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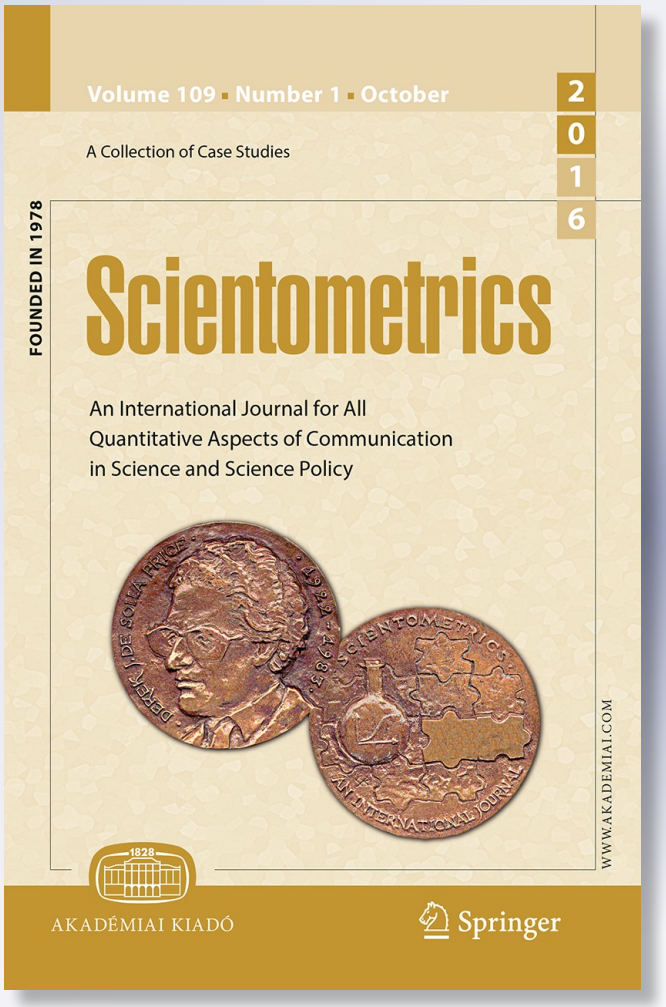

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Highly cited Antarctic articles using Science Citation Index Expanded: a bibliometric analysis

Hui-Zhen Fu[1] · **Yuh-Shan Ho**[2]

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Abstract This study aimed to identify and analyze the characteristics of the highly cited articles in Antarctic field using Science Citation Index Expanded from 1900 to 2012. Articles that have been cited more than 100 times since publication to 2012 were assessed. The analyzed aspects covered distribution of annual production, annual citations, journals, categories, countries/territories, institutions, authors, and research focuses and trends by words in title, author keywords, and *KeyWords Plus*. A total of 852 highly cited articles were published from 1959 to 2011, cited a mean number of 181 citations per article. Two famous journals: *Nature* and *Science* led 184 journals. Typically, the exploration of Antarctic needs multidisciplinary science, also involving more collaboration. The USA with the greatest manpower, took the lead position among 48 countries, while National Aeronautics and Space Administration of the USA and British Antarctic Survey of the UK were the two most productive institutions. European Project for Ice Coring in Antarctica Community was active in Antarctic research. Moreover, the comprehensive analysis of keywords revealed that sea ice, Southern Ocean, climate change, and ozone depletion were recent focuses and would receive more citations in the near future. In addition, citations in the first 3 years after publication (TC_3), in 2012 (C_{2012}), and since publication to 2012 (TC_{2012}), and citations per year of each article (*TCPY*) were used to characterize the citation patterns and citation life of most cited articles.

Keywords SCI-EXPANDED · Bibliometric · Top-cited articles · Article life · Collaboration

✉ Yuh-Shan Ho
ysho@asia.edu.tw

[1] Department of Information Resources Management, School of Public Affairs, Zhejiang University, No. 866 Yuhangtang Road, Hangzhou 310058, People's Republic of China

[2] Trend Research Centre, Asia University, Taichung 41354, Taiwan

Introduction

The exploration of Antarctica could be dated back to 1890s. The International Geographical Congress in London of 1895 made Antarctica the main target for new exploration (Anonymous 1895), which led to a series of national expeditions. The Belgian Antarctic Expedition of 1897–1899, under the leadership of Adrien de Gerlache de Gomery, was the first truly scientific expedition to the Antarctic (Summerhayes 2008). Then, British (Anonymous 1903), Scottish (Anonymous 1902), German (Anonymous 1904), Swedish (Ekelof 1904), Australasian (Anonymous 1911a) and French (Anonymous 1911b) expeditions succeeded in the early beginning of twentieth century. These expeditions were all reported in *Nature*. International Geophysical Year (IGY) of 1957–1958, evolved from International Polar Year, stimulated Antarctic scientific research and international cooperation, with 67 participating nations (Stoneley 1960). After the IGY, Scientific Committee on Antarctic Research was set up to continue the international coordination of Antarctic research, and held its first meeting in 1958 (Summerhayes 2008). Twelve countries (Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the UK, the USA, and USSR) signed Antarctic Treaty in 1959 (http://www.ats.aq/e/ats.htm), as a significant step forward in international cooperation in the field of peace, disarmament, and scientific cooperation (Phleger 1960). In 1991, the Madrid Protocol on environmental protection in Antarctica was added to the Antarctic Treaty (Abu Hanifah and Hashim 2012).

Citation, as an association-of-ideas index, offers an approach to subject control of the literature of science (Garfield 1955). Highly cited articles (Garfield 1974), also called most cited papers (Churchho 1968), most frequently cited articles (Garfield 1973), classic publications (Watkins and Bradford 1988), top papers (Miller 1988), top cited articles (Bentler 1992), and most influential articles (Anonymous 2000) have been characterized in various fields. Consequently findings on highly cited articles are useful to reveal the recognition of scientific advancement and give a historic perspective on the scientific progress (Baltussen and Kindler 2004; Ohba et al. 2007). Most of the early research just identified and listed the basic information with few discussions, such as authors, title, volume, issue, pages, and published year of highly cited articles (Churchho 1968; Dubin et al. 1993). Recently, scientists employ multidimensional indicators and methods to provide more comprehensive characteristics of highly cited articles. Total citations of a paper has been traditionally applied as a bibliometric indicator (Hawkins 1980), while a newly developed indicator, total number of citations of an article from its publication to recent year (TC_{year}), was presented (Chuang et al. 2011; Wang et al. 2011) to overcome the limitations of the former (Fu et al. 2012). The distribution of publication output, categories, journals, contributing institutions, countries (Ho 2012), and collaboration (Aksnes 2003) attach much attention. Citation is an indication of research influence (Wohlin 2005), and then citation life indicates how influence has changed with time. Citation life of most cited article has been identified to provide more detail information of influence (Ho 2012). In addition, the frequency of words in title and author keywords in successive sub-periods has been quantitatively analyzed to figure out research focuses and trends of highly cited articles (Fu and Ho 2013).

This study carried out in-depth analysis of highly cited articles associated with Antarctica using Science Citation Index Expanded from 1900 to 2012 by recently developed bibliometric methods. The analyzed analysis not only covered annual production, citations, journals, Web of Science categories, countries, institutions, and authorship, but

also revealed research emphases by words in title, author keywords, and *KeyWords Plus*, as well as citation patterns.

Methodology

The documents were based on the Science Citation Index Expanded (SCI-EXPANDED) database of Web of Science from Thomson Reuters (updated on 21 June 2013). The schematic for searching highly cited articles is shown in Fig. 1 (Fu et al. 2012). There were 44,693 documents with keywords: Antarctic, Antarctica, Antarctics, Antarcticensis, and Antarctica2, in the topic field (including title, abstract, author keywords, and *KeyWords Plus*) from 1900 to 2012 using SCI-EXPANDED. Secondly, article (39,232 articles) was abstracted as the only considered document type. Other document types including reviews, meeting abstracts, editorial materials, notes, letters, news items, book reviews, corrections, book chapters, correction additions, discussions, abstract of published items, biographical items, items about an individual, chronologies, and reprints, were all excluded. Thirdly, in order to ensure repeatability to provide more scientific and accurate information (Fu et al. 2012), TC_{2012} was used. TC_{2012} was the total citations which were counted since articles were published to the end of 2012 (Chuang et al. 2011). $TC_{2012} \geq 100$ was used as a filter to extract the 1051 articles as the highly cited articles. The final filter was the front page (Fu et al. 2012), which meant only 857 articles with the search keywords in their front page including article title, abstract, and author keywords were searched out for further analysis.

In terms of affiliation, classification was carried out to mend several database defects. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK) (Chiu and Ho 2005). Articles from Federal Republic of Germany (Fed Rep Ger) and Germany were reclassified as being from Germany (Ho 2012). Articles from Hong Kong published after 1997 were included in the China category (Chuang et al. 2011). Articles from USSR and Russia were also reclassified as being from Russia (Ho 2012). Similarly, USSR Academy of Science was recorded as Russian Academy of Sciences. Articles from Reunion were included in France. In addition, Malagasy Republic was recorded as Madagascar. The contributions from institutes' and countries/territories' were identified by the appearance of authors affiliated to the publications. Collaboration type was determined by the affiliations of the authors. Five types of articles were introduced for the evaluation of countries/territories and institutions (Ho 2013). (1) The term "single country article" was assigned if the researchers' affiliations were from the same country. The term "single institution article" was assigned if the researchers' affiliations were from the same institute. (2) The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from multiple countries (Chiu and Ho 2005). The term "inter-institutionally collaborative

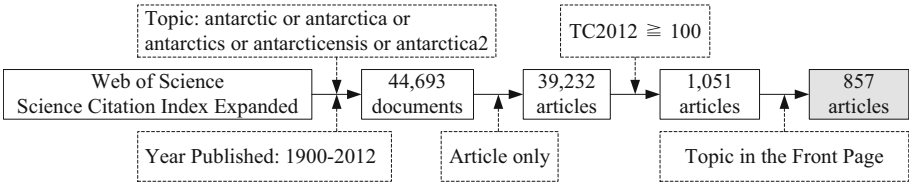

Fig. 1 Schematic for searching the highly cited articles in Antarctic field

article" was assigned if authors were from more than one institutes. (3) The term "first author article" was assigned if the first author was from the country/territory or institute. (4) The term "corresponding author article" was assigned if the corresponding author was from the country/territory or institute for analysis. (5) The term "single author article" was assigned if the article was published by only one author. *TP*, *IP*, *CP*, *FP*, *RP*, and *SP* are the number of total highly cited articles, "single country articles" or "single institution articles", "internationally collaborative articles" or "inter-institutionally collaborative articles", "first author articles", "corresponding author articles", and "single author article" for a country/territory or an institution, respectively. The calculation for all results was processed in the Microsoft Excel 2010.

Results and discussion

Annual production and citations per publication

Altogether 857 articles were found by the method mentioned in Fig. 1. However, though five articles got "Antarctica" in their abstracts, they were not considered to be Antarctic-

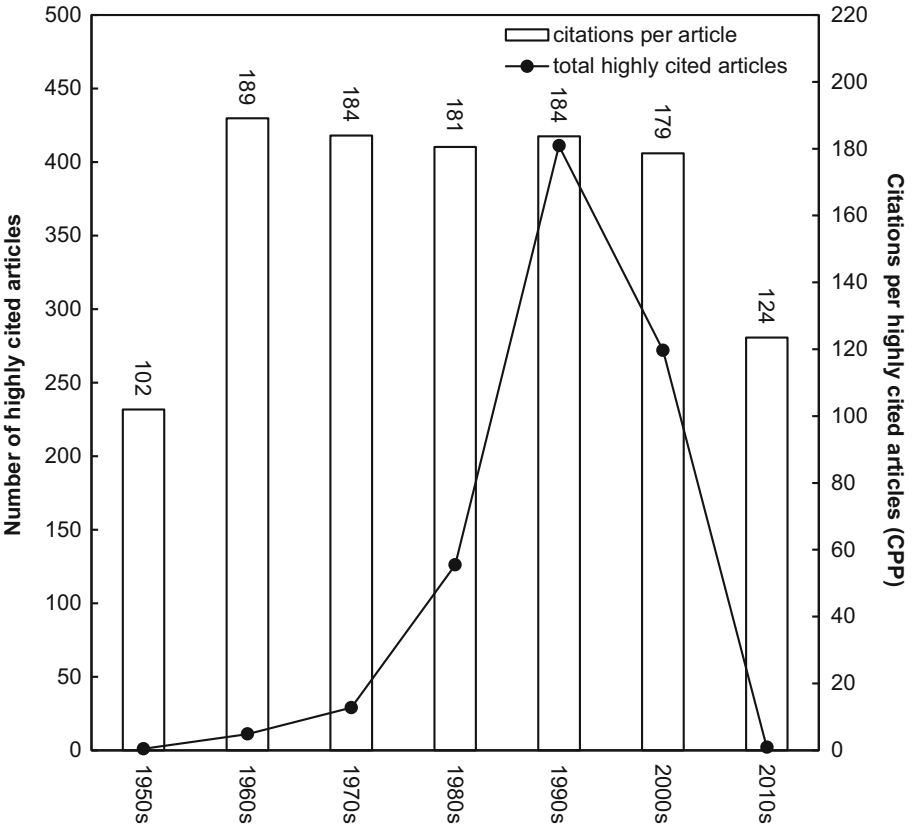

Fig. 2 Citations per article and number of highly cited articles by decades

related articles for further analysis, because the search keyword "Antarctica" appeared as "excluding Antarctica" in these five articles. A total of 852 Antarctic-related articles ($TC_{2012} \geq 100$) were regarded as the highly cited articles. These papers were all published in English between 1959 and 2011. The earliest highly cited Antarctic-related article entitled "sand-wedge polygons (Tesselations) in the McMurdo Sound region, Antarctica: a progress report" (Pewe 1959) was published in *American Journal of Science* in 1959. The latest highly cited article "Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise" (Rignot et al. 2011) was published by research teams from the USA and Netherlands. Figure 2 illustrates the distribution of these 852 articles and their *CPP*s over seven decades. About 48 % of the highly cited articles appeared in 1990s, followed by 2000s with 32 %, and 1980s with 15 %, while the other four decades of 1950s, 1960s, 1970s, and 2010s only took a small percentage of 5.0 %. The first highly cited article was published in 1950s, and then the number of highly cited articles sharply increased to 411 articles in 2000s. There were significant events in 1950s, including International Geophysical Year of 1957–1958 (Stoneley 1960), creation of Scientific Committee on Antarctic Research in 1958 (Summerhayes 2008), and Antarctic Treaty in 1959 (http://www.ats.aq/e/ats.htm), which greatly stimulated the development of Antarctic exploration and scientific research. Only two articles in 2010s could be due to less time for

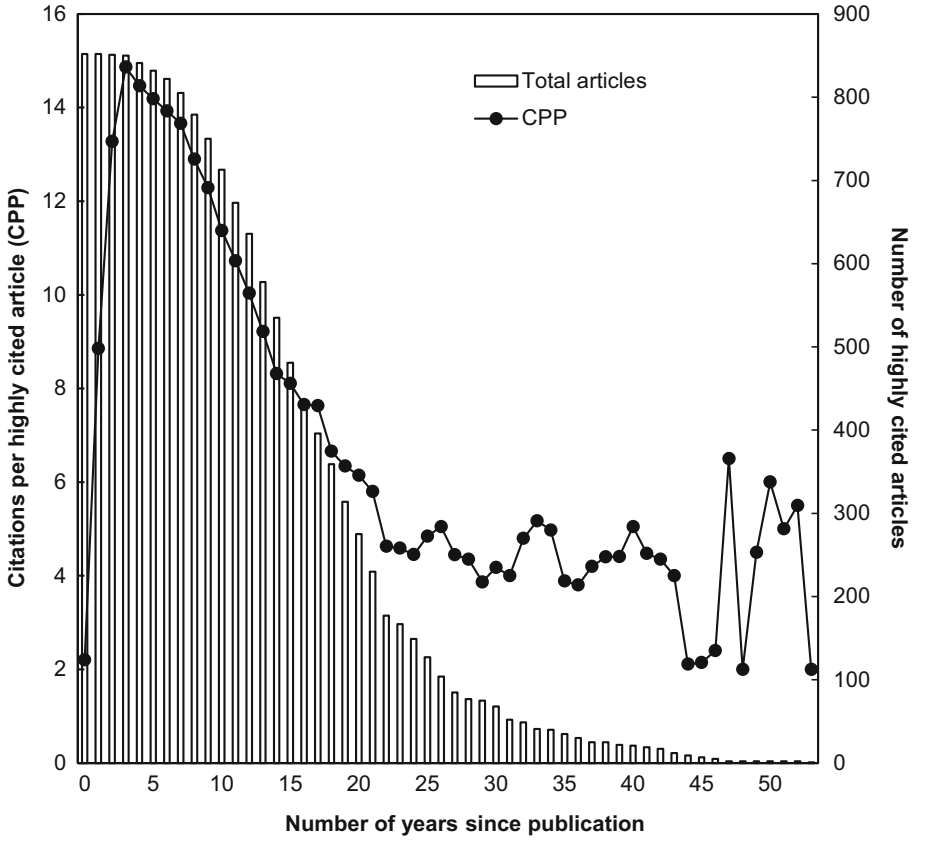

Fig. 3 Citations per article and number of highly cited articles with article life

the accumulation of citations (Picknett and Davis 1999). This phenomenon was similar with previous results of highly cited articles in chemical engineering (Ho 2012) and social science (Ho 2013).

Citation of one's work is a better measure of the impact of an individual's works than how many papers a person has authored (Stern and Arndt 1999). The 852 articles received a total of 154,610 citations. In terms of TC_{2012}, 658 articles (77 %) received 100–200 citations each and totaled 56 % citations; 169 (20 %) of the articles received 200–500 citations each and totaled 31 % citations; 22 articles (2.6 %) received 500–1000 citations each and totaled 9.0 % citations; and three articles received more than 1000 citations each and totaled 5257 citations. TC_{2012} ranged from 100 to 1948 citations with citations per publication (*CPP*) of 181. In particular, the decades of 1950s with one article and the 2010s with two articles had lower *CPP*s of 102 and 124, respectively. The *CPP*s of the other five decades were observed in a small range of 179 and 189.

To provide in-depth information of *CPP* with time in the Antarctic research, the citations per publication (*CPP*) and number of articles (*TP*) for all the 852 highly cited articles in the number of years after publication is displayed in Fig. 3. With respect to the number of years after publication (x axe), the publication year of one article was labeled as zero, and then the first year since publication was one, the second year since publication was two, and so forth. The trends of *CPP* and *TP* were similar with each other, especially in the initial years after publication. After publication year, *CPP* of articles sharply increased to a peak of 15 citations per year in the third year, stayed 14 annual citations in the next four years, and then decreased since the eighth years. The fluctuation of *CPP* in the large number of years after publication could be partly attributed to the small size of production in early years. The peak year of citations per highly cited article (third) was found to be similar with other research disciplines of all related articles where the peak could be shifted to the second year (Chiu and Ho 2005; Chuang et al. 2007), fifth year (Zhang et al. 2009), and sixth year (Li and Ho 2008), and third-seventh years (Hansen and Henriksen 1997).

Table 1 Characteristics of top eight journals in Antarctic field

Journal	TP (%)	IF_{2012}	Web of science category
Nature	125 (15)	38.597	Multidisciplinary sciences
Science	95 (11)	31.027	Multidisciplinary sciences
Journal of Geophysical Research-Atmospheres	48 (5.6)	3.174	Meteorology and atmospheric sciences
Geophysical Research Letters	31 (3.6)	3.982	Multidisciplinary geosciences
Journal of Geophysical Research-Oceans	31 (3.6)	3.174	Oceanography
Paleoceanography	28 (3.3)	3.296	Multidisciplinary geosciences Oceanography Paleontology
Journal of Climate	25 (2.9)	4.362	Meteorology and atmospheric sciences
Geology	20 (2.3)	1.481	Geology

TP total articles of each journal, IF_{2012} impact factor in 2012

Journals and Web of Science Categories

Journals and categories of the highly cited articles were previously concerned (Fu et al. 2012; Ho 2013). The highly cited Antarctic-related articles were published by 184 journals in SCI-EXPANDED. Of these 184 journals, 101 (55 %) journals contained only one article; 28 (15 %) journals contained two articles; 17 (9.2 %) journals contained three articles; and 38 (21 %) journals contained more than three articles. Table 1 shows the top eight productive journals with at least 20 highly cited articles, accounting 47 % of all highly cited articles. *Nature* with the highest impact factor of 38.597 was also the most productive one, having 125 articles (15 %). *Science* with the second highest $IF_{2012} = 31.027$ was the second most productive journal, having 95 articles (11 %). It is not common that the most productive journals also had the greatest influence even for highly cited articles in comparison with other fields, such as the wetland research (Ma et al. 2013) and adsorption research (Fu et al. 2012). *Nature* founded in 1869, is targeted to reflect whatever is important in and around science for the broadest possible scientific readership (Taylor 2011), while *Science* founded by in 1880, ranks as the world's largest circulation general science journal. The domination of *Nature* and *Science* indicated that Antarctic research was hot issue in and around science. In addition, the highly cited articles did not only appear in the high-impact journals (Ho and Kahn 2014). The journals with lower impact factors such as *Copeia* with $IF_{2012} = 0.644$, *Australian Journal of Zoology* with $IF_{2012} = 0.775$, and *New Zealand Journal of Zoology* with $IF_{2012} = 0.889$ also published highly cited Antarctic related articles.

Based on the Journal Citation Reports (JCR) science edition in 2012, the highly cited articles were distributed in 55 Web of Science categories. Multidisciplinary sciences (228; 27 % of all articles) including in 56 journals, was the most productive category followed far away by oceanography (144; 17 %) with 60 journals, multidisciplinary geosciences (140; 16 %) with 170 journals, and meteorology and atmospheric sciences (100; 12 %) with 74 journals. These four main categories contributed to 67 % of all highly cited articles. The domination of multidisciplinary science was consistent with the results related to journal. Two most productive journals of *Nature* and the second *Science* just belong to the category of multidisciplinary science. Antarctic exploration is outstanding planned and organized cooperative research involving oceanographical, glaciological, geological, meteorological, and biological (Kertz 1984).

Countries, institutions, and authorship

Publication performance of institutions and countries was paid attention in terms of number of total, independent, and collaborative publications (Hsieh et al. 2004). Twenty-two highly cited Antarctic articles included 11 in the 1960s, nine in the 1970s, and one in each of 1950 and 2000 were excluded, because they did not have any author affiliation information from the Web of Science. Generally, 830 articles originated from 721 institutions in 48 countries. A total of 48 countries were distributed among six continents. Nineteen European countries contributed to 563 articles (68 %), while six North American countries contributed to 558 articles (67 %). The other continents contributed to much less highly cited articles. Oceania continent published 12 % highly cited articles, followed by Asia (9.0 %), Africa (2.3 %), and South America (2.2 %).

There were 574 independent country articles (69 %), while the other 256 articles (31 %) were contributed by international collaboration. Among the total of 48 countries, 25

Table 2 Top 20 countries with the most highly cited articles in Antarctic field

Country	TP	TPR (%)	IPR (%)	CPR (%)	FPR (%)	RPR (%)	SPR (%)	I (%)	TPS	FO	FL	PP
USA	507	1 (61)	1 (60)	1 (63)	1 (52)	1 (51)	1 (59)	68	6	1955	1965	1000
UK	137	2 (17)	2 (10)	2 (30)	2 (12)	2 (11)	2 (12)	44	7	1947	1975	130
Germany	114	3 (14)	3 (6.8)	3 (29)	3 (7.7)	3 (7.6)	4 (6.0)	34	5	1981	2001	50
France	93	4 (11)	5 (3.7)	4 (28)	4 (6.3)	4 (7.1)	6 (3.0)	23	2	1956	1956	100
Australia	79	5 (10)	4 (6.4)	5 (16)	5 (5.4)	5 (6.1)	3 (7.0)	47	6	1954	1969	70
Canada	47	6 (5.7)	7 (1.9)	7 (14)	7 (2.3)	7 (2.5)	6 (3.0)	23	0	N/A	N/A	N/A
Switzerland	40	7 (4.8)	19 (0.17)	6 (15)	9 (1.6)	8 (1.8)	N/A	2.5	0	N/A	N/A	N/A
Japan	32	8 (3.9)	6 (2.8)	15 (6.3)	6 (2.5)	6 (2.6)	8 (1.0)	50	5	1957	2005	110
Sweden	26	9 (3.1)	11 (0.7)	9 (8.6)	10 (1.3)	14 (0.78)	8 (1.0)	15	2	1989	1989	20
Denmark	25	10 (3.0)	19 (0.17)	8 (9.4)	20 (0.24)	18 (0.26)	N/A	4.0	0	N/A	N/A	N/A
New Zealand	24	11 (2.9)	8 (1.2)	14 (6.6)	8 (2.0)	8 (1.8)	5 (4.0)	29	1	1957	1957	85
Belgium	24	11 (2.9)	9 (1.0)	13 (7.0)	12 (1.0)	11 (0.92)	N/A	25	1	2009	2009	20
Italy	24	11 (2.9)	13 (0.52)	10 (8.2)	16 (0.60)	14 (0.78)	N/A	13	5	1986	2005	90
Russia	23	14 (2.8)	15 (0.35)	10 (8.2)	13 (0.84)	21 (0.13)	N/A	8.7	12	1956	1989	169
Netherlands	22	15 (2.7)	15 (0.35)	12 (7.8)	15 (0.72)	11 (0.92)	N/A	9.1	0	N/A	N/A	N/A
Spain	16	16 (1.9)	10 (0.87)	17 (4.3)	11 (1.1)	10 (1.3)	N/A	31	2	1989	1990	25
Norway	16	16 (1.9)	13 (0.52)	16 (5.1)	17 (0.48)	11 (0.92)	N/A	19	2	1985	1990	40
South Africa	13	18 (1.6)	11 (0.70)	18 (3.5)	13 (0.84)	16 (0.65)	8 (1.0)	31	1	1962	1962	80
China	9	19 (1.1)	15 (0.35)	19 (2.7)	17 (0.48)	17 (0.39)	8 (1.0)	22	3	1985	2009	40
Argentina	9	19 (1.1)	15 (0.35)	19 (2.7)	17 (0.48)	18 (0.26)	8 (1.0)	22	13	1904	1982	150

TPR (%) the rank and percentage of total articles of each country in the world, *IPR (%)* the rank and percentage of single country articles of each country in the world, *CPR (%)* the rank and percentage of internationally collaborative articles of each country in the world, *FPR (%)* the rank and percentage of first author articles of each country in the world, *RPR (%)* the rank and percentage of corresponding author articles of each country in the world, *SPR (%)* the rank and percentage of single author articles of each country in the world; *IP %* the percentage of single country articles to total articles of each country, *TPS* number of facilities, *FO* first opened year of the oldest facility, *FL* first opened year of latest facility, *PP* the maximum number of persons present at the facility at any one time, *N/A* not available

Table 3 Top 20 institutions with the most highly cited articles in Antarctic field

Institution	TP	TPR (%)	IPR (%)	CPR (%)	FPR (%)	RPR (%)	SPR (%)	IP (%)
National Aeronautics and Space Administration, USA	63	1 (7.6)	5 (3.3)	1 (11)	3 (3.4)	1 (4.3)	16 (1.0)	19
British Antarctic Survey, UK	58	2 (7.0)	1 (5.2)	2 (8.4)	1 (4.1)	2 (4.1)	6 (3.0)	33
University of California, San Diego, USA	48	3 (5.8)	1 (5.2)	5 (6.2)	2 (3.6)	3 (3.3)	1 (6.0)	40
Columbia University, USA	45	4 (5.4)	3 (4.1)	4 (6.5)	4 (3.0)	4 (2.6)	2 (4.0)	33
California Institute of Technology, USA	43	5 (5.2)	6 (3.0)	3 (6.9)	5 (2.5)	6 (2.4)	2 (4.0)	26
Alfred Wegener Institute for Polar and Marine Research, Germany	41	6 (4.9)	4 (3.6)	7 (6.0)	6 (2.3)	4 (2.6)	6 (3.0)	32
Centre National de la Recherche Scientifique, France	32	7 (3.9)	24 (0.82)	5 (6.2)	8 (1.7)	8 (1.8)	16 (1.0)	9
University of Colorado, USA	31	8 (3.7)	13 (1.4)	9 (5.6)	7 (2.2)	9 (1.7)	N/A	16
National Oceanic and Atmospheric Administration, USA	31	8 (3.7)	8 (1.9)	10 (5.2)	12 (1.3)	7 (2.1)	2 (4.0)	23
University of Bern, Switzerland	28	10 (3.4)	58 (0.27)	8 (5.8)	10 (1.4)	9 (1.7)	N/A	4
Ohio State University, USA	25	11 (3.0)	8 (1.9)	11 (3.9)	9 (1.6)	11 (1.6)	16 (1.0)	28
University of Washington, USA	22	12 (2.7)	10 (1.6)	13 (3.4)	12 (1.3)	17 (1.0)	12 (2.0)	27
University of Cambridge, UK	21	13 (2.5)	13 (1.4)	13 (3.4)	12 (1.3)	11 (1.6)	12 (2.0)	24
University of Tasmania, Australia	20	14 (2.4)	7 (2.2)	23 (2.6)	12 (1.3)	13 (1.3)	6 (3.0)	40
National Center for Atmospheric Research, USA	19	15 (2.3)	13 (1.4)	17 (3.0)	21 (0.84)	15 (1.2)	N/A	26
Commonwealth Scientific and Industrial Research Organisation, Australia	19	15 (2.3)	24 (0.82)	13 (3.4)	31 (0.6)	21 (0.92)	N/A	16
University of California, Santa Barbara, USA	17	17 (2.0)	18 (1.1)	20 (2.8)	10 (1.4)	13 (1.3)	N/A	24
Harvard University, USA	17	17 (2.0)	18 (1.1)	20 (2.8)	18 (1.0)	17 (1.0)	16 (1.0)	24
University of Copenhagen, Denmark	17	17 (2.0)	N/A	12 (3.7)	128 (0.12)	120 (0.13)	N/A	N/A
U.S. Geological Survey, USA	17	17 (2.0)	58 (0.27)	13 (3.4)	31 (0.6)	24 (0.78)	16 (1.0)	19

TPR (%) the rank and percentage of total articles of each institution in the world, *IPR (%)* the rank and percentage of single institution articles of each institution in the world, *CPR (%)* the rank and percentage of inter-institutionally collaborative articles of each institution in the world, *FPR (%)* the rank and percentage of first author articles of each institution in the world, *RPR (%)* the rank and percentage of corresponding author articles of each institution in the world, *SPR (%)* the rank and percentage of single author articles of each institution in the world, *IP %* the percentage of single institution articles to total articles of each institution, *N/A* not available

countries (52 %) did not have independent articles. The collaboration rate (31 %) of highly cited articles in the Antarctic research was greater than certain fields, such as 14 % of adsorption (Fu et al. 2012), and 20 % of chemical engineering (Chuang et al. 2013). Supporting research in the huge and distant Antarctic requires complicated logistics partnerships (Erb 2011). International scientific cooperation in Antarctica has a remark increase during 1980–2004 (Dastidar 2007). There were 102 main Antarctic facilities operated by National Antarctic Programs in the Antarctic Treaty Area (Updated 15 May 2013) (https://www.comnap.aq/Information/SitePages/Home.aspx). Thirteen facilities had no available information of first opened year. Three facilities were international collaborative by Australia and Romania, France and Italy, and Netherlands and UK. The characteristics of the top 20 countries with their facility information are illustrated in Table 2. The leading country was the USA (507 articles), accounting for 61 %, followed by the UK and Germany. The USA ranked top one by *TP*, *IP*, *CP*, *FP*, *RP*, and *SP*, while the UK was in the second position of these six indicators. As for the 256 internationally collaborative articles, 162 (63 %) were collaborated with the USA. The USA was also the only one country had more than a half independent articles (68 %), followed distantly by the UK (44 %) and France (40 %). The top three countries including the USA, the UK, and Germany owned no less than five national stations. It is noticeable that the maximum number of persons in the USA was 1000 at the facility first opened in 1955, which is much greater than other countries. In particular, the low percentage of independent research of Switzerland, Denmark, and Netherlands could be partly explained by no national facilities of them. Only 13 countries had single author articles, and 25 countries had first author and corresponding author articles, respectively. In addition, Chile, Poland, Finland, and Brazil had national facilities in Antarctic, but contributed to no more than five collaborative articles and no independent highly cited articles.

In total, 365 articles (44 %) came from independent institution, and 465 articles (56 %) were from inter-institutional collaboration. Inter-institutional collaboration rate was much greater than classic articles of some medical fields, such as 12 % of 100 top cited articles in general surgical journals (Paladugu et al. 2002), and 8 % of 100 ophthalmology class citations (Ohba et al. 2007). This phenomenon provides another evidence that Antarctic research involved more collaboration. Table 3 lists the 20 most productive institutions. Similarly, the USA also hold the most institutions of 12, followed distantly by Australia (two institutions), the UK (two), and one each for Switzerland, Denmark, France, and Germany respectively. The National Aeronautics and Space Administration (NASA) of the USA led not only the total highly cited Antarctic articles, but also the inter-institutionally collaborative articles and the corresponding author articles. In second place was British Antarctic Survey of the UK with 58 articles. It also published most first author article and most single institution articles respectively. The remaining institutions among the top five were the University of California at San Diego (48 articles), Columbia University (45), and California Institute of Technology (43). Most articles of Centre National de la Recherche Scientifique (CNRS), University of Bern and University of Copenhagen were inter-institutionally collaborative, with less than 10 % independent articles.

Each author in one publication made contribution to the research work (Coats 2009). In the research of highly cited articles, scientists are the crucial factors in determining the distribution of institutions and countries (Fu et al. 2012). The average number of authors publishing a highly cited Antarctic-related article was 5.0 with the largest number of authors of 113. The average number of authors per article increased from 1.0 in 1950s to 4.1 in 1990s and up to 7.5 in 2000s. It was pointed that the number of authors per article increased. Of the 852 highly cited articles, 104 (12 %) were written by single author, 199

(23 %) by two authors, 153 (18 %) by three authors, and 241 (47 %) by more than three authors. Nearly a half articles were contributed by more than three authors, which is much greater than all related publications in a research field, such as 20 % of ocean circulation (Zhang et al. 2009) and 34 % of biosorption technology in water treatment research (Ho 2008). More collaboration has been found in Antarctic research. The article with the most authors were from four countries including USA, Sweden, Germany, and Belgium in 2001, reporting observation of high-energy neutrinos using Cerenkov detectors embedded deep in Antarctic ice in *Nature* (Andres et al. 2001). This research was supported by more than ten national agencies. Table 4 exhibits 11 most productive authors. Jouzel published the most of 27 articles, whose most cited article is entitled "climate and atmospheric history of the past 420 000 years from the Vostok ice core, Antarctica". It is noticed that Jouzel's most cited article also obtained the greatest citations ($TC_{2012} = 1948$) among all the highly cited articles. The 8th position Holmhansen published articles in earlier years from 1981 to 1997, while the other ten authors had their latest highly cited articles in 2000s. Except Holmhansen, the other ten authors all had collaboration on highly cited Antarctic research. Particularly, Jouzel collaborated with Raynaud for 16 articles; Jouzel, Raynaud, and Petit published 13 articles together; and Jouzel, Raynaud, Petit, and Barnola worked together on nine articles. Furthermore, except Barkov and Holmhansen, the other nine authors were involved in European Project for Ice Coring in Antarctica (EPICA) Community (Augustin et al. 2004). The EPICA Programme (1996–2006) provides co-ordination for EPICA drilling activities at Dome Concordia and Kohnen Station, which are supported by the European Commission and by national contributions from Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland, and the UK (http://www.esf.org/index.php?id=855). The European EPICA project ventured to Antarctica to retrieve two continuous ice cores that extend the historical climate record back 800 000 years. Descartes Prize for Transnational Collaborative Research awarded to EPICA project in 2007, since their analysis of the ice within these cores has made an extremely significant

Table 4 Top 11 authors with the most highly cited articles in Antarctic field

Authors	Institution	R (TP)	R (FP)	R (RP)	PY (range)
Jouzel, J	CNRS, France	1 (27)	1 (6)	1 (7)	29 (1979–2008)
Raynaud, D	CNRS, France	2 (18)	N/A	N/A	17 (1991–2008)
Petit, JR	CNRS, France	3 (16)	34 (2)	11 (3)	27 (1981–2008)
Barnola, JM	CNRS, France	4 (15)	115 (1)	100 (1)	17 (1991–2008)
Stocker, TF	University of Bern, Switzerland	4 (15)	115 (1)	4 (4)	10 (1998–2008)
Chappellaz, J	CNRS, France	6 (12)	115 (1)	36 (2)	15 (1993–2008)
Stauffer, B	University of Bern, Switzerland	6 (12)	115 (1)	100 (1)	22 (1985–2007)
Schwander, J	University of Bern, Switzerland	8 (11)	N/A	N/A	10 (1997–2007)
Barkov, NI	Arctic and Antarctic Research Institute, Russia	8 (11)	N/A	N/A	16 (1985–2001)
Holmhansen, O	University of California, USA	8 (11)	115 (1)	100 (1)	16 (1981–1997)
Fischer, H	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany	8 (11)	115 (1)	36 (2)	9 (1999–2008)

R rank, *N/A* not available, *PY* number of years published highly cited articles, *Range* the period published highly cited articles

contribution to improve understanding of climate change, its mechanisms and consequences (European Commission 2007).

Words in Title, author keywords, and *KeyWords Plus*

The frequency of keywords analysis has been statistically analyzed to identify the leading fields of research in 1990s (Mela et al. 1999). The title, along with the author keywords, provides a reasonably detailed picture of the article's theme, while *KeyWords Plus* generated independently of the title or author keywords, describing the article's contents with greater depth and variety (Garfield 1990). The analysis including words in title, author keywords, and *KeyWords Plus* together could minimize some limitations, such as the uncompleted meaning of single words in title, the small sample size for author keywords, and the indirectly relationship between *KeyWords Plus* and the research emphases (Fu and Ho 2013). Distributions of words in title, author keywords, and *KeyWords Plus* in different periods can provide information for finding research focus (Mao et al. 2010). To reveal the research focuses of highly cited Antarctic research, words in title, author keywords, and *KeyWords Plus* were statistically analyzed. Ten most frequently used title words, author keywords, and *KeyWords Plus* are listed in Table 5. In terms of words in title, "ice" and "sea" was in the second and fourth positions, consistent with "sea ice" in the second position of author keywords. Similarly, "ocean" and "southern" was exhibited as a phase "Southern Ocean" of author keywords and "Southern-Ocean" of *KeyWords Plus*. The title words of "climate" and "changes" appeared as a phrase "climate change" in author keywords list; and the following title word "ozone" was also displayed as a phrase "ozone depletion" by author keywords. These results indicated that the highly cited articles focused on sea ice, Southern Ocean, climate change, and ozone depletion. These topics related to each other in Antarctic research. Sea ice may play a major role in the climatic change on the longer time-scales (Walsh 1983). The relation between Southern Ocean cooling and Antarctic cryosphere expansion has been explored (Shevenell et al. 2004). The Antarctic Peninsula has experienced a major warming from 1951 to 2000, with temperatures at Faraday/Vernadsky station having increased at a rate of 0.56 °C per decade over the year and 1.09 °C per decade during the winter (Turner et al. 2005). The temperature changes are consistent with model predictions of the radiative response to Antarctic polar ozone depletion (Randel and Wu 1999).

Citation patterns of highly cited articles

There is a long history to investigate a mathematical expression describing the typical citing frequency distribution as a function of articles' age (Avramescu 1973, 1979). In the following years, citation patterns of highly cited papers and their relationship to literature aging (Aversa 1985) and citation life cycles of highly cited articles (Cano and Lind 1991) were studied. Recently, except the total citations TC_{2012}, the number of times of an article cited in 2012 (C_{2012}) (Ho 2012), and the number of times of an article cited in its publication year (C_0) were developed to offer more detail information about the impact of a publication (Ho 2013; Ho and Kahn 2014). In terms of C_{2012}, 35 articles (4.1 % of 852 highly cited articles) had no citations, 5.0 % articles had one citation, 6.2 % articles had two citations, and 6.8 % had three citations. Since the peak citation year was the third in Fig. 3, a new indicator TC_3, the sum of C_0, C_1 (the number of citations in the first year after publication), C_2 (the number of citations in the second year after publication), C_3 (the number of citations in the third year after publication) was introduced to characterize the

Table 5 The top ten words of title, author keywords, and *KeyWords Plus* in Antarctic field

Rank	Word in title	TP (%)	Author keyword	TP (%)	KeyWords Plus	TP (%)
1	Antarctic	299 (35)	Antarctica	21 (15)	Ocean	58 (8.8)
2	Ice	158 (19)	Southern Ocean, sea ice	7 (5.1)	Southern-Ocean, record	46 (7)
3	Antarctica	127 (15)				
4	Ocean	72 (8.5)	Gondwana	6 (4.3)	North-Atlantic	45 (6.8)
5	Sea	62 (7.3)	Biogeography, foraging, biodiesel	5 (3.6)	Temperature	43 (6.5)
6	Southern	54 (6.3)			Model	42 (6.4)
7	Climate	53 (6.2)			Variability, evolution	40 (6.1)
8	Changes	37 (4.3)	Climate change, ozone depletion, Antarctic krill, Rodinia, Antarctic, Antarctic peninsula, Methanolysis, temperature, Patagonia, lipase	4 (2.9)		40 (6.1)
9	Glacial	36 (4.2)			Climate, Antarctica	39 (5.9)
10	Ozone	36 (4.2)				

TP, number of articles of a given word; %, the percentage of the frequency of a given word in title, author keywords, or *KeyWords Plus* to the total number of articles

initial influence of highly cited articles. Citations per year (*TCPY*) which took the time for the accumulation of citations into consideration, was presented to give more characteristics of highly cited Antarctic articles. Relationship among TC_{2012}, C_0, TC_3, C_{2012}, and *TCPY* of the 852 articles were tested by correlation of coefficient. The relationship between TC_{2012} and *TCPY* had the highest correlation of coefficient ($r = 0.692$), followed by TC_{2012} and TC_3 ($r = 0.609$), TC_{2012} and C_{2012} ($r = 0.593$), and TC_{2012} and C_0 ($r = 0.206$). Sixty-six percent, 23, 51, and 42 % of the top 100 articles by TC_{2012} were not ranked in top 100 by C_0, TC_3, C_{2012}, and *TCPY*, respectively. Moreover, among 852 articles, 356 articles (42 %) had no citations in their publication year ($C_0 = 0$), while 35 articles (4.1 %) had at least 10 times citations ($C_0 \geq 10$). Article entitled "Cosmological parameters from the first results of boomerang" (Lange et al. 2001) had the highest $C_0 = 78$ citations, but $TC_{2012} = 230$ (rank = 141), $C_{2012} = 6$ (rank = 519), $TC_3 = 165$ (rank = 3), and $TCPY = 21$ (rank = 116). Obviously, number of citations in publication year (C_0) had poor correlation with the total citations, and was not recommended as an evaluation indicator alone.

Table 6 presents the seven most cited articles with more than 800 citations ($TC_{2012} > 800$). Three articles were published in *Nature* ($IF_{2012} = 38.597$). Most of top seven articles differed by each indicator. That means the highly cited articles would not always have high impact or visibility in research society after their publication. It has also been reported that 94 % of most frequently cited articles in *American Journal of Roentgenology* have changed their rankings (Bui-Mansfield 2005). Article entitled "Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica" (Petit et al. 1999) by 19 authors of France, Russia, and the USA, had the greatest influence since 1999. In particular, six authors of 19 authors including Jouzel, Raynaud, Petit, Barnola, Chappellaz, and Barkov were also listed in the top 11 authors of Table 4. It ranked first in both TC_{2012} (1948) and TC_3 (351), and ranked second in *TCPY* (150), third in C_{2012} (143), and 12th in C_0 (150), respectively. Correlation of greenhouse gases and the glacial–interglacial change was pointed out, that gives a basic idea of Earth's climate research especially in the Antarctic. The first article was "Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction" (Farman et al. 1985) in 1985, and the latest one was "Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century" (Rayner et al. 2003) in 2003. Except the eldest article in 1985, another article related to ozone in the top seven focused on the depletion of Antarctic ozone (Solomon et al. 1986). Five articles had C_0 in single digital number ($C_0 < 10$), while the highest C_0 was found to be 32. Low C_0 in the highly cited articles has been noticed in SCI-EXPANDED (Ho and Kahn 2014). This phenomenon is not surprising since previous study revealed that more highly ranked articles had a lower percentage of early citations (Levitt and Thelwall 2008).

The citation life of the top seven articles ($TC_{2012} > 800$) is shown in Fig. 4. Out of these seven articles, two were published in the 1980s, four in the 1990s, and one in the 2000s. Article by Farman et al. (1985) was a typical pattern of citation life for the older highly cited publications, which usually had a longer period for the accumulation of citations. This type of article obtained increasing citations after publication year, and then reached a plateau or fluctuated by low citations. The long period of accumulating time could make it reaching great citations in total. The other typical pattern of citation life usually appeared for the newly published article, such as "Rayner et al. (2003)". There is a sharp increase of citations after its publication, even though the time for citation was much shorter. The main reason why old articles are still highly cited is that they are relevant and valuable even to this day (Oppenheim and Renn 1978). It seems with increasing age papers have an increasing chance of being forgotten (Picknett and Davis 1999). Moreover, citing the

Table 6 Seven most frequently cited articles in Antarctic field ($TC_{2012} > 800$)

Rank (TC_{2012})	Rank (C_{2012})	Rank (TC_3)	Rank (*TCPY*)	Article title (Journal)	Year	Author (years)
1 (1948)	3 (143)	1 (351)	2 (150)	Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica (*Nature*)	1999	Petit et al. (1999)
2 (1732)	32 (50)	12 (182)	14 (64)	Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction (*Nature*)	1985	Farman et al. (1985)
3 (1577)	1 (256)	2 (249)	1 (175)	Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century (*Journal of Geophysical Research-Atmospheres*)	2003	Rayner et al. (2003)
4 (894)	36 (45)	97 (70)	30 (43)	Did the breakout of Laurentia turn Gondwanaland inside-out (*Science*)	1991	Hoffman (1991)
5 (872)	4 (107)	179 (51)	22 (51)	On the Meridional extent and fronts of the Antarctic circumpolar current (*Deep-Sea Research Part I-Oceanographic Research Papers*)	1995	Orsi et al. (1995)
6 (855)	84 (28)	15 (167)	50 (33)	On the depletion of Antarctic ozone (*Nature*)	1986	Solomon et al. (1986)
7 (846)	237 (14)	6 (216)	33 (42)	A new geomagnetic polarity time scale for the late cretaceous and cenozoic (*Journal of Geophysical Research-Solid Earth*)	1992	Cande and Kent (1992)

TC_{2012}, the total citations since articles were published to the end of 2012; C_{2012}, the total number of times of an article cited in the year of 2012; TC_3, the sum of the number of citations in publication year (C_0), the number of citations in the first year after publication (C_1), the number of citations in the second year after publication (C_2), the number of citations in the third year after publication (C_3); *TCPY*, Citations per year

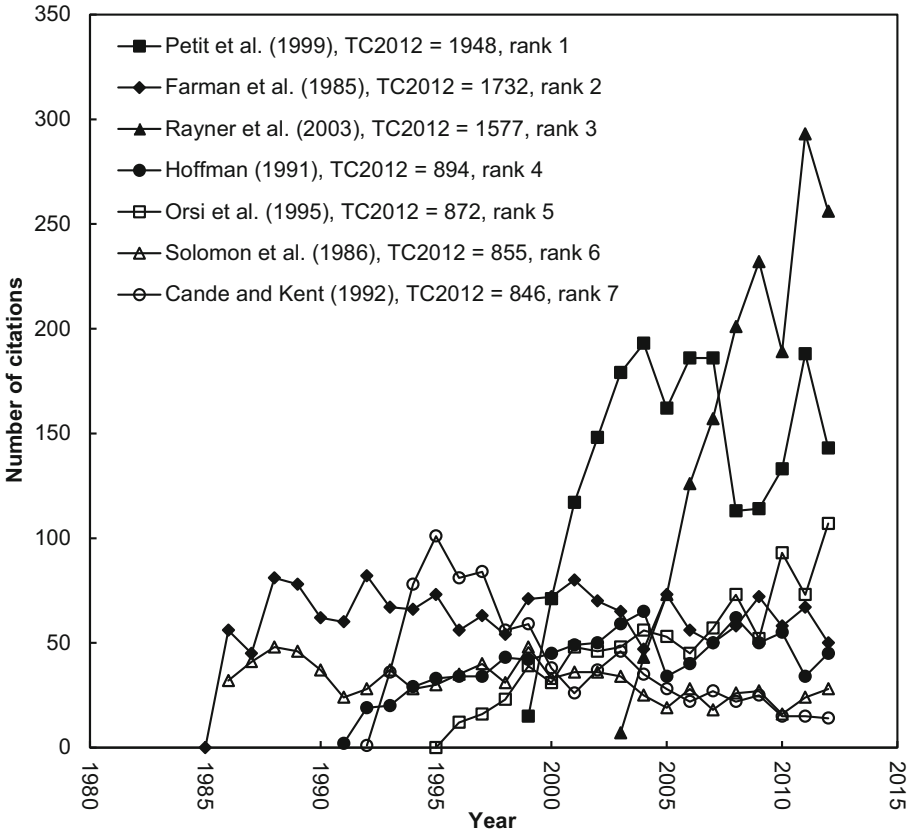

Fig. 4 Citation life of the seven most cited articles with the highest total citations ($TC_{2012} > 800$)

original paper not only respects the work of the authors who presented a novel research idea but also discussed this idea in detail in the body of their paper (Ho 2011). It was also recommended to cite directly from the original article but vast majority of the authors used so called second-handed references due to the difficulty of maintaining the original information (Ho 2004). However, as time passes, even "true classics" are gradually being cited less often because their substance has been absorbed by the current knowledge-a phenomenon called "obliteration by incorporation" (Garfield 1987).

The indicator of total citations per year (*TCPY*) was also applied to compare the highly cited articles. A greater *TCPY* means the article could accumulate more citations along with time, and had a greater possibility to obtain higher citations in total finally. In total, 519 articles (61 % of 852 highly cited) had monthly average citations less than one ($0 < TCPY < 12$); 231 articles (27 %) had $12 \leq TCPY < 24$; and 23 articles (2.7 %) had $TCPY \geq 50$ citations. The article life of for top seven highly cited articles with $TCPY \geq 75$ are displayed in Fig. 5. Two articles including "Rayner et al. (2003)" and "Petit et al. (1999)" were overlapped in Figs. 4 and 5, indicating that these two articles not only had the great influence in the Antarctic history, but also had great annual citations. Article entitled "Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century" (Rayner et al. 2003) was published in *Journal of*

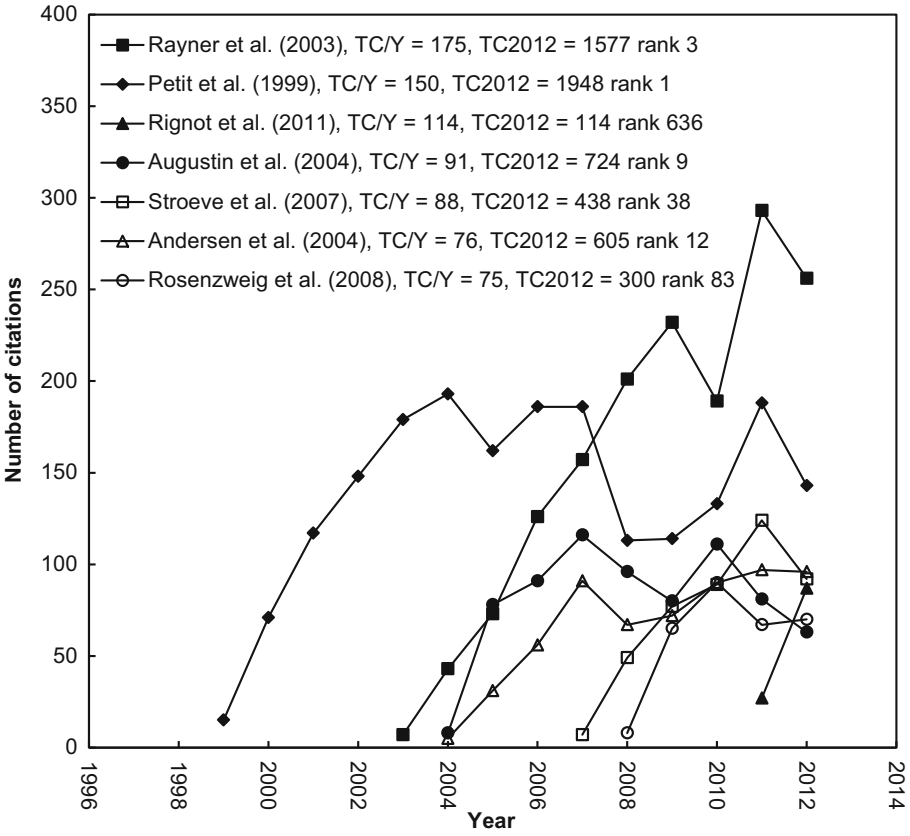

Fig. 5 Citation life of the seven most cited articles with the highest citations per year ($TCPY \geq 75$)

Geophysical Research-Atmospheres ($IF_{2012} = 3.174$) had the highest *TCPY* (175) and C_{2012} (256). This article ranked the third with respect to TC_{2012} (1577) and first in terms of TC_3 (249). The third place "Rignot et al. (2011)" with $TCPY > 100$ is also the latest highly cited article with only 2 years for accumulating citations. This article centered on acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise in *Geophysical Research Letters* (Rignot et al. 2011). According to its citation trends and citation indicators, it might be a potential focus in Antarctic research field.

Conclusions

A total of 852 Antarctica highly cited articles were published for the last 53 years from 1959 to 2011, with an average of 181 cited times. International Geophysical Year, Scientific Committee on Antarctic research, and Antarctic Treaty in 1950s greatly stimulated the prosperity of Antarctic research. *Nature* and *Science* as the leaders in science published the most highly cited articles. Antarctic research is multidisciplinary science involving oceanography, geosciences, and meteorology and atmospheric science. Typically, the Antarctic research was authored by more authors per article, often involving more inter-

institutional and international collaboration. Europe and North America continents dominated Antarctic research, while the USA led 48 countries, deploying the greatest manpower to the continent. National Aeronautics and Space Administration (NASA) of the USA was the most productive institution. Most top authors were involved in European Project for Ice Coring in Antarctica Community (EPICA), receiving 2007 Descartes Prize by European Commission. In addition, the analysis of words in title, author keywords, and *KeyWords Plus* revealed that sea ice, southern ocean, climate change, and ozone depletion were the recent focuses and would receive more citations. Furthermore, more highly cited articles had a closer relation with annual citations per article, but had an estranged relation with initial citation. The most cited articles related to temperature, climate and atmospheric history, and sea level rise experienced high growth rates of citations.

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