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Arctic Research Publication Trends: A Pilot Study

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Content

Introduction

Arctic Research Cooperation

International scientific collaboration in the Arctic has existed for more than 150 years, as exemplified by the International Polar Year collaboration started in 1882-83, and held most recently in 2007-2008. The Arctic environmental protection strategy (AEPS), the predecessor of the Arctic Council (est. 1996), the International Arctic Science Committee (IASC), the International Arctic Social Sciences Association (IASSA), and several other entities are all products of new initiatives started shortly after the end of the Cold War, around 1990.

Today the Arctic Council functions as a policy shaping collaboration between the eight countries surrounding the Arctic - Canada, Kingdom of Denmark (including Greenland and Faroe Islands), Finland, Iceland, Norway, Russia, Sweden, and the United States (US). The Arctic Council is a unique international organization, welcoming the indigenous peoples of the Arctic as permanent participants in this collaboration. The Arctic Council also has a number of observers that includes non-Arctic states, inter-governmental and inter-parliamentary organizations, both global and regional, and non-governmental organizations. UArctic, IASC, and IASSA are observer organizations that represent the scientific community in the Arctic Council.

The main achievement of the Arctic Council is building the Arctic as a zone for peace and collaboration, and raising awareness of the main environmental, development and economic issues affecting the Arctic and its peoples. The Arctic Council is the mother of two binding agreements between the member states: one on search and rescue and the other on Marine Oil Pollution Preparedness and Response. The Arctic Council also took the initiative for creation of two independent organizations: the University of the Arctic in 1998, and more recently the Arctic Economic Council, in 2014.

In fall 2016, the Arctic Council will conclude a binding agreement on Arctic scientific collaboration that intends to simplify access to research areas, movement of samples, data and people among the Arctic eight countries.

With an increasing interest in the Arctic across the globe, along with the long history of scientific collaboration within the region and the engagement in Arctic science by the Arctic Council, it is time to document the state of scientific collaboration in and about the Arctic.

University of the Arctic

The Arctic Council (shortly after its own creation 20 years ago) created the University of the Arctic (UArctic) as a decentralized higher education institution intended to address the challenges of sustainable development in the circumpolar region. In the Iqaluit declaration (1998) the Ministers of the Arctic Council wrote that they hereby “Welcome, and are pleased to announce, the establishment of the University of the Arctic, a University without walls…”

Nearly twenty years later, the world’s attention to the Arctic region has grown tremendously. UArctic, like the Arctic Council, has always placed a strong emphasis on the Arctic’s role as a region of peace and cooperation. The UArctic is now a unique network of over 170 universities and higher education institutions, including all northern academic institutions, as well as the majority of all institutions conducting research and education in and about the Arctic in the eight Arctic Council member states. UArctic also welcome members from non-Arctic states. The membership of UArctic is at the moment evenly distributed across Northern regions, with approximately 50 members in each of, North America, the Nordic countries, and Russia. In addition UArctic has 20 members from non-Arctic states.

Today, UArctic members are pooling and sharing resources to build cooperation based on the strengths each member organization brings. UArctic has become the supporting network that enables much of the international academic collaboration across the circumpolar North, and myriads of collaborative efforts have come to reality as a consequence of twenty years of partnership and cooperation.

UArctic Science & Research Analytics Task Force

The UArctic Science & Research Analytics Task Force was established in 2015 following the UArctic Rector’s meeting in Umeå, Sweden. The Task Force members include a small, but diverse international group of subject-matter experts who are willing to participate and contribute to this unique and challenging endeavour. Members represent all key macro-regions of the UArctic and the Arctic Council – North America, Russia, and the Nordic countries as well as UArctic partners in IASC and IASSA; there is also representation of expertise from the International Polar Year.

The main goal of the Task Force is to identify challenges and gaps in knowledge about the Arctic, using big-data analytics tools and bibliometric/scientometric approaches and methods, and to inform research-based solutions that are possible through the efforts of the UArctic Network. The Task Force has partnered and is liaising with global data and information providers in order to improve the representation and visibility of Arctic research in the global indexed research output.

Given the increasing volume of research data generally, one of the long-term objectives is to monitor the state of Arctic research efforts across institutions and countries and to provide fact-based insights for the Arctic research community, the general public, and policymakers from Arctic Council member[1] and observer[2] states about Arctic education, collaboration, researcher mobility, science & technology trends and collaboration gaps, challenges, and opportunities.

[1] Canada, Finland, Iceland, Kingdom of Denmark, Norway, Russian Federation, Sweden, United States of America.

[2] France, Germany, Italian Republic, Japan, the Netherlands, People's Republic of China, Poland, Republic of India, Republic of Korea, Republic of Singapore, Spain, United Kingdom.

Methodology & Data

Data Sources

This study is built on data from the Scopus dataset, which was transferred to the SciVal data visualization platform for visualization and analysis purposes. Both Scopus and SciVal were developed and are owned by Elsevier, an international provider of data solutions and publisher (www.elsevier.com). The Scopus data contains a variety of indicators and statistics on scientific and scholarly publishing. SciVal uses Scopus content from 1996 on. Scopus was developed by and is owned by Elsevier. It is the largest abstract and citation database of peer reviewed research literature in the world, with abstracts and citation information from more than 60 million scientific research articles in 22,000 peer-reviewed journals published by over 5,000 publishers.[3]

Definition of 'Arctic'

There are many ways to define the Arctic, and there are a myriad of approaches to defining it in daily use. This includes self-perception by its people, culture and history, latitude (arctic circle), political definitions (where the rationale for borders is often driven by national economic or political goals), as well as a set of natural science-based definitions, using climate, eco-systems and eco-regions, animals, vegetation, sea ice, permafrost and so forth. There also are many historical, and partly mythological definitions of the North[4].

A useful definition of "the Arctic" should be able to separate the North and the Arctic as an area with definable ecological / natural systems that are clearly differentiated from those farther south, preferably in a manner that also reflects "northern", as opposed to "not so northern", human realities and activities.

Furthermore, the definition should preferably be close to "common understandings" of the North and or the Arctic, even if this understanding varies by audience. In addition it should be consistent with national (sometimes policy driven) definitions, but not be influenced by country borders. Finally, it must be practical to use. If these goals are attainable, that indicates that easily recognizable concepts can be used to separate the Arctic from the non-Arctic.

The *UArctic Science Analytics Arctic* definition follows the general trend of the Arctic Council-related definitions of the Arctic. This choice is pragmatic; it acknowledges the general acceptance of the Arctic Council as the body representing the Arctic globally.

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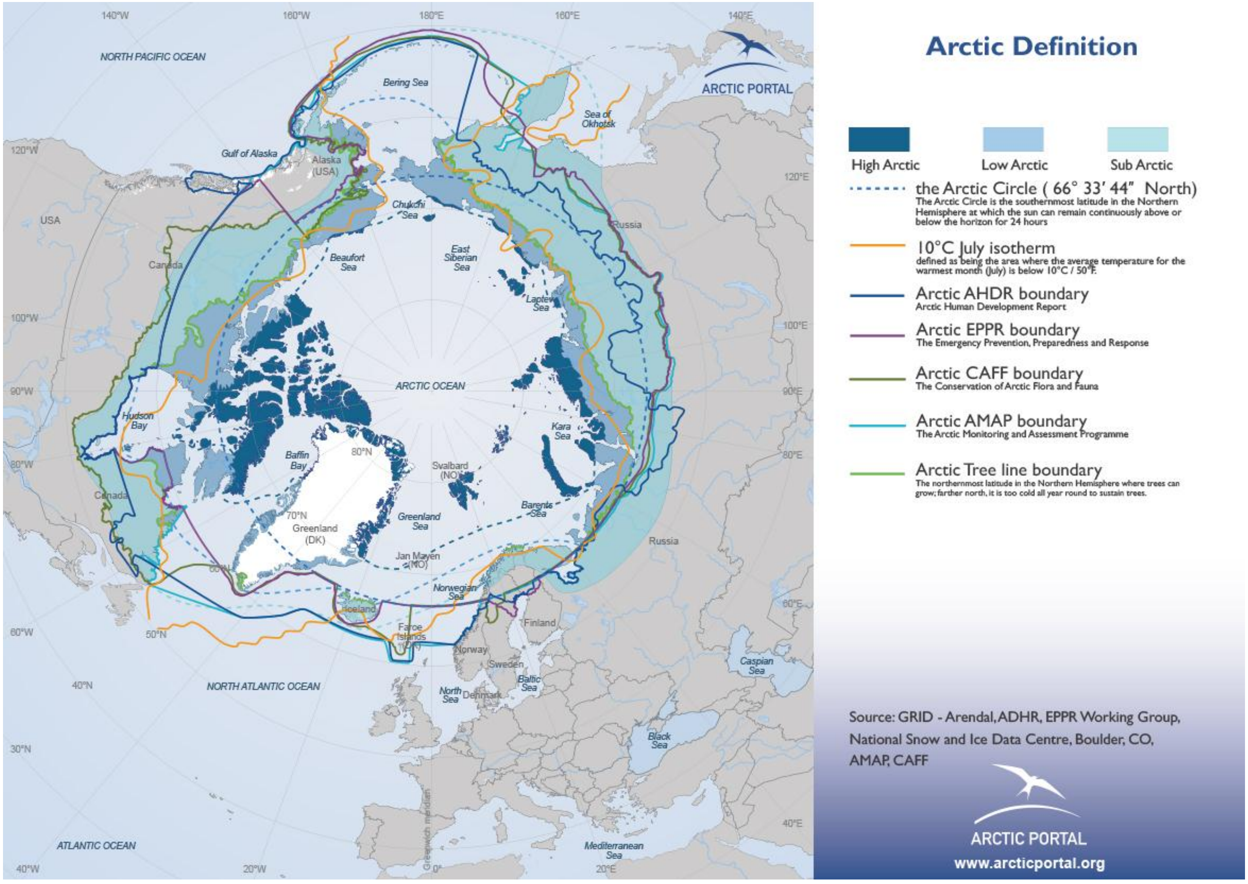
[3] For further information, see: https://www.elsevier.com/solutions/scopus/content
[4] Examples include http://arcticcentre.ulapland.fi/pole_arctique.htm and http://arcticcentre.ulapland.fi/arctic_map_old.htm.

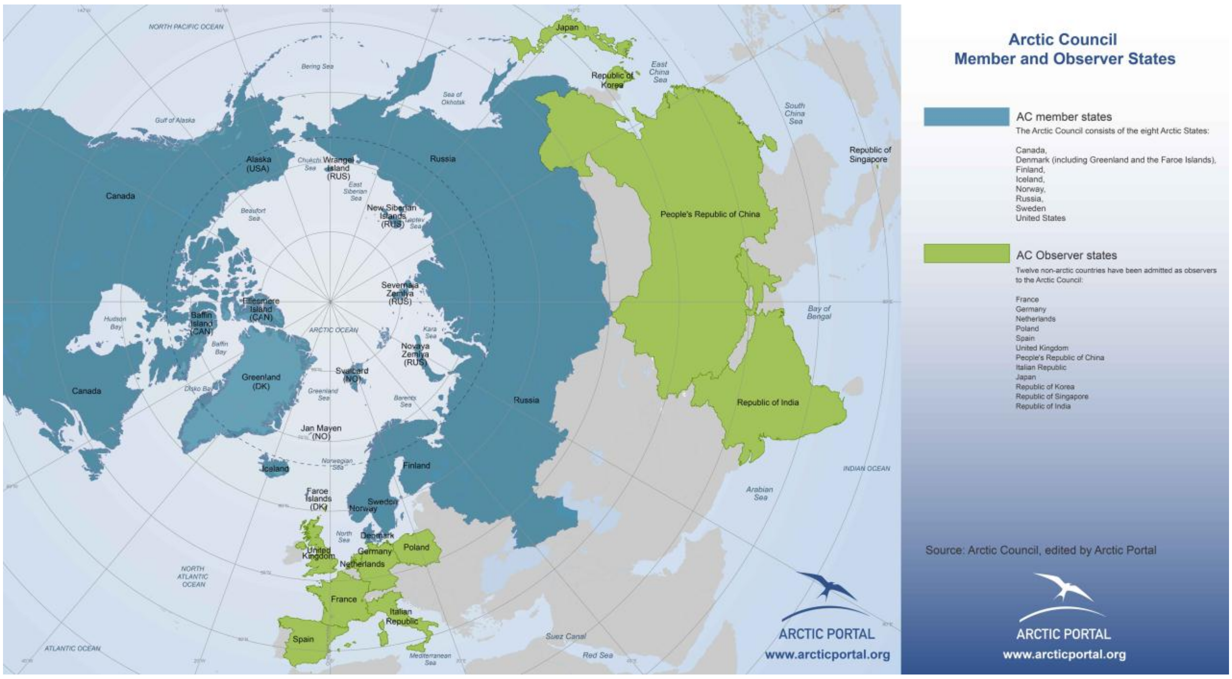
More specifically the UArctic Science Analytics Arctic definition follows the Arctic Human Development Report (AHDR) boundaries, administrative boundaries on land areas when addressing socioeconomic and human related issues, while following the southernmost of either the Arctic Monitoring and Assessment Program (AMAP) and Conservation of Arctic Flora and Fauna (CAFF) boundaries for natural phenomena on land. Further it uses the AMAP border for marine areas with the flexibility that the Search and Rescue Agreement can be used when that would be more appropriate for marine areas.[5]

This study uses the combined Arctic Definitions of the Arctic Council (AHDR+EPPR+CAFF+AMAP) to define the Arctic.

[5] For AHDR, CAFF, AMAP lines see http://arcticportal.org/images/maps/small/1.9.jpg and for the Arctic Search and Rescue Agreement see https://en.wikipedia.org/wiki/Arctic_Search_and_Rescue_Agreement.



Arctic Definition
High Arctic
Low Arctic
Sub Arctic
the Arctic Circle (66° 33′ 44″ North)
The Arctic Circle is the southernmost latitude in the Northern Hemisphere at which the sun can remain continuously above or below the horizon for 24 hours
10°C July isotherm
defined as being the area where the average temperature for the warmest month (July) is below 10°C / 50°F.
Arctic AHDR boundary
Arctic Human Development Report
Arctic EPPR boundary
The Emergency Prevention, Preparedness and Response
Arctic CAFF boundary
The Conservation of Arctic Flora and Fauna
Arctic AMAP boundary
The Arctic Monitoring and Assessment Programme
Arctic Tree line boundary
The northernmost latitude in the Northern Hemisphere where trees can grow; farther north, it is too cold all year round to sustain trees.
Source: GRID - Arendal, ADHR, EPPR Working Group, National Snow and Ice Data Centre, Boulder, CO, AMAP, CAFF
ARCTIC PORTAL
www.arcticportal.org
NORTH PACIFIC OCEAN
Bering Sea
Sea of Okhotsk
Gulf of Alaska
Alaska (USA)
USA
Canada
Chukchi Sea
Beaufort Sea
East Siberian Sea
Laptev Sea
Russia
ARCTIC OCEAN
Hudson Bay
Baffin Bay
Kara Sea
Svalbard (NO)
Greenland (DK)
Greenland Sea
Barents Sea
Jan Mayen (NO)
Norwegian Sea
Iceland
Faroe Islands
Finland
Norway
Sweden
North Sea
Denmark
Baltic Sea
Caspian Sea
Black Sea
NORTH ATLANTIC OCEAN
ATLANTIC OCEAN
Mediterranean Sea



Arctic Council
Member and Observer States
AC member states
The Arctic Council consists of the eight Arctic States:
Canada,
Denmark (including Greenland and the Faroe Islands),
Finland,
Iceland,
Norway,
Russia,
Sweden
United States
AC Observer states
Twelve non-arctic countries have been admitted as observers to the Arctic Council:
France
Germany
Netherlands
Poland
Spain
United Kingdom
People's Republic of China
Italian Republic
Japan
Republic of Korea
Republic of Singapore
Republic of India
Source: Arctic Council, edited by Arctic Portal
ARCTIC PORTAL
www.arcticportal.org
Japan
Republic of Korea
People's Republic of China
Republic of India
Russia
Canada
Alaska (USA)
Greenland (DK)
Iceland
Finland
Norway
Sweden
Poland
Germany
Netherlands
France
Spain
Italian Republic

Overview of Methodology

Only a small portion of research findings are published in specialized Arctic research journals (e.g. *Arctic*). Most of the publications appear in more general scientific and scholarly journals and thematic journals as well as books and monographs. Given the difficulty of defining the Arctic, the Task Force has utilized a keyword search query approach to identify publications relating to the Arctic.

The key challenge is identifying research in and about the Arctic as per the above definition and avoid research on objects and issues outside the Arctic as defined. In order to manage this challenge, we have decided to concentrate on two types of terms: geographical and indigenous peoples' names. In addition we used a few general terms assumed to be unique to the Arctic (e.g. Arctic, tundra). By using place identifiers while avoiding over use of specific disciplinary terms we hope to have avoided a disciplinary bias in the selection of research publications.

We applied geographical search terms for identifying the publications, and carried out a search through the titles and abstracts of all the publications in the database. A similar method was used in previous bibliometric analyses of polar and Arctic research (Dastidar, 2007; Aksnes & Hessen, 2009; Côté & Picard-Atiken, 2009). We have assumed that the geographical locality in which the research had been performed or relates to would generally appear either in the title or in the abstract of the publications. Names of geographical areas in the Arctic were therefore used as an indication of Arctic research content. Based on the geographical delimitation of Arctic (as above), names of mainland areas, islands, oceans, seas, lakes, rivers and key cities and settlements were included. In principle, the number of potential geographical search terms is almost infinite. For practical reasons, however, we limited the terms used to the main geographical localities. In total 350 terms were applied covering the key geographical regions in all eight Arctic Council member states.

In addition to geographical terms, which embody a direct connection to the areas considered "Arctic" by their respective countries, we also assumed that using the names of indigenous nations, peoples, bands, and tribes (e.g. Inuit, Saami, Nenets, etc.) as search terms will provide further precision to the output of the search. According to variety of anthropological, ethnographic and historical studies (Mousalimas 1997, Ingold 1992, Cruikshank 1992), indigenous people and their place names are typically well connected with the land and space, thus providing an additional dimension to the geographic/geological search. It also reflects the Arctic Council focus on Arctic Peoples as a key constituency for its work. We included these names in order to secure that the relevant research within social sciences, history, arts, humanities and life sciences would also be captured by our study. In total 225 such search terms were applied covering the official names and variations on their spelling (including Cyrillic, Swedish, etc.) to the search query, covering all eight Arctic Council member states.

The list of search names and keywords is far from complete and this is a pilot study, which, we hope, will trigger significant methodological and substantive discussions on both the data analyzed and the approach. We do believe that the method we have applied is adequate for the purpose of providing an initial analysis of the global Arctic research as it is reflected in Scopus database. However, there are also several sources of potential errors. First, it is possible that certain relevant publications were not identified because the publications do not specify where the research was carried out, or because names of geographical regions beyond those included in the study were mentioned. To reduce this problem, field-specific search terms (e.g. "sea-ice", "polar bear" etc.) could have been used. However, this was not done in this pilot to avoid disciplinary bias.

Second, the method might identify some irrelevant publications, i.e. publications which should not have been considered as Arctic research. This may be due to the fact that some words have more than one meaning or are used in contexts other than Arctic research. We attempted to avoid this problem by excluding words with multiple meanings, and testing the dataset output based on various scenarios to identify problems of double meaning or words which trigger massive false positive reference without any relevance to Arctic research. Still, there might be some publications left where this is a problem. In addition, there might be cases where particular geographical names are mentioned in the abstract, for example Greenland, but where the research had been carried out or mainly relates to other regions.

Third, the study is based on the SciVal/Scopus database. This database does not cover all scientific and scholarly publishing. Some journals, books and proceedings relevant for Arctic research might be missing. For example the coverage of Russian and Swedish language sources, which contain significant volume of Arctic research, is not present in the database due to language coverage, and the proceedings from the International Congress of Arctic Social Sciences (ICASS) are not yet included.

The problem of language and types of publications create a remaining concern as it produce a systematic bias in the dataset, possibly for specific research areas. We do however believe that the value of the information coming from such a large dataset by far outweigh the challenges as long as this problem is recognised. Most error sources (like double meaning of search terms) create to a large extent "random errors" (not specific to one discipline, institution or country etc.), and in this case the value of the large underlying dataset by far outweigh these errors.

In conclusion, there are limitations with this approach, but for most questions this is of less importance given the large number of publications involved and taking into account that our aim has been to provide a general overview of Arctic research.

Description of indicators used in the study

Publications

The indicator "publications" measures research output. The indicator is defined as the number of publications with at least one author affiliated with the concerned institution or country. A publication may be counted as a publication of multiple institutions and countries if it is a joint work of authors from multiple institutions and countries. If a publication is written by an author with multiple affiliations, the article is counted as a publication of all institutions with which the author is affiliated. A publication which is co-authored by authors from different countries thus counts towards the publication output of each country.[2] SciVal deduplicates all the publications within an aggregate entity (e.g. group of countries), so that a publication is only counted once even if it is co-authored by several of the component entities[3].

Publication share

Publication share is the global share of publications for a specific subject area or groups of countries expressed as a percentage of the total output. Using a global share in addition to absolute numbers of publications provides insight by normalizing for increases in world publication growth and expansion of the field in question or the whole Scopus database (Pan, 2014).

Institutions in SciVal

Institutions are groupings of related Affiliation Profiles which have been manually created as a convenient starting point for SciVal users; approximately 4,500 Institutions have been predefined and are available in SciVal (Colledge & Verlinde 2014).

Field-Weighted Citation Impact

The Field-Weighted Citation Impact in SciVal indicates how the number of citations received by an entity's publications compares with the average number of citations received by all other similar publications in the data universe: how do the citations received by this entity's publications compare with the world average?

- A Field-Weighted Citation Impact of 1.00 indicates that the entity's publications have been cited exactly as would be expected based on the global average for similar publications; the Field-Weighted Citation Impact of "World", or the entire Scopus database, is 1.00

- A Field-Weighted Citation Impact of more than 1.00 indicates that the entity's publications have been cited more than would be expected based on the global average for similar publications; for example, 2.11 means 111% more cited than world average
- A Field-Weighted Citation Impact of less than 1.00 indicates that the entity's publications have been cited less than would be expected based on the global average for similar publications; for example, 0.87 means 13% less cited than world average.

Similar publications are those publications in the Scopus database that have the same publication year, publication type, and discipline.

International Collaboration

International Collaboration is indicated by articles with at least two different countries listed in the authorship list.

Academic-Corporate Collaboration

The organization-types used in SciVal are based on aggregations of the Scopus organization-types to group similar functions together, and to simplify the options for the user. SciVal uses 5 organization-types: Academic, Corporate, Government, Medical, and Other. These are composed of the following Scopus organization-types:

- **Academic:** university, college, medical school, and research institute
- **Corporate:** corporate and law firm
- **Government:** government and military organization
- **Medical:** hospital
- **Other:** non-governmental organization

Academic-Corporate collaboration is indicated by articles with at least two different types of organization - Academic and Corporate one.

Patents

Information about patents in SciVal is obtained from five of the world's largest patent offices:

- WIPO (World Intellectual Property Organization) entity groups
- USPTO (United States Patent and Trademark Office)
- EPO (European Patent Office)
- JPO (Japan Patent Office)
- IPO (Intellectual Property Office), UK

Patent-article citations – specific references in patents to published research. Patent-article citations provide a proxy for innovation and the potential to transfer knowledge to industry, also referred to as the valorization of knowledge – creating value out of knowledge. Patent-article citations can provide an important indicator of the overall socio-economic impact of an institution.

Visualization

Mapping is made using VOSviewer - a computer program for creating maps based on network data and for visualizing and exploring these maps, created in CWTS.

All other graphs are either imported from SciVal and Scopus, or made in Microsoft Excel and R - a programming language and software environment for statistical computing and graphics supported by the R Foundation for Statistical Computing.

1. Publication output: total and by country

The analysis reveals that the global scientific production of Arctic publications has increased significantly during the period 1996-2015. In 2015 almost 11,000 papers were published, compared to Fewer than 5,000 in the years 1996-1999 (Figure 1). The number of publications has been growing at a relatively constant pace, albeit with some annual fluctuations. In total, we identified 148,000 publications that fell within our criteria and were categorized as relating to the Arctic. The figures reflect that the research activities relating to the Arctic have expanded significantly in the recent two decades. A main reason for this is probably the growing awareness that the Arctic has a key role in the understanding of climate change effects.

***Figure 1**. The development of the global output of Arctic scientific publications, 1996–2015.*

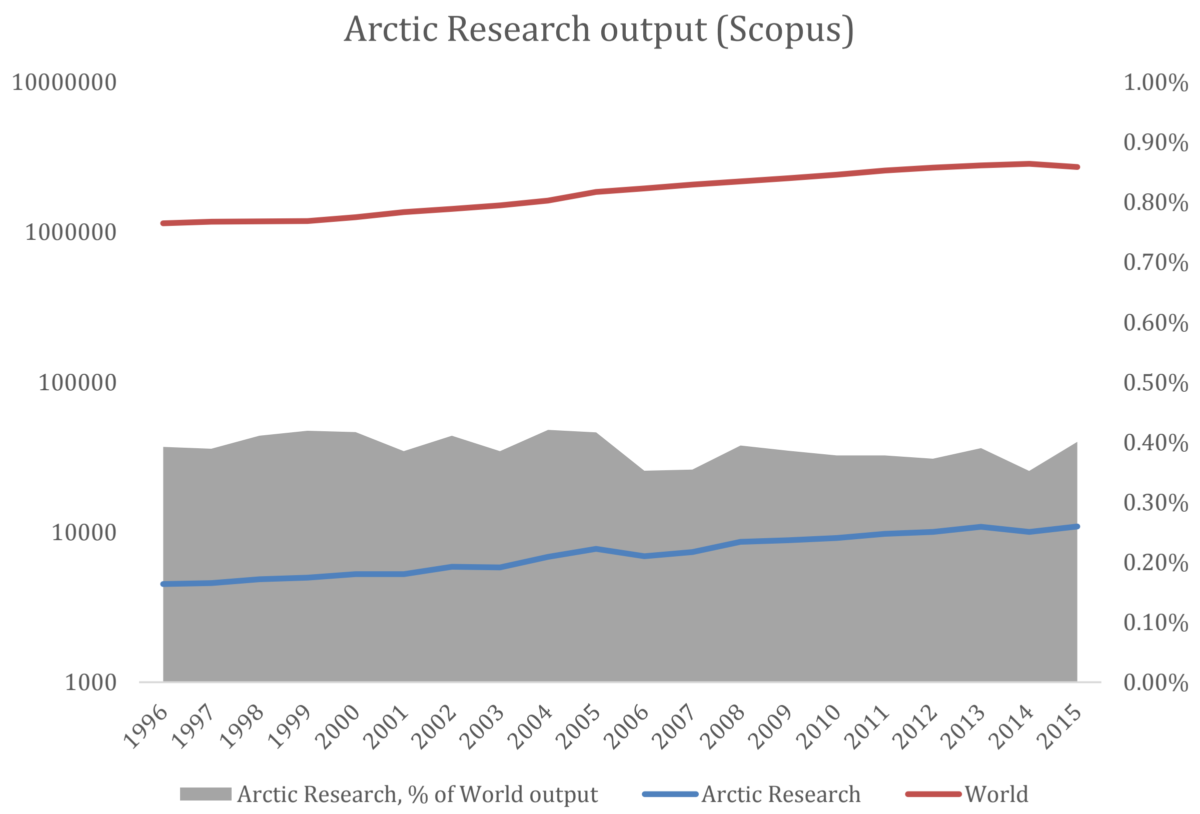


Figure 1 also shows the proportion of the publications in Scopus focused on the Arctic compared with the whole of the database (world). This proportion has been relatively stable during the period shown (in the range of 0.35 to 0.42 per cent). Interestingly, despite the strong increase in the Arctic publication volume, the proportion of the total in the database has not increased. This is due to the fact that total number of scientific publications in Scopus also has increased significantly during the period[6].

One might have assumed that Arctic research would show stronger relative growth than the global average. However, the empirical results do not support that this has been the case. 2007-2008 was the International Polar Year (IPY), an internationally coordinated campaign that represented a major initiative to strengthen research activities in the polar regions. Several countries increased their budgets for polar research considerably as part of the IPY-participation. One might expect that the results of this campaign would be reflected in increased publication numbers, with a one or three year delay. Although the numbers are higher in the 2009-2011 period than in the previous period, there is no obvious break in the trend line. Thus, the impact of this campaign seems to be too limited to be reflected in overall global publication numbers.

Figure 2 shows which countries that make the largest contribution to Arctic research in terms of publication output[7]. As in almost all fields, the U.S. is by far the largest nation with more than 3,100 publications in 2015. Then U.S. is followed by Russia and Canada with almost 2,300 and 1,600 publications, respectively. The United Kingdom and Norway are the fourth and fifth largest countries. The list of countries contributing to Arctic research is very long: however, many countries have only a very small publication output.

Figure 2 also shows the publication numbers in 2006 and 2015. For all countries there is a significant increase during the 10-year period. However, some countries have a stronger relative growth than others. China is by far the nation with the highest relative growth (260 per cent increase), and the republic is now the 7th largest country in terms of Arctic scientific publications. This strong growth is, however, not unique for Arctic research and overall China is now the second largest country in the world in terms of publication output. Of the larger Arctic research nations, Russia shows the strongest relative growth during the period, with a 117 percent increase. USA and

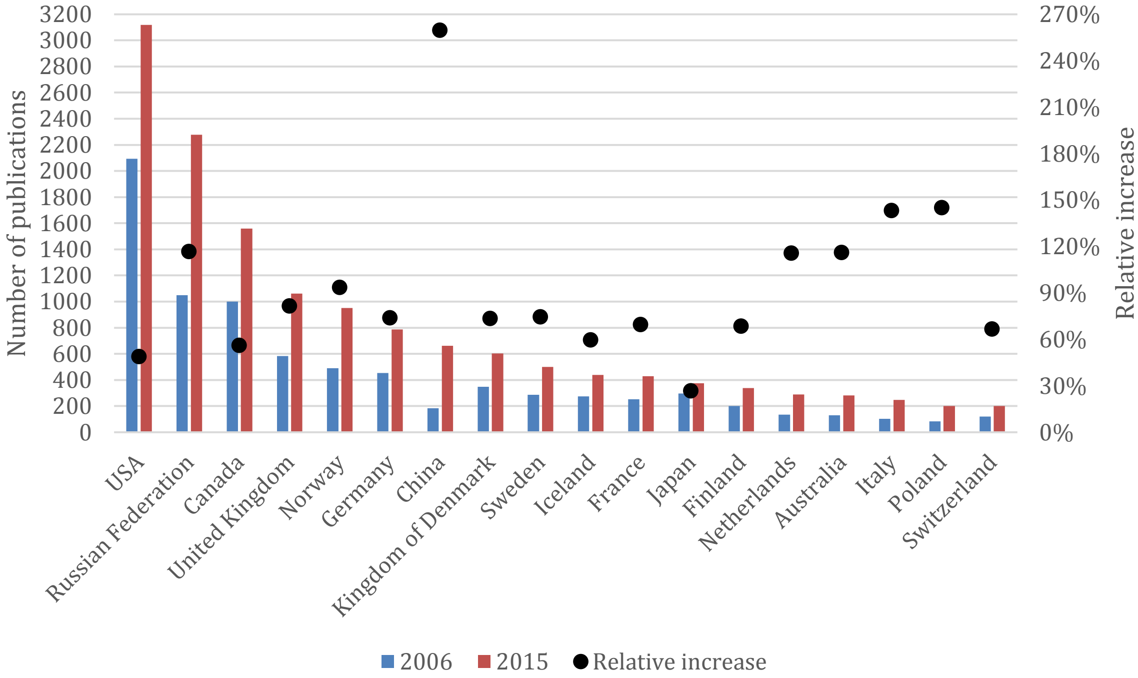
[6] Generally, the growth in publication numbers reflect that the global science system is expanding from year to year. More people are involved in research and more money is being spent. However, in addition there are database effects, as the Scopus' coverage of the global research literature has been increasing during the period

[7] When we are measuring contributions by country, we are are counting contributions according to the location of the institution at which a researcher is based, not the country of origin of individual researchers nor the place studied.

Canada rank among the countries with lowest relative growth, although in absolute numbers the increase in publication output is still very large.

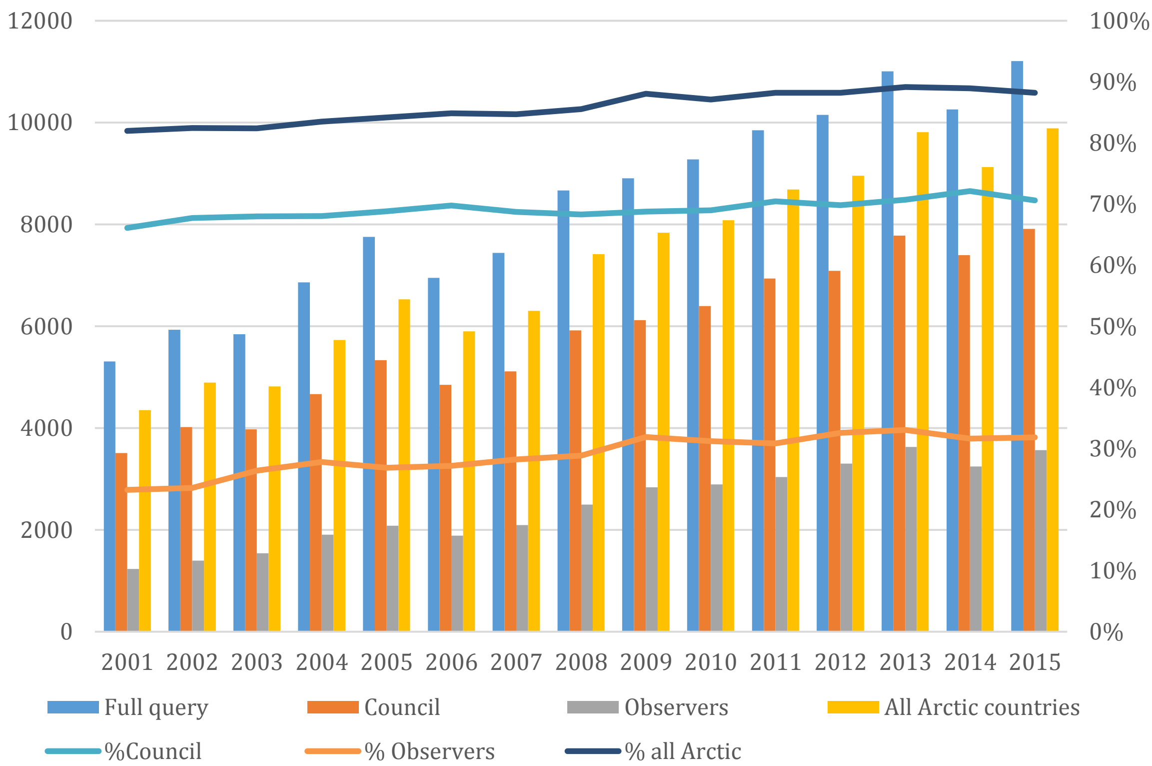
In Figure 3, the countries have been classified in different groups: Arctic Council member, Arctic Council observers, and other countries. Researchers in Arctic Council states have contributed to approximately 70 per cent of the total Arctic publication output, the observer countries to 30 per cent and other countries to 10 per cent (note: these numbers do not add up to 100 due to international co-authorship). These proportions have been fairly stable during the time period of this study

***Figure 2.** Number of Arctic scientific publications by country,* 2006 and 2015, and relative increase.*



*) Limited to countries with more than 200 publications in 2015.

***Figure 3.** Distribution of Arctic scientific publications by groups of countries, 2001-2015.*



2. Publication output by publication channels

In the Scopus database, the majority of Arctic research publications are published in journals (74.8% of all Scopus publications in 2001-2015) and conference papers (13.3%). Reviews make up 4.2% of publications, and books and book chapters together comprise just 2.7% (Figure 4)[8]. Only a very small proportion of the publications are books and books publications. This issue is further discussed below.

More than 80% of all publications are in journals (Figure 5) and the top 25 journals in terms of the number of published papers on Arctic research are the journals in earth and planetary sciences (Figure 6).

The majority of the conference proceedings articles relate to the fields of engineering and energy. Of a total of 15,000 publications within Engineering, 10,000 are proceedings articles (Figure 7).

3. Publication output by subject area

Earth sciences and biology are the two largest disciplines of Arctic research, but there is research in a variety of other disciplines. Figure 8 shows the field distribution, based on the global total of Arctic publications from the period 2011-2015. Earth and planetary sciences, which encompass disciplines such as geology, geophysics and oceanography as well as studies of the cryosphere account for 24 per cent of the publications. The second-largest discipline, agriculture and biological sciences accounts for 15 % of the total papers. These include papers within traditional areas of biology, ecology and marine and fisheries biology. However, there are also many biology publications classified within the third largest category, environmental science. The remaining publications are within other natural sciences, medicine, biomedicine and technology, in addition to the social sciences and arts and humanities. The latter two fields account for 7 and 3 percent of the publications, respectively. The Scopus database mainly includes articles published in scientific and scholarly journals, and the coverage of book publications is more limited. As books are an important publication channel in social sciences and arts and humanities, the actual contribution of these fields to Arctic research is underestimated.

[8] The number of books on Arctic Research is evidently underestimated not only because of language, but also due to the comparatively recent appearance of book indexation in Scopus. The percentage of books and book chapters in Scopus in 2001-2008 is 1.64%, while in 2009-2015 it is already 4.02%. In the period 2001-2016 this percentage is about 3%.

Figure 4. *Distribution of Arctic scientific publications by publication type (2001-2015).*

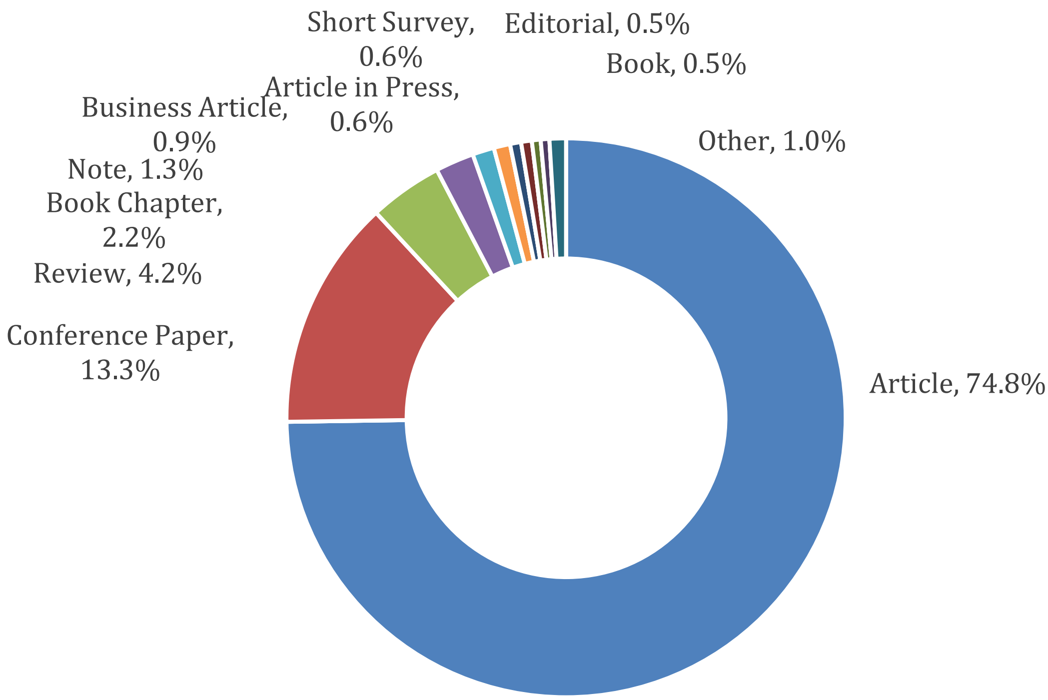


Figure 5. *Distribution of Arctic scientific publications by publication channels (2001-2015).*

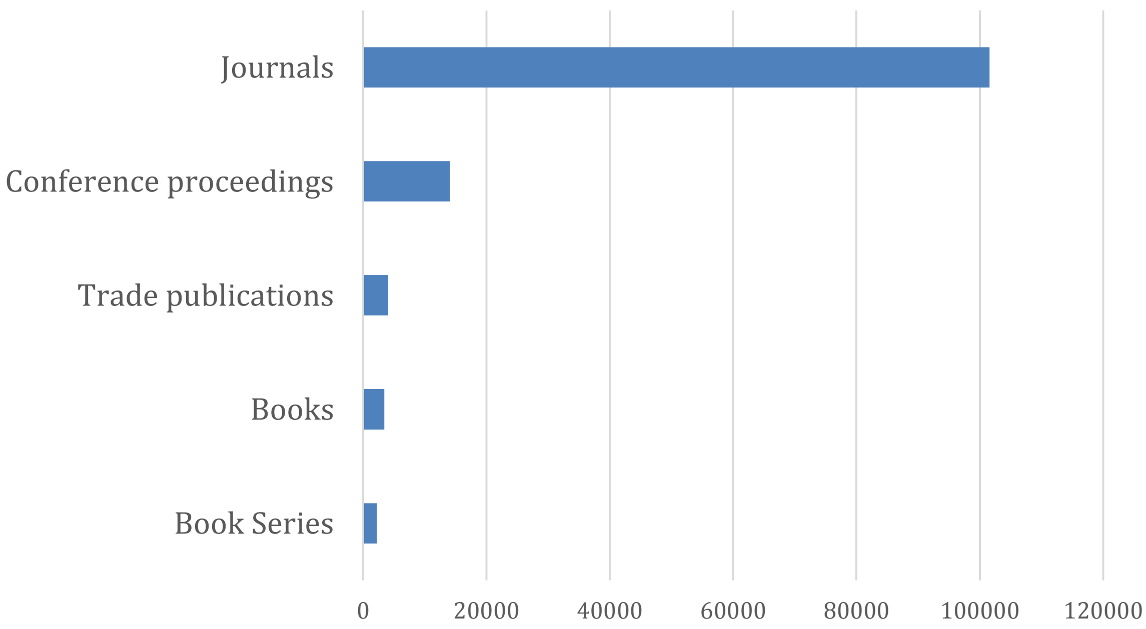


Figure 6. *Top-25 journals by number of publications in Arctic Research (2001-2015)*

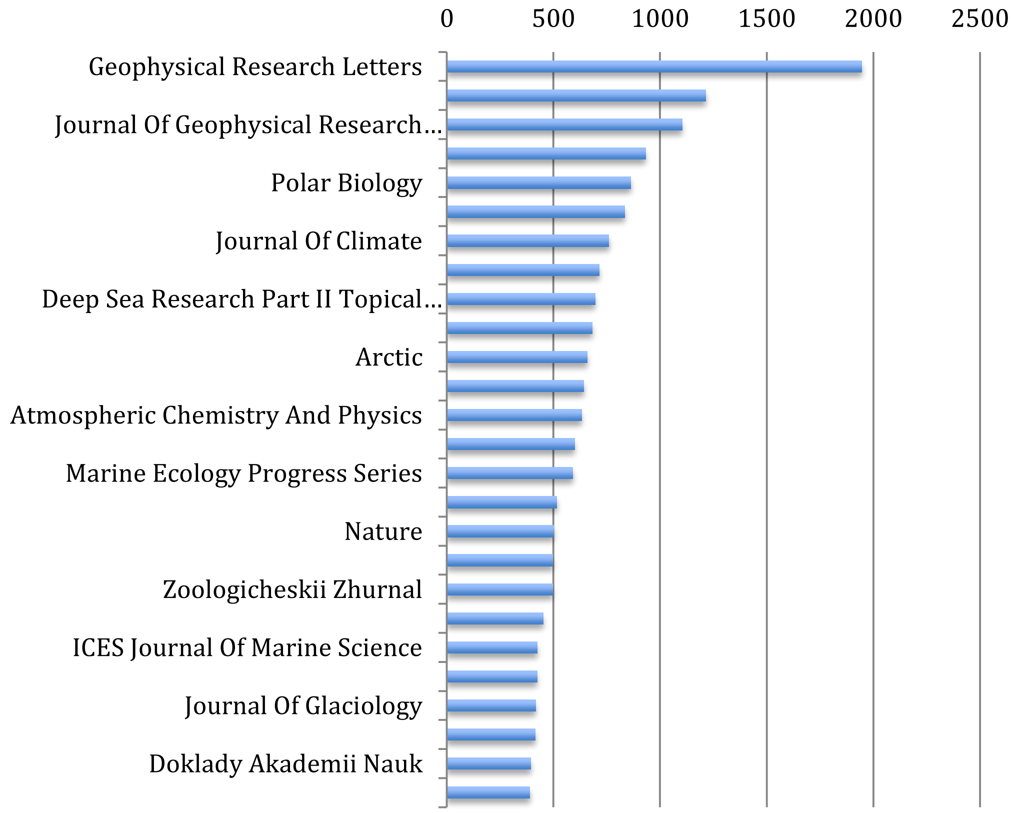


Figure 7. *Number of Arctic conference proceeding articles by subject area, period 2001-2015*

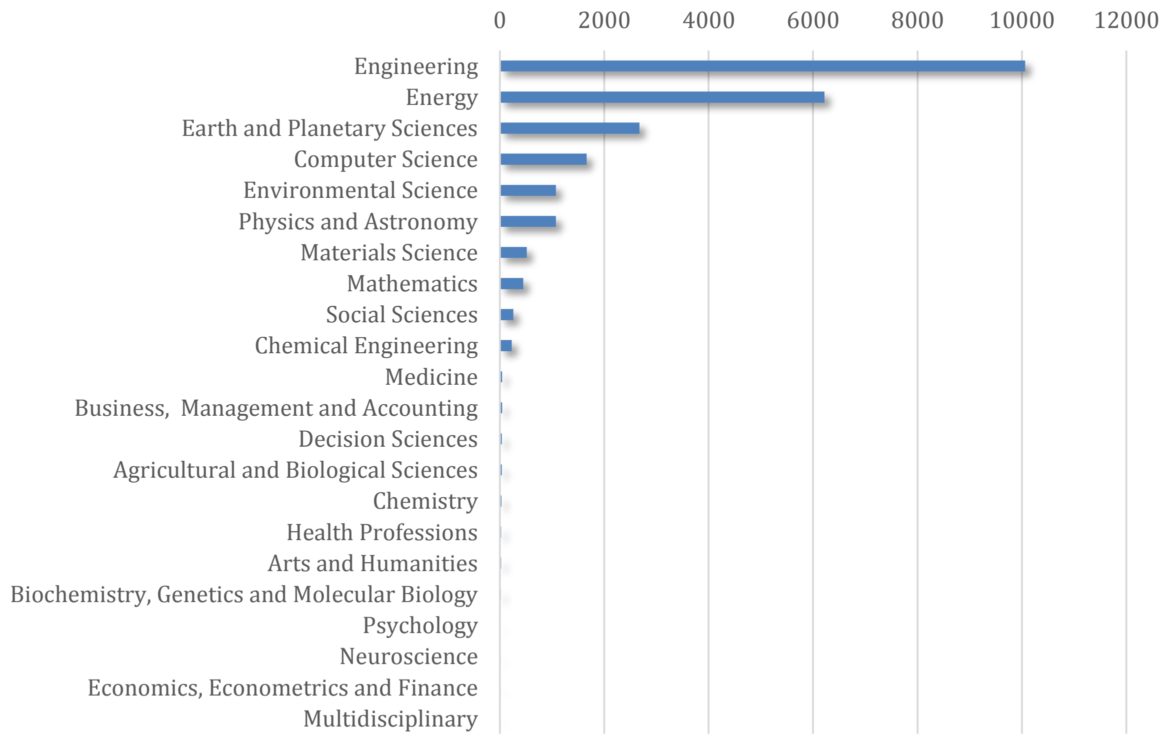
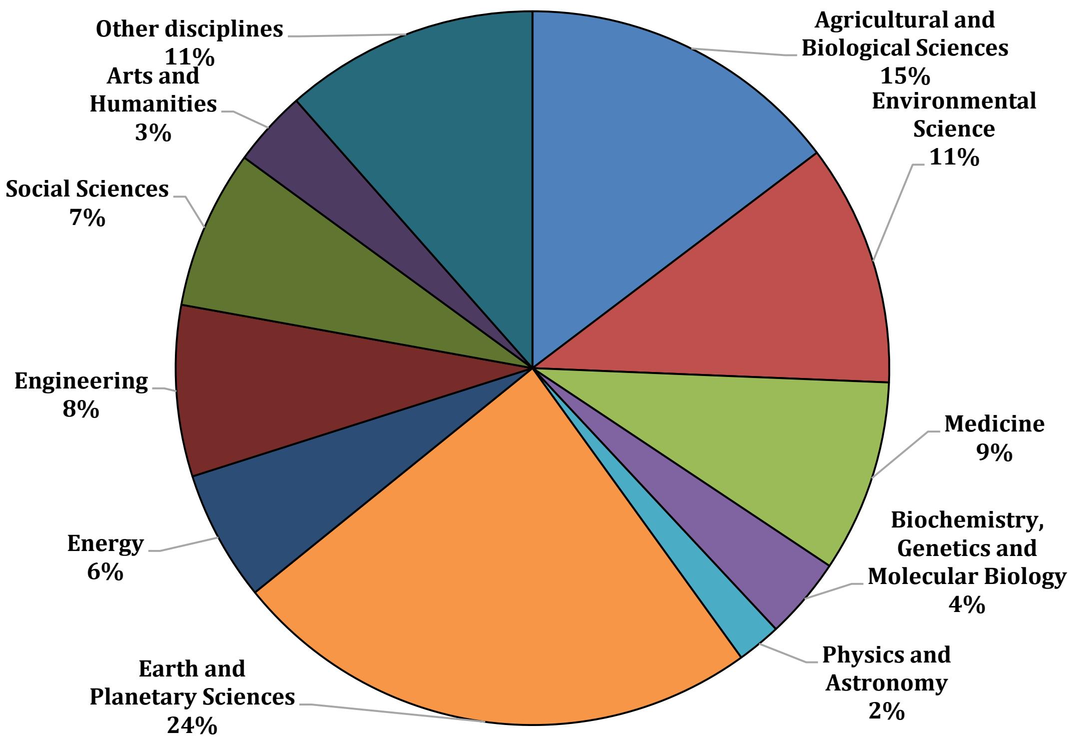


Figure 8. *Distribution of Arctic scientific publications by field, 2011-2015*



From 2001 to 2015, research output grew in all subject areas, but not to the same extent (Figure 9). Medicine and social sciences Arctic research publications grew faster in comparison with other subject areas. This means that their shares of the total Arctic publication output have also increased (Figure 10).

As described above, the proportion of all publications in Scopus that relates to the Arctic is approximately 0.4 per cent. However, this proportion varies significantly across subject areas and is highest for earth and planetary sciences (Figure 11).

Figure 9. *Number of Arctic scientific publications by Scopus Subject Area, top-6, 2001-2015*

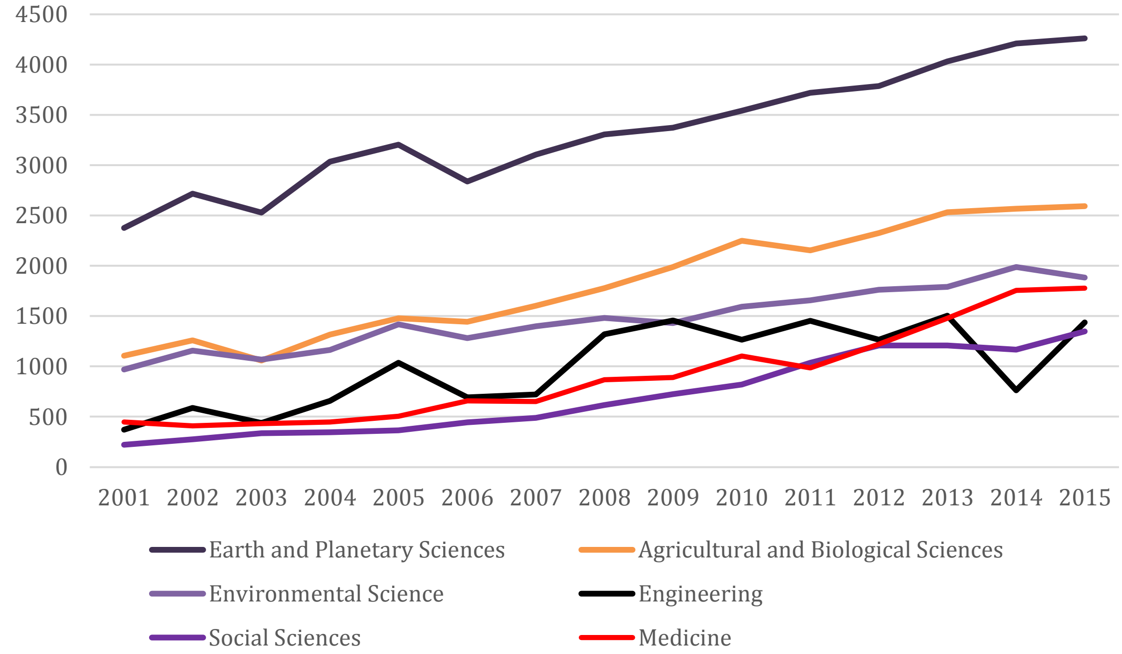


Figure 10. *Proportion of Arctic scientific publications by Scopus Subject Area, top-6, 2001-2015*

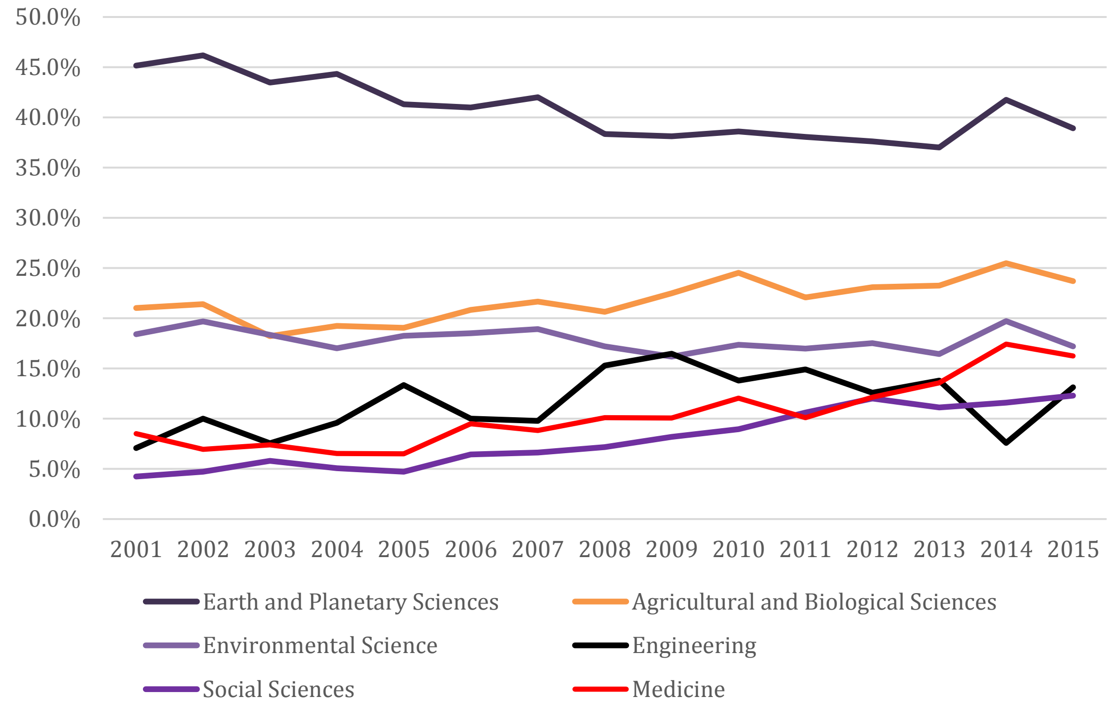
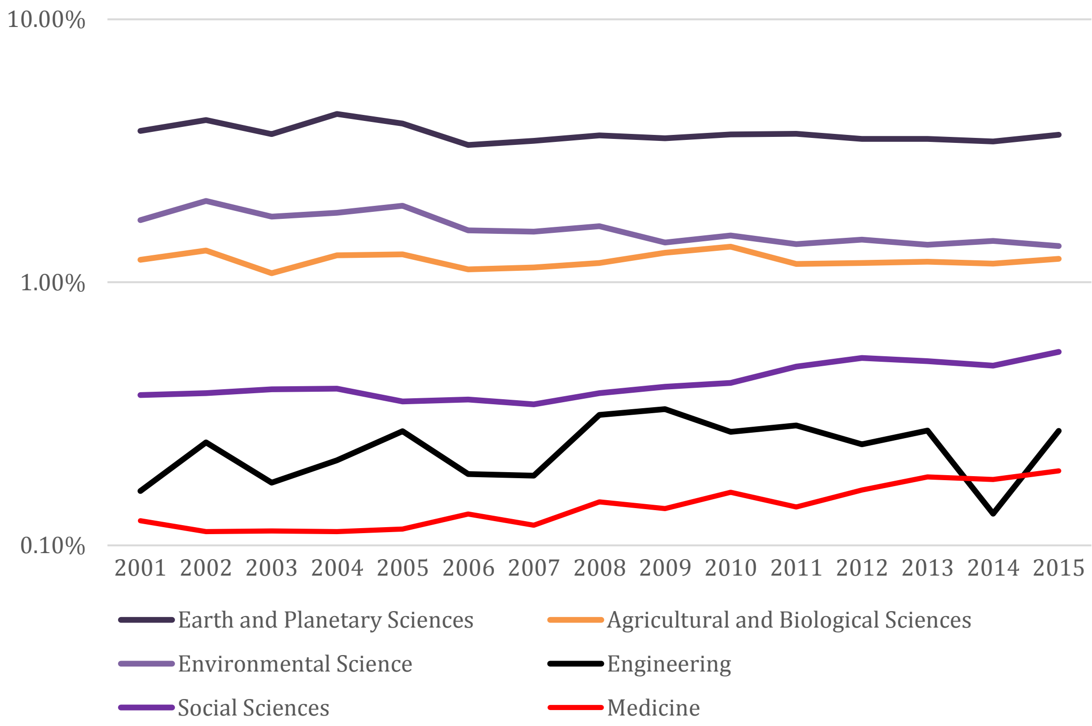
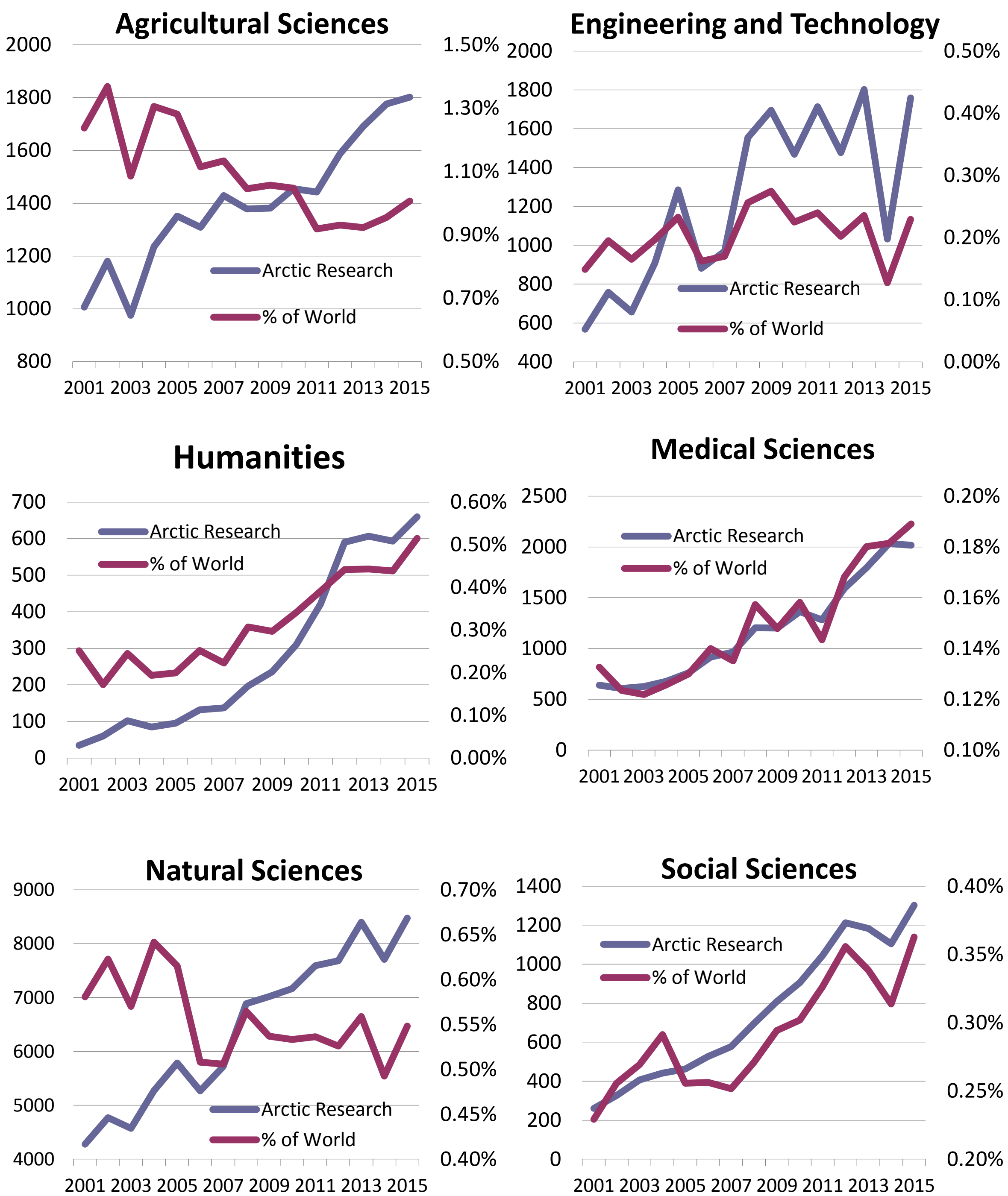


Figure 11. *Proportion the world total of publications that relates to the Arctic by Scopus Subject Area, top-6, 2001-2015, log scale.*



Almost the same picture can be observed while analysing Arctic research by Fields of Science and Technology (FOS) Classification, used in the *Frascati Manual* of the Organisation for Economic Co-operation and Development (OECD). The proportion of Arctic research is growing in humanities, medical sciences and social sciences, decreasing in agricultural science and natural sciences and remaining relatively stable in engineering and technology (Fig.12 a-f). Within the scope of this report, the reasons for the field differences have not be further analysed, and it would be useful in future analyses to look at changes in the Scopus' coverage of the Arctic research literature within different fields.

Figures 12 *(a-f). The number and proportion the world total of publications that relates to the Arctic by FOS categories, 2001-2015*



4. Citation impact

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 of the research. In absolute counts, the countries with the largest production of publications also receive the most citations. However, it is common to use size independent measures to assess whether a country's articles are highly or poorly cited. One such indicator is the field-weighted citation impact which expresses the average number of citations per publication compared to the field average. The global average is normalized to 1.00.

Overall, the Arctic research publications tend to be cited slightly above the field average for all publications in Scopus. The annual counts show some annual fluctuations, from 1.02 to 1.21, but has been above 1 all the years (Fig.13).

Figure 13. *Field-weighted citation impact for Arctic research, 2001-2014*

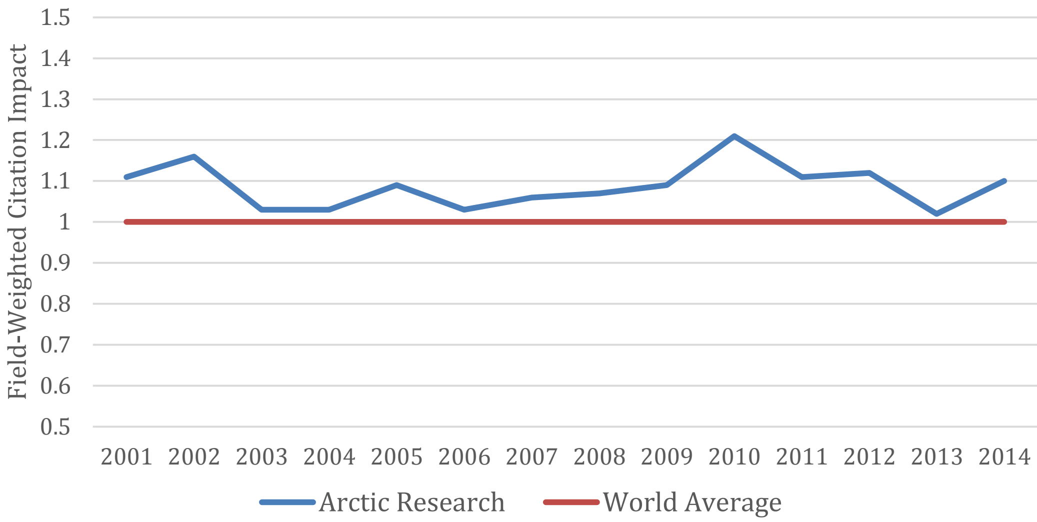
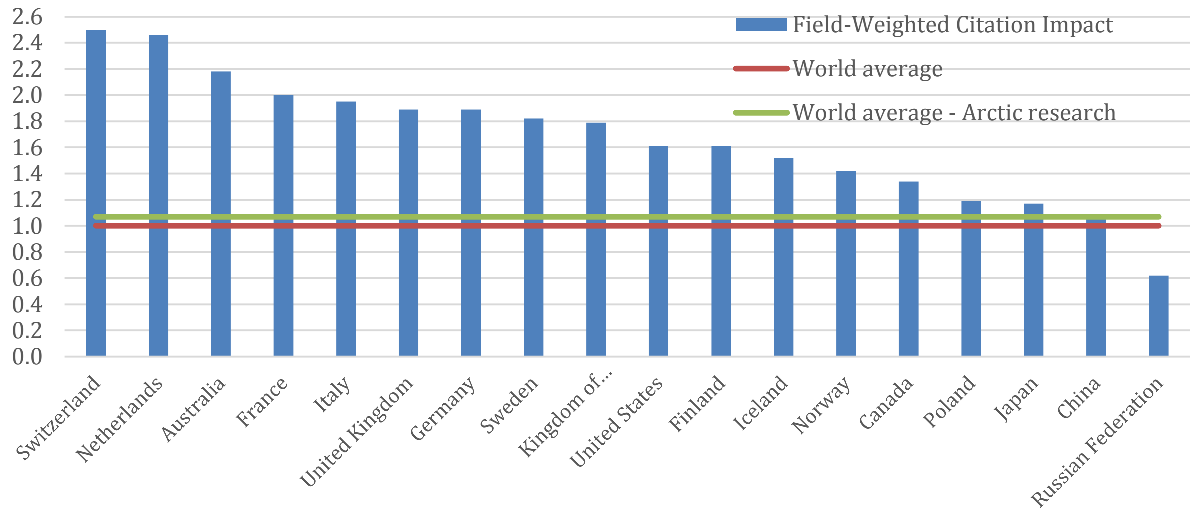


Figure 14 shows the field-weighted citation impact for the largest contributors to Arctic research in terms of publications for the period 2011-2014. As can be seen, the citation impact does not correlate with the volume of total publications. Switzerland and the Netherlands are the countries with the highest scientific impact measured by citations. Although they are relatively small contributors, their publications have on average been cited approximately 150 per cent above the world average. They are followed by the Australia and France with citation impacts of 2.18 and 2.0, respectively. At the other end of the scale we find Russia, which has a citation index of 0.62. Publications from China, Japan and Poland are also poorly cited compared with the other countries, although still slightly above the whole-Scopus-average.

It is surprising that almost all the largest countries rank above the whole Scopus-average. At the moment we are not aware of any possible methodological explanation for this. The whole counting of citations that is used in SciVal is done so in combination with deduplication at the article level, so whole counting does not lead to double counting when looking at internationally authored publications (which could otherwise be a methodological explanation for this phenomenon). Some follow up research may be required on this.

Russia performs significantly worse than the other countries. A possible explanation for this may be that Russian scientists publish frequently in non-English-language (e.g. Russian) scientific journals. As the research results published in such journals would generally would not be available to a global scientific audience, they would have less international impact, leading to fewer citations.

Figure 14. *Field-weighted citation impact for the largest Arctic research nations, based on articles published during the period 2011-2015.*



As described above, the overall field-weighted citation impact for Arctic research has fluctuated from 1.02 to 1.21 during the period 2001-2014. However, at the level of research fields there are significant variations. There are also temporal differences within research fields. This is shown in Table 1 below for research areas by FOS categories.

Table 1. *Field-weighted citation impact for FOS categories of Arctic research, 2001-2015*

	Overall	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015
Humanities	1,31	1,10	1,02	1,23	1,36	1,36
Medical Sciences	1,30	1,05	1,23	1,22	1,58	1,23
Agricultural Sciences	1,14	1,23	1,20	1,12	1,13	1,05
Natural Sciences	1,12	1,19	1,15	1,10	1,11	1,07
Social Sciences	0,91	0,71	0,98	0,85	0,94	0,94
Engineering and Technologies	0,58	0,69	0,49	0,59	0,67	0,48

5. Publication output by institutions

Figure 15 shows the number of Arctic publications per institution. The overview is limited to the 34 largest institutions in terms of Arctic publication numbers from 2011 to 2015. The Russian Academy of Sciences (RAS) ranks as the largest institutional contributor, with more than 3,200 Arctic publications, followed by the University of Alaska Fairbanks and the University of Iceland. It should be noted, however, that there are sub-departments within RAS with separate numbers (e.g. RAS Siberian branch).

There are also significant differences across institutions in the citation impact of their publications. This is shown Figure 16. The figure includes the 34 largest institutions in terms of Arctic publication numbers (2011-2015). Of the institutions included, the University of Colorado Boulder ranks highest with a field-weighted citation impact of 2.6, followed by the University of Cambridge and the University of Washington. As may be expected from the country figures above, several Russian institutions perform less well when it comes to citation impact.

Figure 15. *Number of Arctic publications per institution and number of total publications (all fields), 2011-2015.*

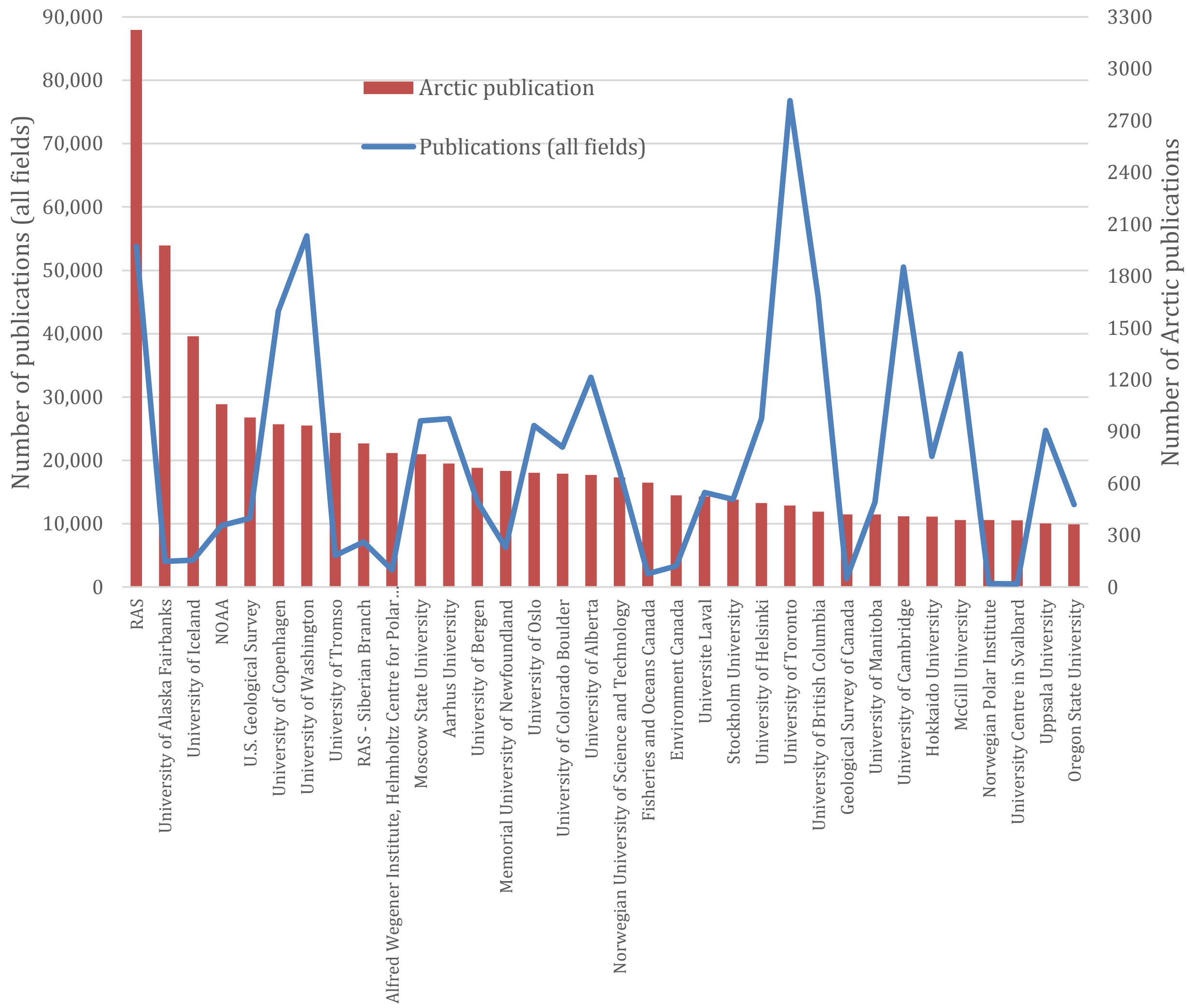
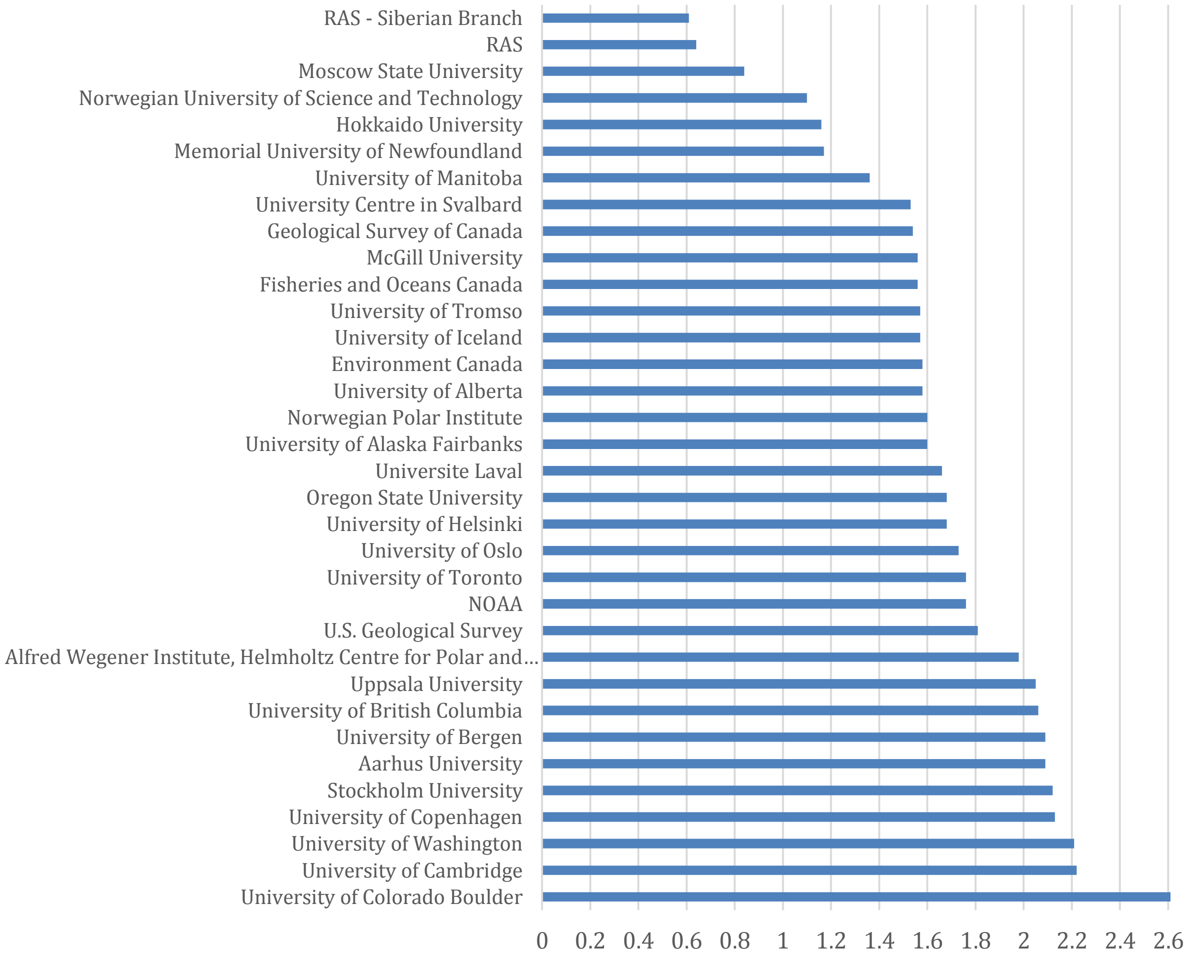


Figure 16. *Field-weighted citation impact for the largest Arctic research institutions, based on articles published during the period 2011-2015.*

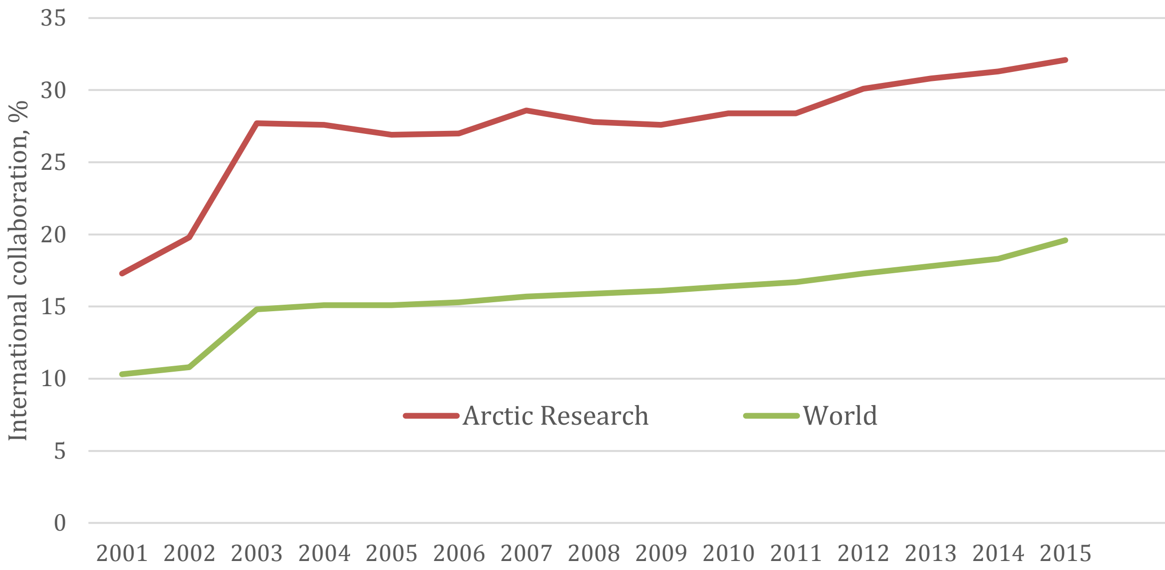


6. International collaboration indicators

International co-authorship is a commonly used indicator of international collaboration. When scientists from different countries together author a publication, this is an indication that the research has involved cooperation. International co-authorship can thus be applied as an indicator of international collaboration.

The extent of international scientific collaboration has increased in recent years, both in general and in Arctic research. In 2015, more than 30 per cent of the Arctic publications involved international co-authorship. In contrast, the average for all fields is slightly below 20 per cent (Figure 17). Arctic research is thus characterized by a relatively high degree of international cooperation.

Figure 17. *The proportion of international co-authorship, 2001-2015*



However, there are major differences among countries with regard to the extent of international co-authorship. Although large scientific nations within Arctic research publish far more collaborative articles than smaller countries, the latter tend to have a much higher percentage of co-authored articles than larger nations. Hence, international collaboration is relatively more important in smaller countries. This is a general phenomenon that is also found for Arctic research (Figure 18). In several countries, the majority of scientific publications are internationally co-authored. One reason for this is that researchers in small countries more often have to look abroad for colleagues and partners within their own field of specialty. Size is, however, not the only factor influencing on the extent of international collaboration; access to funding, geographical location, and cultural, linguistic and political barriers are other important factors (Luukkonen et al., 1992, Melin and Persson, 1996).

In addition to collaboration with colleagues abroad, there is also extensive national collaboration. This can be measured bibliometrically by identifying publications with co-authors from more than one institution within a country. Figure 19 shows the proportion of such co-authorship. These proportions are significantly lower than the ones for international co-authorship. Moreover, the ranking list deviates significantly. For example, among the countries with the highest proportions of national co-authorship we find Japan and the U.S.

Figure 18. *Proportion of international co-authorship and number of publications (total) by country (2001-2015)*

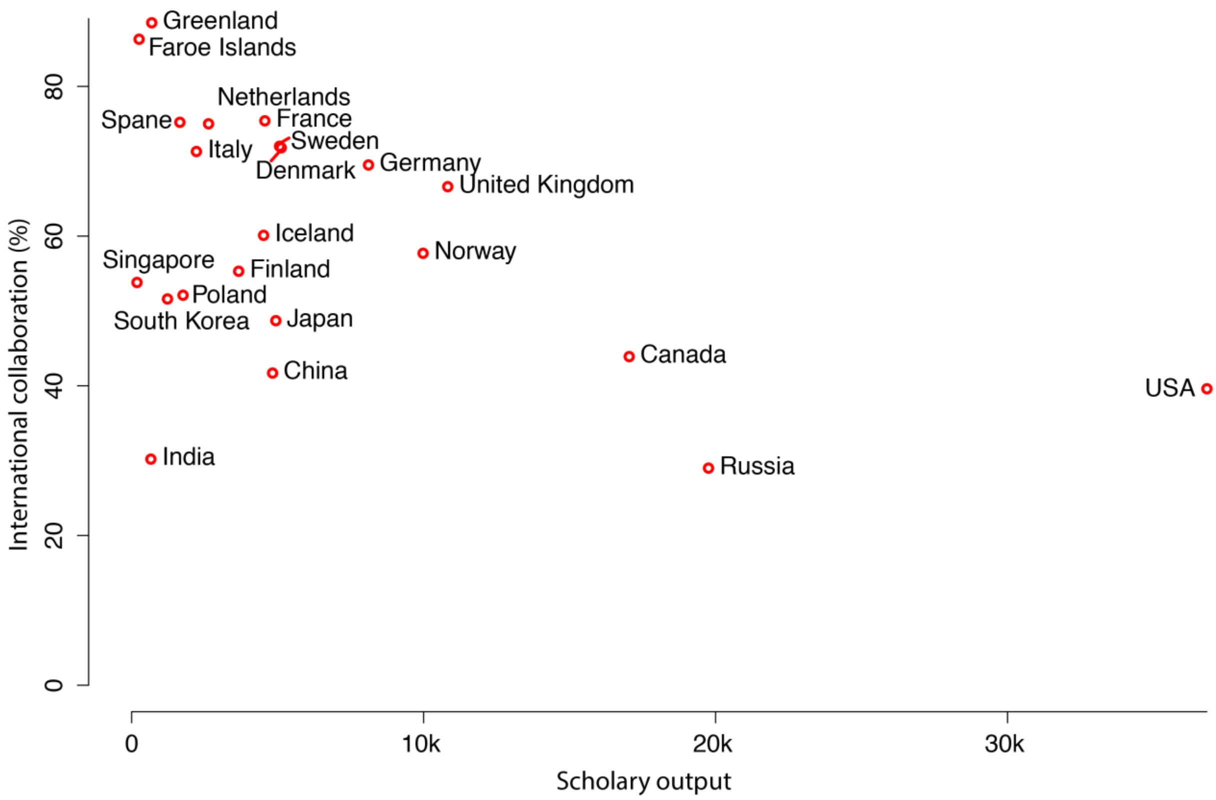
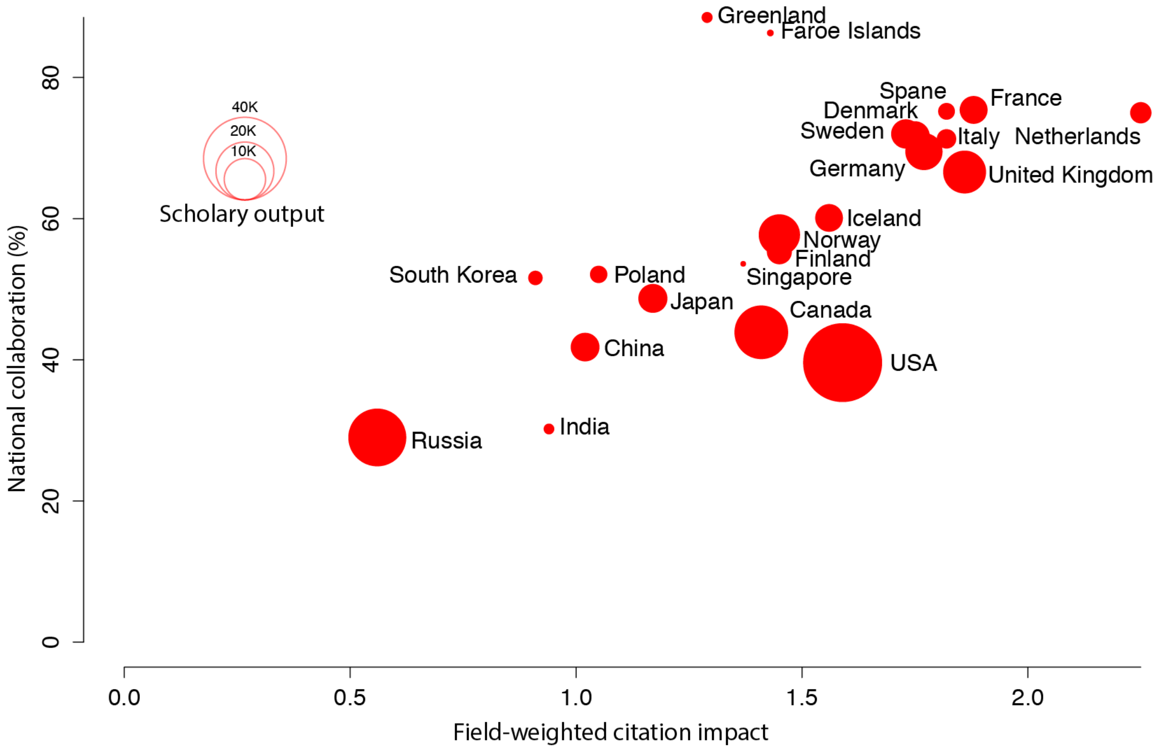


Figure 19. *Proportion of national collaboration and number of publications by country.*

Collaboration also influences the impact of publications. Internationally co-authored papers have generally been shown to be significantly more cited than purely domestic publications (den Hertog et al., 2012, van Leeuwen, 2009). For Arctic research at the country level we also find that there is a strong correlation between the proportion of international collaboration and the citation impact of the publications (Figure 20). Thus, also within Arctic research international collaboration is advantageous for the impact of the research measured through citations. Various factors may explain these patterns (den Hertog, 2012). One reason is that the quality of research may improve due to the involvement of scientists with complementary competencies from different countries. Moreover, large scale multinational analyses are carried out by such collaborations. These types of papers tend to represent more important scientific contributions and are therefore more highly cited.

Figure 20. *International collaboration, Field-Weighted Citation Impact and Scholarly output in the countries involved in Arctic Activities (2001-2015)*

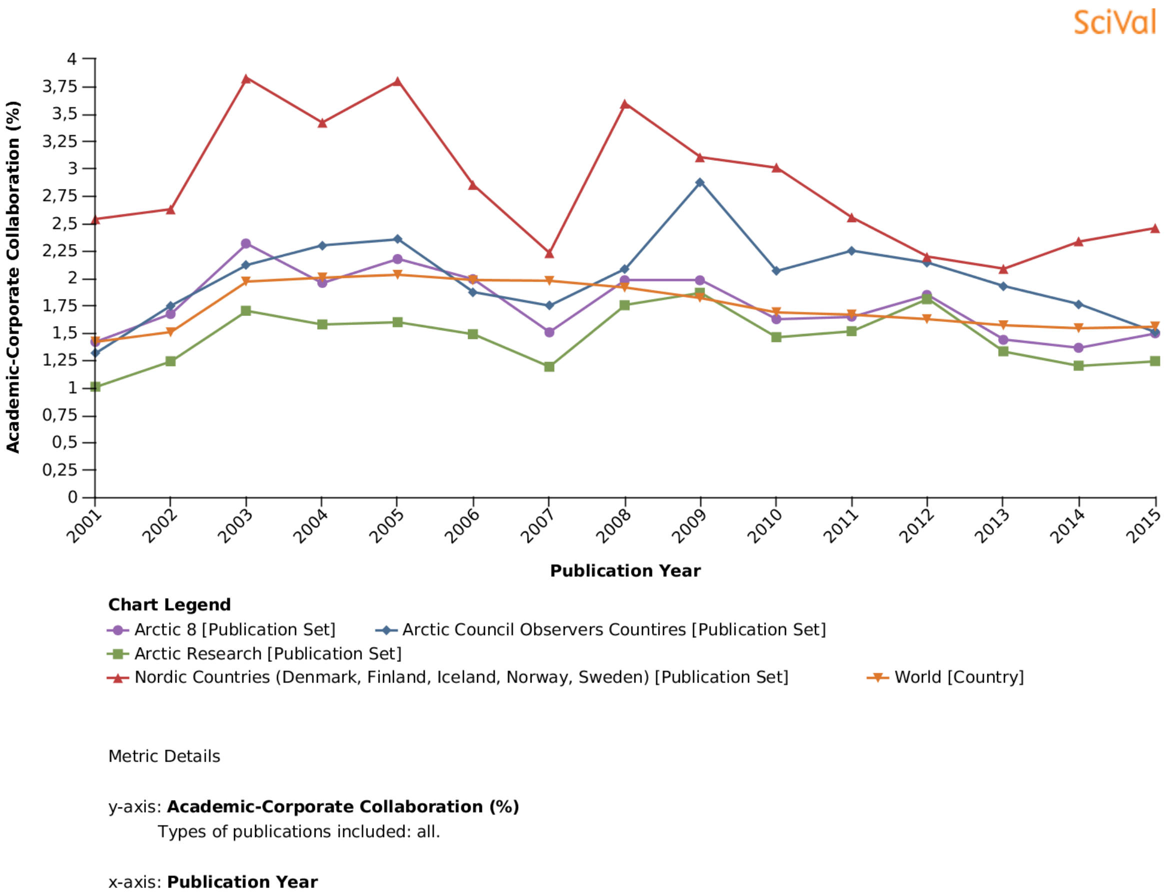


7. Economic impact of Arctic Research

The scholarly output and citation metrics reflect first of all the development of basic and applied research, but any research can influence economics and various social issues. The economic impact of research can be measured by the involvement of industry in research itself, i.e. via academic-corporate collaboration, and by the citing of research results in patents as indicators of practical usage. Although the relevance and impact of such collaborations may be lower in much Arctic research, we have nevertheless included some indicators of impact here.

One of the indicators of the economic impact of research is academic-corporate collaboration. This indicator for Arctic research in total is slightly lower than the global average, but for the Nordic countries, it is almost twice as high. For the Arctic Council nations in total and the Observer nations this indicator shows minor fluctuations near the whole-of-Scopus average (Figure 21).

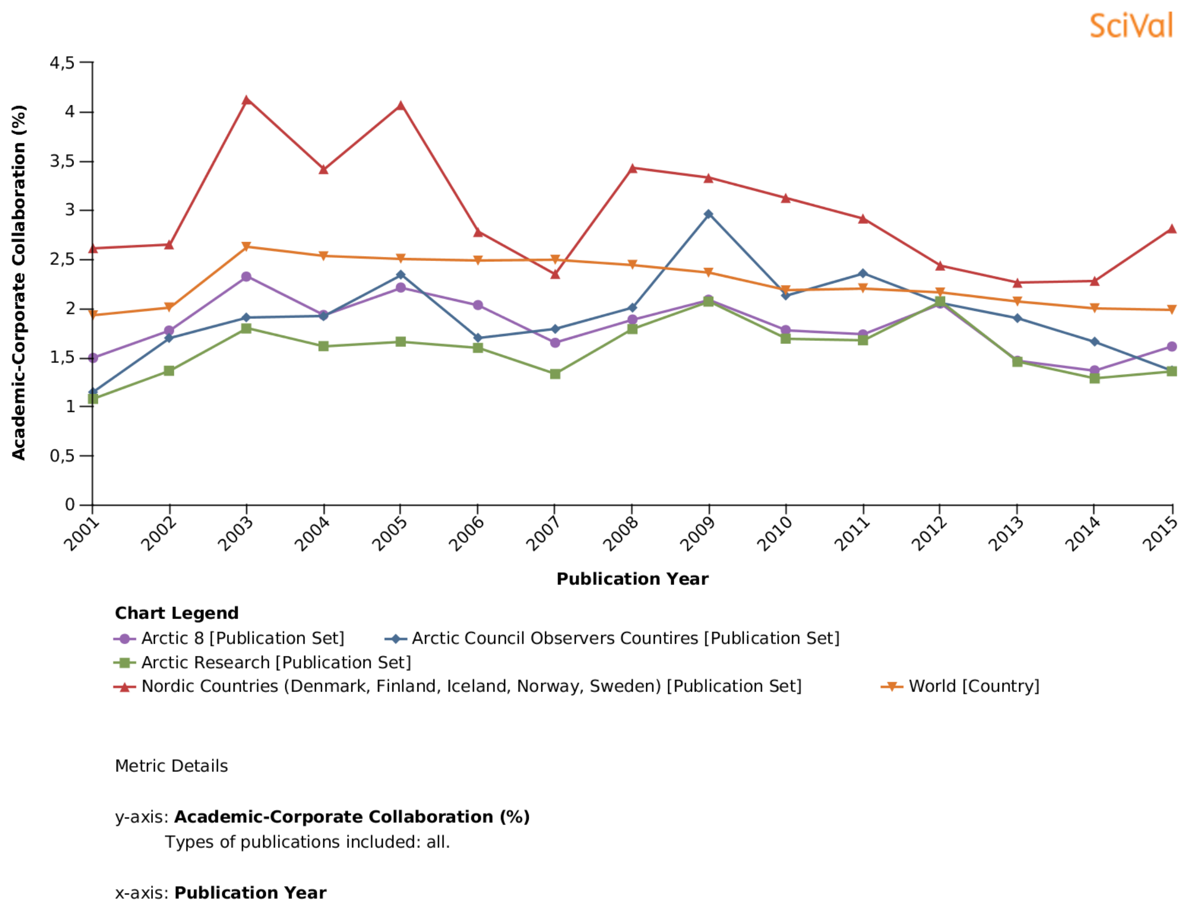
Figure 21. *Academic-Corporate collaboration in the World and Arctic Research*



The total number of publications co-authored by academic institutions and industry in Arctic research is not very high - 1830 publications from 2001 to 2015 of a total of 124,000 publications. The number is increasing though, and was more than twice as high in 2015 as in 2001 (134/53 publications). However, as was shown in Figure 1, the total number of Arctic publications has also increased significantly during the period.

The relatively high percentage of academic-corporate collaboration within the Nordic countries holds for engineering, medical and natural sciences, and at the level of disciplines, the number is highest for earth and related environmental sciences. A comparison of academic-corporate collaboration within natural sciences is shown in Figure 22 for different groups of countries.

Figure 22. *Academic-Corporate collaboration in Natural Sciences*



The analysis of patents shows that the Arctic research publications have been cited in 2172 patents, registered in international patent offices:

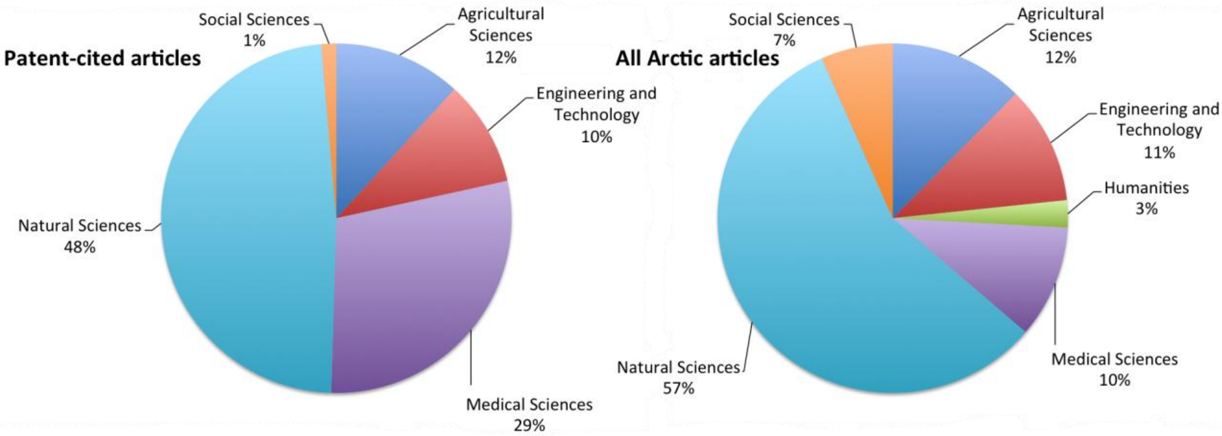
- United States Patent and Trademark Office - 981
- World Intellectual Property Organization - 645
- European Patent Office - 369
- Japan Patent Office - 165
- Intellectual Property Office - 12

The number of patents citing Arctic research grew from 4 in 2001 to 327 in 2015.

The main applicants/owners of the patents are pharmaceutical companies (i.e. Decode Genetics Ehf., Amarin Pharmaceuticals Ireland Limited, Xenon Pharmaceuticals Inc., Janssen Pharmaceutica Nv, etc) and other corporations (Chevron U.S.A. inc., Ball Aerospace & Technologies Corp., Exxonmobil Upstream Research Company, etc).

The 2172 patents mentioned above cited 778 publications in Arctic research from 2001 to 2015, most of them in the areas of biomedicine, environmental studies, geophysics, chemistry and chemical technology, etc. The proportion of medical articles cited in patents is three times higher than that in all Arctic publications (Figure 23).

Figure 23. *Distribution of articles in Arctic research cited in patents and of all Arctic publications. FOS research areas (2001-2015)*

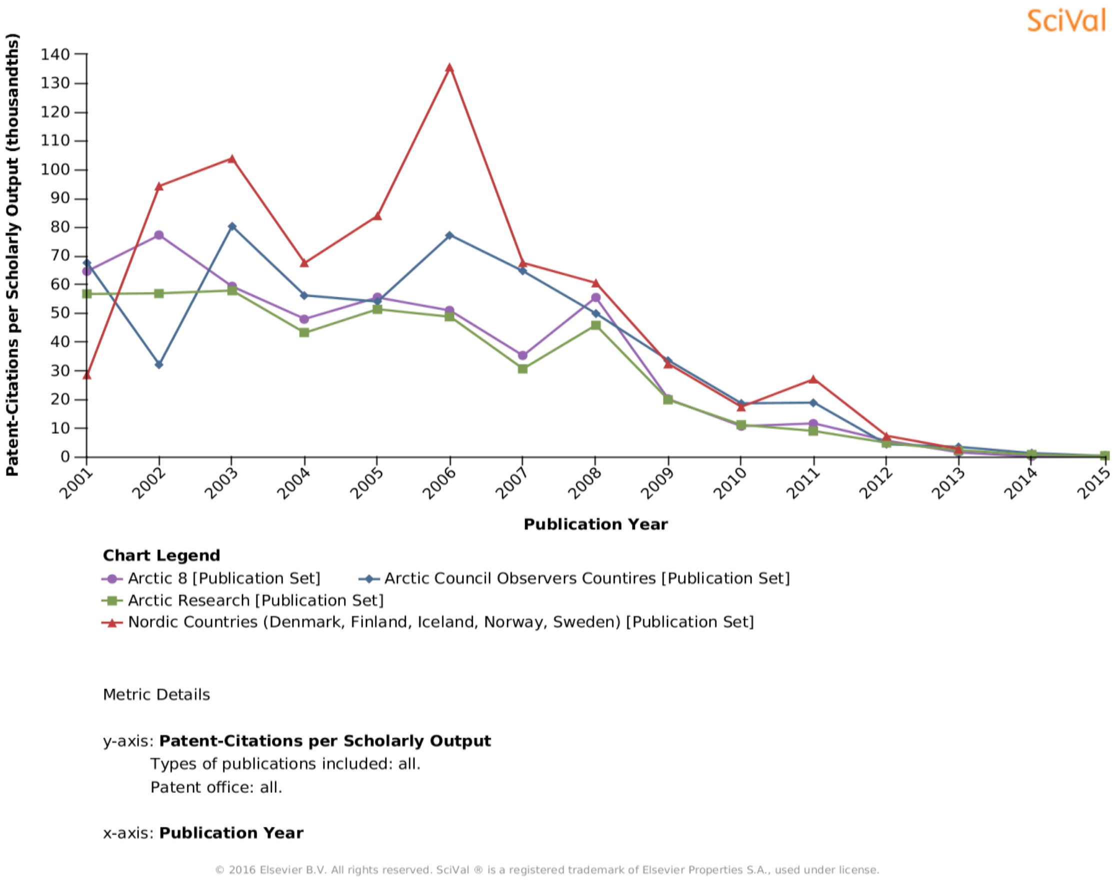


Taking into account the dominance of earth and planetary sciences in Arctic research as a whole we expected the main pool of patents to be devoted to oil and gas industry, but reality differed from expectations. The detailed analysis of patents, using the results of Arctic research, is planned for the future, but even now we see that the overwhelming majority of patents in pharmaceutical and biomedical areas. The preliminary analysis of patent titles is shown in the word cloud, created by Wordle (http://wordle.net).

This word cloud correlates well with key phrases extracted by SciVal from the patent-cited articles from 2011 to 2015, which relate mainly to the fields of biology and medicine.

The size-independent indicator of economic impact - patent-citations per scholarly output - is highest for Nordic countries, though it is very low for Arctic research generally compared with the global average (Figure 24). The decrease in numbers during the period can be explained by the long time period from invention to registration of patents, and the longer citation window for the oldest publications.

Figure 24. *Patent-Citations per Scholarly Output In Arctic Research and in groups of countries*



8. Mapping of Arctic Research

Mapping science is a way to visualize the interconnections between different elements in the publications that might not be evident if the data is analysed by standard statistical methods. Mapping enables us to present various temporal, geographic, and thematic information in compact and understandable forms.

Here we present maps based on bibliographic data (maps for co-authorship relations and bibliographic coupling) and maps based on text data. All maps are created with VOSviewer - a computer program for creating maps based on network data and for visualizing and exploring these maps, created by Nees Jan van Eck and Ludo Waltman in Centre for Science and Technology Studies - Leiden University. The maps are based on various bibliographic data that can be exported from citation databases - authors, their affiliations, sources, references, and so on.

Co-authorship maps demonstrate the intensity of international collaboration between different countries. The distance between countries reflects the number of co-authored publications, and the circle diameter shows the total number of co-authored publications in the analyzed publication set (Figures 25, 26, 27 a).

The distance between countries on the maps, created for bibliographic coupling, shows the number of items citing the same publication, i.e. the thematic similarity of publications (Figures 25, 26, 27 b). It is assumed that if two articles have common items in the reference list they are close in research subject, or methodology. The more shared items in the reference lists, the more similar the analysed publications will be.

The large difference between maps constructed for co-authorship and for bibliographic coupling shows that collaboration depends not only upon similarity of research but more importantly upon geographical and political conditions. For example, comparing the 2009 country maps (Figures 26 a,b) we see that Russia and the U.S. are fairly similar in the sources used as references in publications, but have relatively few co-authored papers (only 7.4% of Russian publications in 2009 in Arctic research are co-authored with US).

Comparing the maps created for different years, we can see a significant growth in the number of countries involved in Arctic research from 2001 to 2015 and the intensification of collaboration resulting in co-authored papers. On all our maps we observe a large number of countries-satellites producing papers on Arctic research only in co-authorship.

The maps based on text data are created using natural language processing techniques. VOSviewer extracts terms from the corpus file, where a term is defined as a sequence of nouns and adjectives. Based on the extracted terms, VOSviewer creates a term map. This is a map in which terms are located in such a way that the distance between two terms provides an indication of the number of co-occurrences of the terms. In general, the smaller the distance between two terms, the larger the number of co-occurrences of the terms. Two terms are said to co-occur if they both occur on the same line in the corpus file (van Eck & Waltman, 2016). The maps created by clusterization of text corpus show that biomedical, social and humanities research developed and grew from 2001 to 2015, while key phrases in natural science and technology were almost the same within selected period (Figures 25, 26, 27 c).

Figure 25a. *Map of co-authorship in Arctic Research in 2001 (Scopus data)*

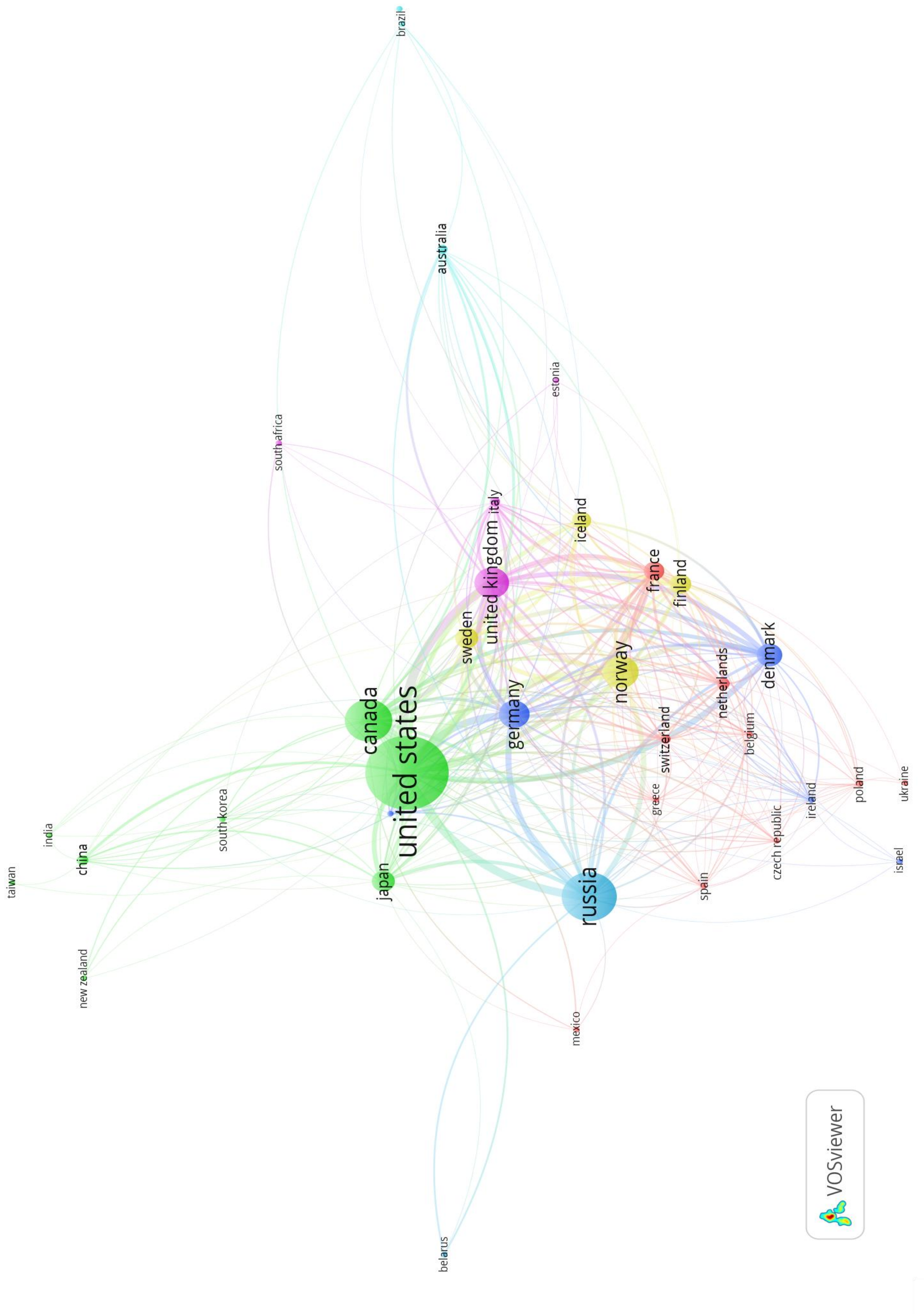


Figure 25b. *Map of Bibliographic coupling in Arctic Research in 2001 (Scopus data)*

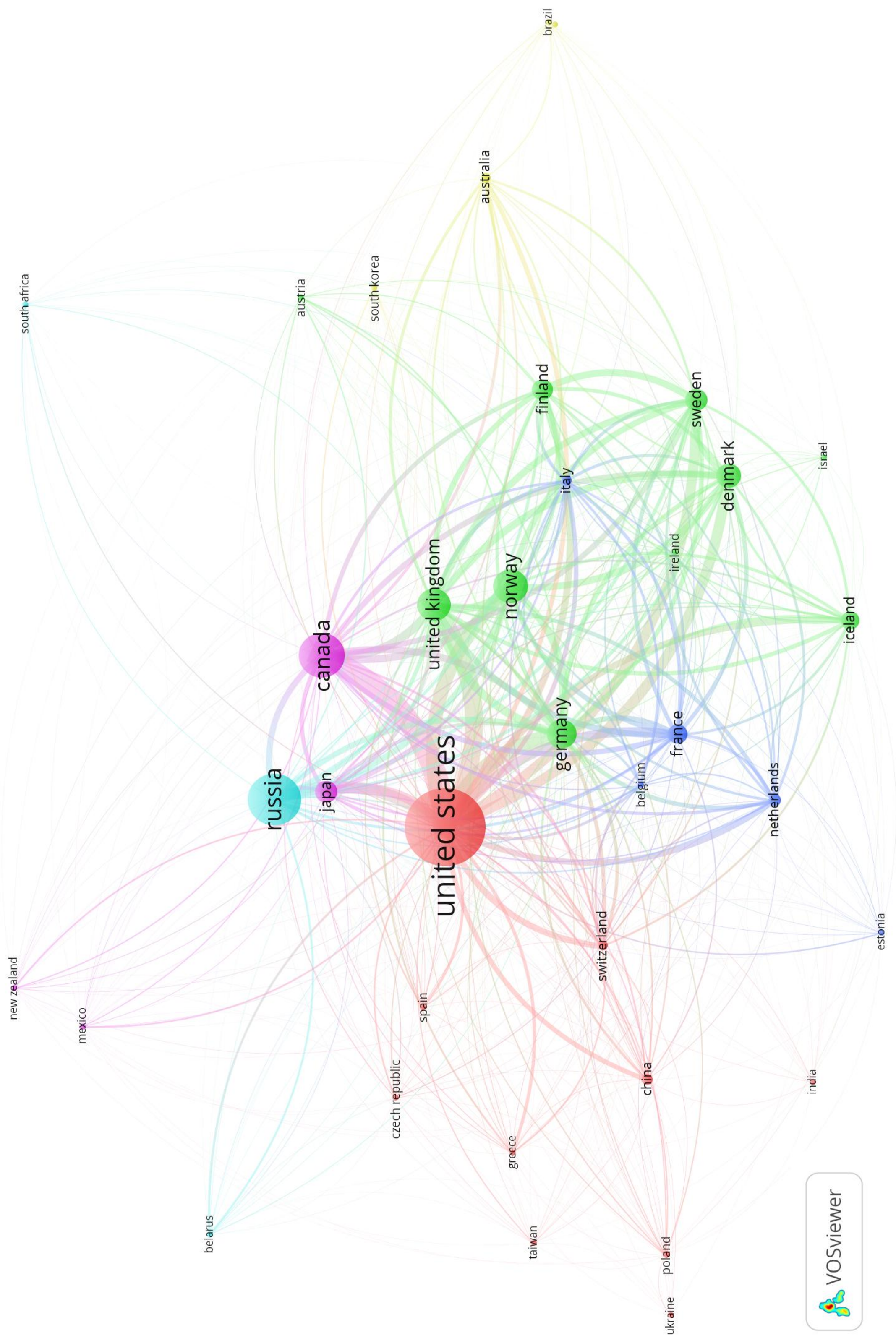


Figure 25c. *Map on text corpus in Arctic Research in 2001 (Scopus data)*

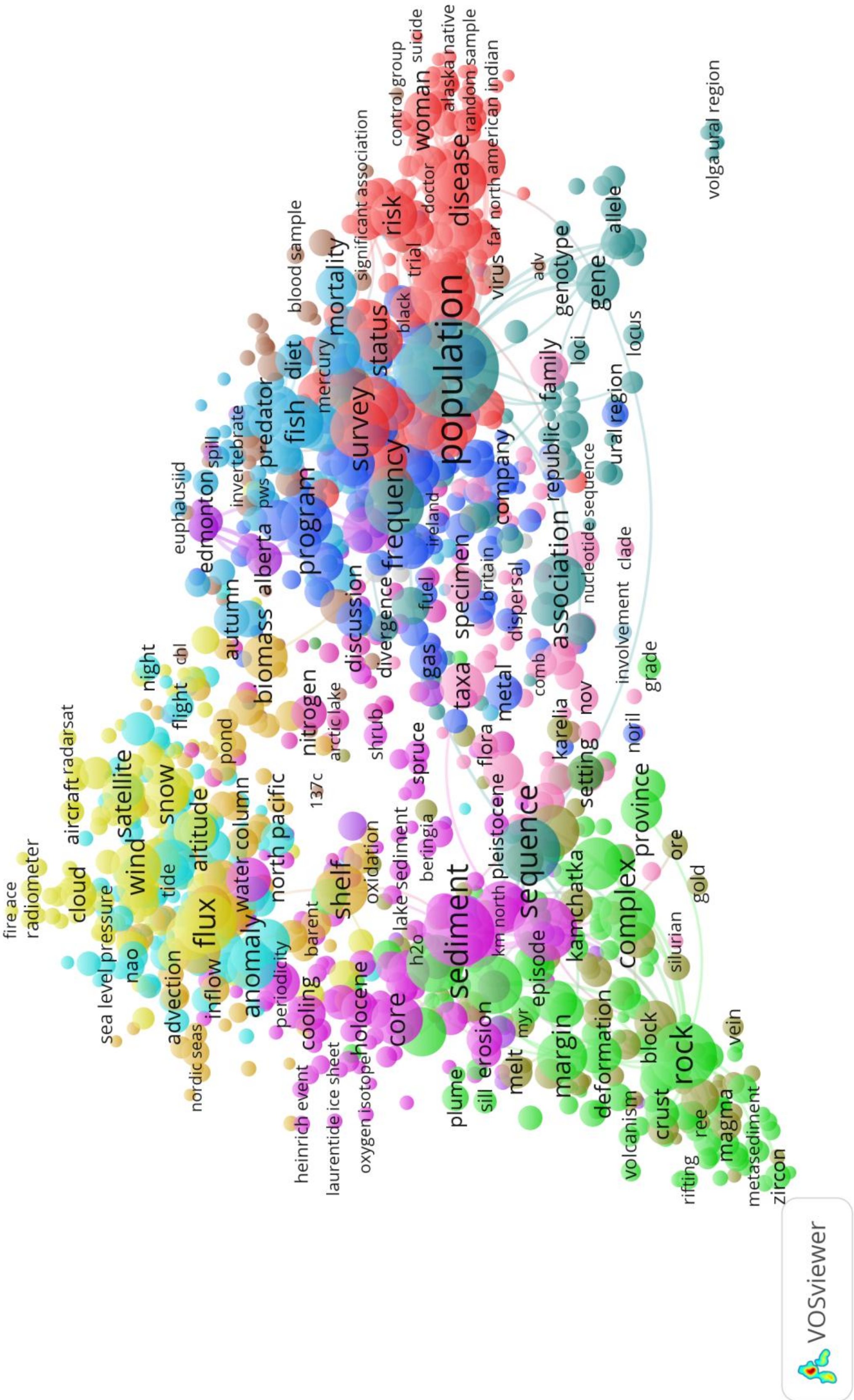


Figure 26a. *Map of co-authorship in Arctic Research in 2009 (Scopus data)*

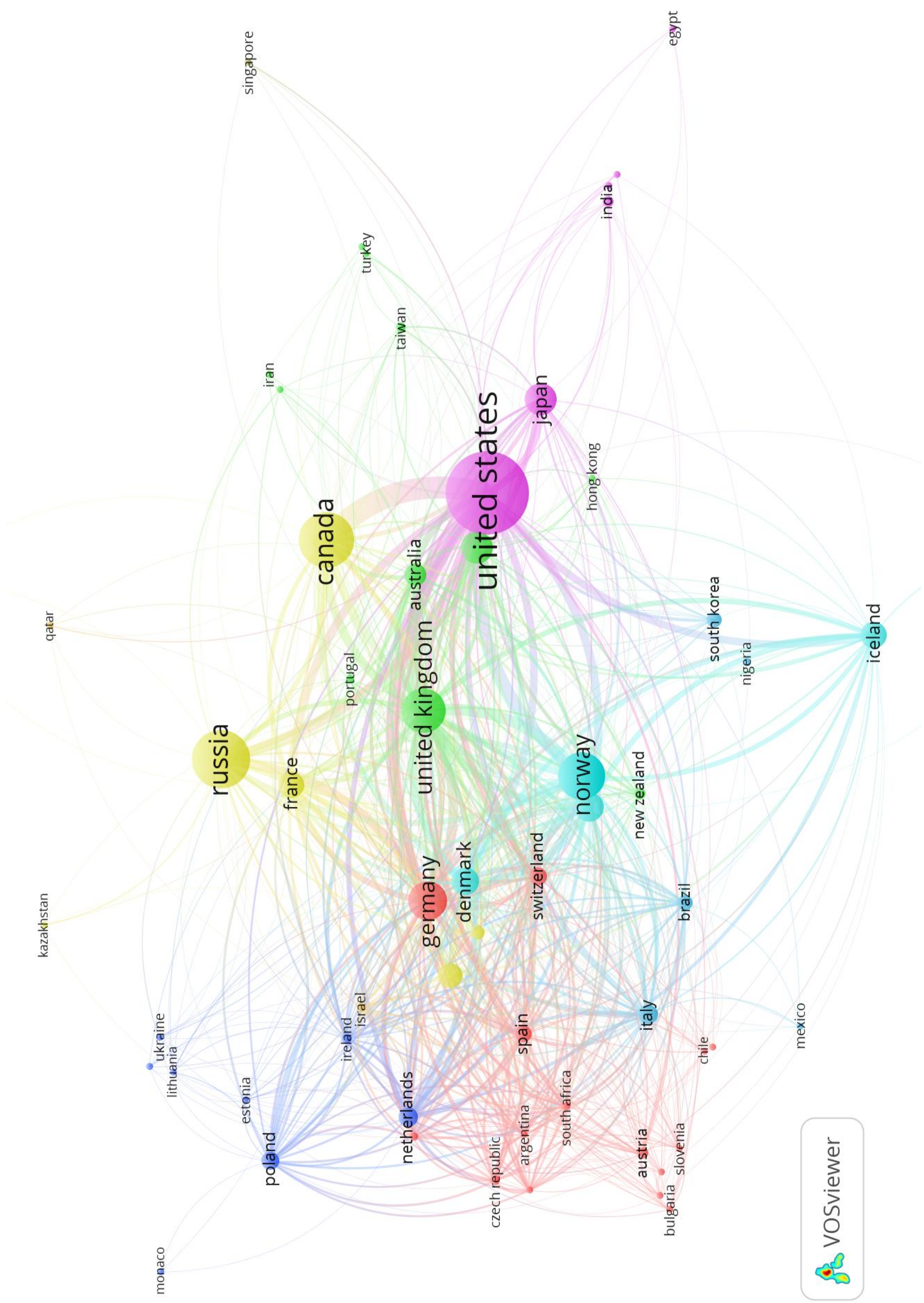


Figure 26b. *Map of Bibliographic in Arctic Research in 2009 (Scopus data)*

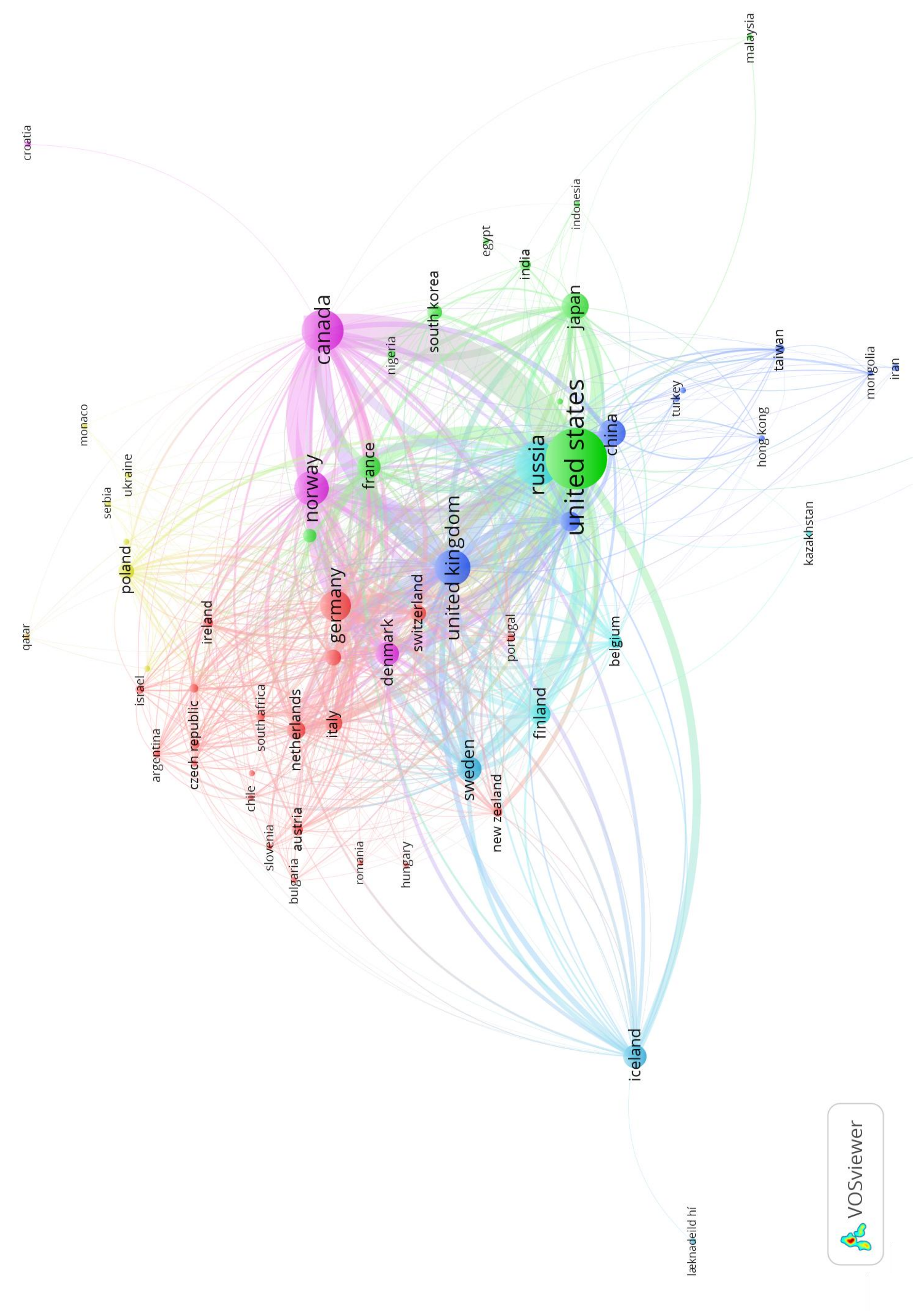


Figure 26c. *Map on text corpus in Arctic Research in 2009 (Scopus data)*

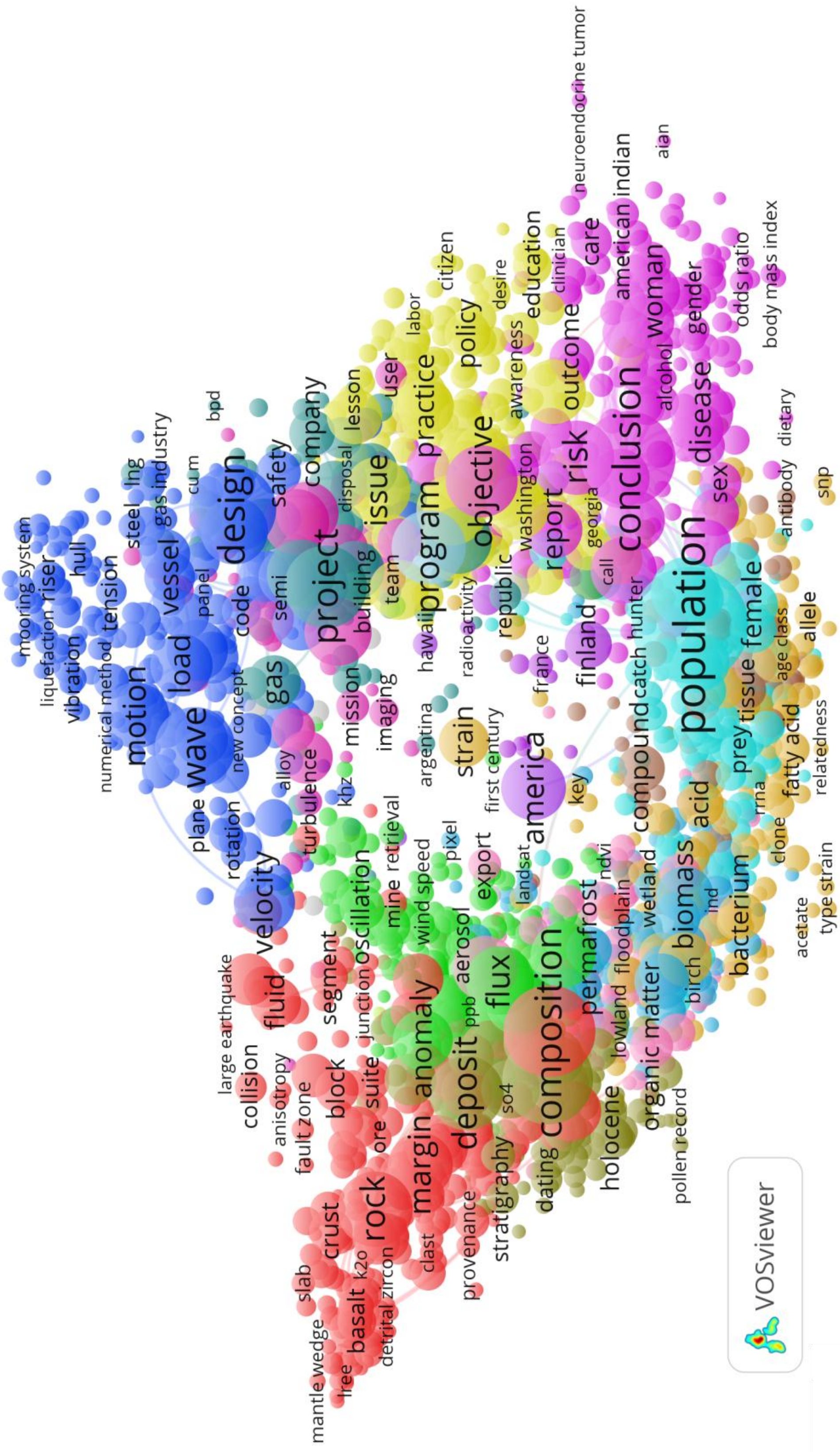


Figure 27a. *Map of co-authorship in Arctic Research in 2015 (Scopus data)*

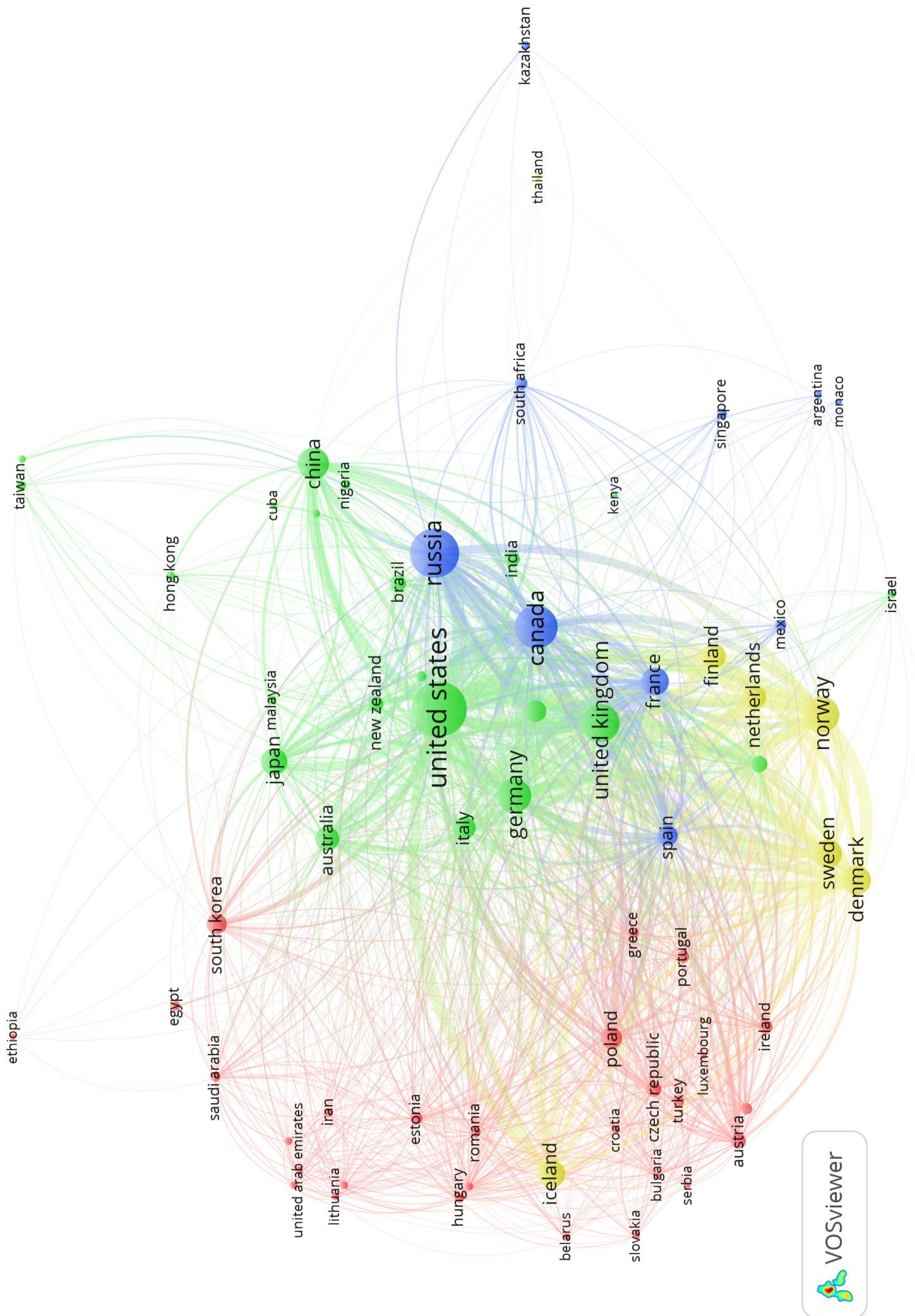


Figure 27b. *Map of Bibliographic coupling in Arctic Research in 2015 (Scopus data)*

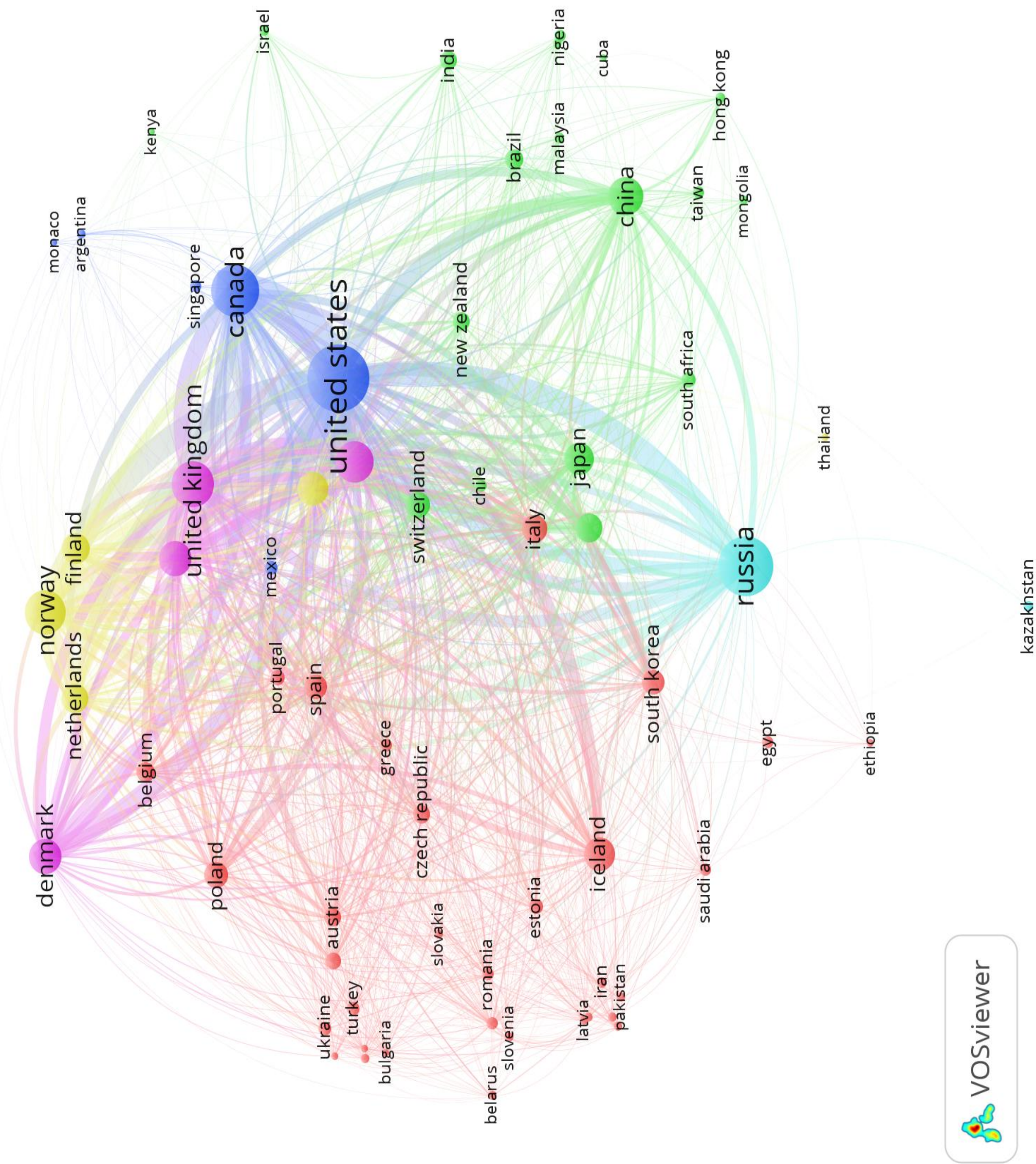
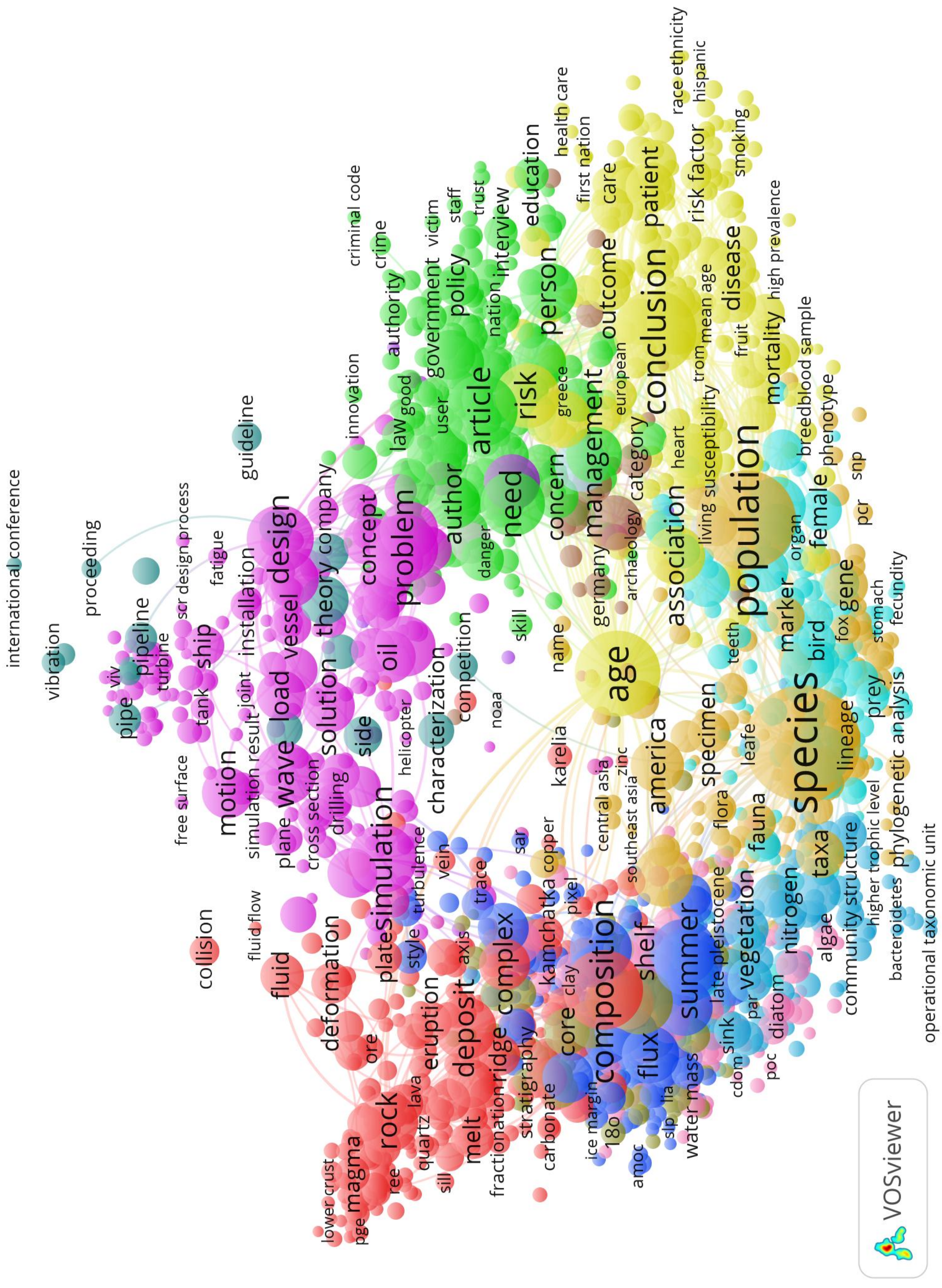


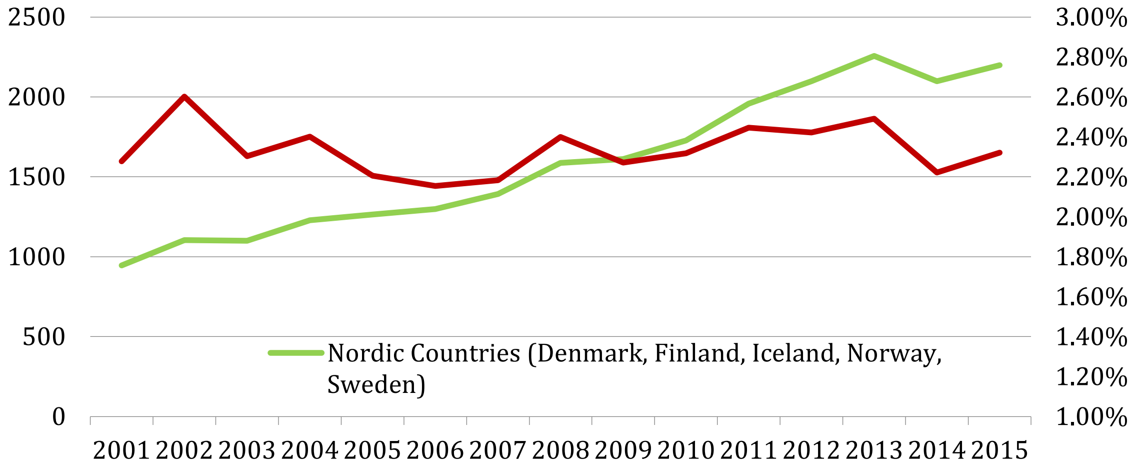
Figure 27c. *Map on text corpus in Arctic Research in 2015 (Scopus data)*



9. The specific features of publication activities in the different country groups: Arctic Council members, Observer nations, and Nordic countries

The proportion of the research in Scopus addressing the Arctic remained relatively stable between 2001 and 2015, at about 0.4%, as was shown in Figure 1. However, within country groups this proportion varies significantly. The highest proportion of Arctic research to total research output (more than 2%) is found for the Nordic countries (Figure 28).

Figure 28. *The total output and proportion of Arctic Research in Nordic countries*



Arctic Council member states (Canada, The Kingdom of Denmark, Finland, Iceland, Norway, Russian Federation, Sweden, United States of America) have an overall proportion of Arctic Research growing from 0.8% in 2001 to almost 1% in 2015 (Figure 29).

As expected, the Arctic Council Observers (France, Germany, the Netherlands, Poland, Spain, United Kingdom, People's Republic of China, Italian Republic, Japan, Republic of Korea, Republic of Singapore, Republic of India) have a lower proportion of Arctic Research compared with their total publication output - from 0.21 to 0.28% in different years, but the absolute number of Arctic publications grew up three times from 2001 to 2015 (Figure 30).

Figure 29. *The total output and proportion of Arctic Research in countries of Arctic Council*

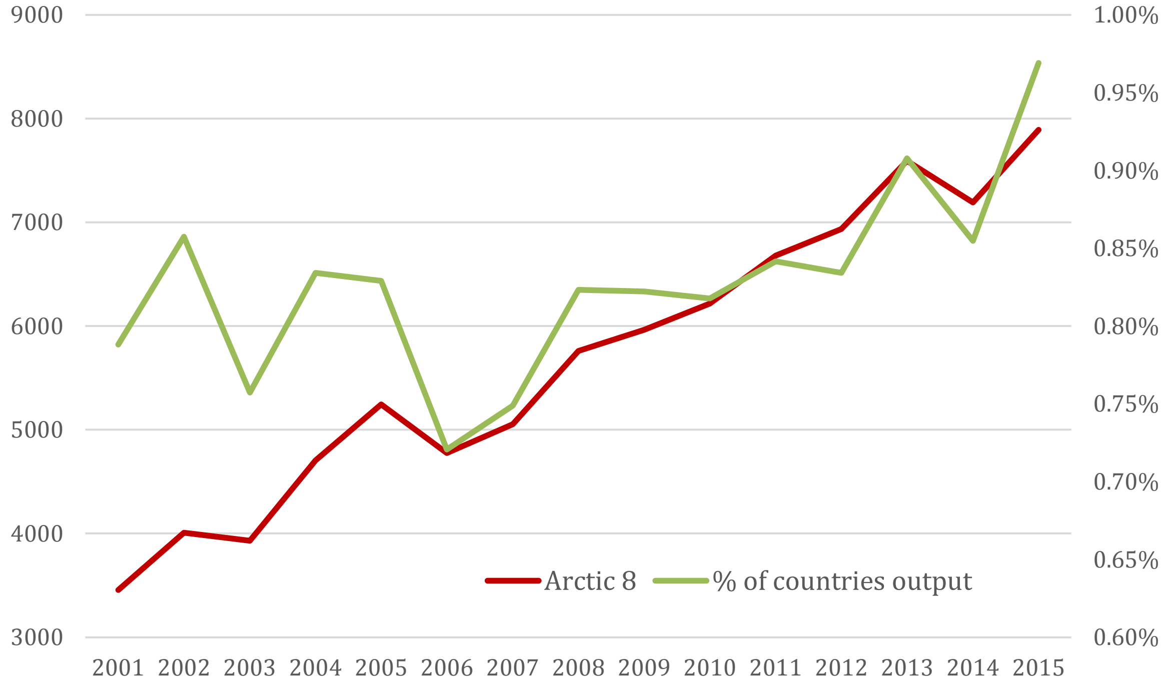


Figure 30. *The total output and proportion of Arctic Research in countries - Arctic Council Observers*

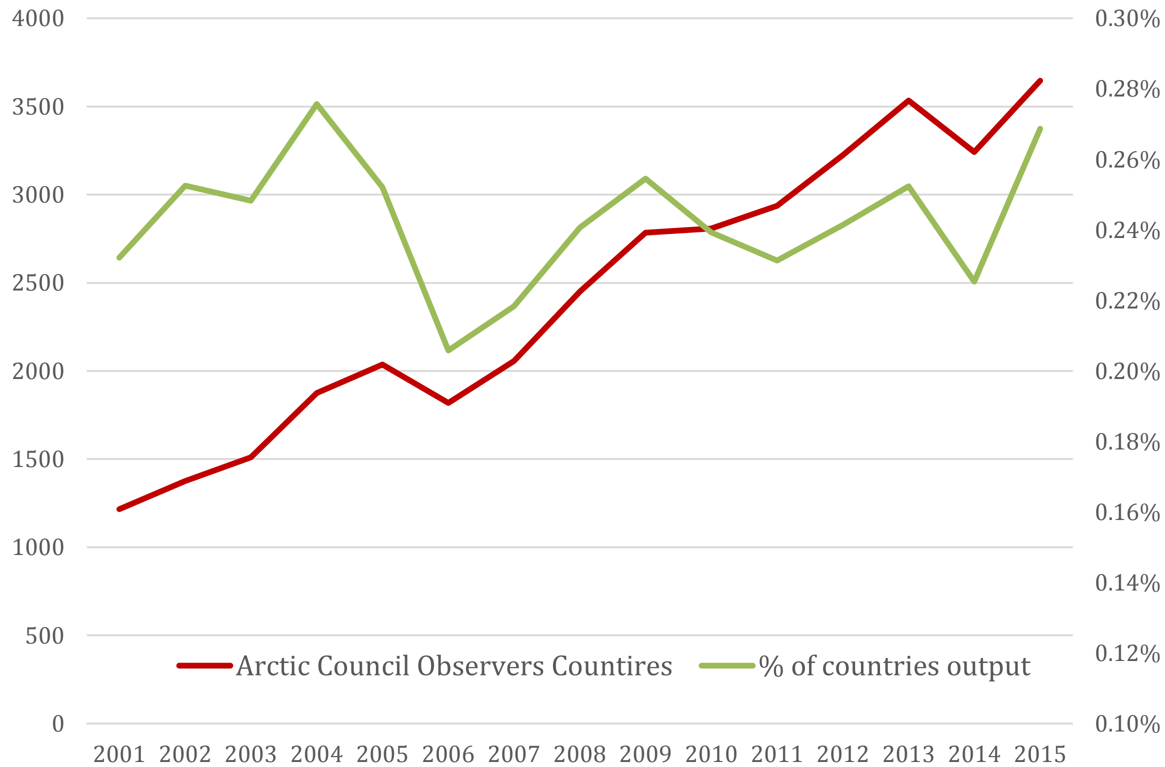
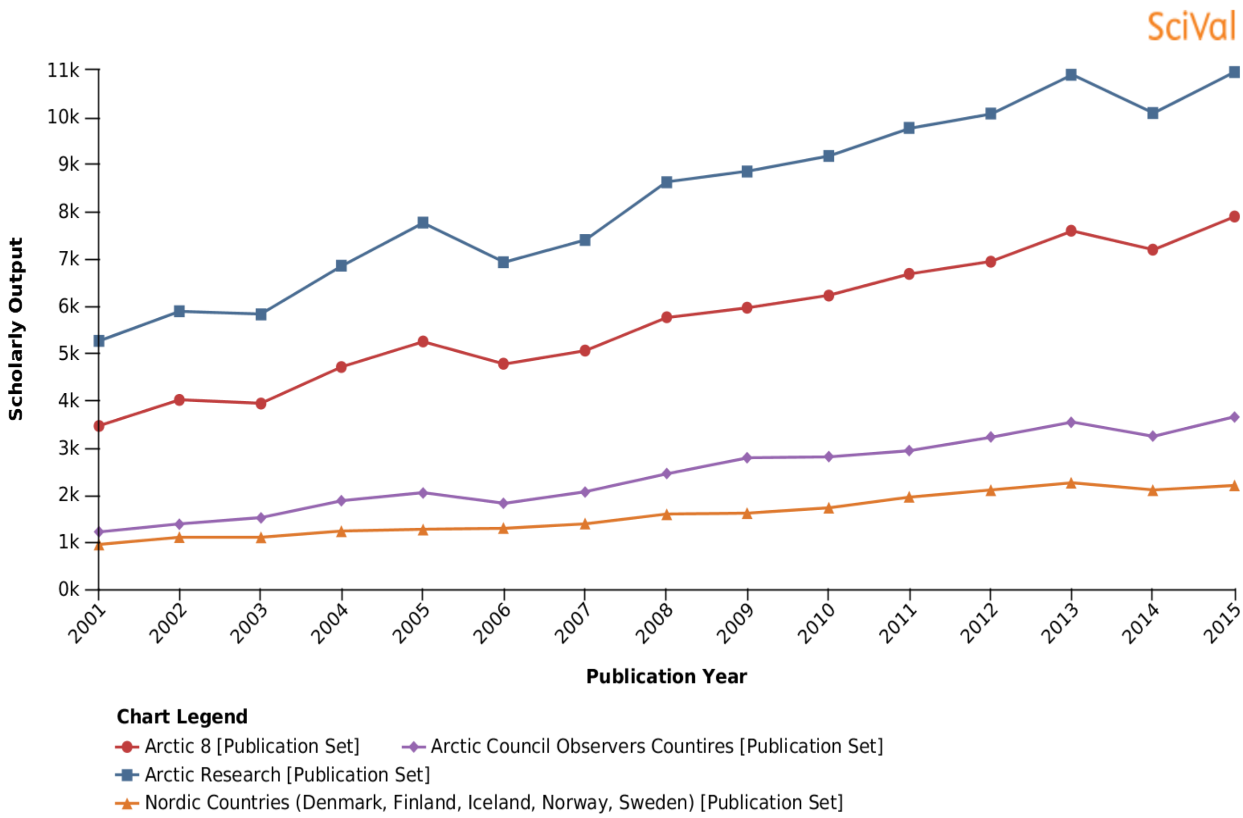


Figure 31. *The distribution of Arctic Research output between country groups (all research fields)*



Metric Details

y-axis: **Scholarly Output**

Types of publications included: all.

x-axis: **Publication Year**

Overall, the proportion of Arctic research in all country groups is quite stable, as is shown when analyses are done not year to year, but for 5-year periods, to eliminate annual fluctuations (Table 2).

Table 2. *The proportion of Arctic research publications by country groups, 2001-2015*

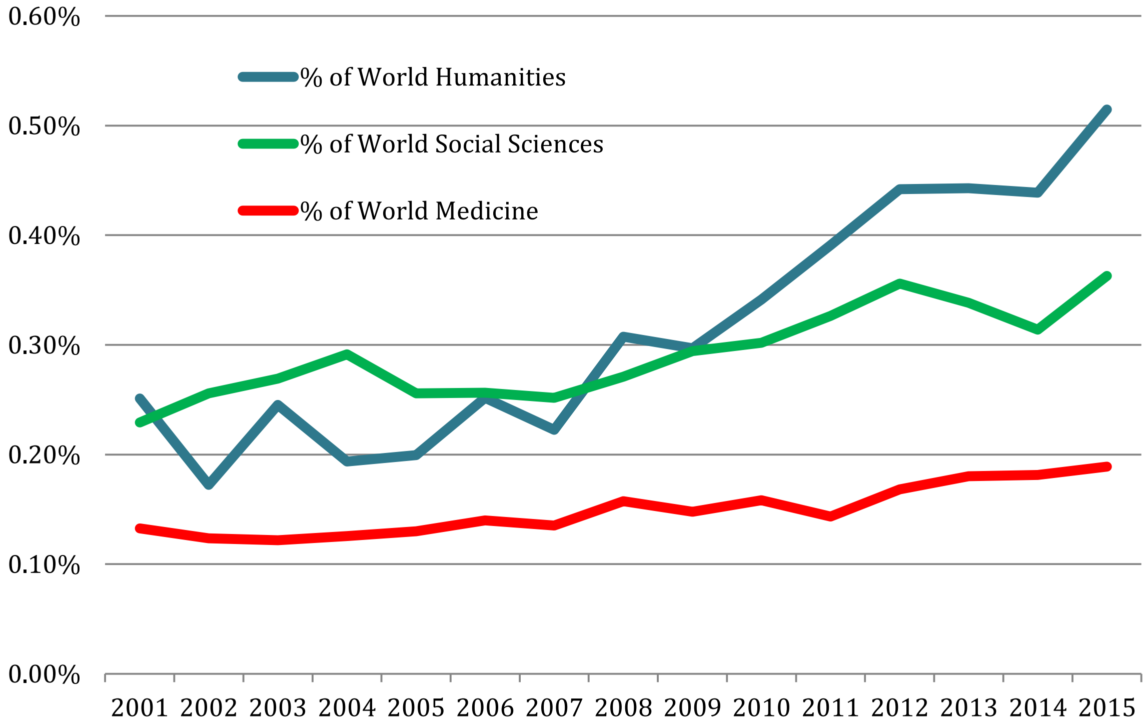
	2001-2005	2002-2006	2003-2007	2004-2008	2005-2009	2006-2010	2007-2011	2008-2012	2009-2013	2010-2014	2011-2015
Nordic	2,35%	2,32%	2,24%	2,27%	2,25%	2,27%	2,33%	2,37%	2,40%	2,38%	2,38%
Arctic Council	0,81%	0,80%	0,78%	0,79%	0,79%	0,79%	0,81%	0,83%	0,85%	0,85%	0,88%
Obser-vers	0,25%	0,24%	0,24%	0,24%	0,23%	0,23%	0,24%	0,24%	0,24%	0,24%	0,24%
Arctic Research	0,40%	0,40%	0,38%	0,39%	0,38%	0,37%	0,38%	0,38%	0,38%	0,37%	0,38%

Detailed analyses of country groups by FOS - Field of Science and Technology (FOS) Classification (OECD) and publication type demonstrates stable growth in scholarly output for all groups of countries, but significant differences among research fields. Agricultural sciences shows minor absolute growth for all countries, while in engineering and technology the leading role in output growth after 2007 belongs to Observers nations.

The preliminary analysis with SciVal demonstrates that initiators of the new dimensions and innovations in Arctic research (humanities and social sciences) is mainly related to the research from five Nordic countries with Arctic council observer states picking these new dimensions up very quickly. The growth of humanities and social sciences in Arctic research is not an artifact of the total increase in such publications in the world, as we can see on Figure 32. The same is true for medical science, though here the increase is not so evident due to the large output in medical sciences in the whole.

Leading contributors of Arctic research, Arctic 8, are more conservative in traditional subject fields of the Arctic research, except Medical Sciences, where the countries, included in Arctic Council, are the main contributors to the most growing fields in the last 5 years - Clinical Medicine and Other medical Sciences.

Figure 32. *The percentage of Arctic publications in Humanity, Social Sciences and Medical Sciences in World output*



A comparison of FWCI for Arctic Research overall and for country groups also shows the leading role of Nordic Countries in of in Arctic Research (Table 3).

Table 3. *Field-Weighted Citation Impact of Arctic Research in country groups*

	Overall	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015
Nordic Countries	1,43	1,39	1,43	1,44	1,43	1,45
Arctic Council Observers	1,38	1,50	1,32	1,33	1,44	1,36
Arctic Council	1,22	1,26	1,15	1,22	1,30	1,16
Arctic Research	1,08	1,10	1,05	1,07	1,15	1,05

Conclusion

In this pilot we have analyzed Arctic research by publication indicators using the databases Scopus and SciVal. Although the project and the method applied are still in an exploratory phase, we have been able to identify several interesting patterns characterizing Arctic research.

There has been a strong growth in the global scientific production of Arctic publications during the period 1996-2015. However, Arctic research does not show a stronger relative growth than the global average. Figures for 2015, reveal that the U.S. is by far the largest contributor to Arctic research in terms of publication output, followed by Russia, Canada, UK, and Norway. The analysis also shows that earth sciences and biology are the two largest disciplines of Arctic research, but there is research in a variety of other disciplines.

Overall, the Arctic research publications have been cited slightly above the average for all publications in Scopus. Thus, the scientific impact of Arctic research is good. However, the citation impact indicator shows large differences across countries. Switzerland and the Netherlands are the countries with the highest scientific impact measured by citations.

Arctic research is characterized by a relatively high degree of international cooperation. This is reflected in the proportion of the publications having co-authors from different countries. In 2015, more than 30 per cent of the Arctic publications involved international co-authorship. In contrast, the overall average for all fields (Scopus) is slightly below 20 percent. However, there are major differences among countries with regard to the extent of international co-authorship. In several of the countries, the majority of the Arctic scientific publications are internationally co-authored.

We are witnessing a significant and visible thematic change inside the Arctic research field, away from geosciences, earth sciences and environmental science towards social sciences, medicine and humanities.

The economic dimensions of the Arctic research output is mainly concerned with the pharmaceutical and biomedicine fields, which are traditionally R&D oriented. It counters our initial assumption that the most economic impact would be in the oil and gas sectors related to the Arctic.

Within the scope of this pilot report, we have only begun to analyze the overall trends in Arctic research. There are many aspects of Arctic research that can be analysed bibliometrically but which have not been explored by the present study. For example, in-depth analyses of fields and research topics, institutional patterns, and collaboration patterns of individual countries and institutions could be conducted.

Indicators addressing these aspects could be included in future analyses as part of a larger monitoring program for Arctic research.

We hope that this report will generate more questions and ideas for expanding the analyses, as well as interest in growing the data sources from which we draw. We believe that Arctic research will continue to grow in size and importance and that it is critical that we document this into the future.

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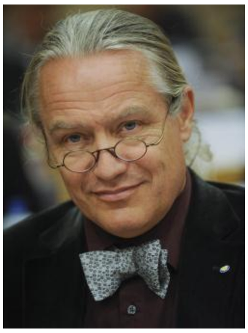

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Lars Kullerud has held the position of President of UArctic since May 2002. As the first president of UArctic Lars has had the pleasure to take part in the journey of developing UArctic. Before joining UArctic he represented UNEP in the early life of the Arctic Council and its predecessor AEPS since 1992 as Polar Manager for GRID-Arendal - UNEP's Key Polar Centre. Lars has background as geologist and have worked for the Norwegian Petroleum Directorate.

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