Bibliometric analysis of aerosol research in meteorology and atmospheric sciences

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Abstract: A bibliometric method was developed to investigate the aerosol research based on the papers from 1991 to 2009 in Science Citation Index Expanded, the Thomson Reuters. The analysed aspects covered scientific output and citation tracking on the basis of journal patterns; country; institute and author research performances. Improved indicators Peak-Year Citation per Publication and Relative Peak-Year Rate were applied. A significant share of the citation impact and the most cited articles distribution were identified. Lotka's law held good in author performance. Finally, the paper discusses the imperfect nature of the indicators and proposes complementary methods for research evaluation procedures.

Keywords: ISI; scientometrics; indicator; citation per publication; relative citation rate.

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Yuh-Shan Ho received his PhD (1995) from the University of Birmingham, United Kingdom. He is the director of the Trend Research Centre at Asia University in Taiwan. He had 26 papers cited more 100 times. One of his papers has been cited more than 1600 times. This paper is the only article with more than 300 yearly citations, and it has been ranked top one in yearly citation in the field of chemical engineering since 2008. His research interests are adsorption process for water treatment and bibliometric studies.

1 Introduction

In a broad sense, scientific research impact assessment is a quantitative and qualitative evaluation of the observable effects, taking a variety of indicators, such as structure and process of scientific fields, publications, citations, peer evaluation, highly cited papers and research activities of nations or research groups (Martin and Irvine, 1983; Martin, 1996). However, the main interest thrust seems to flow along two connected but parallel paths: publication output and citation counts, respectively (Narin, 1976). They are the fundamental basis for the evolution of bibliometrics as a field of study in research evaluation, planning and policy formulation (Garfield, 1979; Moed et al., 1985).

The first means we extensively used is scientific publications, which reflect the size of the scientific activity in the subfield(s) in which a group worked. Using the publications to access the research performance often exhibits a lack of conceptual clarity; the status of production as an indicator of scientific progress is uncertain, as the relative quality or impact of publications has not been assessed (Smith and Fiedler, 1971). Some discussions have been given to the possibility of weighing publication qualities according to the journals in which they appear (Garfield, 1973). Journal Impact Factor (IF) developed by the Institute for Scientific Information (ISI) is a fundamental quasi-qualitative measurement for significance of scientific journals. The IF has a great accessibility, since it is directly provided by the ISI database for the most international and visible journals. The IF is calculated through a two-year citation window, as the typical cited articles are most heavily cited during the 2 years after publication (Garfield, 1972). However, it might be considered too short to detect the real impact of publications in 'slow' evolving disciplines (Glänzel and Schoepflin, 1995; Bordons et al., 2002). Besides, journal IFs provide only average citation rates for all papers published in a particular journal, while their impact or citation scores vary considerably (Smith and Fiedler, 1971). Hence, attempts to attach a 'quality index' or 'impact factor' to journals failed to confront the problem of the wide variation in quality within each journal.

Moreover, a citation index provides an indication of the quality and intensity of the impact of any research finding in a scientific community (Garfield, 1955). Various forms of citation analysis have been employed to study communication in science

(Gilbert, 1977), the history of ideas (Zuckerman, 1987) and the structure of a discipline's literature (Small and Griffith, 1974). Additionally, citation analysis in the research evaluation process has influenced strongly the strategy of politicians, policy-makers and even scientists (Moed and Hesselink, 1996). The so-called Citations Per Publication (CPP) has been a long and widespread used citation indicator, interpreted as dividing the total citations received by a group during a certain period over their total publications (Moed et al., 1985). Another indicator Relative Citation Rate (RCR) is also important to accurately evaluate the level of abstraction or impact of scientific research. For a set of papers, it is referred to as the ratio of the individual citation rates (CPP) over the whole set or 'world average' CPP. If the ratio RCR is above 1.0, this means that the group's oeuvre is cited more frequently than an 'average' publication in the subfield and vice versa. Under proper conditions, RCR makes possible comparisons and even linear ranking of citation impact of publications (Schubert and Braun, 1986).

Nevertheless, there exists a bias on ordinary citation analysis owing to differences of the publication year. The number of times cited for a single article is highly correlated with the length of time span since its publication (Marx and Cardona, 2003). There has been a significant body of relevant literature on citation-time distributions (Oromaner, 1983; Glänzel and Schoepflin, 1995) and functions (Vlachy, 1985; Lewison and Cunningham, 1991) in the past several decades. Moreover, the policy-makers would like to monitor changing research profiles in a more timely fashion (Adams, 2005), while the CPP and RCR were assessed over the entire long-term period investigated. In 1988, King proposed a new approach for citation practice, based on the average citation counts received by papers in their peak year of citation life-cycles. Results were found similar to those from the widely used four-year citation count in previous studies (Martin and Irvine, 1983; Crouch et al., 1986; Hicks et al., 1986), in terms of country-ranking and time trends. However, in this paper, the overall citation profile was based on a small publication sample size, not sufficient to provide meaningful results from the statistical angle. Also, limits had to be imposed because of the time and labour taken up by a manual count. In recent years, Ho addressed several analyses of article citation life in different scientific fields and developed the indictor CPP of short-time windows as proxy measures of research impact of individuals, groups and countries (Hsieh et al., 2004; Chiu and Ho, 2005; Chuang et al., 2007; Li and Ho, 2008; Zhang et al., 2009).

This study would outline the approach for monitoring research performance using integrated indicators of publication output and impact. As the ISI database, including the world's most significant, recognised, influential, mainstream scientific and social journals in different disciplines, is the most important and frequently used source database of choice for a broad review of scientific accomplishment and research performances (Bayer and Folger, 1966; Kostoff, 2000), we attempt to present a case study of research evaluation based on ISI database on aerosol, an important subfield in atmospheric sciences. Since the 2007 ISI offers the citation counts per year per publication directly, the online capture of citation data becomes much easier and more immediate than before, even for a large sample size. The major emphasis placed on this study would deal with citation practice, especially employing improved indicators of CPP and RCR based on peak-year citations.

2 Methodology

Scientific literature was based on the online database of the SCI-Expanded retrieved from the ISI Web of Science, Philadelphia, USA. The raw data were extracted by the keyword search of 'aerosol*' included in titles, abstracts and keywords, which included aerosol, aerosols, aerosolised, aerosolised, aerosolisation, aerosolisation, aerosolise, aerosolsin, aerosols99, aerosolresearch, aerosolise, aerosolic, aerosolising, aerosola, aerosole, aerosoldisinfection, aerosoltherapy, aerosolar, aerosolotherapy, aerosolionisation, aerosoles, aerosoled, aerosolgenerator, aerosoliser, aerosolpackungen, aerosolen, aerosolteilchen, aerosolkonzentration, aerosolmessung, aerosolove, aerosolstreuung, aerosolovych, aerosoltherapie, aerosolisees, aerosolica, aerosolot and aerosolie. According to Journal Citation Reports (JCRs), it indexes 7387 major journals with citation references across 174 scientific disciplines in 2009. We mainly considered papers from 1991 to 2009 in the ISI subject categories of meteorology and atmospheric sciences including for example, 38 in 1999, 40 in 2000, 43 in 2001, 46 in 2002, 46 in 2003, 45 in 2004, 47 in 2005, 48 in 2006, 51 in 2007, 52 in 2008 and 63 journals in 2009, and 16,586 publications met the selection criteria mentioned.

Document information included names of authors, title, year of publication, source journals publishing the articles, contact address and the citation counts in each year for every paper. The records were downloaded into Microsoft Excel software, and additional coding was manually performed for the number of authors, origin country of the collaborators and IFs of the publishing journals. The IFs were derived from the JCR reported in 2009, as a measure of how often articles published in 2007 and 2008 had been cited in 2009. Since the citation data in 2010 had not been included completely in the database, our citation analysis was checked up to the end of the year 2009. Contributions of different institutes and countries were estimated by the corporate addresses given in the byline of the publication. Articles originating from England, Scotland, Northern Ireland and Wales were grouped under the UK heading.

3 Results and discussion

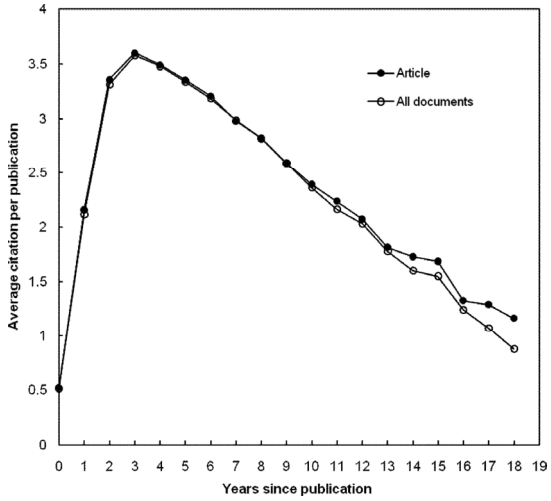
Essentially, our thorough assessment related to two aspects: publications and citations. The emphasis was to determine the citation patterns of scientific articles; journal preferences and research activities, which consisted of three major components: the countries, the institutes and authors working in this subfield.

3.1 Article citation profile

The time dependence of citation growth could be viewed as a sales figure of a research topic (Marx and Cardona, 2003). Figure 1 expresses the 'ageing' profile to the complete set of aerosol scientific literature by yearly citations. The average citations for all document types and the articles were the highest both in the third full year since its publication and began to decrease thereafter, while the citation peak for articles was slightly lower. Similar peak-year phenomena of citation history have been found in other previous studies, though the peak position might be shifted to 2, 3, 4, or more years, depending on the research disciplines (King, 1988; Messina et al., 1994; He, 2003;

Hsieh et al., 2004; Chiu and Ho, 2005; Chuang et al., 2007; Li and Ho, 2008; Zhang et al., 2009).

Figure 1 Average citation rates per publication by paper life



To adjust for that, a variable PCPP is created to assess the visibility or impact of publications, much more appropriate than the previous used indicator CPP. Let *P* be the total number of papers and let *C* be the total peak-year citation counts, other than all citations during the entire period. Thus, the PCPP was an average value for citations per paper received before and in the peak year. In this study on aerosol scientific papers, the PCPP was the total times cited in the publication year and the subsequent three years (TC3) against total publications. In some cases, since there were no data for PCPPs after 2006, we only discuss papers related to aerosol published from 1991 to 2006 for citation tracking. Furthermore, another concept of RPCR was defined accordingly, differing from the indicator RCR. Specifying the mean PCPP score of an overall collectivity as standard, RPCR was presented for comparing the PCPP level of a unit (a country, institute, person, or journal) to the whole.

Upon further examination, document types of papers relevant to aerosol were diversified during the period from 1991 to 2006. Fifteen document types were found in total 12,329 publications, with an average PCPP of 9.2. As shown in Table 1, papers (10,760; 87%) were the most-frequently used document type, leading in distance by proceedings papers (1099; 8.9%) and several other types showing less significance. The overall PCPP value received by articles was 9.3. It was worth noting that reviews held the 1_{st} rank according to RPCRs, more than three times (3.6) that of articles. A review, representing the synthesis of a mass of articles in a specific field, was by far the most-cited paper type, the case of which had also been represented in the previous literature (Sigogneau, 2000). Except articles, proceedings papers and reviews, other 12 document types accounted for just 0.51% of all TC3 citations, and their RPCRs were rather small compared with articles, proceedings papers and reviews. As journal articles represented the majority of document types that were also including whole research information, 7694 articles were identified and further analysed in the following discussion.

Table 1 Document type distributions and the corresponding PCPP and RPCR values

Document type	*P*	*%*	*TC3*	*PCPP*	*RPCR*
Article	10,760	87	100,293	9.3	1.02
Proceedings paper	1099	8.9	5438	4.9	0.54
Review	203	1.6	6897	34	3.70
Editorial material	115	0.93	360	3.1	0.34
Note	68	0.55	165	2.4	0.26
Correction	42	0.34	31	0.74	0.080
Addition correction	13	0.11	4.0	0.31	0.034
Letter	10	0.081	16	1.6	0.17
News item	5	0.041	N/A	0	0
Meeting abstract	5	0.041	1.0	0.20	0.022
Reprint	3	0.024	5.0	1.7	0.18
Item about an individual	2	0.016	N/A	0	0
Biographical-item	2	0.016	N/A	0	0
Discussion	1	0.0081	N/A	0	0
Bibliography	1	0.0081	N/A	0	0

P: number of papers; TC3: total citations of the publication year and the following 3 years; N/A: not available.

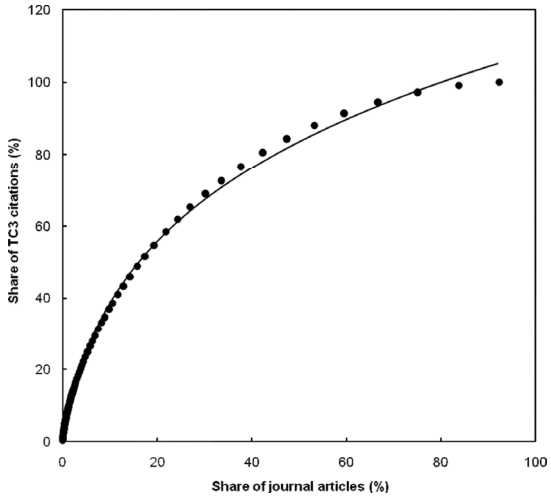
3.2 Citation distribution and the most-frequently cited articles

Covering the complete set of aerosol-related articles, the TC3 was 100,293 in total with an individual frequency from 0 to 307, while 8.1% were not cited at all. Figure 2 illustrates the skewness in the underlying overall citation distribution. The correlation between the share of citation impact and publication output was represented by a mathematic model using try and error non-linear regression method. The equation could be described as follows:

$$F(x) = \frac{Ax}{1 + Bx^C}. \tag{1}$$

The plot of the data revealed a high coefficient of determination ($r^2 = 0.998$). On the highest aggregated level, a small share of the articles contributed with a high share of the citations. Highly cited papers probably featured more prominently when the peak citing year was used. Seglen (1997) pointed out that about 15% of the articles in a typical journal accounted for half of the total citations, and in our case likewise, about half of the TC3 citations were achieved by only 16% of publications in the world database. Another similar example appeared in the bibliometric study of scientific research in Norway, in which a 10% share of articles obtained over 50% of total citations (Aksnes and Sivertsen, 2004).

Figure 2 Cumulative contributions of article citations in – 3 year window (TC3)



Compare total citations since articles publication with 2009 (TC09), 16 most-frequently cited articles of each year from 1991 to 2006 were investigated and shown in detail (Table 2). Six of them were published in Journal of Geophysical Research-Atmospheres, 3 articles in Journal of Climate and 2 articles in Journal of the Air & Waste Management Association. The USA dominated the citation frequency with outstanding production of 13 papers, followed by Germany with 4 papers and Australia, France and Netherlands each with 2 papers. The most-frequently cited papers with indicators of TC3 and TC09 were the same paper in 1999, 2000, 2003, 2004, 2005 and 2006. In shorter period, TC3 agree TC09 but not for the case of long period. It was notably that the most-frequently cited aerosol paper, "improved global sea-surface temperature analyses using optimum interpolation", had been cited 1703 times up to 2009 since published in 1994. It can be recognised as a hot-topic or fast-breaking paper (Small, 2004).

Table 2 Most-frequently cited aerosol articles for each year from 1991 to 2006

Year	*TC09*	*TC3*	*Title*	*Author*	*Country*	*Journal*
1991	267	23	Aerosols, clouds and radiation	Twomey, S	USA	Atmospheric Environment Part A-General Topics
1992	313	39	Delta-eddington approximation for solar-radiation in the NCAR community climate model	Briegleb, BP	USA	Journal of Geophysical Research-Atmospheres
1993	531	66	The halogen occultation experiment	Russell, JM; Gordley, LL; Park, JH; Drayson, SR; Hesketh, WD; Cicerone, RJ; Tuck, AF; Frederick, JE; Harries, JE; Crutzen, PJ	USA, UK, Germany	Journal of Geophysical Research-Atmospheres

Table 2 Most-frequently cited aerosol articles for each year from 1991 to 2006 (continued)

Year	*TC09*	*TC3*	*Title*	*Author*	*Country*	*Journal*
1994	1703	90	Improved global sea-surface temperature analyses using optimum interpolation	Reynolds, RW; Smith, TM	USA	Journal of Climate
1995	338	29	Organics alter hygroscopic behaviour of atmospheric particles	Saxena, P; Hildemann, LM; Mcmurry, PH; Seinfeld, JH	USA	Journal of Geophysical Research-Atmospheres
1996	641	56	Is daily mortality associated specifically with fine particles?	Schwartz, J; Dockery, DW; Neas, LM	USA	Journal of the Air & Waste Management Association
1997	528	87	Radiative forcing and climate response	Hansen, J; Sato, M; Ruedy, R	USA	Journal of Geophysical Research-Atmospheres
1998	554	38	Optical properties of aerosols and clouds: the software package OPAC	Hess, M; Koepke, P; Schult, I	Germany	Bulletin of the American Meteorological Society
1999*	303	82	Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulphur cycle	Roeckner, E; Bengtsson, L; Feichter, J; Lelieveld, J; Rodhe, H	Germany, Netherlands, Sweden	Journal of Climate
2000*	423	86	A flexible inversion algorithm for retrieval of aerosol optical properties from sun and sky radiance measurements	Dubovik, O; King, MD	USA	Journal of Geophysical Research-Atmospheres
2001	443	107	Species contributions to pm2.5 mass concentrations: revisiting common assumptions for estimating organic mass	Turpin, BJ; Lim, HJ	USA	Aerosol Science and Technology
2002	253	67	Concentration and size distribution of ultrafine particles near a major highway	Zhu, YF; Hinds, WC; Kim, S; Sioutas, C	USA	Journal of the Air & Waste Management Association

Table 2 Most-frequently cited aerosol articles for each year from 1991 to 2006 (continued)

Year	*TC09*	*TC3*	*Title*	*Author*	*Country*	*Journal*
2003*	418	156	An inventory of gaseous and primary aerosol emissions in Asia in the year 2000	Streets, DG; Bond, TC; Carmichael, GR; Fernandes, SD; Fu, Q; He, D; Klimont, Z; Nelson, SM; Tsai, NY; Wang, MQ; Woo, JH; Yarber, KF	USA, China, Austria	Journal of Geophysical Research-Atmospheres
2004*	194	103	European aerosol phenomenology-2: chemical characteristics of particulate matter at Kerbside, urban, rural and background sites in Europe	Putaud, JP; Raes, F; Van Dingenen, R; Bruggemann, E; Facchini, MC; Decesari, S; Fuzzi, S; Gehrig, R; Huglin, C; Laj, P; Lorbeer, G; Maenhaut, W; Mihalopoulos, N; Mulller, K; Querol, X; Rodriguez, S; Schneider, J; Spindler, G; ten Brink, H; Torseth, K; Wiedensohler, A	Italy, Germany, Switzerland, France, Austria, Belgium, Greece, Spain, Netherlands, Norway	Atmospheric Environment
2005*	383	264	The Modis aerosol algorithm, products, and validation	Remer, LA; Kaufman, YJ; Tanre, D; Mattoo, S; Chu, DA; Martins, JV; Li, RR; Ichoku, C; Levy, RC; Kleidman, RG; Eck, TF; Vermote, E; Holben, BN	USA, France	Journal of the Atmospheric Sciences
2006*	307	307	The Community Climate System Model Version 3 (CCSM3)	Collins, WD; Bitz, CM; Blackmon, ML; Bonan, GB; Bretherton, CS; Carton, JA; Chang, P; Doney, SC; Hack, JJ; Henderson, TB; Kiehl, JT; Large, WG; McKenna, DS; Santer, BD; Smith, RD	USA	Journal of Climate

*The most cited article in TC09 and TC3 are the same article; TC09: total citation since it publication to 2009; TC3: total citations of the publication year and the following 3 years.

3.3 Journal

In total, 10,760 articles were published in 61 journals listed in the ISI category of meteorology and atmospheric sciences from 1991 to 2006. For journal citation studies, the most reliable source is IF, which has not been replaced by any other worldwide accepted method thus far (Garfield, 1955; Luukkonen, 1990). There were 495 (4.6%)

articles published in 9 journals, which was not included in SCI-Expanded, and thus, had no IF information in the JCR 2009. The name of journal, number of articles published by the journal and the year it was excluded from SCI-Expanded were *Atmospheric Environment Part A-General Topics* (220 articles, 1993), *Journal of Applied Meteorology* (123 articles, 2005), *Izvestiya Akademii Nauk Fizika Atmosfery I Okeana* (86 articles, 2000), *Atmospheric Environment Part B-Urban Atmosphere* (24 articles, 1993), *Indian Journal of Radio & Space Physics* (12 articles, 1995), *Journal of Atmospheric and Terrestrial Physics* (11 articles, 1996), *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere* (9 articles, 2001), *Izvestiya Akademii Nauk SSSR Fizika Atmosfery I Okeana* (9 articles, 1991) and *Meteorological Magazine* (1 article, 1993). With regard to the journals covering the scope of aerosol research, most had IFs, which ranged between 3 and 4, accounting for 52% of all articles studied. Besides, 1.7% of total articles had an IF lower than 1, 11% had an IF of 1~2, and 6.4% had an IF of 4~5. The mean IF for all of the papers in journals was 2.77. The journal with the highest IF (6.123) was *Bulletin of the American Meteorological Society*.

Table 3 presents the 17 journals that published more than 100 aerosol articles through the studied years, including the number of articles with respective percentages; the IFs; the PCPP and RPCR values. The journals were listed in descending order of total articles.

Obviously, the most popular journal in this field was *Journal of Geophysical Research-Atmospheres*, publishing 3364 articles with a high PCPP of 12. Three other journals in the leading position were *Atmospheric Environment*, *Journal of Aerosol Science* and *Aerosol Science and Technology*. These four journals might be widely recognised as the premier journals devoted to the aerosol research, publishing 69% of total articles. As noted by Weller in 1996, over 90% of the authors selecting a journal for manuscript submission gave their first consideration to its subject coverage; these three journals would be appropriate selections on submission of aerosol-related papers (Weller, 1996). In addition, 160 articles in *Journal of Climate* had the highest PCPP (20) with IF 3.363 among the 61 journals listed in category of meteorology and atmospheric sciences. It could be concluded that aerosol articles in this journal were highly influential and had attracted great attention. Nevertheless, there were controversies when using the ISI database to establish the journal publication patterns. As thousands of international journals were rigorously evaluated and screened by the ISI every year, a certain SCI-Expanded journal might be non-SCI journal the next year. In this study, as an example, only 46, 43 and 38 journals listed in the subject category in 2003, 2001 and 1999, respectively, owing to the highly selective nature of the database, though totally 61 journals were analysed during the investigated 16 years. In addition, journal titles could be changed, for instance, *Atmospheric Environment Part A-General Topics* and *Atmospheric Environment Part B-Urban Atmosphere* were incorporated as *Atmospheric Environment* in 1994.

Table 3 The top 17 journals publishing more than 100 aerosol articles with IFs, PCPPs and RPCRs

Journal	*TA* (%)	*PCPP* (*RPCR*)	*IF*
Journal of Geophysical Research-Atmospheres	3,364 (34)	12 (1.3)	3.082
Atmospheric Environment	1,935 (35)	9.8 (1.0)	3.139
Journal of Aerosol Science	1,110 (36)	5 (0.53)	2.529

Table 3 The top 17 journals publishing more than 100 aerosol articles with IFs, PCPPs and RPCRs (continued)

Journal	*TA* (%)	*PCPP* (*RPCR*)	*IF*
Aerosol Science and Technology	1,001 (37)	5.8 (0.62)	2.739
Atmospheric Chemistry and Physics	421 (38)	15 (1.6)	4.881
Journal of the Atmospheric Sciences	239 (39)	13 (1.4)	2.911
Journal of the Air & Waste Management Association	233 (40)	6.7 (0.71)	1.67
Tellus Series B-Chemical and Physical Meteorology	221 (41)	10 (1.1)	4.278
Atmospheric Environment Part A-General Topics	220 (42)	5.9 (0.64)	[a]N/A
Journal of Atmospheric Chemistry	192 (43)	8.7 (0.94)	1.427
Atmospheric Research	189 (44)	4.9 (0.53)	1.811
Journal of Climate	160 (45)	20 (2.1)	3.363
Journal of Applied Meteorology	123 (46)	5.4 (0.58)	[b]1.702
Journal of Atmospheric and Oceanic Technology	118 (47)	6.5 (0.70)	1.588
Water Air and Soil Pollution	112 (48)	3.1 (0.33)	1.676
Quarterly Journal of the Royal Meteorological Society	105 (49)	7.8 (0.83)	2.522

[a]After 1993 it was not listed in SCI-Expanded.

[b]IF in 2005, it was not listed in SCI-Expanded after 2005.

TA (%): Total number of articles (percentage of all articles published in the field).

IF: Impact factor of the journal in 2009.

3.4 Country/territory

The contribution of different countries was estimated by the location of the affiliation of at least one author of the published articles. As there were 40 cases without author address information in the ISI, only 10,720 articles were included in the research pattern analysis of countries and institutes below. There existed a great geographical diversity in aerosol research, covering 115 different countries or territories.

Cooperation, playing a growing role in contemporary scientific research, could usually manifest itself in internationally co-authored papers tracked by bibliometric tools (Schubert and Braun, 1990). Of all the 10,720 articles, 7648 were single-country articles, and the other 3072 articles, or 29%, had International Co-Authorship (ICA). Apparent increasing trend of ICA share of world publication can be noted in Figure 3. ICA articles were more prevalent in recent years than earlier years, though recent proportion of ICA articles began to keep a stable level. It indicated that aerosol research had become more globally connected. The increased ease of communication in a technologically connected world contributed to the increasing collaboration. Moreover, the RPCR value of ICA articles against all papers fluctuated over the years, and a peak appeared in the year 2003. The 3072 articles with an ICA had an average PCPP of 13, while the others by single countries had an average of 8.4. It was concluded that ICA articles had higher visibility or a stronger impact in aerosol research field. As a rule, more international collaboration led to more sharing of ideas and workloads, and would cause more concerns than the national papers (Glänzel et al., 1999).

Figure 3 Relationships among the ICA share of world articles, relative peak citation rates (RPCR) and year

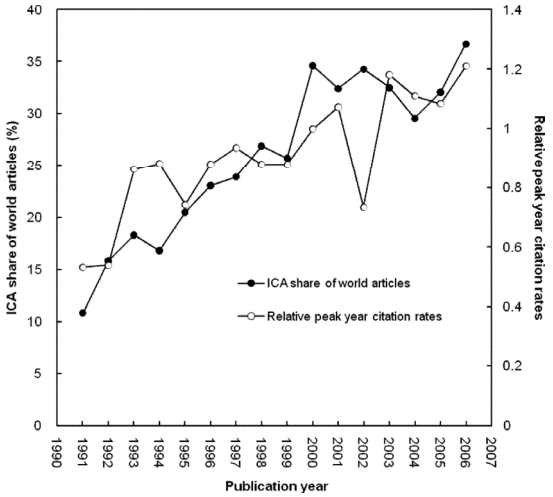


Table 4 listed the top 18 countries published at least 200 articles, by publication output from 1991 to 2006, including the number of single country articles and internationally collaborated articles. The seven major industrialised countries (G7: Canada, France, Germany, Italy, Japan, the UK and the USA) ranked top 6 of world aerosol publications, but Italy ranked top 8. To a certain extent, domination in production from mainstream countries, which also occurred in most scientific fields reflected the high activity and academic level of these countries (Mela et al., 1999; Li et al., 2009). On the other hand, since the early atmosphere aerosol pollution first occurred in industrialised countries, they conducted the earliest and the most relative research performances. The USA showed the greatest quantities of publications. It also had the most-frequent partners, accounting for 58% of world internationally collaborative articles, but presented a low percentage (32%) of collaboration with outside authors. PCPP together with RPCR values of total, independent and internationally collaborative articles are also shown in Table 4. Generally, ICA increased citation attraction. The RCRs for Russian scientific articles were significantly below the world average, with an RPCR of merely 0.22 for its overall publication output. This was an indication that the impact of Russian aerosol research works still had a lot of room for improvement.

Table 4 The top 18 most productive countries on aerosol, including the total, independent, and interracially collaborative articles with the corresponding PCPP and RPCR values

Country	*TA* (%)	$PCPP_T$ ($RPCR_T$)	*IA* (%)	$PCPP_I$ ($RPCR_I$)	*CA* (%)	$PCPP_C$ ($RPCR_C$)
USA	5518 (51)	8.8 (1.4)	3740 (49)	10 (1.2)	1778 (58)	13 (1.0)
Germany	1418 (13)	5.6 (0.89)	531 (6.9)	8 (0.95)	887 (29)	14 (1.1)
UK	944 (8.8)	5.9 (0.93)	410 (5.4)	8.8 (1.0)	534 (17)	13 (1.0)
France	712 (6.6)	4.7 (0.74)	237 (3.1)	6.4 (0.76)	475 (15)	13 (1.0)
Japan	586 (5.5)	4.9 (0.77)	286 (3.7)	5.6 (0.67)	300 (10)	12 (0.93)
Canada	553 (5.2)	6.3 (1.0)	239 (3.1)	8.2 (1.0)	314 (10)	14 (1.1)

Table 4 The top 18 most productive countries on aerosol, including the total, independent, and interracially collaborative articles with the corresponding PCPP and RPCR values (continued)

Country	*TA* (%)	$PCPP_T$ ($RPCR_T$)	*IA* (%)	$PCPP_I$ ($RPCR_I$)	*CA* (%)	$PCPP_C$ ($RPCR_C$)
Finland	399 (3.7)	7 (1.1)	139 (1.8)	10 (1.2)	260 (8.5)	12 (0.93)
Italy	385 (3.6)	5.8 (0.92)	139 (1.8)	8.1 (1.0)	246 (8.0)	15 (1.2)
Sweden	354 (3.3)	4.1 (0.65)	84 (1.1)	7.2 (0.85)	270 (8.8)	12 (0.93)
Russia	297 (2.8)	1.4 (0.22)	180 (2.4)	1.5 (0.18)	117 (3.8)	8.3 (0.65)
China	296 (2.8)	5.2 (0.82)	95 (1.2)	9 (1.1)	201 (6.5)	14 (1.1)
India	274 (2.6)	4.2 (0.66)	225 (2.9)	4.3 (0.52)	49 (1.6)	14 (1.1)
Switzerland	265 (2.5)	6.2 (1.0)	87 (1.1)	7.7 (0.92)	178 (5.8)	17 (1.3)
Netherlands	261 (2.4)	5.3 (0.84)	81 (1.1)	8.2 (1.0)	180 (5.9)	14 (1.1)
South Korea	251 (2.3)	4.1 (0.65)	128 (1.7)	5 (0.60)	123 (4.0)	11 (0.86)
Australia	227 (2.1)	4.7 (0.74)	102 (1.3)	5.5 (0.65)	125 (4.1)	11 (0.86)
Spain	205 (1.9)	4.8 (0.76)	116 (1.5)	5.6 (0.66)	89 (2.9)	11 (0.86)
Austria	201 (1.9)	3.5 (0.55)	72 (0.94)	5.8 (0.69)	129 (4.2)	13 (1.0)

TA (%): Total number of articles (percentage of all articles published in the field).

IA (%): NUMBER of independent articles (percentage of independent articles published in the field)

CA (%): number of collaborative articles (percentage of collaborative articles published in the field).

$RPCR_T$, $RPCR_I$ and $RPCR_C$ were referred to the relative peak-year citation rate of the total, independent and collaborative articles respectively.

3.5 Institute

Among the 10,720 articles with reprint address from 1991 to 2006, 39% were published by single institute, and others were all inter-institute collaborations. In contrast with countries, the percentage of inter-institute collaboration was much higher, which was consistent with our common sense, after all, the collaboration between institutes was much easier. As both internationally and inter-institutionally collaborative articles included, the average PCPP of inter-institute collaborations (7.1) was lower than that of international collaborations (13).

For aerosol articles in the field of meteorology and atmospheric sciences, statistical test was applied to see if peak citation score of an article (PCPP) and the number of institutes participating were related. The result shows that these two variables have a Pearson product-moment correlation coefficient of 0.875 ($p < 0.01$, two tail), indicating a strong, positive relationship between PCPP score and the number of institutes. The high count of active institutes contributed to further understanding of the probabilities in achieving high citation frequency or high impact.

In total, there were 3645 institutes, 2156 (59%) of which published only 1 article and 452 published 2 articles. The most productive institutes from 1991 to 2006 were National Aeronautics and Space Administration (NASA) (955 articles) and National Oceanic and Atmospheric Administration (NOAA) (620 articles) in the USA, respectively. Table 5

listed the nine most productive institutes, which published at least 200 articles. Seven of them were located in USA. Similar to the publication activity of countries, all institutes produce much more collaborative articles than independent articles. Besides, the citation profile also said something about the overall contribution of each research centre. The RPCR for the nine most productive institutes were all above 1, thus these groups were intended to represent a list of world centres of excellence in aerosol research.

Table 5 The top 9 most productive institutes on aerosol, including the total, independent and inter-institutionally collaborative articles with the corresponding PCPP and RPCR values

Institute	*TA* (%)	*PCPPT* (*RPCRT*)	*IA* (%)	*PCPPI* (*RPCRI*)	*CA* (%)	*PCPPC* (*RPCRC*)
NASA, USA	955 (8.9)	15 (1.3)	63 (1.5)	12 (1.6)	892 (14)	16 (1.2)
NOAA, USA	620 (5.8)	15 (1.3)	54 (1.3)	14 (2.0)	566 (8.7)	15 (1.2)
National Centre for Atmospheric Research, USA	427 (4.0)	16 (1.4)	42 (1.0)	17 (2.4)	385 (5.9)	16 (1.3)
California Institute of Technology, USA	354 (3.3)	14 (1.2)	70 (1.7)	11 (1.5)	284 (4.4)	15 (1.2)
University of Colorado, USA	350 (3.3)	15 (1.3)	29 (0.69)	12 (1.6)	321 (4.9)	15 (1.2)
University of Washington, USA	319 (3.0)	15 (1.3)	58 (1.4)	8.1 (1.1)	261 (4.0)	17 (1.3)
Georgia Institute of Technology, USA	252 (2.4)	17 (1.5)	31 (0.74)	11 (1.5)	221 (3.4)	18 (1.4)
Max Planck Institute for Chemistry, Germany	242 (2.3)	15 (1.3)	28 (0.67)	15 (2.2)	214 (3.3)	15 (1.2)
University of Helsinki, Finland	232 (2.2)	13 (1.1)	26 (0.62)	13 (1.8)	206 (3.2)	13 (1.0)

TA (%): Total number of articles (percentage of all articles published in the field).

IA (%): Number of independent articles (percentage of independent articles published in the field).

CA (%): Number of collaborative articles (percentage of collaborative articles published in the field).

$RPCR_T$, $RPCR_I$ and $RPCR_C$ were referred to the relative peak-year citation rate of the total, independent and collaborative articles respectively.

3.6 Authorship

Except for the 27 articles without author information, the 10,733 articles were authored by 16,913 authors, of which 9728 authors (58%) contributed only 1 article, 2698 (16%) authored 2 articles, 1304 (7.7%) authored 3 articles, 763 (4.5%) authored 4 articles and 538 (3.2%) authored 5 articles. Lotka's law, sometimes called "the inverse square law of scientific productivity", describes the frequency of publication by the authors in a given subject (Lotka, 1926; Nicholas, 1980).

$$x^n y = c, \tag{2}$$

where x stands for the number of articles and y is the number of authors making x articles.

Determined by a trial-and-error procedure for the non-linear regression using the solver add-in with Microsoft's spreadsheet, Microsoft Excel, the constants c and n

in equation (1) that could be determined from all the articles were found to be 146 and 0.543, respectively. Thus, the general Lotka's model for the relation was found to exist between the frequency y of authors making x articles published in 1991–2006, which can be written as:

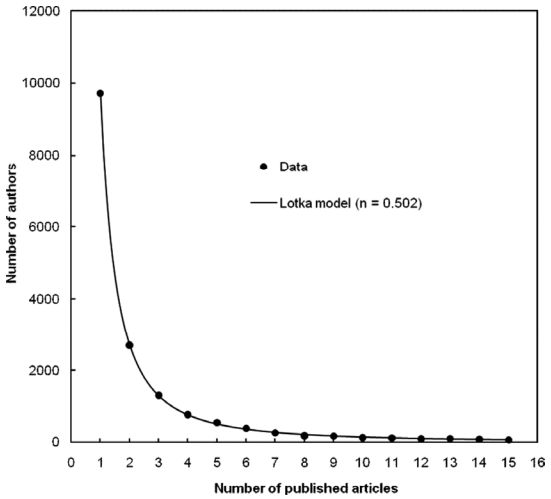
$$x^{0.543} y = 146, \tag{3}$$

or

$$x = 9.73 \times 10^3 \, y^{-1.84}. \tag{4}$$

Figure 4 shows a good correlation between the aerosol article and the number of authors making the specified number of articles according to Lotka's model. As the number of published articles increased, the number of researchers decreased.

Figure 4 Author production distributions on aerosol research in meteorology and atmospheric sciences



The 40 (0.37%) and 627 (5.8%) articles without any author and corresponding author address information, respectively, in the Web of Science. Of all, the 10,760 and 10,133 articles with author and corresponding author addresses were considered for the following study. A detailed list of the 15 most prolific authors from 1991 to 2006 and their total publications basis is shown in Table 6. Dr. Kulmala, M. at the University of Helsinki in Finland was the highest contributing author with 156 articles, which had been cited 4714 times up to 2009 in all. The second most productive scientist was Dr. Seinfeld, J.H. from California Institute of Technology, USA, with 139 articles. Furthermore, it was assumed that the first author of an article performed most of the research and the corresponding author (reprint author) generally provided the most professional support and funding for published studies (Ho, 2007). The same author ranking top in respect to first author, corresponding author and total article analyses was of noteworthy interest. In respect to aerosol research in the meteorology and atmospheric sciences subfield, Dr. Kerminen, V.M. from Finnish Meteorological Institute, Finland, has published the most first author articles and Dr. Hopke, P.K. from Clarkson University, USA, has published the most corresponding author articles. The PCPP and RPCR were also listed in Table 6,

as available indicators of the 'worth' of their research work. It had been convinced that the citations an individual received strongly correlated with other forms of career recognition, for example, academic position, the attainment of Noble prizes, awards and membership in scientific academies (Cole and Cole, 1973; Garfield, 1998).

Table 6 The top 15 most productive authors on aerosol, including the total, first author and reprint author articles with the corresponding PCPP and RPCR values

Author	*Institute*	*TA* (%)	$PCPP_T$ ($RPCR_T$)	*FAU* (%)	$PCPP_{FAU}$ ($RPCR_{FAU}$)	*RP* (%)	$PCPP_{RP}$ ($RPCR_{RP}$)
Kulmala, M	University of Helsinki, Finland	156 (1.5)	14 (1.2)	18 (0.17)	25 (2.7)	22 (0.22)	21 (2.3)
Seinfeld, JH	California Institute of Technology, USA	139 (1.3)	17 (1.4)	3 (0.028)	22 (2.3)	19 (0.19)	22 (2.3)
Wiedensohler, A	Institute for Tropospheric Research, Germany	91 (0.85)	13 (1.1)	6 (0.056)	7.5 (0.80)	6 (0.059)	9 (0.95)
Holben, BN	NASA, USA	87 (0.81)	22 (1.9)	1 (0.0093)	130 (14)	1 (0.010)	130 (14)
Andreae, MO	Max Planck Institute for Chemistry, Germany	87 (0.81)	17 (1.4)	6 (0.056)	18 (1.9)	7 (0.069)	16 (1.7)
Hobbs, PV	University of Washington, USA	78 (0.73)	14 (1.2)	5 (0.047)	10 (1.1)	11 (0.11)	13 (1.4)
Hopke, PK	Clarkson University, USA	77 (0.72)	11 (0.89)	3 (0.028)	9 (0.96)	40 (0.39)	12 (1.3)
Maenhaut, W	University of Ghent, Belgium	77 (0.72)	15 (1.2)	2 (0.019)	8.5 (0.91)	2 (0.020)	8.5 (0.90)
Kerminen, VM	Finnish Meteorological Institute, Finland	70 (0.65)	12 (1.0)	28 (0.26)	8.4 (0.89)	28 (0.28)	8.4 (0.88)
Flagan, RC	California Institute of Technology, USA	70 (0.65)	17 (1.4)	2 (0.019)	5.5 (0.59)	7 (0.069)	6.7 (0.71)
Pandis, SN	Carnegie Mellon University, USA	68 (0.63)	14 (1.2)	5 (0.047)	11 (1.2)	31 (0.31)	13 (1.3)
Kaufman, YJ	NASA, USA	66 (0.61)	23 (2.0)	10 (0.093)	20 (2.2)	10 (0.10)	20 (2.1)
Harrison, RM	University of Birmingham, UK	65 (0.61)	11 (0.91)	17 (0.16)	11 (1.1)	31 (0.31)	11 (1.1)
Baltensperger, U	Paul Scherrer Institute, Switzerland	64 (0.60)	17 (1.4)	4 (0.037)	16 (1.7)	13 (0.13)	14 (1.5)
Heintzenberg, J	Leibniz Institute for Tropospheric Research, Germany	61 (0.57)	10 (0.82)	15 (0.14)	5.3 (0.57)	13 (0.13)	4.9 (0.52)

TA (%): total number of articles (percentage of all articles published in the field).

FAU (%): number of articles as first author (percentage of articles published in the field).

RP (%): number of articles as reprint author (percentage of articles with reprint author information in the field).

$RPCR_T$, $RPCR_{FAU}$ and $RPCR_{RP}$ were referred to the relative peak-year citation rate of the total articles, total articles and articles with reprint author information, respectively.

A bias in analysis of authorship might occur when different authors had the same name or one author used different names (e.g., maiden names) in their articles (Ho, 2007). Another potential confounder arises when an author moves from one affiliation to another

(Macroberts and Macroberts, 1989). It was strongly recommended that an "international publication identity number" for all authors should be created when they published their first paper in an ISI-listed journal, to establish an unambiguous association of each author with his/her articles (Ho, 2007).

3.7 Limitations

The results of this study suggest that the bibliometric indicators, if judiciously applied, may offer a promising way forward for research management and science policy. However, some of the methodological problems and controversies should also be addressed: first, the concept should be clarified as to what the citation count actually measured. A variable PCPP and RPCR obtained by a paper was not only determined by its impact on the advance of scientific knowledge, but also influenced by other factors including the communication practices, the existing visibility of journal articles and the authors' own cognition and favour. The citation was, therefore, just a partial indicator of the scientific impact, rather than a measure of the quality or importance of research publications. Second, numerous social and political factors affect an institute or individual's scientific work. In 1977, Moravcsik highlighted that scientific activities could be conceived as an 'input–output' process (Moravcsik, 1977). In the research evaluation process in a specific field, the output and impact measures should be associated with appropriate research input indictors, including existing knowledge and techniques, financial resources, the history of the discipline and so on (Martin and Irvine, 1983). Third, this study was focusing on worldwide aerosol research evaluations, with the database ISI offering publication and citation data from international perspectives. The shortcomings of the indicators PCPP and RPCR were particularly important for non-central countries, whose national journals were scarcely covered by ISI databases (Arunachalam and Manorama, 1988). Had the analysis been at national institute or department level, methodologies based as far as possible on domestic or local data would, for reasons of logistics and accuracy, be the most appropriate. Fourth, anomalies always arouse in online searches, and there could never be exactly total confidence that all relevant records for a subject have been retrieved. As for the technical limitations and errors, greater standardisation of abstracting and indexing procedures for databases especially in the selection of keywords would be valuable. Besides, a relatively large sample size of publications for research assessment would reduce the deviations and have statistical significances.

4 Conclusions

In this study dealing with aerosol SCI-Expanded papers in meteorology and atmospheric sciences, we obtained some significant points on the worldwide research performance by exploring the bibliometric approach of output and impact assessment. Annual citation counts typically peaked at around the third year after publication. 10,760 articles from 1991 to 2006 for citation tracking analysis had an average PCPP of 9.3, which was lower than that of reviews. A significant 50% share of the TC3 citations was contributed to by the effect of a few highly cited papers (16% of total). The mean IF of the publishing journals was 2.77. As the flagship journal of the field, *Journal of Geophysical Research-Atmospheres* published the most articles, with a high PCPP of 12. The G7, which had a

longer tradition in research in this field, held the majority of total world production. The USA ranked top whether independently or collaboratively. Aerosol research has become more globally connected, and papers written with ICA tended to have higher visibility (PCPP) than others. Articles assigned to this particular subfield exhibited a strong association between the number of institutes participating in and the PCPP of the article, evidenced by a high positive Pearson product-moment correlation coefficient. The most independently and collaboratively productive institutes were California Institute of Technology and NASA at the USA, respectively. Finally, Dr. Kulmala, M. at the University of Helsinki in Finland was the highest contributing author and Dr. Kerminen, V.M. from Finnish Meteorological Institute published the most first author and Dr. Hopke, P.K. from Clarkson University in USA published the most corresponding author papers. However, this paper in no way implied the bibliometric means based on output and impact indictors could be considered as the one and only research evaluation criterion. Publication, PCPP and RPCR might be combined with other existing indicators as complementary data in the assessment, for example IF, peer evaluation, and the ISI tailor-made evaluation tools involving ISI Essential Science Indicators, and ISI Highly Cited Comn. Properly used, the output, impact (PCPP and RPCR) and other assistant indicators could provide a reasonable and reliable estimate of scientific research performances.

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