LUSO-AMERICAN
FOUNDATION

# CLIMATE CHANGE AND POLAR RESEARCH


DOCTOR SABIT ABYZOV

*Winogradsky Institute of Microbiology, Russian Academy of Sciences, Moscow*

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DOCTOR DONALD PEROVICH

*Cold Region Research and Engineering Laboratory, Hanover, NH, USA*



Luso-American Foundation
Lisbon, Portugal. March 14, 2007

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*The Luso-American Development Foundation (FLAD) is a private foundation that strives to contribute toward the development and modernization of Portugal. Aiming to achieve this objective, the Foundation has been active in supporting research and furthering the field of Ocean Science. The country's geographic location and its past efforts to increase our knowledge of the oceans during the era of Portugal's maritime discoveries have motivated FLAD to become increasingly involved in supporting discussions on a wide range of ocean-related topics.*

*In line with these aims, FLAD has decided to organize a yearly "Lecture on Marine Sciences" to be presented by a renowned guest expert in the field. The initiative is also designed to strengthen ties among scientists from around the world and their Portuguese counterparts.*

*We are pleased to publish the 9th Lecture of the Series: "Climate Change and Polar Reseach", given by Doctor Sabit Abyzov and Doctor Donald Perovich at the Luso-American Development Foundation, on March 14, 2007.*

**Doctor Sabit Abyzov** received a Ph.D. at the All-Union Institute of Agricultural Microbiology in 1956 in Leningrad. He is a Senior Researcher at the Winogradsky Institute of Microbiology of the Russian Academy of Sciences in Moscow. He participated in four oceanographic expeditions and seven Antarctica expeditions to the Vostok Station, where he initiated the study of the depth distribution of microorganisms in ice. The Kapitsa Medal (1995) recognized his discovery of super long anabiosis of microorganisms in cold environments. Dr. Abyzov is a long-standing member of the Russian Committee for Antarctic Research. He is the author of over 100 scientific articles on microorganisms in ice.

**Doctor Donald Perovich** received a Ph.D. degree in Geophysics from the University of Washington in 1983 in Seattle. He is a Research Geophysicist at the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. He has participated in numerous field experiments including serving as the Chief Scientist of the international Surface Heat Budget of the Arctic Ocean (SHEBA) Program, which included a year-long ice drift experiment. He also conducted sea ice studies during a 2005 Trans Arctic icebreaker expedition to the North Pole. The U.S. National Science Foundation Arctic Service Medal (1999) and the Department of the Army Meritorious Civilian Service Award (1999) recognized his accomplishments. He is the author of over 100 scientific articles on sea ice properties and processes.

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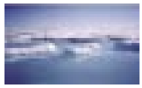
AND POLAR RESEARCH



# *MICROBIOLOGY OF THE ANTARCTIC GLACIER ABOVE THE LAKE VOSTOK*


*S. S. Abyzov*

*I. N. Mitskevich*

*M.V. Ivanov*


**Lecture presented by**

**Doctor Sabit Abyzov**

## INTRODUCTION

The microbiological investigations on the Central Antarctic ice sheet can be conventionally divided into three parts.

1. First of all it was necessary to work out a reliable method of aseptic sampling from different layers of the ice sheet.
2. Then on the basis of these investigations it was possible to make the microbiological characteristics of the whole ice sheet thickness.
3. At last the application of the molecular biology methods are important step in the investigation of Antarctic glacier basal strata.

There are rather favorable conditions for aseptic sampling of cores in case of boring of glacier. It's a reason why we investigated distribution, activity and biodiversity of ancient microorganisms in ice core collected from borehole near Russian Antarctic station "Vostok" in Central Antarctica [Fig. 1]. You can see that the

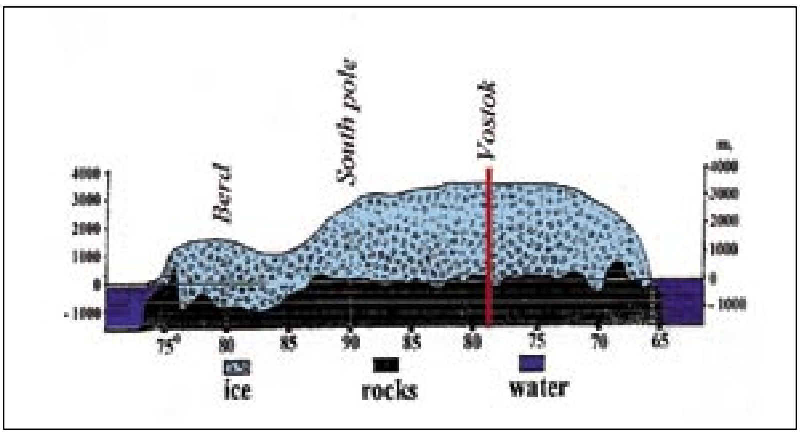



Fig. 1. Cross-section over Central Antartica.

thickness of ice in this region reach up to 3750 m. The age of lowest part of glacier is 420 thousands years. Main part of this glacier was formed from atmospheric precipitation migrated to Antarctica from more warm part of South Hemisphere.

The flow winds bring to Antarctic not only atmospheric liquid but also a lot of aerosolic microparticles including mineral dust, spores and remains of p1ants microorganisms and unicellular algaes. All these microparticles are preserved in ice thickness during long period of time.

The drilling of borehole was started in Central Antarctica in 1967 and was stopped in February 1998 at depth 3623 m. Now the deep of borehole reached 3659 m. Scientists from Institute of Microbiology of RAS collected samples of ice cores from upper layers of glacier up to depth about 3660 m in framework of russian-french-american international project.

## METHODS

The development of aseptic sampling of melting water from ice cores was a first task of our investigation (Abyzov et al, 1979). The special microbiological rig at Vostok Station has been constructed for this purpose. It has three modules: a drilling facility, a microbiological laboratory, and an aseptic sampling unit [Fig. 2], common view of rig [Fig. 3], plan of interior.

The drilling facility consists of a tower installed over the mouth of the well, a bobbin with cable, a drilling machine, and a control panel. The microbiological laboratory is equipped with an autoclave, a thermostatically controlled incubator, a glove-box and UV - lamps on the walls and in the glove-box. The aseptic sampling unit is shown schematically in Figure 4. This design is to sample from an ice core aseptically by melting out the interior of the sample (1). Its main part is a cupper or aluminum

**Fig. 2.** Common view of microbiological laboratory at Vostok Station.

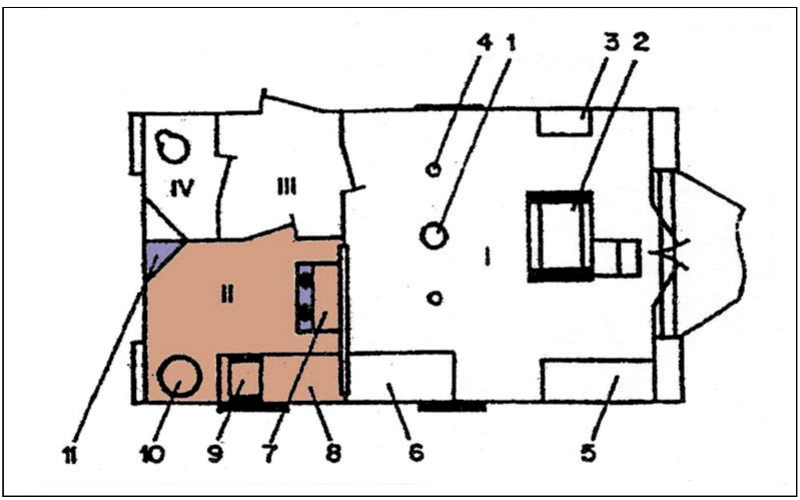



**Fig. 3.** The housing for the microbiological deep-core drilling at Vostok Station: I - drilling section; II - microbiological section; III - entry; IV - washing space; 1 - the mouth of the borehole, 2 - the winch, 3 - drilling control, 4 - foundations of the drilling rig, 5 - table, 6 - storage box for sterile extraction of ice core samples, 7 - box for sterile ice sample analyses, 8 - working table, 9 - thermostat, 10 - hot steam pot, and 11 - water tank.

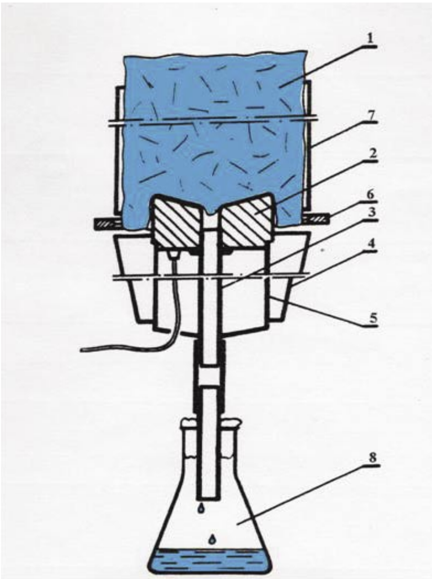



**Fig. 4.** A device for sterile extraction of ice samples from the ice core station:

1 - ice core, 2 - heater, 3 - sterile meltwater pipe, 4 - water collection cup, 5 - support for heating element, 6 - ring of breaking device, 7 - ice core support, and 8 - sterile bottle.

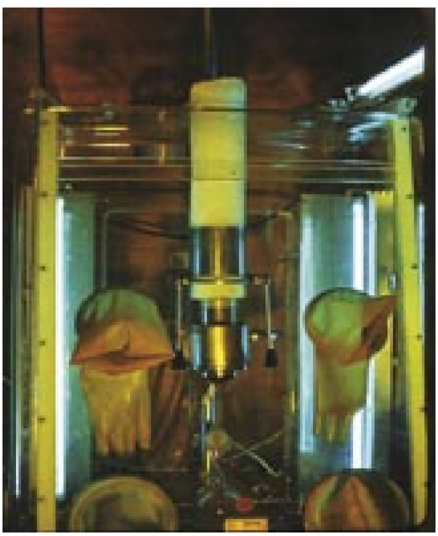


**Fig. 5.** A General view of sampling unit installed in a glove-box. Process of sampling of a core segment at Vostok Station.

heater (2). Its working surface is in the shape of a concave cone, slightly smaller in diameter than the core water from the melting core interior flows through the central hole in the heater along the water-receiving pipe (3) into the sterile receiver (8). The heater, tightly covered with a metal lid, and the water-receiving pipe are sterilized in autoclave. [**Fig. 5**], sampling unit inside of glove box.

Just before sampling, the end of the core is chopped off to expose a surface area free from contamination. [**Fig. 6**], chopping device. The end of the core is quickly lowered onto the sterile surface of the heater, and when the heater is turned on, sampling starts.

Before being sent to the Antarctica, the device was tested for reliability in aseptic sampling from ice cores (Abyzov et al., 1979). For this purpose, sterile water was frozen in cylindrical molds under laboratory conditions, and the surface of the resulting ice "core" was coated with a dense suspension culture of bacteria *Serratia marcescens.*

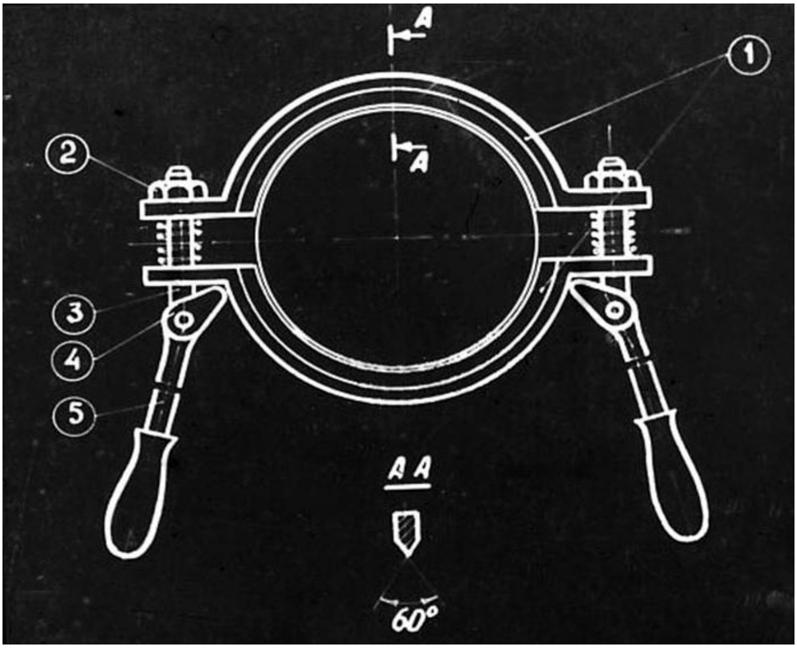



**Fig. 6**. Chopping device: 1 - circular knife: 2 - fixator: 3 - pivot for spring; 4,5 - lever of chopping device.

The lower end of the core mounted in the sampling device was then chopped off, and its central portion sampled. Repeated inoculation of meat-peptone broth (MPB) with the resulting melt water demonstrated that microorganisms spread on the ice-core surface did not penetrate into interior layers and this technique described above ensures sterile sampling from the interior of the core.

Samples from the drilling hole at Vostok station were tested for permeability by microorganisms. Subsequently the petrography of thin sections of the tested core was studied. The results demonstrated the reliability of ice cores for microbiological research.

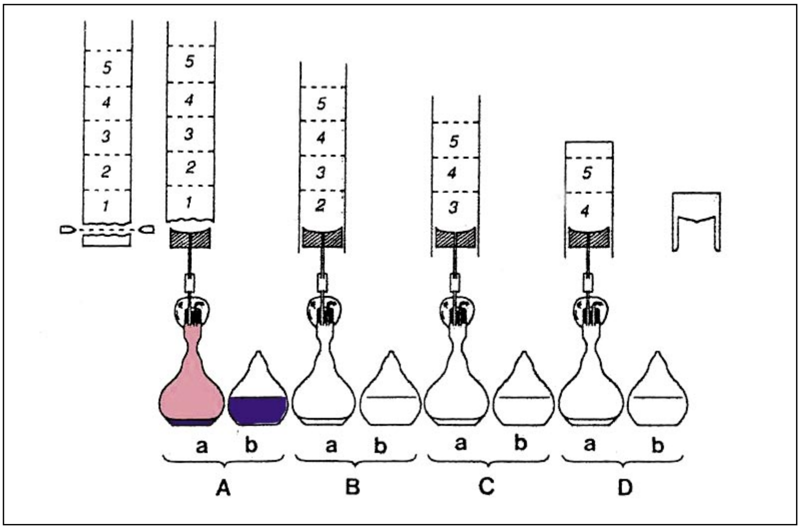



**Fig.** 7. Scheme of sampling from the central part of ice core: A: test sampling; B-D: samples inoculated on nutrient media; [1-5] studied parts of core segment; a: inoculation; b: flask sealed.

As shown in **Figure** 7 (Scheme of sampling), successive samples were cultured separately, the first sample on rich medium. The absence of microbial growth in the first test sample and its presence in subsequent samples provided further demonstration of the reliability of the technique.

The samples were collected in specially prepared 1-liter narrow-necked flasks. The first of them were aseptically connected to the sampling device by means of a rubber tube pipe before sampling was started. Each flask contained a concentrated nutrient solution designed to be diluted to the required concentration by addition of the sample water. As each water sample was completed, the heater was switched off to terminate flow of sample water into the recipient flask. The narrow neck of the flask was then fused with a gas burner, another flask was aseptically connected to

the device, and the sampling process was repeated. [Fig. 8] flask with nutrient media before and after sampling. [Fig. 9] remains of ice core segments after sampling of the central parts of the cores.

Sealed in Antarctica flasks were carried in the refrigerator of the ship, incubated at about 20°C for up two months, and subsequently opened in a sterile box, where samples were inoculated on different nutrient media.

The method of sampling of melted water was used not only for cultivation of viable microbial cells. The part of water was used for investigation of total count of microbial cells on nuclear porous filters and for electronic microscopy. For this manipulations we used glove box filled with sterile air under high pressure [Fig. 10 (a, b)].

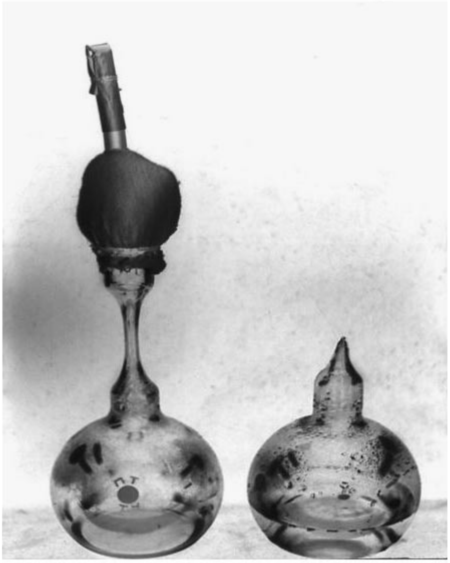
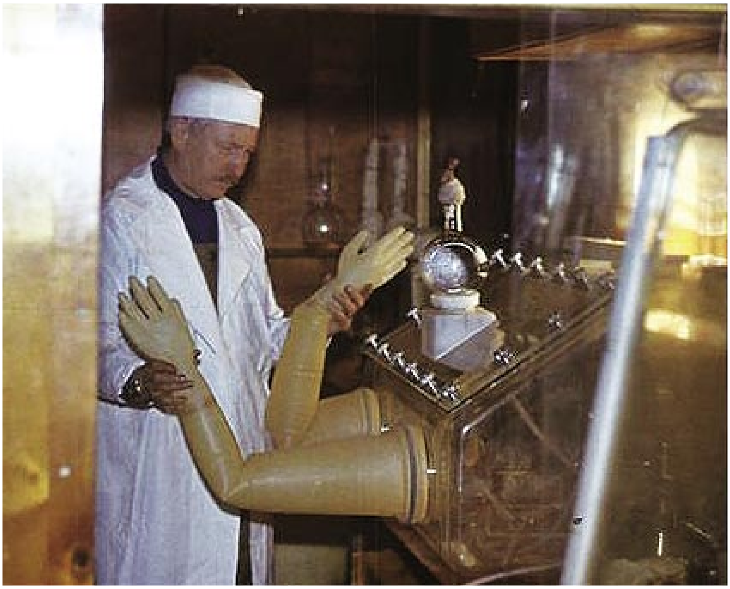


Fig. 8. Flask with nutrient media before and after sampling.

Fig. 9. Remains of ice-core segments after sampling of the central parts of the cores.



[a]

[b]

**Fig. 10** [a, b]. Manipulations with glove box filled with sterile air under high pressure.

## RESULTS

It is well known that organic remnants of animals and plants preserved for millennia years in glacial ice. Our investigation with the use of luminescent and scanning electron microscopy made it possible to characterize morphological diversity of microbial population within the antarctic glacier. All microorganisms conditionally grouped by taxonomic principle were found by us in certain quantities almost everywhere in the thickness of ice sheet. Among them there were:

• small and big cocci, single and double rods (from 0,2-0,4 mm to 1-2 mm), straight and curved rods, chains of rods, and actinomycetes;

• representatives of various yeast's species;

• remains of diatomic algae, unicellular algae, and in some cases well preserved shells [Fig. 11-15]. Diatoms and unicellular algae.

The total count of microbial cells in melted water varied from 1 to 12 thousands per 1 ml.

Fig. 11. Different cells of bacteria and actinomycet.

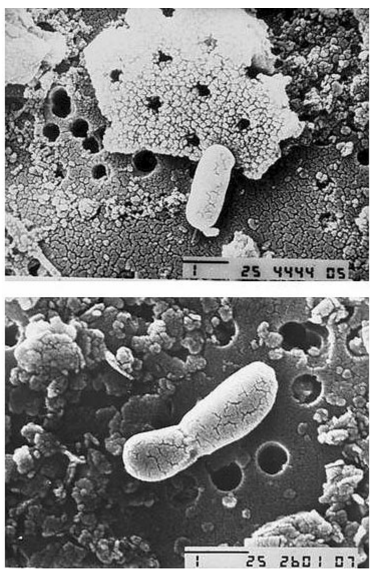


Fig. 12. Diatoms shell and bacterial cells.

**Fig. 13**. 1203 m. Diatom_fragment.

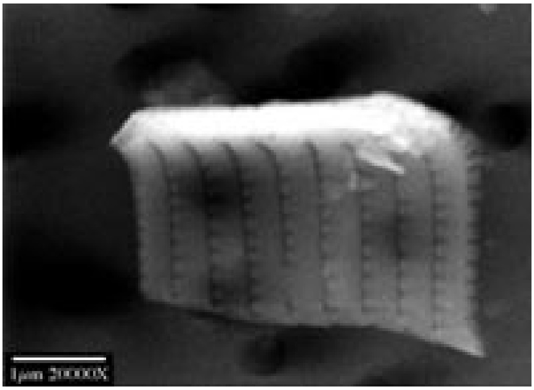



**Fig. 14**. 1249 m. Cyanobacteria_sp.

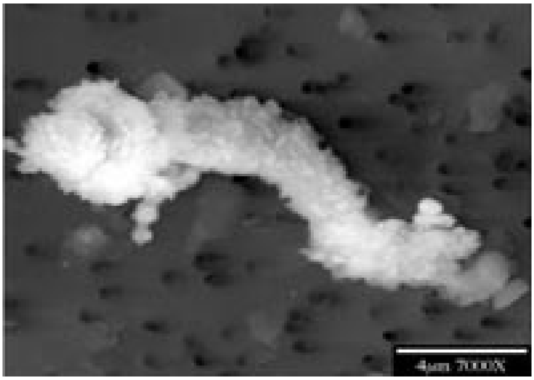



**Fig. 15**. 2827 m. Fragilariopsis_sp.

Maximum value was in samples of ice formed in time of severe cooling of climate when level of ocean dropped and wind erosion increased (Abyzov et al., 1998, Hoover et al., 1999). It is a reason why total count of microbial cells have a correlation with number of dust particles in different horizons of ice thickness [FIG. 16]. Distribution of numbers of microorganisms and dust particles along the length (age) of the Vostok Station ice core).

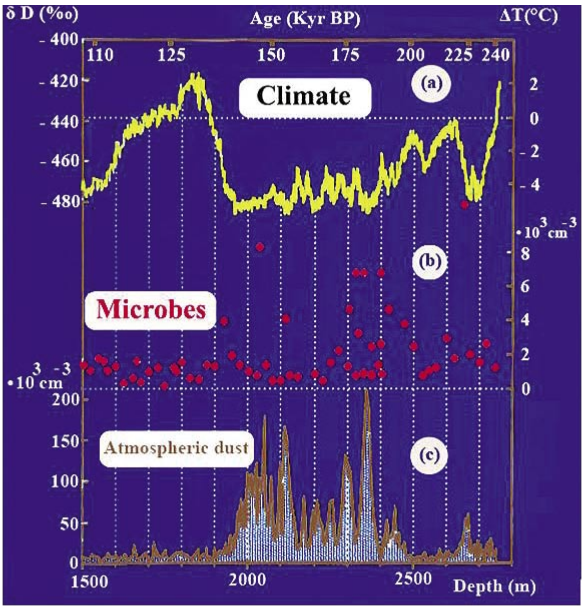



FIG. 16. Distribution of numbers of microorganisms and dust particles along the length [age] of the Vostok Station ice core

[a] – Climate change

[b] – Concentration of microbial cells along the core

[c] – Concentration of dust particles along the core

The viability of microorganisms presented in ice cover was investigated by two independent methods. The microbial activity in samples of melted water was stimulated by small quantity of $^{14}$C-protein hydrolisate. Viable microbial cells included organic matter in biomass actively (Tabl. 1).

The second approach is the search of viable microorganisms by means of cultivation on meat-peptone broth and potato broth with 0,1% yeast extract. The number of positive results obtained for

**Table 1** Including the organic substrate (14C-protein hydrolisate) into microbial biomass of melted water taken aseptically from ice cores (Abyzov et al., 1999).

| Depth, m | Age, thousands of years | Incubation time, hours | Substrate uptake, $\mu g$ C $l^{-1}h^{-1}$ | | Number of cells per ml of sample |
|---|---|---|---|---|---|
| | | | At 18° C | At 12° C | |
| 1665 | 118 | 4 | $4.4x10^{-3}$ | $7.0x10^{-4}$ | $1.6x10^{3}$ |
| 2035 | 147 | 24 | 0 | $3.0x10^{-4}$ | $8.3x10^{3}$ |
| 2115 | 155 | 24 | 0 | $1.0x10^{-4}$ | $4.1x10^{3}$ |
| 2376 | 187 | 18 | $1.3x10^{-3}$ | $1.0x10^{-4}$ | $2.5x10^{3}$ |
| 2425 | 192 | 24 | $1.0x10^{-1}$ | * | $4.6x10^{3}$ |
| 2500 | 202 | 24 | $6.0x10^{-4}$ | * | $2.5x10^{3}$ |
| 2570 | 217 | 24 | $2.0x10^{-4}$ | $6.0x10^{-4}$ | $1.2x10^{3}$ |
| 2626 | 220 | 7 | $1.4x10^{-3}$ | 0 | $1.8x10^{3}$ |
| 2673 | 227 | 40 | $5.0x10^{-4}$ | 0 | $2.0x10^{3}$ |
| 2719 | 236 | 40 | $1.0x10^{-4}$ | 0 | $2.5x10^{3}$ |
| 2750 | 242 | 20 | $2.0x10^{-4}$ | 0 | $1.2x10^{3}$ |

* - no determination

different ice cores presented in Table 2. Probability of discovering viable microorganisms decreases with increasing depth of ice. If, for example, 20% of all samples from the superficial 100 m of an ice sheet contain viable microorganisms, at depth of 200 and 300 m the proportions will have decreased to 14% and

**Table 2** Numbers of viable microorganisms at various depth in the ice cores of Central Antarctica

| Glaciers layers analyzed | | | No. of core seg- ments ana- lyzed | No. of inocula- tions | No. of positive probes | Percent of positive probes |
|---|---|---|---|---|---|---|
| Depth (m) | Length (m) of core analyzed | Aproximate age (years) | | | | |
| 0-105.00 | 105.00 | 0-3000 | 26 | 144 | 29 | 20 |
| 105.10-206.70 | 101.60 | 3000-7400 | 57 | 129 | 18 | 14 |
| 206.70-320.80 | 113.10 | 7400-12500 | 86 | 250 | 14 | 10 |
| 330.00-1500.00 | 1170.00 | 12500-107000 | 62 | 207 | 14 | 6 |
| 1500.00-2405.00 | 905.00 | 107000-200000 | 39 | 176 | 6 | 3 |

10%, respectively. In the deepest layers of the ice sheet 300-1500 m and 1500-2405 m, the numbers samples yielding growth have not exceeded 6% and 3%, respectively (Abyzov et al., 1979 a; Abyzov, 1982). [Fig. 17] Percentage of vital microorganisms of different types decreasing with depth (and age) of the ice core.

Isolation of more as 160 strains of viable microorganisms from Antarctic glacier is one of important results of our investigation (Table 3 and 4). In relatively young layers of the ice sheet a great variety of viable microflora was observed (Abyzov, 1982). In older layers, between 500 and 2405 m, microflora is sparse, and, according to our results (Abyzov, 1993) only spore-forming bacteria are viable [Fig. 17].

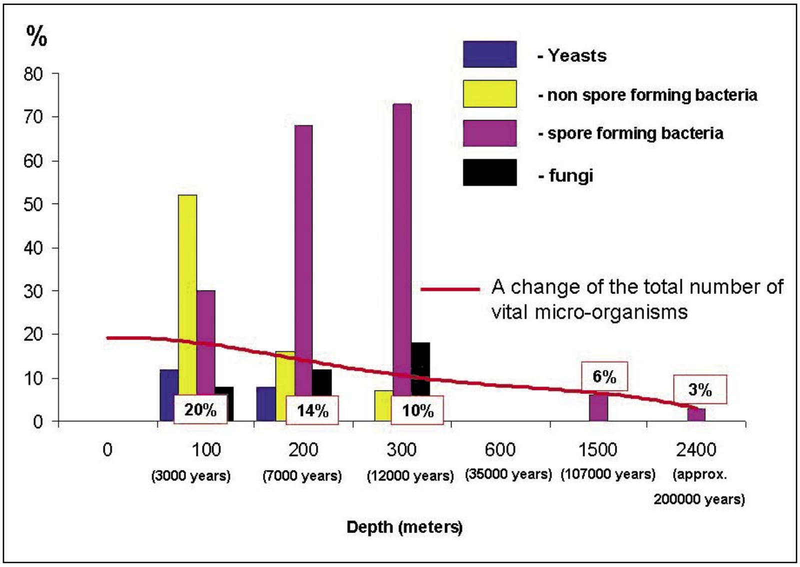



FIG. 17. Percentage of vital microorganisms of different types decreasing with depth (and age) of the ice core.

## Spore-Forming Bacteria

Many authors noted the exceptional ability of bacterial spores to survive for long periods, from several hundred thousand to several million years, especially at low temperatures and with protection from harmful environmental factors. It is not surprising that these organisms predominate in the most ancient ice layers, where conditions were ideal for longevity. The data are presented in Table 3.

Different species of spore-forming sporogenous bacteria are spread along the whole core in the 320-m ice layer, but they have not been found in all layers studied, confirming our conclusions about the haphazard and uneven distribution of viable microorganisms in the ice sheet. It is interesting to note that the increase with depth in the ratio of spore-forming to non spore-forming bacteria was found (Table 3).

**Table 3** The biodiversity and distribution of different species of the genus Bacillus in the Ice Shield of Central Antarctic

| Species | Number of positive results | % of positive results* | Age of Samples (years) |
|---|---|---|---|
| *B. megaterum* | 10 | 25 | 160, 355, 3250, 4900, 5400, 5800, 8900, 9800, 12000, 17000 |
| *B. subtilis* | 9 | 22.5 | 160, 8500, 9350, 11600, 12500, 30000, 34000, 50000, 200000 |
| *B. brevis* | 6 | 14 | 160, 1500, 2100, 2900, 3250, 7450 |
| *B. firmus* | 4 | 10 | 1800, 3250, 5800, 11000 |
| *B. coaguians* | 4 | 10 | 2100, 3650, 7650, 9350 |
| *B. badis* | 4 | 10 | 7650, 10800,11000, 11600 |
| *B. circuians* | 3 | 7.5 | 2900, 7100, 11600 |
| *B. pumitis* | 2 | 5 | 2900, 3800 |
| *B. cereus* | 2 | 5 | 3650, 3400 |

* The total number of samples–40

** *B. polymyxa, B. macroides, B. stearothermophilus, B. popilie, B. laterosporus, B. licheniformis, Clostridium aurantibutiricum and Cl. tertium* have been isolated from single ice cores.

**Table 4** The microscopic fungi isolated from the Central Antarctic ice cores

| Fungus species | Depth of ice sample (m) | Approximate age of the ice layer (years) |
|---|---|---|
| *Penicillium verrucosum var. cyclopium* | 11 | 160 |
| *Penicillium simplicissimum* | 70 | 1760 |
| *Penicillium granulatum* | 70 | 1760 |
| *Aspergillius versicolor* | 73 | 1800 |
| *Penicillium roqueforti* | 73 | 1800 |
| *Penicillium paxilli* | 80 | 2100 |
| *Mucor circinelloides* | 81 | 2100 |
| *Penicillium paxilli* | 93 | 2500 |
| *Alysidium resinae* | 114 | 3300 |
| *Aspergillius versicolor* | 194 | 6900 |
| *Mucor racemosus* | 212 | 7500 |
| *Aspergillius repens* | 222 | 8150 |
| *Penicillium chrysogenum* | 233 | 8500 |
| *Penicillium ochro-chloron* | 234 | 8530 |
| *Penicillium chrysogenum* | 234 | 8530 |
| *Penicillium lanosum* | 260 | 9770 |
| *Mucor circinelloides* | 280 | 10640 |
| *Aspergillus sydovii* | 286 | 10800 |
| *Phialophora bubakii* | 315 | 1200 |
| *Penicillium sp.* | 340 | 1500 |
| *Penicillium sp.* | 651 | 38600 |

The growth-temperature range of the strains studied has been rather broad, from 4 to 50°C. Abundant growth has been observed at 40-50°C, which is not characteristic for many modern strains of mesophilic spore-forming bacteria. According to Cameron et al. (1972a), also, many species of Antarctic spore-forming bacteria have growth optima in the interval 37-45° C.

The strains isolated from the ice sheet have synthesized enzymes usual for this group of microorganisms - dehydrogenase, amylase, protease and esterase (Abyzov et al., 1988) - but the activity of these enzymes was lower than in the same species isolated at the temperate latitudes, a fact that corresponds to the decrease, established earlier, in physiological activity of microorganisms after long inactivity (Beker et al., 1981).

We have also studied the gradual restoration of physiological activity of strains of spore-forming bacteria isolated by our group in comparison with that in the control strain, *Bacillus subtilis* (Ehrenberg) Cohn. We have cultivated them for two months at + 37° and observed a 1,5 - to 3-fold increase in activity, as compared to that of the control strain the activity of which was unchanged during the experiment (Abyzov et al., 1988, 1990b).

## Non-Spore Forming Bacteria

In contrast with spore-forming bacteria non-spore-forming bacteria were prevalent in younger surface ice layers (Abyzov et al., 1982b). Among these bacteria, the best studied are members of the genus *Pseudomonas*. Many investigators found gram-negative rods in the natural substrates of the Arctic and Antarctic regions, *Pseudomonas* spp. are unusual inhabitants of the cold soils.

We have no previous information about the presence of bacteria *Pseudomonas* spp in the ice sheet. Our data showed that they comprised up to 7% of the total biomass of microorganisms

found in the upper 100 m of the ice sheet (Sorokina and Abyzov, 1986).
During our work with the *Pseudomonas* strains from the ice sheet we have observed distinct dissociation.
Dissociation is known to take place when bacteria are kept for long periods under laboratory conditions. In our case, the longevity of bacteria under anabiosis has also stimulated it (Sorokina and Abyzov, 1986).

**Yeasts**
Viable yeasts have been isolated only from the upper younger ice-sheet horizons (700 - 3250 years old). Our isolates include six strains of two yeast species, *Cryptococcus albidus* (Saito) Skinner and *Rhodotorula glutinis* (Fresenius) Harrison, from the 100-m ice layer. All strains studied have grown equally well at temperatures from 18 to 24°C, but the minimum growth temperatures are quite different for two species. Although the *Rhodotorula glutinis* strain shows slight growth at 0-2°C, *Cryptococcus albidus* begins to grow only at 5°C. Its temperature optimum is also higher, 22°C, *Rhodotorula glutinis* has a temperature maximum at 28°C (Abyzov et al., 1983a).

**Fungi**
Mycelial fungi were found at depths up to 651 m (the age is about 38 600 years), but have not been found in deeper layers. These fungi are the same as isolated by many investigators from snow, ground and air of the Antarctic continent and adjacent islands. In descriptions of the Antarctic species of mycelial fungi, some authors have raised the possibility that these fungi have been carried in from other areas by modern expeditions. However our data show that the same species of mycelial fungi occur in the ancient ice layers and therefore these fungi microorganisms arrived regularly in to the central parts of the Antarctica

long before humans. We isolated *Aspergillus versicolor* (Vuill,) Tiraboschi, several representatives of the genus *Penicillium*, *Mucor circinelloides* V. Tiegh, and *Phialophora bubakii* (Laxa,) Schol-Schwarz from ice layers 160 - 38 600 years old. The mycelial fungi we found in the ice sheet are listed in Table 4.

Mycelial fungi isolated from ice have some morphological and cultural peculiarities. Comparison with the same species isolated from temperate latitudes has shown that species from the ice sheet have reduced spore-forming capabilities and that some morphological characters become indistinct, which caused definite difficulties in their identification (Abyzov and Belyakova, 1982).

The comparison of cultural and morphological changes in mycelial fungi with those found in yeast after the same prolonged existence in anabiosis has allowed us to suggest that both groups are adapted to life under the severe conditions of Antarctica.

These organisms may have been brought in with air flows from the temperate latitudes or from littoral parts of the Antarctic continent and surrounding islands, where conditions favorable for propagation of microorganisms may be created during short periods of slightly elevated temperatures.

**Actinomyces**

Among Actinomyces we found in the ice sheet only three genera - *Nocardia, Nocardiopsis* (Abyzov et al., 1983b, 1987), and the closely related Streptomyces (Abyzov et al., 1990a). *Nocardia*-like organisms were also found in the Antarctic snow, ice and soil surface by other investigators (Bollen et al., 1969; Cameron, 1971) and in the deep layers of the ice sheet by us. All Actinomyces detected were psychrotolerant forms. On the basis of taxonomic investigation of strain number 25 - 145, isolated from the ice at a depth of 85 m about 2 200 years old, we have named it as a new species, *Nocardiopsis antarcticus* Abyzov, Philippova and Kuznetzov (Abyzov et al., 1983b).

Our discovery of members of the genus *Nocardiopsis* (Meyer, 1976), and particularly of this new species, in layers of the Antarctic ice more than 2 000 years old has opened the possibility that species of microorganisms might be found in the ancient ice that have disappeared elsewhere as a result either of changing conditions or of competition with other organisms.
Our finding Nocardia and the closely related *Nocardiopsis* and *Streptomyces* in ice layers 160 - 9 400 years old (Abyzov et al., 1987) and even 47 000 years old (Abyzov et al., 1990a) demonstrates that these organisms existed in Antarctica long before humans appeared there and confirms the conclusions of Cameron et al, (1976), who believed these forms to be part of the native Antarctic flora.

So microbial cells at a depth of 1.500-2.759 m in the ice sheet below Vostok Station remained viable for 110.000 – 240.000 years. We experimentally established for the first time that microorganisms could exist in anabiosis for this period of time in Antarctic ice. However, the number of viable cells decreases with increasing depth (and age) and does not correlate with the total number of intact cells at the same horizons (see FIG. 17).
The discovery of accreted ice at the bottom of the ice sheet opened the way for a microbiological study of Lake Vostok water through ice core studies (Priscu et al., 1999; Karl et al., 1999; Abyzov et al., 1999; Bulat et al., 2004) because there are about 70 m of the ice sheet remaining between the bottom of the borehole and the ice/lake water interface. However, the danger of contamination of the Lake is a major issue preventing further drilling. [FIG. 18] Main boring complex at Vostok station.
The preliminary study of accreted ice from different horizons shows the existence of different microorganisms in the core. The number and diversity of these microorganisms is different of each of the different horizons and correlates with organic and

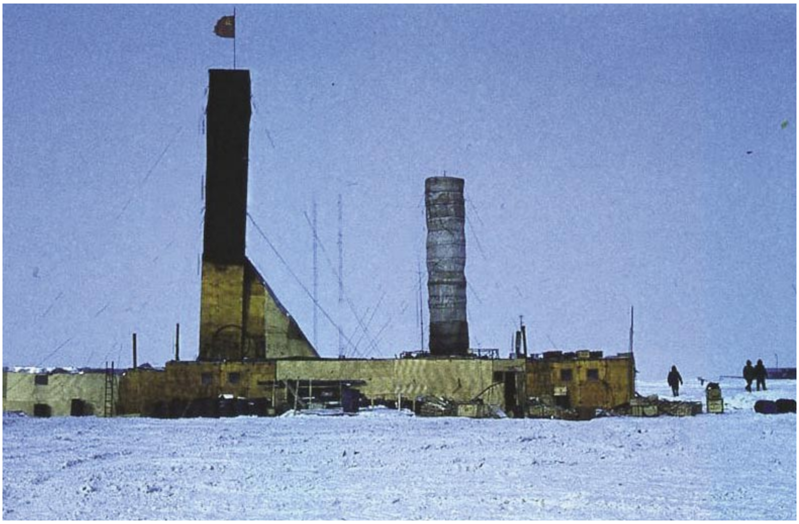


FIG. 18. Main boring complex at Vostok Station.

inorganic inclusions in the ice samples, but there is no distinct evidence that the number and types organisms in accreted ice differ dramatically from ice of glacial origin.

The study of accreted ice included studies of the chemistry of the lake water and presence and types of organisms that might be expected in Lake Vostok. According to Priscu et al. (1999) and Karl et al. (1999) a number of microbes have been detected in accreted ice, and data reveal that bacterial diversity is low with DNA detected being typical of modern DNA.

However, molecular biological studies of this ice (Bulat et al., 2004) suggest that there are few if any microbes in the accreted ice, and most microbes detected until now may be related to contamination of drilling fluid and core handling. Some molecular biology studies identified a strain of bacteria whose DNA is similar to hemophilic bacteria (Bulat et al., 2004). That suggest the possibility of hydrothermal activity in Lake Vostok.

## GENERAL CONCLUSIONS

Microbiologists of Institute of Microbiology in collaboration with mining engineers developed, tested in laboratory conditions and used for investigation of Antarctic ice shield the unique equipment for aseptic sampling of melted water samples from ice cores.

Microbial biodiversity and distribution of different taxonomic group of microorganisms have been investigated in Central Antarctic's glacier near Russian station "Vostok".

Microorganisms, including viable microbial cells, have been found in the whole of thickness of the glacier up to layer with depth 2750 m which have been formed 242 thousands years ago.

The distribution of viable microorganisms at different depths in the ice sheet is clearly regular. It depends on depth in the ice and on the characteristics of the organisms involved. Fungal spores and especially bacterial spores are able to survive for many thousands of years, and the latter have been found in the very oldest layers studies.

More than 160 pure cultures of yeast, mycelial fungi, actinomyces, spore-forming and non-spore-forming bacteria have been isolated from ice cores of borehole, drilled at Central Antarctic glacier.

Most part of microorganisms, found in ice cores, have been brought in Antarctica with air flows from temperate latitudes of the South Hemisphere.

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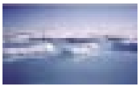
CLIMATE CHANGE
AND POLAR RESEARCH



# *A FROZEN OCEAN IN A CHANGING CLIMATE*

*Doctor Donald Perovich*

## INTRODUCTION

It is just a graph, and a rather simple graph at that, X versus Y [Figure 1]. It is only under closer examination that we realize the true complexity and importance of this graph. It shows global temperature as a function of time for the past 200 years (data courtesy of NASA Goddard Institute for Space Studies). This plot is at the center of the most important environmental issue of our time: the question of global climate change. Or more precisely, the *questions* of global climate change. Is the Earth warming? If it is warming, is it just a fluctuation or is it a trend? If indeed there is a warming trend, is it part of a natural cycle or a consequence of human activity? These are very important, and very complex, questions.

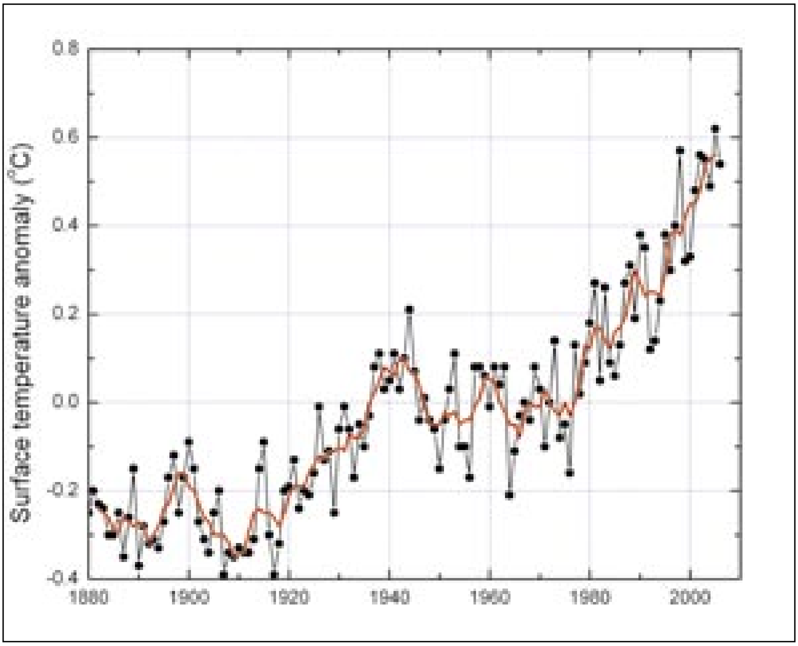



Fig. 1.

As we explore these questions, one of our most important tools is general circulation models (GCM). These large sophisticated computer programs simulate the global climate system, including atmosphere, land, ice, and ocean. GCMs allow us to look into the future and predict the climate for continued increases in atmospheric carbon dioxide. FIGURE 2 shows GCM projections of the global temperature change that would result from

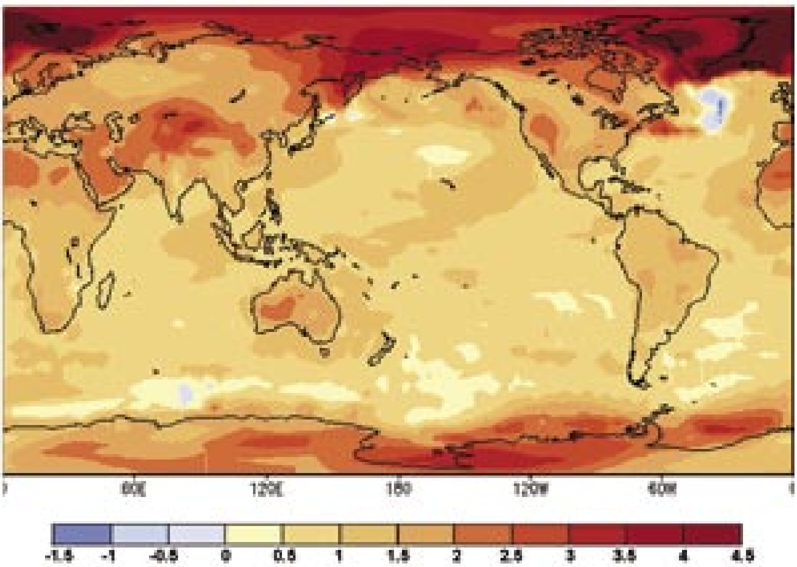



FIG. 2.

a doubling of atmospheric carbon dioxide (Washington et al., 2000). This plot has two key features. It is predominantly red, showing a widespread increase in temperature. The darkest red, the region where the temperature increase will be in the greatest, is in the Arctic. This means that the Arctic is a critical early indicator of climate change, acting like a canary in a coal mine. More than just an indicator, it is also a region that may potentially amplify climate change.

The Arctic sea ice cover is a key component of the Arctic system. It is the frozen ocean at the top of the world. Temperatures are so cold in the Arctic that the ocean itself freezes, forming sea ice. This floating ice cover is a thin veneer covering millions of square kilometers (roughly the size of Europe), but only a few meters thick. It is in constant motion driven by winds and ocean currents and can move up to tens of kilometers per day. There are places where the ice cover breaks apart, leaving the ocean exposed, and places where sheets of ice come together, forming pressure ridges tens of meters thick [**Figure 3**]. In the winter there are storms and blowing snow, while summer brings melting and ponds of surface meltwater. For much of the year the ice is snow-covered, is white in appearance, and reflects most of the incoming sunlight. The ice cover is also a grand integrator of heat. Stated simply, warming results in less ice, and cooling results in more ice. Consequently, the amount of sea ice is an indicator of climate change.

**Fig. 3.**

## ARCTIC SEA ICE EXTENT

The areal extent of the sea ice cover has been monitored since the 1970s using satellite-based visible, infrared, and microwave sensors. Microwave detectors, in particular, have been a valuable tool in determining the extent of the ice cover because they work during both the day and the night and can penetrate through clouds. Satellite observations have established that the Arctic sea ice cover undergoes large seasonal variations. **Figure 4** shows the areal ice extent in February and September 1982. In February the ice cover is at its maximum, filling up the Arctic basin and covering the Bering Sea, the Sea of Ohkotsh, Hudson

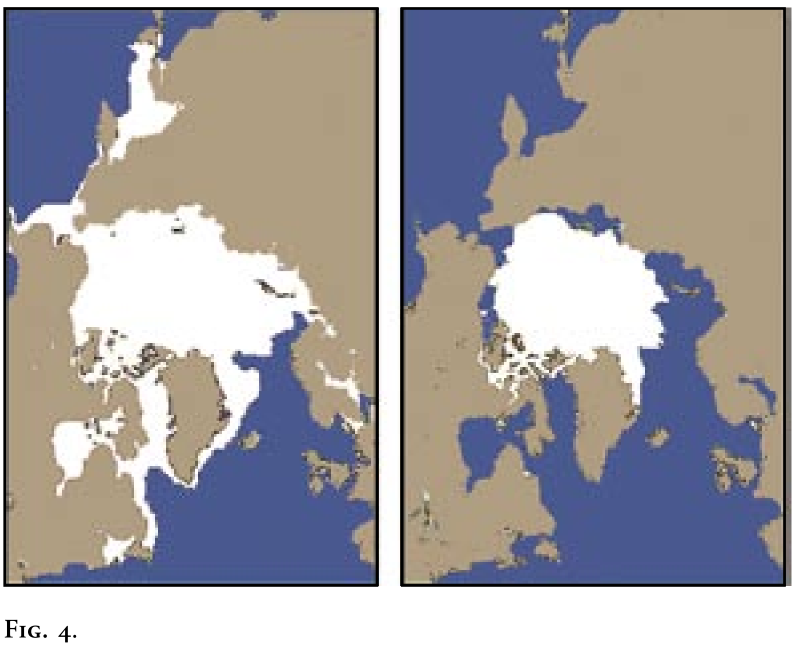


**Fig. 4.**

Bay, along the coasts of Greenland, and the Gulf of Bothnia. In summer, with 24 hours of sunlight daily and air temperatures around the melting point, the ice cover melts, reduces in size,

and retreats to the Central Arctic basin. The summer minimum is approximately half the area of the winter maximum.
From a climate change perspective the main focus is not the seasonal variability of the ice cover, but the long-term trends in ice extent. Monthly values of the total areal extent of the ice cover from 1979 to 2006 are plotted in FIGURE 5. The large seasonal

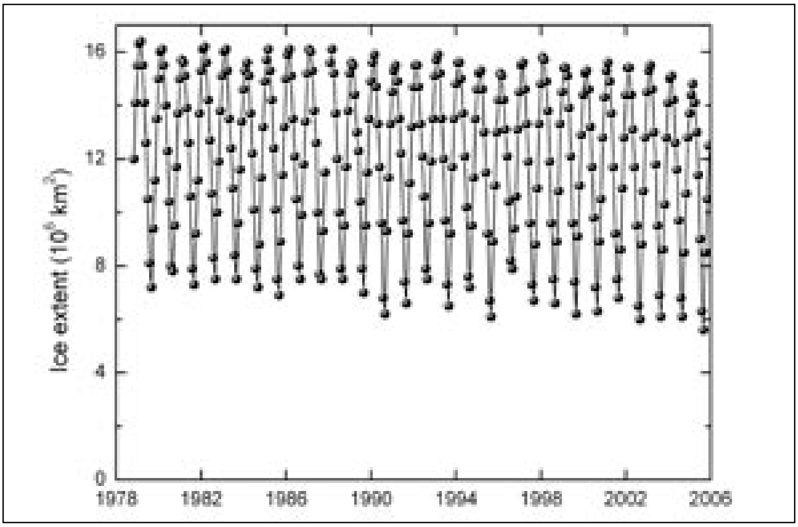



FIG. 5.

swings in ice extent are clearly evident, but any long-term trend is hard to discern. This is typical when examining climate data; a small climate change signal may be embedded in a complex time series with large seasonal, interannual, and decadal variability. One common approach to this variability problem is to simplify the time series. This is done in FIGURE 6, where values are plotted only for the month of September, thus removing the large seasonal variability. September is selected as it is typically when the ice cover is at its minimum and the climate change signal is the greatest. Also, to help highlight trends, the difference in ice extent from the mean September value is plotted. Even here we still see

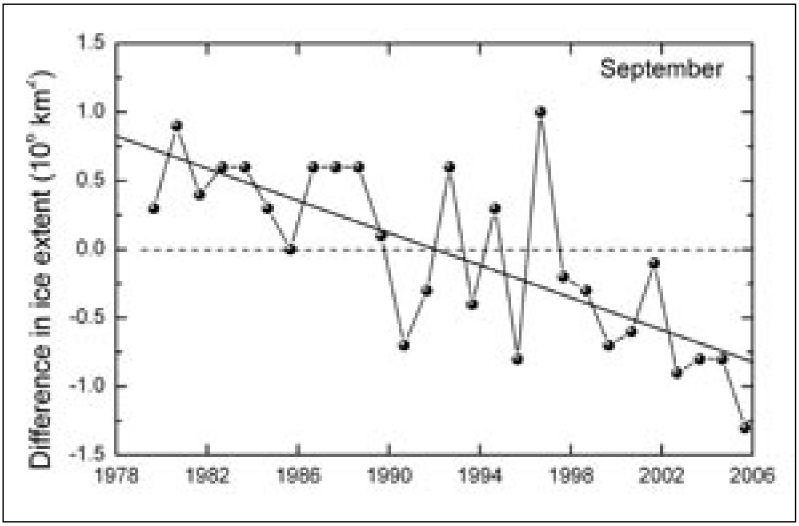



FIG. 6.

a complicated signal. For example, the largest ice extent occurs in 1996, one year after a major minimum. However, a close examination reveals inklings of a trend in this dataset. Values in the early part of the record tend to be above average ice extent, while in the 1990s and beyond values mostly lie below average. Fitting a straight line to the data illustrates this decrease. In spite of the large interannual variability, there is a distinct downward trend of a 6.5% decline in the September ice extent per decade (Stroeve et al., 2005).

FIG. 7.

The spatial distribution of the reduction in sea ice extent between 1982 and 2005 is shown in FIGURE 7. The red area

denotes the ice that was lost during this period. There was a retreat of the ice cover everywhere around the Arctic basin, with retreat being greatest off the Russian coast for a total loss of 1.9 million square kilometers (25%). **Figure 8** puts this loss

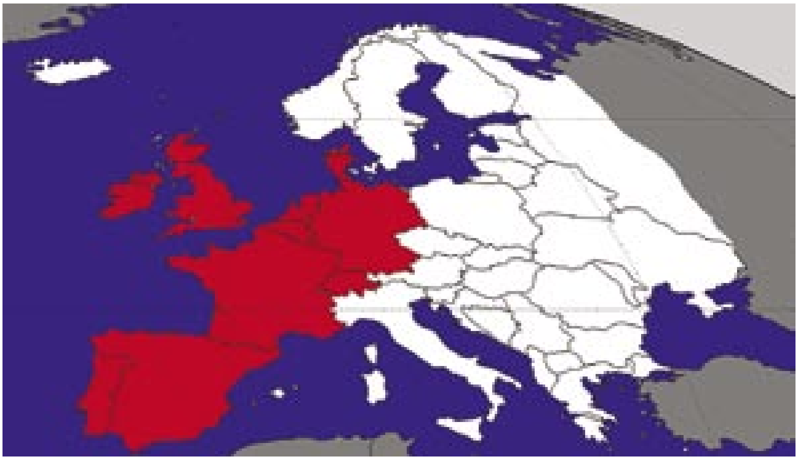


**Fig. 8.**

into context. Remembering that in the summer of 1982 the total ice extent was roughly comparable to Europe, the red area shows what has melted away: England, Germany, Switzerland, Belgium, the Netherlands, France, Spain, and Portugal.

## ARCTIC SEA ICE THICKNESS

The areal ice extent is just one component of the total amount of sea ice. Another important dimension to consider is the thickness of the ice. Unfortunately at present, the technological means to measure ice thickness from satellites are still being developed. There are occasional ice thickness measurements made during arctic field campaigns. However, these observations are


FIG. 9A.

episodic and not comprehensive. The most extensive set of observations were made by nuclear submarines traveling under the ice from the 1950s to the present. During these cruises, continuous ice thickness observations were made by profiling the depth of the underside of the ice for submarine operational purposes. These measurements provide the best source of ice thickness data. This thickness dataset is not as complete as the satellite record for ice extent, as there was not a routine monitoring every few days of the entire Arctic ice cover. There were only occasional cruises, in various parts of the Arctic, at different times. However, Rothrock and others (1999) were able to combine all the submarine-gathered data to make a meaningful comparison. They defined two separate time periods; 1958 through 1976 and 1993 through 1997. For these two time periods, they compared the average ice thickness in seven separate regions [FIGURE 9A]. A histogram [FIGURE 9B] of the area thickness for the two periods and seven locations shows substantial thinning in all regions. The average decrease was 40%, from an ice thickness of 3 m to less than 2 m.

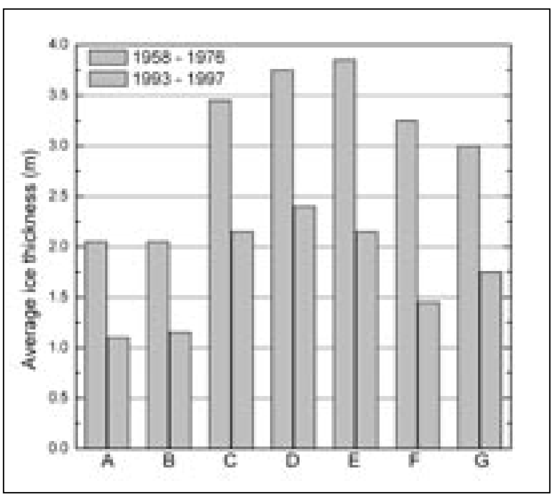



FIG. 9B.

## SEA ICE MASS BALANCE

Taken together, satellite and submarine results show a reduction in the amount of sea ice through decreases in both areal extent and thickness. These observations, however, do not indicate how this reduction is occurring. To understand how, we need to examine additional factors, including the mass balance of sea ice. The mass balance is a simple concept; it is the decrease in ice thickness due to melting on both the top and bottom of the ice and the increase in thickness due to ice growth. Ice mass balance instruments can also be simple [FIGURE 10]. There is an ablation stake, which is a stick frozen into the ice, for keeping track of the position of the ice surface; combined with a thickness gauge, which is a wire frozen into the ice that is used to monitor the ice bottom. Mass balance measurements illuminate whether observed decreases in the ice cover are a result of decreases in ice growth in the winter, more melting on the bottom due to changes in the ocean, or enhanced melting on the surface due to changes in the atmospheric driving forces.

FIG. 10.

Unfortunately the ice mass balance can not be monitored from space or from submarines. In the past, these measurements were only made from ice camps, severely limiting the number and frequency of ice mass balance measurements . Now, autonomous ice mass balance buoys [FIGURE 11] provide the next best thing to being there. These buoys have electronic instruments to measure the changing positions of the ice surface and ice bottom and a vertical string of temperature sensors arrayed in the snow, ice,

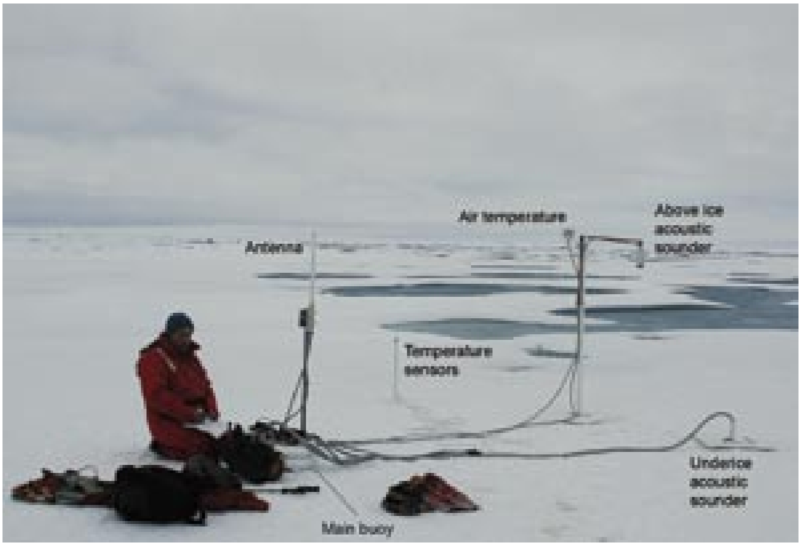



FIG. 11.

and upper ocean. There are also instruments to measure barometric pressure, air temperature, and buoy position. Data are transmitted from the field via a satellite communication link. Data from an ice mass balance buoy that was deployed near the North Pole in September of 2005 are presented in FIGURE 12. This buoy drifted with the ice for 19 months, exiting the Arctic via the Fram Strait in March 2007. The colorful contours show temperature within the ice, with the blues representing temperatures of -20°C and the reds representing temperatures near freezing. The seasonal cycle is clear in both the air and ice temperature plots. In the summer, the ice was isothermal at its freezing point (0°C). In the winter, air temperatures reached as low as -50°C with ice surface temperatures near -20°C. Ice growth didn't start until December because it took two months for the cold air temperature pulse to travel down to the bottom ice and cause freezing. There was a total ice growth of 60 cm between December and the following June. During summer there was

25 cm of melting on the bottom of the ice and a modest 10 cm of surface melting.

While these results are interesting, they represent only one year and one location. A network of ice mass balance buoys is needed to obtain the broader perspective of the ice mass balance needed for climate change studies. The map in Figure 13A shows the beginnings of such a network, with the drift tracks of over 25 ice mass balance buoys that have been deployed in the past decade. Mass balance results from selected buoys are shown in Figure 13B. The amount of snowfall and of snowmelt is similar in both locations for all years. However, mass balance observations are still sparse and they exhibit considerable spatial and interannual variability.

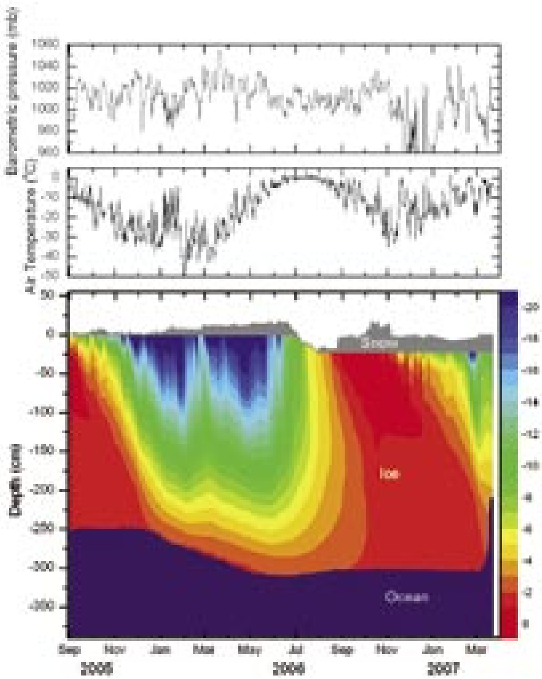



Fig. 12.

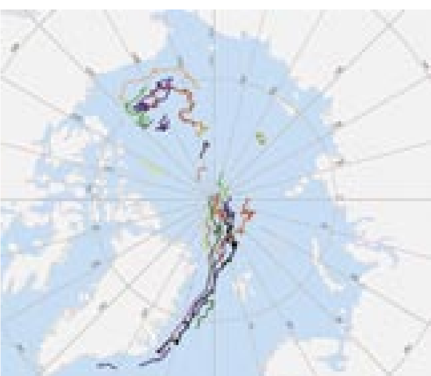


Fig. 13A.

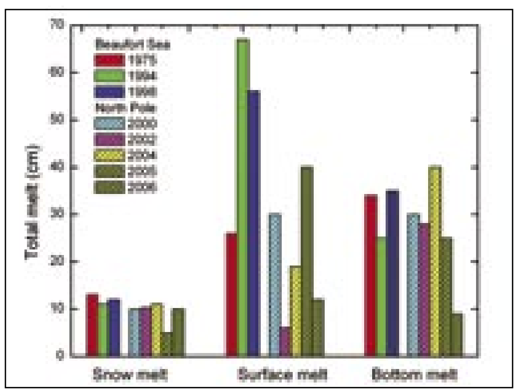



Fig. 13B.

Surface melting varies interannually by a factor of three, while bottom melting has fluctuations of about 50%.

## ICE ALBEDO FEEDBACK

In addition to its role as an indicator of climate change, the Arctic sea ice cover can also be an amplifier of climate change. It does this through positive feedback mechanisms such as the ice albedo feedback. To understand the ice albedo feedback, we first must examine the albedo. The albedo is a simple yet powerful geophysical parameter. It is simple because it is just the fraction of the incident sunlight that is reflected by the surface. A perfectly white surface that reflects everything has an albedo of one. In contrast, a perfectly black surface that reflects nothing has an albedo of zero. While the albedo is simple, it is also a powerful parameter. Sunlight is the primary source of heat for the Earth and the amount of sunlight that is reflected from the surface is a fundamental factor in the global climate system.

FIG. 14A.

FIGURE 14A shows a simulated view of the Arctic from space in spring just as melting is beginning. The snow covered sea ice is bright and white and reflects most of the sunshine. However, some of the sunlight is absorbed, resulting in melting and the retreat of the ice edge. As the ice edge retreats,

the white, snow-covered sea ice is replaced by black, open water. As FIGURE 14B shows, these two surfaces have widely different albedos. Snow-covered sea ice reflects around 85% of the incident sunlight (Perovich et al., 2002), while open water reflects only 7% (Pegau and Paulson, 2001), a large contrast of more than one order of magnitude. This is the greatest possible difference in albedo because snow is the best naturally occurring reflector and the ocean is the worst. As the ice cover retreats, the best reflector is being replaced by the worst reflector.

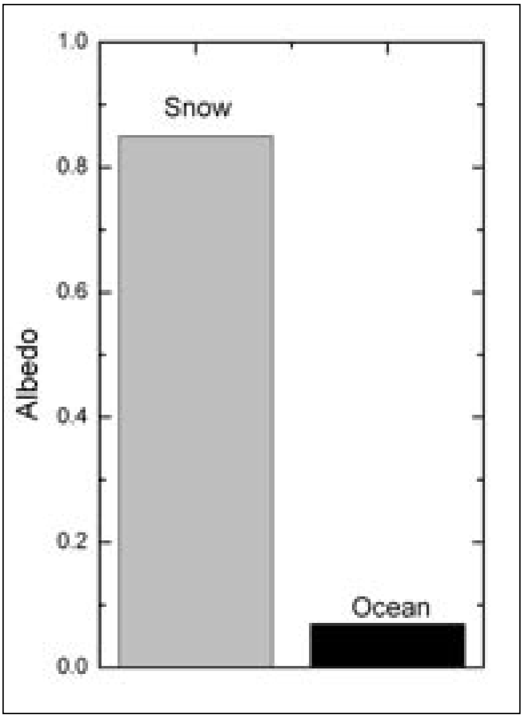



FIG. 14B.

In addition to the retreat of the ice edge, there are also changes occurring in the interior of the ice pack during the summer melt season. FIGURE 15 shows a photograph of a typical Arctic scene in April. The ice is snow-covered, uni-


FIG. 15.

form in appearance, and has a large albedo. By August, however, changes in the surface due to melting are apparent. The surface has a variegated appearance, with bare ice, melt ponds, open water and a greatly reduced albedo.

Together these two phenomena create the ice albedo feedback [FIGURE 16]. In spring there are 24 hours of sunlight. Most of the sunlight is reflected, but some is absorbed, eventually

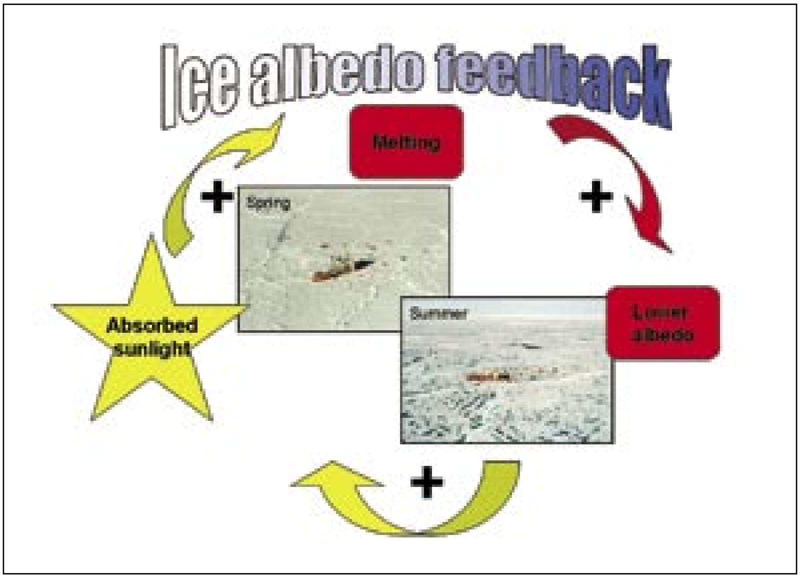



FIG. 16.

resulting in melting. This melting in turn lowers the albedo, which means more sunlight is absorbed. This in turn causes more melting and a further decrease in albedo leading to more absorbed sunlight, more melting, and a lower albedo still. This is a positive feedback: a mechanism that builds upon itself and accelerates. Positive feedbacks are of great interest for climate change studies because they provide mechanisms where gentle nudges to the system can be amplified into large shoves.

This is a brief qualitative description of the ice albedo feedback. However, what is needed from a climate perspective is a quantitative explanation of the ice albedo feedback. This explanation needs to numerically consider the entire Arctic sea ice cover over a number of years. A complete quantitative analysis of the ice albedo feedback is extremely complex and entails integrating changes in the ice cover with changes in the incident sunlight.

One component of this problem is determining how changes in the amount of open water affect the amount of solar heat absorbed by the ocean. Such an analysis was performed by Perovich et al. (2007) taking a synthetic approach, combining field observations of ocean albedo, satellite-derived ice concentrations, and incident irradiances determined from meteorological models. The data were placed on a 25 km by 25 km grid encompassing the full range of Arctic sea ice coverage (colored region in Figure 17) and the amount of solar heat input directly to the upper ocean was computed for every day from 1979 through 2005 for every grid cell.

The trends in the annual amount of solar heat absorbed by the ocean for each grid cell from 1979 to 2005 are mapped in Figure 17. Positive trends are pervasive over much of the Arctic with values as large as 4% per year. A smaller region with a negative trend in solar

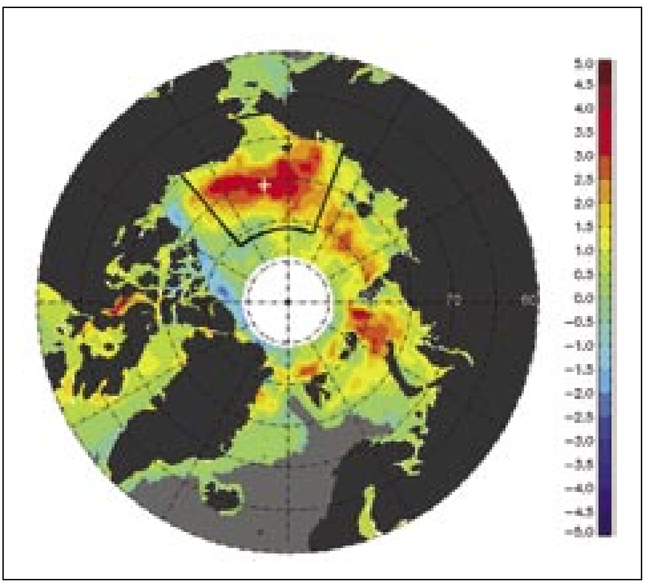



Fig. 17.

heat input is evident along the northern edge of the Canadian Archipelago, where ice motion has caused increases in ice concentration. Overall 89% of the area has a positive trend of increasing solar heating and 11% has a negative trend. Trends were typically modest in magnitude, with the median and mean trend equal to an increase of 0.64 % $yr^{-1}$ and 0.81 % $yr^{-1}$ respectively. The mean and median trends appear rather small; a few cm per year of ice thinning, less than one Watt per square meter of additional heat flux per year. But the trends in heat input are cumulative and after a few decades the total changes are substantial. For example, the median solar heat increase accumulates to a total increase of 17% by 2005 and the solar heat input is more than doubled in the area of maximum heat increase. Work is underway on the next and most difficult step in the ice albedo feedback analysis; developing a quantitative treatment of the seasonal evolution of ice albedo.

## THE ARCTIC SYSTEM

The reduction in sea ice area and the decrease in ice thickness tell a story of warming. In addition, the observed increase in solar heat input into the ocean shows that the changes in the ice cover may be amplifying the warming trends. However, sea ice is only part of the story. It is only one component of the Arctic system. The nine primary components of the Arctic system are graphically represented in **Figure 18** (Overpeck et al., 1999). In addition to sea ice, there is thermohaline circulation, permafrost, precipation, terrestrial biomass, marine productivity, terrestrial ice, population, and economic activity. Many of these components also exhibit changes associated with a warming climate. The portion of the Greenland ice sheet that experiences summer melt (pink area in the Greenland map) has been increasing in


FIG. 18.

recent years. Terrestrial biomass has been changing, with shrubs moving northward into tundra landscapes (Sturm et al., 2000). Marine ecosystems have been changing, with northward shifts in habitats (Grebmeier et al., 2006). There are indications that permafrost is thawing. From an engineering and infrastructure perspective melting permafrost is trouble, with immediate negative impacts for both infrastructure and transportation.

There are other economic impacts. Retreating sea ice will ease access to the Arctic Ocean, facilitating both shipping and natural resource extraction. As the ice retreats, a northern sea route becomes viable in the summer, providing a shortcut across the top of the world by reducing the shipping distance between Europe and Asia from approximately 21 thousand kilometers to 12 thousand kilometers [FIGURE 19]. The growing access to natural resources in the Arctic Ocean as the ice retreats has political ramifications. There is extensive exploration of the sea floor of the Arctic Ocean as countries vie for sovereignty

FIG. 19.

under the Law of the Sea Treaty. The combination of unclear sovereignty and untapped and valuable resources holds potential for conflict in the Arctic Ocean.

## CONCLUDING REMARKS

Sea ice is melting and the amount of sunlight absorbed in the Arctic Ocean is increasing. The "canary in the coal mine" is indicating a warming trend. Other components of the Arctic system are changing in a complex and intricate manner. Studies such as the recent report by the inter-government panel on climate change (IPCC, 2007) have answered the questions posed at the beginning of this essay. Yes, the Earth is warming. Yes, this warming is a trend, not a fluctuation. Yes, a component of this trend is due to human activity. But what of the future? Even as one set of questions is answered a new set has emerged. How much warming will there be? How fast will it happen? Are there tipping points?

Consider **Figure 20**, which presents the same data as in **Figure 6**, but in a slightly different way. In this case the ice extent data are broken up into the two time periods, the first 20 years and the most recent decade. For the first period there is a decrease in September ice extent of 4% per decade, while for the most recent decade the decrease was 12% per decade. These are compelling results, since they show not only a decrease, but an accelerating decrease. Accelerating change heightens concern, since the faster the change occurs the more difficult it is to respond.

Components of the system may reach a tipping point as change continues. Tipping points are transitions from one state to another, such as a boat tipping over. After passing a tipping point, returning to the initial state is problematic, just as righting an overturned boat is difficult. In the case of sea ice, a potential

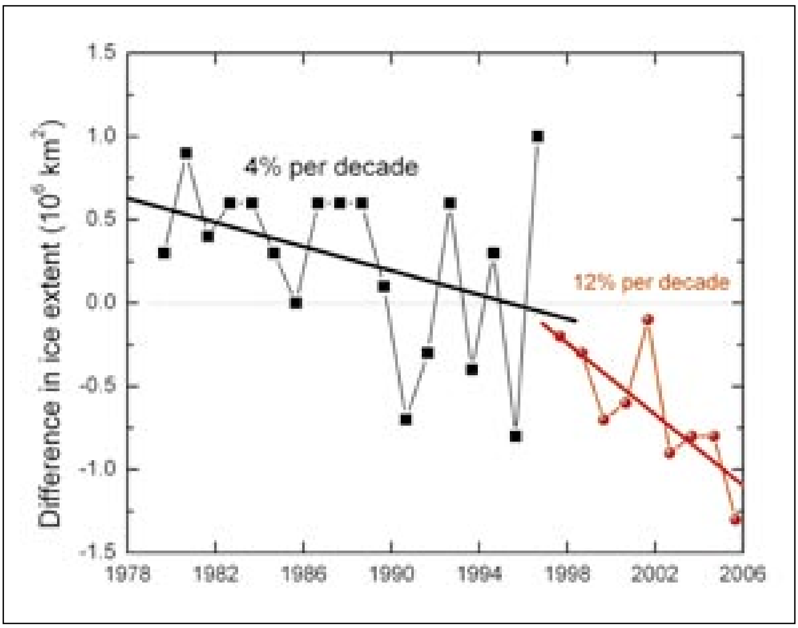



Fig. 20.

tipping point is the transition from an ice-covered summer Arctic Ocean to an ice-free summer Arctic Ocean. An Arctic Ocean ice-free in summer will absorb much more solar heat, retarding ice growth in the fall and winter. It would be enormously different from the ice-covered status quo in terms of energy budget, precipitation, ecosystems, and commercial activity.

The new set of questions of how much, how fast, and tipping points is difficult to answer, but of prime importance. The International Polar Year (IPY) is underway, providing an opportunity to study the Arctic system and provide insight on climate change. The IPY is a massive international effort involving thousands of scientists from more than 60 countries examining the role of the polar regions in the earth system. There is a large educational outreach component aimed beyond the scientific community towards the public. During IPY there will be opportunities for field experiments to improve our understanding of the processes that drive the polar regions and chances to integrate this improved understanding into large scale climate models.

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