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A historical review and bibliometric analysis of GPS research from 1991–2010

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Abstract We performed a bibliometric analysis of published research on Global Positioning System (GPS) for the period of 1991–2010, based on the Science Citation Index and Social Sciences Citation Index databases. Our search identified a total of 15,759 GPS-related publications in the period. We analyzed the patterns of publication outputs, subject categories and major journals, international productivity and collaboration, geographic distribution of authors, and author keywords. The annual number of publications in GPS research increased from 98 in 1991 to 1934 in 2010. "Geochemistry & Geophysics", "Geosciences, Multidisciplinary", and "Engineering, Electrical & Electronic" were the top 3 most popular subject categories. As the flagship journal in the field, Geophysical Research Letters had the highest publication count. The USA, the UK and Germany were the top 3 most productive countries. The most productive institution was the California Institute of Technology (Caltech), followed by the Chinese Academy of Sciences and the University of Colorado. The USA was the most frequent partner in international collaborations. Caltech took the central position in the collaboration network. The major spatial clusters of authors were in the USA, the Europe Union, and East Asia (including China, Japan and South Korea). "Ionosphere", "Remote Sensing" and "Monitoring" are growing research subjects in the field of GPS, while "Deformation", "Geoid" and "Tectonics" are becoming gradually less significant. Our study revealed underlying patterns in scientific outputs and academic collaborations and may serve as an alternative and innovative way of revealing global research trends in GPS.

Keywords Bibliometrics · GPS · Research trends · Scientific outputs

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Introduction

GPS (Global Positioning System) is a space-based satellite navigation system for positioning, navigation and timing services under all weather conditions anywhere on or near the Earth. In the 1970s, the US Department of Defense (DoD) began the GPS development as a military force enhancer. In 1983, President Reagan offered GPS civil services to the world, free of direct charges, as a result of the Korean Air Lines Flight 007 disaster. Its nominal constellation consists of 24 satellites and its full operational capability was declared in 1994. GPS has been used to support a wide variety of applications (Zhong et al. 2008), including surveying, navigation, ionospheric monitoring, space weather, agriculture, and travel (MacGougan et al. 2010; Sun et al. 2010; Ji et al. 2011; Fisher and Kunches 2011; Santana-Fernández et al. 2010; Bricka et al. 2009). Recently, GPS-like systems—GLONASS, Galileo, Compass and QZSS systems have attracted more and more attention. GLONASS is the Global Navigation Satellite System (GNSS) of Russia. Galileo system is the European self-determination and self-governed Global Navigation Satellite System (GNSS). Compass is the Global Navigation Satellite System (GNSS) planned by China. The Japanese Quasi-Zenith Satellite System (QZSS) is a three-satellite navigation/positioning system (Kawano et al. 2004). Continued improvement of GPS and GPS-like systems should significantly enhance the accuracy, availability, and integrity.

Research on GPS has been published in a large number of journals from authors distributed all over the world. However, there have been few attempts at gathering systematic data on the global scientific production of GPS research. A common research tool is the bibliometric method which has already been widely applied in scientific production and research-trend studies in many disciplines of science and engineering (Almind and Ingwersen 1997; Cronin 2001; Moed et al. 1995). The conventional bibliometric methods center on citation and content analysis, while the newly-developed bibliometric analysis evaluates the scholarly outputs of authors, institutions, and countries, identifies the temporal evolution of research patterns, and underlies international collaboration and author distribution (Chiu and Ho 2007; Li et al. 2009, 2011; Zhang et al. 2009).

In this paper, we performed a bibliometric analysis of published GPS research from the period 1991 to 2010. The aim of this study was to reveal underlying patterns in scientific outputs, characteristics of the international collaboration and author distribution of GPS research, and provide a potential guide for future research related to GPS.

Data sources and methodology

Data were based on the online versions of the Scientific Citation Index (SCI) and Social Sciences Citation Index (SSCI) accessed through the Web of Science. SCI and SSCI are multidisciplinary databases of the Institute for Scientific Information (ISI), Philadelphia, USA. As publications before 1991 did not include abstracts in articles, in order to assure all articles were compared using the same standards, only papers published from 1991 onwards were considered. Articles published after 1991 lacking an abstract were also not included. The online versions of the SCI and SSCI were searched for topics "GPS", "Global Positioning System", "GLONASS", "Galileo System", "Compass System" and "QZSS" to compile a bibliography of all papers related to GPS research. In all the papers we searched, we removed publications in which GPS is not used as an abbreviation for Global Positioning System, including general plane strain, generalized processor sharing, geometrical product specification, generalized pattern search, etc. We then retrieved

information on individual documents, including author name(s), author affiliation(s), subject category(ies), journal name(s), publication title(s), and publication year(s), and eliminated duplicated records.

All publications identified in the SCI and SSCI databases as being GPS-related were assessed by the following criteria: publication outputs; subject categories and major journals; international productivity and collaboration; geographic distribution of authors; and author keywords using Microsoft Excel 2007. Publications originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Publications from Hong Kong or Taiwan were not included in China. The reported impact factor (IF) of each journal was obtained from the 2010 JCR. Contributions of different institutions and countries were estimated by the affiliation of at least one author to the publications. Collaboration type was determined by the addresses of the authors, where the term "single country publication" was assigned if the researchers' addresses were from the same country. The term "international collaborative publication" was designated to those articles that were coauthored by researchers from multiple countries. The term "single institute publication" was assigned if the researchers' addresses were from the same institution. The term "inter-institutionally collaborative publication" was assigned if authors were from different institutions.

Results and discussion

Publication outputs

From 1991 to 2010, a total of 15,759 GPS-related publications were identified. The annual number of publications in GPS research increased from 98 in 1991 to 1934 in 2010. The cumulative progression was represented by an exponential model (Fig. 1). The fit produced a high coefficient of determinations to the collected data ($R^2 = 0.977$). It could be concluded that the number of scientific papers concerning GPS was growing at a high rate. The exponential best fit for GPS research was found to be: $y = 113.33 \times \exp(0.153x)$, where y is the cumulative number of publications and x is the number of years since 1991. Extrapolating from the exponential model, it can also be calculated that the number of scientific papers on the topic of GPS in 2014 would be twice that in 2010.

Eleven document types were found in all GPS-related publications during the 20-year period. Article was the most frequently used document type, comprising 84 % of total production, followed by proceedings papers (2,003; 12.7 %), reviews (348; 2.2 %), editorial materials (68; 0.43 %), and letters (49; 0.31 %). Ninety-seven percent of all journal articles were published in English (15,281), followed by Chinese (167), French (57), German (53), and Portuguese (50). The average article lengths fluctuated from 9.8 pages in 1991 to 11.8 pages in 2010, with an overall average length of 11 pages. 15.1 references were cited per article in 1994, compared to 34.2 references per article in 2010. There was an average of 2.9 authors per GPS-related article in 1991, steadily increasing to 4.3 in 2010.

Subject categories and major journals

There was great diversity within the research topic of GPS, including 194 subject categories identified by the ISI during the past 20 years. The top 10 distribution of subject categories is shown in Table 1. It indicates that "Geochemistry & Geophysics" (3,212, 20.4 %), "Geosciences, Multidisciplinary" (2,737, 17.4 %), and "Engineering, Electrical & Electronic"

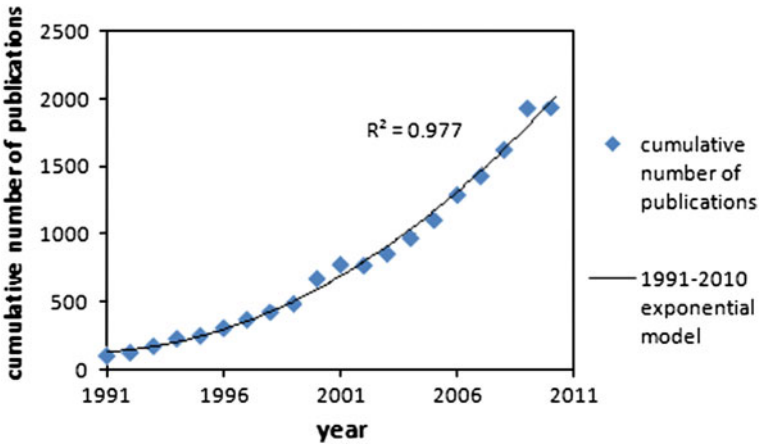

Fig. 1 Exponential model of cumulative publication count from 1991 to 2010

Table 1 Top 10 subject categories distribution

Subject categories	TP	TP R (%)
Geochemistry & Geophysics	3,212	1 (20.4)
Geosciences, Multidisciplinary	2,737	2 (17.4)
Engineering, Electrical & Electronic	1,737	3 (11.0)
Meteorology & Atmospheric Sciences	1,596	4 (10.1)
Remote Sensing	1,530	5 (9.7)
Astronomy & Astrophysics	1,132	6 (7.4)
Telecommunications	1,025	7 (7.2)
Engineering, Aerospace	1,172	8 (6.5)
Engineering, Civil	684	9 (4.3)
Instruments & Instrumentation	662	10 (4.2)

TP is the total publications, *R* is the rank, % is the share in publication

(1,737, 11.0 %) were the top 3 most popular subject categories. As the use of statistics in any scientific discipline could be considered a key element in evaluating its degree of maturity (Palmer et al. 2005), the results provide a current view of the research emphasis of this topic.

The number of journals publishing GPS-related research increased from 58 in 1991 to 744 in 2010. Table 2 showed the distribution of outputs in the top 10 journals. Geophysical Research Letters (655, 4.2 %) was the top journal by publication count, followed by Journal of Geophysical Research—Solid Earth (568, 3.6 %), and the Journal of Geodesy (385, 2.4 %). Impact factor (IF) is usually used to evaluate the relative importance of a journal, especially among others in the same field (Benavent et al. 2004). However, when used as an indicator of article quality, journal IF may overestimate the value of less important articles at the expense of higher impact ones (Gisvold 1999). As a journal's impact may vary between fields, average citations (TC/TP) in GPS research, which only considers citations within a field, is a more relevant measure of a journal's relative importance in a specific field. The 568 GPS-related publications published in Journal of

Table 2 Top 10 journal distribution

Journals	TP	TP R (%)	TC	TC/TP	IF
Geophysical Research Letters	655	1 (4.2)	12,502	19.1	3.505
Journal of Geophysical Research-Solid Earth	568	2 (3.6)	16,656	29.3	3.303
Journal of Geodesy	385	3 (2.4)	3,371	8.8	1.88
Geophysical Journal International	285	4 (1.8)	4,393	15.4	2.411
Earth Planets & Space	262	5 (1.7)	1,931	7.4	1.112
Journal of Navigation	253	6 (1.6)	612	2.4	0.691
Journal of Geophysical Research-Space Physics	228	7 (1.4)	3,513	15.4	0.95
Radio Science	212	8 (1.3)	2,826	13.3	1.483
GPS Solutions	190	9 (1.2)	822	4.3	3.303
Tectonophysics	167	10 (1.1)	2,665	16.0	2.509

TP is the total publications, *TC* is the total citations, *IF* is the impact factor, *R* is the rank, % is the share in publication

Geophysical Research-Solid Earth had average citations of 29.3, and an IF of 3.303, ranked 1st and 2nd. Geophysical Research Letters had the highest IF (3.505) and the second-highest average citations (19.1) among the 10 journals listed in Table 2.

International productivity and collaboration

The contribution of different countries/territories was estimated by the location of the affiliated institutions of at least one author. The top 10 countries/territories were ranked by total publications, including both single-country/territory publications and international collaborations. As shown in Table 3, the USA headed the productivity rankings with 5,277 publications, of which 3,439 were solely produced in the USA and 1,838 were international collaborations. The UK published the second-highest number of total publications, followed by Germany, China, and France. Among the top 10 countries/territories, only the UK, France and Germany published more internationally collaborative publications than single country publications. The proportion of China's single country publications in its total publications was the highest (65.2 %). Out of these 10 countries/territories, 4 were from Europe, 3 were from Asia, 2 were from North America, and 1 was from Oceania. Most of these 10 countries/territories were developed countries/territories.

The collaboration network of the top 20 most productive countries was visualized using Ucinet (Fig. 2). Each point represents one country/territory and the thickness of interconnecting lines represents the strength of collaboration. As can be seen, collaborations among the top 20 most productive countries were frequent. The USA took the central position in the collaboration network, as it was the principal collaborator with the most productive countries, including France and the UK.

The contribution of different institutions was estimated by affiliated institution of at least one author. As shown in Table 4, the most productive institution was the California Institute of Technology (Caltech) with 486 papers, followed by the Chinese Academy of Sciences with 399, the University of Colorado with 271, the United States Geological Survey with 249, and the Russian Academy of Sciences with 236. The Chinese Academy of Sciences published the most single institution publications, followed by the Russian Academy of Sciences, Caltech and the United States Geological Survey. Caltech published the most inter–institutional collaborative publications, followed by the Chinese Academy

Table 3 Top 10 most productive countries/territories during 1991–2010

Country/territory	TP	TP R (%)	SP	SP/TP (%)	CP	CP/TP (%)
USA	5,277	1 (33.5)	3,439	65.2	1,838	34.8
UK	1,224	2 (7.8)	591	48.3	633	51.7
Germany	1,173	3 (7.4)	493	42.0	680	58.0
People's Republic of China	1,121	4 (7.1)	730	65.1	391	34.9
France	1,058	5 (6.7)	386	36.5	672	63.5
Japan	1,043	6 (6.6)	654	62.7	389	37.3
Italy	848	7 (5.4)	467	55.1	381	44.9
Canada	802	8 (5.1)	474	59.1	328	40.9
Taiwan	616	9 (3.9)	395	64.1	221	35.9
Australia	593	10 (3.8)	318	53.6	275	46.4

TP is the total publications, *SP* is the single country publication, *CP* is the internationally collaborative publication, *R* is the rank, % is the share in publication

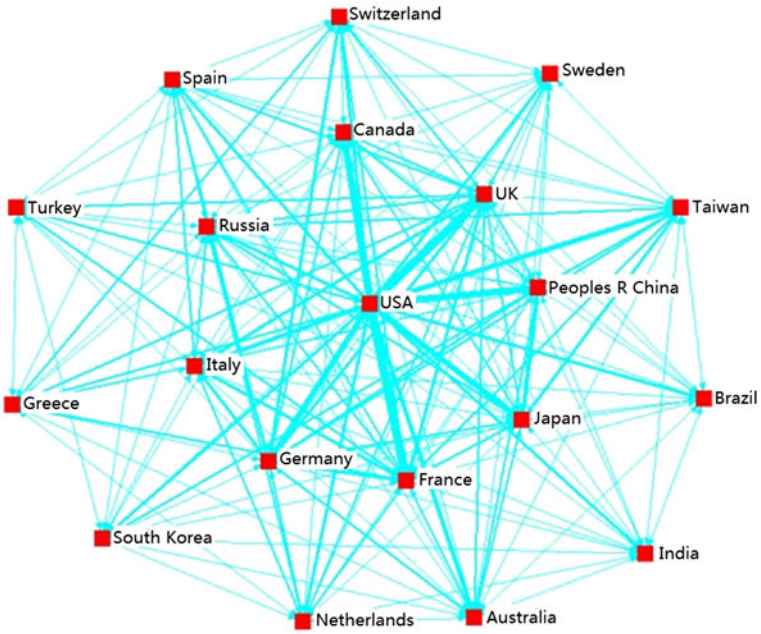

Fig. 2 Collaboration network of the top 20 most productive countries/territories

of Sciences and the University of Colorado. Though the UK, France, Germany, Canada, Italy, and Australia were in the top 10 most productive countries/territories, none of these countries' institutions were in the top 10 most productive institutions. Among these 10 institutions, 5 were from the USA, 2 were from Japan, with China, Russia, and Taiwan having one each. Though Russia was not in the top 10 most productive countries/territories, the total publications of the Russian Academy of Sciences ranked 5th.

Figure 3 depicts the collaboration network of most productive institutions. Each point represents one institution and the thickness of interconnecting lines represents the strength

Table 4 Top 10 most productive institutions during 1991–2010

Institution	TP	TP R (%)	SP	SP/TP	CP	CP/TP
Caltech, USA	486	1 (3.1)	106	21.8	380	78.2
Chinese Academy of Sciences, China	399	2 (2.5)	119	29.8	280	70.2
University of Colorado, USA	271	3 (1.7)	52	19.2	219	80.8
United States Geological Survey, USA	249	4 (1.6)	84	33.7	165	66.3
Russian Academy of Sciences, Russia	236	5 (1.5)	110	46.6	126	53.4
University of Tokyo, Japan	203	6 (1.3)	38	18.7	165	81.3
Massachusetts Institute of Technology (MIT), USA	193	7 (1.2)	55	28.5	138	71.5
University of Kyoto, Japan	187	8 (1.2)	26	13.9	161	86.1
National Oceanic & Atmospheric Administration (NOAA), USA	167	9 (1.1)	44	26.3	123	73.7
National Central University, Taiwan	167	10 (1.1)	22	13.2	145	86.8

TP is the total publications, *SP* is the single institute publication, *CP* is the inter-institutional collaborative publication, *R* is the rank, % is the share in publication

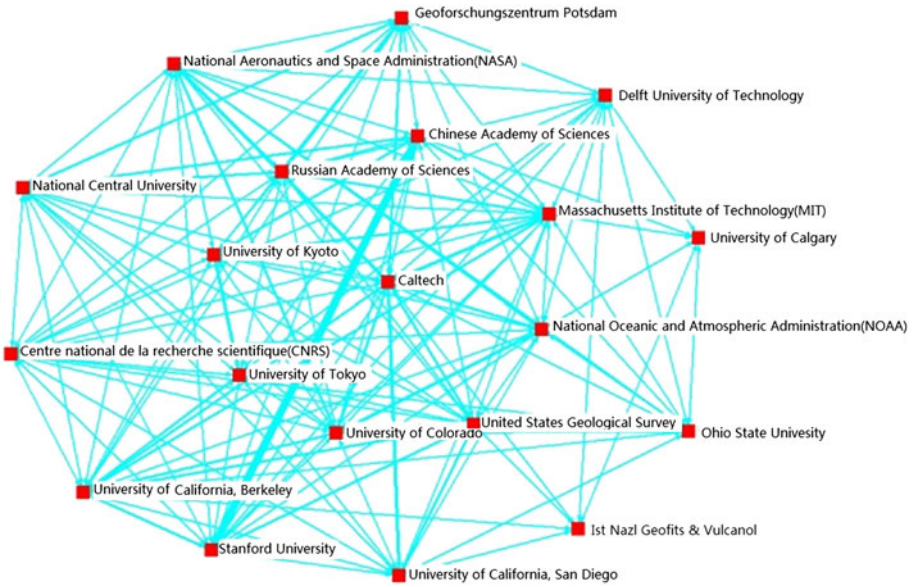

Fig. 3 Collaboration network of the top 20 most productive institutions

of collaboration. Caltech, the Chinese Academy of Sciences, the United States Geological Survey, the University of Colorado, the University of Kyoto, and the University of Tokyo were the most collaborative institutions. We found that institutions in the same country tended to have a higher rate of collaboration, e.g. the University of Tokyo and the University of Kyoto, the University of Colorado and Caltech, Caltech and the United States Geological Survey, Caltech and the Massachusetts Institute of Technology, and the University of Colorado and the National Oceanic and Atmospheric Administration.

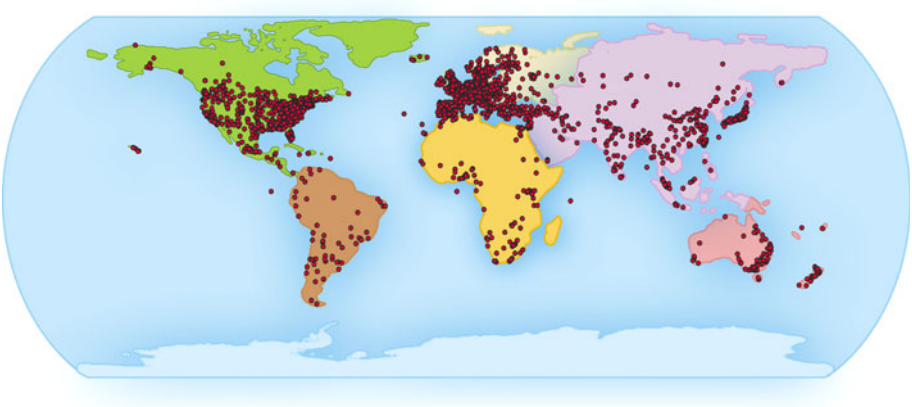

Fig. 4 Global geographic distribution of authors

Geographic distribution of authors

Of the 15,759 publications from 1991 to 2010, 2,166 (13.7 %) were by a single author, 2,862 (18.2 %) by two authors, 2,740 (17.4 %) by three, 2,071 (13.1 %) by four, and 1,340 (8.5 %) by five. Figure 4 shows the global geographic distribution of authors as visualized by CiteSpace. Major spatial clusters of authors were found in the USA, the Europe Union, and East Asia, with several minor clusters in other parts of the world. The GDP of the USA, the Europe Union, and East Asia (including China, Japan and South Korea) are all top ranked. For further analysis, we gathered GDP and automobile ownership data of 26 countries and analyzed their correlation with academic outputs. Automobile ownership data in 2008 were gathered from China's National Bureau of Statistics, Ward's Auto, the Japan Automobile Manufacturers' Association (JAMA), the German Association of the Automotive Industry (VDA) etc. Correlation between automobile ownership in these 26 countries and academic outputs was analyzed with SPSS Statistics and the correlation coefficient was found to be 0.98. GDP information about the same 26 countries in 2008 was gathered from The World Factbook. The correlation coefficient between GDP and academic outputs was found to be 0.96 as determined by SPSS Statistics.

Author keywords

Author keywords analysis offers insight into research trends, revealing areas of researcher interest. In Table 5, the top author keywords appearing in articles from 1991 to 2010 are listed and ranked. In the data set, a total of 45,758 keywords were used, among which 17,189 (37.6 %) appeared only once and a further 2,925 (6.4 %) appeared twice. This abundance of singly-used keywords suggests a lack of continuity in research and a wide disparity in research focuses.

During the studied period, some keywords have markedly increased in activity. For example, the ranking of "Ionosphere" moved from 35th in 1991–1995 to 3th in 2006–2010; "Remote Sensing" moved from 15th in 1991–1995 to 6th in 2006–2010; and "Monitoring" moved from 35th in 1991–1995 to 15th in 2006–2010, showing possible changes in focus to new areas of GPS research. "Monitoring" contains many aspects such as weather monitoring, volcano monitoring, deformation monitoring, traffic monitoring

Table 5 Top 20 author keywords by 5-year period

Author keywords	TP	TP R (%)	1991–1995		1996–2000		2001–2005		2006–2010	
			P	R	P	R	P	R	P	R
GPS	1,853	1 (11.8)	24	1	189	1	594	1	1,046	1
Global Positioning System	476	2 (3.0)	18	3	95	2	155	2	208	2
Ionosphere	311	3 (2.0)	2	35	14	12	100	3	195	3
Global Positioning System (GPS)	292	4 (1.9)	0	–	19	8	82	4	191	4
GIS	243	5 (1.5)	4	7	32	4	75	5	132	5
Remote Sensing	197	6 (1.3)	3	15	25	5	65	6	104	6
Navigation	143	7 (0.9)	3	15	36	3	41	8	63	9
Crustal Deformation	122	8 (0.8)	0	–	13	13	46	7	63	9
GNSS	121	9 (0.8)	0	–	20	7	17	29	84	7
Geodesy	107	10 (0.7)	2	35	17	10	38	9	50	13
Kalman Filter	105	11 (0.7)	2	35	18	9	17	29	68	8
Total Electron Content	90	12 (0.6)	1	96	2	163	27	13	60	11
Deformation	83	13 (0.5)	2	35	7	27	33	10	41	21
Precision Agriculture	83	14 (0.5)	0	–	6	33	30	11	47	13
Monitoring	77	15 (0.5)	2	35	4	60	25	16	46	15
Accuracy	73	16 (0.5)	3	15	9	18	16	32	45	17
TEC	69	17 (0.4)	0	–	0	–	23	19	46	15
Earthquake	68	18 (0.4)	1	96	3	98	27	13	37	25
Geoid	65	19 (0.4)	0	–	8	24	26	15	31	33
Tectonics	64	20 (0.4)	1	96	9	18	30	11	24	50

TP is the total publications, *P* is the publications in the study period, *R* is the rank, % is the share in publication

and so on. From 1991 to 2006, there were no papers about weather monitoring, which first appeared in 2007 and steadily increased in activity from 2007 to 2010. On the contrary, it is surprising to find that some previously popular topics have declined in significance. For example, "Deformation", "Geoid" and "Tectonics" were ranked 10th, 15th and 11th in 2001–2005, but declined to 21th, 33th and 50th in 2006–2010.

Conclusions

We conducted a bibliometric analysis of the patterns of publication outputs, subject categories and major journals, international productivity and collaboration, geographic distribution of authors, and author keywords on GPS-related papers from 1991 to 2010. Our research pointed to several significant trends in global research performance throughout the period.

In total, 15,759 publications were published during the period from 1991–2010. The publications added year by year, the annual growth rate of publications in GPS research is 98.7 %.

Geophysical Research Letters, Journal of Geophysical Research-Solid Earth, and Journal of Geodesy were the top 3 journals with the most publications in GPS research. "Geochemistry & Geophysics", "Geosciences, Multidisciplinary", and "Engineering, Electrical & Electronic" were the top 3 most popular subject categories.

The USA, the UK and Germany were the top 3 most productive countries. The USA was the most frequent international partner. The most productive institution was the California Institute of Technology (Caltech), followed by the Chinese Academy of Sciences and the University of Colorado. Caltech took the central position in the collaboration network.

The major spatial clusters of authors were in the USA, the Europe Union, and East Asia, with several minor clusters in other parts of the world.

Author keywords analysis offers insight into research trends, revealing areas of research interests. "Ionosphere", "Remote Sensing" and "Monitoring" are growing research subjects in the field of GPS, while "Deformation", "Geoid" and "Tectonics" are becoming gradually less significant.

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References

Almind, T. C., & Ingwersen, P. (1997). Informetric analyses on the World Wide Web: Methodological approaches to 'webometrics'. *Journal of Documentation, 53*(4), 404–426.

Benavent, R. A., Zurian, J. C. V., & Gomez, M. C. (2004). Impact factor of the Spanish medical journals. *Medicina Clinica, 123*(18), 697–701.

Bricka, S., Zmud, J., & Wolf, J. (2009). Household travel surveys with GPS an experiment. *Transportation Research Record, 2105*, 51–56.

Chiu, W. T., & Ho, Y. S. (2007). Bibliometric analysis of tsunami research. *Scientometrics, 73*, 3–17.

Cronin, B. (2001). Bibliometrics and beyond: some thoughts on web-based citation analysis. *Journal of Information Science, 27*(1), 1–7.

Fisher, G., & Kunches, J. (2011). Building resilience of the Global Positioning System to space weather. *Space Weather, 9*, S12004.

Gisvold, S. E. (1999). Citation analysis and journal impact factors—is the tail wagging the dog? *Acta Anaesthesiologica Scandinavica, 43*(10), 971–973.

Ji, S. Y., Chen, W., Ding, X. L., & Zhao, C. M. (2011). Equatorial ionospheric zonal drift by monitoring local GPS reference networks. *Journal of Geophysical Research, 116*, A08310.

Kawano, I., Mokuno, M., Kogure, S., & Kishimoto, M. (2004). Japanese experimental GPS augmentation using quasi-zenith satellite system (QZSS). In: *Proceedings of the 17th international technical meeting of the satellite division of the institute of navigation (ION-GNSS'04)* (pp. 175–181).

Li, J., Zhang, Y., Wang, X., & Ho, Y. S. (2009). Bibliometric analysis of atmospheric simulation trends in meteo-rology and atmospheric science journals. *Crotica Chemica Acta, 82*, 695–705.

Liu, X. J., Zhang, L., & Hong, S. (2011). Global biodiversity research during 1900–2009: A bibliometric analysis. *Biodiversity and Conservation, 20*, 807–826.

MacGougan, G., O'Keefe, K., & Klukas, R. (2010). Accuracy and reliability of tightly coupled GPS/ultra-wideband positioning for surveying in urban environments. *GPS Solution, 14*, 351–364.

Moed, H. F., Debruin, R. E., & Vanleeuwen, T. N. (1995). New bibliometric tools for the assessment of national research performance—database description, overview of indicators and first applications. *Scientometrics, 33*(3), 381–422.

Palmer, A. L., Sese, A., & Montano, J. J. (2005). Tourism and statistics—Bibliometric study 1998–2002. *Annual Tourism Research, 32*(1), 167–178.

Santana-Fernández, J., Gómez-Gil, J., & del-Pozo-San-Cirilo, L. (2010). Design and implementation of a GPS guidance system for agricultural tractors using augmented reality technology. *Sensors, 10*, 10435–10447.

Sun, D., Petovello, M. G., & Cannon, M. E. (2010). Use of a reduced IMU to aid a GPS receiver with adaptive tracking loops for land vehicle navigation. *GPS Solution, 14*, 319–329.

Zhang, W. W., Qian, W. H., & Ho, Y. S. (2009). A bibliometric analysis of research related to ocean circulation. *Scientometrics, 80*(2), 305–316.

Zhong, P., Ding, X. L., & Zheng, D. W. (2008). Adaptive wavelet transform based on cross-validation method and its application to GPS multipath mitigation. *GPS Solution, 12*, 109–117.