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Global remote sensing research trends during 1991–2010: a bibliometric analysis

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Abstract According to the articles related to remote sensing of SCI and SSCI databases during 1991–2010, this study evaluated the geographical influence of authors by the new index (geographical impact factor), and revealed the auctorial, institutional, national, and spatiotemporal patterns in remote sensing research. Remote sensing research went up significantly in the past two decades. Imaging science & photographic technology was the important subject category. *International Journal of Remote Sensing* was the top active journal. All authors were mainly concentrated in North America, Western Europe, and East Asia. Jackson TJ from USDA ARS was the most productive author, Coops NC from University of British Columbia had more high-quality articles, and Running SW from University of Montana carried the greatest geographical influence. The USA was the largest contributor in global remote sensing research with the most single-country and internationally collaborative articles, and the NASA was the most powerful research institute. The international cooperation of remote sensing research increased distinctly. Co-word analysis found the common remote sensing platform and sensors, revealed the widespread adoption of major technologies, and demonstrated keen interest in land cover/land use, vegetation, and climate change. Moreover, the remote sensing research was closely correlated with the satellite development.

Keywords Remote Sensing (RS) · Bibliometric analysis · Geographical impact factor (GIF) · Geographic information system (GIS) · Satellite

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Introduction

Bibliometrics is an effective tool for evaluating research trends in different science fields (Wang et al. 2011; Sinha 2012; Fu et al. 2012; Nederhof 2006; Pritchar 1969). The traditional bibliometric method analyzed research trends of certain field mainly from publication output, subject category and journal, author, country and research institute, and keyword frequencies, etc. (Liu et al. 2012; Chiu and Ho 2007; Almeida-Filho et al. 2003; Grossi et al. 2003). In recent years, the bibliometric network analysis was increasingly applied to analyze the relationships of keywords, country and research institute, and author. The common network analysis included co-word analysis (Zhao and Zhang 2011; Ding et al. 2001), co-citation analysis (Lai and Wu 2005; He and Hui 2002), co-authorship analysis (Glanzel 2000; Seglen and Aksnes 2000), and co-publication analysis (Schmoch and Schubert 2008), etc. Additionally, CiteSpace and ArcGIS software have been used to demonstrate geographic distribution of authors or research institutes based on the author address (Liu et al. 2011; Wang et al. 2012). The bibliometric network analysis and various visualization technologies intuitively showed the analysis results.

Moreover, various standard indicators, such as the TP (total number of publications), TC (total number of citations), and CPP (average number of citations per publication), were adopted to analyze researchers' performance (Van Raan 2006; Skram et al. 2004). In 2005, Hirsch proposed an easily computable index, *h-index*, as a useful index to further characterize the importance, significance, and broad impact of a researcher's cumulative research contributions (Hirsch 2005). The *h-index* is a simple single number incorporating both quantity (publication) and quality (citation) scores (Egghe 2006). Based on the foundation laid by the *h-index*, its variant indexes were established, such as the *g-index* (Egghe 2006), the *R-index* and *AR-index* (Jin et al. 2007), the h_m*-index* (Schreiber 2008), and the *p-index* (Prathap 2010). These indicators measured the researcher's scientific performance from different perspectives, whereas the researchers' geographical influences have not been analyzed. Although all mentioned indexes are of the same value among different researchers, the geographical distribution of their citing articles may vary, that is, the geographical impact of researchers may be different. So we considered the geographical influence as an important part of a researcher's academic influence. In this study, we established a new index, the geographical impact factor (GIF), to measure the geographical influence of researchers in a specific scientific field during a certain period.

Remote sensing, as a practical and advanced space exploration technology, offered a lot of valuable data about the earth surface for global analysis, detailed assessment, environmental monitoring, mapping, change detection, disaster management, and civil and military intelligence (Benz et al. 2004; Hijmans et al. 2005; Song et al. 2001; Jackson et al. 1999; Tralli et al. 2005). However, a comprehensive comment of the global remote sensing research has never been applied. Accordingly, we revealed the comprehensively and systematically global research trends in remote sensing by combining the new index and the traditional bibliometric methods.

Data sources and methodology

Data collection

The Science Citation Index (SCI) and Social Sciences Citation Index (SSCI) databases are deemed as most reliable bibliographic sources and have been widely applied to reveal patterns in a variety of scientific fields (Liu et al. 2011). The data were obtained from SCI and SSCI databases during 1991–2010. “Remot* sens*” (including “remote sensing”, “remote sense”, “remote sensor”, “remoting sensing”, “remote sensory”, “remoted sensing”, “remotely sensing”, “remotely sense”, “remote sensed”, “remotely sensed”, “ground remote sensing”, “aerial remote sensing”, “space remote sensing”, “satellite remote sensing”, etc.) was used to search all publications that contained these words in title, abstract, and keywords. In addition, all publications from the journals, categorized as “remote sensing” in Journal citation reports (JCR), were also gathered. We subsequently combined all the records and deleted duplicated records.

New index construction

The citing countries/territories (CTTs) are registered by all authors of all citing articles for a given researcher. The GIF is defined as the average number of CTTs per article of a given researcher. The GIF is represented as shown below.

$$\mathrm{GIF} = \frac{\sum_{i=1}^{\mathrm{TP}} \mathrm{CCT}_i}{\mathrm{TP}}$$

where, CCT_i is the citing countries/territories of the ith article for a researcher, TP is the published total articles of a given researcher. The GIF is between 0 and the total number of global countries/territories, and the GIF is equal to 1 when each article was cited on average 1 country/territory.

Research trend analysis

We plotted the geographic distribution of authors using CiteSpace (Chen 2004). The CPP, *h-index* and GIF were used to overall analyze the author’s academic influence.

In the analysis of international collaboration, publications originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK), and publications from Hong Kong and Taiwan were not included in China (Liu et al. 2011). Collaboration type was determined by author addresses. At the country/territory level, “single-country articles” was assigned if the authors’ addresses were from the same country; “internationally collaborative articles (ICAs)” was designated to those articles that were coauthored by authors from multiple countries (Zhang et al. 2010). At the research institute level, “single-institute articles” was assigned if the authors’ addresses were from the same institute; “inter-institutional collaborative articles (IICAs)” was assigned if authors were from different institutes.

Co-word analysis, based on social network analysis (SNA) and k-core analysis (Zhao and Zhang 2011; Yang et al. 2012), was employed to reveal the patterns and trends in the remote sensing field. The main output of SNA is the sociogram, which provides information about the number and strength of connections between members of a collaboration network. *K*-core analysis is commonly used in SNA to find core-edge topics. A *k*-core is a subgraph in which each node is connected to at least a minimum number (k) of other nodes in the subgraph. As k becomes larger, the relationship among the nodes will be tighter (Yang et al. 2012).

Results and discussion

Characteristics of article outputs

Using the above mentioned searching strategy, a total of 48,754 publications were identified as being remote sensing-related during 1991–2010. The annual publications related to remote sensing during 1991–2010 were displayed in Fig. 1. The annual publications increased from 1,136 in 1991 to 4,611 in 2010, which illustrated the significant increase of remote sensing research in the past 20 years. This growing scientific productivity was commonly ascribed to the increasing amount of SCI and SSCI-indexed publications (Liu et al. 2011), and there was significantly linear correlation between the articles related to remote sensing and total publications in SCI and SSCI database ($y = 224.19x + 668{,}007$, $r^2 = 0.9648$, $p < 0.0001$). Furthermore, the number of relative publications on remote sensing, defined as the ratio of the annual number of publications on remote sensing to the annual number of publications in the SCI and SSCI database, also showed a growth trend. This rising of the relative publications suggested a clear research interest in remote sensing. Article was the most-frequently used document type comprising 90.97 % of the total publications. As consistent with other bibliometric research (Liu et al. 2011; Zhang et al. 2010), only 44,353 original and peer-reviewed articles were used for further analysis as relevant citable items.

Based on the classification of subject categories in the 2010 Journal Citation Reports (JCR), remote sensing research covered 111 subject categories. Top 10 subject categories were remote sensing (24,571), imaging science & photographic technology (12,966), geochemistry & geophysics (10,002), engineering (8,969), environmental sciences & ecology (7,884), geology (7,171), meteorology & atmospheric sciences (5,765), physical geography (4,574), astronomy & astrophysics (3,272), and telecommunications (2,657). We also demonstrated annual articles of top 5 subject categories in Fig. 2. Other than remote sensing, the imaging science & photographic technology kept primacy after 2002. The number of articles in environmental sciences & ecology leaped to third in 2010 from fifth in 2007. This showed the recent emphasis on remote sensing research in imaging science & photographic technology and environmental sciences & ecology. Moreover, the volatile growth of articles of these subject categories suggested that the research focus in remote sensing shifted frequently.

Articles on remote sensing appeared in 2,327 journals, and the top 20 active journals are summarized in Table 1. There was a high concentration of remote sensing publications in these top journals. These 20 or 0.86 % out of the 2,327 journals had published 25,099 or 56.59 % of the total 44,353 articles. *International Journal of Remote Sensing* ranked first with 5,712 articles, followed by *IEEE Transactions on Geoscience and Remote Sensing* (4,901), *Remote Sensing of Environment* (3,318), *Radio Science* (2,407), and

Fig. 1 Characteristics by year of remote sensing-related articles

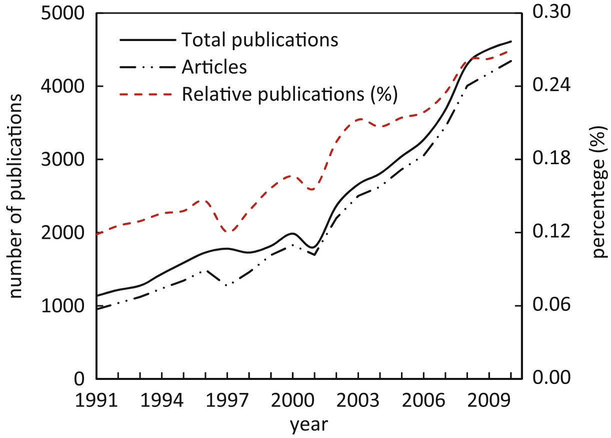
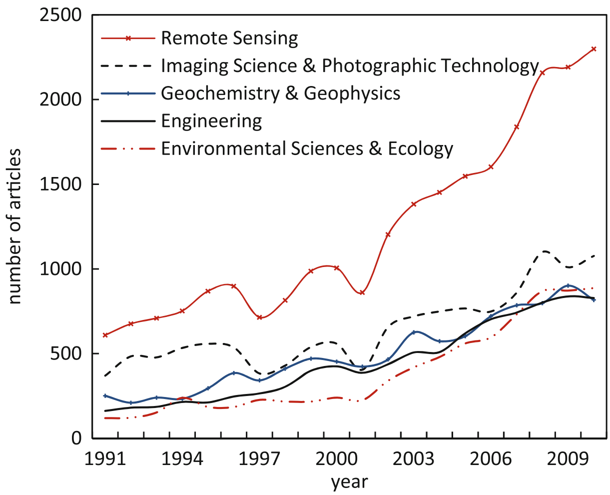


Fig. 2 Characteristics by year of the top 5 subject categories



Photogrammetric Engineering and Remote Sensing (1,884). Out of the 2,327 journals, 2,300 (98.84 %) journals have not been categorized as "remote sensing" in JCR, indicating that remote sensing has extensively applied in various fields. From the titles and themes of these top journals, we also observed the important position of geoscience, environmental sciences, radio science, and photogrammetry as subjects in remote sensing research.

Author performance and geographic distribution

A total of 43,958 articles included the author addresses. Based on the author addresses, the global geographic distribution of authors was plotted in Fig. 3. Color shades represented the number of articles, the intensity of spots represented geographic distribution of authors. The major spatial clusters of authors located in North America, Western Europe, and East Asia, followed by Russia and Australia. Africa, South America, Eastern Europe, West Asia, Central Asia, and Southeast Asia did relatively less research. The denser authors distributed in a region, the more articles on remote sensing were published in that region.

Table 2 listed the 20 most productive authors. Jackson TJ from United States Department of Agriculture, Agricultural Research Service (USDA ARS) contributed the most articles (102), followed by Wulder MA from Natural Resources Canada (94), Gong P from University of California-Berkeley (90), Ustin SL from University of California-Davis (87), and Kustas WP from USDA ARS (82). Meanwhile, the number of articles they published as the first author or the corresponding author (FCA) was also counted. Obviously, the FCA of Wulder MA ranked first (40), though he ranked second to Jackson TJ in the total number of articles. The CPP, *h-index*, and GIF were used to measure the academic impact of authors. Considering the fact that older articles are likely to higher citations, we used 5-year as fixed analysis window. Coops NC from University of British Columbia ranked first in 5-year total citations and h-index, with the CPP of 14.33, which indicated Coops NC had more high-quality articles in remote sensing research. By analyzing the citing countries/territories, the GIF of Running SW from University of Montana (15.77) was the largest, which indicated Running SW carried a greater geographical influence than other authors, followed by Baret F from French National Institute for Agricultural Research (INRA) with 14.17, and Cohen WB from USDA with 13.14.

Table 1 Top 20 active journals in remote sensing research

Journal	TA (%)	IF (R)
International Journal of Remote Sensing	5,712 (12.88)	1.117 (12)
IEEE Transactions on Geoscience and Remote Sensing	4,901 (11.05)	2.895 (6)
Remote Sensing of Environment	3,318 (7.48)	4.574 (1)
Radio Science	2,407 (5.43)	1.075 (14)
Photogrammetric Engineering and Remote Sensing	1,884 (4.25)	1.048 (15)
IEEE Geoscience and Remote Sensing Letters	960 (2.16)	1.56 (11)
Journal of Geodesy	849 (1.91)	2.414 (8)
Journal of Geophysical Research-Atmospheres	722 (1.63)	3.021 (4)
Canadian Journal of Remote Sensing	653 (1.47)	0.56 (18)
ISPRS Journal of Photogrammetry and Remote Sensing	610 (1.38)	2.885 (7)
Geophysical Research Letters	391 (0.88)	3.792 (2)
Earth Observation and Remote Sensing	379 (0.85)	0.229 (20)[a]
Applied Optics	347 (0.78)	1.748 (9)
Photogrammetric Record	331 (0.75)	1.098 (13)
Journal of Geophysical Research-Oceans	327 (0.74)	3.021 (4)
Survey Review	301 (0.68)	0.277 (19)
Journal of Applied Remote Sensing	300 (0.68)	0.818 (17)
International Journal of Applied Earth Observation and Geoinformation	260 (0.59)	1.744 (10)
Journal of Quantitative Spectroscopy and Radiative Transfer	237 (0.53)	3.193 (3)
Optical Engineering	210 (0.47)	0.959 (16)

TA (%) total articles (percentage), *IF* journal impact factor from the 2011 JCR, *R* rank in the list

[a] Journal impact factor from the 2003 JCR

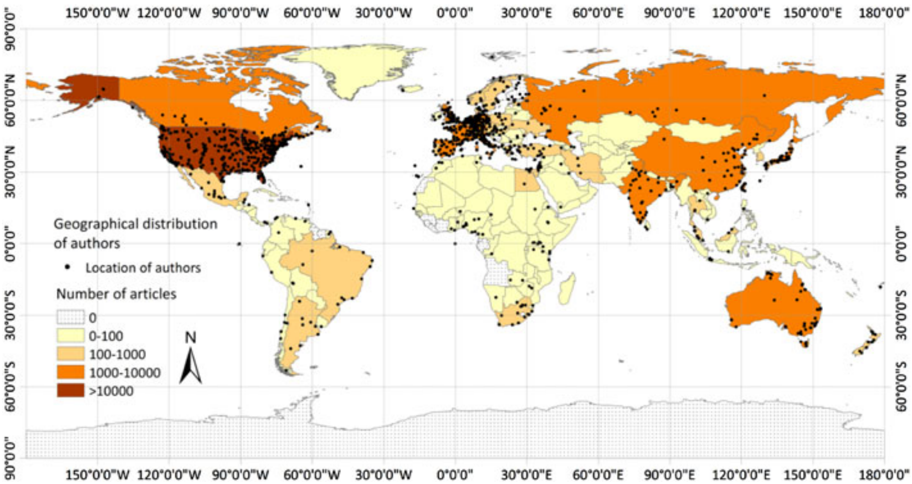


Fig. 3 Spatial distribution of authors and the article outputs of different countries

Table 2 Top 20 productive authors in remote sensing research

Author/research institute	TA	FCA (R)	In 5-year window			
			TC (R)	CPP (R)	*h*-index (R)	GIF (R)
Jackson TJ/USDA ARS	102	27 (5)	634 (9)	20.45 (9)	16 (5)	9.29 (10)
Wulder MA/Natural Resources Canada	94	40 (1)	979 (2)	15.3 (13)	20 (1)	6.98 (16)
Gong P/University of California-Berkeley	90	12 (15)	585 (10)	14.63 (14)	13 (9)	6.48 (17)
Ustin SL/University of California-Davis	87	11 (17)	638 (8)	15.95 (12)	15 (7)	9.05 (11)
Kustas WP/USDA ARS	82	27 (5)	415 (12)	20.75 (8)	13 (9)	11.4 (6)
Coops NC/University of British Columbia	75	23 (8)	1,046 (1)	14.33 (15)	20 (1)	8.1 (13)
Asner GP/Stanford University	73	33 (3)	875 (4)	21.88 (5)	18 (3)	12.43 (4)
Kaufman YJ/NASA	72	19 (13)	95 (18)	13.57 (17)	6 (17)	10.14 (9)
Cohen WB/USDA	69	22 (9)	827 (6)	29.54 (2)	17 (4)	13.14 (3)
Bruzzone L/University of Trent	66	20 (11)	870 (5)	18.91 (10)	16 (5)	9.00 (12)
Everitt JH/USDA ARS	65	31 (4)	90 (19)	4.5 (20)	6 (17)	3.30 (20)
Wigneron JP/INRA	65	21 (10)	545 (11)	25.95 (4)	12 (12)	11.52 (5)
Baret F/INRA	65	12 (15)	656 (7)	27.33 (3)	13 (9)	14.17 (2)
Tsang L/University of Washington	63	10 (18)	199 (16)	16.58 (11)	8 (15)	7.67 (15)
Running SW/University of Montana	62	6 (19)	876 (3)	39.82 (1)	15 (7)	15.77 (1)
Liang SL/University of Maryland	62	18 (14)	405 (13)	10.38 (19)	12 (12)	6.36 (18)
Strahler AH/Boston University	60	1 (20)	169 (17)	21.13 (6)	6 (17)	10.75 (8)
Karnieli A/Ben-Gurion University of the Negev	60	27 (5)	220 (14)	10.48 (18)	9 (14)	7.76 (14)
Foody GM/University of Southampton	59	38 (2)	209 (15)	20.9 (7)	7 (16)	11.00 (7)
Cihlar J/Canada Centre for Remote Sensing (CCRS)	59	20 (11)	14 (20)	14 (16)	1 (20)	6.00 (19)

TA total articles, *FCA* the number of articles published as the first author or the corresponding author, *TC* 5-year citations, *CPP* 5-year citations per articles, *h-index* 5-year h-index, *GIF* 5-year geo-influencing index, *R* rank in the list

International collaboration

Based on the author addresses, there were 174 countries/territories participated in remote sensing research. The top 20 countries/territories were ranked based on the total number of articles (Table 3). Out of these 20 countries, 12 were from Europe, 4 were from Asia, 2 were from North America, 1 was from South America, and 1 was from Oceania. The result was as same as geographic distribution of authors. The productivity ranking of countries was headed by the USA, which was responsible for the most single-country and internationally collaborative articles. China published the second highest number of articles (3,542), followed by UK (3,540), France (3,218), Germany (3,043), and Canada (3,021).

At the country/territory level, 33,257 (75.66 %) were single-country articles and 10,701 (24.34 %) were ICAs, which indicated that independent research dominated in these countries/territories. Although both single-country articles and ICAs increased in the last 20 years, the annual percentage of single-country articles decreased from 88.70 % in 1991 to 68.62 % in 2010, in contrast, the annual proportion of ICAs increased from 11.30 % in 1991 to 31.38 % in 2010 (Fig. 4), which suggested that the academic communities of remote sensing research gradually became more internationally connected. Moreover, the USA is main partner of other 17 countries/territories except Switzerland and Greece

Table 3 Top 20 major countries/territories in remote sensing research

Country/territory	TA	Single-country		ICAs		
		SA	%	CA	%	MC (A)
USA	17,852	12,773	71.55	5,079	28.45	China (686)
China	3,542	2,076	58.61	1,466	41.39	USA (686)
UK	3,540	1,806	51.02	1,734	48.98	USA (553)
France	3,218	1,448	45.00	1,770	55.00	USA (633)
Germany	3,043	1,486	48.83	1,557	51.17	USA (445)
Canada	3,021	1,795	59.42	1,226	40.58	USA (581)
Italy	2,778	1,574	56.66	1,204	43.34	USA (386)
India	2,063	1,704	82.60	359	17.40	USA (149)
Japan	1,605	865	53.89	740	46.11	USA (279)
Australia	1,534	855	55.74	679	44.26	USA (271)
The Netherlands	1,424	545	38.27	879	61.73	USA (209)
Spain	1,313	669	50.95	644	49.05	USA (195)
Russia	1,092	628	57.51	464	42.49	USA (175)
Brazil	786	439	55.85	347	44.15	USA (198)
Switzerland	668	231	34.58	437	65.42	Germany (132)
Sweden	618	298	48.22	320	51.78	USA (86)
Finland	617	318	51.54	299	48.46	USA (60)
Belgium	549	233	42.44	316	57.56	USA (88)
Taiwan	532	295	55.45	237	44.55	USA (170)
Greece	491	261	53.16	230	46.84	UK (83)

TA total articles, *SA* single-country articles, *CA* internationally collaborative articles, *R* rank in the list, *MC (A)* major collaborator (the number of collaborated articles between two countries)

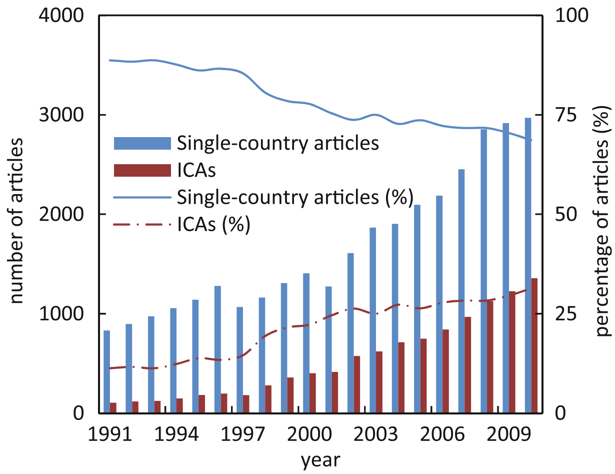


Fig. 4 Characteristics by year of single-country articles and ICAs

(Table 3), which indicated that USA took the core position in international collaboration on remote sensing research.

There were 14,384 research institutes participated in remote sensing research. The USA's dominance in remote sensing research has extended to institutional level. Among top 20 institutes in Table 4, 15 were in the USA, 2 were in China, and other 3 institutes were from Italy, Russia, and France, respectively. The National Aeronautics and Space Administration (NASA) led institutional productivity with 2,367 articles, followed by the Chinese Academy of Sciences with 1,385, the Caltech with 1,019, the University of Maryland with 856, and the National Oceanic and Atmospheric Administration (NOAA) with 838. Inter-institutional collaboration was more prevalent than international collaboration, as 12,633 (44.00 %) were single-institute articles and 18,726 (56.00 %) were IICAs (Fig. 5). The annual proportion of single-institute articles decreased from 65.46 % in 1991 to 36.18 % in 2010, and the annual proportion of IICAs increased from 34.54 % in 1991 to 63.82 % in 2010, in particular, the number of IICAs exceeded the number of single-institute articles in 2000. We also found that institutions in the same country tended to have a higher rate of collaboration, e.g. the NASA and the University of Maryland, the Chinese Academy of Sciences and the Beijing Normal University, the CNR and the University of Florence, and the CNRS and the Université Paris VI (Table 4).

Hot issues

Author keywords provided important information about research trends that concern researchers (Zhang et al. 2010). In this paper, in order to trace the dynamic changes of the remote sensing field, the whole 20-year period was further separated into four 5-year periods. Then we examine co-occurrence relationships among top 30 high-frequency keywords in each period, and the co-word networks were visualized using Ucinet6.0 (Fig. 6). The nodes are high-frequency words, the size of which is proportional to the occurrence frequency. The lines depict the connection relationship between two words, the thickness of which indicates the strength of connection. Moreover, the different colors mark degree of core or edge, and the red nodes represent the core themes in each 5-year period.

Table 4 Top 20 major research institutes in remote sensing research

Research institute/country	TA	MC (A)
NASA/USA	2,367	University of Maryland (296)
Chinese Academy of Sciences/China	1,385	Beijing Normal University (156)
Caltech/USA	1,019	NASA (136)
University of Maryland/USA	856	NASA (296)
NOAA/USA	838	University of Colorado (157)
University of Colorado/USA	670	NOAA (157)
Consiglio Nazionale delle Ricerche (CNR)/Italy	591	University of Florence (32)
United States Navy (USN)/USA	556	NASA (48)
USDA ARS/USA	527	NASA (65)
United States Geological Survey/USA	465	NASA (44)
Russian Academy of Sciences/Russia	463	NASA (12)
University of Arizona/USA	446	NASA (69)
University of Washington/USA	427	NASA (51)
University of Wisconsin/USA	403	NASA (79)
Ohio State University/USA	398	Caltech (22)
Centre National de la Recherché Scientifique (CNRS)/France	361	Université Paris VI (52)
University of California, Santa Barbara/USA	361	NASA (30)
Beijing Normal University/China	349	Chinese Academy of Sciences (156)
Boston University/USA	349	NASA (67)
Colorado State University/USA	339	NASA (45)

TA total articles, *MC (A)* major collaborator (the number of collaborated articles between two institutes)

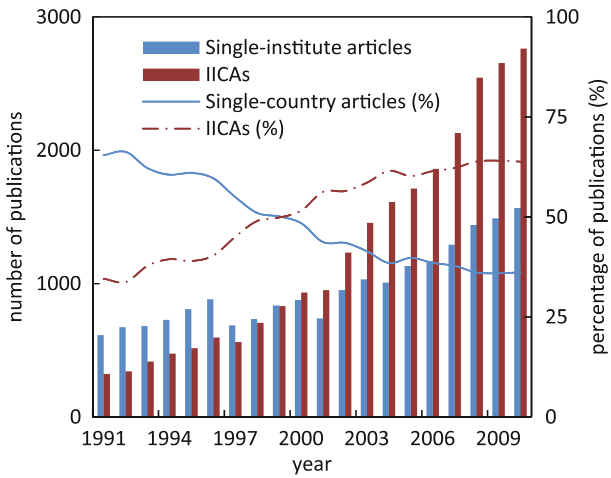
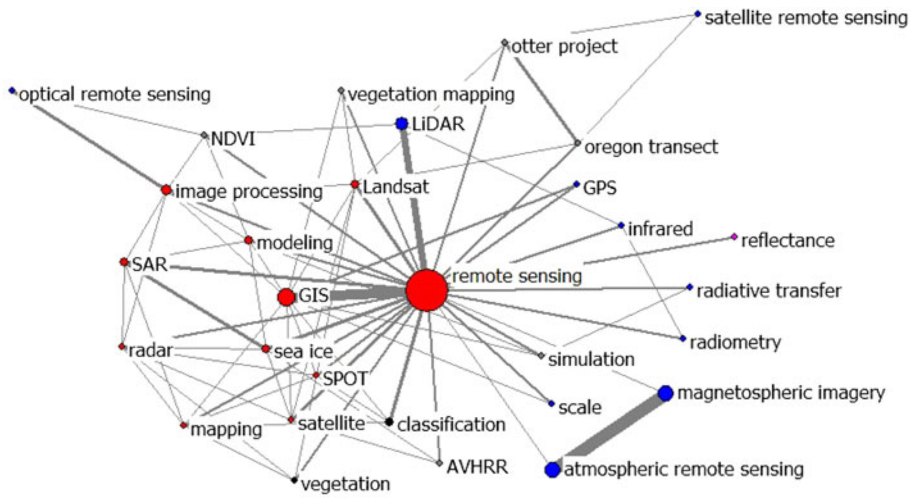
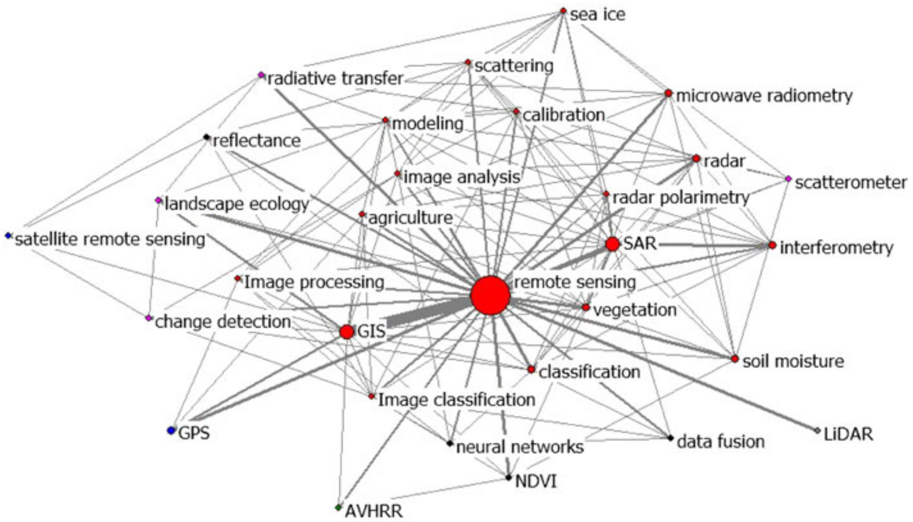


Fig. 5 Characteristics by year of single-institute articles and IICAs

Apart from "remote sensing", "GIS" was the most frequently used word during 1991–2010. Most obviously, the cooperation frequency between remote sensing and GIS has been the largest during the 4 periods. This observation revealed the integration of RS and GIS has been a main development tendency of remote sensing research (Faust et al.



a Co-work network in 1991-1995 (red nodes, *k*=5; black nodes, *k*=4; grey nodes, *k*=3; blue nodes, *k*=2; pink nodes, *k*=1)

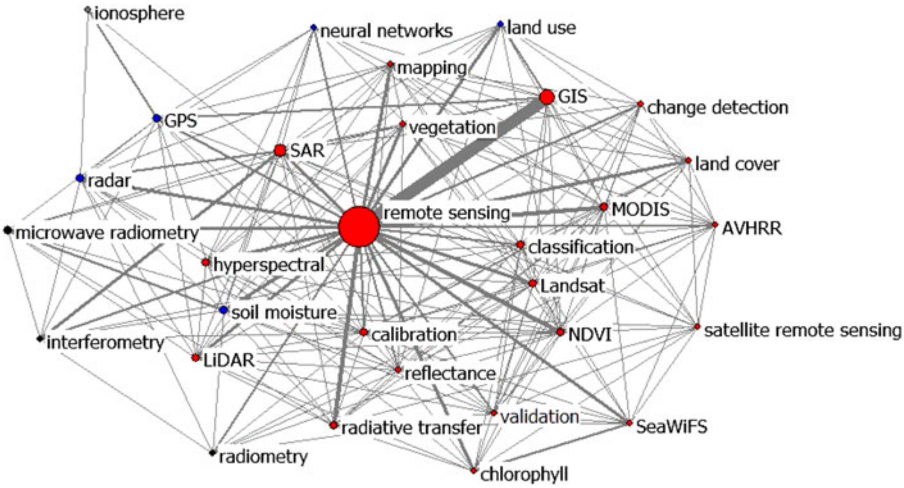


b Co-work network in 1996-2000 (red nodes, *k*=7; pink nodes, *k*=6; black nodes, *k*=5; blue nodes, *k*=4; green nodes, *k*=3; grey nodes, *k*=1)

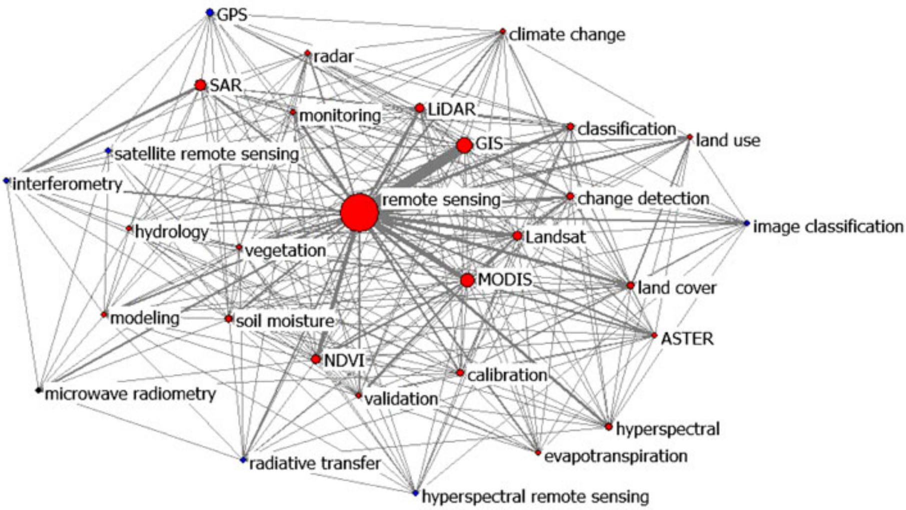
Fig. 6 Co-work networks in four 5-year periods

1991). Additionally, "hyperspectral" and "hyperspectral remote sensing" are emerging core themes in 2001–2010, revealing that "hyperspectral remote sensing" is another development tendency of remote sensing research. Hyperspectral data were effectively used to monitor the vegetation and map land cover/use (Rulinda et al. 2012; Petropoulos et al. 2012).

As high-frequency keywords, "GIS", "GPS", "modeling", "mapping", "classification", "change detection", "monitoring", "simulation", "image processing", "change



c Co-work network in 2001-2005 (red nodes, *k*=11; blue nodes, *k*=10; black nodes, *k*=9; grey nodes, *k*=3)



d Co-work network in 2005-2010 (red nodes, *k*=13; blue nodes, *k*=12; black nodes, *k*=10)

Fig. 6 continued

detection", "image analysis", "data fusion", and "calibration", "microwave radiometry", "radiative transfer", "neural networks", and "validation" were the most prevalent techniques during 1991–2010. According to *k*-core analysis, "GIS", "modeling", "monitoring", "validation", "calibration", "classification", and "change detection" are the core themes during the last 5 years. Two of the most common uses of satellite images are mapping land cover via classification and land cover change via change detection (Song et al. 2001). Timely and accurate change detection was distinctly important for understanding relationships between human and natural phenomena in order to promote better decision making (Lu et al. 2004).

The “satellite”, “landsat”, and “satellite remote sensing” continuously appeared in co-word networks in the past 20 years, which were also the core themes during 1991–1995, 2001–2010, and 2001–2005, respectively. Since its inception in 1972, the Landsat program, has been serving as a unique source for monitoring global changes, and been widely used in a sheer number of studies. The wide reception of LiDAR, radar, AVHRR, and SAR in remote sensing was revealed from co-word networks. LiDAR sensors can directly measure the distribution of vegetation and acquire three-dimensional or volumetric characterization of vegetation structure (Lefsky et al. 1999). SAR was a major tool for the investigation of ocean, agricultural crop, and forest in the last years (Tebaldini and Rocca 2012; Sletten and Hwang 2011; Jia et al. 2012). “MODIS” had not appeared in the co-work network until the period of 2001–2005, and the frequency of which was next only to “GIS” in 2006–2010. Therefore, the rise of MODIS would be a noticeable change in the recent decade. Since its launch with the Terra Satellite in 1999 and Aqua satellite in 2002, MODIS gave an unprecedented opportunity for earth remote sensing and can provide nearly global coverage and enable advanced studies of land, ocean, and atmospheric properties (King et al. 2003; Platnick et al. 2003).

“Land cover/land use” and “vegetation” are the core themes during 2001–2010, and “climate change” is the emerging core theme in 2006–2010. Remote sensing provided the best tool to predict global climate change (Robock et al. 2000; Platnick et al. 2003; King et al. 1999; Christy et al. 2007). Specifically, “NDVI”, “soil moisture”, “evapotranspiration”, and “chlorophyll” were often used to analyze land cover, vegetation, and climate (Loveland et al. 2000; He et al. 2012).

Moreover, the *k* values of red nodes in 4 periods are 5, 7, 11, and 13, respectively. The increasing trend of the *k* values showed that the relationship between core themes is increasingly tight in remote sensing field.

Relationship between remote sensing research and satellite development

There are various factors influencing the number of articles related to remote sensing, mainly including the increase of total publications in SCI and SSCI databases (as described

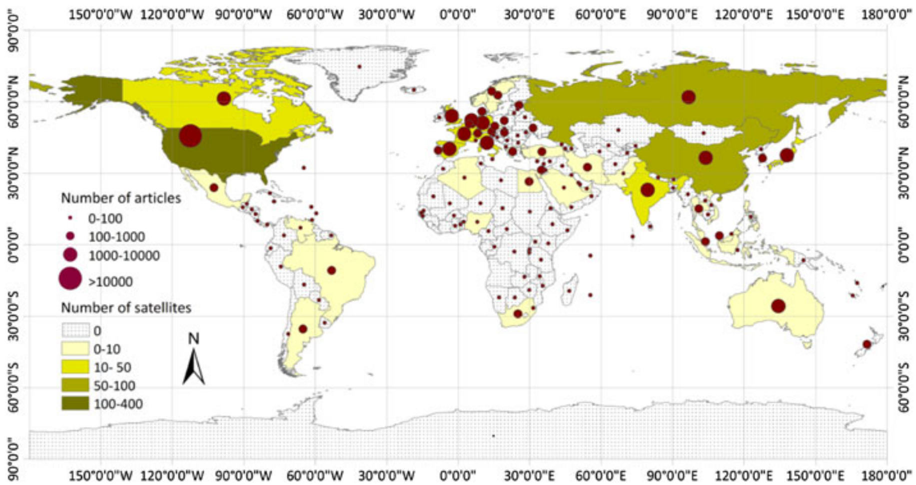


Fig. 7 Comparison spatial distributions of remote sensing research with satellites development of different countries

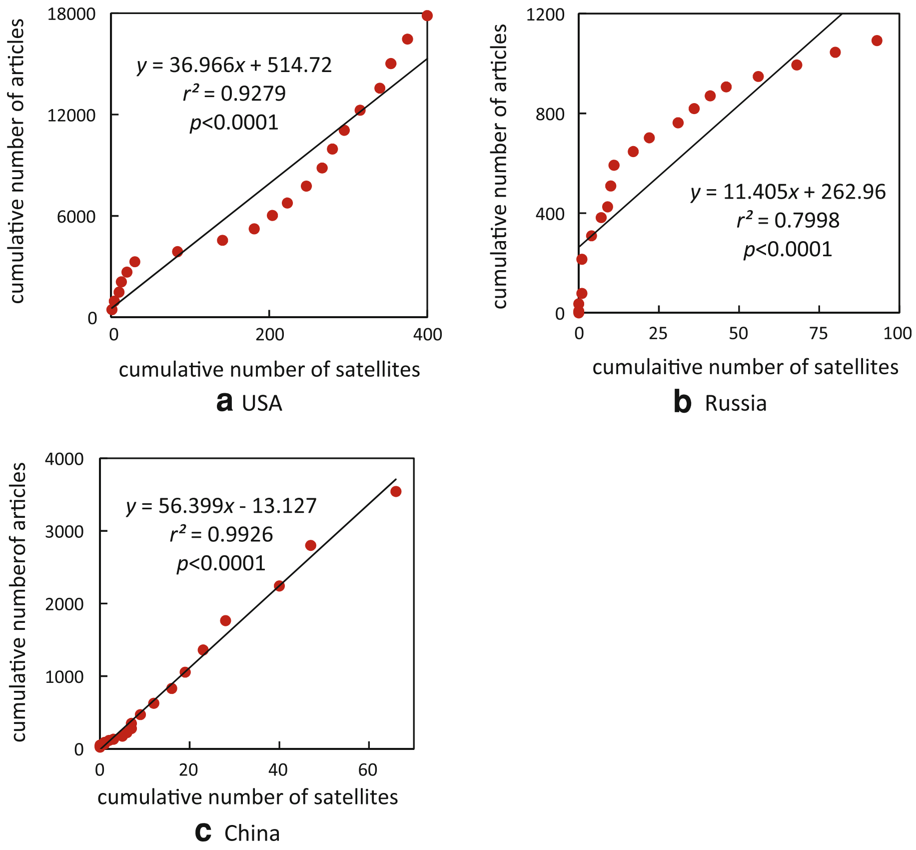


Fig. 8 Relationship between the cumulative number of articles and satellites of USA, Russia, and China during 1991–2010

in "Characteristics of article outputs"), and satellite development, etc. In this Chapter, we merely focused on the relationship between remote sensing research and satellite development.

As important remote sensing platform, satellites provided a large number of basic data for remote sensing research, which was also verified in the co-word analysis. There are 899 satellites launched all over the world until December 2010 (UCS Satellite Database, 8/1/2012: http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html). As shown in Fig. 7, the countries with more satellites produced more articles. The USA has owned and operated the most satellites (400) during 1991–2010, which is consistent with the fact that the USA produced most articles on remote sensing. Russia ranked the 2nd (93) in the number of satellites, followed by China (66). Therefore, we emphatically analyzed the correlation between the number of articles related to remote sensing and the number of satellites of these three countries by a linear regression. There were significantly linear correlations between cumulative articles and satellites of USA, Russia, and China, with the correlation coefficients r^2 of 0.9279 ($p < 0.0001$), 0.7998 ($p < 0.0001$), and 0.9926 ($p < 0.0001$), respectively (Fig. 8). This observation again revealed that satellite development is one of the main driving forces of remote sensing research.

Conclusions

This study provided an alternative perspective on the global research trends in remote sensing studies during 1991–2010. The new index, GIF, was applied to estimate author's geographical influence.

A total of 44,353 articles were listed 111 subject categories and 2,327 journals. The number of articles increased rapidly in the past 20 years. Imaging science & photographic technology and environmental sciences & ecology were important subjects in remote sensing studies. *International Journal of Remote Sensing*, *IEEE Transactions on Geoscience and Remote Sensing*, and *Remote Sensing of Environment* published most articles on remote sensing, and top 20 journals were responsible for 56.59 % of the total articles.

The spatial distribution of authors was visualized, and the main study area distributed in North America, Western Europe, and East Asia with strong scientific research capabilities, followed by Russia and Australia. Among top 20 productive authors, Jackson TJ from USDA ARS produced the most articles, Coops NC from University of British Columbia had more high-quality articles, and Running SW from University of Montana carried a greater geographical influence than other authors.

174 countries/territories and 14,384 research institutes participated in remote sensing research. At the country level, the USA attained a dominant position in global remote sensing research by contributing the largest number of single-country and internationally collaborative articles. At institutional level, NASA, Chinese Academy of Sciences, Caltech, University of Maryland, and NOAA were top five productive research institutes. Moreover, the international cooperation of remote sensing research increased distinctly.

Co-word analysis reveals trends in remote sensing research. The integration of remote sensing and GIS was the main development trend of remote sensing technology; Landsat, LiDAR, radar, AVHRR, SAR, and MODIS were the common remote sensing platform and sensors; various technologies, including GIS, modeling, monitoring, validation, calibration, classification, and change detection were widespread applied in remote sensing field; and land cover/land use, vegetation, and climate change were the major research objects.

In general, the satellite development is one of main driving forces of remote sensing research.

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