# Polarnet Technical Report

SCIENTIFIC AND TECHNICAL REPORT SERIES
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# 8th Ny-Ålesund Seminar

16-17 Octorber 2007
Cambridge, UK

Edited by R. Azzolini
Polarnet Support Unit

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CNR Earth and Environment Department

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# Polarnet Technical Report - PTR

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*The National Research Council is very pleased to offer its contribution to the 8th Ny-Ålesund seminar, by reporting the proceedings edition on its main polar journal "The Polarnet Technical Report".*

*At the end of 2006 the Italian station "Dirigibile Italia" and the CNR Network of Polar Research itself, were moved under the aegis of the new Department of Earth and Environment. The Department, throughout the CNR Network of Polar Research, renewed the contract for the Italian station "Dirigibile Italia" and the marine lab, funded a number of selected strategic actions, endorsed and improved the cooperation at national and international level and the application of FP7 calls. The general strategy of the Italian station at Ny-Ålesund was re-oriented into four main topics, i.e. atmosphere and climatology, adaptation and evolution, oceanography and upper atmosphere physics.*

*The CNR shares the view of the international scientific community in considering Ny-Ålesund a reference station of crucial importance in a network of Arctic environmental and geophysical observatories. It gives the opportunity to collect and manage important long-term environmental data sets from the High-Arctic of primary importance for worldwide phenomena.*

*The Ny-smac Committee is reinforcing its role of main reference body in the harmonization process of the huge and increasing amount of science carried out in Ny-Ålesund, and is actively working to encourage, stimulate and inspire young scientists and new projects to choose Ny-Ålesund and contribute to improving the legacy of the International Polar year.*

*Among the cooperation initiatives at international level, I would like to underline the ARCFAC V transnational access programme. As a follow-up to the Envinet experience, the ARCFAC V programme is a very valuable instrument to enlarge the scientific cooperation in Ny-Ålesund and allow young scientists to join the Ny-Ålesund community. In 2008 Italy will work closely with teams from AWIPEW and NPI to improve research activities into atmosphere physics, marine biology, microbiology and upper atmosphere physics. The CNR is also very interested in the Esfri Road Map proposal of considering and implementing Svalbard as an international Scientific Platform, and endorsed such proposal at the last Esfri meeting.*

*The CNR intends to encourage its partners to choose Ny-Ålesund as a scientific platform for common projects in a networking vision, and promote all the initiatives oriented towards the implementation of this scenario.*

*Dr. Giuseppe Cavarretta*
*Director of Earth and Environment Department*

# 8th Ny-Ålesund Seminar,

16-17 October 2007, Cambridge, UK

## FOREWORD

The 8th NySMAC Seminar, “NY-ÅLESUND AND IPY” took place on 16 – 17 October 2007 at Cambridge, UK, at the time a quarter of the way through the International Polar Year 2007 -2008. The scientific results and knowledge shared during the thirty-four presentations and eleven posters were a testimony to the important research carried out at Ny-Ålesund. Selected presentations are summarized in the form of articles in this Seminar Proceedings.

Studying the mission statement for Ny-Alesund, given below, carefully, one notices, it is applicable word for word also to IPY, by solely replacing the local place names with Polar Regions. They aim at a common object, though the geographical scales are different.

NySMAC is pleased to have held the Seminar and joined Ny-Alesund to IPY more tightly. NySMAC is grateful to the generous hosts, the Natural Environment Research Council (NERC) and the British Antarctic Survey (BAS). Thanks also go to the Consiglio Nazionale delle Ricerche (CNR), Italy, which offered to publish the Seminar Proceedings in its journal "Polarnet".

Hajime Ito
Chair of the Ny-Ålesund Science Managers Committee

***The mission of Ny-Ålesund, Svalbard, is to***

1. *serve as an international station for scientific research and monitoring;*
2. *encourage international scientific cooperation;*
3. *give priority to scientific research and monitoring that is dependent on the near pristine environment or unique qualities of the Ny-Ålesund area, in particular research related to long range pollution, climate change and polar ecology;*
4. *preserve the near pristine environment of the Brøgger Peninsula and the Kongsfjorden area, as well as the cultural heritage of Ny-Ålesund;*
5. *keep local human environmental impacts at the lowest possible level so as not to jeopardize scientific research and monitoring;*
6. *give scientific research and monitoring priority over other local human activities, such as tourism and commercial fishing;*
7. *be a prime example of the sustainable operation and development of a research station in the polar regions.*

*The success of the station will be judged on its scientific merits and achievements.*

[The Mission Statement for Ny-Ålesund was adopted by NySMAC, 24 August 1997]

# 8th Ny-Ålesund Seminar,

16-17 October 2007, Cambridge, UK

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# Life Science

# Microbial Communities of Cryoconites as Sensitive Indicators for Radioactive Impact on Arctic and Alpine Glaciers - Project Description

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**Abstract:** since vast snow and ice fields of the Earth's cryosphere have been recognized as habitats for different organisms, *life in ice* is no longer a paradox. According to the latest trend in cryo-research, cryoconites are now seen as micro-ecosystems with high ecological relevance for glaciers worldwide. In alpine glaciers cryoconites are often found to contain rather high concentrations of radioactive remnants from atmospheric atomic bomb tests and the Chernobyl accident, suggesting a distinct microbial community capable to cope with higher radioactive doses as usual. GLIMCOs (**gl**acier **i**ce **m**icrobial **co**mmunities) seem to be relevant for the formation of cryoconites and, thus, determine the chemical milieu which in turn is responsible for the efficient accumulation, retention and release of radionuclides and other pollutants. Therefore, an investigation of the functional biodiversity of GLIMCOS is crucial for the study of nutrient fluxes and accumulation, absorption and biological uptake of fallout compounds in glaciers. Since glaciers are retreating worldwide the accumulated radionuclides may be washed out within a short time, thus a better understanding of the processes involved in storage and release of radionuclides are urgently needed. On the other hand, radioactive tracers may help to recognize the dynamics of origin and transformation of cryoconites and possibly their erosion, ablation and weathering. A more detailed study will follow this preliminary description of scenarios.

**Keyword**: glaciers, cryoconite holes, microbial communities, radionuclides, Alps, Svalbard.

Frozen environments comprise 25% of the Earth´s surface. Arctic permafrost, temperate mountain glaciers and polar ice sheets are examples of icy environments. Previously thought devoid of life, ice in any conceivable habitat like ice sheets (Christner *et al.*, 2000), permafrost (Rivkina *et al.*, 2000), polar ice caps (Carpenter *et al.*, 2000), glaciers Christner et al., 2005), sea-ice (Sullivan and Palmisano, 1984), subglacial lakes (Priscu *et al.*, 1999; Karl *et al.*, 1999), icy clouds (Sattler *et al.*, 2001), etc. is increasingly recognized as a habitat for life (Priscu and Christner, 2003). These reports demonstrate that life within ice is far more prevalent and active than ever imagined, especially if we consider that more than 2 thirds of all freshwater on Earth is stored in ice, while lakes and streams contain much less than 1%.

Recent research has accrued compelling evidence for the existence of viable microbial food webs upon the surfaces of polar glaciers and ice sheets, especially within small melt pools known as cryoconite holes (Figure 1). These observations challenge the conventional assumption that icy surfaces in the polar regions are largely abiotic environments. Further, since life thrives in these environments, they might even offer vital refugia during more extreme conditions such as those upon "Neo-Proterozoic Snowball Earth" and other icy planets. If we consider, that the northern hemisphere is glaciated since 2.8 million years and that only 10% of this time can be considered as interstadial, it becomes evident that the cryosphere was dominant in shaping not only landscapes abut also the biodiversity and dynamics of glacial habitats.

Cryoconite holes offer a unique addition to the list of frozen environments that harbour life. The Swedish explorer A.E. Nordenskjöld first named these features, from "cryo" (ice) and "conite" (dust), during his 1870 Greenland expedition (Leslie, 1897).

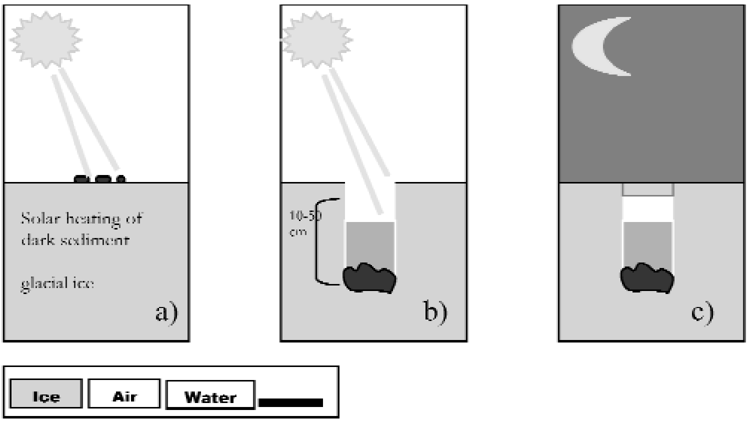

**Fig. 1** Evolution of a cryoconite hole. c) shows freeze-up of a cryoconite hole during sub-zero temperatures or polar night where radionuclides can be accumulated for longer periods. Modified after: http://people.cornell.edu/pages/bhk8/undergrad1.htm

Sediments residing on the glacier surface absorb more solar radiation than the surrounding ice and melt into the ice eventually forming a cylindrical water-filled hole with a layer of sediment on the bottom. Because microorganisms, inorganic elements, nutrients and organic materials are often associated with the mineral components of soils and sediments (Paul and Clark, 1989), chemical properties of the cryoconite dust initially reflect properties of the nearby aquatic and terrestrial environments. Cryoconite holes only form on the lower, ice-covered and snow-free parts of glaciers (ablation zone). Higher on glaciers the net accumulation of snow rapidly buries the sediment.

Cryoconite holes are common for glaciers worldwide. On temperate glaciers at lower latitudes the open holes exchange water with the surrounding melt surfaces and gases with the atmosphere (Tranter *et al.*, 2004). These holes contain biota (Steinböck, 1936; Müller *et al.*, 2001; Margesin *et al.*, 2002), including microfauna such as tradigrades, rotifers (Takeuchi *et al.*, 2001; Grongaard *et al.*, 2000; De Smet and Van Rompu, 1994) protozoans, copepods, insect larvae (Kikuchi, 1994) and cyanobacteria (Wharton *et al.*, 1981). Sawström *et al.* (2002) identified bacteria, viral like particles, nanoflagellates, cyanobacteria, ciliates, and rotifers from Midre Lovénbréen Glacier in Spitsbergen (Svalbard 79°N). These funnel-shaped structures can cover up to 20% of the glacial surface and are characterized by a lower albedo, therefore having more heat capacity which enhances glacial melt processes and contributes to glacial retreat and global warming. Depressions on glacial surfaces are filled with organic and inorganic matter where highly active microbial communities (Figure 2) are thriving and contributing to the carbon budget of glaciers and their runoffs.

In summer 2003 Alpine glaciers looked very "dirty". Due to the unusual hot and dry weather large amounts of snow and ice melted, leaving behind dark sediments now exposed on the glacier surface. They appeared to consist mainly of locally eroded rock, soil and plant material, but also fine particles from long-range transport, as was impressively demonstrated by a deposition episode of brownish Saharan dust onto Alpine glaciers in November 2002. The dark colour of the cryoconites leads to increased heat absorption by the ice and thus enhances melting, therefore they are part of a positive feedback-process (Frey *et al.*, 2001).

Radionuclides attached to aerosols were deposited after the atmospheric nuclear bomb explosions (Mainly 1950s to 1960s) and in the days after the Chernobyl accident (27 April

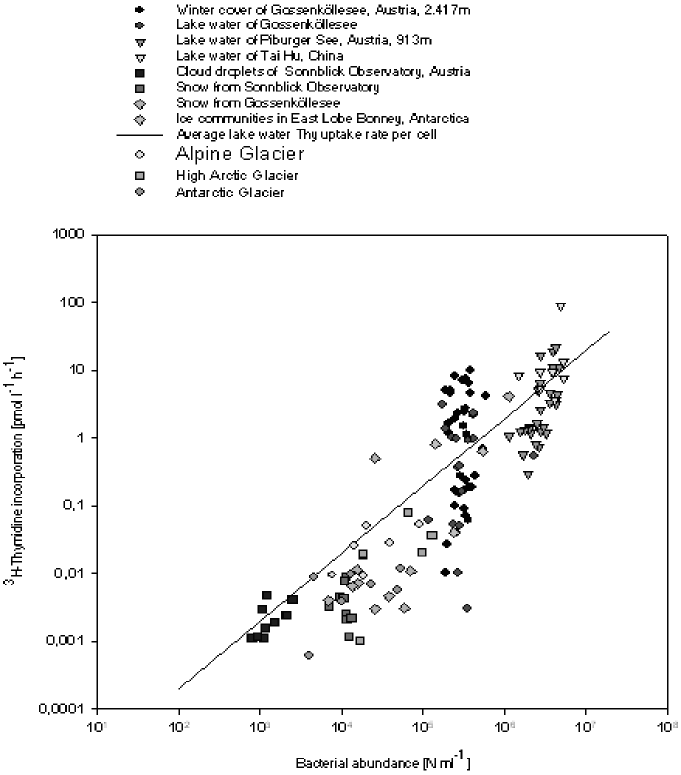

**Fig. 2** Bacterial activity in various (ice) ecosystems compared to Alpine, Arctic and Antarctic glaciers.

1986). The resulting contamination of snow or ice layers has been located by various researchers (Austria: Ambach *et al.* (1969, 1989), Switzerland: Häberli *et al.* (1988), France: Pinglot *et al.*, 1995), Greenland and Spitsbergen (Pourchet 1986, Pourchet *et al.*, 1995). However, over longer periods the often very complicated patterns of glacier ice movement will generally distort such layers. On temperate glaciers (most of Austrian glaciers) soluble radionuclides are expected to be removed with melt water soon after fallout, but particulate fallout may stay where it has been deposited, apart from local redistribution in course of the cryoconite formation process, that is, relative to the glacier surface, which is in constant slow movement relative to the surrounding terrain. Investigating the spatial pattern of cryoconite occurrence and composition may therefore help to understand small scale redistribution processes.

As representatives of different chemical elements the radionuclides behave differently in a chemically reactive environment. Therefore, the fractions of various radionuclides in an environmental medium are not identical to those in the fallout from where they originate. Transport and transfer processes may differentiate between elements; for example, in water, different ions have different solubilities. For cryoconites, very little is known about such processes so far, although high radionuclide concentrations make them interesting, but potentially hazardous candidates for scientific investigations.

Recent studies by Lettner *et al.* (2004) have shown, in some cases, surprisingly high concentrations of anthropogenic radionuclides in cryoconites of alpine glaciers in Austria (Hohe Tauern region). Apparently, these sediments act like a sink of pollutants such as $^{134}$Cs, $^{137}$Cs, $^{90}$Sr, $^{238, 239, 240, 241}$Pu, $^{241}$Am, $^{207}$Bi and others from Chernobyl and global fallout. It seems that large fractions of the original fallout are still stored in cryoconites. Recent investigations (Lettner op. cit., Bossew *et al.*, 2006) indicate though, that some chemical fractionation appears to take place in the glacial environment – either during cryoconite formation or in weathering phases or due to biological activity as the low temperature will minimize the velocity of chemical reactions. The details, however, are completely unknown. The spatial variability of dust and radionuclide distribution over the glacier surface and possibly also vertically is very high. This fact makes it difficult to quantify the mass and activity of the cryoconites of a glacier. Even if a qualitative interpretation of the varying $^{137}$Cs load can be given in terms of the Chernobyl layer hitting the glacier surface, no quantitative model appears feasible so far, basically because the cryoconite formation, redistribution and agglomeration process is still far from being well understood. Cryoconites may thus represent an archive of airborne pollution on glaciers. However, fractionation processes of, either physical, chemical or biological character are far from being elucidated.

One can plausibly anticipate (further investigations, e.g. trace element and mineralogical analyses, will be part of the project) that the raw matter of cryoconite is mainly of local or regional origin, and subsequently resuspended and translocated weathered rock, soil and plant material. However, the actually observed "typical" cryoconite is a rather homogeneous, fine grained, often sooty dark grey substance which has obviously undergone some transformation. We hypothesize that the microbial activity of cryoconite holes is a key responsible for this process, making these sediments an efficient sink for radionuclides and other pollutants. One would as well expect subsequent removal by flushing and outwash of the cryoconite holes, but apparently considerable amounts of radioactive fallout are accumulated and strongly bound to minerals or organic material therein. It can be anticipated that sorption kinetics is partly controlled by the mineral and organic constituents of the cryoconite but nothing is known about this in detail; the microbial activity may well be able to introduce significant changes in the chemical milieu and thus the sorption behaviour. Microorganisms in extreme environments often show a distinct adaptation to the specific conditions of their habitat, in this case low temperature, frequent freeze and thaw cycles, high UV-radiation, and strong gradients of nutrients between cryoconite holes and the surrounding ice fields. We may assume that microbes in cryoconite can be subjected to high radiation doses; however, no data exist in this respect so far.

The role of cryoconites in enhancing glacier melting due to their low albedo has been mentioned. The fate of cryoconites, however, if a glacier melts is unknown They may ultimately enter the alpine agricultural biosphere, contribute to soil formation (Kaštovská *et al.*, 2005), or may form a long-term (however low-level) contamination source in freshwaters. The desorption behaviour of the cryoconites in respect to various pollutants is of crucial importance to this.

In this study, it is achieved that radionuclides will be used as tracers for a large class of airborne pollutants which accumulate in the cryoconite, a process that is not well understood so far.

By following this two-pronged approach, i.e. the study of GLIMCOS and the use of radionuclide tracers, the proposed study aims at a better understanding of the physical, chemical and biological nature of cryoconites, the dynamics of their formation, their distribution and ecological role in the glacier and possibly sub-glacial ecosystems. It should result also in steps towards modelling these processes, as part of cryosphere modelling. Furthermore, with the tool of an extensive inventory and areal mapping of different types of cryoconites a rough estimation of the impact of cryoconites on glacial retreat will be possible.

In this study, radionuclides will be used as tracers for a large class of airborne pollutants which accumulate in the cryoconite, a process that is not well understood so far.

## Acknowledgements

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# Preliminary studies on diversity of soil microfungi from Ny-Ålesund, Svalbard

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**Abstract:** this paper presented diversity of soil microfungi in Svalbard, Arctic and their thermal classes. Soil samples were collected during summer expedition in July, 2006. Twenty-three soil samples were plated using Warcup's soil plating technique. Potato dextrose agar (PDA) was used as the culturing medium. Soil plates were incubated under 4 and 25°C to determine their thermal classes. In total, 89 species were isolated. Forty-five species were found to grow only in 25°C, 28 species only in 4°C and 16 species were found to grow in both 4 and 25°C. This study shows different species occurred at different temperature and only 16 out of 89 species that are adapted to high temperature differences. Soils from runnel, old mine mound and glacial sediment gave the highest number of isolated species. There was no fungi recorded from soil under twin lake-foam and 6-8 cm 20m deep sea sediment coring. Sp.1, Sp. 3 and Sp. 2 were the most frequent isolated fungi in this study.

**Keyword**: soil microfungi, psychrophilic, psychrotrophic, mesophilic.

## Introduction

Animal faeces and carcasses and plants in Arctic soil contributed in the nitrogen (N) and phosphorus (P) cycles. Plants presence stimulates mobilization of growth-limiting N but it does not affect growth-sufficient P in soil (Jonasson *et al.*, 2006). Hence, presence of litter in soil decreases N and increase P mineralization. However, it does not affect plant and microbial N and P sequestration (Jonasson *et al.*, 2006). Fungi played an important role in phosphorus cycle in soil. It was suggested that increment of P and decrement of inorganic N in soil after litter addition might have been due to transportation of the said elements by fungal hyphae during the decomposition (Hart *et al.*, 1993).

Microbes are known to survive extreme environment and it's respiration can be detected until -39°C (Panikov *et al.*, 2006). In the alpine, soil respiration rates during winter are substantial (Brooks *et al.*, 1997). There are also significant shift of microbial populations. During winter in Arctic region, fungi dominate the soil microbial community (Schadt *et al.*, 2003), while during growing season, bacteria dominates the microbial community (Lipson *et al.*, 2002). Soil depth determined the type of microbial abundance. Fungi biomass was found to decrease with soil depth but increase within organic horizon whilst bacterial biomass was found to live deep within the soil (Schmidt and Bölter, 2002). Fungal flora in soils of Arctic can be traced back to more than 300 - 400 000 years. *Cadophora, Heliocybe, Entoloma, Cryptococcus, Phialophora* and *Exophiala* are some of the examples of fungi genera exist more than 300 - 400 000 years ago (Lydolph *et al.*, 2006).

Ingraham and Stokes (1959) and Sinclair and Stokes (1963) stated that psychrophiles are micro-organisms which grow rapidly enough at 0ºC to form macroscopically visible colonies in about one or two weeks, and subdivided them into strict or obligate and facultative, depending on whether they grow most rapidly below or above 20ºC. Morita (1975) debated the validity of this definition since the 'facultative' psychrophiles do not prefer a low temperature. He proposed that psychrophiles be redefined as organisms having an optimum temperature for growth at about 15ºC or lower, a maximum temperature for growth at 20ºC or below. He used the term psychrotrophic for cold-tolerant organisms, previously referred as facultative psychrophiles, the maximum temperature for their growth being above 20ºC.

Mycological research in Arctic can be traced as early as 19th Century. The earliest record of mycological research in Arctic was probably made by Kaye Greville in 1822. In his paper he described montane *Amanita nivalis* found in British isle part of Arctic. Most of the researches focused on higher fungi (Greville, 1822; Watling, 1987), parasitic or saprophytic fungi that can be found on or near plants (Rostrup, 1906; Lind, 1910; Debaud, 1987; Metsänheimo, 1987) and lignicolous fungi found on woods or stem (Leuchtmann, 1987). There was no report on report on occurrence of soil microfungi from Svalbard, Ny-Ålsund. Therefore, a preliminary work on occurrence of microfungi on soils of Ny-Ålesund, Svalbard, Norway was undertaken during the familiarisation trip in July 2006 and the results are presented in this paper.

## Materials and methods

Twenty three soil samples were collected during recent familiarisation trip to Ny-Ålesund, Svalbard, Norway in co-operation with Korean Polar Research Institute (KOPRI) in July 2006. Nineteen samples were collected around Ny-Ålesund while another four were contributed by Alfred-Wagner Institute (AWI), Germany. These four samples were from deep sea sediment coring and the rest were of various locations such as runnels and abandoned railway tracks.

Soil samples were plated using modification of Warcup's soil plating method (1958). Approximately 1 gram of soils was placed in Petri dish and cooled autoclaved potato dextrose agar (PDA) was poured on the Petri dish containing the soil. The Petri dishes were shook horizontally to distribute the soils evenly. Soil plates were incubated at 4 and 25°C (room temperature). Species identification are based on culture and spore morphology.

Analysis of data was done where percentage of fungal occurrence in this study at different site was calculated. Percentage of occurrence was calculated using this equation:

$$\frac{\text{Total occurrence of fungus species}}{\text{Total number of plates}} \quad \text{x} \quad 100$$

## Results

In total, 89 fungal species including three yeasts were isolated from soil of Svalbard, Norway (Figure 1). Sixty one species were isolated from plates incubated in 25°C and 44 species were isolated from 4°C. Sixteen species occurred in both 25 and 4°C. High number of fungal species recorded in 25°C than 4°C, while about 18 percent of total isolated fungi live in both 4°C and 25°C.

Sediment from runnel gives the highest number of fungal occurrence followed by sample '34 Old Mine Mound' and sample '15 Glacial Sediment' (Table 1).

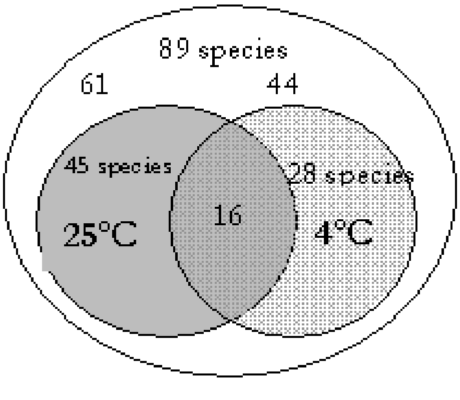

**Fig. 1** Isolated soil microfungi from Svalbard, Norway.

Sample '05 Runnel' showed the highest number of occurrence with 33 fungal species occurred in total. Twelve species occurred at 4°C and 22 species occurred at 25°C. Twenty five fungal species occurred from sample '34 Old Mine Mound' where eight species were isolated at 4°C and 18 species were isolated at 25°C. Twenty one fungal species occurred from sample '15 Glacial Sediment', 13 species were isolated from plates incubated at 4°C and nine species at 25°C.

The most frequent occurred species in this study are Sp. 1 and Sp. 3 with 15.76 and 14.67 percent of total occurrence respectively. Sp. 1 was isolated from 15 sites with 29 occurrence recorded while Sp. 3 was isolated from 12 sites and 27 occurrence recorded. Sp. 2, 6, 9 and 10 were isolated more frequent than the rest of the fungal species.

| **Collection site** | **Number of species** | | **Total number of species occurred** |
|---|---|---|---|
| | **4°C** | **25°C** | |
| 05 Runnel | 12 | 22 | **33** |
| 09 Above lake | 12 | 2 | **14** |
| 10 Twin lake (sediment) | 7 | 3 | **10** |
| 15 Glacial sediment | 13 | 9 | **21** |
| 17 Tundra | 7 | 5 | **11** |
| 31 Soil at 41m from sea level | 3 | 11 | **13** |
| 34 Old mine mound | 9 | 18 | **25** |
| 39 Melt lake sediment (31m from sea level) | 1 | 9 | **10** |

**Table 1** List of fungal species occurred at different site.

| **Species** | **Number of occurrence** | | **Total site of occurrence** | **Total fungal occurrence** | **Percentage of occurrence (%)** |
|---|---|---|---|---|---|
| | **4°C** | **25°C** | | | |
| **Sp. 1** | 13 | 16 | **15** | **29** | **15.76** |
| **Sp. 2** | 9 | 8 | **8** | **17** | **9.24** |
| **Sp. 3** | 22 | 5 | **12** | **27** | **14.67** |
| **Sp. 6** | 7 | 4 | **8** | **11** | **5.98** |
| **Sp. 9** | 7 | 1 | **5** | **8** | **4.35** |
| **Sp. 10** | 6 | 1 | **5** | **7** | **3.80** |
| **Sp. 45** | 6 | 0 | **4** | **6** | **3.26** |

**Table 2** Most commonly occurred fungi species.

## Discussions

Of the 89 isolated fungal species, only 28 species are psychrophilic. Sixteen species are psychrotrophic fungi while 45 species are mesophilic. Low number of psychrophilic fungi was recorded compared to mesophilic fungi. Psychrotrophic fungi can be considered as all season fungi because they survived cold and warm temperatures. Psychrotrophic fungi are equipped with temperature adapting mechanism that enables them to survive in both and warm temperature.

Schadt *et al.* (2003) found that fungi dominates microbial community during winter and this shows that probably during extreme winter only 28 species are active. Mesophilic fungi were found abundant in this study. Jonasson *et al.* (2006) found that higher soil mass were recorded after warming treatment on soil with litter addition. Fungal hyphae were probably the P transport agent from soil (Hart *et al.*, 1993), this shows that fungi plays an important role in litter decomposition in soil and warmth plays an important role in increasing decomposition rate in soil.

Psychrotrophic fungi are fungi which can live in cold temperatures, have optimum growth rate at 10-15°C and can live up to 25°C. While researchers are busy searching for psychrophilic organisms, we have forgotten that the winner is always those who can brave through all situations and obstacles. This study shows that psychrotrophic fungi although they are easy to isolate but the number of the species is lower than those which can stand extreme temperature. In the present study, based on identification of fungi using conventional methods, culture and spore morphologies, the biodiversity and species composition of soil microfungi is considered high. Identification based on molecular biology dan DNA extraction will undoubtedly yield higher number of soil microfungi.

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# A Checklist of Microalgal Isolates from Ny-Ålesund, Svalbard

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**Abstract**: the first Malaysian expedition to Ny-Ålesund took place from 17 to 24 July 2006. The objective of the expedition was to collect samples for the isolation of Arctic microalgae, as part of our International Polar Year (IPY) activities. At Ny-Ålesund, we collected samples from 44 sites, comprising a variety of habitats including soil, dry tundra, ponds, runnel, snow and ice. A checklist of 29 microalgal isolates has been compiled, consisting of 15 chlorophytes, ten bacillariophytes, two cyanophytes and one euglenophyte. The most common species found were *Stichococcus bacillaris, Heterothrix sessilis* and *Chlorococcum humicola,* which were mainly soil algae. The collection of Artic microalgae is useful for our comparative studies on adaptive mechanisms of Polar, Temperate and Tropical species to UVR and temperature stress.

**Keywords**: Ny-Ålesund, Arctic microalgae, UVR stress, temperature stress, soil algae.

## Introduction

Members of the Algae Research Group of the University of Malaya have gone on several expeditions to Casey, Antarctica and Marion Island, sub-Antarctica for the collection of samples for the isolation of Antarctic microalgae since 2000 (Chu *et al.*, 2002). A collection of more than 50 isolates of Antarctic microalgae has been established. The collection is important for our comparative studies on the response of Antarctic, Tropical and Temperate microalgae to temperature and UVR stress (Teoh *et al.*, 2004; Wong *et al.*, 2007). Such studies are important in view of the concern about the impacts of climate change on microalgae, which form the basis of the food chains (Chu *et al.*, 2005).

The scope of our studies has been expanded to cover the Arctic microalgae under our IPY project (EOI 96) (Phang and Chu, 2007). Members of the Group have gone on an expedition from 17 to 24 July 2006 to collect samples from Ny-Ålesund for the isolation of Artic microalgae. Here, we report on a checklist of microalgal isolates from the samples collected during the expedition.

## Materials and methods

Samples were collected from various habitats including soil, dry tundra, ponds, runnels, ice and Kings Fjord. The samples were stored in sterile bottles and kept in the cold before transporting back to the laboratory for analysis.

The freshwater and soil samples were inoculated into Bold's Basal Medium while the marine samples were inoculated into Provasoli 50 Medium (Phang and Chu, 1999). The cultures were grown in a controlled-environment incubator under 12 : 12 h light-dark cycle (40 $\mu$mol $m^{-2}$ $s^{-1}$) at 4 $^{O}$C. Identification of the microalgae was based on the descriptions given in Cavacini (2001), Ohtani *et al.* (2000) and Nakano *et al.* (1991).

## Results and Discussion

A total 29 taxa of microalgal isolates, consisting of 15 chlorophytes, ten bacillariophytes, two cyanophytes and one euglenophyte were identified (Table 1). The checklist is important as the distribution of microalgae other than snow algae from Spitbergen has not been documented so far. Leya *et al.* (2004) have established a collection of snow algae from Spitsbergen and studied their growth physiology and molecular phylogeny.

The common taxa of chlorophytes isolated were *Stichococcus bacillaris*, *Heterothrix sessilis* and *Chlorococcum humicola* (Figure 1), which were mainly isolated from soil samples. Such microalgae have also been reported to occur in soil from Antarctica (Ohtani *et al.*, 2000; Cavacini, 2001). *Chlorococcum oviforme* and *Stichococcus* sp. isolated from snow or ice samples (e.g. Site 13 and 16) are likely to be soil algae instead of true psychrophilic snow algae. Soil algae are known to be brought onto snow surface due to wind action, as reported for *Raphidonema nivale* (Stibal and Elster, 2005). Soil algae such as *Chlorella* and *Stichococcus* isolated from Casey , Antarctica have been shown to grow at temperatures much higher than the ambient (Teoh *et al.*, 2004).

Selected species from the collection are important for our studies comparing the response and adaptation of Polar, Tropical and Temperate microalgae to temperature and UVR stress (Teoh *et al.*, 2004; Wong *et al.*, 2007). Some are also useful for phylogenetic and biogeography studies. In addition, some may have biotechnological applications. For instance, the marine diatoms may be potential producers of long chain PUFA such as eicospentaenoic acid (EPA) and docosahexaenoic acid (DHA).

## Acknowledgements

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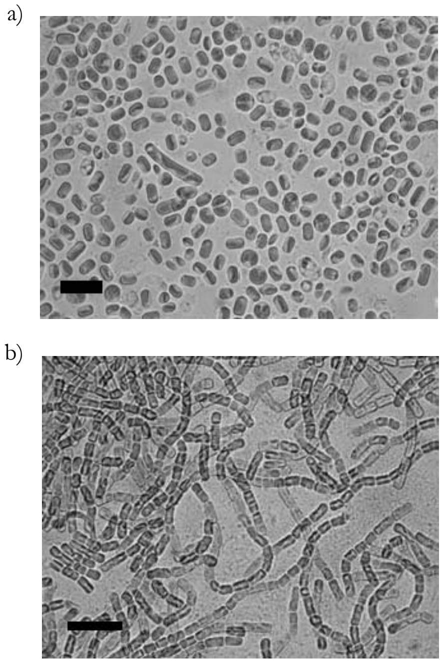

**Fig. 1** Two of the most common microalgae found in Ny-Ålesund. a) *Stichococcus bacillaris;* b) *Heterothrix sessilis*; Scale bar = 10 µm

**Table 1** Details of collection sites of algae at Ny-Ålesund, Svalbard.

| Site | GPS | Description of site |
|---|---|---|
| 01 | 78°55.65’N<br>11°56.24E | Near harbor – marine soil (stony) (FW + M)* |
| 01A | 78°55.65N<br>11°56.24E | Near jetty below road, rock pools, brown filaments (M) |
| 02 | 78°55.61N<br>11°56.05E | Rail track- soil (FW) |
| 03 | 78°55.53’N<br>11°56.16’E | Rail track- 2 cm below , soil (FW) |
| 04 | 78°55.53’N<br>11°56.16’E | Water runnel – water sample (FW) |
| 05 | 78°55.53’N<br>11°56.16’E | Water runnel – sediment (FW) |
| 06 | 78°56.53’N<br>11°56.17’E | Duck pond –soil (sediment water) (FW) Duck pond - water (FW) |
| 07 | 78°56.53’N<br>11°56.17’E | Duck lake, moss (FW) |
| 08 | 78°55.38’N<br>11°53.00’E | Storvatnet-under airport; Lake (FW) |
| 09 | 78°55.36’N<br>11°52.88’E | Dry tundra – above lake (FW) |
| 10 | - | Twin lakes- top sedment (FW) |
| 11 | - | Twin Lakes (FW) |
| 12 | - | Dry tundra – above lakes (rocks) (FW) |
| 13 | 78°54.85’N<br>11°58.73’E | Ice (iced stream down to sea) (FW) |
| 14 | 78°54.82’N<br>12°01.21’E | Glacial water (runnels) (FW) |
| 15 | - | Glacial sediment (FW) |
| 16 | 78°54.85’N<br>11°59.11’E | Pink layer of snow (FW) |
| 17 | 78°54.85’N<br>11°59.02’E | Tundra (FW) |
| 18 | 78°54.92’N<br>11°59.48’E | Tundra green algae (FW) |
| 19 | 78°54.89’N<br>12°01.00’E | Patterned soil (cyanobacteria) (FW) |
| 20 | - | Rocks-runnel (FW) |
| 21 | - | Green algae (M) |
| 22 | 78°55.41’N<br>11°55.98’E | Green filament + macroalgae in ditch under King’s Bay Headquarter (FW) |
| 23 | 78°55.42’N<br>11°55.98’E | Core – 10 m deep; Top – 1 cm (M) |
| 24 | - | Core – 10 m deep; 2 - 4 cm (M) |
| 25 | - | Core – 10 m deep; 4 – 6 cm (M) |
| 26 | - | Core – 10 m deep; 6 - 8 cm (M) |
| 27 | - | Core – 20 m deep; Top – 1 m (M) |
| 28 | - | Core – 20 m deep; 2 – 4 cm (M) |
| 29 | - | Core – 20 m deep; 4 – 6 cm (M) |
| 30 | - | Core – 20 m deep; 6 – 8 cm (M) |
| 31 | 78°54.42’N<br>11°57.24’E 52 m | Old mine; sediment below ice (FW) |
| 32 | 78°54.41’N<br>11°51.13’E 71.9 m | Soil next to glacier (FW) |
| 33 | 78°54.41’N<br>11°57.15’E 660 m | Soil (higher level) next to glacier (FW) |
| 34 | 78°54.43’N<br>11°57.42’E 42 m | Old mine mound; Ice (glacier ends) (FW) |
| 35 | 78°54.95’N<br>11°52.53’E 0 m | Freshwater lake sediment (FW) |
| 36 | 78°54.92’N<br>11°52.61’E 42 m | Runnel near freshwater lake-green algae (FW) |
| 37 | 78°54.92’N<br>11°52.61’E 42 m | Glacier above freshwater lake (ice) (FW) |
| 38 | 78°55.00’N<br>11°51.54’E 32 m | Melt lake algae (FW) |
| 39 | - | Melt lake sediment (FW) |
| 40 | 78°59.77’N<br>12°05.95’E | King Fjord-near glacier/island (M) |
| 41 | 78°59.63’N<br>11°57.23’E | King Fjord-Sea<br>pH: 8.21 |
| 42 | 78°57.12’N<br>12°03.05’E | King Fjord-Inside King’s Bay (near glacier; between 40 & 43) (M) |
| 43 | - | King Fjord – jetty (M) |
| 44 | - | Iceberg – melted, collected near 40 (FW + M) |

*FW: Freshwater; M: Marine.

**Table 2** Checklist of microalgal isolates from Ny-Ålesund, Svalbard.

| Taxon | Site / Habitat |
|---|---|
| **Bacillariophyta** | |
| Achnanthaceae | |
| 1. *Amphora* sp. Ehrenberg | Site 08 (FW) |
| 2. *Fragilaria capucina* Desmazieres | Site 05, 20 (FW, FS) |
| 3. *Fragilaria pinnata* Ehrenberg<br>Meridionaceae | Site 42 (MW) |
| 4. *Meridion circulare* Grev.) Agardh | Site 22 (FW) |
| 5. *Meridion* sp. Agardh<br>Naviculaceae | Site 08 (FW) |
| 6. *Navicula septentrionalis* (Grunow) Gran. | Site 01A, 42 (MW) |
| 7. *Navicula* sp.1 Bory | Site 01, 01A, 25, 29 (MW, MS) |
| 8. *Navicula* sp. 2 Bory | Site 26, 28 (MS) |
| 9. *Navicula* sp. 3 Bory | Site 28, 40, 43 (MW, MS) |
| 10. *Pinnularia* sp. Ehrenberg. | Site 08 (FW) |
| **Chlorophyta** | |
| Chaetophoraceae | |
| 11. *Gongrosira* sp. Kutzing | Site 06 (FW) |
| 12. *Chlorella vulgaris* Beijerinck | Site 15 (FS) |
| 13. *Chlorococcum humicola* (Nag.)Rabenhorst | Site 06, 10, 14, 32 (FW, FS) |
| 15. *Chlorococcum oviforme* Archibald & Bold<br>Cladophoraceae | Site 16 (Ice-soil) |
| 16. *Cladophora* sp. Kutzing<br>Coccomyxaceae | Site 01A (MW) |
| 17. *Coccomyxa dispar* Schmidle | Site 08 (FW) |
| 18. *Coccomyxa gleobotrydiformis* Reisigl<br>Desmidiaceae | Site 33 (SL) |
| 19. *Cosmarium connatum* Brebison Microsporaceae | Site 08 (FW) |
| 20. *Microspora quadrata* Hazen | Site 08 (FW) |
| 21. *Microspora tunida* Hazen<br>Oocystaceae | Site 02 (SL) |
| 22. *Monoraphidium arcuatum* (Korshi.) Hindak Trebonemataceae | Site 06 (FW) |
| 23. *Heterothrix sessilis* Vitnazar<br>Ulothrichaceae | Site 03, 08, 21, 23. 27, 32 (FW, FS, MS) |
| 24. *Stichococcus bacillaris* Nageli | Site 03, 09, 12, 19, 20, 32, 34 (FW, FS, SI, Ice) |
| 25. *Stichococcus* sp. Nageli | Site 13 (Ice) |
| 26. *Ulothrix variabilis* Kutzing | Site 18 (SL) |
| **Cyanophyta** | |
| Oscillatoriaceae | |
| 27. *Oscillatoria geminata* Meneghini | Site 14 (FW) |
| 28. *Oscillatoria prolifica* (Grev.) Gomont | Site 01A. 02 (SL) |
| **Eugenophyta** | |
| Euglenaceae | |
| *Euglena* sp. Ehrenberg | Site 06 (FW) |

*FW: Freshwater; FS: Freshwater sediment; MW: Marine water; MS: Marine sediment; SL: Soil.

# Minimal latitudinal variations in the metabolic rates of temperate but not polar gammarid amphipods

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**Abstract:** to further examine the ability of polar marine invertebrates to adapt to climate change, the existence of metabolic cold adaptation (MCA) was examined in several species of marine gammarid amphipods living at different latitudes (78-38°N). Comparisons were made between an Arctic species, *Gammarus setosus,* a cold-temperate species, *G. oceanicus,* a warm-temperate species with Mediterranean ancestry, *G. locusta,* and an upper intertidal species *G. duebeni.* Metabolic rates (MRs), measured as rates of oxygen uptake, were taken at the habitat temperatures recorded at the time of capture and scaled to a standard wet mass of 1mg. Between species, MRs were significantly lower (Krusskal-Wallis $P<0.001$) in *G. setosus* (7.7±2.6 $nmolO_2.h^{-1}.mg^{-1}$) and Arctic populations of *G. oceanicus* than in *G. locusta* (25.0±1.6 $nmolO_2.h^{-1}.mg^{-1}$). Arctic populations (78°N) of *G. oceanicus* had significantly (Krusskal-Wallis $P<0.05$) lower MRs (10.5±1.4 $nmolO_2.h^{-1}.mg^{-1}$) than more temperate populations (58°N; 22.1±4.0 $nmolO_2.h^{-1}.mg^{-1}$). In contrast, latitude had no effect on the MRs of *G. locusta* or *G. dubeni.* It appears that warm-temperate gammarid species exhibit MCA, compensating for latitudinal shifts in temperature, whereas the Arctic/cold-temperate species do not. Such differences are thought to be related to variations in the fitness costs of MCA, and to the ancestral origins and thermal histories of the various species. Moreover, such differences could have an effect on the ability of marine gammarids to respond to further environmental change.

**Keywords:** amphipods, metabolic rate (MR), temperature, latitude, Metabolic cold adaptation (MCA).

## Introduction

The metabolic rate of marine ectotherms varies with temperature according to physical laws. Many species, however, are able to compensate for the drop in temperature seen over temporal (season) or spatial (latitude) scales. Recent studies on Antarctic marine ectotherms have come to the conclusion that metabolic cold adaptation (MCA), previously proposed by Krogh (1916), does not apply to many invertebrate groups living in the permanently cold waters of the Southern Ocean (Clarke, 1991, 1993). Instead, these marine ectotherms simply reduce their metabolic rates in keeping with the low water temperatures leading to a reduction in maintenance costs. Such organisms have slower growth rates than more temperate or warm water species, and show a reduction in the ability to increase metabolic rates when faced with increasing temperatures/or exercise i.e. they have reduced aerobic scopes (Pörtner *et al.*, 2007). The overall affect, is that these marine ectotherms are very sensitive to temperature changes and it could be that their inability to up-regulate metabolic rates at low temperatures indicates that they have become specialised to operate at the cold and narrow range of temperatures experienced at the poles. This makes them more vulnerable to the increases in temperature predicted as a result of climate change.

The examination of MCA in marine invertebrates has depended on comparisons between species, with a bias towards Antarctic species as the polar comparison. Surprisingly little is known of the differences in metabolic rate between polar species and populations of the same species living in warmer thermal environments. Such comparisons are useful because they standardise for genetic variability and differences in activity levels which is an inherent problem with the majority of interspecific studies. One of the few studies to be carried out on the polychaete worm, *Clymenella torquata*, showed that individuals living at high latitude (41°15'N) had higher rates of oxygen uptake than those at a lower latitude (34°40'N) (Mangum, 1963). Compensatory responses are also observed in other physiological functions, such as pumping rates in *M. trossulus*, where pumping rates in 3 different latitudinal populations on the West coast of the States were similar at the respective temperatures at which the animals were found (Bullock, 1955). Clearly compensation of physiological function has occurred here in order for the animals to operate at a given rate despite latitudinal changes in temperature. Whether marine ectotherms with representatives of the same species in polar and cool-temperate climates can show the same response is unclear, although more recently, the capacity to adjust aerobic metabolism has been attributed to the size of a species geographical range (Zakhartsev *et* *al.*, 2003; Calosi *et al.*, 2007).

The Arctic provides a good opportunity to study relationships between metabolic rates and temperature as this polar environment is not as isolated as the Antarctic, with marine gammarids showing a wide latitudinal distribution along the fringes of the Arctic and North East Atlantic Oceans. The aim of the present study was to determine whether polar amphipods behave the same as Antarctic ectotherms and do not show any metabolic compensation for the cold water temperatures, or whether the shorter geological history of the Arctic and the wider range distribution of some marine species have led to compensatory responses as found in the polychaete worms. Metabolic rates were determined on several different species of gammarid amphipods at several different latitudes in order to make within species and between species comparisons. More importantly, measurements were carried out at the temperatures experienced by the animals on the shore. Ultimately the study aimed to examine the importance of metabolic restrictions on thermal tolerance ranges and the survival of gammarid amphipods collected from natural latitudinal populations with overlapping distribution patterns from Portugal up to Svalbard.

## Materials and Methods

Animals were collected from the lower shore at 6 different latitudinal locations (Figure 1). *Gammarus setosus* and *G. oceanicus* were collected from Ny-Ålesund, Svalbard (78°N); *G. oceanicus* was also collected from Tromsø, Norway (69°N) and the Isle of Skye, Scotland (58°N). *G. locusta* was collected from Anglesey, North Wales (53°N); Brittany, France (48°N); and Troia, Portugal (38°N). In addition, *G. duebeni* was collected from the upper shore in Tromsø, Skye and Anglesey. In all cases, animals were collected in the summer between the months of June and September. Temperatures at the time of capture were recorded and the animals returned to the lab and housed at their respective in situ temperatures. Adult males and females were used in the study, but brooding individuals were omitted. Animals collected in Scotland, Wales and France were retuned to Bangor University; those captured in Tromsø and Ny-Ålesund were held at The NERC Station Ny-Ålesund; and those collected in Portugal were returned to NOVA University, Lisbon. This ensured that all measurements of oxygen uptake were taken within 24-48h.

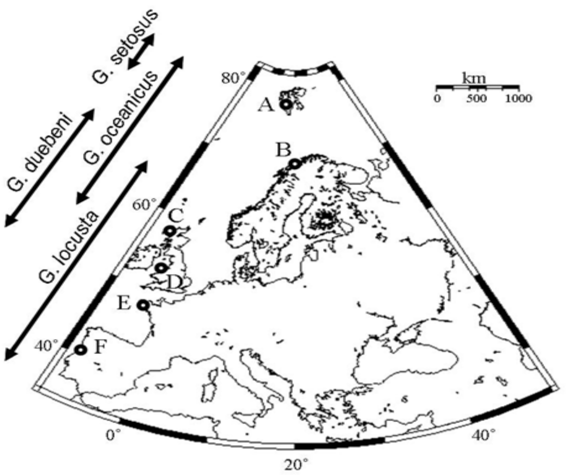

**Fig. 1** Latitudinal distribution of the four gammarid species examined in the study and the location of the various collection sites; A, Ny-Ålesund , Svalbard (78°N); B, Tromsø, Norway (69°N); C, Isle of Skye, Scotland (58°N); D, Anglesey, North Wales (53°N); E, Brittany, France (48°N); F, Troia, Portugal (38°N).

For the acclimation studies, *G. locusta* and *G. oceanicus*, each from two different latitudes, were held in aerated sea water at a constant temperature of 10°C, and at a 12h:12h L:D regime for 4 weeks prior to measurements. A third of the holding water was replaced each week before a feed of algal fish food. Individual animals were placed into stop-flow respirometers maintained at their respective capture temperatures. Animals were allowed to settle for at least 4h before the flow of water was stopped for 30 min and the partial pressure of oxygen ($PO_2$) in the water measured non-invasively at regular intervals. A magnetic stirrer at the base of the respirometer, separated by a perforated platform, prevented oxygen gradients from forming within the chamber.

Measurements of $PO_2$ were taken using an optical oxygen sensor (OxySense®101 Non-invasive Oxygen Analyzer System, OxySense Inc). An "oxy dot" made from a ruthenium complex was fixed onto the inside surface of each respirometer in a convenient position to be read by a UV sensor on the outside, which was aligned parallel to the oxydot and held firmly in position. Fluorescent measurements were logged every 5 seconds for the length of the stop-flow period. All measurements were taken in low light conditions; first, as ambient light causes high noise to the live fluorescence signal; and second, to minimise stress to the animal. Controls were run with no animals in the respirometers.

OxySense®101 software (OxySense Inc) converted fluorescent readings into changes in $PO_2$ against time. Rates of oxygen uptake were calculated as the change in $PO_2$ per hour multiplied by the solubility coefficient for oxygen (adjusted for salinity and temperature) and the volume of water within the respirometer. Whole animal values for oxygen uptake rates in µl $O_2.h^{-1}$ were standardised to S.T.D.P. and expressed as nmol $O_2$. $h^{-1}$ animal$^{-1}$. As body mass significantly increased with latitude, all the oxygen uptake data was standardised to a wet body mass of 1mg using a weight exponent of 0.7 (eg. Whiteley *et.al.*, 1996). Kruskal-Wallis and Mann-Whitney non-parametric tests were employed to evaluate any significant differences between populations and species.

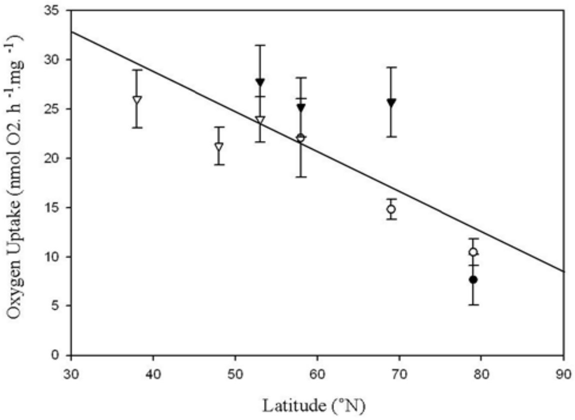

**Fig. 2** Relationship between whole animal rates of oxygen uptake standardised for a wet mass of 1mg and the latitudes at which the various species/populations were collected. *Gammarus setosus* (closed circles), *G. oceanicus* (open circles), *G. dubeni* (closed triangles), *G. locusta* (open triangles). Mean values ± SEM.

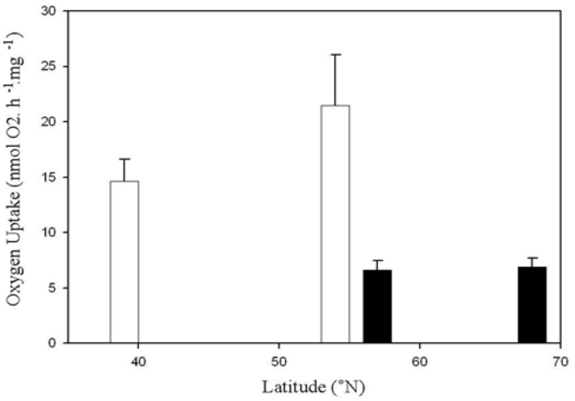

**Fig. 3** Within species comparisons of oxygen uptake rates in latitudinal populations of *G. locusta* (open bars) and *G. oceanicus* (closed bars). All data collected from animals acclimated to 10°C. Mean values given ±SEM.

## Results

Standardised, whole-animal rates of oxygen uptake are plotted against latitude in Figure 2. There was significant variation (Krusskal-Wallis $P<0.001$) in the rates of oxygen uptake between latitudinal populations, with an almost 4 fold increase between Arctic populations of *G. setosus* (7.7±2.6 nmolO$_2$.h$^{-1}$.mg$^{-1}$) at 78°N, and Portuguese populations of *G. locusta* (29.8±3.3 nmolO$_2$.h$^{-1}$.mg$^{-1}$) at 38°N. Between species, mean rates of oxygen uptake were significantly lower (Krusskal-Wallis $P<0.001$) in *G. setosus* than in the more temperate species *G. locusta* (25.0±1.6 nmolO$_2$.h$^{-1}$.mg$^{-1}$) and *G. duebeni* (26.1±1.9 nmolO$_2$.h$^{-1}$.mg$^{-1}$). *G. dubeni* that inhabit the upper shore also exhibited higher rates of oxygen uptake than *G. oceanicus* or *G. locusta*, which inhabit the lower shore at the same latitude.

Within species, Arctic populations of *G. oceanicus* from Svalbard (78°N) at 5°C had significantly (Krusskal-Wallis $P<0.05$) lower rates of oxygen uptake (10.5±1.4 nmolO$_2$.h$^{-1}$.mg$^{-1}$) than more temperate Scottish populations (58°N; 22.1±4.0 nmolO$_2$.h$^{-1}$.mg$^{-1}$) at 13°C. In contrast, latitude had no significant effect on oxygen uptake rates in *G. locusta*, with similar rates reported in populations from Anglesey (23.9±2.3 nmolO$_2$.h$^{-1}$.mg$^{-1}$), Brittany (21.2±1,9nmolO$_2$.h$^{-1}$.mg$^{-1}$) and Troia (29.8±3.3 nmolO$_2$.h$^{-1}$.mg$^{-1}$) at 13, 18 and 21°C, respectively. *G. duebeni* also exhibited no significant variation in rates of oxygen uptake between Arctic and more temperate populations.

When acclimated to a common temperature of 10°C, there was no significant difference in oxygen uptake rate between *G. oceanicus* at 69°N (6.9±0.8 nmolO$_2$.h$^{-1}$.mg$^{-1}$) and *G. oceanicus* at 58°N (6.6±0.8 nmolO$_2$.h$^{-1}$.mg$^{-1}$). In contrast, *G. locusta* form more northerly populations (53°N; 21.5±4.6 nmolO$_2$.h$^{-1}$.mg$^{-1}$) exhibited higher rates of oxygen uptake than their southern counterparts (38°N; 14.6±2 nmolO$_2$.h$^{-1}$.mg$^{-1}$). Overall, acclimated rates of oxygen uptake were significantly higher (Mann-Whitney $P<0.001$) in *G. locusta* than in *G. oceanicus*.

## Discussion

Previous measurements of oxygen uptake in *G. oceanicus* and *G. setosus* are available for comparison to the present data. Opalinski and Weslawski (1989) reported rates of oxygen uptake in *G. oceanicus* from Svalbard to be 10.84 nmol O$_2$.h$^{-1}$.mg$^{-1}$, which is similar to the value reported in the present study. However, the same authors reported slightly higher values for *G. setosus* at 13.8 nmolO$_2$.h$^{-1}$.mg$^{-1}$. This may be caused by differences in the methodology used to measure oxygen uptake with Opalinski and Weslawski (1989) using a sealed-chamber technique which is known to induce stress and result in artificially high values (Luxmoore, 1984). Data from *G. oceanicus* is also in agreement with that obtained from more recent, direct calorimetric studies on *G. oceanicus* from the Southern Baltic (53°N) (Normant *et al.,* 2004a; Normant *et al.,* 2004b). Consequently the use of stop flow respirometry and the optical system was deemed to be a suitable means of measuring oxygen uptakes rates in marine amphipods.

Metabolic cold adaptation (MCA) was not evident between the various gammarid species, as rates of oxygen uptake decreased with latitude resulting in lower MRs in the Arctic and cold-temperate species, *G. setosus* and *G. oceanicus* (Figure 2). The lack of MCA has also been demonstrated in many Antarctic marine invertebrates (*cf.* Clarke, 1991, 1993). However, the geographical and evolutionary isolation of Antarctica have made it difficult to include comparisons between temperate conspecifics, or indeed, congenerics. The present data set overcomes theses problems to show that MCA does not occur in conspecies living along a latitudinal cline. Moreover, it still appears that that polar/cold-water representatives do not compensate for living at low temperatures by increasing their metabolic rates, despite living in the Arctic where permanent ice cover has only been present for approximately 0.7 my (Eastman, 1997). Despite the overall lack in MCA, differences in response were observed when the gammarid species were examined separately.

Low temperature, Arctic populations of *G. oceanicus* exhibited depressed rates of oxygen uptake compared to temperate populations at their respective *in situ* temperatures, providing no evidence of MCA. Also, the rates of oxygen uptake exhibited by temperate populations were the same as those reported in Arctic populations when acclimated to a common temperature. The latter confirmed that there was no up-regulation of metabolic rate in *G. oceanicus* caught in Ny-Ålesund, despite living at temperatures of below 6°C. In contrast to the high latitude *G. oceanicus*, populations of *G. locusta* showed no variation in oxygen uptake rates across their latitudinal range when measured at their respective *in situ* temperatures (Figure 2). A similar response was reported for the pumping rates of northern (48°N, 6.5°C) and southern (34°N, 12°C) populations of the mid-temperate mussel, *Mytilus californianus* (Bullock, 1955). Compensation for latitudinal temperature shifts resulted in the maintenance of a common pumping rate thoughout the species latitudinal thermal-range. In the present study, acclimation of *G. locusta* from both a northern and a southern population to 10°C revealed that oxygen uptake rates were up-regulated in the northern population, supporting the presence of MCA in this mid-latitude gammarid species. It appears that MCA could be a feature of mid-latitude marine invertebrates as a similar response was reported in *Clymenella torquata* (Mangum, 1963), *Uca pugilator* (Vernberg and Costlow, 1966) and *Drosophila melanogaster* (Berrigan and Partridge, 1997).

Increased metabolic rates at higher, cooler latitudes, as a result of MCA, may allow species to meet elevated ATP costs of growth and development allowing them to complete life cycles in the colder shorter growing seasons (*cf.* Somme and Block, 1991), as well as compensate for the slower catalysation rates of enzymes at low temperatures. However, many species have thermal-adaptive isoenzymes to compensate for this (*cf.* Hochachka and Somero, 2002) and may have no need of MCA. MCA may also lead to fitness costs in marine organisms making it less likely to be under selective pressure (Clarke, 1991; 1993), with lower metabolic rates expected to be advantageous in very low energy Artic/Cold-temperate environments. In contrast, at higher energy mid-temperate latitudes, where the fitness costs of MCA might not be as high, metabolic compensation is more likely to be beneficial. Ancestral origins may also play a part in defining differences in MCA response with latitudinal distribution, as a recent phylogenetic study suggests that *G. setosus* is more closely related to other Arctic species such as *G. wilketski*, than *G. locusta* which groups with Mediterranean gammmarids (Costa and Rock, *Pers. Comm.).* In the present study, species-related differences between *G. oceanicus* and *G. locusta* persisted even when individuals were acclimated to a standard temperature (Figure 3), supporting the involvement of a genetic component. MCA, therefore, occurs in species such as *G. locusta* with warmer water ancestries which have spread to higher latitudes comparatively recently, but not in those species with cold-water origins. Consequently, the warm-water species are less likely to have evolved thermal adaptations to allow them to operate at lower metabolic rates. This suggests a fundamental difference in the ability of Arctic/cold-temperate and mid-temperate species to compensate for shifts in environmental temperature. Such differences could have an effect on their ability to respond to further environmental change.

## Acknowledgements

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# Climate change and the polar ichthyofauna: molecular evolution of hemoglobin

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**Abstract**: two important factors are contributing to push and drive research on organisms of extreme marine environments: (i) recent climatic changes, attracting the concerned attention of the world's public opinion; and (ii) the International Polar Year (IPY), a compelling "rendezvous" of the world's polar science. The Arctic and Antarctic marine faunas differ by age and isolation, and fishes have undergone different regional histories which have driven the physiological diversities. Antarctic fish are highly stenothermal, in keeping with stable water temperatures; Arctic fish, being exposed to seasonal temperature variations, exhibit higher physiological plasticity. In this framework, the Arctic and the Antarctic, in view of their status of extreme environments, fulfil a critical role. Dramatic changes (also anthropogenic) are occurring in the seas of both poles, calling for monitoring adaptation responses of fishes, useful sentinels of impacts of climate changes. Hemoglobin (Hb) is interesting for studying the relationships between environmental conditions and molecular evolution. Fulfilling its primary function under extremely variable conditions, Hb has experienced strong evolutionary adaptive pressure. The study of the structure and function of Arctic fish Hbs saw the first molecular characterisation of the oxygen-transport system of a zoarcoid species and of three species of the family Gadidae. Unlike in notothenioids (the dominant Antarctic suborder), the blood of these Arctic fish displays high Hb multiplicity similar to many other acanthomorph teleosts. Arctic and Antarctic globins have different phylogenies, and lead us to suggest that the selective pressure of environment stability allows the phylogenetic signal to be maintained in the Antarctic sequences, whereas environmental variability would tend to disrupt this signal in the Gadidae sequences. The unique Marine Laboratory, recently opened in Ny-Ålesund, will ensure that the fishes of Kongsfjord will become very important in research developments.

**Key words**: Antarctic, Arctic, evolution, fish, haemoglobin.

## Introduction

Temperature, hydrostatic pressure, medium cellular composition and oxygen availability may profoundly affect cell physiology. Adaptation means keeping the structural and functional features of the cellular biochemical constituents and an adequate level of energy turnover in response to variable environmental conditions. Certainly, temperature is the most important physical factor affecting life.

Low temperature may strongly influence metabolic-process rates. It slows all physiological processes, changes protein–protein interactions, reduces membrane fluidity and increases the viscosity of biological fluids. In general proteins from organisms living at low temperature are less stable in comparison to those isolated from organisms living at temperate latitudes. Lower stability seems to be due to greater conformational flexibility. Cold-adapted species have enzymes with higher catalytic activity either over a wide temperature range, or specifically at low temperature. Increased protein flexibility is generally conferred by few amino-acid replacements. The changes that enable enzymes and proteins to function in cold habitats are subtle and often challenging to identify, as it can be difficult to discriminate which changes are due to selective pressure, and which are instead functionally neutral. Enzymes with low optimal temperatures frequently contain specific replacements, with higher number of polar and lower number of hydrophobic residues, and fewer hydrogen bonds and ion pairs.

Undoubtedly, the knowledge of the physiological costs linked to thermal adaptation may help to understand how species have responded to climate change in the past and how different communities respond to climate change nowadays. An organism may respond to environmental temperature changes, in attempting to maintain physiological rates, by one or more of three strategies: (*i*) the quantitative strategy, changing the amount of a given molecule; (*ii*) the qualitative strategy, expressing a molecule variant with different thermal response; (*iii*) the modulative strategy, adjusting the membrane composition to maintain membrane fluidity.

Here we review recent advances in our knowledge on the structure, function and evolution of the oxygen-transport system, in particular hemoglobin (Hb), in polar fish. Molecular phylogeny has revealed different adaptive scenarios in the two polar regions.

## Adaptations in Hbs of Antarctic and Arctic Fish

Most research at the molecular and ecological level in cold-adapted habitats has been, for very good reasons, concentrated exclusively on Antarctic species. Recently the Arctic habitat is beginning to receive attention. The urge to study the molecular mechanisms underlying fish thermal adaptations and biodiversity in the high Arctic becomes stronger as scientific efforts to understand cold adaptation widen and shift to a more analytical phase. As polar scientists, we are fully acknowledging the absolute need to shed light on the links between northern and southern regions.

The perciform suborder Notothenioidei, mostly confined within Antarctic and sub-Antarctic waters, is the dominant component of the southern ocean fauna. Red-blooded Antarctic notothenioids differ from temperate and tropical species in having fewer erythrocytes (one order of magnitude lower in number, and three orders lower in channichthyids, than in temperate fish) and reduced Hb concentration and multiplicity (none in channichthyids). Arctic fish are characterised by higher biodiversity and, unlike Antarctic notothenioids, have high Hb multiplicity.

For instance, the blood of the spotted wolffish *Anarhichas minor*, a benthic, sedentary fish of the family Anarhichadidae (Zoarcoidei) contains three functionally distinct major Hbs (Verde *et al.*, 2002). High multiplicity and functional differences have also been observed in *Arctogadus glacialis* (Arctic cod), *Boreogadus saida* (polar cod) and *Gadus morhua* (Atlantic cod), all belonging to the family Gadidae (Verde *et al.*, 2006). Their blood also contains three major Hbs. In comparison with notothenioids, which lost globin variability probably because of environmental (temperature) stability, the oxygen-transport system of Arctic species has plesiomorphic features secondarily involved in cold adaptation and temperature fluctuations (namely higher multiplicity and higher globin diversity).

The presence of multiple Hbs may contribute to maintain Hb concentration in erythrocytes higher than if there were only a single Hb.

The temperature gradient covered by these species of the same family may offer important advantages in studying specific molecular adaptations in their Hb systems in response to local environment changes.

## Globin Evolution

In Arctic and Antarctic fish, molecular phylogenies are complete enough to allow the interpretation of trees based on primary structures of macromolecules of physiological interest (e.g. globins), in the light of trees based on other molecules used as markers of species phylogeny.

The inferred Neighbour Joining trees for $\alpha$ and $\beta$ globins are reported in Figure 1 and Figure 2. When evolutionary pressures and rates of change are the same across taxa, similarity is proportional to phylogeny, and in that case the gene (or protein) tree reflects the species tree. The topologies shown by the two trees suggest different evolutionary histories for the $\alpha$ and $\beta$ chains. Presumably, the two clusters of Antarctic major and minor (or embryonic) Hbs were generated by gene-duplication events which occurred independently for the a-and b-globin genes. The duplication event that gave origin to the two groups of Antarctic globins involved a mechanism of positive selection (i.e. changes that improve the fitness of the species), characterised by higher rate of non-synonymous (amino-acid replacing) to synonymous (silent) substitutions (Bargelloni *et al.*, 1998).

The globin sequences of the Arctic zoarcoid *A. minor* follow the track of species history, as *A. minor* consistently appears close to the notothenioid clades as predicted by teleost phylogenies. By contrast, Arctic gadid sequences occupy different positions in the two trees with regard to temperate and Antarctic sequences. On one hand, gadid $\alpha$ chains appear related to the notothenioid-zoarcoid group. On the other, the $\beta^1$ chains of *A. glacialis*, *B. saida* and *G. morhua* are excluded from the $b^2$ chains of the same species and from major and minor Antarctic globins with very good bootstrap proportion (99%).

As clearly shown by phylogenetic analysis, under the constant physico-chemical conditions of marine habitats we are able to recover teleost phylogeny (zoarcoids with notothenioids, gadids as sister-group to both) in globins of fish from the Antarctic, whereas the variability typical of the Arctic ocean seems to correspond to high sequence variation in gadid β globins. The well known position of gadids with regard to zoarcoids and notothenioids allows to hypothesise that the basal position of the $\beta^1$ sequences of Arctic gadids in the β-globin tree (Figure 2) is probably artefactual, whereas the α-globin tree mostly recovers the species tree plus a few duplications (Figure 1). Such position may be interpreted as an effect of the extreme perturbation of the available mutational space in gadid $\beta^1$-globin sequences, possibly due to the variability of thermal conditions experienced by these migratory Arctic fish in comparison with the thermal stability in the life style of zoarcoids and notothenioids, two groups that display unperturbed phylogenetic signal in β sequences (Dettaï *et al.*, 2008).

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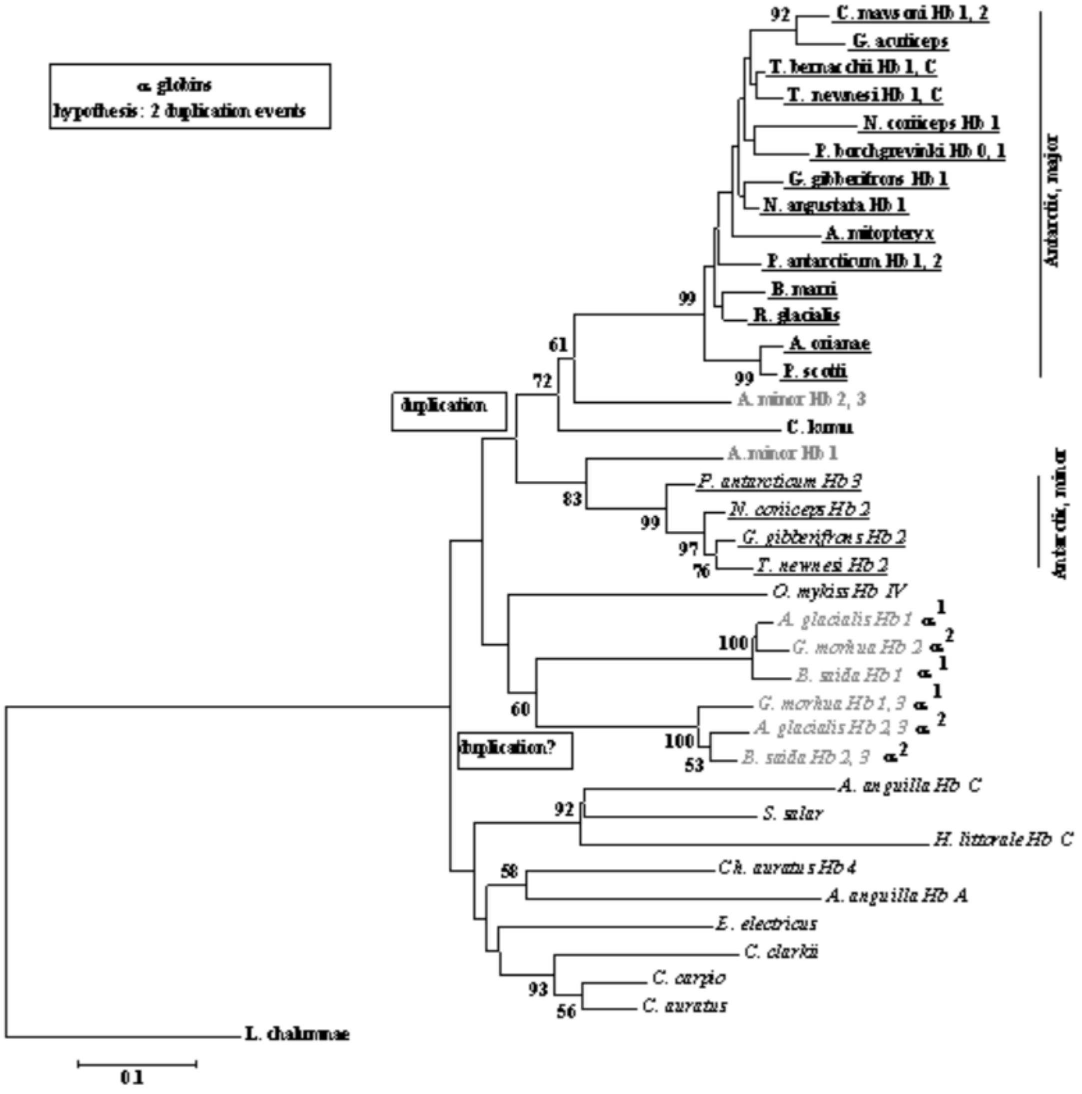

**Fig. 1 Neighbour Joining tree of amino-acid sequences of α chains of Arctic, Antarctic and temperate fish Hbs, showing the degree of similarity among sequences.** Bootstrap proportions (BP, percentage of 10,000 replicates) are given at the nodes. Globin sequences of notothenioids are in black, of zoarcoids in grey, of gadids in grey and italic, of other fishes in black and italic.

**Fig. 2 Neighbour Joining tree of amino-acid sequences of β chains of Arctic, Antarctic and temperate fish Hbs, showing the degree of similarity among sequences.** For details see Fig. 1.

# Physical Science

# Measurements of airborne natural radionuclides at Mt. Zeppelin GAW Station, Svalbard during IPY-2007/2008

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**Abstract:** data on airborne $^{210}$Pb can be used as a tracer to help to identify natural, e.g. due to the North Atlantic Oscillation, and anthropogenic variations in the transport behaviour of air masses and thus also air pollutants in the Arctic region. Beryllium-7 has a half-life of 53.3 days. High $^{7}$Be concentrations in the air indicate subsidence from the upper atmosphere.

The Finnish Meteorological Institute (FMI) has measured concentration of lead-210 in the air at Mt. Zeppelin Global Atmosphere Watch (GAW) station, Ny-Ålesund, Svalbard (78°58´N, 11°53´E) since December 2000 in collaboration with the Norwegian Institute for Air Research (NILU) and the Norwegian Polar Institute (NPI). The station is located 474 m above sea level. High-volume aerosol particle samples are collected onto glass-fibre filters. The exposed filters together with field blanks have been assayed for $^{210}$Pb with alpha counting.

The observed $^{210}$Pb activity concentrations in 2001-2005 present a clear seasonal variation with highest concentrations in winter and lowest in summer. The factors for this variation are the amount of precipitation, speed of air chemistry and atmospheric mixing conditions. Owing to the International Polar Year 2007/2008 the measurement programme will be expanded to $^{210}$Po and $^{7}$Be. These measurements are expected to bring new information concerning aerosol particle residence time and vertical movement of the air in the High Arctic.

**Key words:** natural radioactivity, atmosphere, aerosols, Svalbard, IPY-2007/2008.

## Introduction

During the past three decades, there has been increasing interest in the presence of airborne pollutants in the Arctic region. However, the interpretation of the results has suffered from the lack of data concerning the transport and removal processes in the atmosphere.

The Finnish Meteorological Institute (FMI) has measured concentration of lead-210 in the air at Mt. Zeppelin Global Atmosphere Watch (GAW) station, Ny-Ålesund, Svalbard (78°58´ N, 11°53´ E) since December 2000 in collaboration with the Norwegian Institute for Air Research (NILU) and the Norwegian Polar Institute (NPI). The data on airborne $^{210}$Pb can be used as a tracer to help to identify natural, e.g. due to the North Atlantic Oscillation (NAO), and anthropogenic variations in the transport behaviour of air masses and thus also air pollutants in the Arctic region.

Lead-210 is formed in the atmosphere from the radioactive noble gas radon-222 ($^{222}$Rn) emanating from the Earth's crust. 99 % of the airborne $^{222}$Rn originates from land and only 1 % from the sea (Baskaran *et al.*, 1993). Owing to the long half-life (22 years) of $^{210}$Pb, its removal from the atmosphere is governed by the different scavenging processes affecting the aerosol particles carrying it, rather than radioactive decay.

The daughter product of $^{210}$Pb is polonium-210 ($^{210}$Po) which has a half-life of 138 days. A mean aerosol particle residence time in the atmosphere can be calculated from the activity ratio of $^{210}$Po to $^{210}$Pb. Beryllium-7 ($^{7}$Be) is produced in the upper troposphere and lower stratosphere from atmospheric nitrogen and oxygen by nuclear interactions with cosmic radiation. Beryllium-7 has a half-life of 53.3 days. High $^{7}$Be concentrations in the air indicate subsidence from the upper atmosphere.

## Experimental

The sampling site is at Mt. Zeppelin Global Atmosphere Watch (GAW) station, Ny-Ålesund, (78°58´ N, 11°53´ E), on the western coast of Spizbergen, the largest island in the Svalbard archipelago. The station is located 474 m above sea level. High-volume aerosol particle samples are collected onto glass-fibre filters (Munktell MGA). Three samples per week are collected with filter changes on Mondays, Wednesdays, and Fridays. The air flow is about 3000 m$^3$ per day. One out of 25 filters is left unexposed and is used as a field blank sample. The sampling programme was started in December 2000. The exposed filters together with field blanks are assayed for $^{210}$Pb six months after the sampling with an automatic alpha/beta gas-flow proportional counter instrument (Mattsson *et al.*, 1996). The measurement is based on the alpha counting of the ingrown daughter nuclide $^{210}$Po. In the future the samples will be analysed for $^{210}$Po with alpha counting and for $^{7}$Be with semiconductor gamma spectrometry.

## Results and discussion

The observed $^{210}$Pb activity concentrations present a clear seasonal variation with highest concentrations in winter (170-240 µBq/m$^3$, Figure 1). This is attributed to the small amount of precipitation, reduced air chemistry and stagnant mixing conditions in the troposphere during the Arctic night. These factors increase the aerosol residence time and thus the accumulation of $^{210}$Pb into the air. The phenomenon is similar to the Arctic haze, accumulation of soot and sulphate particles into the Arctic atmosphere during the winter (e.g. Shaw, 1983). The maximum concentrations are only moderately lower in the High Arctic compared to Finland. For example, in Northern Finland the average January…March activity concentration was about 280 µBq/m$^3$ and in Southern Finland 300 µBq/m$^3$ in 1995-1997 (Paatero and Hatakka, 2002).

The minimum $^{210}$Pb activity concentrations (30-40 µBq/m$^3$) occur in the High Arctic in summer when the continuous solar radiation induce efficient vertical mixing of the troposhere. Also the amount of precipitation, which causes wet deposition, and atmospheric chemistry induced by solar radiation, are at their seasonal maximum. This is in agreement with observations in Finland. For example, in Northern Finland the average May…July activity concentration was about 140 µBq/m$^3$ and in Southern Finland 200 µBq/m$^3$ in 1995-1997 (Paatero and Hatakka, 2002). However, the concentrations are even lower in the High Arctic. In southern Germany the seasonal variation is much less profound than at Svalbard even though the monthly mean concentrations are much higher, 400-700 µBq/m$^3$ (Winkler and Rosner, 2000).

To analyse the $^{210}$Pb observations at Mt. Zeppelin a set of three-dimensional 5-day air mass back-trajectories was calculated using the trajectory model FLEXTRA (Stohl and Seibert, 1998). The meteorological fields were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, UK. Figure 2 depicts the starting points of the trajectories coinciding with the lowest 5 per cent of the $^{210}$Pb activity concentrations, <10 µBq/m$^3$. Most of the air masses with a low $^{210}$Pb content were five days earlier over the Arctic Ocean, the North Atlantic Ocean or over Greenland. Only a few starting points are over Northern Europe or over the coastal regions of Siberia. On the other hand, most of the trajectory starting points coinciding with the highest 5 per cent of the $^{210}$Pb activity concentrations, >400 µBq/m$^3$, are located over Siberia (Figure 3). A number of starting points are located also between the Bering Straight and the North Pole. The long residence time and therefore the accumulation of $^{210}$Pb-carrying aerosol particles into the Arctic atmosphere during winter explains why the Arctic Ocean apparently is a source area of $^{210}$Pb.

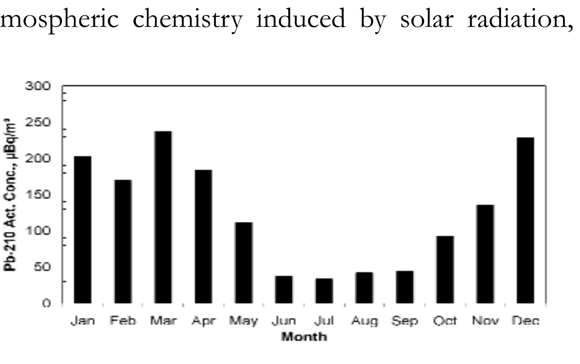

**Fig. 1** Seasonal variation of airborne $^{210}$Pb (µBq/m$^3$) at Mt. Zeppelin GAW station, Svalbard 2001-2005.

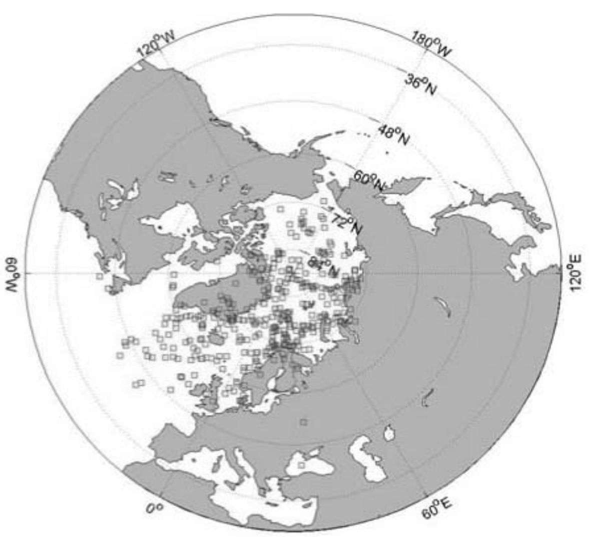

**Fig. 2** Starting points of the five days long air mass backtrajectories coinciding with the lowest 5 per cent of the $^{210}$Pb activity concentrations, <10 µBq/m$^3$ at Mt. Zeppelin GAW station.

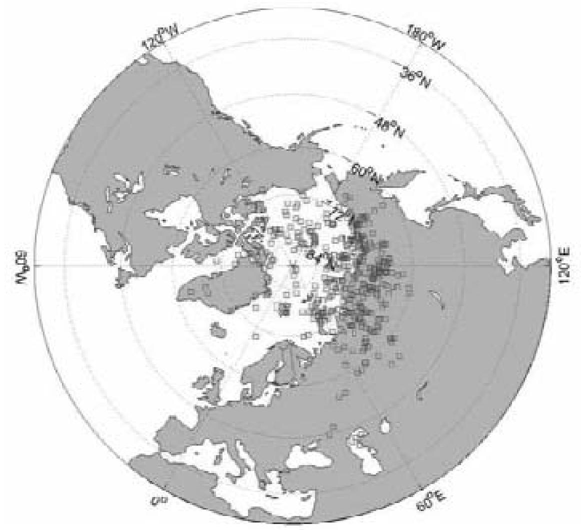

**Fig. 3** Starting points of the five days long air mass backtrajectories coinciding with the highest 5 per cent of the $^{210}$Pb activity concentrations, >400 µBq/m$^3$ at Mt. Zeppelin GAW station.

## Conclusions

Here we have presented a summary of a five years long observation series of airborne $^{210}$Pb at the Mt. Zeppelin Global Atmosphere Watch station, Svalbard. In winter the $^{210}$Pb activity concentrations found in Svalbard are comparable to those found in Finland. In summer, however, the concentrations are much lower than in continental areas. An air mass trajectory analysis indicated that in summer $^{210}$Pb can be used as a tracer for air masses having a contact to land areas within past five days. In winter this cannot be done due to the Arctic haze type accumulation of $^{210}$Pb-carrying aerosol particles into the atmosphere. But even in winter a low $^{210}$Pb activity concentration indicates that the associated air mass has had little if any contact with land areas. Owing to the International Polar Year 2007/2008 the measurement programme will be expanded to $^{210}$Po and $^7$Be. These measurements are expected to bring new information concerning aerosol particle residence time and vertical movement of the air in the High Arctic.

## Acknowledgements

This work was started in 2000 with the financial support of the Ny-Ålesund LSF Project, European Community – Access to Research Infrastructure action of the Improving Human Potential Programme. The extension of the measurement programme is receiving financial support from the European Commission under its FP6 Programme in Structuring the European Research Area, Specific Support Action: Transnational Access to the European Centre for Arctic Environmental Research (ARCFAC V), contract no. RITA-CT-2006-026129. The authors are also indebted to Kings Bay AS for logistical support.

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# Intercomparison and analysis of radiation data obtained by Russian and Norwegian standard radiation sensors on example of Barentsburg and Ny-Ålesund research stations

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**Abstract:** the preliminary results of intercomparision measurements of radiative characteristics obtained during I field phase of International Polar Year (IPY) on Svalbard are presented. The place of measurements is a Barentsburg research station of Russian Hydrometeorological Service on Svalbard. The scientific, technical and logistic collaboration between AARI, NPI and MHMS was a good foundation of these measurements. The data about parallel measurements of incoming global radiation obtained by Russian and Norwegian standard radiation sensors were considered. The line regression approach was used for analysis of row data. The preliminary results and suggestions for future experiments are discussed.

**Kay words**: IPY, global radiation, intercomparision measurements.

International practice of comparison and joint analysis of historical and current data of radiation observations obtained in different countries indicates a need for performing an important procedure connected with comparing readings of instruments used in particular at the Russian and Norwegian stations on Svalbard and Franz Josef Land. Beginning from the start of regular Russian radiation measurements at the Franz Josef Land (Hayes Island) and Svalbard (Barentsburg settlement) and up to present (only Barentsburg) the observation program is based on using standard Russian sensors (Yanishevsky-Savinov pyranometer M-80 or M-115M). At the present time based on the research stations of several European countries (Norway, Germany, Italy, Great Britain, USA, Chine, South Korea and France) compactly located in the Norwegian settlement Ny-Ålesund (Kings Bay), all radiation measurements are combined into one common network in the framework of the international "Kongsfjorden International Research Base" (Figure 1).

Both short- and long-wave radiation balance components of the underlying surface are recorded separately. As a rule, the aforementioned countries use universal common measurement instruments on the basis of "Epply" and "Kipp & Zonen" sensors (CM6, CM11, CM21). It seems to be extremely advisable and needful to include the Russian observations conducted in Barentsburg to this network. The preliminary negotiations with the NPI representatives responsible for this program revealed a justified interest of its executors. This was expressed in the proposals to include the Russian observations in Barentsburg to the network and undertake intercalibration studies in the framework of this program with participation of Russian and Norwegian instruments (International Polar Year project #729 – "Climate and meteorological regime of West Arctic", IPY, CMRWA). The firsts test series of joint measurements was carrying out in May 2002 when Russian pyranometers were set up in parallel with the Norwegian ones at the base of the Sverdrup research station in Ny-Ålesund (NPI). A joint measurement series was completed in September 2002. The next official series was carrying at Barentsburg research station in April 2007 in framework of IPY project mentioned above. The realized joint measurements by pyranometers M-115M and CM6, CM11 allow us to obtain representative data for a combined analysis, reveal discrepancies between the Russian and Norwegian sensors and take into account these corrections in the analysis of historical and current data aimed at comparative studies of radiation climate of this region. In particular, it is proposed to use for comparative climatic studies, the data of the Russian station on Hayes Island (Franz Josef Land) and the Norwegian stations in Ny-Ålesund, Longyearbyen, Icefjorden radio (Svalbard) as the reference and most representative and long-term stations. Proposed research will grant mutual access

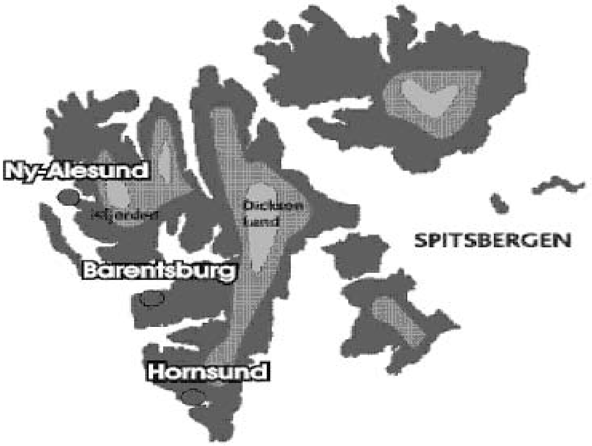

**Fig. 1** Situation of stations with radiation measurements on Svalbard.

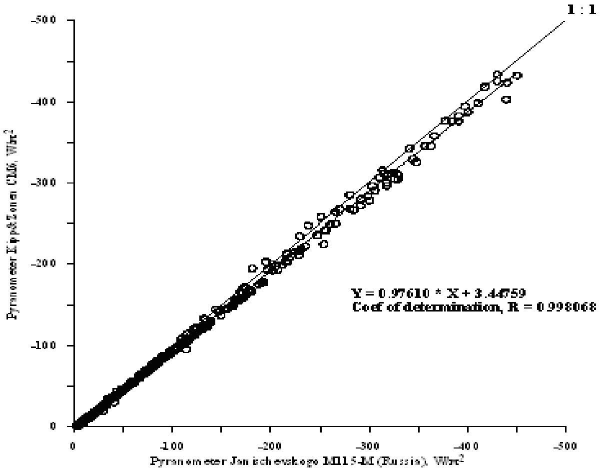

**Fig. 2** Relationship between Russian and Norwegian pyranometers.

to national data sources for the both partners thereby providing the data for their joint analysis. The proposed project is a continuation and development of the complex scientific program «Research of a meteorological regime and climatic changes on Svalbard», carried out by the AARI in the framework of the IPY and NPI projects «Arctic Climatic Diversity» (ARCDIV).

## The main goals

1. Revealing possible systematic discrepancies between the readings of standard Russian and Norwegian radiation sensors.
2. An estimation of opportunities for further development of the program of radiation observations at the Barentsburg research station and their integration in the network within the framework of the international program «Kongsfjorden International Research Base ».

## Research problems

1. Parallel measurements of incoming global radiation obtained by Russian and Norwegian pyranometers.
2. Joint analysis of the obtained data.
3. Development of the method for intercalibration.
4. Recommendations for carrying out of joint statistical analyses of climatic series of the radiation data.

## Planned activities

1. Measurements of incoming global radiation;
2. carrying out of standard meteorological observations;
3. carrying out of hourly visual and instrumental observations of characteristics of the cloud cover and atmospheric phenomena.

## Preliminary results

The conformity between diverse sensors (M115-M and CM6) is quite satisfactory apparently from Figure 2. The discrepancies of average values are makes 6.3 ±5.6 W/m$^2$ for all period of observation in the average (April 18 - May 2, 2007). The discrepancies were maximal at midday o'clock, reaching 36 W/m$^2$. Thus, values of pyranometer ?115-M were above than pyranometer CM6 (Kipp & Zonen), as a rule.

## Conclusions

1. The observations of cloud characteristics (low, middle and high levels, height of low border) should be to carry out every hour as minimum during of intercalibration measurements. The parallel measurements of diffuse and direct solar radiation are very extremely useful for the subsequent analysis of results.
2. The basic of statistics of radiating characteristics are concern to month intervals (monthly average values and monthly sums) in various climatic archives. It would be very expedient to carry out an annual series of joint measurements (March - October for Svalbard conditions). It will allow to reveal possible discrepancies between estimations of radiating characteristics received for these time intervals and to use the received results in comparative climatic analyses.

## Acknowledgment

This work is a synthesis of several research projects (funding in brackets): "Investigation of meteorological regime and climate variability on Svalbard" (AARI), "Norwegian-Russian collaboration on fast ice grows and decay in Kongsfjorden and Gronfjorden (Svalbard)" (NRC, NPI).

# Sky-radiometer measurement for monitoring column aerosol optical properties in Ny-Ålesund: Recent results from the spring 2006-2007 measurements

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**Abstract**: sky-radiometer measurements have been performed in Ny-Ålesund with Prede POM-01 since March 2000, and followed by POM-02 since May 2004. Aerosol optical properties, i.e., optical thickness, single scattering albedo and refractive index for selected wavelengths at 400, 500, 675, 870 and 1020 nm, and the volume size distribution are retrieved from spectral measurements of the direct solar attenuation and the sky radiance distribution by the sky-radiometer. These optical properties are compared for normal conditions and a smoke event in spring. The result shows extremely high optical thickness and contamination of light absorbing particles for the smoke event in 2006. It is suggested from retrievals of the refractive index and size distribution that the smoke event aerosol included soot and organics origin particles in addition to sulfate and sea-salt particles that are dominant for normal conditions.

**Keywords**: sky-radiometer, Arctic aerosol, optical properties, Ny-Ålesund.

## Introduction

Atmospheric aerosol has a potential to modulate the global climate by direct and indirect effects on the energy balance in the planetary atmosphere – surface system. Optical properties of aerosol are essential parameters for the aerosol direct effect. Sky-radiometers, Prede POM series, are designed for measuring the column aerosol optical properties and have been deployed for SKYNET in Asia.

National Institute of Polar Research (NIPR) promotes atmospheric research in both polar regions. Atmospheric research by NIPR includes ground-based remote-sensing of aerosol and clouds for long-term and continuous basis measurements at Rabben Station in Ny-Ålesund, Svalbard (78.9N, 11.9E). In March 2000 the sky-radiometer measurement started with a Prede POM-01 model, and was followed by POM-02 in May 2004.

Extremely high aerosol optical thickness (AOT) was recorded in spring 2006. The high record event has been analyzed and was found to be caused by intrusion of fire smoke mainly from crop fields in Eastern Europe (Myhre *et al.*, 2007; Stohl *et al.*, 2007; Treffeisen *et al.*, 2007). In this paper, we will report column aerosol optical properties retrieved from sky-radiometer measurements in the Arctic spring including the 2006 Arctic smoke event.

## Measurement and analysis methods

Sky-radiometer is a kind of spectral photometers to measure not only direct solar attenuation but also scattered radiance distribution in the sky (Shiobara *et al.*, 1991; Aoki and Fujiyoshi, 2003). This instrument is similar to Cemel sun-photometers, and the measurement and analysis are similar to those employed in AERONET (Holben *et al.*, 1998). During the spring 2006-2007 measurements, a Prede POM-02 sky-radiometer was operated at Rabben. Measurements were acquired every 10 min under clear-sky condition in the daytime.

The POM-02 sky-radiometer can measure light in the ultra-violet to near-infrared region through narrow-bandpass interference filters with maximum transmission at the wavelengths of 315, 340, 380, 400, 500, 675, 870, 940, 1020, 1600, and 2200 nm. In the following analysis, five channels at 400 – 870, and 1020 nm are used. A silicon PIN photodiode is employed for the detector and controlled to a constant 20 C operating temperature. The full FOV angle is 1 degree (2.4E-4 sr). The electronic dynamic range of the system is designed to measure over $10^7$. Calibration to obtain the extraterrestrial output values at each channel is based on a modified Langley method which have been proposed by Tanaka *et al.* (1986) and adopted in the SKYRAD analysis package.

The SKYRAD analysis package includes an inversion algorithm developed by Nakajima *et al.* (1996). In the sky-radiometry analysis, the input data are the spectral AOTs and scattered radiance distributions that are measured by sky-radiometers. Using the sky-radiometer data, the SKYRAD analysis can retrieve the volume size distribution (VSD), complex refractive index (CRI) and single scattering albedo (SSA) of column aerosols. The SKYRAD.pack Version 4.2 inversion scheme was applied in this study. The surface pressure and the column amount of ozone were assumed to be 1 atm, and 300 DU for calculating AOT from total optical thickness, and the ground albedo was assumed to be 0.5 in the inversion analysis. In order to confirm the reliability of inversion results, it is important to compare the measurement and reconstructed values. In this study, we adopt the result that does not exceed 10% root-mean square error between measured and reconstructed values. Particularly in this paper, the following discussions focus on AOT, Angstrom exponent (AE), SSA and CRI, and their variations in the Arctic spring.

## Results and discussion

Temporal variations of aerosol optical properties in spring of 2006 and 2007 are inferred from the sky-radiometer two-month measurements, and are summarized in Figure 1. From top to bottom, plotted are AOT, AE, SSA, and the real (CR) and imaginary (CI) part values of CRI, respectively at the wavelength of 500 nm; circles are for 2006, and squares for 2007. The average values of optical parameters for each year are indicated by arrows on the left axis in Figure 1, and also summarized in Table 1. Looking at the averages, there are no significant differences between 2006 and 2007, except for AOT and AE. Herber *et al.* (2002) have reported the average AOT for the Arctic background in spring to be 0.067 at the wavelength of 532 nm, based on long-term sun photometer measurements for 9 years at Ny-Ålesund. The present result for 2007 is close to the Arctic background, and the 2006 average shows a higher value due to extremely high AOD in May. To

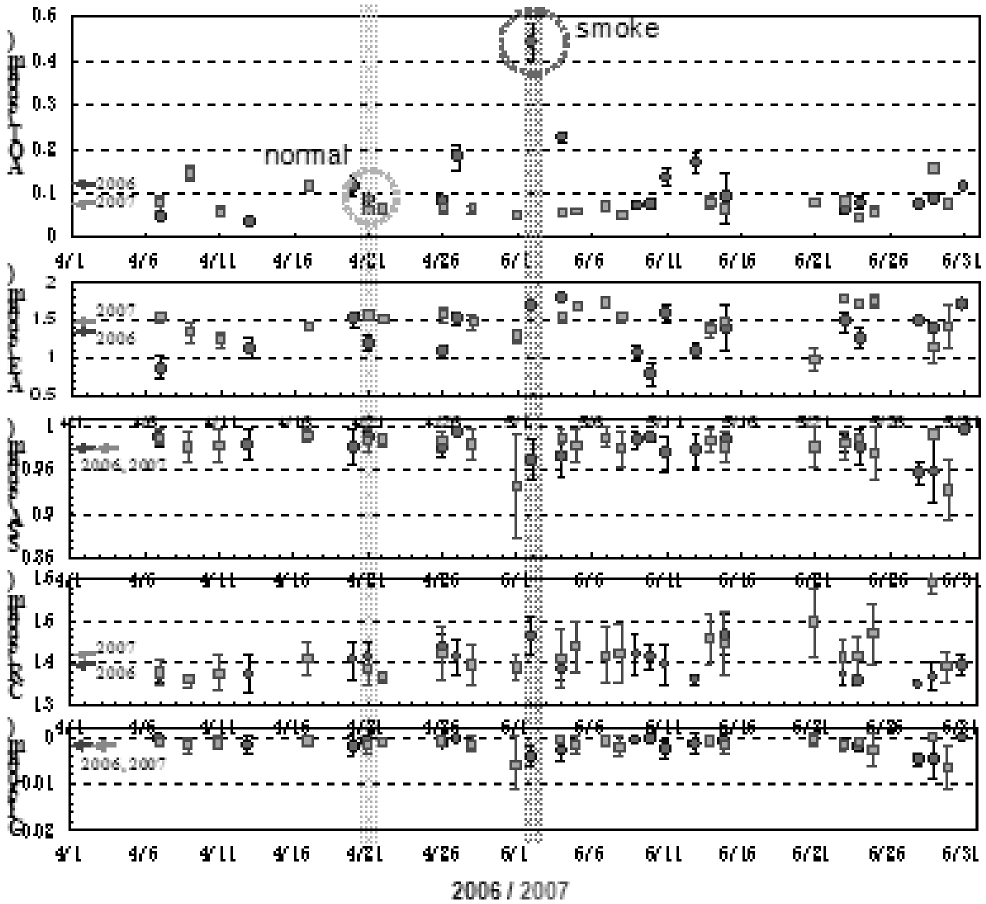

**Fig. 1** Temporal variations of aerosol optical properties at Ny-Ålesund, Svalbard for April and May of 2006 (circles) and 2007 (squares). Top to bottom: Aerosol optical thickness (AOT), Angstrom exponent (AE), single scattering albedo (SSA), and real and imaginary part values of complex refractive index (CR, CI), respectively at the wavelength of 500 nm. Arrows indicate the average values for the period of each year.

extract the high turbidity event from normal conditions in the following discussion, data for 2 May and 21 April 2006 are highlighted in Figure 1 and summarized in Table 2.

For normal conditions in Ny-Ålesund, bi-modal size distributions are often retrieved from the sky-radiometer measurement. It is supposed that fine particles around 0.1 mm radius consist of sulfate and coarse mode particles around 1 mm radius consist of sea-salt. Both particles are rather transparent and have high SSA values as shown in Tables 1 and 2.

As shown in Figure 1, very high record of AOT took place on 2 May 2006. This irregular event was precisely investigated from different points of view (Myhre *et al.*, 2007; Stohl *et al.*, 2007; Treffeisen *et al.*, 2007). It was found that the high turbidity event was caused by agricultural fire smoke occurred in Eastern Europe. In general for normal cases in spring, the backward air trajectory analysis likely indicates the air coming from Siberia. The smoke air, however, for the May 2006 case was originated from crop fields in Eastern Europe. The MODIS measurements revealed that there were a lot of agricultural fires in this area during the above mentioned period. And then the air including fire smoke aerosol had come over Svalbard Islands (Stohl *et al.*, 2007).

Even for the smoke case, SSA and CRI values were ranged in the normal observation in this season, and there was no significant correlation among these parameters. Precisely looking, there was found a weak positive correlation between AOT and AE. In general, we know a positive correlation between AOT and AE for the anthropogenic aerosols due to enhancement of small particles of sulfate aerosol. More precisely looking at the result, relatively low SSA was observed, and thus relatively large value of CI was retrieved as shown in Table 2. Large CI of aerosol suggests existence of light-absorbing particles. On the other hand, relatively high values of CR may reflect a feature of organics origin aerosol. These compositions are generally expected to be included in agricultural fire smoke. In fact, Stohl *et al.* (2007) have reported an abrupt increase of elemental carbon and organic carbon in aerosols which were sampled during the smoke event period at the Zeppelin site.

**Table 1** Aerosol optical parameter average (avr) values and standard deviation (std) for spring (April and May) of 2006 and 2007

| | | AOT | AE | SSA | CR | CI |
|---|---|---|---|---|---|---|
| 2006 | avr | 0.121 | 1.330 | 0.977 | 1.397 | -0.0017 |
| | std | 0.050 | 0.290 | 0.014 | 0.034 | 0.0015 |
| 2007 | avr | 0.075 | 1.470 | 0.977 | 1.420 | -0.0017 |
| | std | 0.029 | 0.205 | 0.017 | 0.053 | 0.0015 |

**Table 2** Comparison of normal state and smoke event in 2006

| | | AOT | AE | SSA | CR | CI |
|---|---|---|---|---|---|---|
| normal | avr | 0.086 | 1.190 | 0.988 | 1.412 | -0.0007 |
| (4/21) | std | 0.008 | 0.097 | 0.006 | 0.039 | 0.0005 |
| smoke | avr | 0.444 | 1.683 | 0.963 | 1.462 | -0.0040 |
| (5/2) | std | 0.039 | 0.138 | 0.023 | 0.046 | 0.0024 |

## Summary

Optical properties of column aerosols in the Arctic spring have been investigated based on sky-radiometer measurements in Ny-Ålesund, Svalbard. The SKYRAD.pack Ver.4.2 inversion scheme was applied for obtaining volume size distribution, single scattering albedo (SSA), complex refractive index (CRI; CR and CI) as well as aerosol optical thickness (AOT) and Angstrom exponent (AE).

From the 2006 and 2007 measurements, temporal variation and average values of AOT, AE, SSA, CR, and CI for the Arctic spring aerosols were obtained. Aerosol optical properties for a high-turbidity smoke event in early May 2006 well contrasted with those for normal state. The size distribution and complex refractive index of smoke aerosol on 2 May retrieved by SKYRAD analysis suggested the smoke aerosol included organics origin aerosol and light absorbing particles in addition to sulfate and sea-salt particles that are dominant for normal state.

## Acknowledgments

This study was supported with a Grant-in-Aid for Scientific Research (A), Grant No. 16253001, provided by the Ministry of Education, Culture, Sports, Science and Technology, Japan. The authors sincerely thank NPI's on-site staff for their help on the sky-radiometer measurement at Rabben Station. The authors' gratitude is expressed also to Kings Bay A.S. for maintaining the infrastructure in Ny-Ålesund.

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# Black Carbon Aerosols in Arctic Snow and Implications for Albedo Change

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**Abstract:** the impact of black-carbon aerosols from fossil fuel and biomass combustion on the Earth's climate is diverse, as black carbon absorbs sunlight and has semi-direct and indirect effects on clouds. Also black carbon deposits in snow and reduces the albedo of the surface. The overall net effect of black carbon is warming. However, it is not straightforward to measure the black-carbon content of snow and derive the corresponding alteration of albedo, due to relatively low black-carbon concentrations, lateral variability in black-carbon distribution on small special scales, and large natural variability of snow albedo. This paper presents results from a project bringing together two groups, both performing measurements of black carbon in snow and corresponding albedo measurements. Key issues include: sampling procedures, melting and filtering procedures, equipment used and methods for analyzing the filters for black carbon content. This paper focuses on black-carbon measurements from a joint field campaign carried out in Ny-Ålesund in spring 2007.

**Keywords**: aerosols, Black carbon, Arctic, Albedo, Climate Forcings.

## Introduction

Black-carbon atmospheric particles strongly absorb solar radiation (direct effect), giving a positive radiative forcing (Haywood and Shine, 1995). These particles also have significant semi-direct effects as the absorbing aerosols both inhibit cloud formation and increase cloud evaporation (Hansen *et al.*, 1997; Ackerman *et al.*, 2000; Cook and Highwood, 2004). Interest in black carbon in Arctic snow has recently re-emerged (IPCC, 2007; Hansen and Nazarenko, 2004), as it was shown that relatively small concentrations of black carbon can alter the surface energy balance substantially. Also, black carbon was found to be three times as effective as $CO_2$ (per unit of radiative forcing) in altering the surface temperatures (Flanner *et al.*, 2007).

The direct albedo effect has been modelled by several groups (Jacobsen, 2004; Warren and Wiscombe, 1980), but few *in-situ* field measurements exist (Bøggild *et al.*, 2007). This work is part of two projects where we will utilize field measurements of black carbon in snow and corresponding albedo measurements to separate the black-carbon signature on the optical properties of snow from the natural albedo variability. This paper focuses on measurements of black carbon in snow at Svalbard in spring 2007.

## Black carbon

The term "black carbon" has two main meanings in the literature (Andreae and Gelencser, 2006). In this paper (and commonly in the climate modeling communities) black carbon is equivalent to the soot carbon particles released during the incomplete combustion of biomass and fossil fuel. But, as soot carbon in snow is difficult to measure directly, the analysis procedure requires use of proxies. The two most commonly used proxies are black carbon ($BC_e$) and elemental carbon ($EC_a$), having their origin in two different methods (optical and thermo-optical, respectively, Andreae and Gelencser, 2006). If the atmospheric soot particles were pure graphite, both $EC_a$ and $BC_e$ would give exactly the mass concentration of soot carbon as intended (Andreae and Gelencser, 2006). But this is not the case, and $EC_a$ and $BC_e$ proxies are usually different (Sec. 3.1). However, in literature and daily talk the terms $EC_a$ and $BC_e$ are used interchangeably as synonyms for black carbon.

### *Measurements in Arctic snow*

Snow sampling for black-carbon concentrations were carried out on Svalbard in spring 2007 (Figure 1). In total 86 samples were collected, of which 48 were surface samples, 8 bulk samples and the rest from particular snow layers. The samples were collected in 2-liter glass jars, then taken to the lab for melting and analyses. The melting and storage procedure can affect the measurement, since different melting speeds, melting timing relative to sampling, and time between melting and filtering can result in loss of black carbon particles before the meltwater is filtered. Most samples in this study were melted overnight; some were melted rapidly in a microwave oven and a few were left at room temperature for longer periods (weeks). The samples were then filtered through a pre-burned quartz substrate with a vacuum pump. The filters were analyzed with the thermo-optical method (Krecl *et al.*, 2007; Birch and Cary, 1996), providing $EC_a$ proxies.

## Results

All sites show relatively low concentrations of black carbon, with medians below 10 ng of carbon per g of snow (ng $g^{-1}$, Figure 1), except the site at Linnebreen which is located close to the settlement of Barentsburg, being contaminated from the coal mines there. Previous black-carbon measurements for Svalbard from 1983 show a range of 7-52 ng $g^{-1}$, with an average value of 31 ng $g^{-1}$ (Clarke and Noone, 1985, Table 1); i.e., substantially higher concentrations than what we measured. However, these concentrations can not be compared directly, as (i) strong emission controls started in the 1990s, thus reducing the black carbon amount substantially, and (ii) the concentrations from Clarke and Noone (1985) were $BC_e$ proxies, while we have $EC_a$ proxies (this topic is further discussed in Sec. 3.1). Black carbon measurements were also carried out during the *Surface Heat Budget of the Arctic Ocean* (SHEBA) experiment in the Arctic Ocean in 1998. $BC_e$ proxies ranged from 1 to 7 ng $g^{-1}$, with mean values of 4-5 ng $g^{-1}$ (Grenfell *et al.*, 2002), thus more comparable to our findings.

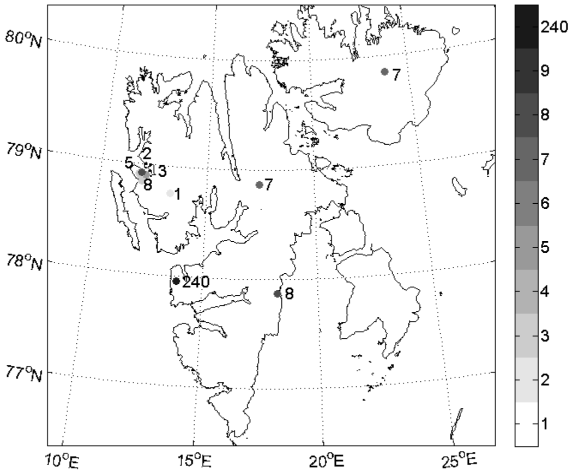

**Fig. 1** Median black carbon proxy ($EC_a$, ng $g^{-1}$) at Svalbard, February-April 2007. The one site with high concentration is contaminated by a coal mine.

| Location | BC concentration (ng $g^{-1}$) |
|---|---|
| Svalbard (2007) | 7, 4 (1-13) |
| Svalbard (1983)[1] | 31, 34 (21-48) |
| Arctic (1983-1984)[1] | 34, 25 (7-76) |
| Arctic Ocean (SHEBA, 1998)[2] | 4 (1-7) |
| Antarctic[3] | 0.2 |

**Table 1** Black-carbon concentrations in snow. The first row represents the new Svalbard $EC_a$ proxies (excluding one site contaminated from a coal mine), while the others are previous $BC_e$ proxies. The first three rows provides mean, median (and 10th-90th percentile in brackets), while the two last give mean and (range in brackets). [1]Clarke and Noone (1985); [2]Grenfell *et al.* (2002); [3]Warren and Clarke (1990).

The black-carbon proxies demonstrate relatively large variability, both spatially and from the analysis method. Figure 2 shows an example of four "identical" surface samples (upper 0.02 m of snow) from Austfonna (79,85° N 23,80° E) at Svalbard the 18th April 2007. All four samples were collected and handled identically. One sample stands out with higher concentration, but there were no indications or evidence that this particular sample should have higher concentrations compared to the others. The spatial variability shown is the standard deviation of the $EC_a$ proxy for the four samples, while the analysis variability was calculated by performing several analyses on the same filter, thereby providing an error estimate of the thermo-optical method. For an $EC_a$ content on the filter of about 2 $\mu$g $cm^{-2}$, the relative root-mean-square error was 8%, and decreased for increasing concentrations.

### *Comparison of black-carbon proxies*

Parallel snow samples were taken and analyzed for black carbon with both the thermo-optical method ($EC_a$ proxies) and optical method ($BC_e$ proxies), to compare the two methods. However, for the $BC_e$

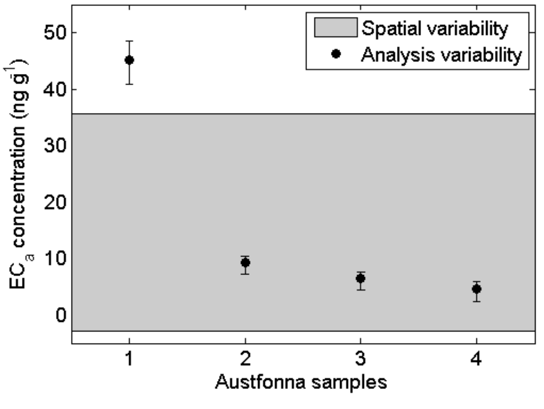

**Fig. 2** Test regarding analysis and spatial variability for black carbon proxy $EC_a$ for Austfonna, Svalbard, 18. April 2007. The four samples are all surface samples of 0.02 m depth for the same site.

only preliminary visual estimates (visual comparison against standards) is currently available. The visual $BC_e$ concentrations were overall higher than the $EC_a$ concentrations. For each comparable sample, $BC_e$ was higher than $EC_a$ by a factor of 2-7 (neglecting samples with very low concentrations). The $EC_a$ concentrations ranged from 2 to 8 ng $g^{-1}$, while the $BC_e$ ranged from 8 to 47 ng $g^{-1}$ (very similar to the range 7-52 found in 1983, Table 1). Also in the literature, $EC_a$ and $BC_e$ concentrations were found to differ by up to a factor of seven among different methods, and a factor of two is common (Watson *et al.*, 2005). However in previous comparison studies the sign of the differences between the proxies was not consistent. The longer storage time of the sample in the glass jar before the analysis ($EC_a$ proxies) may be responsible for some of the underestimation of black-carbon amounts.

## Albedo implications

Black carbon in snow reduces the albedo, but the amount of black carbon required to have a significant effect, and the magnitude of the effect, are more uncertain. The investigations are further complicated since the snow albedo depends on other factors such as snow grain size, snow thickness (and for thin snow, the underlying surface), other contaminants (e.g. mineral dust) and light conditions (both the amount of clouds and the solar zenith angle). However, black carbon alters the spectral properties of snow only in the visible part of the solar spectrum, below 900 nm, in contrast to e.g. grain size and clouds (Wiscombe and Warren, 1980).

A model by Warren and Wiscombe (1980, 1985) found black carbon mixed with coarse-grained snow to be more effective in reducing the albedo compared to black carbon in new snow. A black-carbon concentration of 10 ng $g^{-1}$ in new snow or 4 ng $g^{-1}$ in coarse-grained old snow may reduce the broadband albedo by 1% at the most sensitive wavelength (470 nm, Warren and Wiscombe, 1985). The effect is less at other wavelengths. Those calculations were for an external mixture of snow and black carbon. However, black carbon can be up to a factor of two more effective if the mixing is internal (black carbon particles embedded within snow grains). Another issue to consider is the vertical redistribution of black carbon in the snowpack as the snow melts. Black carbon has a larger effect on albedo if it is concentrated at the top surface.

For 2008 we plan to measure black carbon in snow as well as the corresponding spectral albedo. Albedo measurements will be made with an ASD Field Spec Pro spectrometer (wavelength range 350-2500 nm). We plan to design several experiments, particularly at sites where we expect to find relatively high black-carbon concentrations, aiming for a strong black-carbon signal to be able to separate it from the natural variability of snow albedo. However, the sites have to be selected with care to avoid emphasizing possible large black-carbon particles from local contamination sources.

## Conclusions

Relatively low black-carbon concentrations in snow were measured on Svalbard, with average concentrations of 7 ng $g^{-1}$ (range 0-69 ng $g^{-1}$) using the thermo-optical method. The optical method gave somewhat higher values. Warren and Wiscombe (1985) showed that a black-carbon concentration of 10 ng $g^{-1}$ in old snow (or 40 ng $g^{-1}$ in new snow) was sufficient to reduce the integrated albedo with 1%. Further, a 1.5% albedo reduction in the Arctic and a 3% reduction in northern hemisphere land areas were found to cause a shortwave radiative forcing averaged over the northern hemisphere of +0.3 W $m^{-2}$ (Hansen and Nazarenko, 2004). IPCC (2007) estimated the global radiative forcing of BC in snow to be 0.1 ± 0.1 $Wm^{-2}$. Thus the black-carbon direct albedo effect in snow may be substantial. We aim for verifying the direct snow-albedo effect with measurements in spring 2008.

## Acknowledgements

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# The warm winter temperatures of 2006 and 2007 in the Kongsfjorden Water Masses compared to historical data

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**Abstract:** time series of temperature and salinity content in the Kongsfjorden water masses and in the core of the West Spitsbergen current are expressed. The time series are based on CTD profiles collected since 1935; the profiles being irregularly spaced in time and location. Mean values of upper 50m and 100m-300m are presented. The Atlantic Water in the West Spitsbergen Current has an increasing trend during the last decade, indicating a warming of 2-3°C as well as an increasing tendency in salinity. In Kongsfjorden waters the winter/spring of 2006 and 2007 were exceptionally warm, while a clear trend in summer data cannot be seen. The explanation for the high temperatures in 2006 is an inflow of Atlantic Water in the deeper layers, whereas in spring 2007 a prevailing inflow of Atlantic Water in the surface is a plausible explanation. These two years show up as extreme events in the historic hydrographic data-set, and are not correlated with the local winter/spring atmospheric conditions.

**Keywords:** hydrography, Atlantic Water, Kongsfjorden, warming, front.

## Introduction

During the recent two years, 2006 and 2007, conditions which seem unusually warm have been observed in the Kongsfjorden water masses in late winter; February-May. The explanation for this must be sought among the processes forming the characteristics of the water. Kongsfjorden water masses are formed by local production through cooling and ice freezing during winter, combined with mixing with intruding Atlantic Water (AW) from the West Spitsbergen Current (WSC), and shelf water. During summer the local sources are surface heating, glacial and sea ice melting and river runoff. At any time the water in the fjord is a product of the source waters and the water previously present in the fjord, thus the history of the fjord water is also important.

AW and shelf water are advected into the region from distant sources; AW is advected by the Norwegian Atlantic Current (NwAC) entering the Nordic Seas through the Faroe Shetland Channel, and shelf water is advected northward by the coastal current. These two water masses form a front along the shelf edge, and are modified by cross frontal exchange all the way along the front. Although shelf water is located closer to the fjord, AW may be topographically steered into Kongsfjorden via the southern slope of Kongsfjordrenna, see Figure 1. The mouth of the fjord system sometimes blocks the inflow of water masses to the fjord (Cottier *et al.*, 2005), with the result that the fjord is sometimes isolated from the shelf and slope waters.

A hydrographic database including historic data from Kongsfjorden is constructed in order to explain the observed warming in 2006 and 2007, and to decide if these two years really are unusual compared to variability in previous years.

## Time series

One task of the ongoing MariClim project (http://mariclim.npolar.no) is to assemble a database on all known hydrographic data in

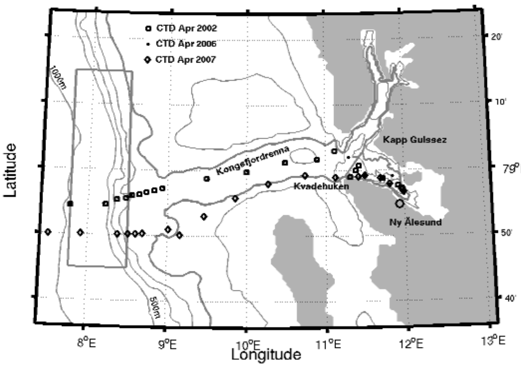

**Fig. 1** Map of the Kongsfjorden-Krossfjorden system and adjacent shelf and shelf slope area. The 100m, 200m, 300m, 400m, 500m and 1000m isobaths are shown, the 200m isobath is drawn as a thick line.

Kongsfjorden and adjacent seas. Two different data-sets are presented from this database; the WSC data-set and the Kongsfjorden data-set. The WSC data-set contain data from all known CTD-sections across the WSC within a box limited by latitudes 78.75ºN-79.25ºN and longitudes 007ºE-011ºE, and are interpolated onto a grid with 500m horizontal and 10m vertical grid spacing (from the surface to 700m). Altogether 26 sections are gathered in this data-set, covering 14 years in the period 1980-2007. The Kongsfjorden data-set contains one average CTD-profile for each cruise, made of profiles taken in the central Kongsfjorden basin during that cruise. The central basin is defined as limited by the 200m isobath and a straight line between Kvadehuken and Kapp Guissez. This line is shown in Figure 1. This data-set now contains 37 profiles from 20 different years in the period 1935-2007.

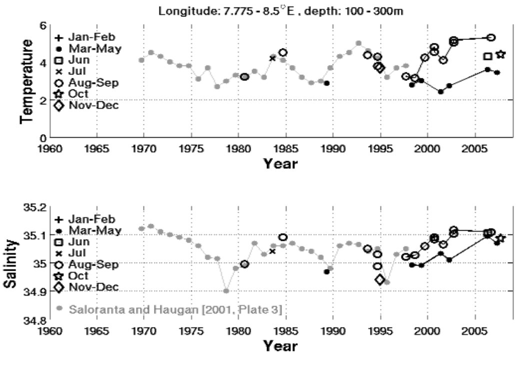

**Fig. 2** Time series of temperature and salinity compiled from the WSC data-set. The values are averages between 100m-300m and longitudes 007º45'E-008º30'E. Time of the year is indicated by the symbols. Gray points are taken from Saloranta and Haugan (2001).

Raw data for the Kongsfjorden data-set are first of all collected from the numerous cruises that has taken place in the area since 1994 by the Geophysical Institute, Univ. of Bergen (GFI), the Norwegian Polar Institute (NPI), the University Centre in Svalbard (UNIS), Norwegian College of Fishery Science, Univ. of Tromsø (NFH) and Institute of Oceanology, Polish Academy of Science (IOPAS). The compilation of data from these cruises is not yet completed. In addition, historical data up to 1990 are provided by the International Council for the Exploration of the Sea (ICES).

The WSC data-set contains data held by NPI and UNIS, or more precisely sections made by RV Ymer 1980, RV Lance 1983, 1984, 1993, 1997, 2001, 2002, 2006, 2007, RV Akademic Shuleykin 1989, RV Håkon Mosby 1994, 2000, 2001, 2002, RV Jan Mayen 1994, 2006, MV Polarsyssel 1998, 1999, and RV Polarstern 1998, 1999.

Figure 2 shows time series compiled from the WSC data-set, the values are averaged in a box which is comparable to a time series published by Saloranta and Haugan (2001, Plate 3). Their ensemble E1 has the areal limits 78.90ºN-79.55ºN and 7.5ºE-8.8ºE, only slightly north of the box taken from the WSC data-set: 78.75ºN-79.25ºN and 7.775ºE-8.5ºE, shown in Figure 1. The Saloranta E1 data are plotted as gray dots in Figure 2. Our Aug-Sep-values from 1997-1999 also agree well with the values calculated by Schauer and Fahrbach (2004, Figure 9) from the same data. All values in Figure 2 are averages between 100m-300m depth.

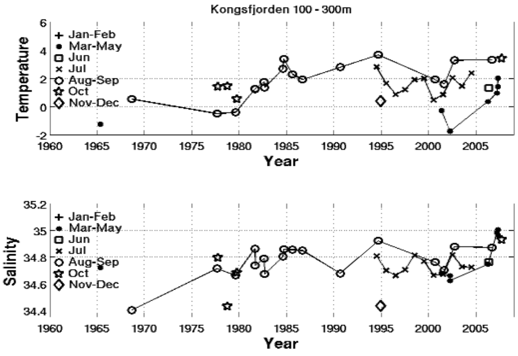

**Fig. 3** Time series of temperature and salinity compiled from the Kongsfjorden data-set. The values are averages between 100m-300m. Time of the year is indicated by the symbols.

Figure 3 shows time series compiled from the Kongsfjorden data-set, and averaged in the same depth range as the WSC data in Figure 2; 100m-300m. Note that the scales on the y-axis are not the same in Figure 2 and Figure 3. Data earlier than 1965 are sparse, and are not shown. There are not many spring data in the data-set, but it may be noted that the temperatures in the last four spring data point (April 2006 and March, April and May 2007) are comparable to earlier summer values. The salinity values in spring 2007 are peak values in the time series.

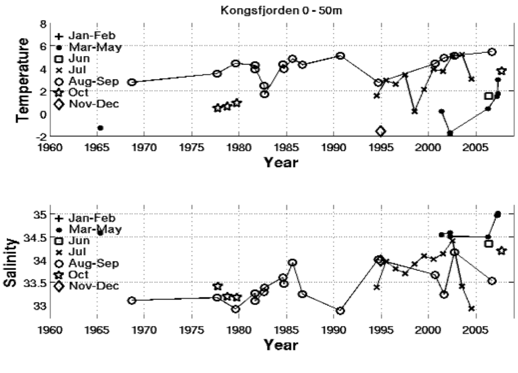

**Fig. 4** Time series of temperature and salinity compiled from the Kongsfjorden data-set. The values are averages of upper 50m. Time of the year is indicated by the symbols.

In Figure 4 mean values of the upper 50m of the Kongsfjorden data-set is shown. Also here the spring data from 2007 are peak values in the time series. As early as March the mean temperature is almost +2 ºC, and salinity stays close to 35 through all three months.

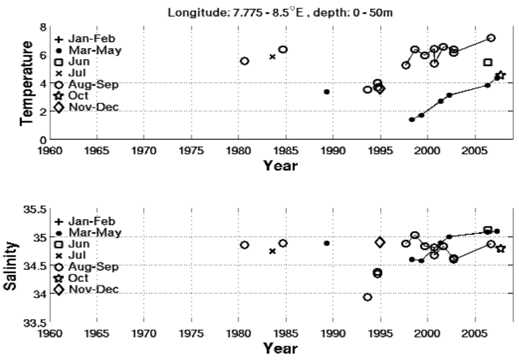

**Fig. 5** Time series of temperature and salinity compiled from the WSC data-set. The values are averages of upper 50m and longitudes 007.775°E-008.5°E. Time of the year is indicated by the symbols.

For comparison with the Kongsfjorden surface waters, also mean values of the upper 50m of the same areal box as used for Figure 2 are shown in Figure 5. The scales on the y-axes of Figure 5 are again not the same as on Figure 4. There is an increase in spring temperatures of more than 3 Kelvin from 1997 to 2007. Fairly warm values were found also in 1989. A similar behavior is present in the summer data; the increase from 1993 to 2007 is 3 Kelvin, but equally warm values can be found in earlier data. The salinity does not have clear trends.

## Discussion

The data assembled in the database are irregularly spaced both in time and exact location. And in the Kongsfjorden data-set also the number of CTD-profiles from each cruise is varying. The central basin is chosen for the Kongsfjorden data-set to avoid large variance between profiles, because it is subject to the least short term variation due to e.g. inflowing AW along the southern slope and freshwater outflow along the northern shore. Interannual comparisons should then be quite robust.

The time series from the WSC data-set agrees well with previously published data (Saloranta and Haugan, 2001; Schauer and Fahrbach, 2004). The increase in both temperature and salinity the last decade, seen in Figure 2, is within the same range as the interannual variability in the Saloranta time series. Since 1999 there is a clear seasonal variation in temperature, but previous data are too sparse that it can be concluded that this is a change. The upper 50m data in Figure 5 has a much clearer warming trend during the past decade. The warming trend agrees with several reports of warm anomalies advected into the region by the NwAC (e.g. Polyakov *et.al.*, 2005; Walczowski and Piechura, 2007).

The Kongsfjorden time series in Figure 3 and Figure 4 shows both the interannual and seasonal variability in the water masses. The July data fits well into the seasonal variation, showing a transition water mass between the winter produced water and the late summer water. These data are the crosses linked together with lines, and are all collected by IOPAS during their annual RV Oceania cruises. The interannual variation in these data may indicate that July water masses are more influenced by winter type water in some years, and other years more influenced by AW, as suggested by Cottier *et al.* (2005). The recent late summer values are in the upper limit of the value ranges both in temperature and salinity, but not anomalously high compared to earlier years.

There are unfortunately few data from winter and spring. No data from January and February are available. From the end of the winter season; March-May there are three April cruises (2002, 2006 and 2007), two May cruises (2001 and 2007), some profiles from March 2007, and one profile from 7th of May 1965. This old profile seems to have conditions closest to the April 2002 profile, so we propose that April 2002 is the 'normal' spring.

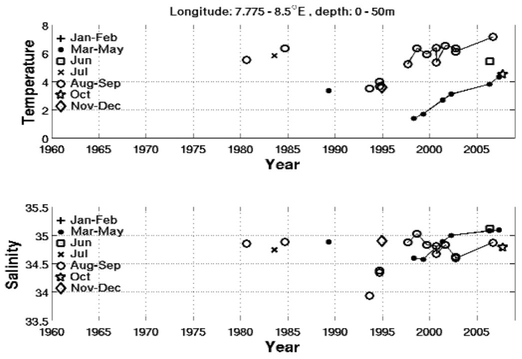

**Fig. 6** TS-plot of data from April 2002, 2006 (NPI-data) and 2007 (UNIS-data). Black lines are profiles from Kongsfjorden basin, dark gray lines are profiles from WSC core, light gray lines are all stations along transect from WSC to Kongsfjorden.

Then both spring of 2006 and 2007 stands out as unusual. The incidents that led to the spring conditions of 2006 is described in Cottier et.al. (2007), and were basically a result of a massive intrusion of AW to the fjord during February, due to prevailing winds from the north. This deep intrusion prevailed until it finally filled the fjord completely. The extremely warm and saline water masses in Kongsfjorden during March-May 2007 though, can not be explanation the same way.

Viewing the CTD-data from the April cruises in 2002, 2006 and 2007 in a TS-diagram, Figure 6, helps the interpretation. The whole sections from the WSC to the station between Ny Ålesund and Blomstrand are plotted in light gray. One station from each year in the central core of the WSC is plotted in slightly darker gray. The stations from the central Kongsfjorden basin are plotted in black marked with the corresponding year.

The WSC profiles are close to similar all three years, but the Kongsfjorden profiles are distinctly different each year. In 2002 and 2006 the stratification is in salinity, while in 2007 the water column is stratified in temperature - the warmest water is in the surface. The temperature of the 2006 data is determined by the amount of local surface cooling, as shown in Cottier *et al.* (2007). The water column in February-March was quite homogeneous in salinity, so any surface cooling would lead to vertical convection, thereby cooling the whole water column. In April 2006 the air was quite warm, as indicated in Table 1, showing monthly mean temperatures during February-March 2002, 2006 and 2007, and the 30 year monthly mean based on the 1961-1990 time period. The warm air led to melting and thus stratification in salinity, and no further cooling took place.

| | Feb | Mar | April | May |
|---|---|---|---|---|
| 2002 | -12.5 | -14.6 | -7.4 | -4.0 |
| 2006 | -10.7 | -13.2 | -1.0 | +0.2 |
| 2007 | -8.8 | -8.2 | -11.4 | -1.3 |
| 1961-1990 mean | -14.6 | -14.2 | -11.1 | -4.0 |

**Table 1** Mean monthly air temperatures in ºC in Kongsfjorden February-May in 2002, 2006 and 2007 compared to 30 year monthly mean. Data are provided by met.no, Ny-Ålesund weather station.

In April 2007 the surface is warmest despite the fact that air temperatures are cold, actually a bit colder than the normal. The only way such stratification can be upheld is by prevailing and steady intrusion of warm AW in the surface. It is also likely that the flow is strong because hardly any meltwater is seen; it might be flushed out of the fjord. The salinity in the whole water column is close to AW values. And AW is the only source for this high salinity values in this region. Cooling of such high salinity water produce very high density water, and comparisons of densities (not shown) reveals that the density of the bottom water in Kongsfjorden and the shelf (300m depth) is equal to densities at 500-600m in the WSC. The density gradient with lightest water in the WSC prevails in the whole water column.

## Concluding remarks

The normal response to northerly winds is intrusions of AW in the deep onto the shelf and into the fjord system, and this was found happening in February 2006 by Cottier *et al.*, (2007). The water in Kongsfjorden February 2006 was equally warm as in April 2007, but was cooled to about +0.5 ºC by the time the April cruise in 2006 took place. This could happen because the fjord system was isolated from further intrusion of AW for a long period. The isolation is probably controlled by the mouth of the fjord system.

The northerly wind response is hardly possible with the high density water present on the shelf in spring 2007. That would require a probably unrealistic amount of upwelling in the WSC. The consequence of this high density shelf water is that the inflow of AW is forced to be in the surface, and it seems likely from the small amount of meltwater that a large portion of the outflow is also in the surface. Surface cooling on the shelf and in the fjord increase the density of the water there even more, and thus acts as a positive feedback to this scenario.

## Acknowledgement

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# Fast ice evolution in Kongsfjorden compared with other Svalbard fjords

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**Abstract:** seasonal fast ice is an important feature for Svalbard fjords, both concerning the physical environment (surface energy balance) and the ecosystem. Sea ice in general is a climate indicator, since it responds relatively fast to climate change. The fast ice evolution in Kongsfjorden is monitored as a part of a longterm project at the Norwegian Polar Institute systematically since 2003. As a consequence of the ongoing International Polar Year 2007/2008, more intensive fjord ice studies were performed at several of the Svalbard fjords during winter 2006/2007. In Kongsfjorden, the standard monitoring programme of the NPI continued. Additional information is available through "MariClim" studies. In Rijpfjorden (Nordauslandet), ice thickness was systematically measured from March to July as a part of the project "Cleopatra". Storfjorden had the third time in a row a wintering of the French boat "Vagabond", where data are collected as a part of the "DAMOCLES" project. Also this last winter, the Arctic and Antarctic Research Institute (AARI) in St. Petersburg conducted sea ice observations in Grønnfjord near Barentsburg, which are also part of a Norwegian-Russian collaborative research project. 2006/2007 was, similar to 2005/2006, a relatively mild winter with less and thinner ice than observed earlier for some of the sites where earlier observational data are available.

**Keywords:** sea ice, climate, ice thickness, snow thickness, Arctic.

## Introduction

Fast ice in Svalbard fjords consists solely of seasonal ice, i.e. ice that melts completely in summer. Each autumn and winter, new fast ice forms. The fast ice evolution responds directly to the conditions in the atmosphere and ocean (fjord hydrography), therefore fjord fast ice can be used to indirectly assess atmospheric and oceanic changes.

In this paper we present a setup and recent results regarding assessing the seasonal evolution of fast ice in Kongsfjorden at the northwestern coast of Spitsbergen, Svalbard. The Kongsfjorden results from early 2007 are related to other Svalbard fjords – from several of them observations were possible as a part of the increased activities in the framework of the International Polar Year 2007/08 (IPY).

## Fast ice thickness monitoring Kongsfjorden and other fjords

Kongsfjorden is located at about 79° N and 12° E. The fjord is about 20 km long and between 4 and 10 km wide. In most of the years where observations exist, fast ice in Kongsfjorden formed usually between December and February; snow and ice started to melt after the onset of melt, often around end of May/early June (Gerland *et al.*, 1999; Svendsen *et al.*, 2002; Gerland *et al.*, 2004). The Kongsfjorden fast ice evolution is affected by Atlantic water from the West Spitsbergen Current, which reaches the inner fjord.

The systematic fast ice monitoring at Kongsfjorden was started in 2003, and it consist of ice extent mapping and *in-situ* measurements of ice and snow thickness, and freeboard at several locations in the fjord (for details see Gerland and Renner 2007). During seasons 05/06 and 06/07, the thickness monitoring was logistically more difficult due to unstable ice conditions during most of the time. Access to the fast ice was only possible by boat.

Here, fast ice in four other Svalbard fjords will be briefly compared with Kongsforden fast ice in season 06/07:

i) *Grønnfjorden*, which is a fjord arm of Isfjorden (south of Kongsfjorden).

ii) *van Mijenfjorden*, sheltered by an island at the fjord entrance (south of Isfjorden).
iii) *Storfjorden*, a large fjord or bay east of Spitsbergen.
iv) *Rijpfjorden*, on Nordaustlandet, open towards the north and hardly affected by Atlantic water.

These four fjords and Kongsfjorden have both similarities and differences in size, geographical and hydrographical setting, and connection to relevant oceanic currents. Here, some of the relevant issues for the intercomparison will be mentioned and discussed below.

At Grønnfjorden, thin ice did not allow any *in- situ* measurements. In van Mijenfjorden, thickness data became available as a by-product of UNIS fieldwork. In Storfjorden (Inglefieldbukta), a systematic thickness monitoring is part of the sea ice and oceanography surveys of DAMOCLES during the yacht's "Vagabond" wintering, and in Rijpfjorden thickness data were collected to support ecosystem studies.

## Results

In most years since 1997, the fast ice extent in Kongsfjorden covered both the innermost part of the fjord to the archipelago of the Lovenøyane, and parts of the area between the Lovenøyane and the line Ny-Ålesund-Blomstrand(halv)øya (for extent maps 2003-2005, Gerland and Renner, 2007). During the last two winters (2005/06 (Cottier *et al.*, 2007) and 2006/07), the ice cover was both less extensive and of shorter duration. In 2007, the southern shore of Kongsfjorden was never properly connected to the fast ice cover in the inner fjord (Figure 1).

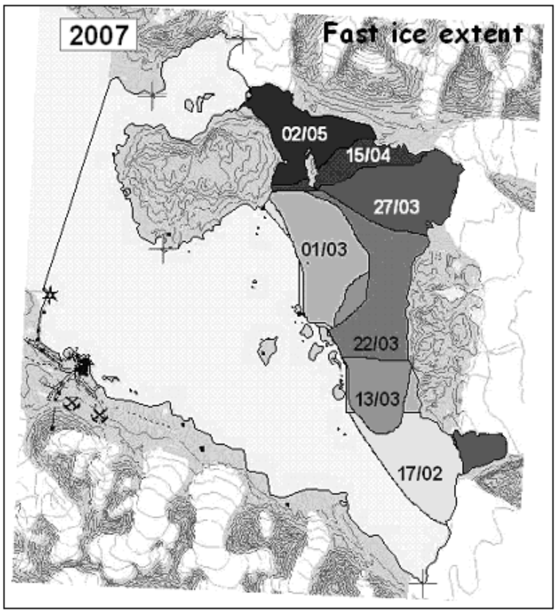

**Fig. 1** Kongsfjorden fast ice extent in early 2007. Ny-Ålesund is located at the fjord's southern shore to the left in the map. Dates mark the position of the fast ice edge from the field the date is on towards open water. The southern shore of Kongsfjorden was ice-free all winter.

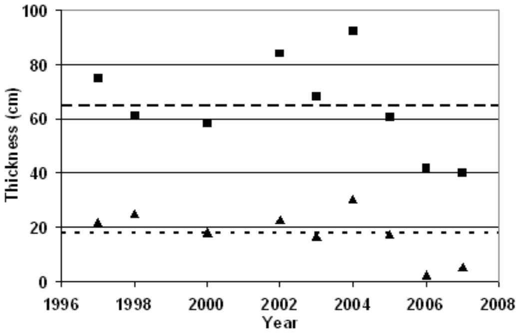

**Fig. 2** Maximum seasonal ice (squares) and snow thickness (triangles) at Kongsfjorden (1997-2007). The horizontal lines show averages for the entire time (ice=65 cm, long dashes; snow=18 cm, short dashes). 2002 data are from Nicolaus *et al.* (2003).

Seasonal maximum ice thickness in Kongsfjorden ranges usually between about 60 and 90 cm, but was substantial lower during the most recent seasons (2005/06 and 06/07) than in the years before (1997-2005). Since both the ice formation started in these last two seasons late and it decayed early, it is not surprising that maximum snow thicknesses covering the fast ice were with less than 10 cm also less than earlier observed (Figure 2).

## Comparison with other Svalbard fjords

An earlier intercomparison of Kongsfjorden, van Mijenfjorden and Hornsund, all at the western coast of Spitsbergen, revealed relatively similar fast ice thicknesses in spring 2004 (Gerland and Hall, 2006), a year with more ice than during the last two minimum seasons 05/06 and 06/07.

In season 06/07, data from three fjords at the western coast show a spread from (estimated) 20 cm at Grønnfjorden to 66 cm at van Mijenfjorden for the maximum (observed) fast ice thickness (Figure 3). The two fjords further east, Storfjorden (Inglefieldbukta, 90 cm) and Rijpfjorden in the northeast (114 cm), have much thicker ice.

## Discussion

First focusing on the three fjords in western Spitsbergen: With less maximum ice thickness one can expect a larger spread between the fjords than in a season with thicker fast ice and a stable fast ice cover in all fjords. In Grønnfjorden, no stable cover was reached at all, and in inner Kongsfjorden only a very small part appeared to be stable. Van Mijenfjorden had a stable fast ice cover in its inner part (due to its setting), but less ice than usual in the other part of the fjord. Ice growth rates are fastest for thin ice, and small differences in the local climate and boundary conditions lead to different ice formation scenarios for the fjords. New hydrographic observations (Cottier *et al.*, 2007) revealed and

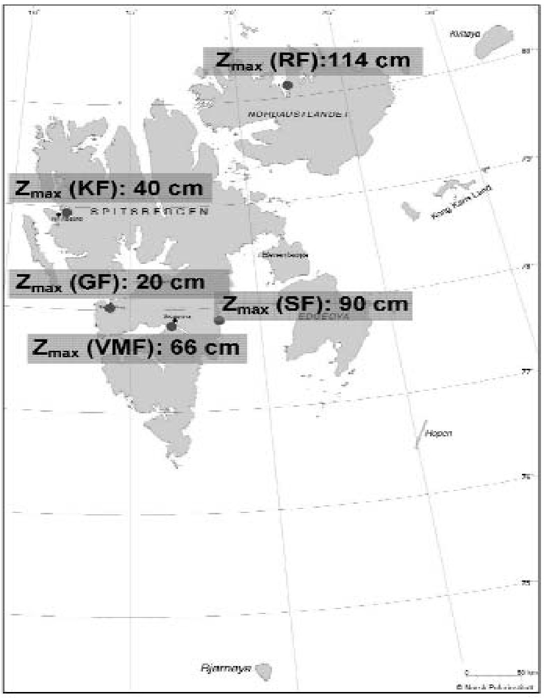

**Fig. 3** Maximum fast ice thicknesses observed at five Svalbard fjords- during winter 2006/07. Grønnfjorden (GF) data are an estimate from ice type classification.

important role of wind-driven water masses that brought more Atlantic water to Kongsfjorden and other western Svalbard fjords than usual, contributing to less fast ice formation. This in combination with relatively mild winters can be seen as main factors changing fast ice conditions in those fjords during the last two seasons versus the years before.

Moving to the fjords in the east (Storfjorden) and northeast (Rijpfjorden), it is obvious that those boundary conditions are more fundamentally different for those fjords, compared with the three western fjords. In the east and northeast, both lower air temperature and less influence by warm Atlantic water from the West Spitsbergen Current (Svendsen *et al.*, 2002) ease fast ice formation.

## Conclusions

Both 2005/2006 and 2006/2007 were winters with less fast ice than ”usual” in several of the observed Svalbard fjords, and a shorter fast ice season.

For a more detailed analysis, atmosphere and ocean-related drivers need to be reviewed, and more observation data are necessary. So far, time series are both too short, and data are necessary for (at least) both a fjord that is and another fjord that is not directly influenced by the Atlantic water from the West Spitsbergen Current.

Consequently, it is suggested to keep both a western (Kongsfjorden) and an eastern Svalbard fjord (Storfjorden) in a long-term fast-ice monitoring setup, as a legacy of the IPY.

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