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A bibliometric analysis of research related to ocean circulation

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This study is a bibliometric analysis on ocean circulation-related research for the period 1991–2005. Selected documents included "ocean circulation, sea circulation, seas circulation, marine circulation, and circulation ocean" as a part of the title, abstract or keywords. Analyzed parameters included the document type, the article output, the article distribution in journals, the publication activity of countries, and institutes and the authorship. An indicator, citation per publication (CPP) was applied to evaluate the scientific impact of a publication. The relationship between cumulative articles and the year was modeled. Three dominant categories were picked out, and their output increase was modeled. The USA was found to be leading the research with 47% share of total articles, with a CPP up to 5.9. Woods Hole Oceanography Institute in the USA was the most productive institute with a CPP of 6.8. In the citation analysis, a 5th year citation mode was found. A paper life model was applied to compare the cumulative citations increasing rates of different years.

Introduction

Ocean circulation is the large scale movement of waters in the ocean basins [SIEDLER & AL., 2001]. Covering more than two-thirds of the earth surface, ocean waters move in a global circulation system, driven by subtle density differences and transporting huge amounts of heat, become an active and highly nonlinear player in the global climate game [RAHMSTORF, 2002]. One of the key points of its impact on the climate, was the interaction between air and sea at the mixing layer, by exchanging carbon dioxide, freshwater, and momentum [ANDERSON & OLSEN, 2002; ARDHUIN & AL., 2004; STAMMER & AL., 2004]. Research of Ocean circulation can also affect the research of other disciplines. In geosciences, a better understanding of ocean circulation can illuminate the glaciations [EYLES, 1993]. For marine biologists, changes in ocean circulation was one of the main threats to Lophelia Pertusa in the North-East Atlantic [ROGERS, 1999], and the variability of ocean circulation patterns can affect coral community composition [GLYNN & AULT, 2000].

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Some international events in the field of ocean science and technology can boost the research levels [DASTIDAR, 2004]. A famous global oceanographic research program, the World Ocean Circulation Experiment (WOCE), was conducted to collect data from the global ocean and to understand the long-term variability of ocean circulation and its relation to climate variability [CHAPMAN, 1998]. New achievements were accomplished and new technologies were developed to improve the understanding of ocean circulation by WOCE. Data quality control [HANSEN & POULAIN, 1996], data assimilation [FERRON & MAROTZKE, 2003], and modeling production analysis [DIDDEN & SCHOTT, 1992] were utilized in WOCE.

Bibliometric analysis to a special field of scientific research advance is a science of science [GARFIELD, 1998]. Publications of a certain discipline can represent its research trend whether it focuses on the present, previous or future research, and the utility of Science Citation Index as a retrieval device was rarely questioned [GARFIELD, 1970, 1998]. The bibliometric could be used to outline the advances of ocean circulation in the last 15 years. However, little bibliometric study could be found in the topic of ocean circulation or even the whole field of ocean. DASTIDAR [2004] analyzed the articles appeared in the year 2000 under the oceanography category, deciphered the scientist to scientist, organization to organization and country to country network structure. DASTIDAR & RAMACHANDRAN [2005] found out a similar information structure from ocean engineering in 2000.

In this study, attempts were made to recognize the bibliometric characteristics of the research related to ocean circulation from several aspects: the document type, the article output, the article distribution in journals, research activity of countries and institutes, and authorship. Citation per publication (CPP) was applied to evaluate the impact of a publication group.

Materials and methods

Documents used in this study were derived from the Science Citation Index (SCI) database of Institute of Scientific Information (ISI), Philadelphia, PA, USA. Documents, with 'ocean circulation, oceanic circulation, oceanographic circulation, oceanographical circulation, oceans circulation, sea circulation, seas circulation, marine circulation, and circulation ocean' in titles, abstracts and keywords, were downloaded from 1991 to 2005. The total output was 2,879 documents from 349 journals. The document type contained articles, reviews, editorial materials, notes, meeting abstracts, book reviews, corrections, letters, biographical-items, correction & additions, news items and reprints. Articles originating from England, North Ireland, Scotland, and Wales were grouped under the UK heading. Collaboration type was determined by the address of each author, where "independent" was assigned for papers with authors from only one country or institute, "international collaboration" or "institutional collaboration" were assigned for papers with authors from more than one country or institute.

The most widely used derivative metric for citation analysis is the journal impact factor (IF), since1979 in the Journal Citation Reports (JCR) [GARFIELD, 1998]. In previous study, good agreements were found between journal impact factor and overall citation frequency of papers in clinical physiology and nuclear medicine [HANSEN & HENRIKSEN, 1997]. However, in this study, CPP was used to assess the biblometric impact of publications. In a given time interval, the CPP was defined as the total number *C* of cited times divided by the total number of publications *P*. The CPP, which was the mean cited times of the publications, can be used as an indicator to denote the citation impact of a particular group of publications. Considering articles originated at different time, a two-year interval after the publication was taken for the CPP calculation, in accordance with the concept of the IF, to establish a unified criterion to evaluate all of the publications. In some cases, documents published between 1991 and 2003 were taken into account, because there were no data for CPP after 2003.

Results and discussions

Document type

Twelve document types were found in totally 2,879 documents. There were 2,649 articles, which comprised 92% of the total productions, followed by reviews (171; 5.9%), editorial materials (25; 0.87%), notes (13; 0.45%), meeting abstracts (8; 0.28%), book reviews (3; 0.10%), corrections (3; 0.10%), letters (3; 0.10%), biographical-items (1; 0.035%), addition corrections (1; 0.035%), news items (1; 0.035%), and reprints (1; 0.035%).

Article output

Table 1 lists the article output results from 1991 to 2005. An increasing trend of the number of authors per article can be found with the minimum 2.2 in 1991 and the maximum 3.7 in 2004. The article number of each year increased from 88 in 1991 to 296 in 2005. Figure 1 shows that there were two significant power relationships between the yearly cumulative number and the year, and the coefficients of determination were both greater than 0.998. The increase during the period from 1994 to 2005 was faster than that from 1991 to 1994. The increasing exponent for the earlier period was 1.01 and 1.62 for the later one.

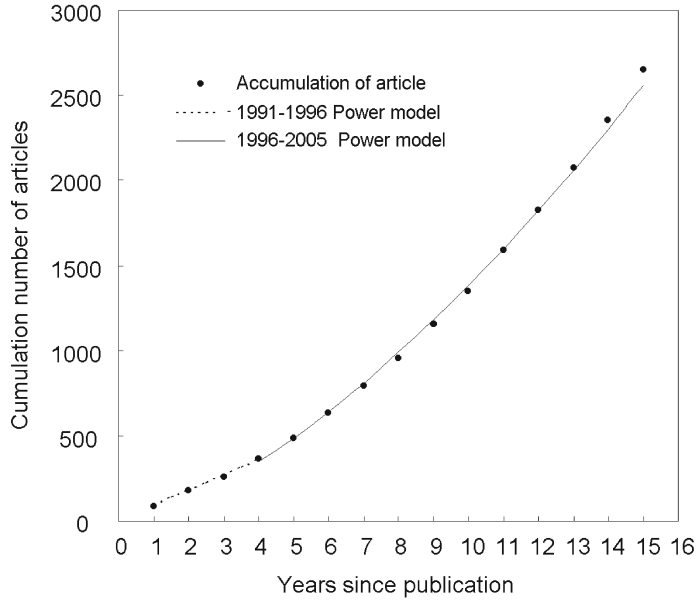

Figure 1. Cumulative number of articles by year

Table 1. Annual publication output related to ocean circulation

Year	Number of articles	Number of authors	Author per article	%	CPP
1991	88	190	2.2	3.3	4.4
1992	89	239	2.7	3.4	5.4
1993	80	205	2.6	3.0	4.3
1994	108	315	2.9	4.1	5.9
1995	119	374	3.1	4.5	4.9
1996	149	454	3.0	5.6	5.4
1997	158	489	3.1	6.0	5.7
1998	161	457	2.8	6.1	5.6
1999	204	563	2.8	7.7	4.9
2000	194	644	3.3	7.3	5.7
2001	242	821	3.4	9.1	5.5
2002	231	778	3.4	8.7	4.4
2003	254	833	3.3	9.6	3.7
2004	276	1024	3.7	10	
2005	296	998	3.4	11	

%: the percentage of the total articles in the year

Of the 2,649 articles, 2,648 had subject category information. The yearly number of categories related to ocean circulation showed a positive trend in Figure 2.

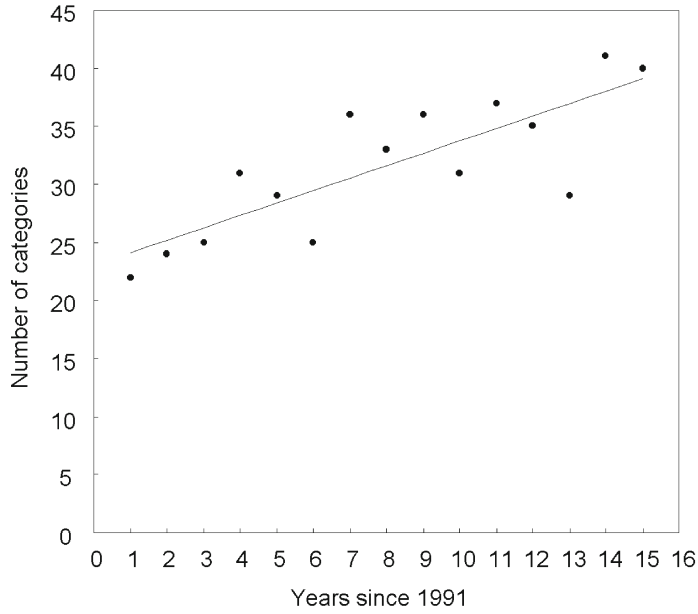

Figure 2. The number of categories from 1991–2005

Oceanography, multidisciplinary geosciences, and meteorology & atmospheric sciences were the most dominant categories, each of which held more than 10 percent of the total articles. Figure 3 shows that the percentage of oceanography decreased through the 15 years, while the other two increased. The increasing trends of the three categories were shown in Figure 4. Before 1997, the increasing exponent of oceanography was 1.11, larger than 1.08 of meteorology & atmospheric sciences, and 1.09 of multidisciplinary geosciences. However, after 1994, articles in multidisciplinary geosciences increased by an exponent of 1.83, and the exponent for articles in meteorology & atmospheric sciences were 1.69. Both of the former two exponents were larger than 1.49 of oceanography.

Article distribution in journals

Totally, 2,649 articles were published in 319 journals. Among those journals, 143 (45%) contained only one article, 52 (16%) contained two, 28 (8.8%) contained three, and 11 (3.4%) contained four. The number of journals increased from 39 in 1991 to 100 in 2005. The most active journals were *Journal of Geophysical Research–Oceans* and *Journal of Physical Oceanography*. During the 15 years, the former journal published 14% of the total articles, and the latter published 11%. They were the most published journals each year, but since the number of journals was increase, the proportion of articles they published was decreasing.

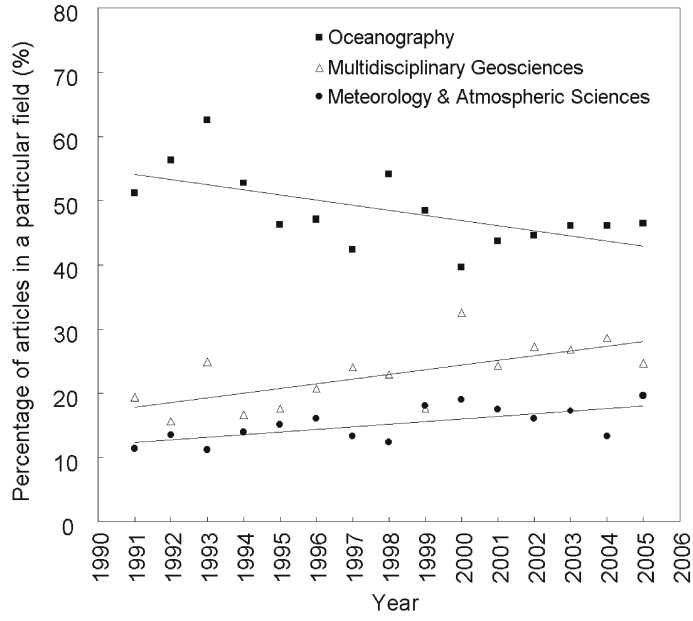

Figure 3. The variability of percentage of three major categories

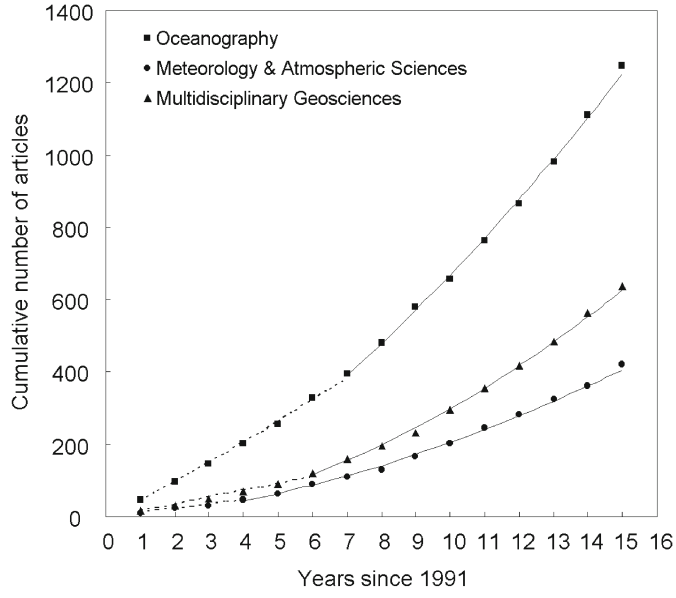

Figure 4. Cumulative number of articles of the three dominant categories

Publication activity and citation analysis of countries

Among the 2,644 articles with author address information, 2,073 were published from 1991 to 2003. Twenty-seven percent (563) were productions of international collaboration, completed by 61 countries/ territories. Seventy-three percent (1,510) were productions of one country independently, and they were independently produced by 40 countries/territories. Twenty-six countries/territories did not have independent articles, and 4 did not have collaborative articles. Twenty-eight countries contributed less than 1 percent of the independent articles, and 55 contributed less than 1 percent of the collaborative ones. Most articles originated from the USA (637; 42%), Germany (170; 11%), the UK (147; 9.7%). This distribution was similar to the bibliometric study of ocean science and technology, in which the result ordered from the USA (50%), the UK, Germany, France, Japan and Canada [DASTIDAR, 2004; 2005). The USA produced the most independent articles at 42% (637). A possible reason for its highest proportion may be that 23% (203) of the institutes with collaborative articles were in the USA.

Table 2 lists the countries that published more than 20 articles. Only three countries in Asia, Japan, China, and India, are in the table.

Table 2. Publication activity of countries from 1991 to 2003

	Total			Independent articles			Collaborative articles		
Country	P	P%	CPP	IP	IP%	CPP	CP	CP%	CPP
USA	968	47	5.9	637	42	5.4	331	59	6.7
Germany	311	15	6.7	170	11	6.1	141	25	7.5
UK	254	12	4.8	147	10	3.8	107	19	6.1
France	228	11	5.9	111	7.4	3.8	117	21	7.8
Canada	165	8.0	5.8	87	5.8	5.4	78	14	6.2
Australia	106	5.1	5.8	47	3.1	5.4	59	10	6.2
Netherlands	86	4.1	4.9	49	3.2	3.4	37	6.6	6.8
Japan	74	3.6	2.8	50	3.3	2.5	24	4.3	3.4
Russia	57	2.7	4.1	29	1.9	0.6	28	5.0	7.8
Norway	54	2.6	3.3	23	1.5	3.1	31	5.5	3.4
Denmark	45	2.2	7.6	11	0.73	1.8	34	6.0	9.4
Switzerland	43	2.1	12	12	0.79	8.2	31	5.5	14
P.R. China	41	2.0	3.2	18	1.2	0.4	23	4.1	5.3
Italy	38	1.8	1.9	13	0.86	1.6	25	4.4	2.0
New Zealand	27	1.3	4.1	13	0.86	2.8	14	2.5	5.4
Spain	27	1.3	3.1	6	0.40	2.2	21	3.7	3.3
Sweden	24	1.2	7.8	8	0.53	5.4	16	2.8	9.1
India	23	1.1	2.3	16	1.1	2.4	7	1.2	1.9
Belgium	20	1.0	6.9	7	0.46	7.0	13	2.3	6.8

P: Total articles; P%: the corresponding percentage of P
IP: Independent articles by single country; IP%: the corresponding percentage of IP
CP: Collaborative articles by international cooperation; CP%: the corresponding percentage of CP

The five most productive countries published more independent articles than the collaborative ones. The international collaborative articles had higher CPP than independent ones, except for India.

Publication activity and citation analysis of institutes

There were five articles without author address information on the ISI Web of Science. Among the 2,073 articles with author address published from 1991 to 2003, 52% (1,083) were institutional collaborations by 876 institutes, and 48% (990) were independently published by 318 institutes. The most productive institutes published more than 40 articles were listed in Table 3. The 8 most productive institutes were all from the USA. Most institutes published more collaborative articles than independent ones, but the CPP for the former was not consistently larger than the latter, which implied a relatively constant scientific impact. Woods Hole Oceanography Institute and Massachusetts Institute of Technology in the USA were the two most productive institutes, and there were two articles addressed to a joint program of the two institutes, but finally they were grouped to neither two.

Table 3. Publication activity of institutes from 1991 to 2003

Institute	Total articles		Independent articles		Collaborative articles	
	P	CPP	IP	CPP	CP	CPP
Woods Hole Oceanography Institute, USA	135	6.8	32	5.4	103	7.2
Massachusetts Institute of Technology, USA	83	7.1	33	6.3	50	7.6
University of Clifornia, San Diego, USA	75	4.6	23	2.4	52	5.6
Columbia University, USA	71	8.3	10	10	61	8.0
National Ocean and Atmosphere, USA	67	6.8	9	3.4	58	7.3
University of Miami, USA	67	5.2	14	1.9	53	6.1
Princeton University, USA	65	6.3	18	5.6	47	6.6
US Navy, USA	61	4.2	22	4.8	39	3.9
Southampton Oceanography Center, UK	54	4.1	22	2.7	32	5.1
Alfred Wegener Institute of Polar & Marine Research, Germany	52	4.9	20	5.2	32	4.7
University of Washington, USA	50	6.0	10	6.5	40	5.9
University Kiel, Germany	49	7.6	14	8.3	35	7.3
CSIRO, Australia	42	8.8	13	6.4	29	9.8
University of Bremen, Germany	42	6.1	13	3.8	29	7.2
National Center of Atmosphere Research, USA	41	7.7	12	10	29	6.8

P: Number of articles
CPP: Citation per publication

Authorship

In total, 2,077 articles were published by 3,898 authors in 66 countries from 1991 to 2003. Of these 2,077 articles, 404 (15%) were single author work, two authors published 839 (32%), 609 (23%) were written by three, 345 (13%) by four, and 188 (7.1%) by five. The most productive authors with more than ten articles during the period 1991–2003, are listed in Table 4. The number of articles published as the first and the corresponding author was shown with CPP for comparison. Eight authors in the table were both the first author and the corresponding author to their articles. In the above discussion, a bias may occur when two or more authors have the same name, or the same authors use different names on different publications. If the authors' working institutes had changed, the confirmation of their names would be difficult.

Table 4. The most productive authors between 1991 and 2003

Author name	Total articles		First author		Corresponding author	
	P	CPP	P	CPP	P	CPP
Dijkstra, HA	22	3.3	6	3.2	10	3.4
Wunsch, C	20	11	7	4.7	7	4.7
Weaver, AJ	19	11	4	27	5	22
Marotzke, J	18	6.9	3	5.3	5	6.8
Stocker, TF	17	9.9	5	13	5	13
Greatbatch, RI	16	3.7	10	3.9	10	3.9
Marshall, J	15	11	4	9.8	4	9.8
Verron, J	15	2.3	3	2.7	3	2.7
McWilliams, JC	14	9.2	3	3.0	3	3.0
Oppo, DW	14	9.6	4	13	3	14
Rahmstorf, S	14	23	7	17	7	23
Seidov, D	14	4.1	10	3.6	10	3.6
Madec, G	13	7.3	1	7.0	1	7.0
Mysak, LA	13	5.1	2	4.5	1	9.0
Sarmiento, JL	13	15	3	23	3	23
Mikolajewicz, U	12	11	3	11	4	9.0
Erlenkeuser, H	11	14	0	0	0	0
Gerdes, R	11	3.6	3	3.7	1	6.0
Heywood, KJ	11	4.5	1	3.0	1	3.0
Stammer, D	11	11	8	12	7	13

P: Number of articles
CPP: Citation per publication

Cited history and article life

All of the 2,649 articles were analyzed on their citation behavior, by statistic calculation of CPP. The citation history of articles is shown in Figure 5. There was a mode in the CPP distribution. The mode appeared at the fifth year after the publication during 1991–2005 and 1996–2005, while during 2001–2005 it occurred at the third

year. HANSEN & HENRIKSEN [1997] found that the number of citations per year reached a maximum or plateau 3–7 years after publication, while a general maximum was 2–3 years. The phenomenon that the citation mode may drift from 2–3 years also existed in other disciplines, like typology [VLACHY, 1985], medicine and biochemistry [CANO & LIND, 1991].

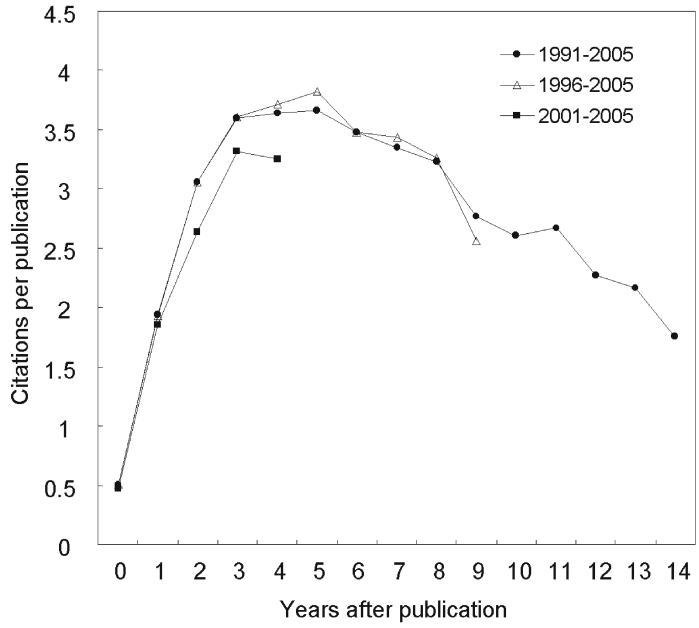

Figure 5. The citation history of articles from 1991–2005

For the period from 1991 to 1997, the cumulative number of citations was increasing. In the publishing year, the total number of citations was of tens, but if the number was cumulated from the publishing year to 2005, it would be of thousands. The ages of the articles originated in different years were also checked, using the linear model introduced by CHIU & HO [2005]. The relationship between the cumulative number of citations and the article age is shown in Figure 6. All of the simulated models from 1991 to 1997 have coefficients of determination higher than 0.995. A similar linear relationship had been found before in clinical physiology and nuclear medicine [HANSEN & HENRIKSEN, 1997]. The articles in 1997 had the highest citation increasing rate, while articles published in 1991 had the highest visibility potential. The numbers of articles for every year from 1991 to 1997 are 88, 89, 80, 108, 119, 149, and 158, the correlation coefficient between the yearly article numbers and the citation rate was 0.969, which meant that a higher citation rate mainly accredits to a larger article

number. Therefore, the citation rate sequence from the lowest to the highest curve should be 1993, 1991, 1992, 1994, 1995, 1996, and 1997, but 1994 has a higher citation rate as in Figure 6. Further investigation on the articles published in 1994 revealed the contribution of several most heavily cited articles. Till 2005, the articles by PELTIER [1994], FU & AL. [1994] and SARNTHEIN & AL. [1994] were cited for 489 times, 272 times, and 218 times respectively.

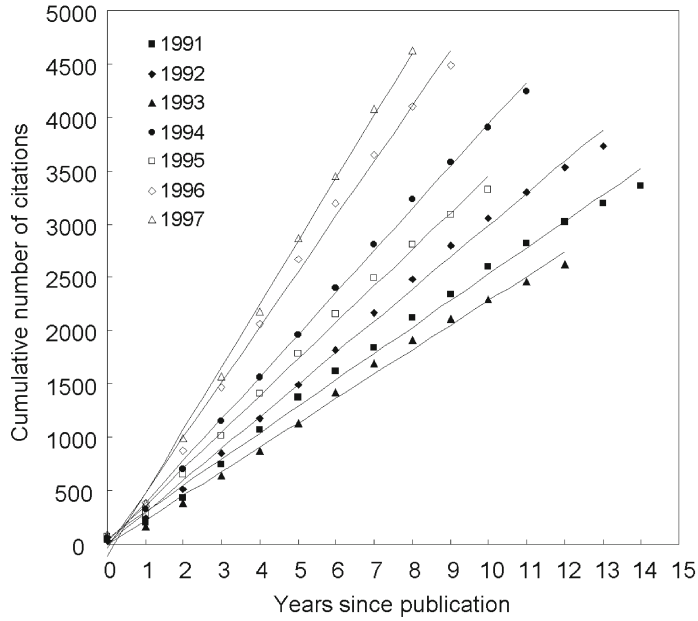

Figure 6. The relationship between the cumulative number of citations and the article life with simulated models

Conclusions

Articles comprised 92% of the documents, and two power functional relations existed between yearly cumulative number of articles and the year, one is from 1991 to 1994, and the other one is from 1994 to 2005, with exponents of 1.01 and 1.62. Three major categories published more than 90% of total articles. Decrease trend of articles percentage in subject category of oceanography was due to the larger increasing exponent of multidisciplinary geosciences and meteorology & atmospheric sciences. *Journal of Geophysical Research–Oceans* and *Journal of Physical Oceanography* were identified as the two popular journal-of-the-years. USA, Germany, and UK were the

most productive countries comprising 63% of the independent articles, while the highest CPP went to Switzerland. Woods Hole Oceanography Institute in USA, Massachusetts Institute of Technology (MIT) in USA, and University of California, San Diego in USA were the most productive three institutes. The collaborative articles tended to have higher CPP. Considering the high correlation coefficient between increasing rate and the article number of each year, the citation life analysis gave prominence to the articles in 1994, articles of which were vigorously cited since publication. In addition, a citation mode around the fifth year was found in the ocean circulation research field.

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