The Structure and Development of Polar Research (1981–2007): a Publication-Based Approach

Authors: Aksnes, Dag W., and Hessen, Dag O.

Source: Arctic, Antarctic, and Alpine Research, 41(2) : 155-163

Published By: Institute of Arctic and Alpine Research (INSTAAR), University of Colorado

URL: https://doi.org/10.1657/1938-4246-41.2.155

Arctic, Antarctic, and Alpine Research, Vol. 41, No. 2, 2009, pp. 155–163

The Structure and Development of Polar Research (1981–2007): a Publication-Based Approach

Dag W. Aksnes and*
Dag O. Hessen†

*Corresponding author: Norwegian Institute for Studies in Innovation, Research and Education (NIFU STEP), Wergelandsveien 7, NO-0167 Oslo, Norway
Dag.W.Aksnes@nifustep.no
†University of Oslo, Department of Biology, Center of Ecological and Evolutionary Synthesis (CEES), PO Box 1066 Blindern, NO-0316 Oslo, Norway

Abstract

The present article explores the structure of and recent developments in research activities in the polar regions. Based on a bibliographic study of published papers indexed in the *ISI Web of Science* during the period 1981–2007, we have analyzed trends in publication, scientific disciplines and subdisciplines, coauthorship, and international collaboration within the field of polar research. We have uncovered several rather striking trends. Scientific output in terms of refereed publications has increased far more rapidly in polar research compared to science in general, quadrupling rather than doubling over the surveyed period. There is a nearly 1:1 ratio between papers covering the Arctic relative to the Antarctic, with the vast majority within either the geosciences (40%) or biology (33%). There has been particularly a steep rise in the number of climate-related papers. The U.S.A. is by far the largest contributor to polar research on both the Arctic and the Antarctic, followed by Canada, the U.K., Germany, Norway, and Russia. The number of coauthored papers has grown markedly, reflecting geopolitical shifts and changing national and international funding priorities during the period. We believe our publication-based survey reveals interesting developments in scientific activities and international cooperation in general, and in polar science strategies and priorities in particular.

DOI: 10.1657/1938-4246-41.2.155

Background

Research activities in the polar regions have expanded significantly in recent decades. This is due in part to the growing awareness that the Arctic and the Antarctic play key roles in global environmental phenomena such as climate forcing and climate change effects, ozone depletion, organic pollutants (particularly in the Arctic), and the exploitation of biological resources. Moreover, prospects for oil and gas in polar oceans and potential expansion of sea-based transport on the basis of predictions of reduced ice cover, as well as fisheries management, have raised the needs and interests for increased research activities. The complexity of major research areas (e.g. climate research) and the climbing costs of carrying out big science in terms of equipment, analytical tools, and labor have also promoted cooperative efforts. The International Polar Year (IPY) 2007–2008 is an internationally coordinated campaign for research that represents a major initiative to strengthen research activities in the polar regions.

Despite the focus on international collaboration, polar research still has a strong geopolitical dimension connected to sovereignty claims and access to hydrocarbon and biological resources. This is particularly evident in the case of the polar treaties. In order to become a Consultative Party to the Antarctic Treaty a country needs to demonstrate its commitment to Antarctica by carrying out substantial scientific activity in the region. The Svalbard Treaty gives signatory states equal rights to engage in scientific and commercial activities on Svalbard, although the archipelago remains under Norwegian sovereignty. Several nations have established major research facilities and research stations in both the Antarctic and the Arctic. A significant number of international large-scale facilities have been established in Longyearbyen on Svalbard, and there are a number of national research stations in Ny-Ålesund, also on Svalbard, which also has the status of a European Centre for Arctic Environmental Research with support from the European Union. The polar areas are also to an increasing extent the targets for large national and international research cruises.

Against this background, the aim of the present paper is to provide more knowledge about the structure of and developments in polar research during the past 25 years. Based on a publication analysis, we will address questions such as: Which countries are the largest contributors in terms of publication output in scientific journals? Which trends in scientific collaboration and scientific focus can be identified over the past 25 years? What is the impact of the research conducted by the various countries in terms of citation rates? What collaboration patterns can be identified among the countries engaged in polar research? This paper will provide overall results based on the entire global output of research publications as well as separate analyses of the Arctic and the Antarctic.

The study is based on the database *ISI Web of Science* produced by Thomson Scientific, which is the most commonly used database for bibliometric studies. Although its coverage is not complete, the database includes all major scientific journals within the sciences, medicine, and technology and is generally regarded as constituting a satisfactory representation of international mainstream scientific research (Moed, 2005). Social sciences and humanities may admittedly not be well represented by the database, but will likely contribute marginally to the overall volume of paper. A recent survey of Norwegian polar research

1523-0430/09 $7.00

(Aksnes and Rorstad, 2008), revealed that the social sciences and humanities accounted for 4% of the national total of person-years on polar research, and 1.4% of the polar research papers (indexed in *ISI Web of Science*). Thus, this exemplifies that there is an under-representation of the social sciences and humanities in the database. Although not necessarily representative for other countries, the figures also indicate that the volume of polar research representing the social sciences and the humanities is rather insignificant compared to the volume of other polar research.

Data and Methods

Polar research is not a traditional scientific discipline. Rather than being defined according to thematic focus, it is geographically delimited, although how it should be delimited may be a matter of controversy. Polar research encompasses a range of disciplines from the humanities to technology and engineering, although the greatest proportion of research is carried out within the natural sciences. In this study we have used the following definition (cf. Ministry of the Environment, 1993):

- Research carried out on the basis of material from the polar areas (Arctic and Antarctic) or concerning phenomena localized in the polar areas.
- Arctic: The land areas north of the tree line with continual permafrost and the ocean areas north of the limits for maximal sea ice.
- Antarctic: The areas south of the Antarctic convergence (the borderline between cold and warm water at 50 to 60°S).

In contrast to many other areas of science, it is hard to identify polar research from the scientific outlet or journal. Only a limited portion of research findings are published in specialized journals for polar research (e.g. *Arctic*, *Polar Biology*, *Polar Research*, etc.). Most of the articles appear in more general scientific journals and thematic journals. In order to identify publications that should be assigned to the category ''polar research,'' we have used two principles. First, we have included all publications from the journals that entirely or mainly cover polar research.* Second, following the geographical delimitation of polar research, we have applied geographical search terms for identifying the publications. We have done a search through the titles and abstracts of all the publications in the database. We assumed that the geographical locality in which the research had been performed would generally appear either in the title or in the abstract. Names of geographical areas in the Arctic and the Antarctic were therefore used as an indication of polar research content. With regard to the Arctic, the names of mainland areas, islands, and oceans were included. With regard to the Antarctic, the name of the entire continent was used (antarc*) in addition to the names of the oceans surrounding it.† In the analyses we have accordingly used the geographical terms to distinguish between Arctic and Antarctic research papers.

The study is based on the database *ISI Web of Science*, which currently includes 9300 journals. The searches for publications were limited to the period 1981–2007 and only regular articles and review articles were included. The bibliographic details of the publications identified were downloaded and further analyzed using software developed for the purpose (Leydesdorff, 1989). The searches were carried out in mid-December 2007 (the publication counts for the year 2007 were not entirely complete at that time, thus the year has been omitted in some of the analyses).

We believe the method we have applied is adequate for the purpose of providing a general analysis of efforts within global polar research. A previous study (Schild, 1996) used field-specific search terms (e.g. ''sea-ice'', ''polar bear'' etc.) in addition. We did not consider this necessary, as the geographical locality is usually specified either in the title or in the abstract of the publications. Nevertheless, it might be the case that certain relevant publications have not been identified because the articles do not specify where the research has been carried out, or because other geographical names than those included in the study were mentioned. For example, certain space-type research based on equipment localized in the polar regions, for example on solar wind or aurora, might not have geographical names specified, and would be left out by our search strategy. An examination of a subsample of the selected papers using our approach showed high relevance. We noticed a few cases where particular geographical names were mentioned, for example Svalbard, but where the research had been carried out in other areas. In a similar previous study (Dastidar, 2007), only search terms present in the titles of the publications were used as a basis for identifying Antarctic research. This resulted in a subset of papers significantly lower than ours, and such a method would accordingly greatly underestimate the size of the production output. Although there are limitations also with our approach, we consider these sources of errors to be of minor importance given the large number of papers involved and taking into account that our aim has been to provide a general overview of polar research.

In total we identified 65,043 publications (regular articles and reviews) that fell within our criteria and were categorized as polar. In the searches we used quotation marks to search for exact phrases (e.g. ''Beaufort sea''). However, this only applied to title searches. In abstract searches, articles containing all the specified words (e.g. Beaufort AND sea) were included. As a consequence, a number of articles were incorrectly identified. These records were subsequently removed. We also removed publications identified through the expressions ''subarctic'' and ''Arctic Bramble,'' both of which dealt with research outside the polar regions. This systematic screening process removed some 10% of the original papers, leaving us with 53,685 papers.

It should also be noted that article abstracts were not indexed in *ISI Web of Science* prior to 1991. Searches for publications

* *Antarctic Science; Arctic; Arctic and Alpine Research; Arctic Anthropology; Arctic, Antarctic and Alpine Research; British Antarctic Survey Bulletin; Permafrost and Periglacial Processes; Polar Biology; Polar Record; Polar Research.*

† The following search terms were used (including variations in spelling of these names). *ARCTIC*: Arctic, Svalbard, Spitsbergen, Longyearbyen, Ny-Alesund, Hornsund, Barentsburg, Kongsfjord, Hopen, Bjornoya (Bear Island), Greenland, Baffin Island, Queen Elizabeth Islands, Ellesmere Island, Devon Island, Somerset Island, Prince of Wales Island, Banks Island, Ellef Ringnes Island, Amund Ringnes Island, Bathurst Island, Axel Heiberg Island, Prince Patrick Island, King William Island, Prince Charles Island, Bylot Island, Bathurst Island, Southampton Island, Brooks Range, St Lawrence Island, St Matthew Island, Seward Peninsula, Nunivak Island, Novaya Zemlja, Severnaja Zemlja, Novosibirskije Ostrova, Jan Mayen, Victoria Islands, Nunavut, Greenland Sea, Fram Strait, Beaufort Sea, North Pole, Davis Strait, Barents Sea, Kara Sea, Storfjorden, Baffin, Hudson Bay, Siberian Sea, Laptev Sea, Chukchi Sea, Bering Strait, Bering Sea, Karskoje Sea. *ANTARCTIC*: *antarc*, South Pole, D'Urville Sea, Ross Sea, Amundsen Sea, Pine Island Bay, Weddell Sea, Davis Sea.

within the first few years of the period were only based on the title of the papers. Accordingly, the number of publications from these years is significantly lower. In order to analyze the increase in total production for the period 1981–2006, we have made estimates for the first years.

To assess the publication output for individual countries, all articles were classified according to the nationality of the affiliated authors (i.e. the country of their institution addresses). Many papers are multi-authored, with an international list of authors. In the publication analyses concerning relative proportions, each country was assigned their respective fraction of these papers. For example, if an article had one author address from France and one from Germany, each country would receive a value of 0.5. For the sake of simplicity we have chosen not to give weight to the author order. In this way, the publication measures reflect the contribution of individual countries to the international polar research. The indicator can be interpreted as an indirect measure of the size of the countries as polar research nations. However, it should be noted that our survey includes primarily English-language journals. Certain countries, particularly Russia and Latin American countries, may publish their research in non-English-language (e.g. Russian or Spanish) scientific journals. Thus, the true extent of these countries' polar research activities may be larger than reflected in the figures of this study. However, the research results published in such journals would generally have less international impact and would not be available to a global scientific audience.

The database also includes information on how many times the articles have been referred to or cited in the subsequent scientific literature. These data have been used to calculate citation indicators. In absolute counts, the countries with the largest number of articles would of course also receive the highest number of citations—these countries have more papers that can be cited. It is, however, common to use a size-independent measure to assess whether a country's articles have been highly or poorly cited. One such indicator is the relative citation index showing whether a country's scientific publications have been cited above or below the world average (=100). Here, each article is compared with the average paper in the respective area of polar research and year, and on this basis an overall index is calculated.

Results

The analysis reveals that the global scientific production of publications on polar research has increased significantly during the period 1981–2007, and the number of publications has been growing at a relatively constant pace. Approximately 3500 papers were published in both 2005 and 2006. The corresponding figure for 1991 was 1700 publications and for 1981, 900 publications. Figure 1 shows the development for the total number of articles and for "core publications." The latter group consists of articles from the specialized journals for polar research and articles where the geographical search terms are present in the title of the publications. In the total number also the articles where the names are mentioned in the abstracts are included. As described above, the abstracts were not indexed in database until 1991; therefore the total numbers for the period 1981–1990 have been estimated (based on a factor representing the average ratio between the total and the core for the period 1991–2007).

The global science system is expanding from year to year. More money is being spent on research activities, which are involving an increasing number of persons. This is also reflected in the publication counts. At the same time it should be noted that the database applied in this study does not have a full coverage of

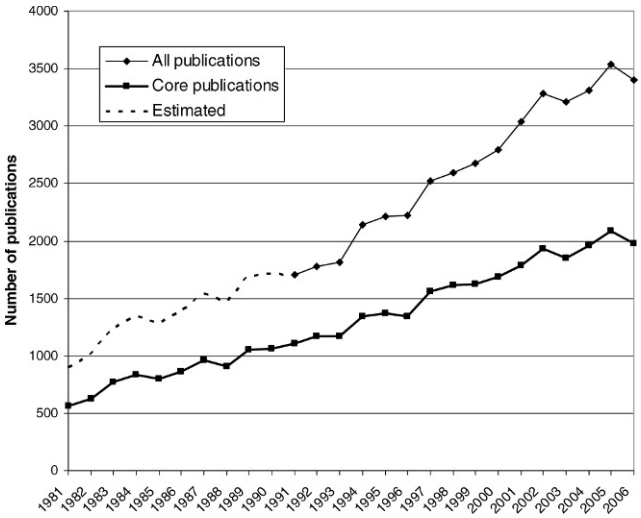


FIGURE 1. The development of the global scientific output of polar research articles, 1981–2006.

the global research literature. Besides, the coverage of database in terms of the number of journals indexed has grown during the period analyzed. Whether this increase in the database coverage correlates with the increase in the total scientific literature globally is hard to assess. Probably the database covers a larger part of the research literature today than it did in the past.

During the period 1981–2006 the global production of scientific papers (i.e. in all fields and indexed in *ISI Web of Science*) doubled. During the same period the number of polar research publications increased fourfold (278%). A slightly higher proportion of the polar articles address the Arctic than the Antarctic, 51% and 43%, respectively. The remaining 6% comprise articles in which both regions are mentioned (e.g. they are so-called bipolar papers) or articles on alpine research.‡

We also analyzed the field distribution of the articles. In the database each article is assigned to one or more scientific fields based on the journals they are published in. Although such a journal-based field classification is not very accurate (Aksnes et al., 2000), it provides a rough picture of the overall profile. The large majority of the publications were either within the geosciences or biology. Almost 40% of the published papers fall under the geosciences category, which encompasses disciplines such as geology, geophysics, and oceanography, as well as studies of the cryosphere. The second-largest discipline, biology, accounts for 33% of the total papers. These include papers within traditional areas of biology, more specialized papers on species and their adaptations, as well as on biodiversity at the species or genetic level, in addition to broader papers on ecology within marine, terrestrial, or freshwater ecosystems. The remaining publications are within other natural sciences, biomedicine, and technology. In spite of considerable public interest in indigenous peoples, only 2% of the published papers are within the social sciences and the humanities. Because the database only includes articles published in scientific and scholarly journals (not books which are an important publication channel in these areas), the actual contribution of these fields to polar research is probably somewhat underestimated. It is interesting to note that the relative

‡ Certain journals defined as polar research journals, e.g. *Arctic*, *Antarctic*, *and Alpine Research*, also include articles on alpine research, e.g. research carried out in the Himalayas.

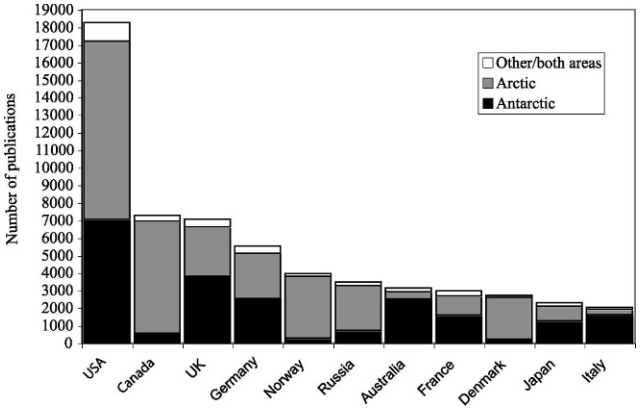


FIGURE 2. Total number of polar research articles per country (whole counts), 1981–2007, by geographical area.

contribution of the different disciplines to polar research has remained fairly constant over the time period studied. In other words, the number of papers in each discipline has grown at a constant rate.

However, the type of research carried out *within* the disciplines has changed during the period. For example, in the early 1980s, before the public awareness of the thinning of the ozone layer over the Antarctic caused by anthropogenic emissions of chlorinated compounds (Farman et al., 1985), there were hardly any polar research papers dealing with ozone. In 1991, approximately 70 papers were identified in which the term "ozone" was included either in the title or in the abstract, and in 2006, almost 130 such articles were identified. The signing of the Montreal Protocol in 1987 has led to a significant reduction in emissions of chlorinated compounds in Western countries; it is therefore reasonable to expect that the number of ozone-related papers will level off or decline in the years to come. Similarly, in the beginning of the 1980s, very few polar articles included the term "climate." In 1991, 90 such articles were identified. This number has increased dramatically during the past decade: almost 600 such articles were published annually in 2005 and 2006.

The U.S.A. is by far the largest contributor in terms of publications on both the Arctic and the Antarctic (Fig. 2). Canada is the second-largest contributor, followed by the U.K., Germany, and Norway. There are large differences among the countries in their geographical profile. The research output of certain countries primarily focuses on the Arctic (Canada, Norway, Russia, Denmark), while the output of others mainly relates to the Antarctic (Australia, Italy). Research output in several countries is more evenly distributed (the U.S.A., the U.K., Germany).

RESEARCH IN THE ANTARCTIC

Under the Antarctic Treaty a country can become a Consultative Party and obtain voting rights in the Antarctic Treaty System by carrying out substantial scientific activity in the region. The number of countries with such status has increased over the years and today totals 26 nations. Against this background, it is interesting to analyze how the various countries perform with regard to research activities in the Antarctic. Table 1 provides further details on the distribution of papers for three periods: 1981–1983, 1991–1993, and 2005–2007. U.S. scientists are responsible for the highest proportion of publications relating to the Antarctic during the entire period of our study, but the U.S. share declined from 34% in 1981–1983 to 24% in 2005–2007. The U.S.A. is followed by the U.K., which has also experienced a decrease in its share of Antarctic papers from 17% to 11% of world output. Then come Australia and Germany with proportions of 8% and 7%, respectively, in the last period (2005–2007). Certain countries have increased their share of scientific output on the Antarctic over the periods (Italy, Spain, China, Argentina), while others have seen the reverse development (Japan, New Zealand, Russia [U.S.S.R.], Poland). It should be noted, however, that although the publication share of certain countries may have decreased in relative terms, production in terms of the number of papers may still have increased. Table 1 provides data on the number of national research stations in Antarctica and the number of persons (researchers plus support staff) involved in such research (annual maxima). This information has been obtained from the website of COMNAP—the Council of Managers of National Antarctic Programs (http://www.comnap.aq/facilities). While not necessarily accurate, these figures nevertheless give an indication of the volume of the various countries' engagement in Antarctic research. There was a positive correlation between the scientific output in terms of the number of publications and the number of research staff present (Spearman's rank-correlation coefficient $r = 0.67$, significant at the 0.01 level), yet there was a pronounced scatter.

RESEARCH IN THE ARCTIC

The High Arctic is more accessible than the Antarctic, and on the whole its climate is less harsh (Schild, 1996). In contrast to the Antarctic, research is not governed by an international treaty for the region. Research output in terms of refereed papers related to the Arctic is provided in Table 2. The table shows that the five Arctic-rim states—the U.S.A. (Alaska), Canada, Norway (Svalbard), Russia (Siberia), and Denmark (Greenland)—are among the seven largest contributors. Together they account for 63% of all Arctic papers in the most recent period (2005–2007) and 85% in the first (1981–1983). U.S. scientists are responsible for a slightly higher proportion of the publication output relating to the Arctic than to the Antarctic (27.3% vs. 24.1%, respectively, in the period 2005–2007). As for Antarctica, the U.S. proportion has notably declined over the three periods (from 37.4% in 1981–1983). This does not mean that research output has decreased in absolute numbers. In fact, the number of papers increased by 60% between 1991–1993 and 2005–2007. We find a similar development for Canada, while most of the other nations listed in Table 2 have increased their proportion of publication output. This output also reveals that the number of countries engaged in polar research over the past 25 years has grown.

THE IMPACT OF THE RESEARCH IN TERMS OF CITATION

The number of citations (i.e. how many times a paper has been referred to or cited in the subsequent scientific literature) is a common indicator of the scientific impact or international visibility of the research. In widespread interpretation, frequently cited papers have been more useful or important than publications which are hardly cited at all. The same reasoning can be used for aggregated levels of articles. The more citations they draw, the greater their influence must be. Many studies have also found that citation indicators correspond fairly well, especially in the aggregate, with various measures of research performance or scientific recognition which are taken as reflecting quality (Aksnes, 2006). Nevertheless, an article may be cited for a variety of reasons, some of which have little to do with its scientific

TABLE 1

Proportion* of articles relating to Antarctic by consulting countries, 1981–1983, 1991–1993, and 2005–2007. Number of stations in Antarctica and manpower deployment.**

Signatory state	Proportion 1981–1983	Proportion 1991–1993	Proportion 2005–2007	Number of stations***	Manpower (annual peak)***
U.S.A.	34.03%	30.62%	24.14%	4	1293
United Kingdom	17.22%	12.10%	11.23%	5	205
Australia	9.91%	7.25%	8.13%	3.5	206
Germany	6.33%	9.50%	7.35%	2	78
Italy	0.10%	5.16%	5.67%	5.5	113
France	3.81%	5.14%	4.62%	3.5	123
Japan	7.04%	3.94%	4.18%	3	125
Spain	0.00%	1.30%	3.30%	2	28
New Zealand	5.57%	3.79%	3.18%	1	85
China	0.22%	0.97%	3.07%	2	70
Argentina	0.23%	1.30%	2.84%	6	417
Russia (U.S.S.R.)	5.80%	3.14%	1.96%	7	429
Netherlands	0.43%	1.18%	1.90%	0	
India	0.22%	1.72%	1.76%	1	65
Sweden	0.00%	1.69%	1.55%	1	20
South Africa	1.96%	2.50%	1.51%	1	80
Brazil	0.05%	0.60%	1.40%	1	40
Belgium	0.14%	0.94%	1.29%	0	
Norway	1.15%	0.86%	1.25%	2	44
Poland	3.35%	0.93%	0.95%	1	40
Chile	0.14%	0.65%	0.93%	5	224
South Korea	0.00%	0.10%	0.90%	1	60
Finland	0.00%	0.35%	0.47%	1	20
Ukraine	0.00%	0.24%	0.23%	1	24
Bulgaria	0.14%	0.00%	0.20%	1	15
Uruguay	0.00%	0.00%	0.04%	1	60
Ecuador	0.00%	0.00%	0.01%	2	26
Peru	0.00%	0.03%	0.00%	1	28
Other/non-consulting countries	2.16%	4.00%	5.94%		
n	*696***	*2452*	*4414*		

* In the case of international coauthorship, each country has been assigned their receptive fraction of the articles.

** Core publications only, i.e. articles identified by title words.

*** This information is from the website of COMNAP, the Council of Managers of National Antarctic Programs (http://www.comnap.aq/facilities). In the case of joint stations, the numbers have been divided equally.

contribution. To what extent this affects the use of citations as performance indicators is a matter of debate.

Figure 3 shows the relative citation index for the largest contributors to polar research in terms of publications for the period 2001–2007 (countries with more than 200 publications during this period). As can be seen, the citation index does not correlate with the quantitative measures of total publications (Spearman's rank-correlation coefficient $r = 0.41$, not significant at the 0.01 level). Switzerland (not shown in the figure) and Belgium are the countries with the highest scientific impact measured by citations. Although they are relatively small contributors, their publications have on average been cited 80% and 30%, respectively, above the world average for polar research. They are followed by the U.S.A. and the U.K., with citation indexes of 128 and 126, respectively. In other words, their publications are 28% and 26% more cited than the corresponding world average. At the other end of the scale we find Russia, which has a citation index of 60. Publications from Poland, China, and Argentina are also poorly cited.

INTERNATIONAL COLLABORATION

The extent of scientific collaboration has increased significantly over the past decades. This growth in collaboration is well-documented by the number of authors and institutions listed on publications. In the early 1980s, less than 10% of the articles on polar research involved international coauthorship, while in 2007 this proportion had increased to 41% (Fig. 4), which is twice the global average for all fields (21% in 2005). Strong international collaboration appears to be a characteristic of polar research. This holds true for both Arctic and Antarctic projects: the annual rates of international coauthorship are approximately equal for Arctic and Antarctic papers.

Based on data for the period 2005–2007, we have further analyzed each country's propensity to collaborate internationally (Table 3). It is interesting to note that all the largest countries (countries with more than 200 publications during the period 2005–2007) have a proportion of internationally coauthored papers greater than 50%, which is much higher than the corresponding world average for polar research publications (39%). This might seem rather counterintuitive, but it is due to the multiple counting of publications involving coauthorship between persons from more than one country. Switzerland has the highest proportion of internationally coauthored papers with 88%. In other words, almost all articles which list at least one institutional address in Switzerland also have coauthors from other countries. France and Denmark follow with proportions of 77% and 74%, respectively. At the other end, approximately 50%

TABLE 2

Proportion* of articles relating to Arctic by countries, 1981–1983, 1991–1993, and 2005–2007.**

Country	Proportion 1981–1983	Proportion 1991–1993	Proportion 2005–2007
U.S.A.	37.4%	33.0%	27.3%
Canada	28.2%	20.5%	14.9%
Norway	5.7%	10.0%	9.0%
United Kingdom	6.2%	5.8%	7.2%
Germany	0.8%	4.9%	7.2%
Russia (U.S.S.R.)	5.5%	6.4%	6.3%
Denmark	8.6%	5.4%	5.1%
Sweden	2.7%	2.5%	3.0%
Japan	1.2%	1.1%	2.6%
France	1.0%	2.4%	2.4%
China	0.0%	0.1%	2.0%
Finland	0.4%	1.3%	1.7%
Australia	0.3%	0.9%	1.2%
Netherlands	0.2%	0.9%	1.2%
Poland	0.3%	0.4%	1.1%
Switzerland	0.8%	0.9%	1.1%
Other countries	0.6%	3.7%	6.5%
n	*1105***	*2889*	*5581*

* In the case of international coauthorship, each country has been assigned their receptive fraction of the articles. Only countries with a proportion of above 1% in 2005–2007 have been shown.

** Core publications only, i.e. articles identified by title words.

of U.S., Chinese, and Canadian publications involve international coauthorship.

International scientific collaboration has not only increased in volume, there has been a shift in the geographical patterns of collaboration as well (Fig. 5). We have calculated the frequencies of coauthorship by region (number of pairs of collaborative links): the European Union (EU), North America, and other countries for the period 1981–2007. In the EU category the current 27 EU member states are included, as well as the three associated European Economic Area (EEA) countries.

Over this period the relative importance of collaboration between the EU and North America has decreased, while the relative importance of collaboration among the EU countries has increased. In 1981–1983, 45% of the collaborative links between countries identified in internationally coauthored polar research papers were between the EU countries and North America (the U.S.A. and Canada). In 2005–2007, this proportion was only 24%. During the same period, collaboration among EU countries rose from 27% to 34% of the total collaborative links identified in

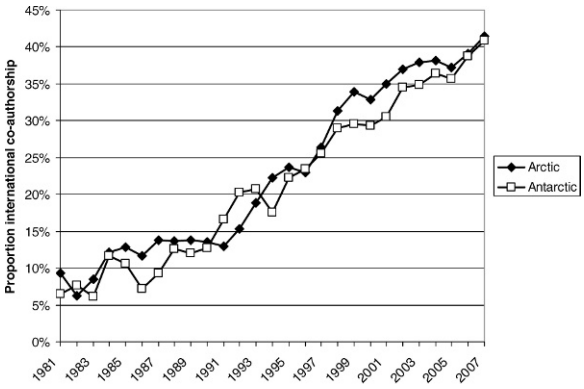


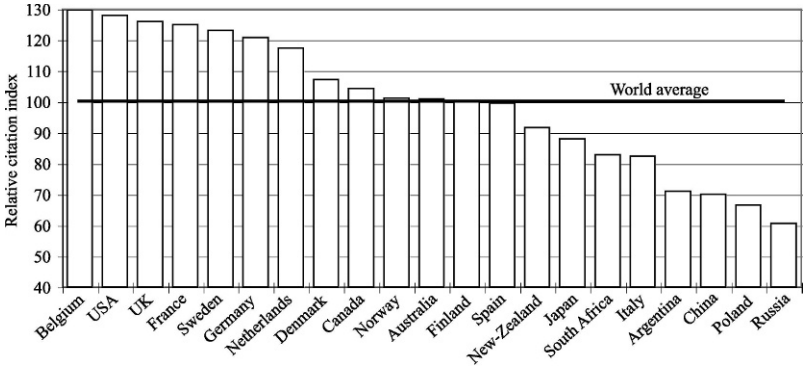
FIGURE 4. The proportion of international coauthorship, 1981–2007, for articles relating to Arctic and Antarctic.

internationally coauthored polar research publications. Interestingly, collaboration between North America and non-EU/EEA countries has declined in relative (but not absolute) terms during the period. This is not a sign that North American researchers collaborate less frequently with foreign scientists than they used to; rather, it is a consequence of the declining U.S. and Canadian share of polar research publications. In absolute numbers, the publication counts for all the regions rose considerably during the period, and collaboration as measured by coauthorship has also increased for all the regions, albeit at different rates.

Our analysis reveals that international collaborative papers have a higher citation score than national papers (Table 4). This effect is most obvious in the case of Russia. The impact of Russian research is very low, except when Russian scientists collaborate with foreign scientists, and even then those papers do not achieve a citation score of 100 (the world average).

Discussion

Our study reveals a number of rather interesting patterns with regard to polar research efforts. In terms of publications, polar research—a heterogeneous and geographically delimited field—has grown at a much faster rate than the global scientific output in general. This might be due in part to the growing importance of the Arctic and Antarctic regions to major global climate and resource issues, which has led to intensified research efforts. The traditional polar research nations have increased their research output, and new countries have entered into the polar research arena. The study identifies several major trends, some of which are general to science, others of which are specific to polar research.



*Countries with more than 200 publications during the period. Switzerland has a citation index of 180 but has been omitted from the figure for visibility reasons.

FIGURE 3. Relative citation index for the largest polar research nations, based on articles published during the period 2001–2007.*

TABLE 3

The proportion of international coauthorship, 2005–2007, by countries.*

Country	Total number of articles	Number of articles with international coauthorship	Proportion international coauthorship
Switzerland	226	200	88%
France	647	522	81%
Denmark	520	398	77%
Sweden	451	334	74%
Netherlands	293	216	74%
New Zealand	281	202	72%
Germany	1205	821	68%
Finland	201	131	65%
United Kingdom	1457	949	65%
Spain	300	189	63%
Norway	862	541	63%
Italy	490	296	60%
Australia	629	374	59%
Japan	512	296	58%
Russia	659	378	57%
Canada	1292	664	51%
China	334	167	50%
U.S.A.	3439	1716	50%
TOTAL	9807	3827	39%

* Only countries with more than 200 publications during the period 2005–2007 have been shown.

The total includes all countries.

TABLE 4

Difference in the citation index values of domestic and internationally coauthored publications, 2001–2007, by countries.*

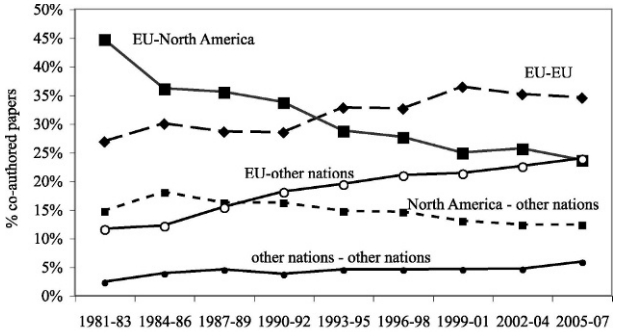
Country	Difference	Country	Difference
Switzerland	108	Argentina	42
Russia	74	New Zealand	36
Poland	70	Japan	36
Italy	69	South Africa	34
China	56	Norway	33
Sweden	52	Germany	32
Belgium	50	Finland	32
Denmark	48	Australia	31
Netherlands	46	Spain	30
France	46	United Kingdom	23
Canada	45	U.S.A.	13

* Only countries with more than 200 publications during the period have been shown.

The increase in output of scientific papers reflects a universal trend, but the increase is markedly steeper for polar science than for science in general. Within the primary disciplines of geosciences and biology, polar researchers are heavily engaged in climate-related issues, such as climate forcing and climate change. Moreover, international scientific consortia involving various subdisciplines and multilateral funding play an important role in polar research (Drivenes and Jolle, 2006). This is exemplified by large-scale installations such as the EISCAT radar facilities and the SvalSat satellite station on Svalbard, as well as large-scale initiatives such as the European Project for Ice Coring in Antarctica (EPICA), which involves 10 nations and a number of large international cruises.

In addition to a scientific dimension, there is a geopolitical dimension to the growth in polar research activities. This deals with security issues and sovereignty claims over marine areas including access to natural resources (oil, gas, fish stocks). Ever since the first polar expeditions, scientific aims have been intertwined with national and territorial ambitions (Schild, 1996). In the case of the Antarctic, a country may become a Consultative Party in the Antarctic Treaty System by carrying out substantial scientific activity in the region. It is interesting to note that with regard to scientific publication, many of the Consultative Parties have apparently not been very active. Some countries have sizable field stations and field staff, with little science of substance going on—at least research that lead to publications. Thus, their presence may be more due to a political interest of having people stationed in the region. At the same time it should be acknowledged that not all research relating to the Antarctic presuppose field staff (e.g. involving computer simulations, modeling, remote sensing etc.).

Seven countries maintain sovereignty claims in the Antarctic: Argentina, Australia, Chile, France, New Zealand, Norway, and the U.K. These countries contribute to a varying degree to the overall publication output. The U.K. and Australia make large contributions, while Chile and Norway make very modest contributions. Chile has, nevertheless, many stations and persons working in Antarctica. As an Antarctic claimant, Norway's position appears anomalous with both few publications and little field staff present. According to Schild (1996), this may reflect "the difficulty of maintaining healthy Arctic *and* Antarctic research programmes in a small country with concomitant financial and manpower constraints. Further, Norway has traditionally set greater national store by her responsibility for Svalbard than by her Antarctic interests" (p. 122).



*The current 27 EU member states are included in the EU category even if they have not been members during the entire period. The three associated European Economic Area countries are also included in this category. Collaborative links between the U.S.A. and Canada have been omitted from the calculations.

FIGURE 5. Collaboration by region (the European Union [EU], North America, and other countries),* 1981–2007, share of collaborative links in internationally coauthored polar articles.

It is well known that geopolitical arguments serve as national justifications for engaging in research activities in the Antarctic, and it has been argued that the quality of some of the science carried out there is weak. For example, the proliferation of stations and scientific activities in the region may lead to duplication of data collection and research (Schild, 1996). Interestingly, we do find that publications related to the Antarctic are cited less often than publications related to the Arctic, although the difference in frequency is not very large. (The relative citation indexes for the two categories of publications are 98 and 104, respectively.)

Polar research is a field where international cooperation traditionally has been relatively common. Factors that might explain this are the extra-national setting in which polar research is often carried out, the interdisciplinary nature of polar research, and the small size of national polar research communities. According to Elzinga and Bohlin (1993), there are important differences between Arctic and Antarctic science with regard to international collaboration: "In the Arctic the exertion of national sovereignty, as well as the military and economic interests in a number of countries have hindered the far-reaching international collaboration found in the Antarctic" (p. 7). Our study does not provide empirical data to support this claim. On the contrary, the prevalence of international collaboration as reflected in coauthorship is almost identical in the two regions. Possibly, it might still be the case that formal collaboration in the form of research programs is more widespread in the Antarctic than in the Arctic. This issue cannot be assessed through coauthorship data, which reflect the total patterns, both formal and informal types of research collaboration.

The increase in international collaboration in science in general is indicated by the proportion of papers involving international coauthorship. In 2005, 21% of all papers published in journals worldwide involved such collaboration (National Science Board, 2008). Today, in some countries, the majority of scientific publications are internationally coauthored (Aksnes et al., 2008). Generally, nations with large-scale scientific communities do of course publish far more international collaborative articles than countries with smaller communities. Nevertheless, the proportion of internationally coauthored papers tends to increase as the volume of national publication decreases (Luukkonen et al., 1992). Hence, international collaboration is relatively more important in smaller countries. This is to a certain extent also true in the case of polar research. The largest nation in polar research, the U.S.A., has the lowest proportion of international coauthorship, while Switzerland, a very small nation in terms of polar research, has the highest. The picture is not, however, unambiguous. For example, two of the largest nations—the UK and Germany—have high proportions of internationally coauthored articles.

An interesting feature of internationally coauthored publications is that they generally achieve higher citation rates than purely domestic publications (i.e. publications with authors from one country only) (Narin et al., 1991). This is also true in the case of polar research, where international collaborative articles are more frequently cited than national publications. Apparently, the scientific influence of the research increases when researchers from more than one nation collaborate. Different reasons might explain this phenomenon. International collaborative projects will typically involve more manpower and resources, which will be beneficial for the scientific importance and quality of the research. Sharing of mutual competences may also be advantageous in this respect. In addition, the visibility of the research and the publications will increase when institutions located in different countries collaborate, and thereby the potential for receiving more citations.

As shown in Table 4, scientists from certain countries benefit more from international collaboration than others do. Generally, the effect is strongest for the nations with low citation rates, for example Russia, Poland, and China. The findings can be taken as an indication that the polar research carried out in these countries tend to be mediocre, not worth citing, and that in order to attain a sufficient level of research quality, scientists from these countries need to collaborate internationally. Possibly, scientists in these countries tend to concentrate on topics not being dealt with by their western colleagues, or which are at the margins of what interest western scientists; consequently, their publications are being cited less.

One of the most striking findings of our study is the extent of the growth in international collaboration in polar research. The rise in international collaboration in polar research applies to marine programs and cruises as well land-based research. It is evident in major European collaborative initiatives, such as the EPICA project (http://www.esf.org/index.php?id=855) in which ice-core drilling is used to reveal climate history over the past 500,000 years. Such initiatives require a large-scale collaborative effort and co-funding by various national funding agencies as well as the European Science Foundation. The extent of internationalization represents an important difference in how polar science—and science in general—is carried out today, compared to the recent past. It also reflects a turning away from a kind of nation-based competition and an embracing of joint projects to address major challenges and highly complex issues (e.g. polar drivers for climate change and impacts of climate change on the polar regions). Joint projects typically involve sizeable consortia of scientists from various disciplines, including oceanography, geophysics, meteorology, and biology, as well as models and modelers that integrate input from these disciplines. Large-scale projects require extensive infrastructure and are often too costly to be carried out by an individual country. This has been instrumental in shifting focus from national discoveries of phenomena to integrative efforts to understand the large-scale dynamics at play (Elzinga, 1991).

With regard to funding, the EU Framework Programmes play a key role for the EU countries. During the 1980s, the EU launched its first Framework Programme to encourage international collaboration. This represented a fundamental change to European science and appears to have had a direct impact on collaboration patterns (Aksnes et al., 2008), also within polar research. Our findings correspond well with previous studies. According to Schild (1996), in the early 1980s the U.S.A. was the focal point of European polar scientists: "However, as the US National Science Foundation was reportedly becoming 'less hospitable than before towards European polar scientist', and as national budgets stagnated, and the European common source grew, polar scientists found ways of tapping European Union research funds (which are necessarily collaborative), even though the European Union was not committed to funding polar research" (p. 161).

Perhaps the most interesting turn of events resulted from politically driven changes in funding policy at the end of the Cold War. Mikhail Gorbachev opened his famous Murmansk speech (1987) by calling for closer international cooperation on Arctic research. In spite of the subsequent downplaying of the geopolitical aspects of such cooperation (at least temporarily), Russia did not become much involved in international polar research efforts. This might seem counterintuitive, but probably has to do with internal problems of science funding in Russia.

Another striking trend has been a marked relative decrease in collaboration between North America and other countries in general, and between North America and the EU/EEA nations in particular (cf. Fig. 3). Meanwhile, cooperation within the EU itself has increased steadily, as has cooperation between the EU and other countries (including Russia). This has been driven by changes in funding policy, and declining collaboration between the U.S.A. and Europe has given rise to the need for new initiatives (ARCUS, 2000).

We believe the trends concerning growth and internationalization revealed in this survey will continue in the foreseeable future as an increasing share of big science issues (e.g. joint cruises on large vessels, multinational research efforts funded by EU or other international agencies, joint use of large infrastructure facilities for remote sensing, space research, etc.) also demands an increased share of interdisciplinary and international efforts. The strong growth in overall research activities and collaboration will in the polar regions most likely continue in the years to come. In the short term, the effect of the International Polar Year (IPY) has not yet appeared in the publication counts. The polar areas are at the core of several major scientific issues of the coming decades, including the most important environmental challenges such as global change, both in terms of climatic forcing and ecosystem effects, harmful levels of organic pollutants, and sustainable harvesting management of natural resources. These include not only oil and gas but also biological resources such as commercial stocks of fish and invertebrates as well as future genetic or biochemical resources (e.g. bioprospecting). In terms of geopolitical issues, we have probably only seen the beginning of a renewed interest in the polar areas (since the end of the "cold war"), and while the ties between science and geopolitical issues have become less tight, there still is a mutual feedback between science and politics in the polar regions.

Acknowledgments

This article is based on a project funded by the Norwegian National Committee on Polar Research, the Research Council of Norway. The authors would like to thank three referees for valuable comments on an earlier version of this article.

References Cited

Aksnes, D. W., 2006: Citation rates and perceptions of scientific contribution. *Journal of the American Society for Information Science and Technology* (*JASIST*), 57: 169–185.

Aksnes, D. W., and Rorstad, R., 2008: *Norsk polarforskning—forskning paa Svalbard*. Oslo: NIFU STEP Rapport 8/2008 (in Norwegian).

Aksnes, D. W., Olsen, T. B., and Seglen, P. O., 2000: Validation of bibliometric indicators in the field of microbiology. A Norwegian case study. *Scientometrics*, 49: 7–22.

Aksnes, D. W., Slipersaeter, S., and Frolich, N., 2008: Science policy and the driving forces behind the internationalisation of science: the case of Norway. *Science and Public Policy*, 35: 445–457.

ARCUS, 2000: *Opportunities for Collaboration between the United States and Norway in Arctic Research: a Workshop Report*. Fairbanks, Alaska: Arctic Research Consortium of the University of Alaska.

Dastidar, P. G., 2007: National and institutional productivity and collaboration in Antarctic science: an analysis of 25 years of journal publications (1980–2004). *Polar Research*, 26: 175–180.

Drivenes, E. A., and Jolle, H. D. (eds.), 2006: *Into the Ice: the History of Norway and the Polar Regions*. Oslo: Gyldendal.

Elzinga, A., 1991: The Antarctic as Big Science. *In* Hicks, E. K., and van Rossum, W. (eds.), *Policy Development and Big Science*. Amsterdam: Noord-Holland, 15–25.

Elzinga, A., and Bohlin, I., 1993: The politics of science in polar region. *In* Elzinga, A. (ed.), *Changing Trends in Antarctic Research*. Dordrecht: Kluwer Academic Publishers, 7–30.

Farman, J. C., Gardiner, B. G., and Shanklin, J. D., 1985: Large losses of total ozone in Antarctica reveal seasonal CLOx/Nix interactions. *Nature*, 315: 207–210.

Leydesdorff, L., 1989: Words and co-words as indicators of intellectual organizations. *Research Policy*, 18: 209–223.

Luukkonen, T., Persson, O., and Sivertsen, G., 1992: Understanding patterns of international scientific collaboration. *Science, Technology and Human Values*, 17: 101–126.

Ministry of the Environment, 1993: *Report No. 42 (1992–93) to the Storting, Norwegian Polar Research*. Oslo: Norsk polarforskning (in Norwegian).

Moed, H. F., 2005: *Citation Analysis in Research Evaluation*. Dordrecht: Springer.

Narin, F., Stevens, K., and Witlow, E. S., 1991: Scientific cooperation in Europe and the citation of multinationally authored papers. *Scientometrics*, 21: 313–323.

National Science Board, 2008: *Science and Engineering Indicators—2008*. Arlington, Virginia: National Science Foundation.

Schild, I., 1996: *The Politics of Collaboration in Polar Research*. Sussex: SPRU.

MS accepted January 2009