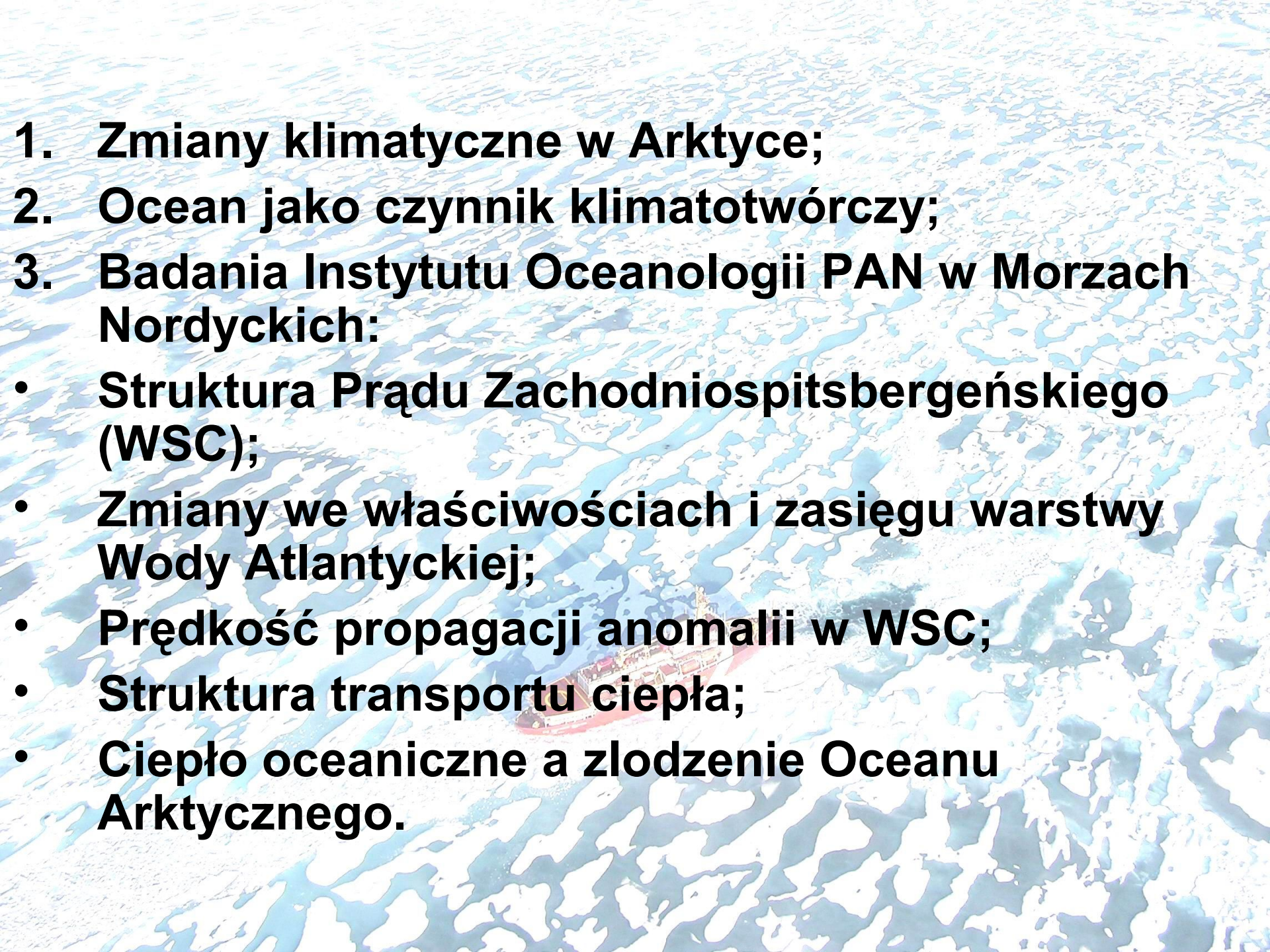
Zmiany klimatu Arktyki w świetle badań Prądu Zachodniospitsbergeńskiego

***Waldemar Walczowski
Zakład Dynamiki Morza***

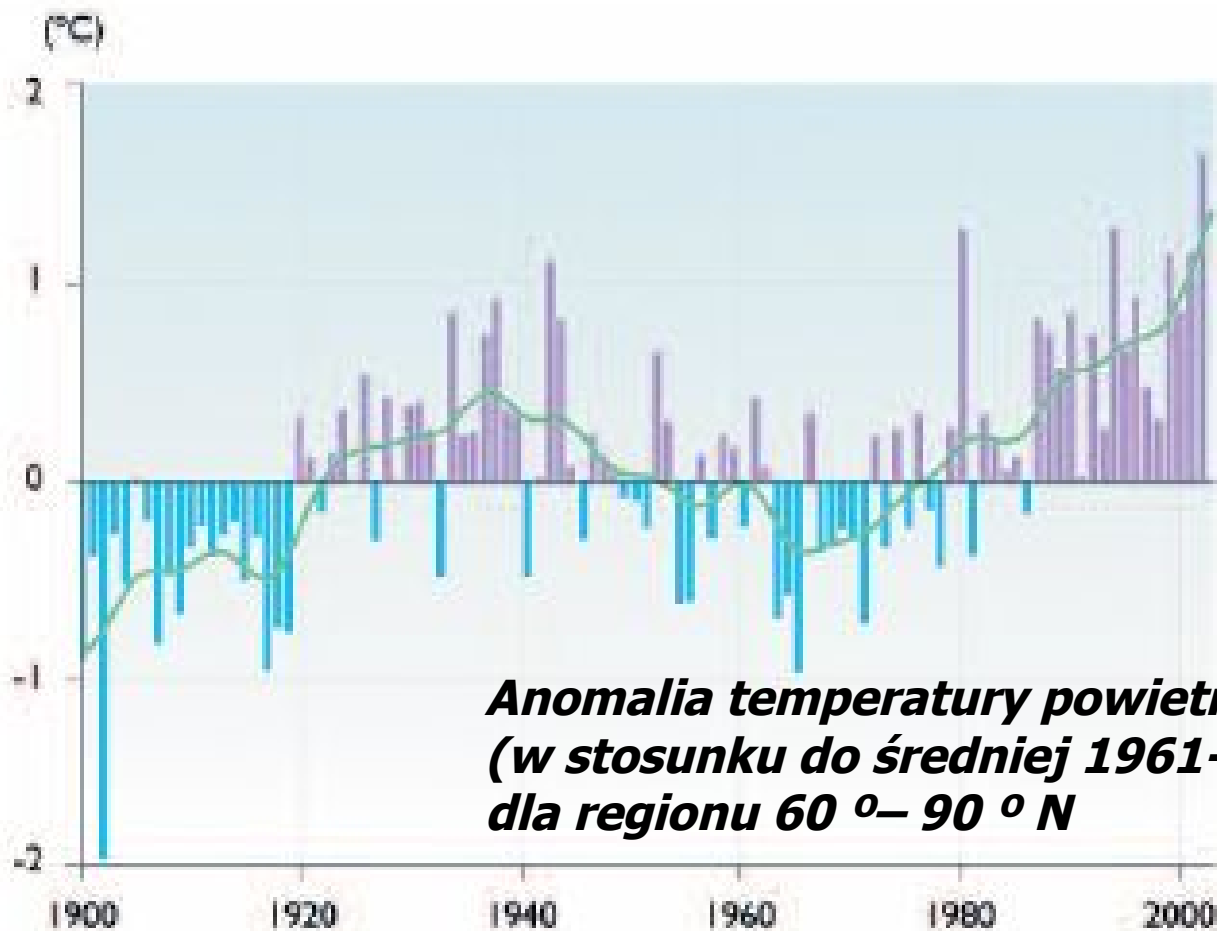


**INSTITUTE OF OCEANOLOGY
POLISH ACADEMY OF SCIENCES**



- 
- 1. Zmiany klimatyczne w Arktyce;**
 - 2. Ocean jako czynnik klimatotwórczy;**
 - 3. Badania Instytutu Oceanologii PAN w Morzach Nordyckich:**
 - Struktura Prądu Zachodniospitsbergeńskiego (WSC);**
 - Zmiany we właściwościach i zasięgu warstwy Wody Atlantycznej;**
 - Prędkość propagacji anomalii w WSC;**
 - Struktura transportu ciepła;**
 - Ciepło oceaniczne a zlodzenie Oceanu Arktycznego.**

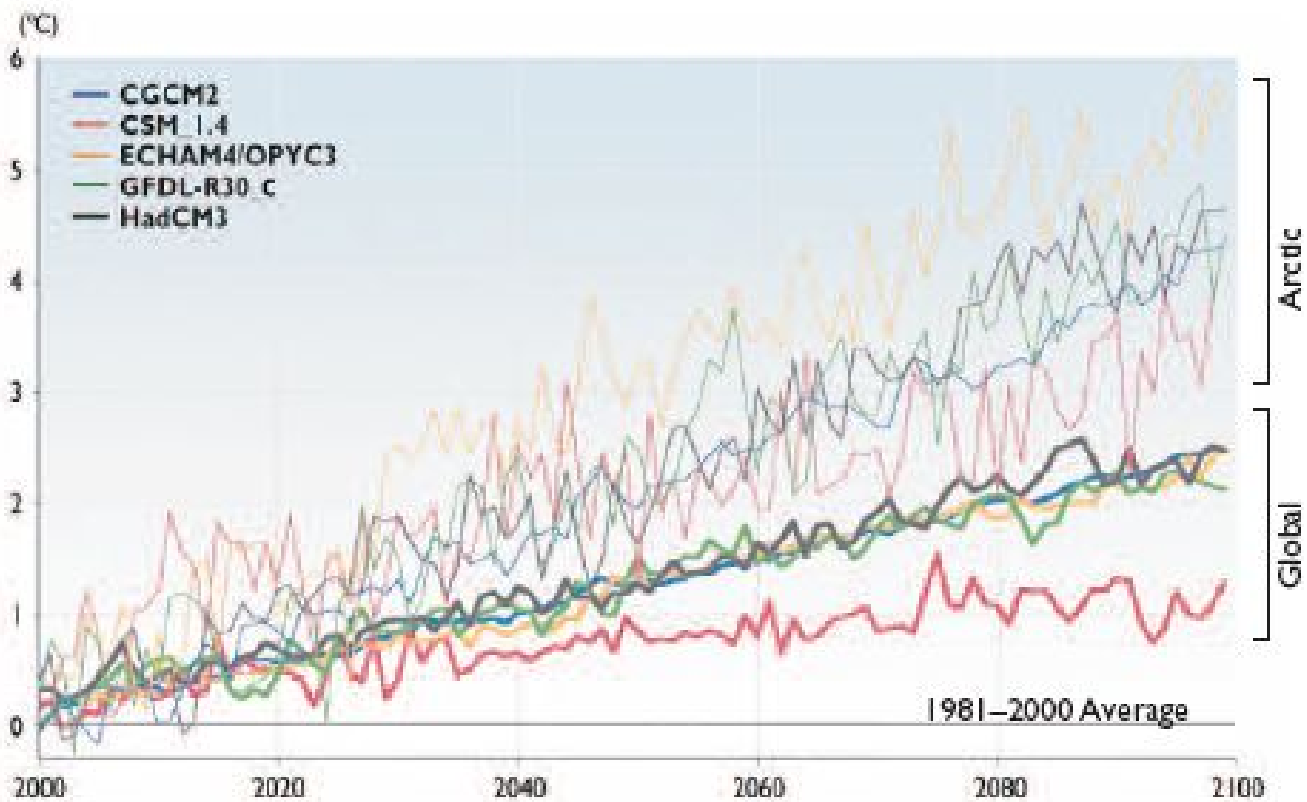
W dobie globalnego ocieplenia, Arktyka doświadcza największego wzrostu temperatury



***Anomalia temperatury powietrza
(w stosunku do średniej 1961-1990)
dla regionu 60°–90° N***



Badania modelowe wskazują, że proces ten będzie w przyszłości nasilał się



**Od roku 1950 średnia roczna temperatura
wzrosła o 2-3° C**

Temperatura zimowa wzrosła o 4° C

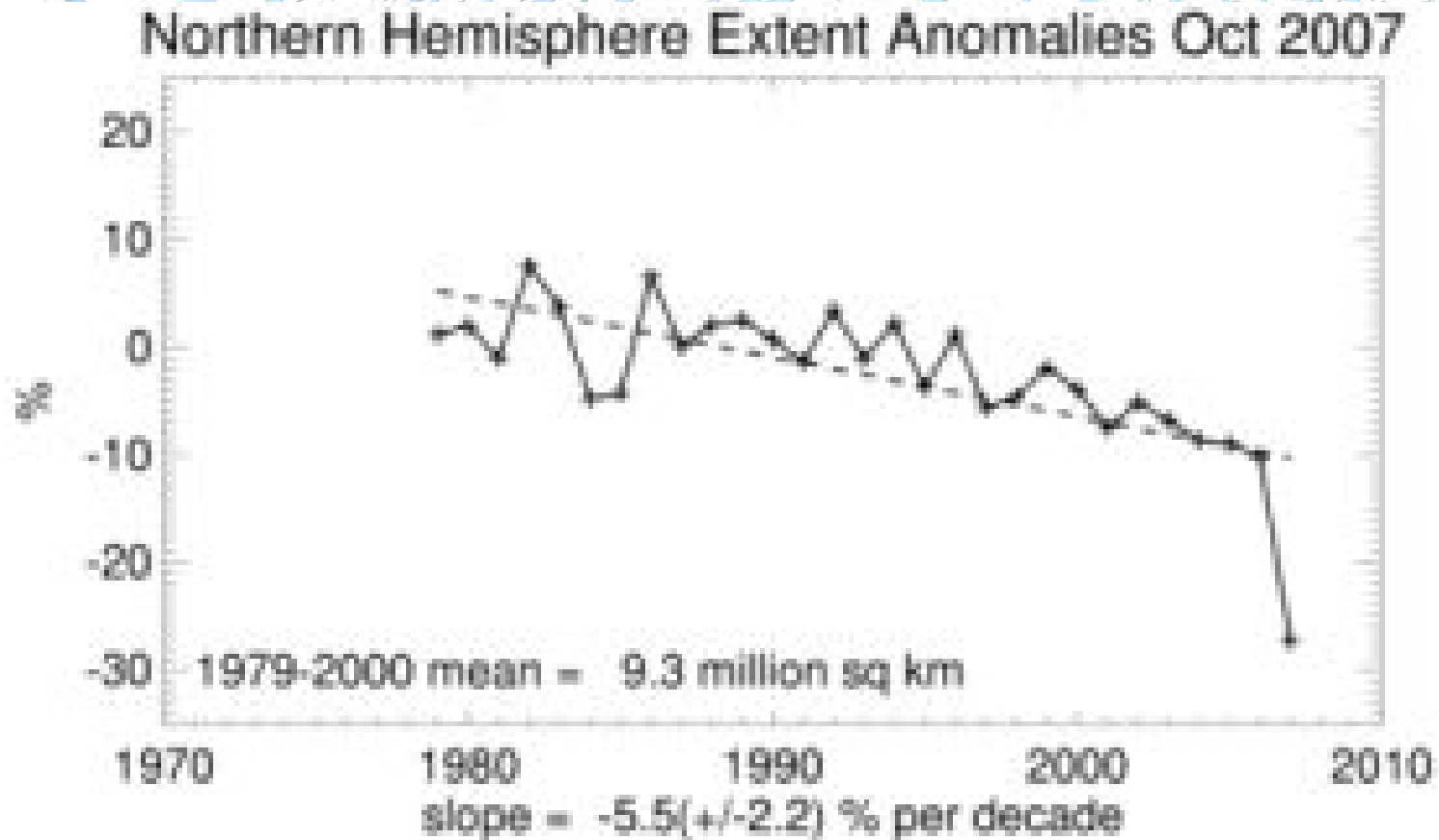
Spowodowało to:

- **Topnienie lodowców;**
- **Topnienie wiecznej zmarzliny;**
- **Zwiększenie opadów, lecz skrócenie czasu zalegania pokrywy śnieżnej;**
- **Redukcję pokrywy lodu morskiego.**

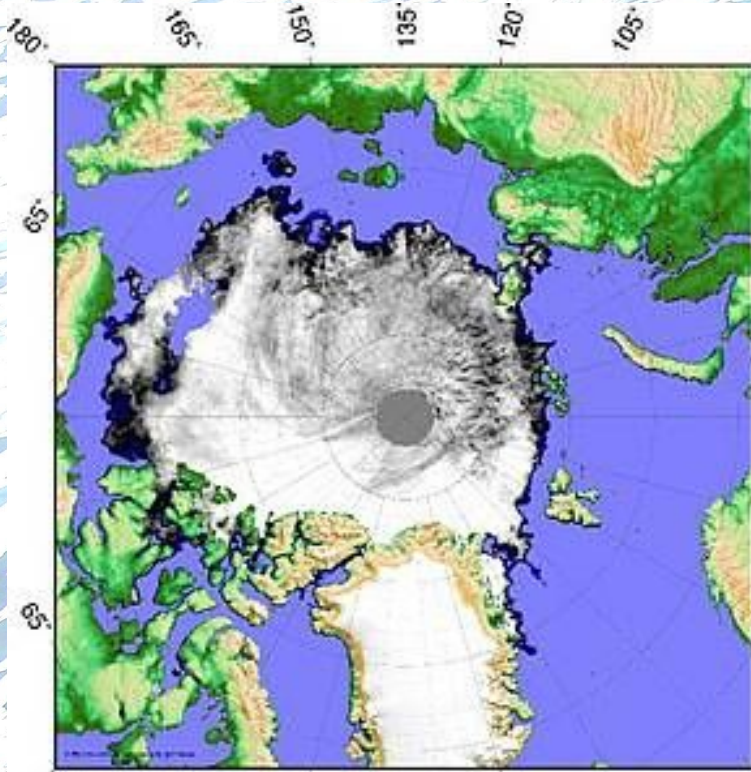


"A linear increase in heat in the Arctic Ocean will result in a non-linear, and accelerating, loss of sea ice."

Norbert Untersteiner,, University of Washington, July 2006



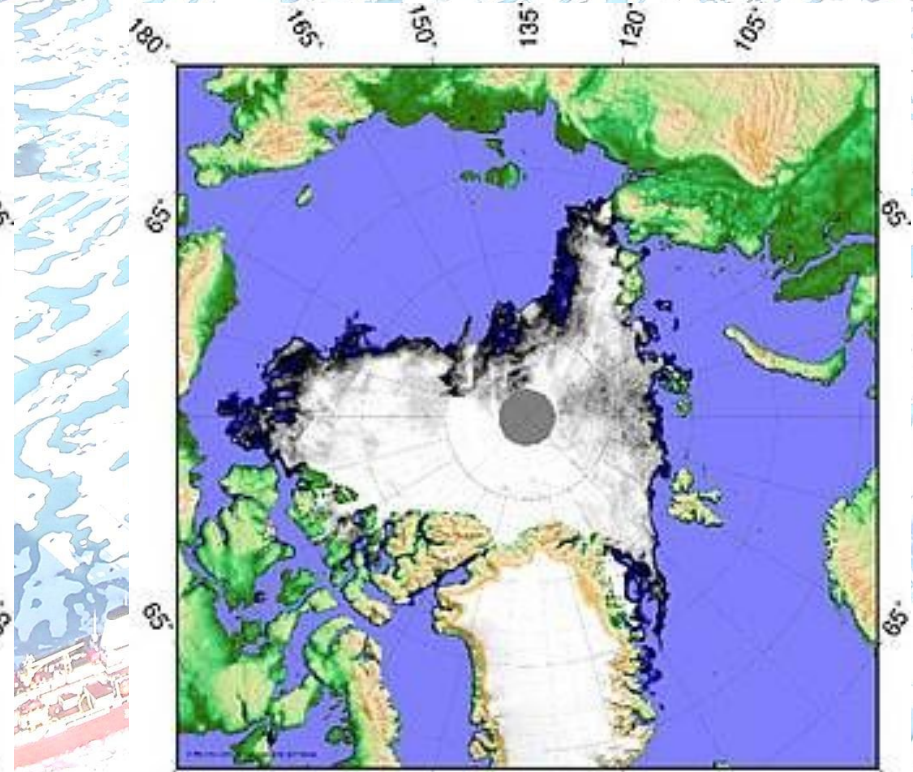
http://nsidc.org/data/seaice_index/



Meereisbedeckungsgrad 3. September 2006
Datenquelle: SeaWiFS/AQUA Service AMSR-E (NASA/JAXA)



Wrzesień 2006

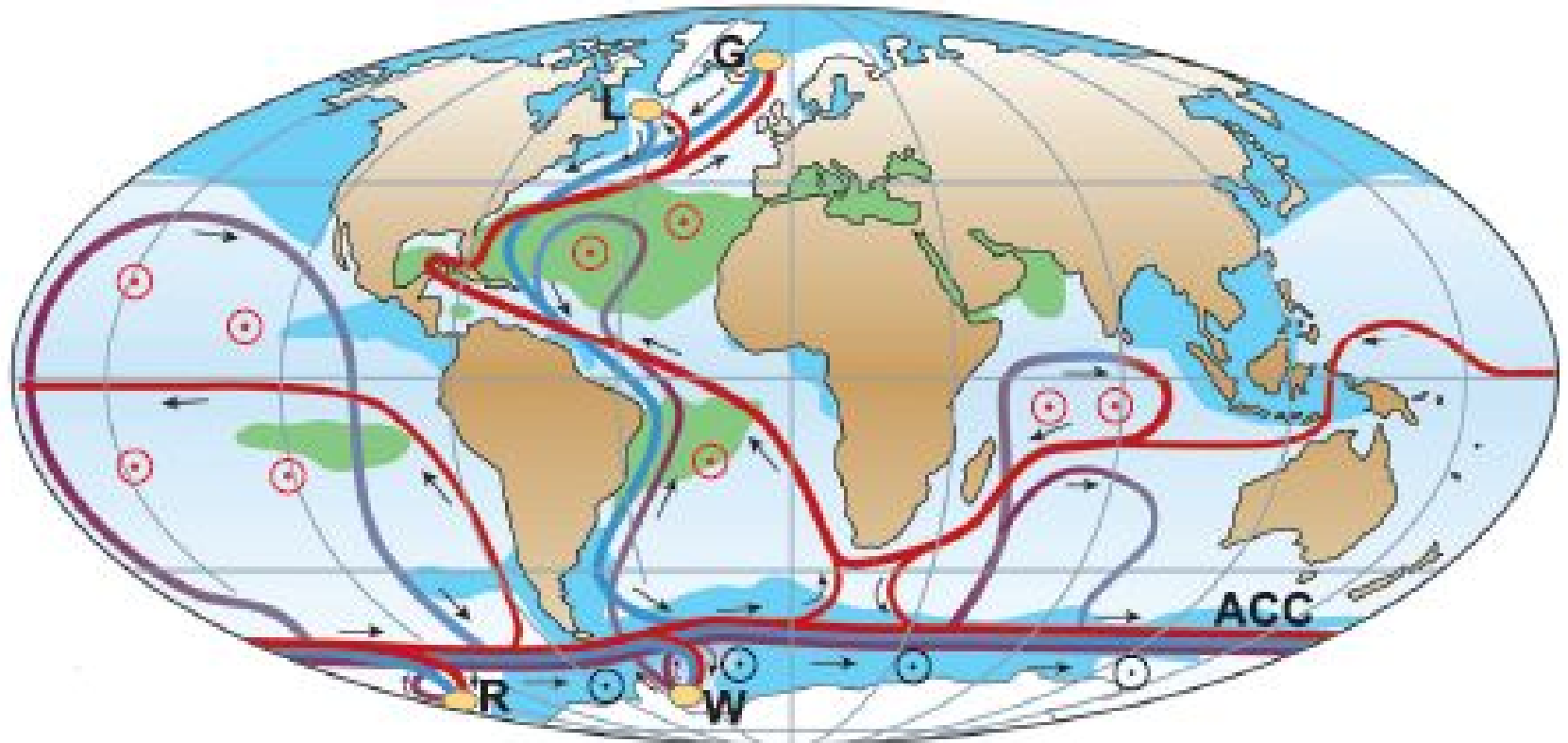


Meereisbedeckungsgrad 3. September 2007
Datenquelle: SeaWiFS/AQUA Service AMSR-E (NASA/JAXA)



Wrzesień 2007

Schemat globalnej cyrkulacji termohalinowej (THC)

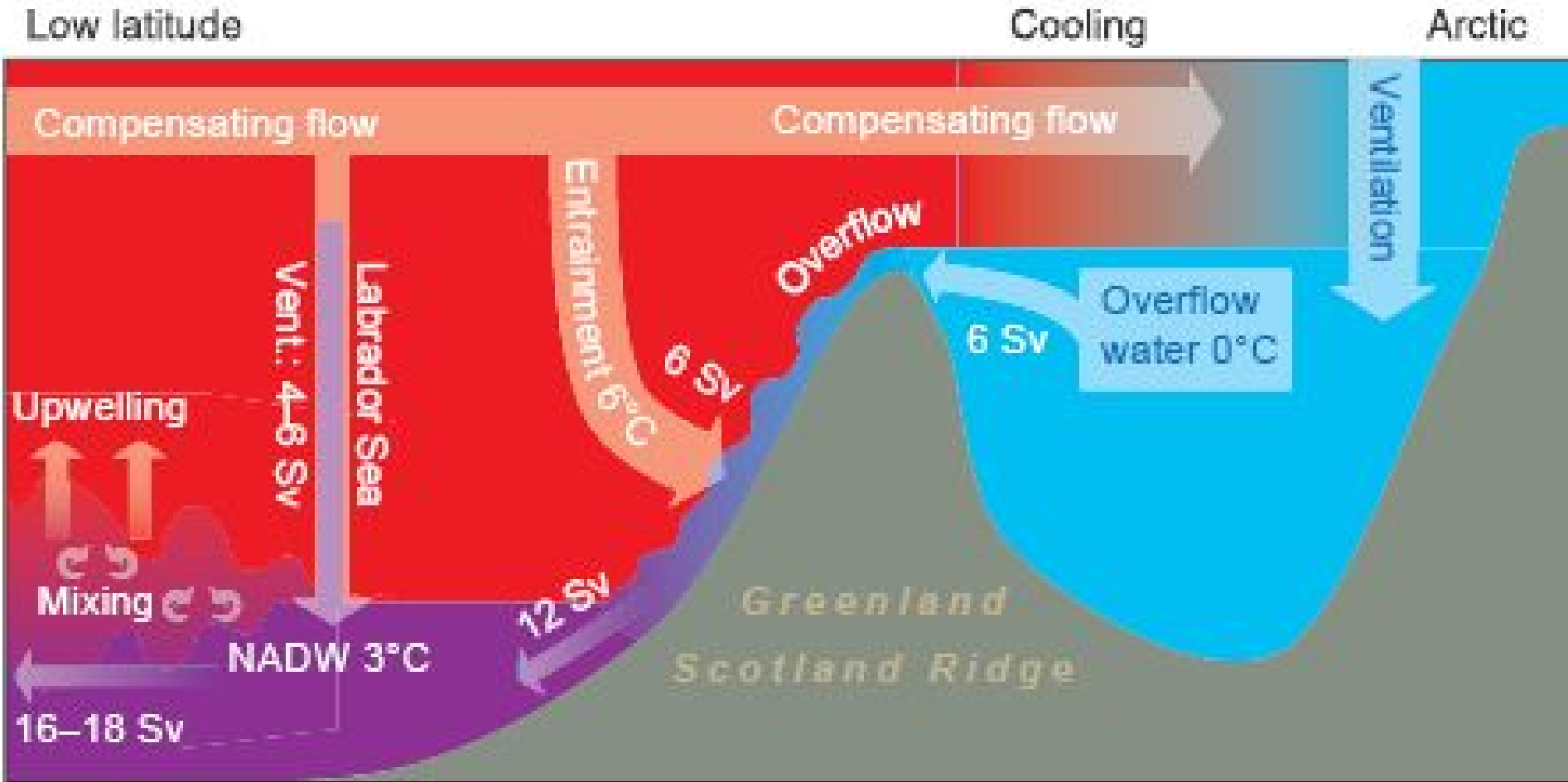


- Surface flow
- Deep flow
- Bottom flow
- Deep Water Formation

- Wind-driven upwelling
- Mixing-driven upwelling
- Salinity > 36 ‰
- Salinity < 34 ‰

- L Labrador Sea
- G Greenland Sea
- W Weddell Sea
- R Ross Sea

Schemat Meridional Overturning Circulation



Właściwości i transport Wody Atlantyckiej w Morzach Nordyckich - główny cel badań hydrologicznych IOPAN w Arktyce

Badania Mórz Nordyckich w programach międzynarodowych (VEINS, ASOF, DAMOCLES, IPY) i własnym (AREX)

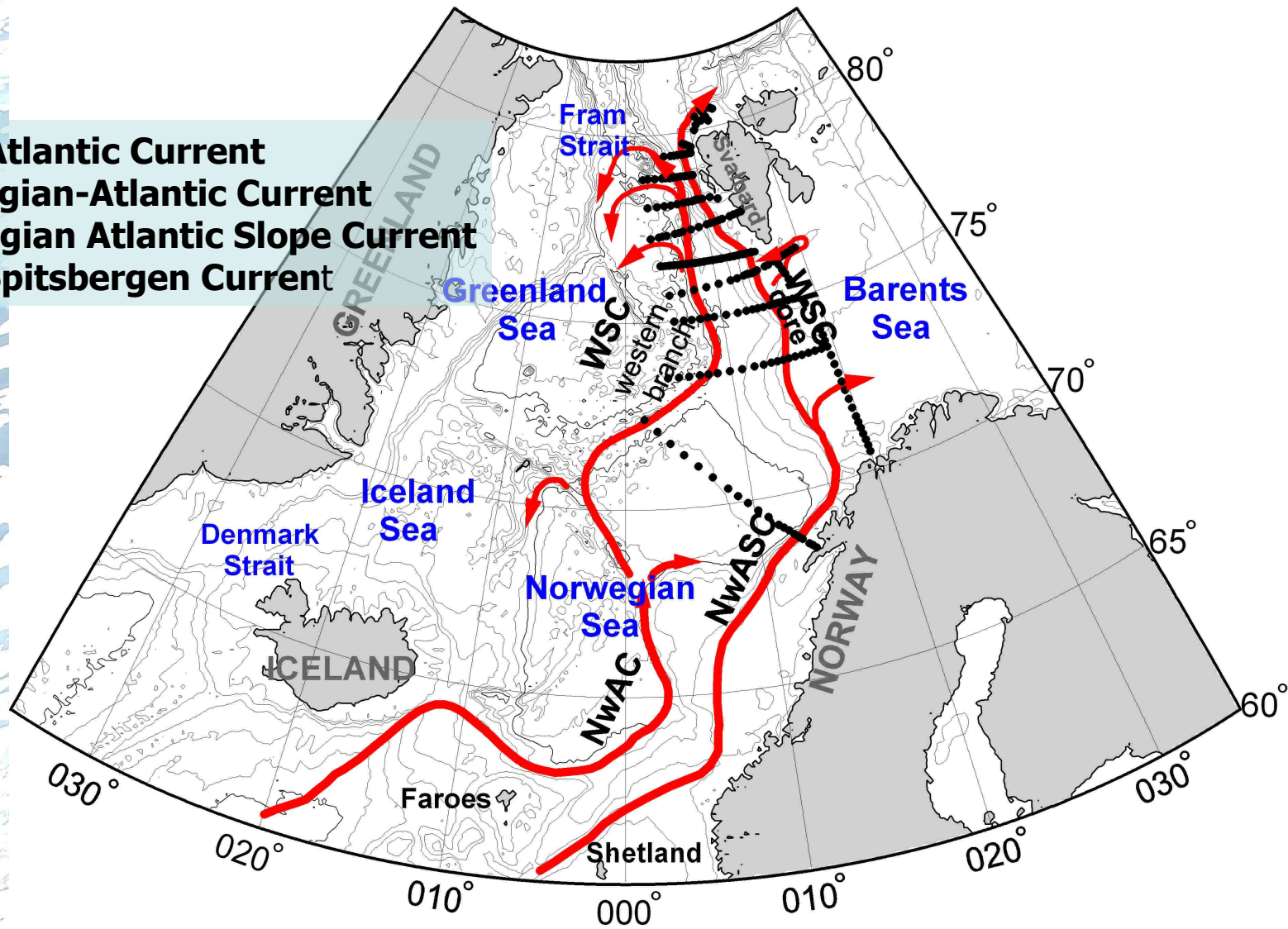
Prąd Zachodniospitsbergeński:

- **struktura, dynamika WSC;**
- **procesy frontalne;**
- **struktury mezoskalowe**
- **wymiana pomiędzy szelfem Spitsbergenu i głębokim basenem;**
- **warstwa Wody Atlantyckiej:**
 - **zmienność właściwości AW;**
 - **transport objętości i ciepła w AW;**
 - **transport AW do Oceanu Arktycznego**



Strategia pomiarów podporządkowana jest tym celom

- NAC** North Atlantic Current
- NwAC** Norwegian-Atlantic Current
- NwASC** Norwegian Atlantic Slope Current
- WSC** West Spitsbergen Current



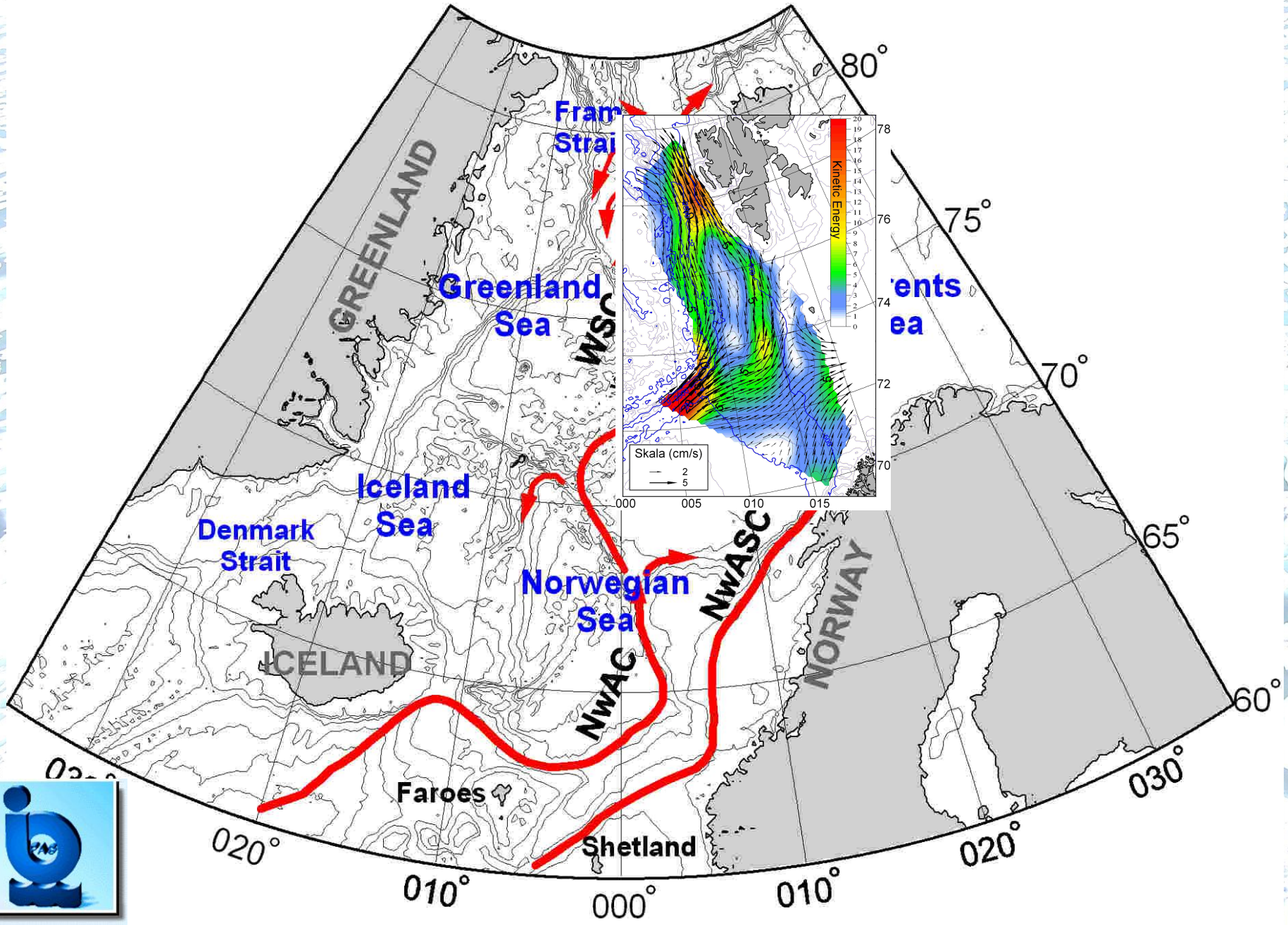


OCEANIA

GDANSK



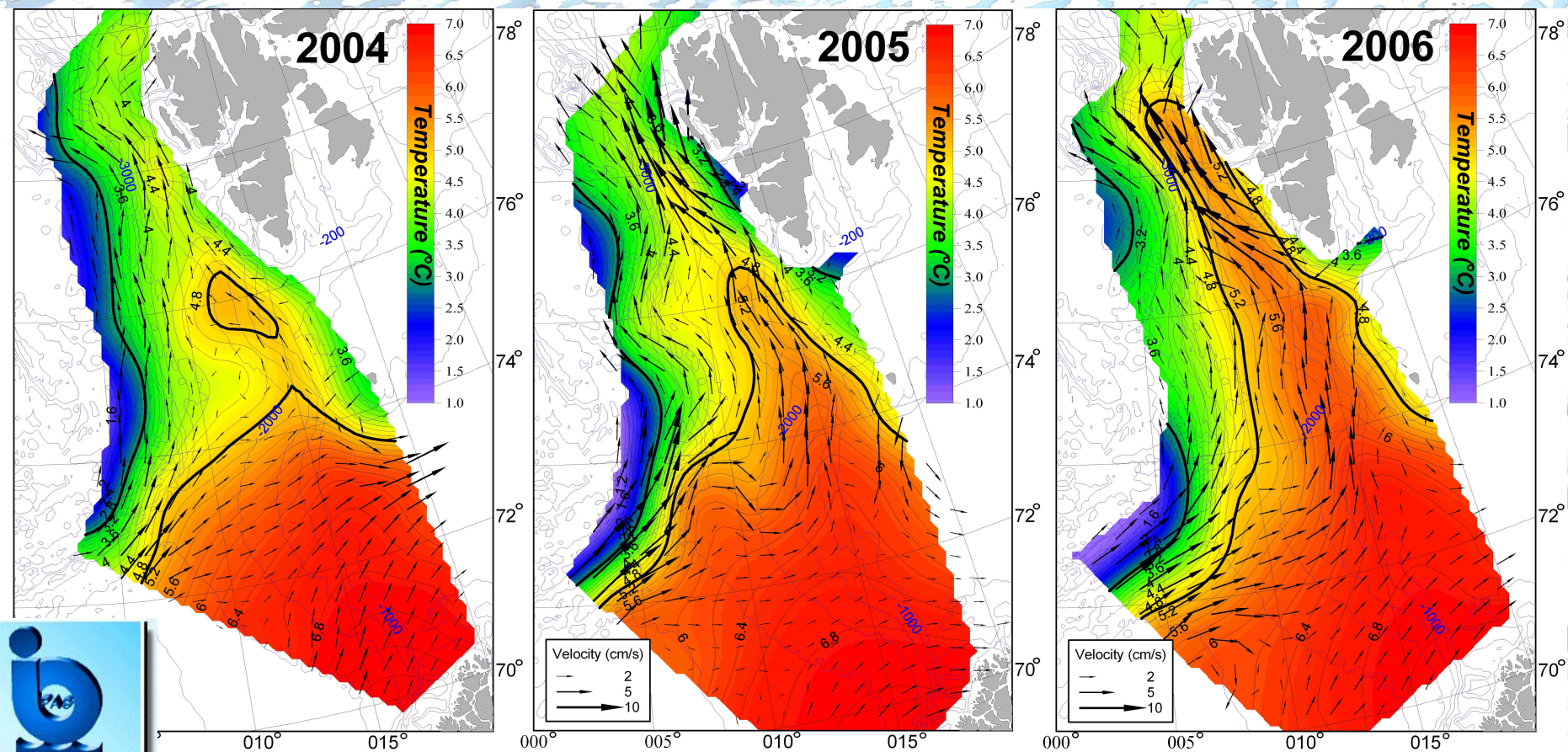
Średnia energia kinetyczna prądów baroklinowych



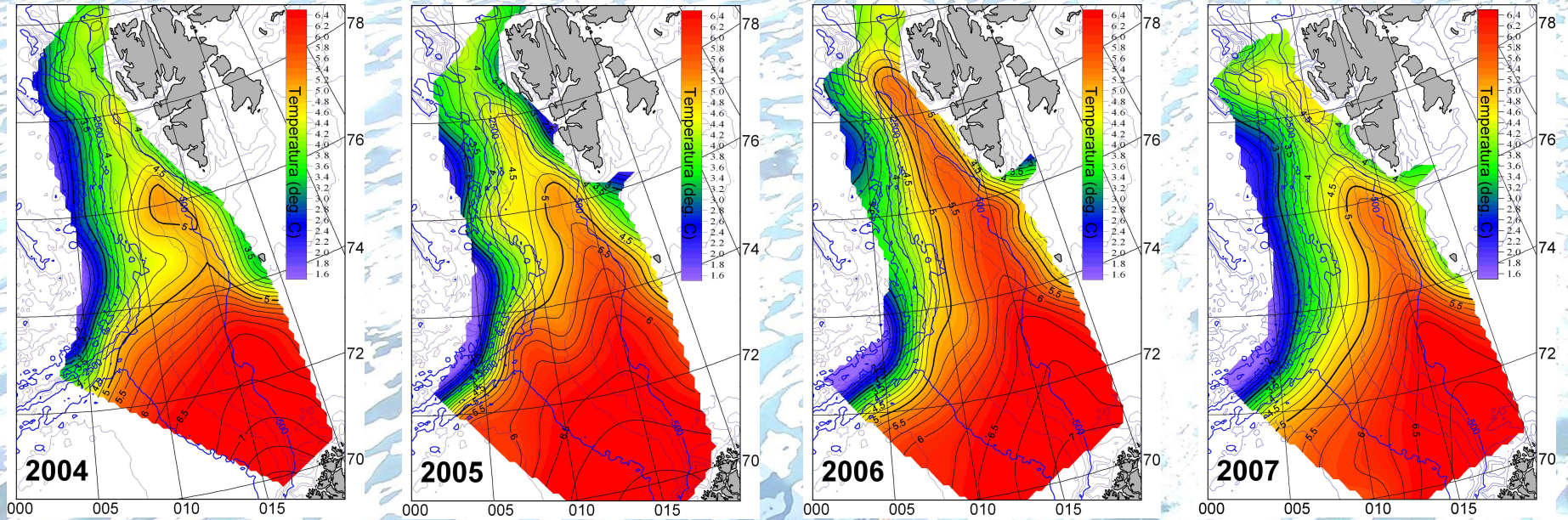
Rozkład temperatury i prądów baroklinowych na 100 dbar, lato 2004-2006.

Izolinie 2°C i 5°C pogrubione.

Przesunięcie się izolinii 5°C o 2° szerokości/rok = 0.7 cm/s



Rozkład temperatury na 100 dbar, lato 2004-2007.



Koniec ciepłego trendu ?





Pathways of the Greenland Sea warming

Waldemar Walczowski¹ and Jan Piechura¹

Received 12 March 2007; revised 23 April 2007; accepted 1 May 2007; published 30 May 2007.

[1] Progressive warming of the West Spitsbergen Current (WSC) has been observed since 2004. During summer 2006 temperature and salinity of the core of Atlantic Water (AW) reached the highest ever observed by the Institute of Oceanology Polish Academy of Sciences (IOPAS) values. The structure of the WSC, the heat content and the extent of AW in the Fram Strait (FS) region has also changed. Temperature changes resulted from the upstream warming of the Norwegian-Atlantic Current (NwAC); the structure of the WSC and its heat content were modified by the northward advection of large mesoscale eddies observed within the western branch of the WSC in summer 2005. These changes may have large impacts on the Arctic Ocean (AO) climate and ecosystem. Citation: Walczowski, W., and J. Piechura (2007), Pathways of the Greenland Sea warming, *Geophys. Res. Lett.*, 34, L10608, doi:10.1029/2007GL029974.

1. Introduction

[2] Two branches of the NwAC, slope and offshore, carry warm, salty AW northward through the Norwegian Sea [Orvik and Nilner, 2002] (Figure 1). The eastern branch, called the Norwegian Atlantic Slope Current (NwASC), is a nearly barotropic flow related to the Norwegian shelf break. This current continues northward over the Barents Sea slope and along the West Spitsbergen shelf break as the WSC. The WSC carries only part (about 60%) of the AW transported by the NwASC; the other part, after passing northern Norway, branches eastward into the Barents Sea. Skagseth *et al.* [2004] claimed that the large-scale variability of the NwASC is a coherent mode extending from the shelf edge west of Ireland to the Fram Strait. They also describe this system as the main conduit of heat and salt between the North Atlantic Ocean and the Arctic Ocean.

[3] Considering northward transport of the AW, the WSC has been traditionally described as this barotropic flow along the Barents Sea and the West Spitsbergen shelf-break. The existence of a second, mostly baroclinic, western branch over the Mohns and Knipovich Ridges was postulated earlier [Walczowski *et al.*, 2005] but its role in AW

while the other fraction recirculates westward between 76° and 78°N. The bottom configuration causes the poleward flowing branches of the WSC to converge in the region of western Spitsbergen, at latitude of about 78°N. Continuing north, the current diverges again into three paths. The Svalbard and Yermak branches flow into to the AO through the FS (Figure 1), while the offshore branch recirculates westward and then southward [Manley, 1995]. The Svalbard Branch is fed by the along-slope core of the WSC, and recirculation is maintained by the western branch of the WSC. The postulated origin of the central, Yermak Branch, by the splitting of the Svalbard Branch due to bottom topography is not clear. Current investigations indicate that this central WSC branch may influence both, transport through the FS, and AW recirculation.

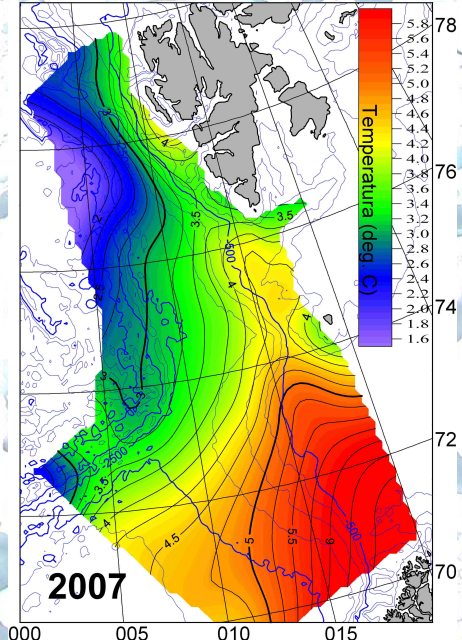
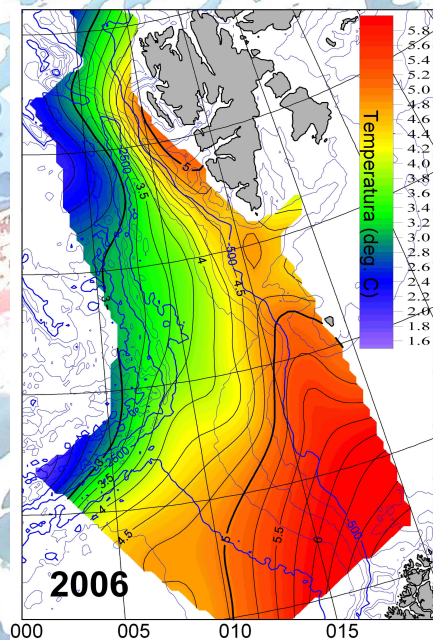
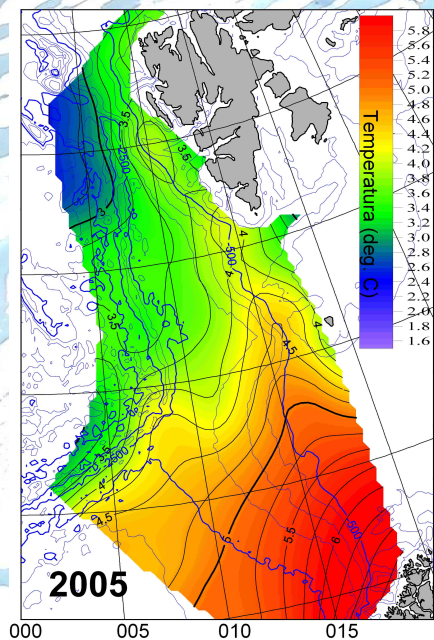
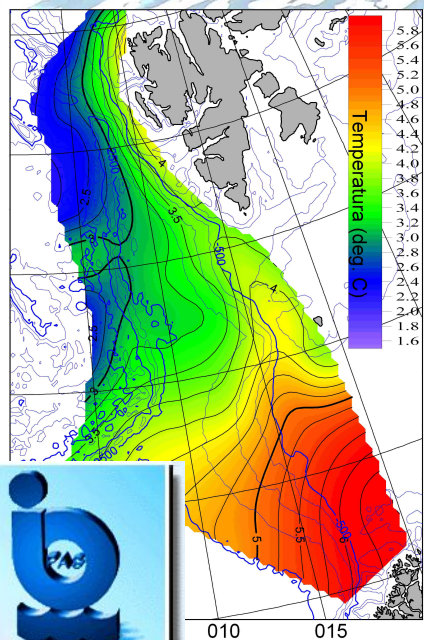
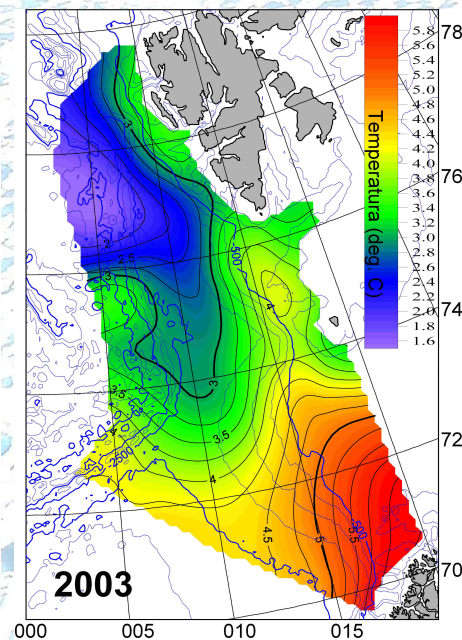
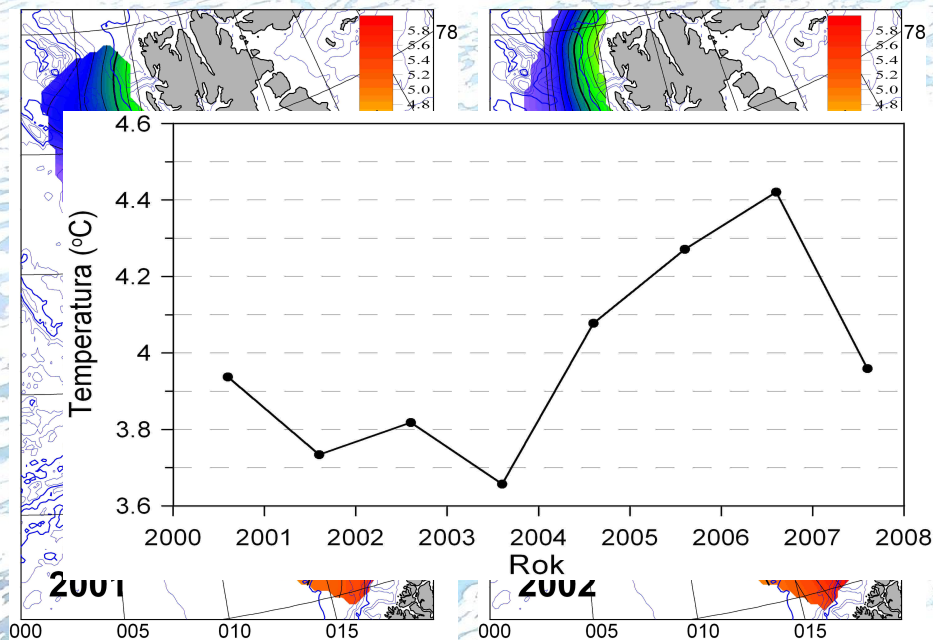
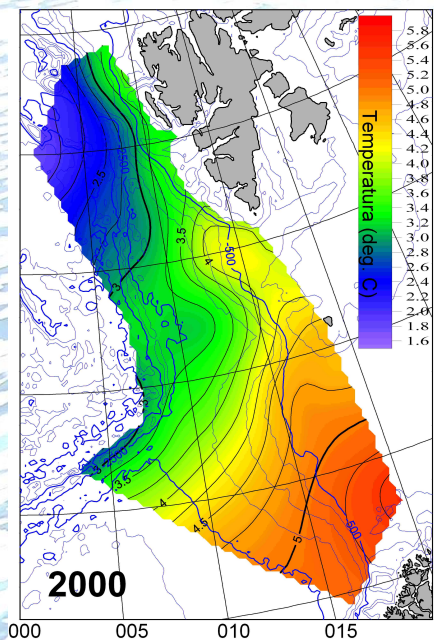
[4] Since summer 2004, substantial increases have been observed in the temperature, salinity and heat transport of the WSC [Walczowski and Piechura, 2006; Beszczynska-Möller *et al.*, 2007]. Holliday *et al.* [2007] found that the anomaly observed in 2004–2005 had been formed in 1998 in the eastern subpolar gyre. Hakkinen and Rhines [2004] and Hátún *et al.* [2005] showed that the intensification of northward flow of warm, saline subtropical water was caused by changes in the subpolar gyre and increasing entrainment of AW into subarctic circulation. Increasing AW temperature, salinity, and heat transport by the NwASC was reported by Orvik and Skagseth [2005]. The time needed for the warm anomaly to travel from the Svinoy Section (~63°N) to FS (79°N) was estimated at 18 months [Polyakov *et al.*, 2005], which indicates that the mean speed of anomaly propagation was ~3.8 cm/s. A similar value is derived using results from the Svinoy Section published by Orvik and Skagseth [2005] and IOPAS data for section 'N' along the 76°30'N parallel, which indicate a time lag of 18 to 21 months between the temperature increase in the Svinoy Section and the 'N' section. This differs from the mean signal propagation speed from the Rockall Trough (~57°N) to the Fram Strait, which was estimated based on information in the work of Holliday *et al.* [2007] at about 1.6 cm/s.



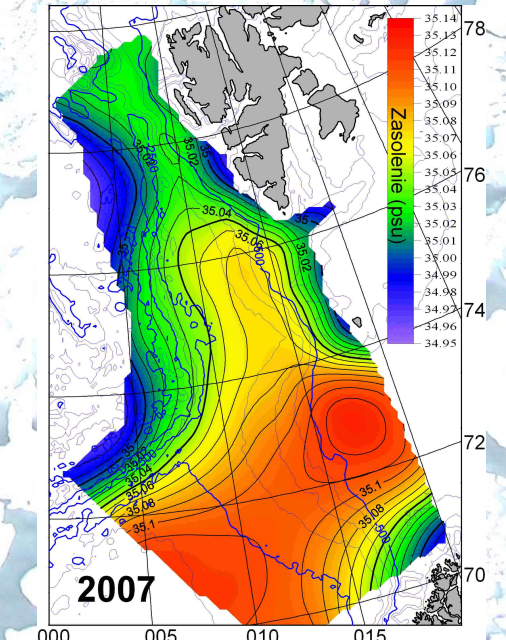
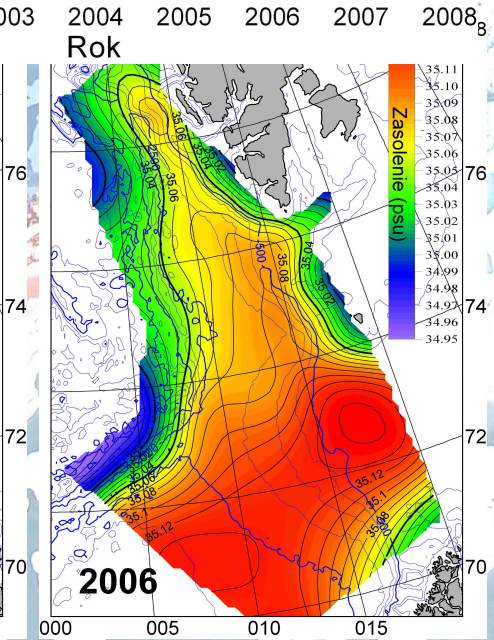
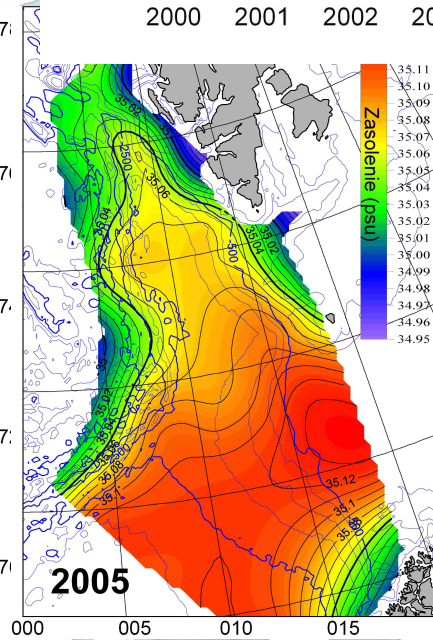
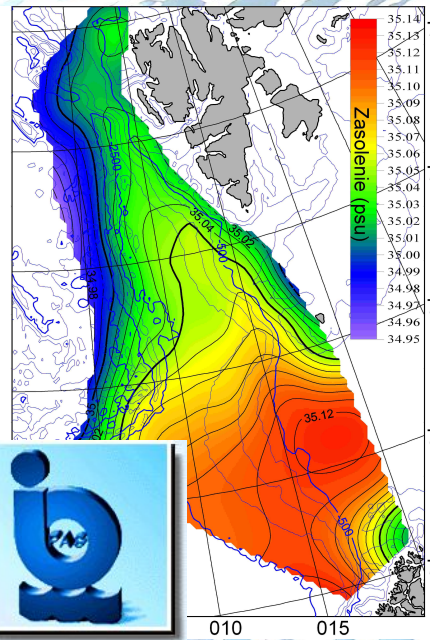
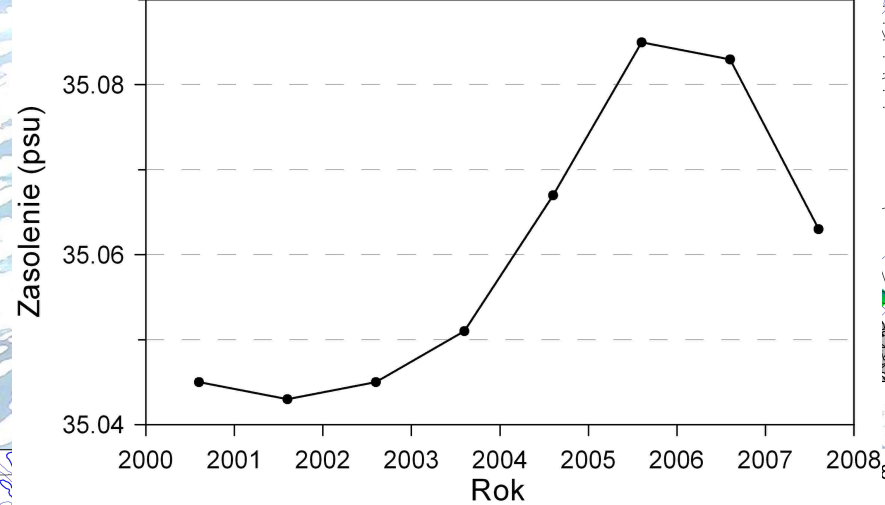
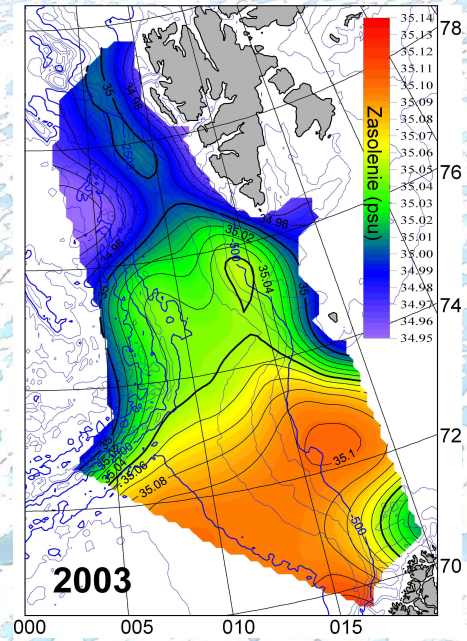
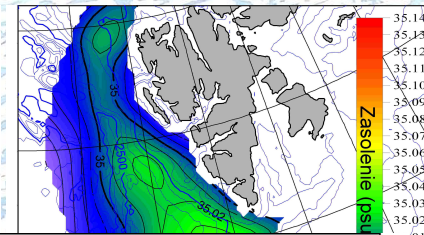
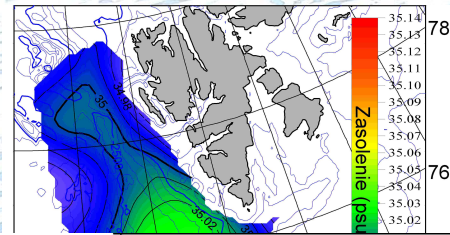
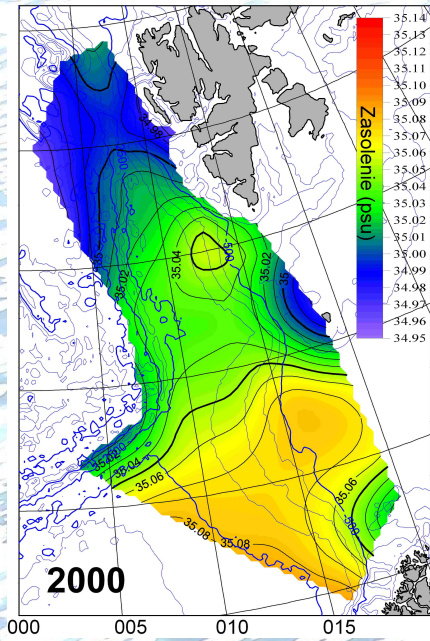
[13] Similar to *Holliday et al.* [2007], the authors concluded that the unusually warm inflow into the Arctic Ocean will continue; however, the IOPAS upstream data further suggest that the local maximum of WSC warming has already occurred or should do so before summer 2007: in the southern part of the study area, the highest AW temperature in the summer of 2006 was already lower than that in 2005. Since the increased heat inflow into the AO was mostly due to the higher AW temperature [*Beszczynska-Möller et al.*, 2007], and upstream data show temperature decreasing already in 2006, we anticipate that in 2007 heat inflow into the AO will decrease. These 'short-term' predictions were constructed based on the hydrographical situation in summer 2006 in the area between Norway and the Fram Strait. In contrast, the time series for locations far upstream that were presented by *Holliday et al.* [2007] suggest a renewed warming of AW inflow in subsequent years.



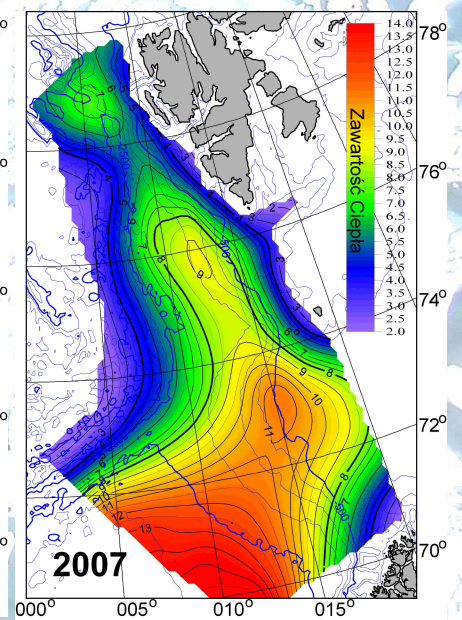
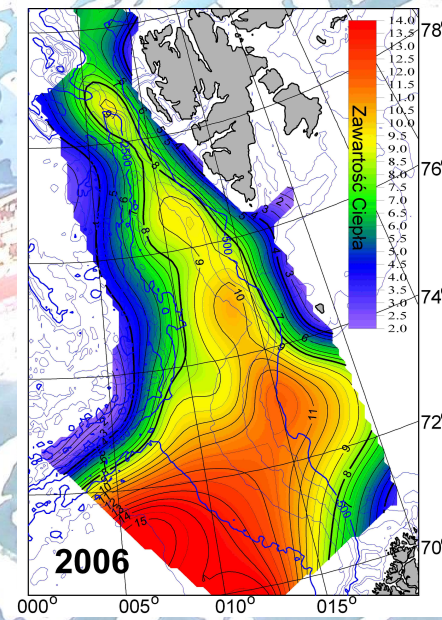
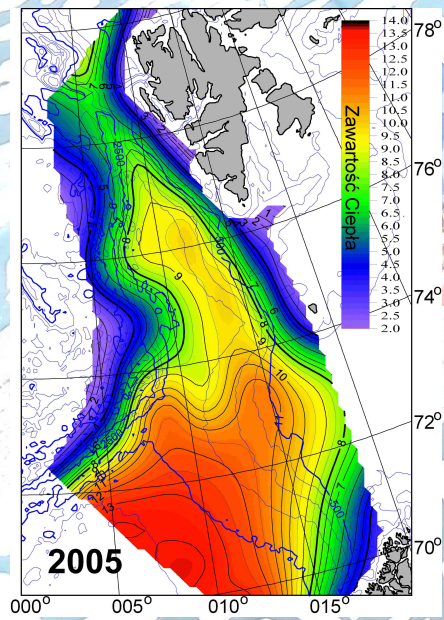
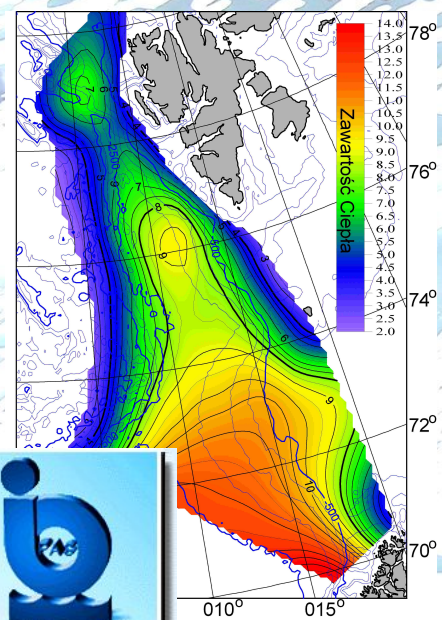
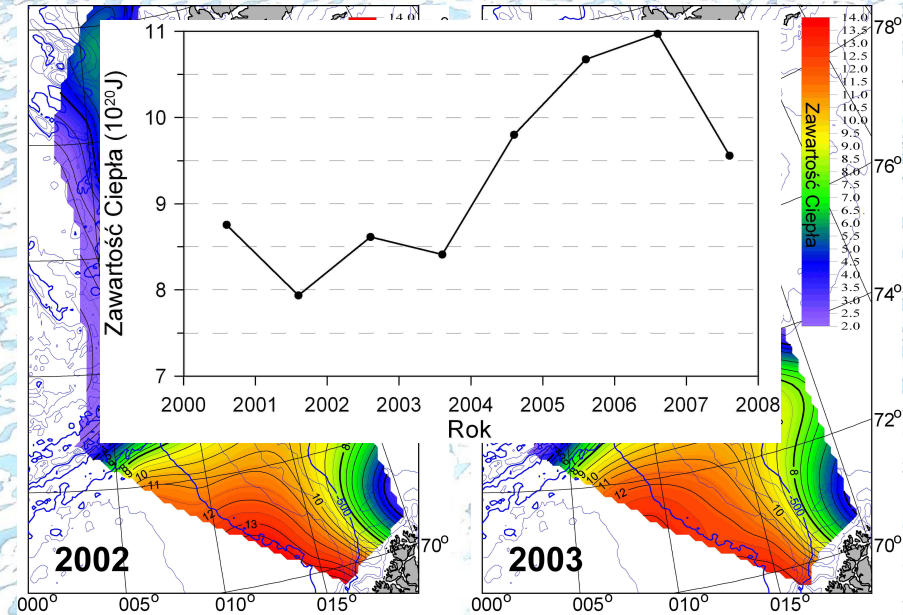
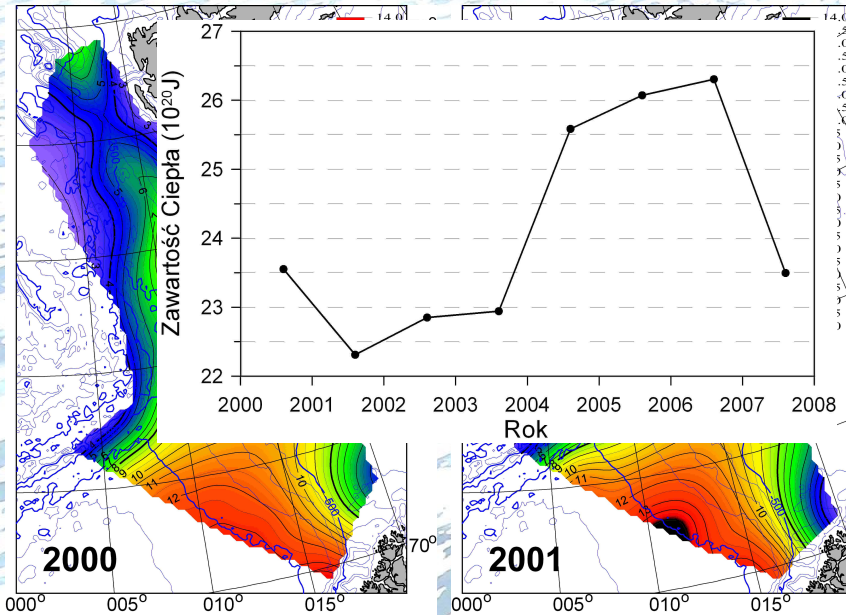
Lato 2000-2007 średnia temperatura warstwy AW.



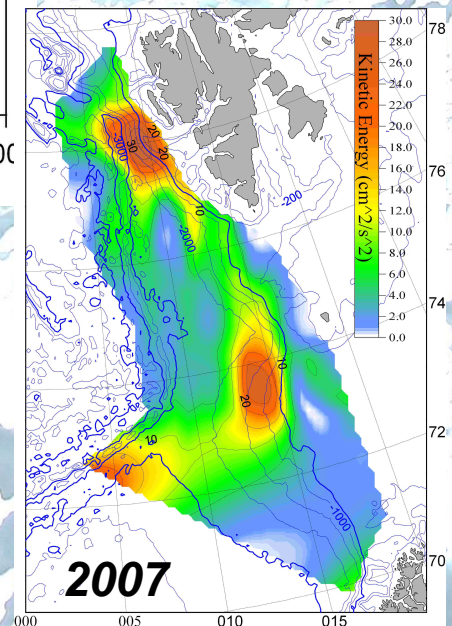
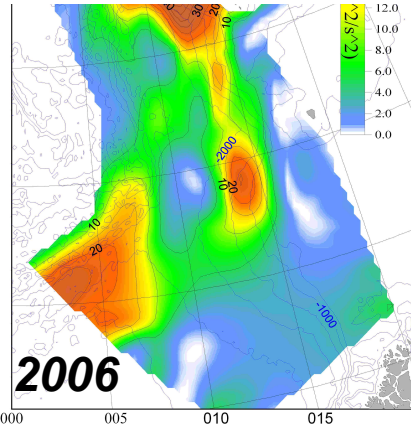
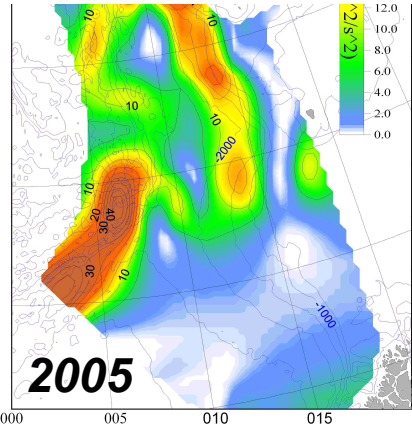
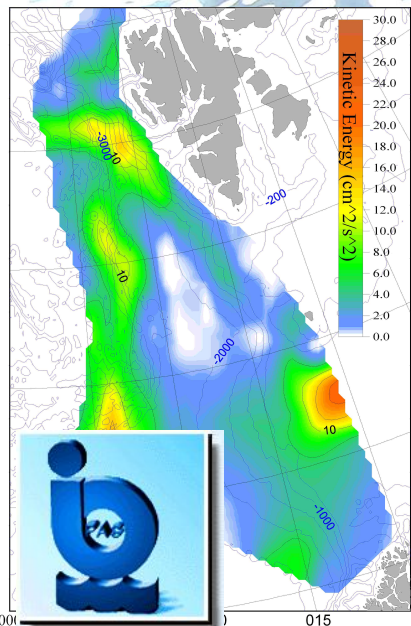
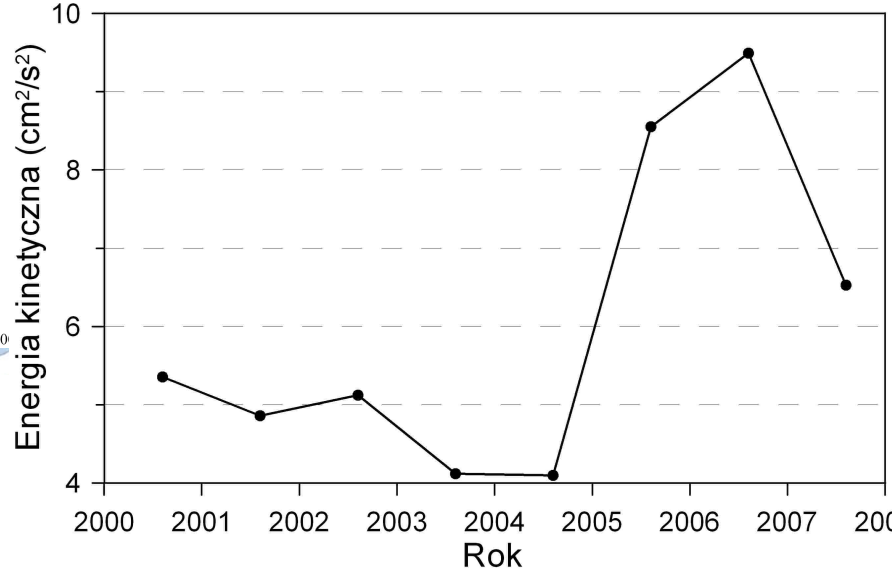
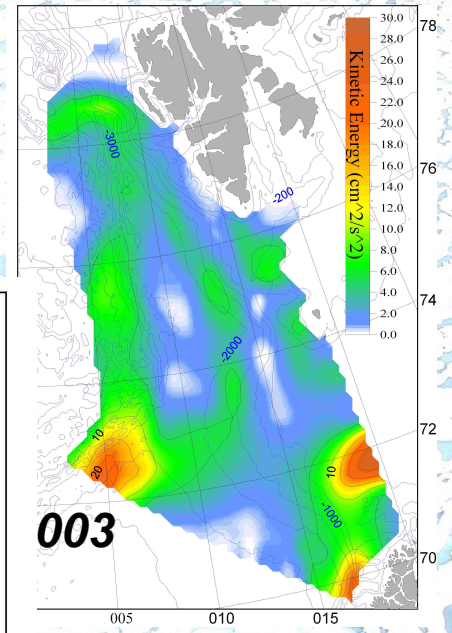
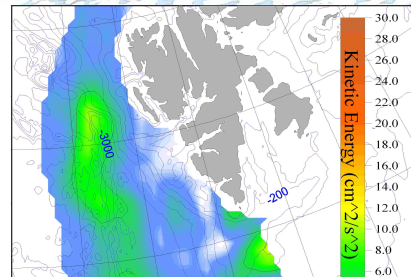
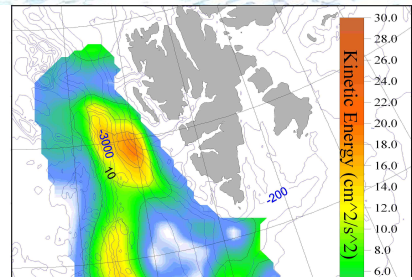
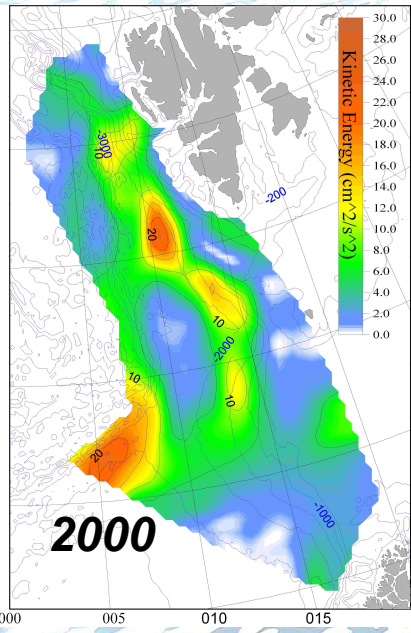
Lato 2000-2007 średnie zasolenie warstwy AW



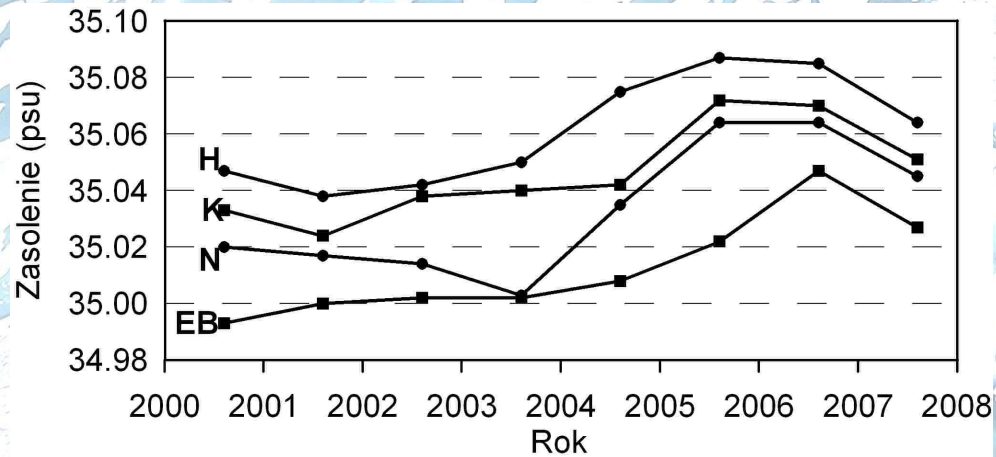
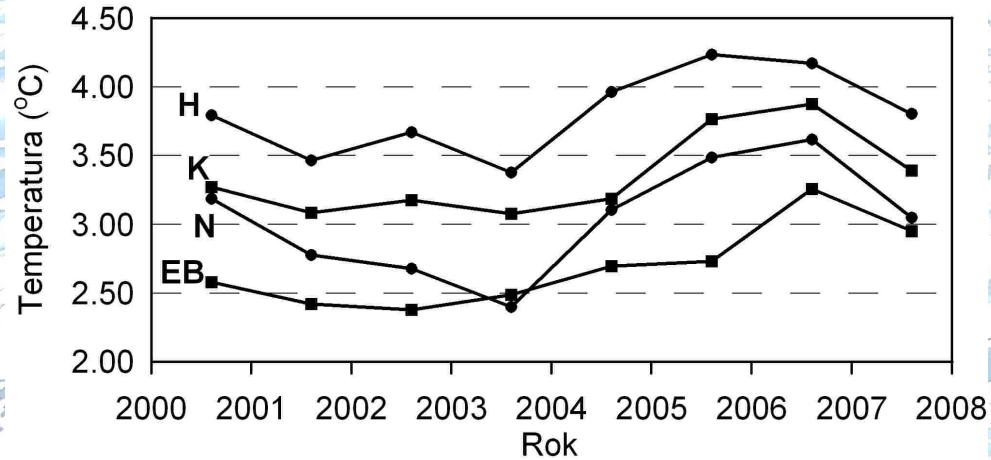
Zawartość ciepła (GJ/m²) w warstwie Wody Atlantycznej



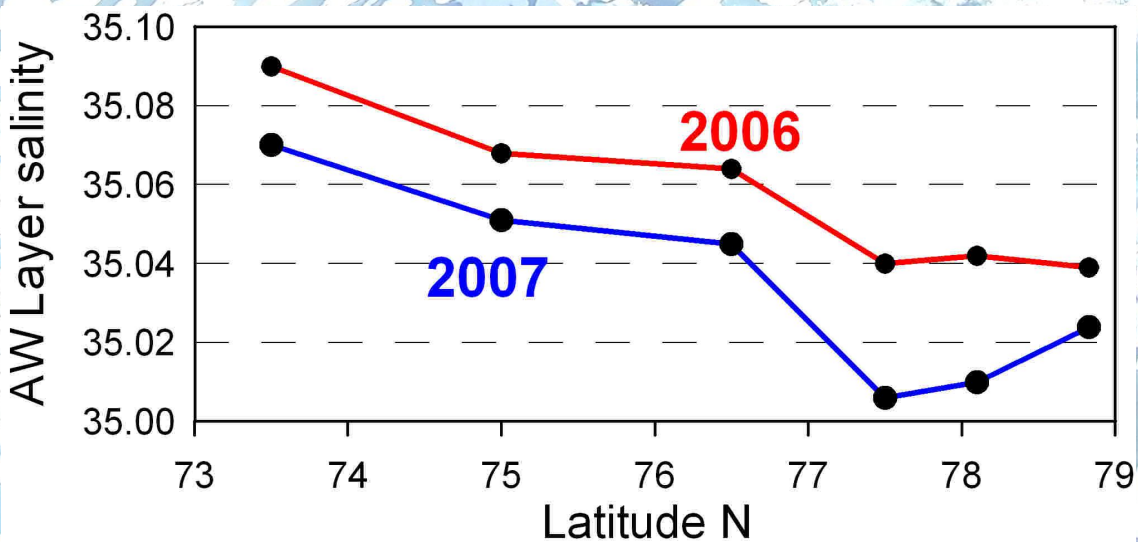
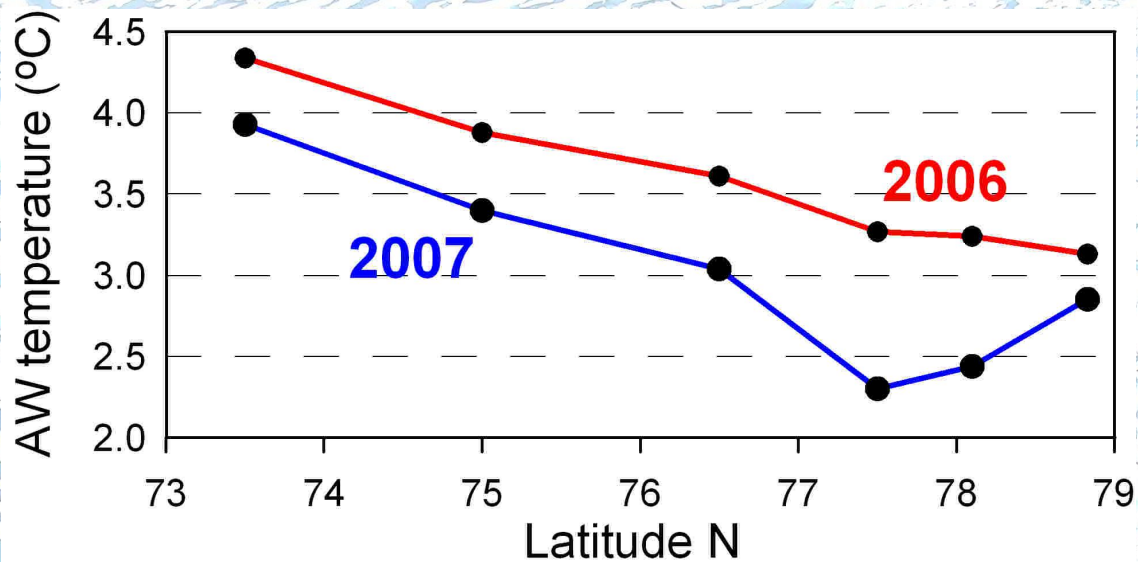
Energia kinetyczna prądów baroklinowych na 100 dbar



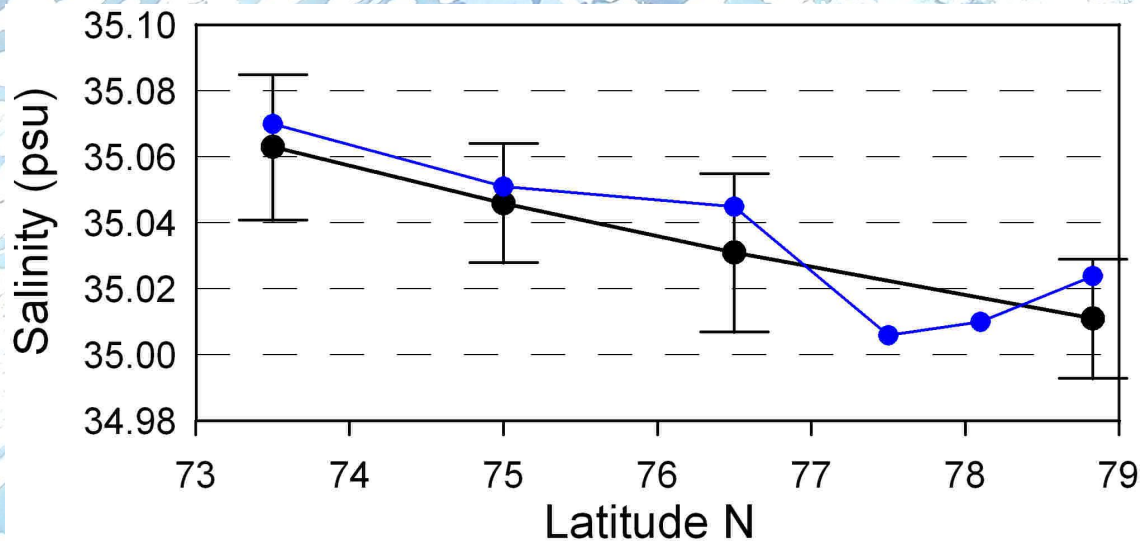
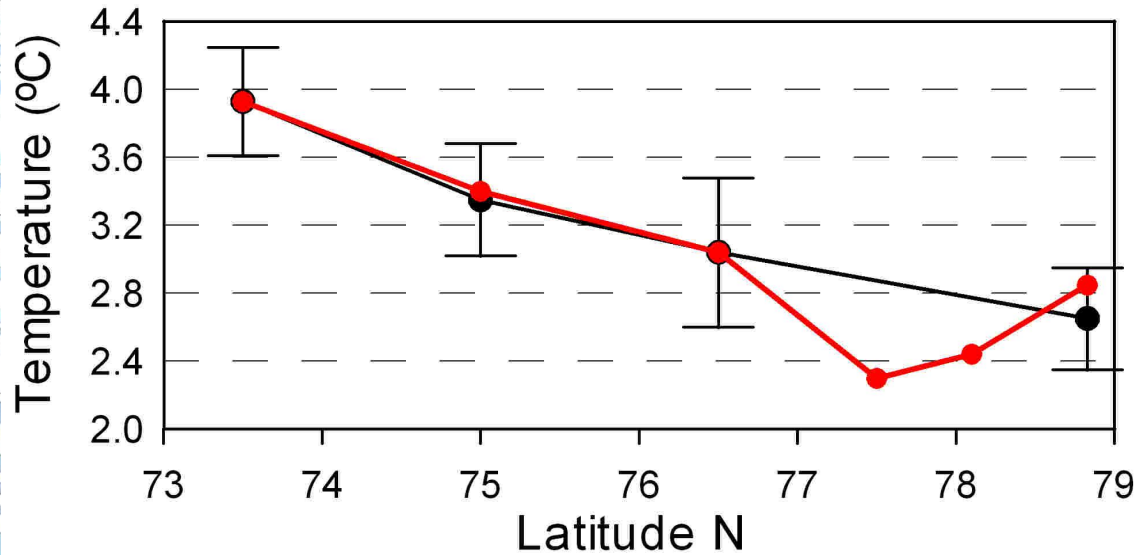
Serie czasowe średniej temperatury i zasolenia AW dla przekrojów H, K, N i EB.



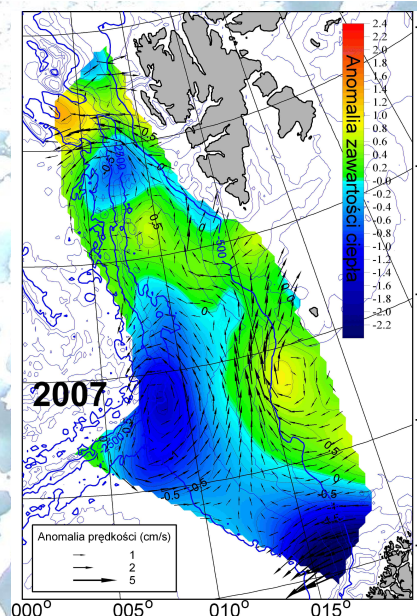
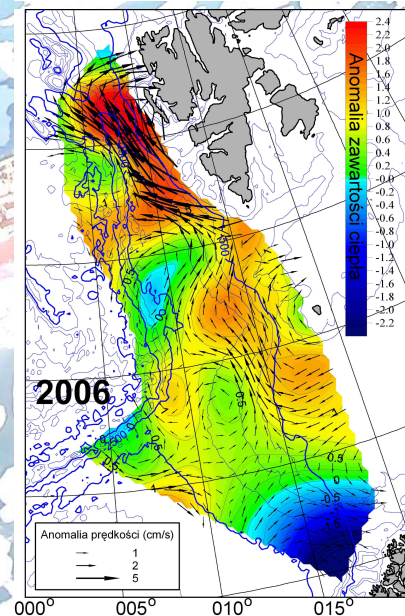
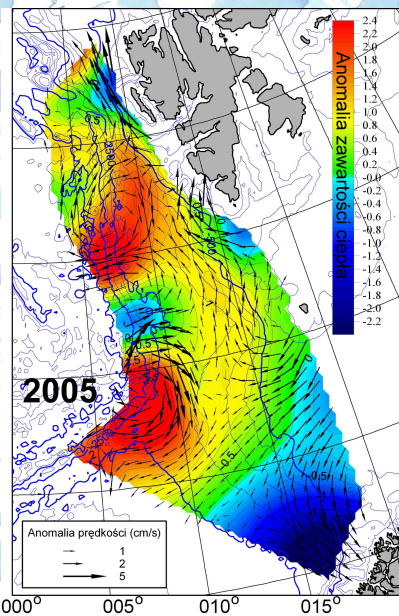
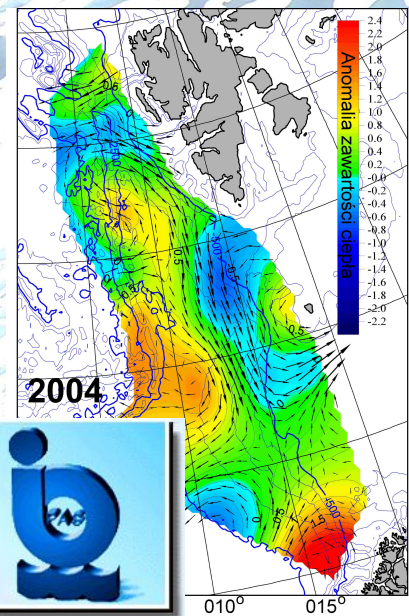
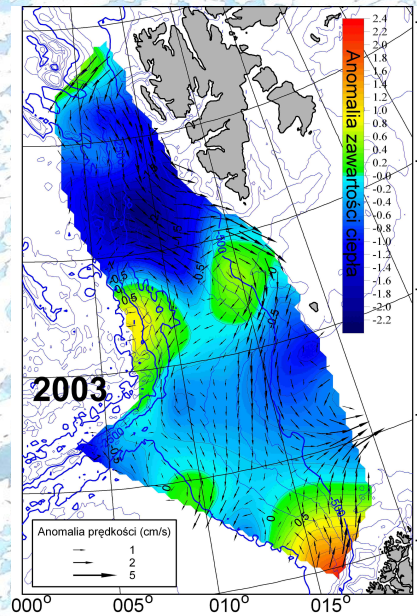
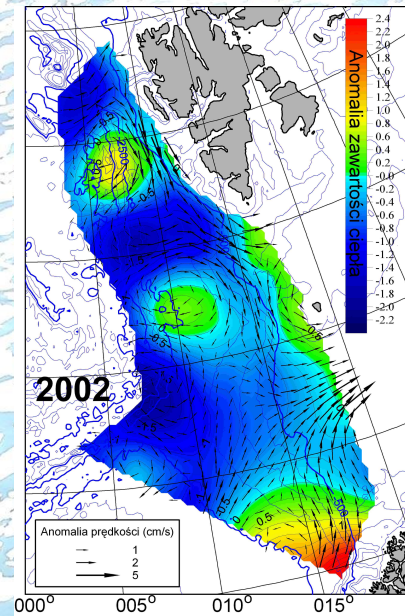
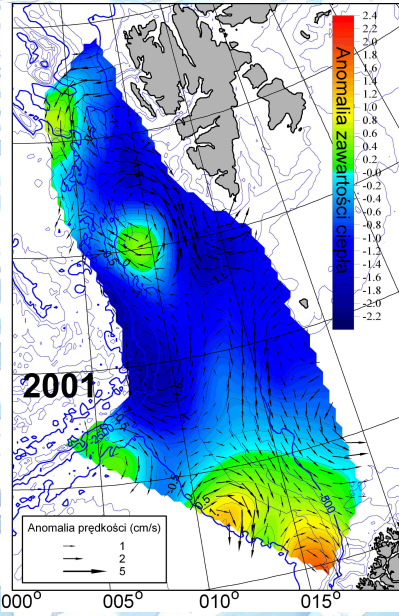
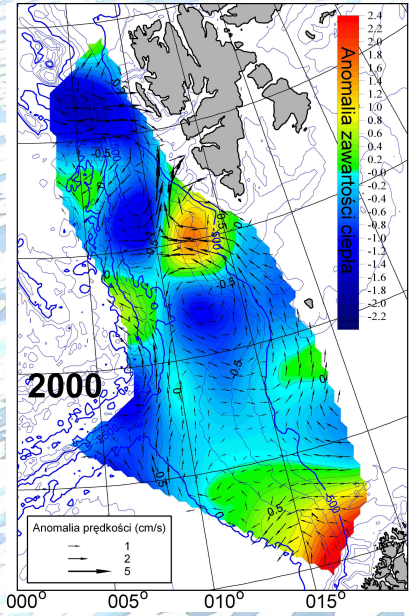
Temperatura i zasolenie warstwy AW pomiędzy szerokościami geograficznymi 73°30' -78°50'N lato 2006 i 2007



2000-2006 średnia temperatura i zasolecie AW pomiędzy szerokościami geograficznymi 73°30' - 78°50'N oraz latem 2007



Anomalia zawartość ciepła w warstwie Wody Atlantycznej (GJ/m²) i anomalia prędkości geostroficznego na 100 dbar.



The end of a trend? The progression of unusually warm and saline water from the eastern North Atlantic into the Arctic Ocean.

N.P. Holliday¹, S. L. Hughes², A. Lavín³, K. A. Mork⁴, G. Nolan⁵, W. Walczowski⁶, A. Beszczynska-Möller⁷.

¹National Oceanography Centre, Southampton, UK. ²Marine Laboratory, FRS, Aberdeen, Scotland. ³Instituto Español de Oceanografía, Santander, Spain. ⁴Institute of Marine Research and Bjerknes Centre for Climate Research, Norway

⁵Marine Institute, Galway, Ireland ⁶Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

⁷Alfred-Wegener-Institute, Bremerhaven, Germany

Corresponding author: nph@noc.soton.ac.uk

In the context of recent reports describing long-term freshening of the subarctic North Atlantic (Curry and Mauritzen, 2005, Peterson et al, 2006), it is surprising to observe that the upper ocean (500-1000 m) of the eastern North Atlantic and Nordic Seas in 2004-2006 are dominated by the most saline water observed for over 50 years (Hughes and Holliday, 2006). Here we show that changes in the subpolar gyre in the mid-1990s led to an increase of warm saline subtropical water being entrained into subarctic circulation (Hátún et al, 2005); a different regime that has continued to the present day (2006). The progression of the subtropical-influenced water has been traced along the pathway of Atlantic inflow into the Nordic Seas, and finally in 2004 was observed to enter the Arctic Ocean (Walczowski and Piechura, 2006). Based on observational evidence, we predict that this unusually warm and saline water will continue to flow into the Arctic Ocean and Greenland Sea for at least the next 6 years (Holliday et al, in prep).

from section to section is not feasible. However, the increase in salinity from the mid-1990s onwards has been continuing for 10 years and has become visible as a multi-year trend along the AI pathway. In the longest time series at OWS Mike in the southern Norwegian Sea, it can be seen that the recently reported multi-decadal freshening trend come to an end in the mid to late 1990s. Indeed, the 2005 salinity values exceeded the previous highest level which occurred in 1961, making the 2005 salinities them the highest observed since 1949.

Figure 2 shows the temporal progression of sea surface temperature (SST) anomalies along the eastern margin of the region (locations of data points given by red dots). It can be seen that south of 57°N the temperature anomalies show no indication of propagation and are somewhat disconnected features. This suggests they are the result of local processes. However, from the Rockall Trough northwards, ie from the start of the Atlantic inflow path influenced by the subarctic front,

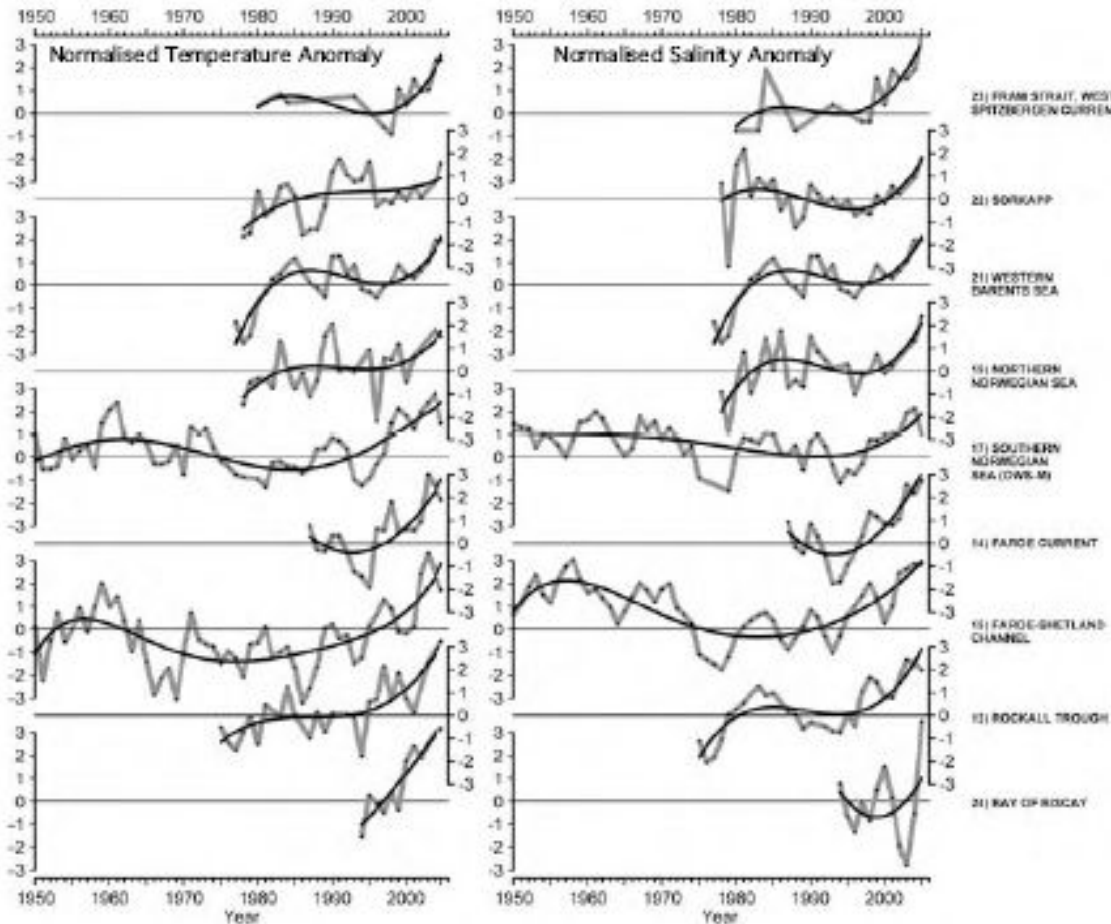


Figure 1. Time series of upper ocean temperature anomalies (left panel) and salinity anomalies (right panel) from sustained ocean observations along the pathways of Atlantic Inflow from the intergyre Biscay region (bottom) to the Fram Strait (top). Locations of sections are shown in Figure 2. Data are presented as normalised anomalies from the long-term mean (1971-2000).

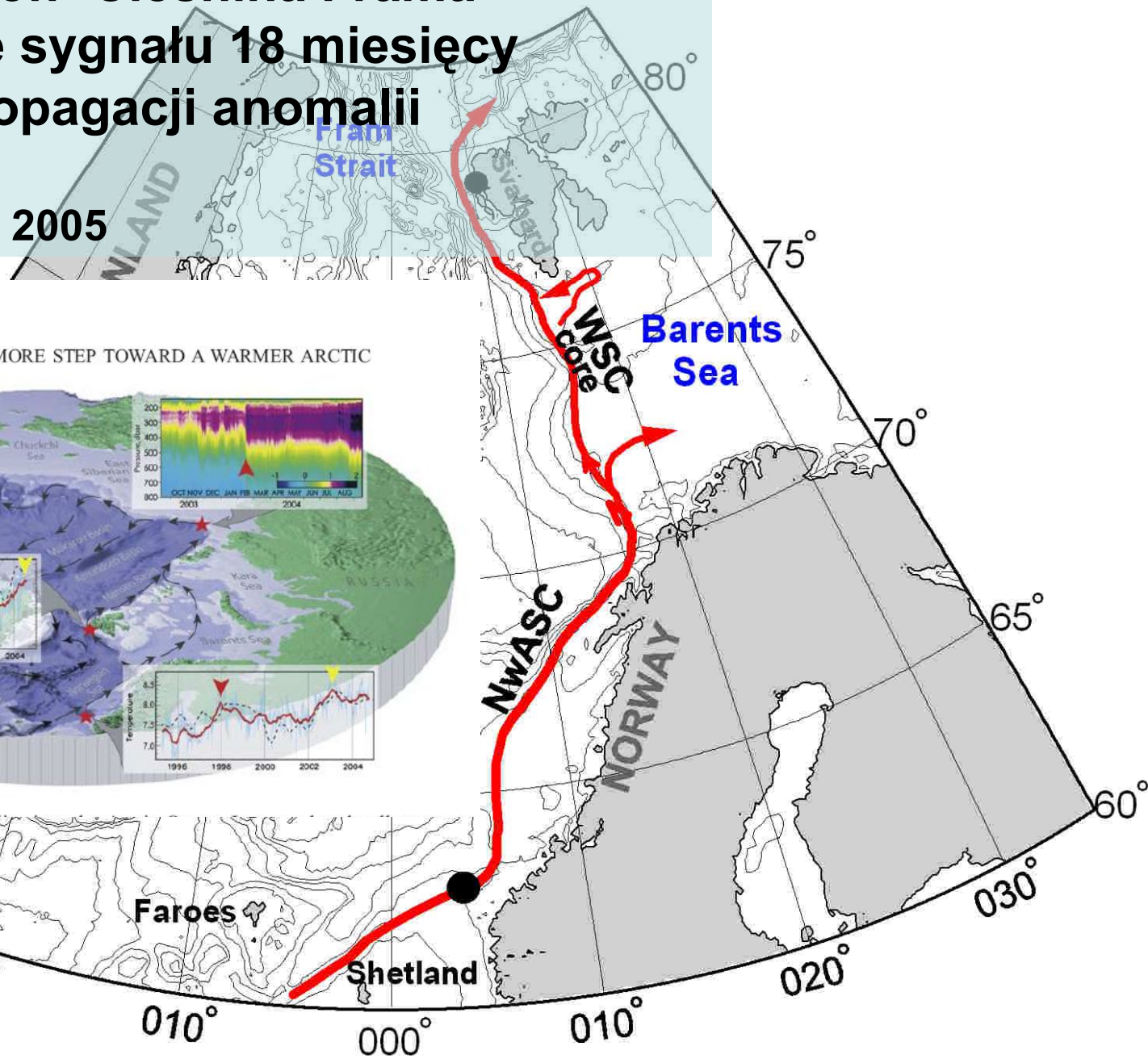
Svinoy Section- Cieśnina Frama

Przesunięcie sygnału 18 miesięcy

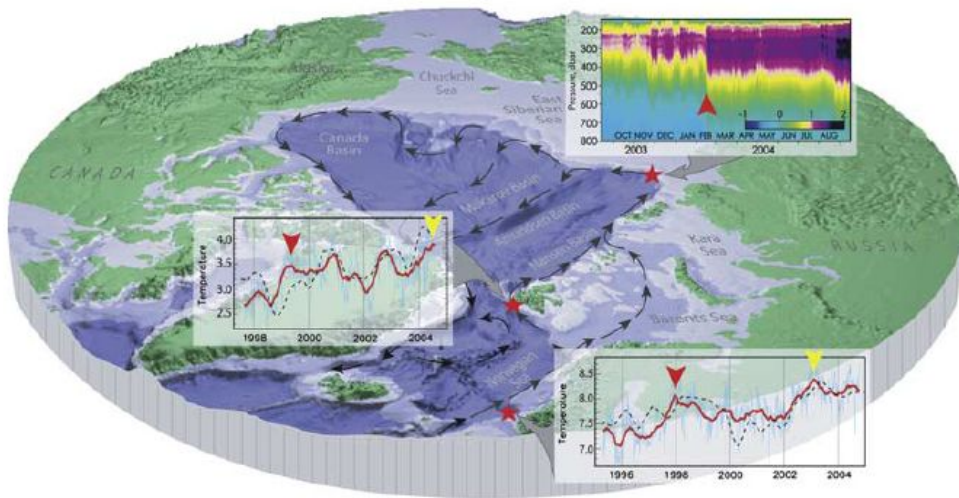
Prędkość propagacji anomalii

3.8 cm/s

Polyakov et al., 2005

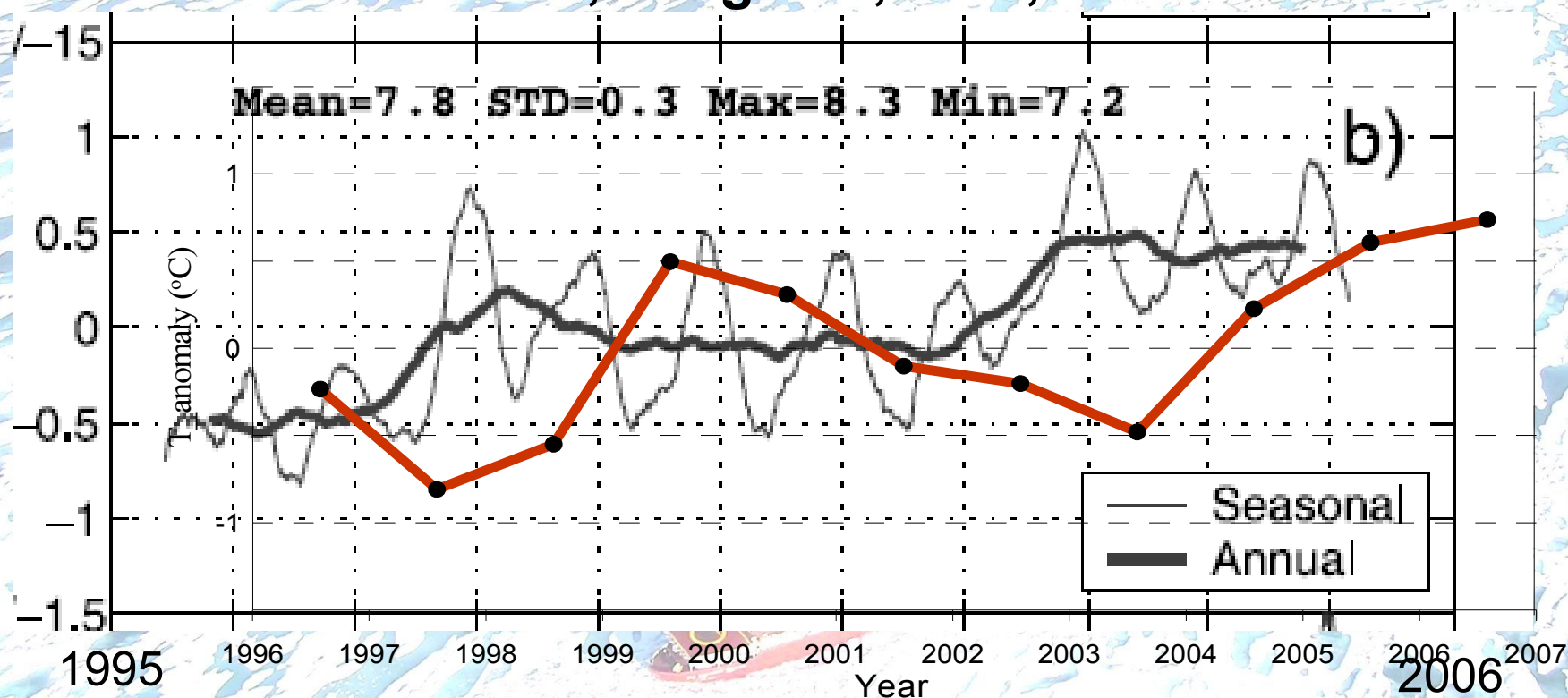


POLYAKOV ET AL.: ONE MORE STEP TOWARD A WARMER ARCTIC



Heat flux variations in the eastern Norwegian Atlantic Current toward the Arctic from moored instruments, 1995–2005

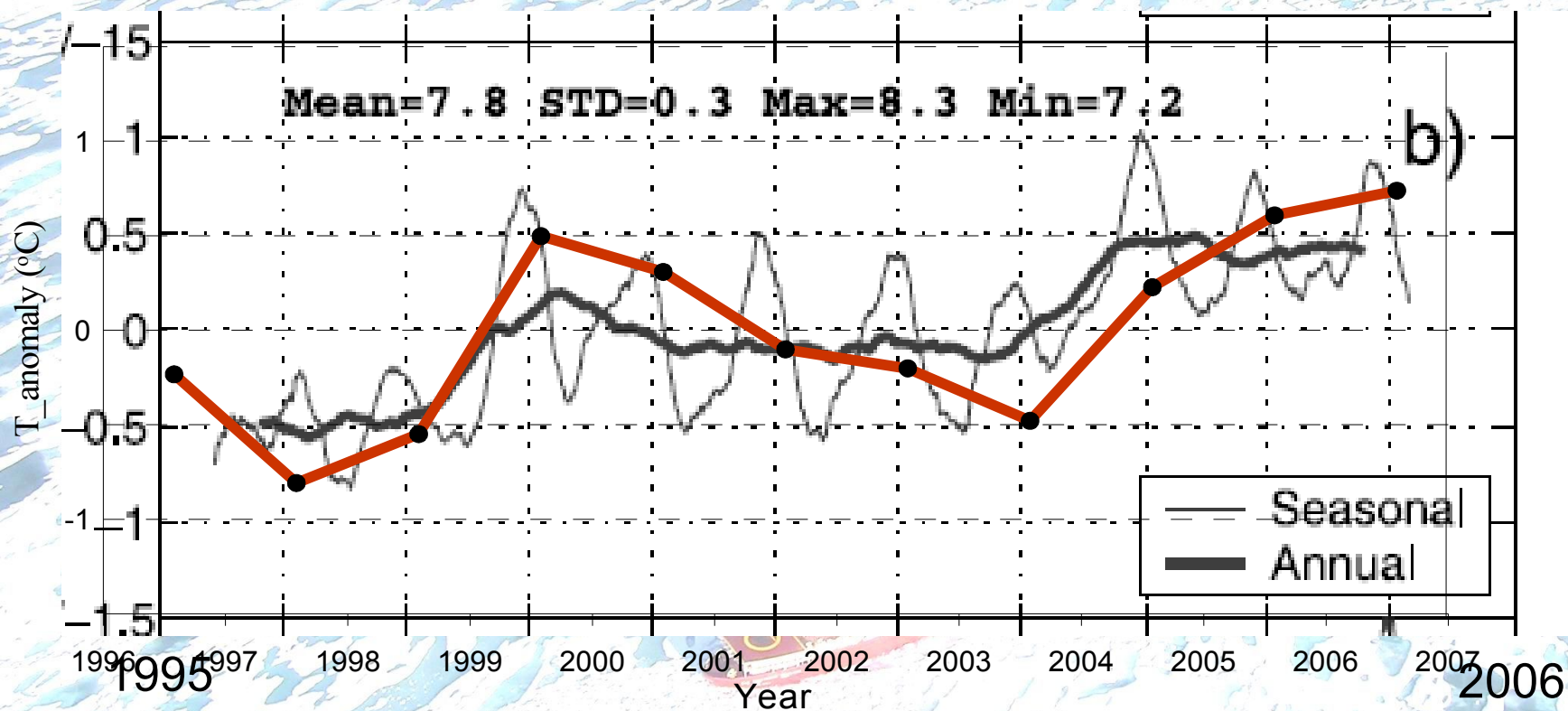
Orvik, Skagseth, GRL, 2005



Seria czasowa anomalii temperatury w NwASC (czarna linia)

Seria czasowa anomalii temperatury AW na szerokości 76°30 N (czerwona linia)



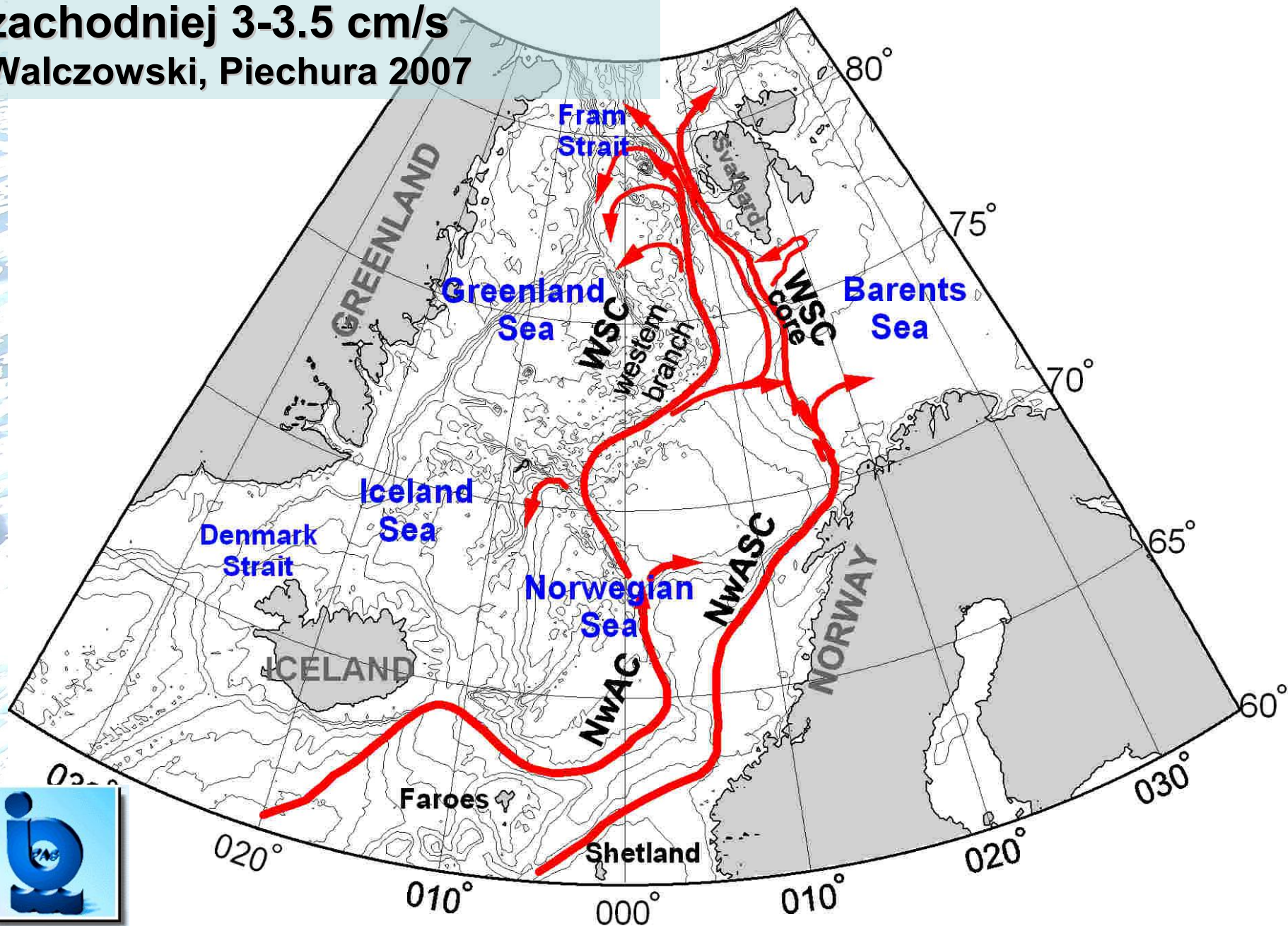


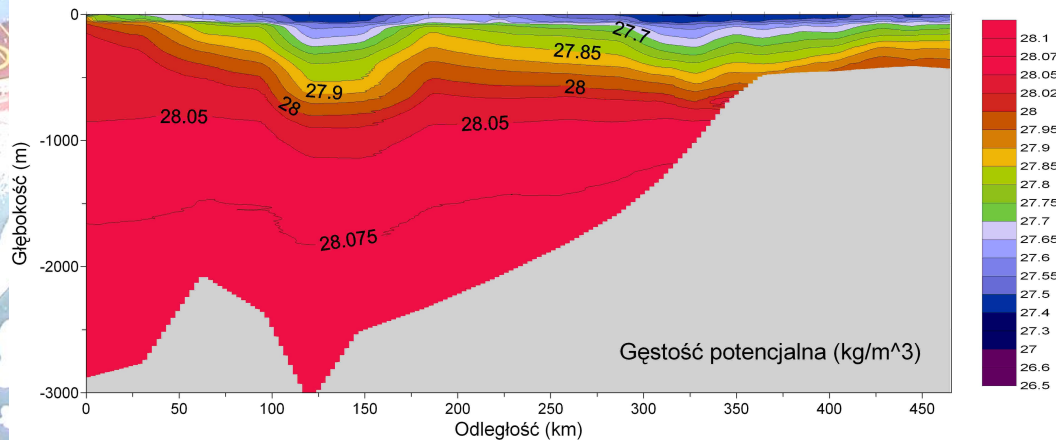
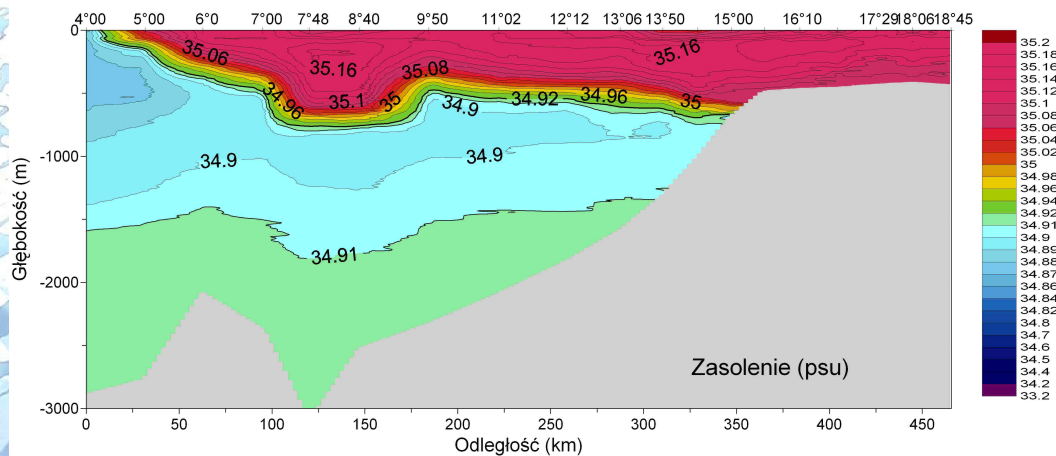
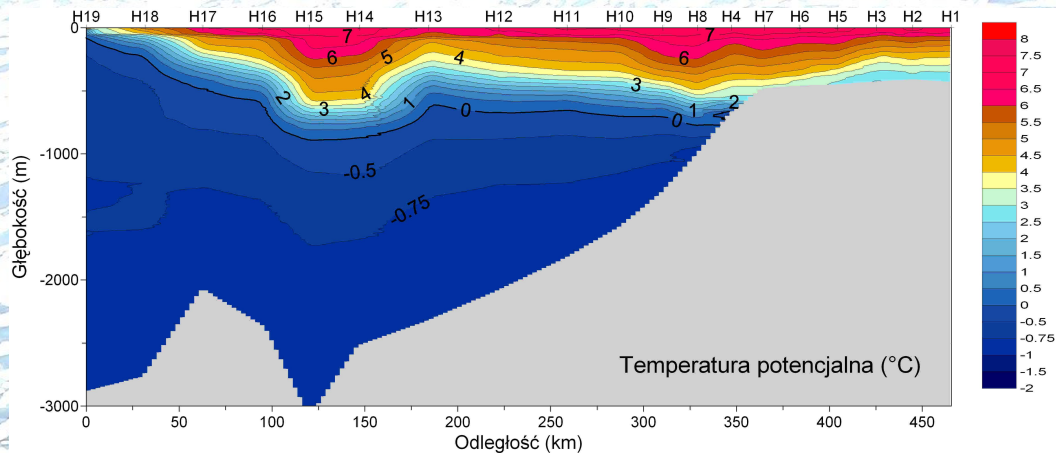
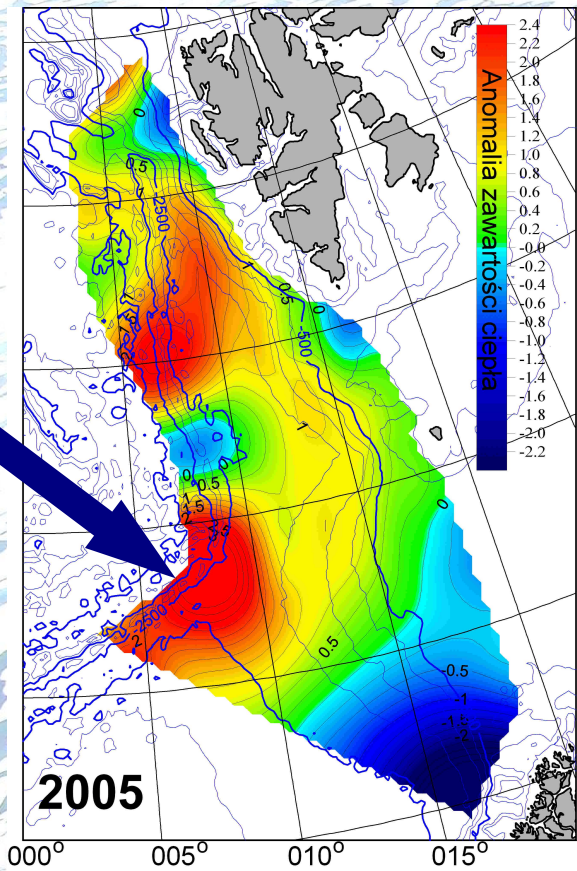
Svinoy Section – przekrój N - 76°30
Przesunięcie czasowe 18-21 miesięcy

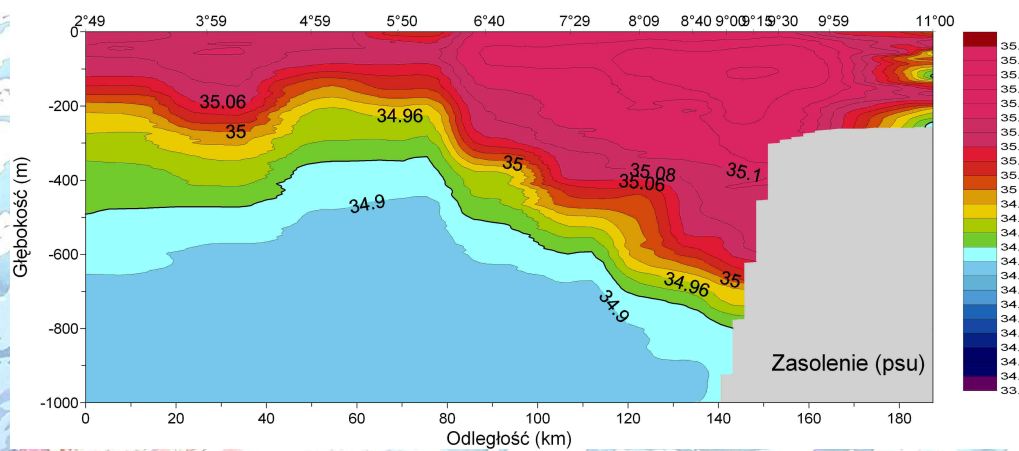
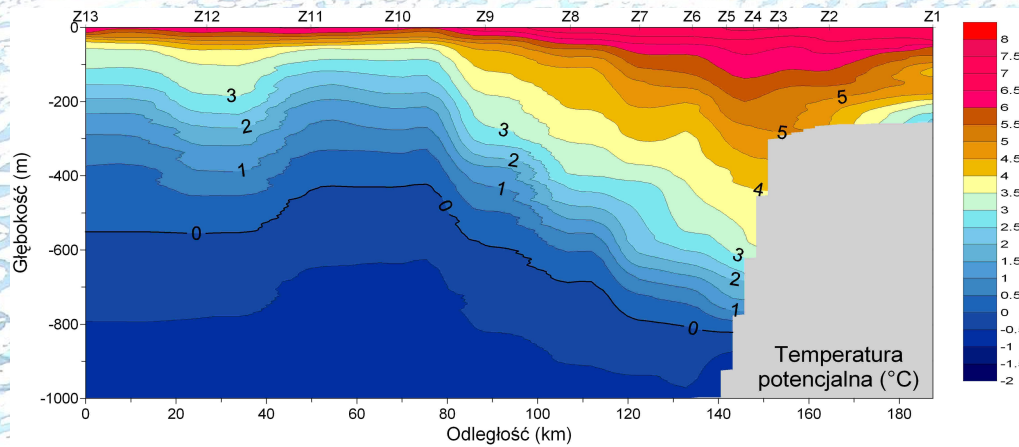
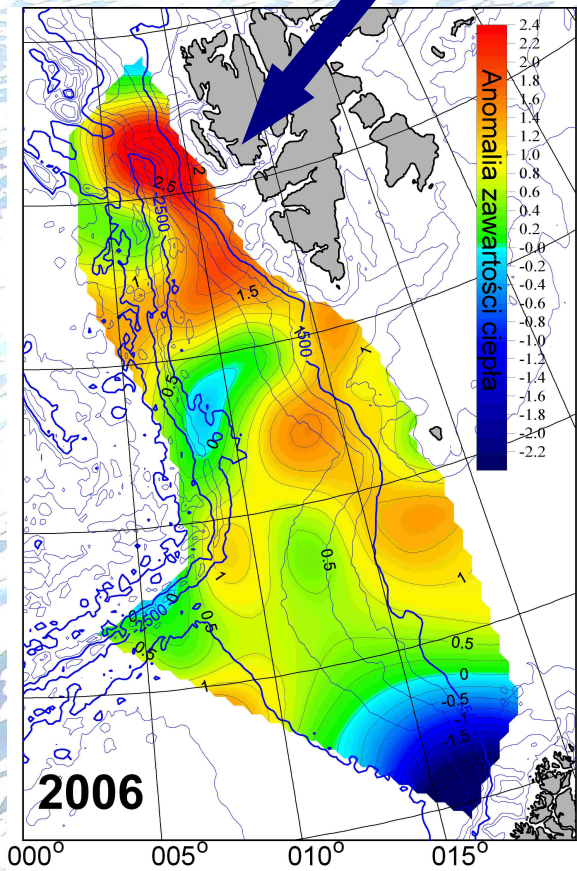


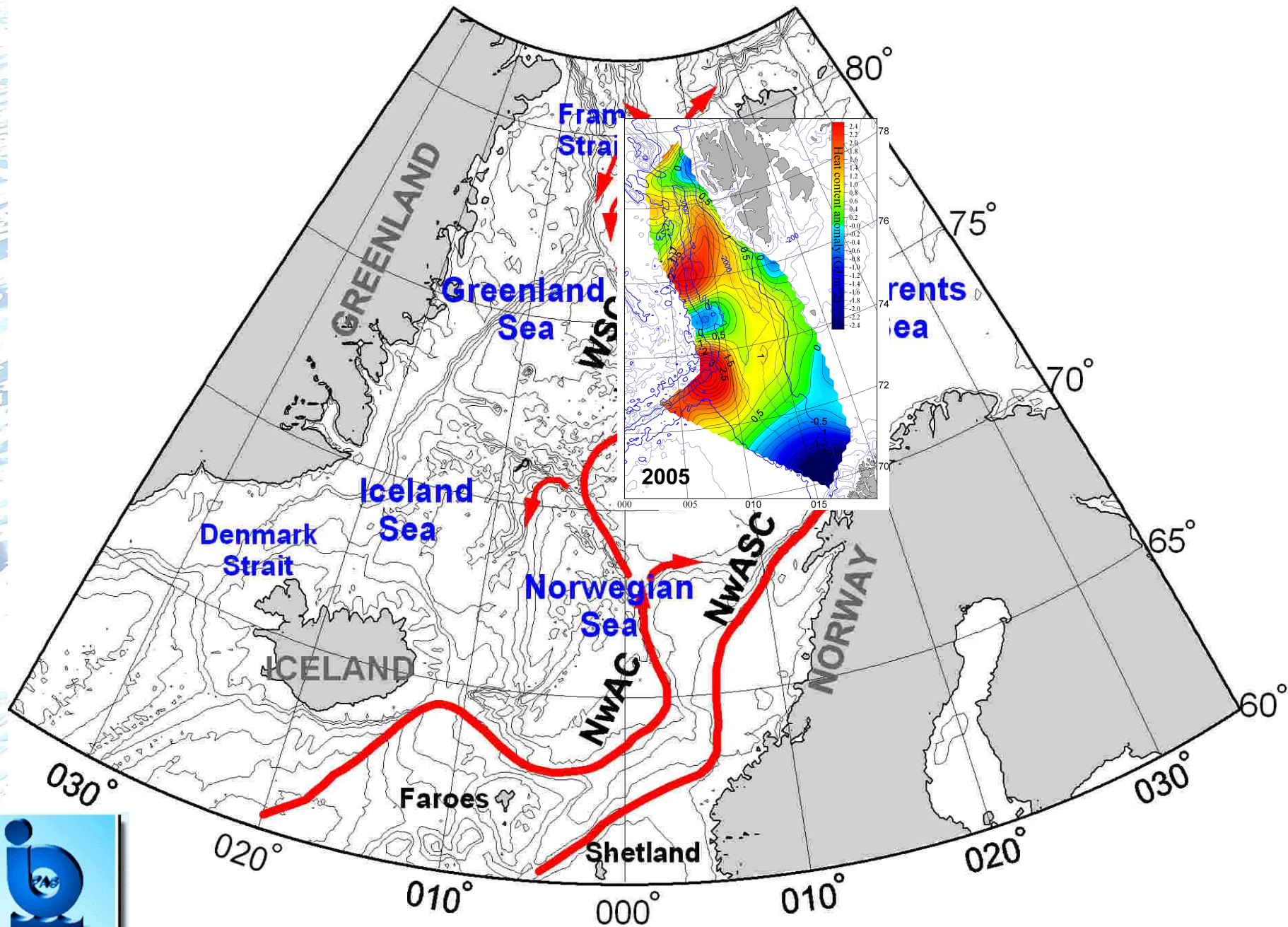
Anomalia prędkości w gałęzi zachodniej 3-3.5 cm/s

Walczowski, Piechura 2007









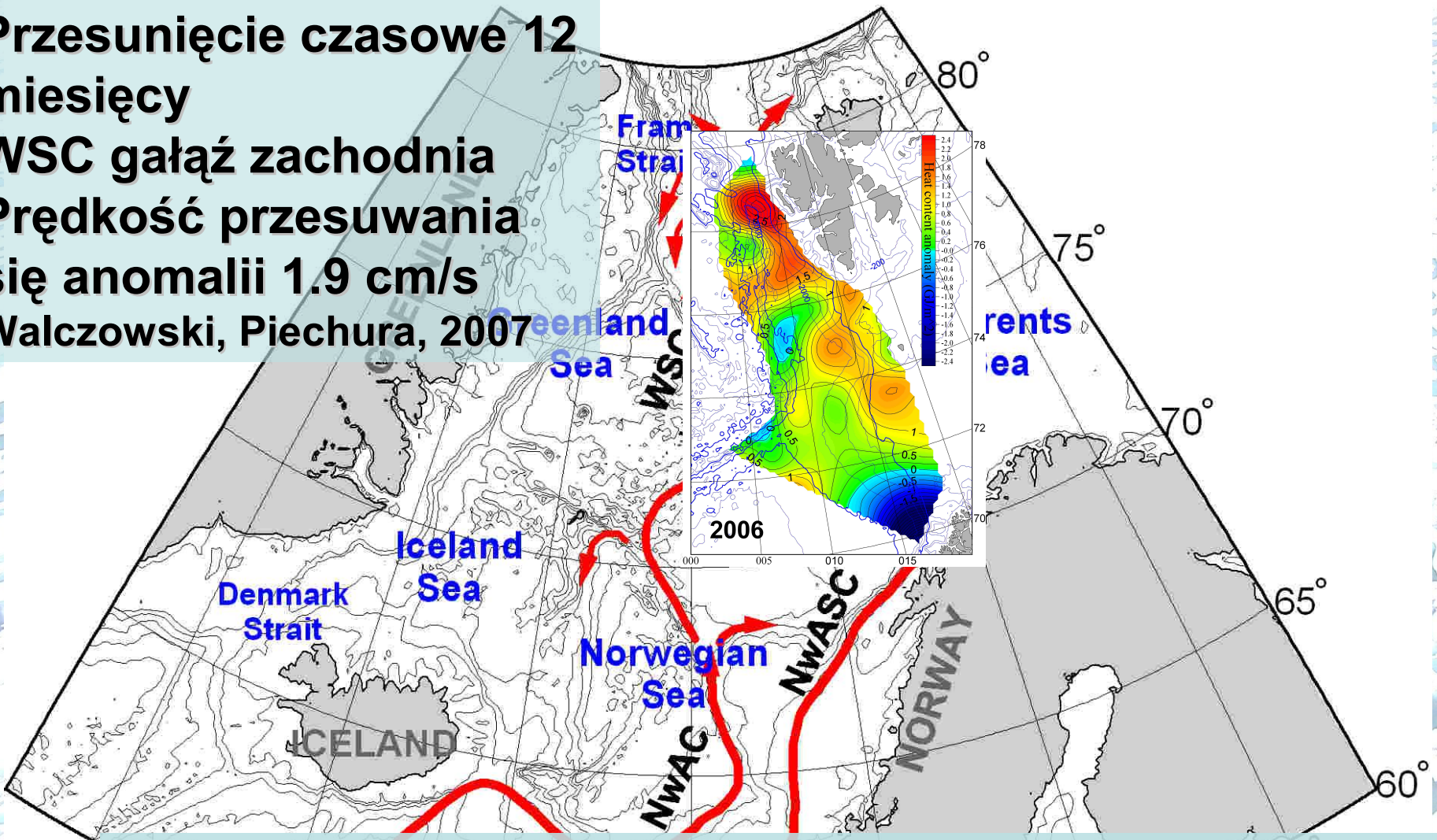
73°30 N - 78°40 N

Przesunięcie czasowe 12
miesięcy

WSC gałąź zachodnia

Prędkość przesuwania
się anomalii 1.9 cm/s

Walczowski, Piechura, 2007

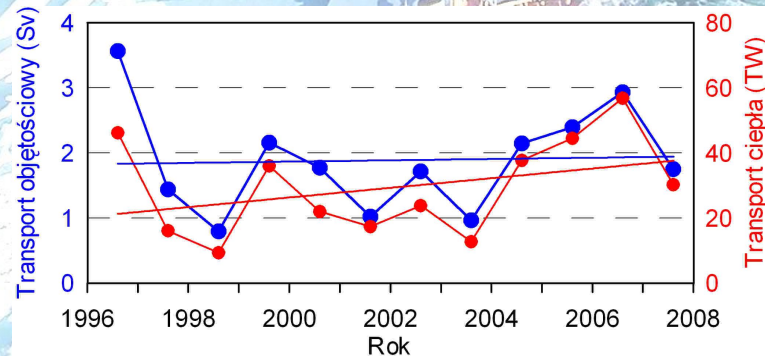
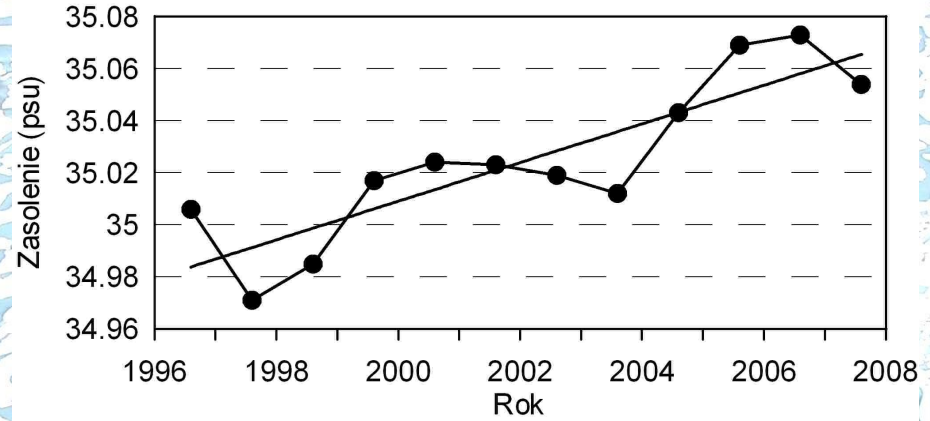
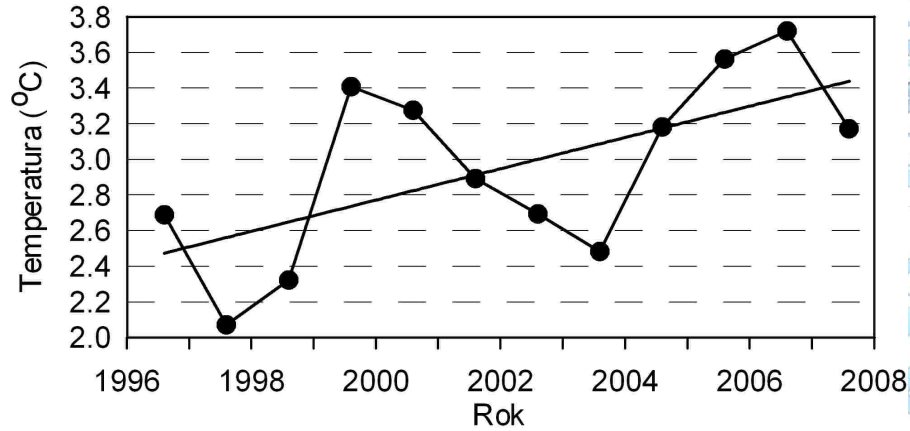


Anomalia ciepła obserwowana w 2006 na północ od szerokości 78°N zawierała $4 \cdot 10^{20}$ J i AW uwalniając tą nadwyżkę ciepła była w stanie stopić 130.000 km² lodu o grubości 1m

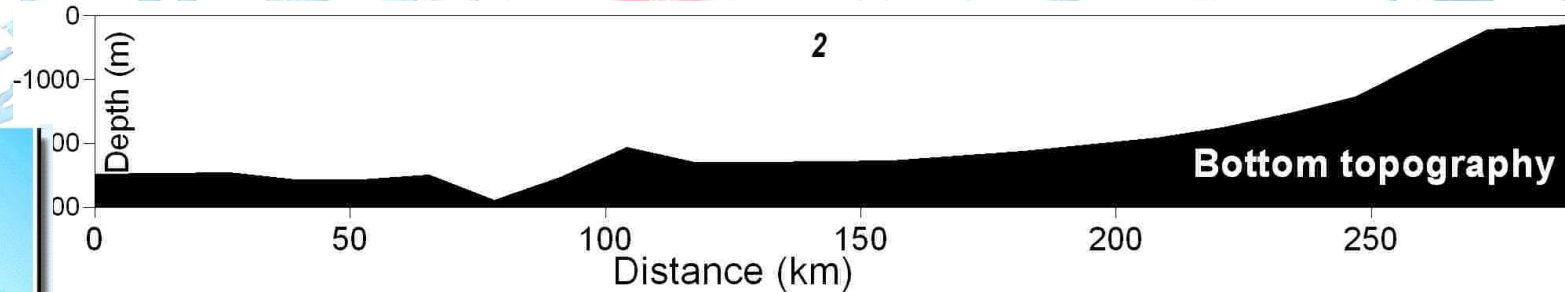
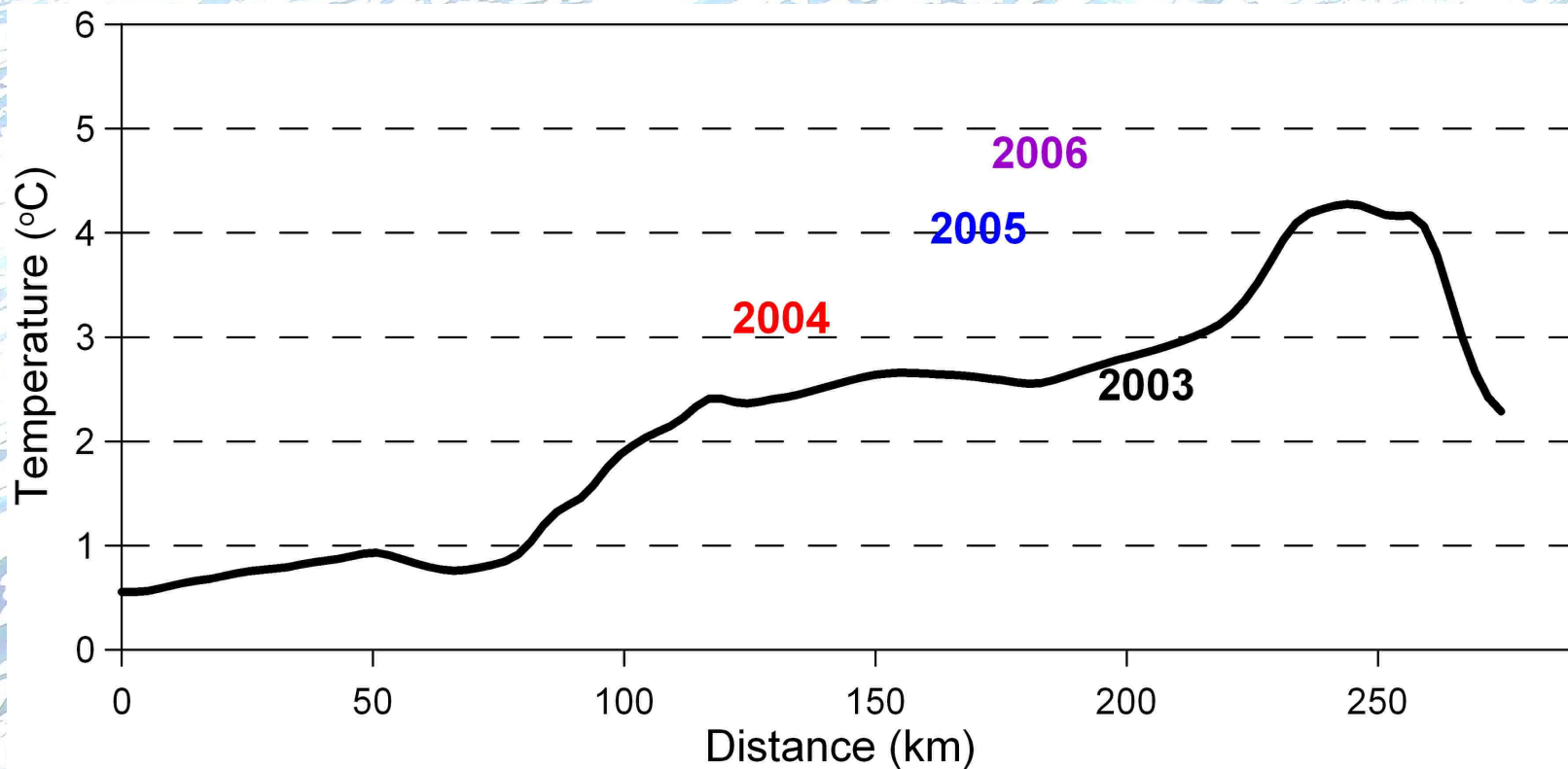


Transect 'N' (76°30'N) , pomiędzy długościami 04° -15° E

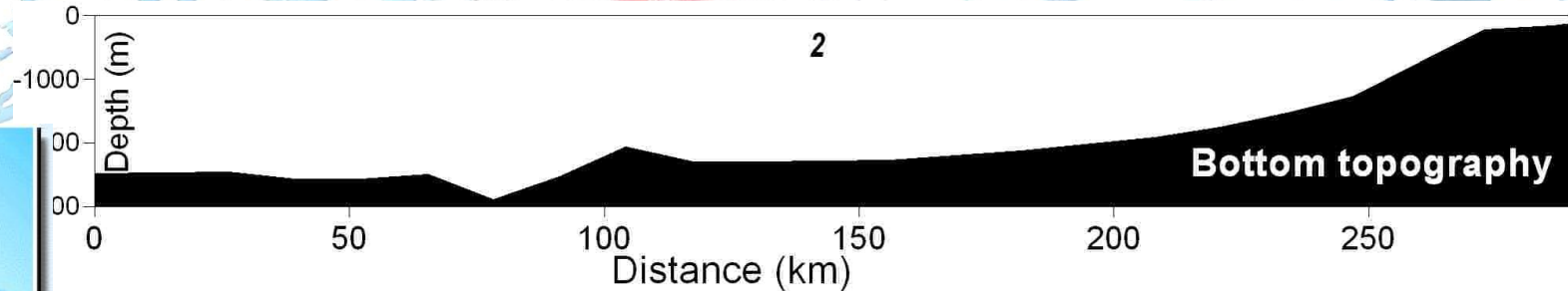
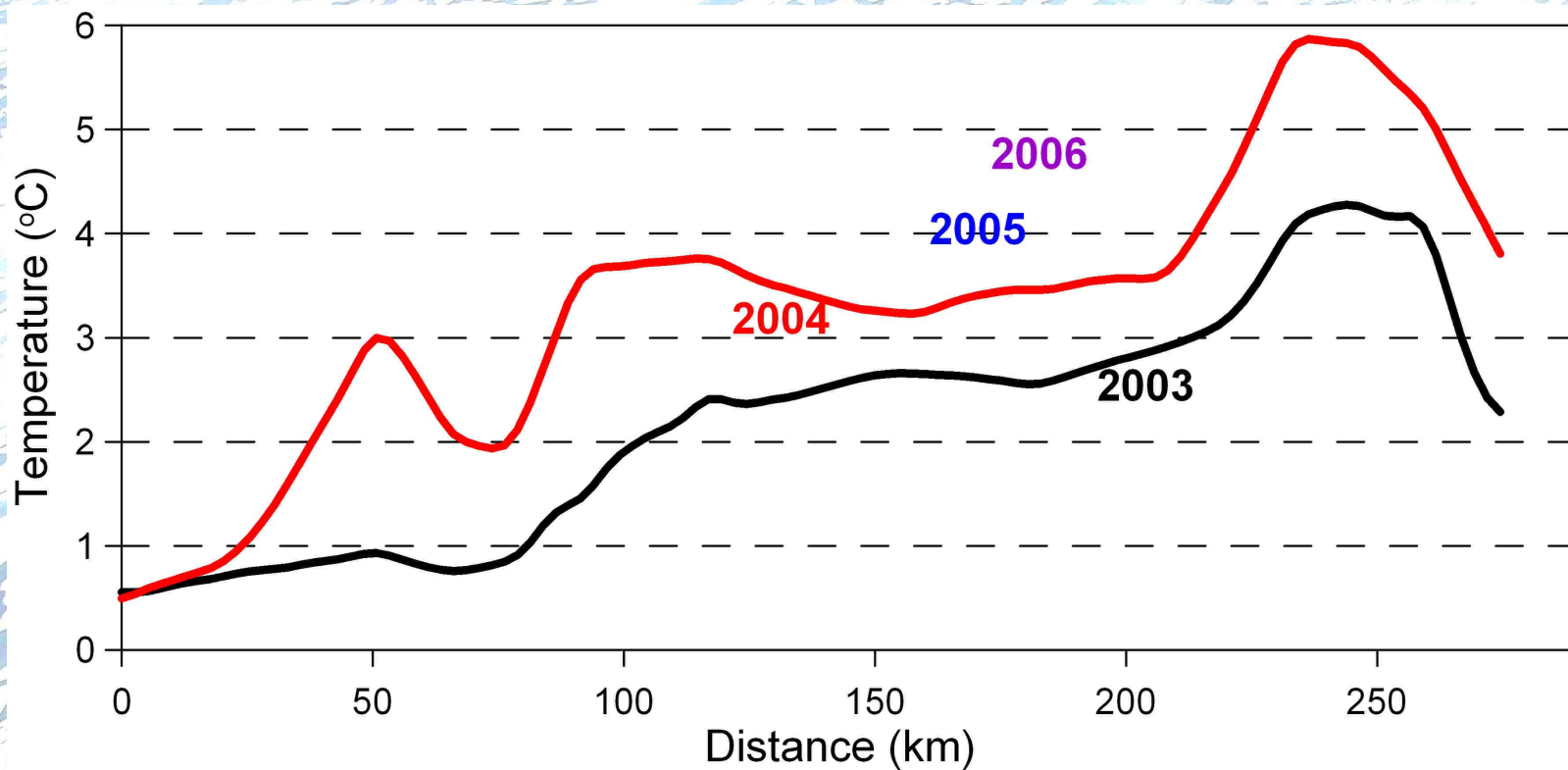
Właściwości AW



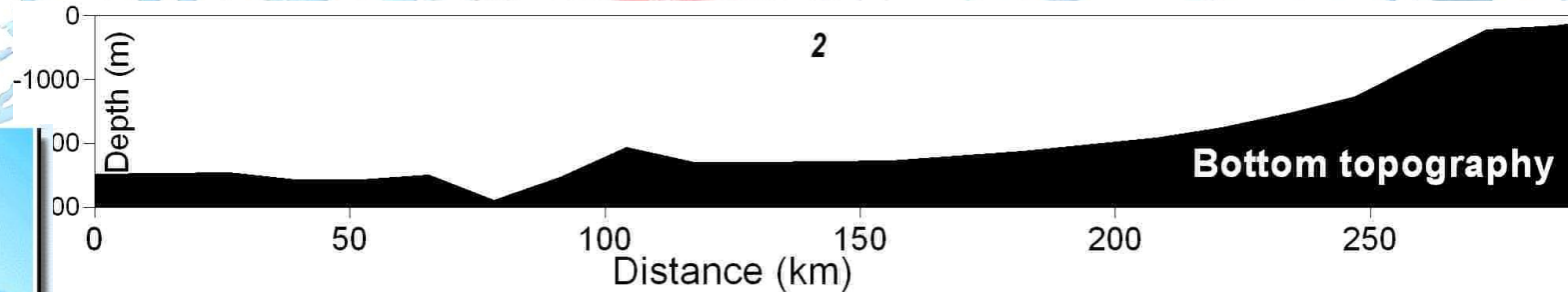
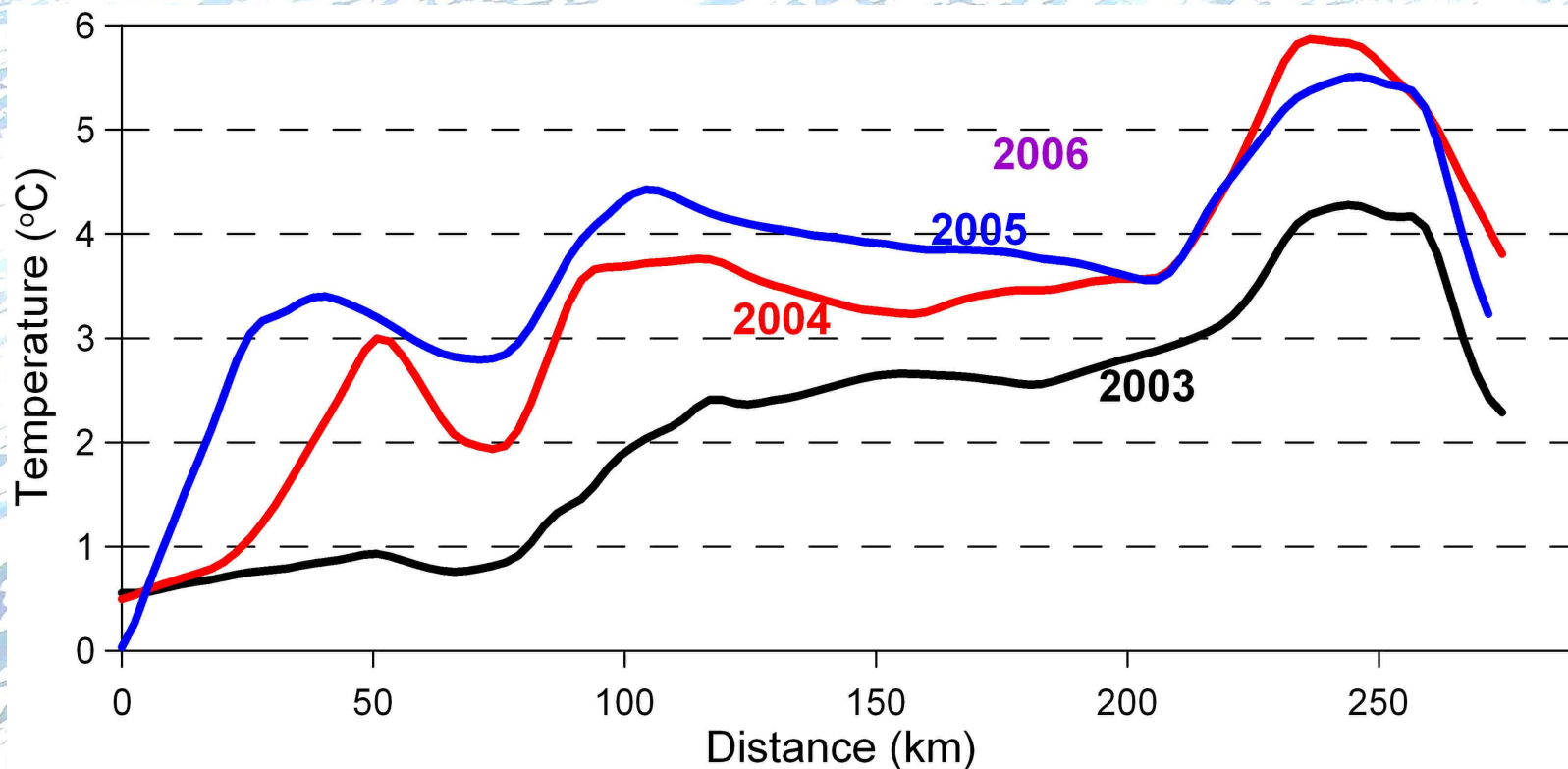
Temperatura wzdłuż sekcji 'N' (76°30'N) na 200 m pomiędzy długościami geogr. 04° -15° E



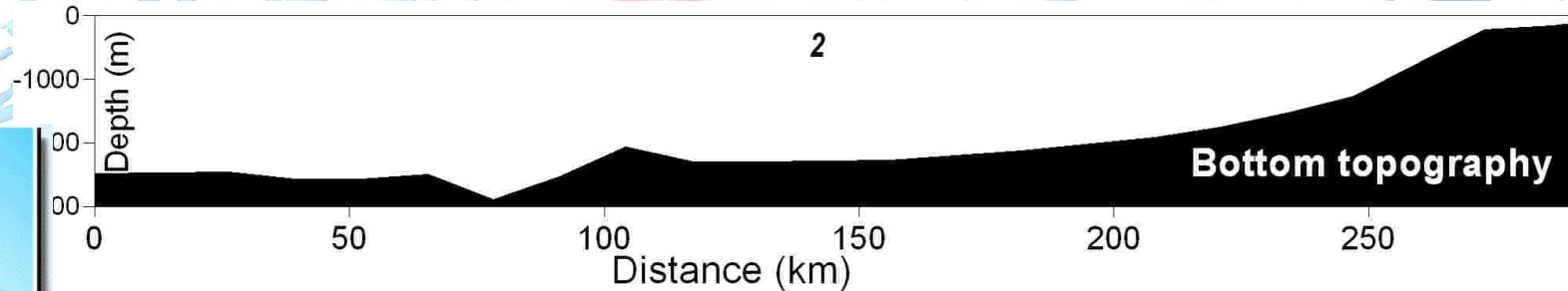
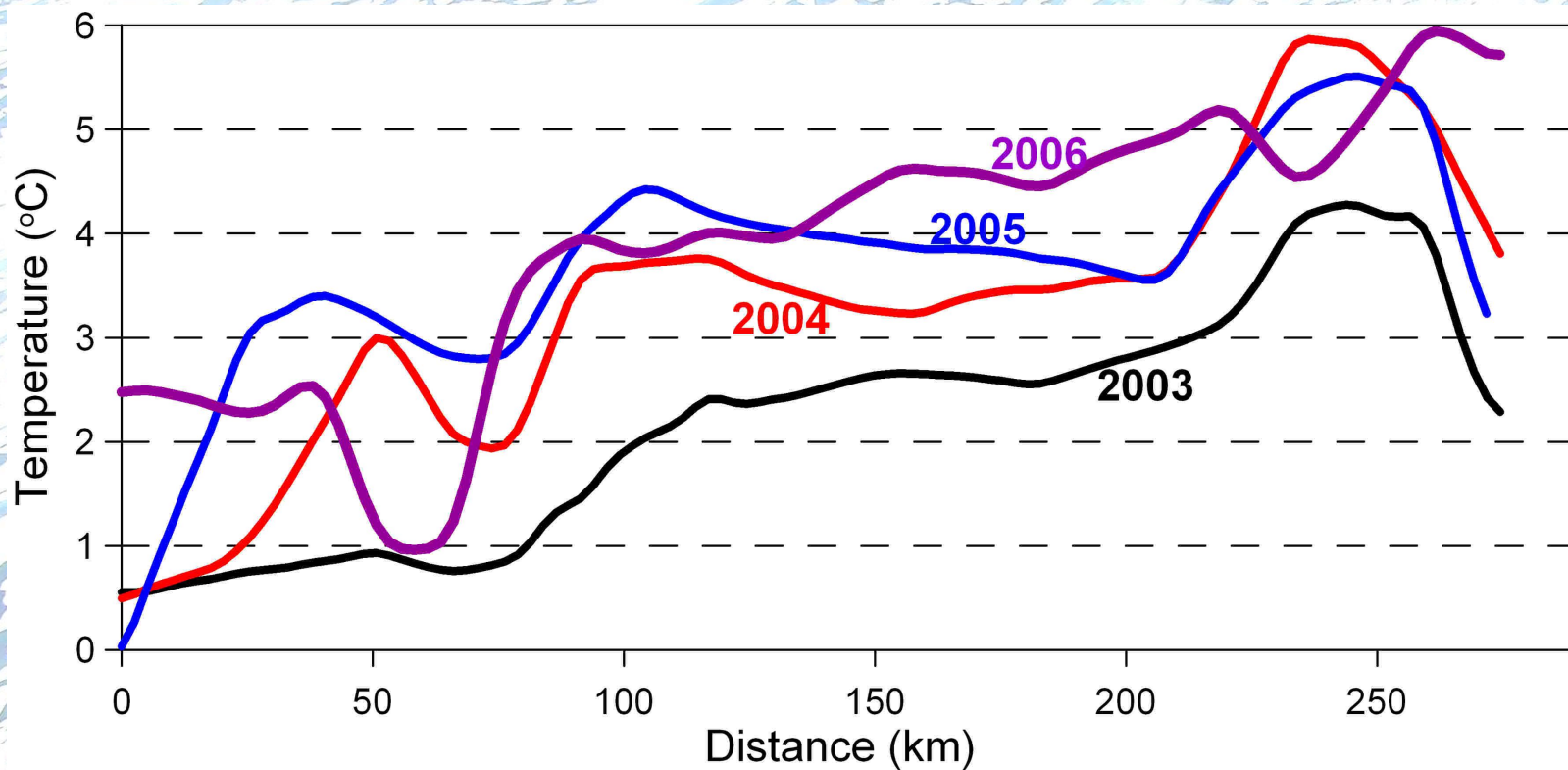
Temperatura wzdłuż sekcji 'N' (76°30'N) na 200 m pomiędzy długościami geogr. 04° -15° E



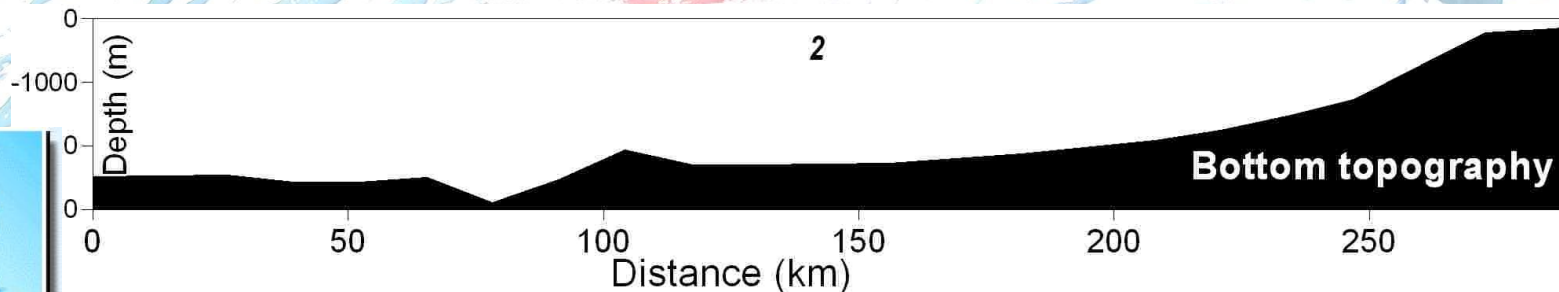
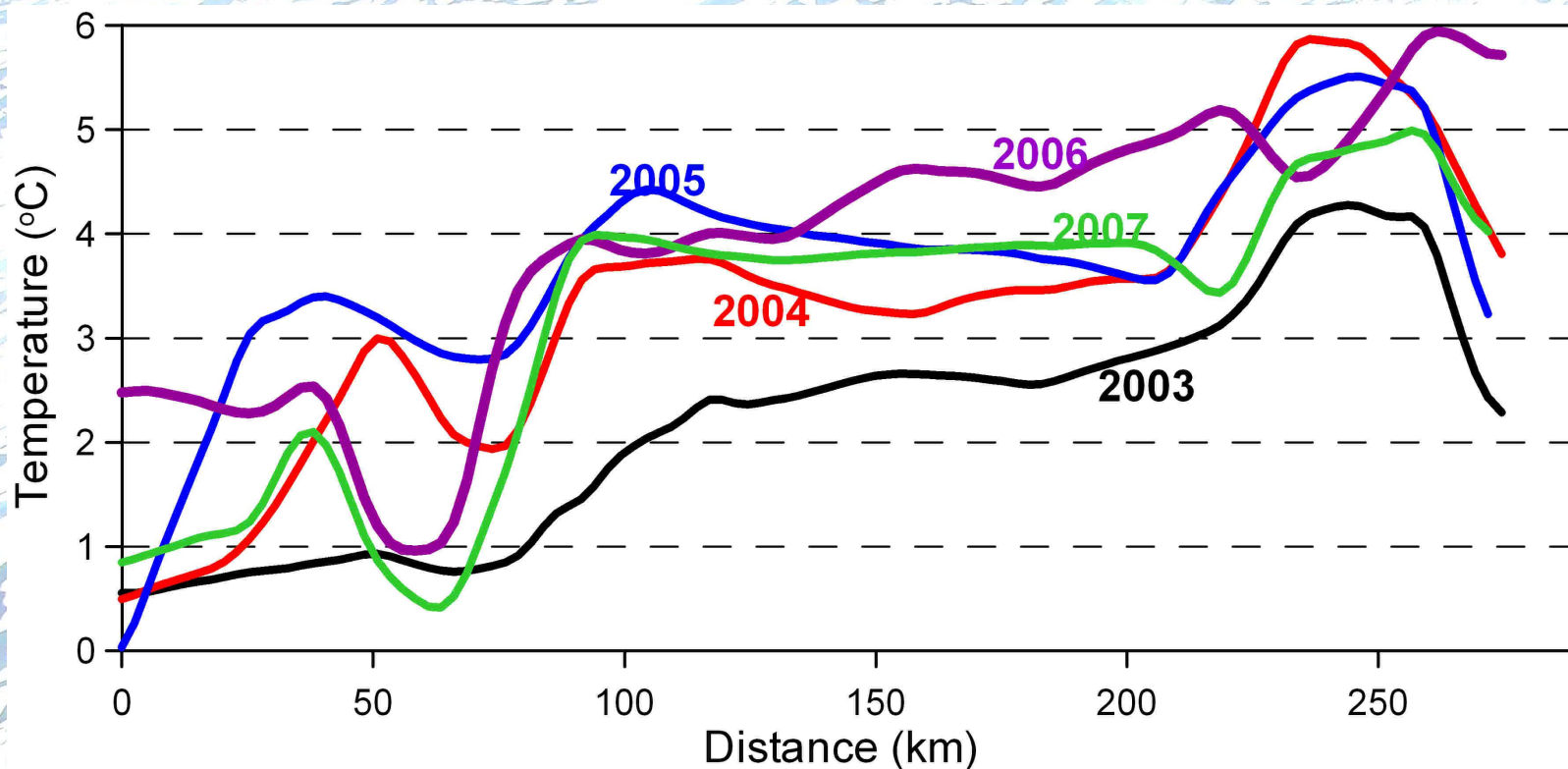
Temperatura wzdłuż sekcji 'N' (76°30'N) na 200 m pomiędzy długościami geogr. 04° -15° E



Temperatura wzdłuż sekcji 'N' (76°30'N) na 200 m pomiędzy długościami geogr. 04° -15° E

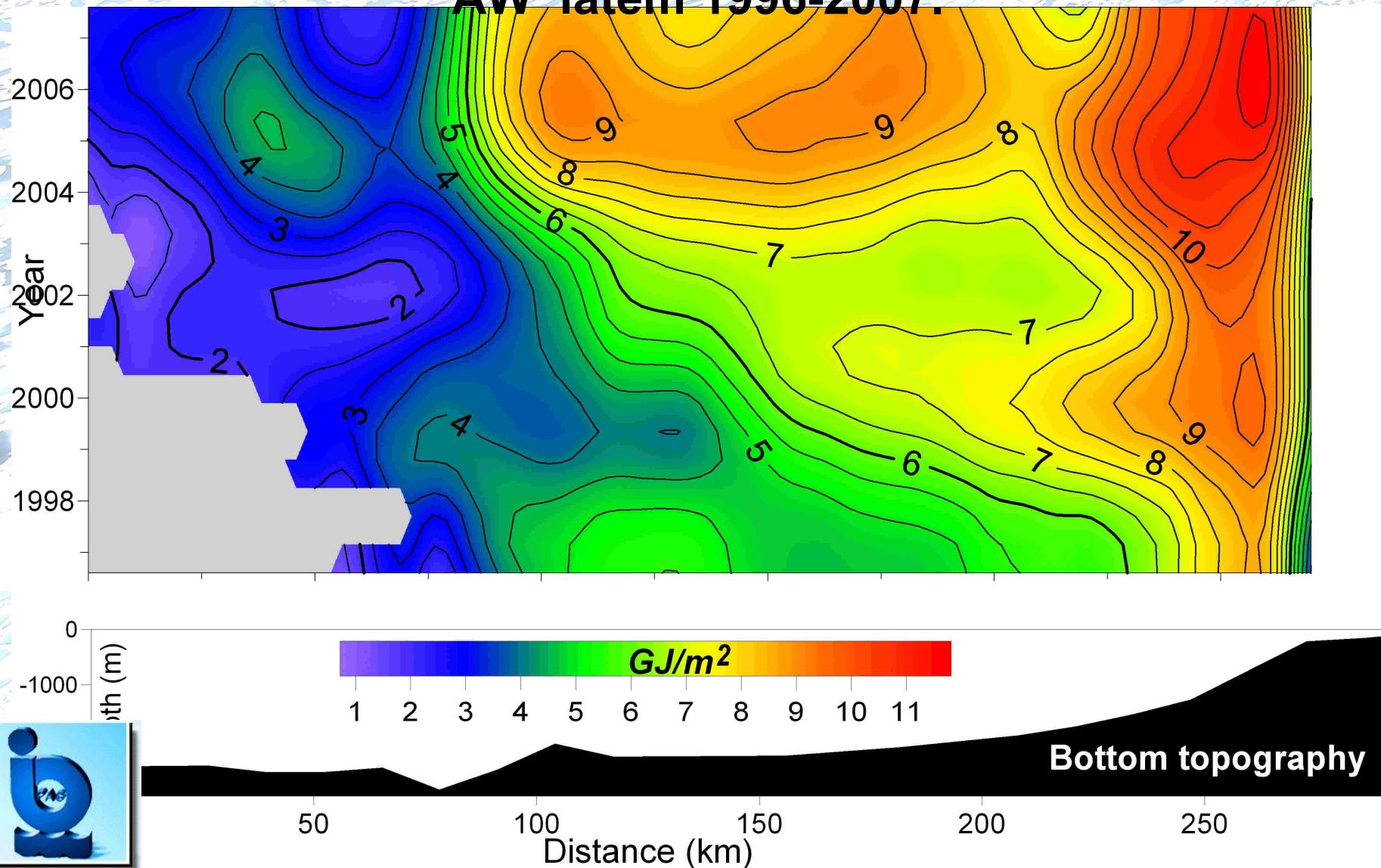


Temperatura wzdłuż sekcji 'N' (76°30'N) na 200 m pomiędzy długościami geogr. 04° -15° E

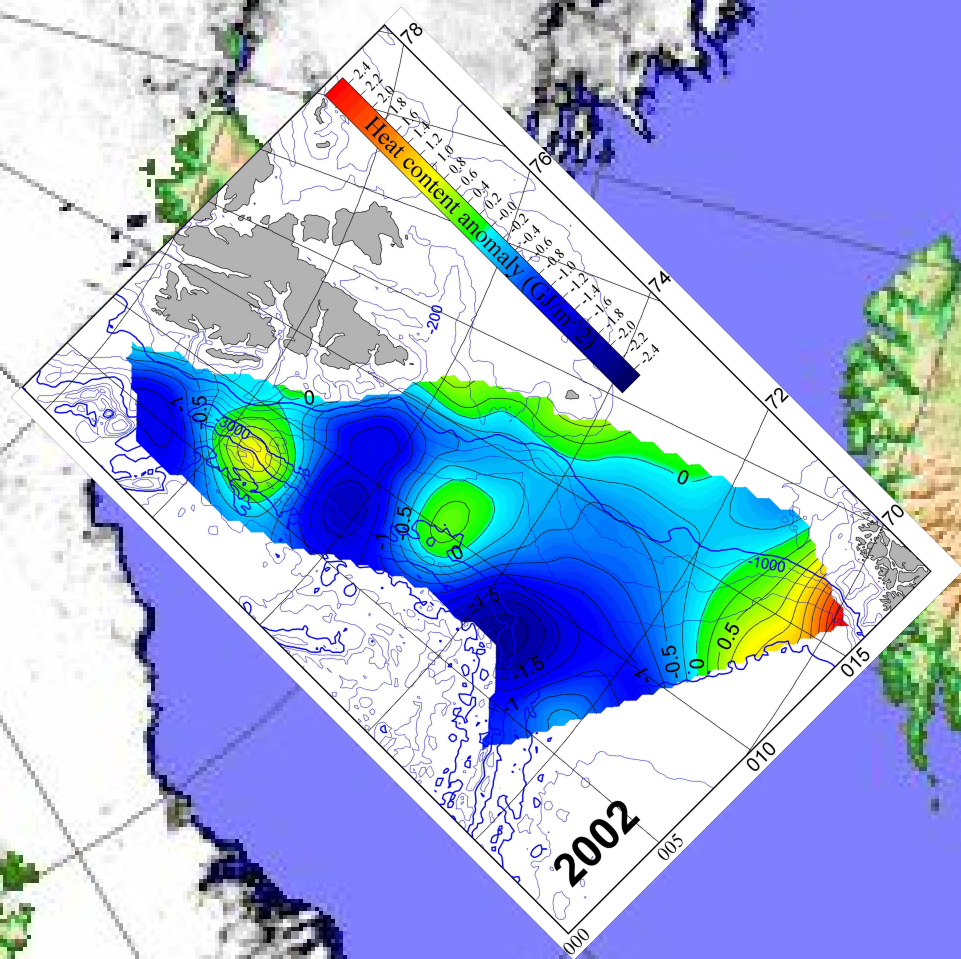


Sekcja wzdłuż równoleżnika 76°30' pomiędzy południkami 04°E-15°E.

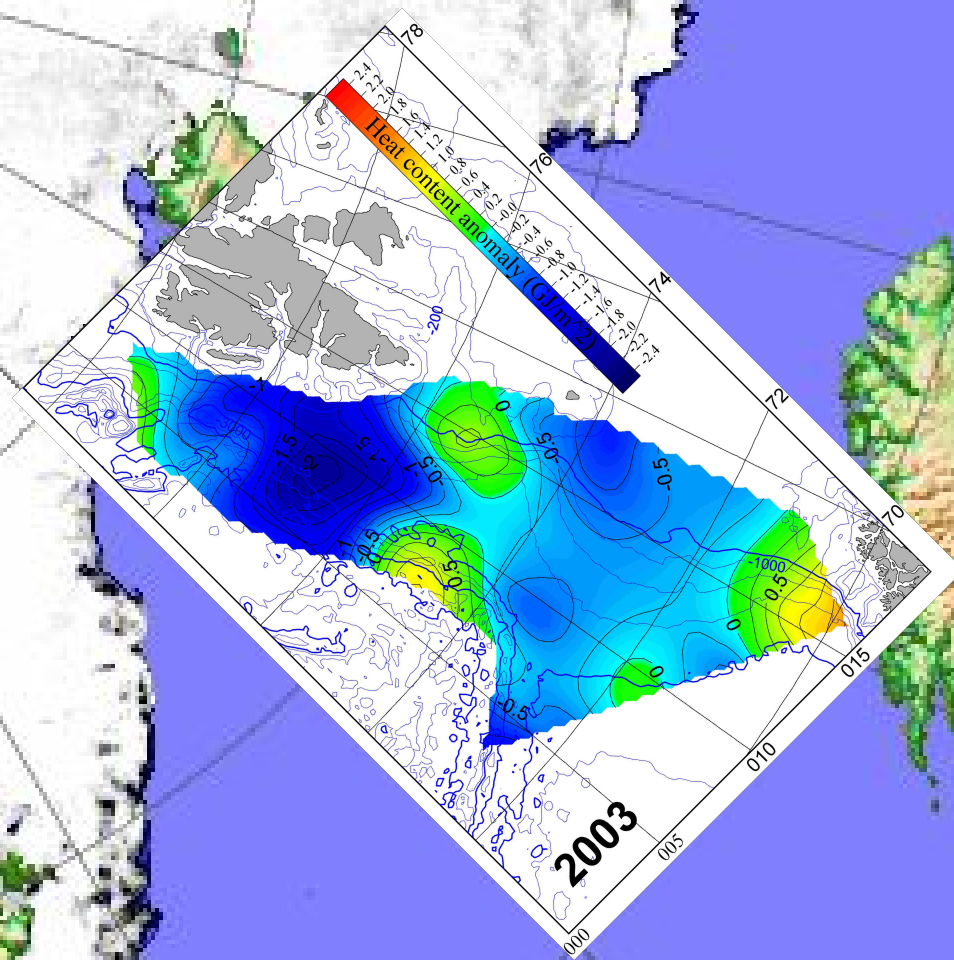
Diagram Hovmoellera zawartości ciepła (GJ/m²) w warstwie AW latem 1996-2007.



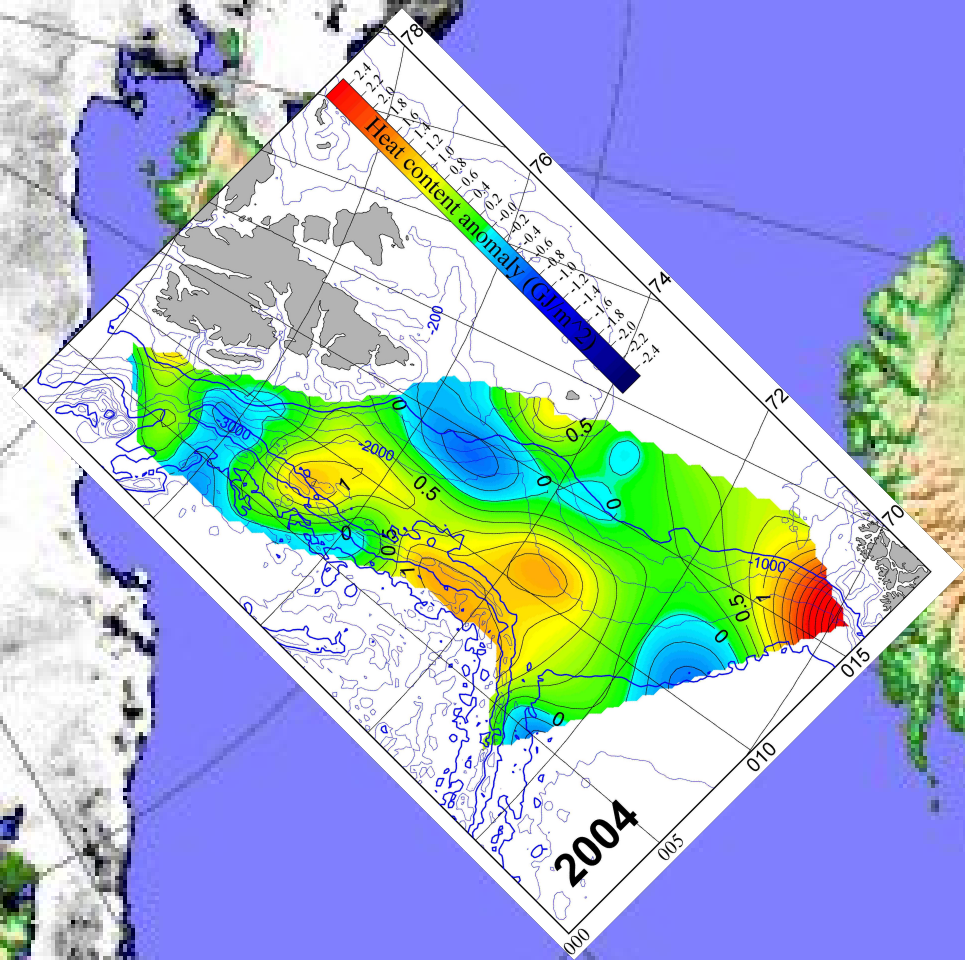
Styczeń 2003



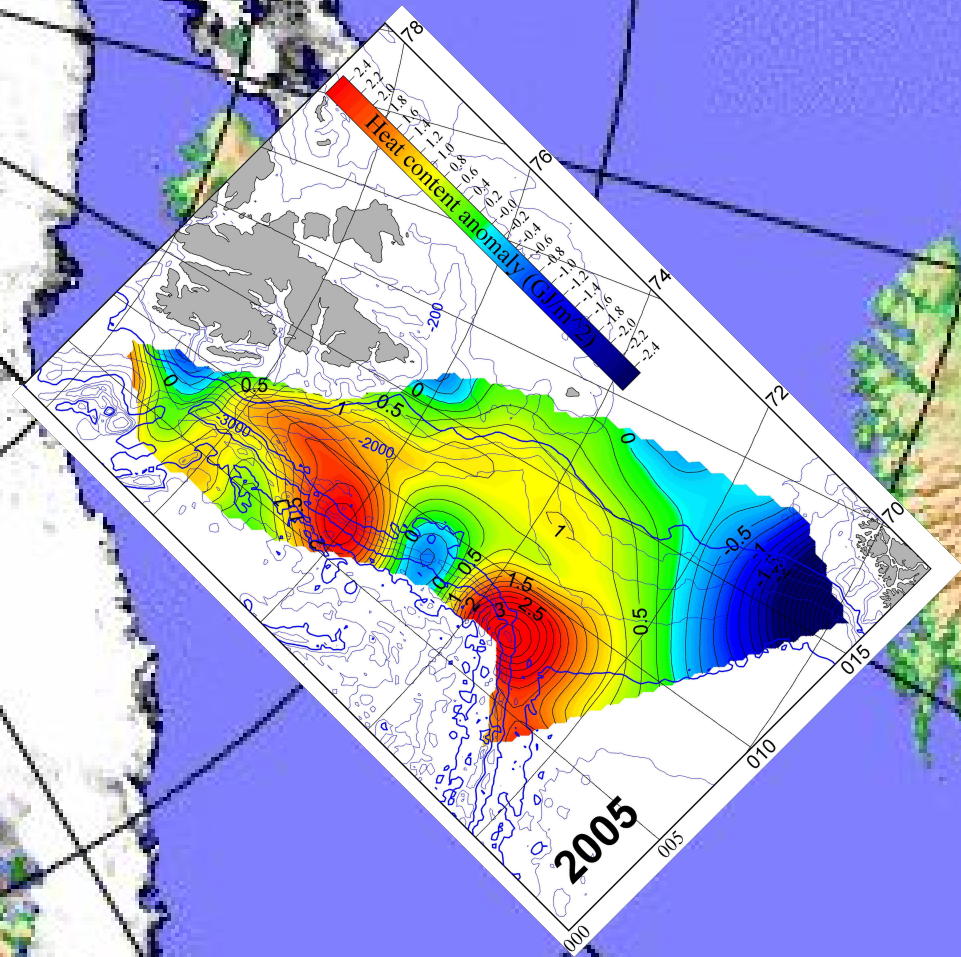
Styczeń 2004



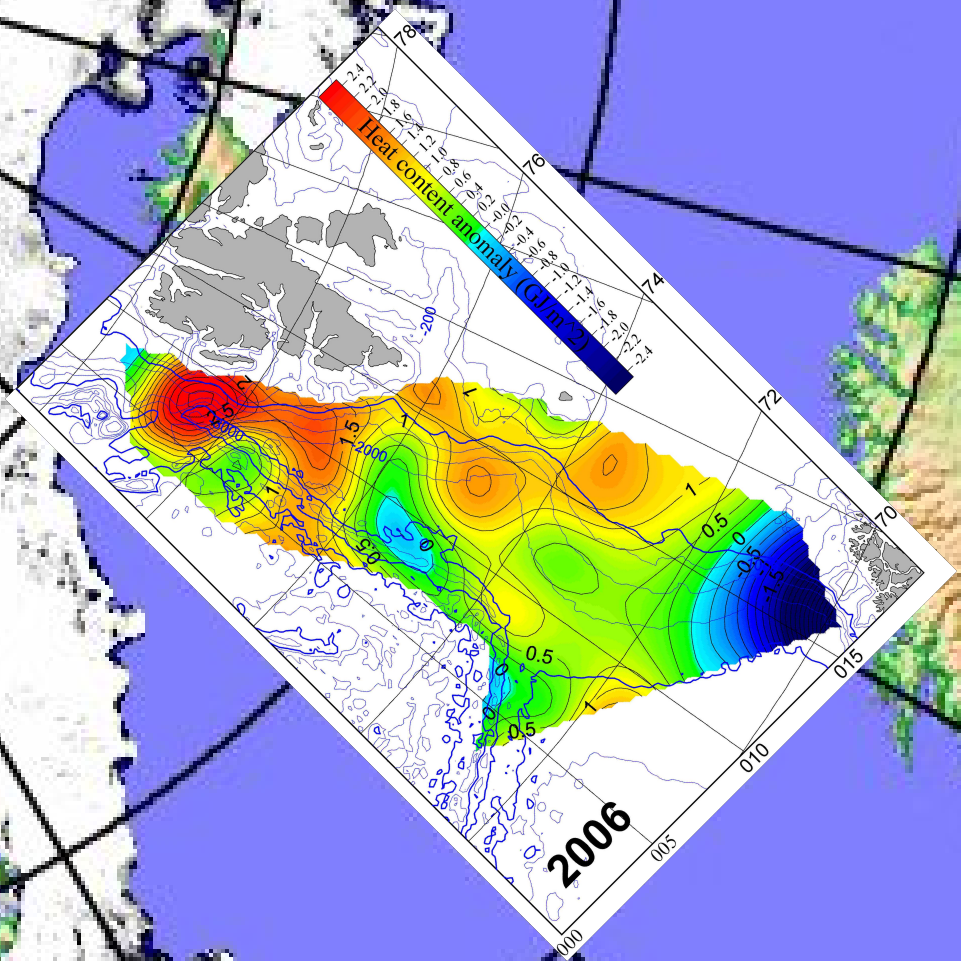
Styczeń 2005



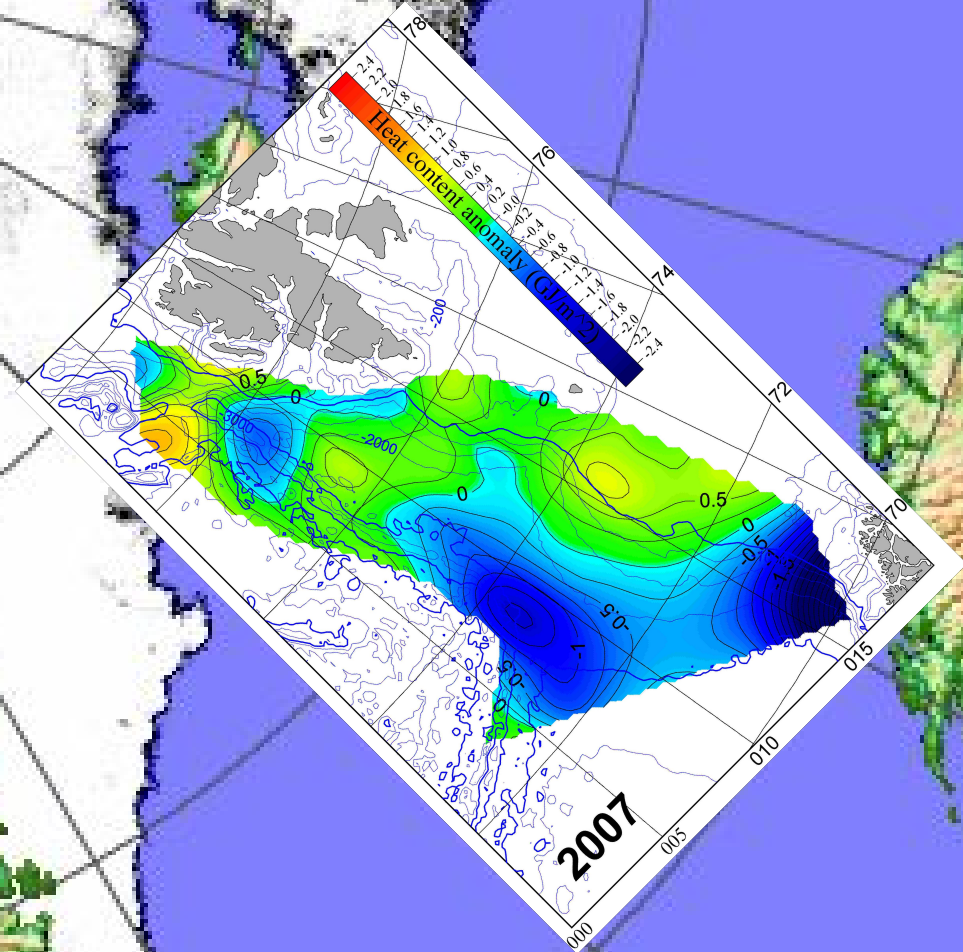
Styczeń 2006



Styczeń 2007



Styczeń 2008



- **Dwie gałęzie WSC niosące Wodę Atlantycką o różnym pochodzeniu i różnych własnościach fizycznych;**
- **Różne procesy przenoszenia ciepła w gałęzi wschodniej i zachodniej;**
- **Różne prędkości propagacji sygnału we wschodniej (~ 3.8 cm/s) i zachodniej (~ 1.9 cm/s) gałęzi WSC;**
- **Wielkie anomalie ciepła obserwowane w gałęzi zachodniej latem 2005;**
- **Nakładanie się i unifikacja sygnału z gałęzi wschodniej i zachodniej w Cieśninie Fram;**
- **Znaczenie ciepła oceanicznego w topieniu lodów Arktyki.**

- 
- **Niska temperatura AW do 2003;**
 - **Wzrost temperatury i zawartości ciepła w warstwie Wody Atlantyckiej od 2004;**
 - **Lato 2006 – najcieplejsza obserwowana przez IOPAS Woda Atlantycka w WSC;**
 - **Ekspansja ciepłej AW w stronę Cieśniny Fram, na szelf Spitsbergenu i do fiordów;**
 - **Zima 2006 i 2007 – najcieplejsze z obserwowanych na Spitsbergenie;**
 - **Wzrost transportu w gałęzi zachodniej jako jedna z przyczyn ocieplenia WSC;**
 - **Spadek temperatury AW latem 2007;**
 - **Przewidywany dalszy spadek średniej temperatury AW.**

