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Two geographic information system-linked bibliometric indices to quantify the knowledge flow: A case of Qinghai-Tibet plateau research

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ABSTRACT

Cited information is an important pathway of scientific influence. It can reflect the knowledge flows among research units. This study develops two new bibliometric indices—the Citation Flow Index (CFI) and the Normalized Citation Flow Index (NCFI)—to measure knowledge flows based on scientific literature citations. The CFI measures the interactions of knowledge flows among different research units. The NCFI measures the number of papers that a research unit cited and the number of papers by a research unit that are cited. The newly developed indices were tested on a country-wide scale using the literature on the Qinghai-Tibet Plateau (QTP) as an example. The results indicate that the worldwide flow of knowledge on the QTP can be quantitatively measured and spatially displayed. Additionally, the annual NCFI change trend is analyzed for each research unit.

1. Introduction

Scientific literature is one of the most important types of knowledge, and the citation of such literature is a basic form of the flow of knowledge. Against the backdrop of the rapid development of computer and Internet technologies, knowledge flow has become faster, more convenient, and internationalized (Storper, 2000). Researchers can index and download scientific literature more easily, which promotes citation. The citation of scientific literature is a bidirectional flow. Researchers cite and are cited by others. That is, a researcher demonstrates the influence of other researchers by citing their publications, which is knowledge inflow. The influence of the researcher on other researchers can also be demonstrated when papers are cited by them, which is knowledge outflow. This knowledge export through citation reflects the true value of research (Cummings, 2003). The knowledge flow expressed by citation occurs primarily among scientists. This flow can be measured at group, institution, or country levels, i.e., among collaborating researchers and researchers who contribute to more than one field (Gupta & Govindarajan, 2000; Chen, Ibekwe-SanJuan, & Hou, 2010; Ho, 2013).

2. Problem statement

The quantification of the knowledge flows among different research units (e.g. countries, regions, cities, institutions) is very important, as it can enhance understanding of a research unit's original contributions of some research results to other research units. Nowadays assessment agencies or authorities place a string emphasis on the influence of original contributions. Therefore accurate and informative indices are needed to quantitatively estimate the influence of original contributions.

The influence of original contributions is normally reflected by citation. Therefore the knowledge flow of citation is one form of information flow, and can be quantified by various bibliometric indices (Vinkler, 2010). The most common indices mainly focus on the amounts of the knowledge outflow (Garfield, 1998; Schubert & Glänzel, 2006; Hassan & Haddawy, 2013). But knowledge flow also includes knowledge inflow, and few researchers have measured these two phenomena simultaneously. To quantify knowledge flow, this study develops two bibliometric indices which are linked to geographic information systems (GIS). These two indices have the potential to provide information about knowledge inflow and outflow at the same time. The study presented here addresses the question: Can scientific knowledge inflow and outflow be spatially quantified by bibliometric indices at the same time?

3. Literature review

Several bibliometric indices have been described in the literature. The impact factor (IF) is a measure that reflects the average number of references to recent articles published in journals, in particular, academic journals (Garfield, 1998). Although the IF should indicate the likelihood of an article being cited, the IF indicates the average citation level of a journal, which does not express the true citation level of an individual paper. Other indices similar to the IF have been designed for

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citation assessment at the journal level. For example, the Gini concentration coefficient was designed as a measure of the unevenness of citation distribution (Stegmann & Grohmann, 2001). The number of times that a paper is cited is more meaningful than the IF. For a scientist, both the IF and the total number of times that all of his or her articles have been cited are typically used to assess the influence of a scientist's work. The *h*-index attempts to measure both the productivity and citation impact of the published body of work of a scientist or scholar (Hirsch, 2005). It is intended to measure simultaneously the quality and quantity of an individual's scientific research output, and was widely applied after being introduced. Since then, several variants of the *h*-index have been presented (Bornmann, Mutz, & Daniel, 2008; Schreiber, 2008).

The indices noted above involve the quantified estimation of one direction of knowledge flow: outflow. In contrast, Schubert & Glänzel (2006) used matrixes of international co-authorship, cross-references, and cross-citations to present knowledge inflow and outflow at the country level. The International Scholarly Impact of Scientific Research (ISISR) index is designed to measure the ability of a country to compete by calculating the citations made to the country's authors or researchers from outside the country in a given subject area. This represents a quantified estimation of the single direction of knowledge inflow (Hassan & Haddawy, 2013). Additionally, the distance factor is used to measure the spatial distribution pattern of bidirectional knowledge flow. Spatial distance is calculated among citing and cited papers based on the GoogleMap application programming interface (API) and Yahoo! PlaceFinder (Ahlgren et al., 2013; Wu, 2013).

4. Methods

4.1. Data and study area

The Qinghai-Tibet Plateau (QTP; 25° ~ 40°N, 74° ~ 104°E) is the world's highest and largest plateau, with an area of 2.6 million km^2 (Fig. 1). The average elevation is over 4500 m, and all 14 of the world's 8000-m and higher peaks are found in this region; it is occasionally referred to as "the roof of the world" (Qiu, 2008). It is surrounded by massive mountains. The Qinghai-Tibet Railway, Qinghai-Tibet Road, Qingkang Road, and Sichuan-Tibet Road are the main traffic corridors that connect the eastern or western regions. There are 1091 lakes of more than 1.0 km^2 in the area, which account for 49.4% of the total area of lakes in China (Jiang & Huang, 2004). Because the QTP responds to climate and environmental change rapidly (Schwalb et al., 2008), it has long been considered one of the world's "hot spots". A large number of scientific articles have been published on this region, which increases the significance of this study.

This study focuses on the international knowledge flow within the QTP literature. Therefore, the emphasis of the calculations and analysis is placed on international publications. The Web of Science maintains the world's most comprehensive, multidisciplinary, bibliographic database of research information. This database exhibits better representation when used to search scientific papers and analyze the status and trends of specific subject areas. Scientific papers, including articles, reviews, and letters, are indexed in the Science Citation Index Expanded (SCIE). This index was searched with the title keyword query "Tibet* or Xizang or Qinghai or Qinghaitibetan or Kunlun or Hengduan or Himalayas or Qilian or Gangdise or Muztagata or (Muztag Ata) or Everest". This rendered 7448 papers published from 1900 to 2012 that focus on the QTP. There were 31,445 papers published from 2000 to 2012 that cited these papers. The total number of citations was 92,468.

4.2. Citation Flow Index

Citation Flow Index (CFI) measures the knowledge flow of literature citations. This index can be described by the following formula:

$$CFI = \frac{C_{a\to b} - C_{b\to a}}{C_{a\to b} + C_{b\to a}} \quad (2)$$

where $C_{a\to b}$ denotes the number of studies by research unit *a* cited by research unit *b* in the given research areas during a given time period. Conversely, $C_{b\to a}$ indicates the number of times that research unit *b* is cited by research unit *a* in the given research areas during a given time period. To explain the meaning of the CFI, a test was performed. The $C_{a\to b}$ ranges from 0 to 1000 times at the step of 10 times, and $C_{b\to a}$ ranges from 1000 to 0 times at the step of 10 times. Then, the CFI

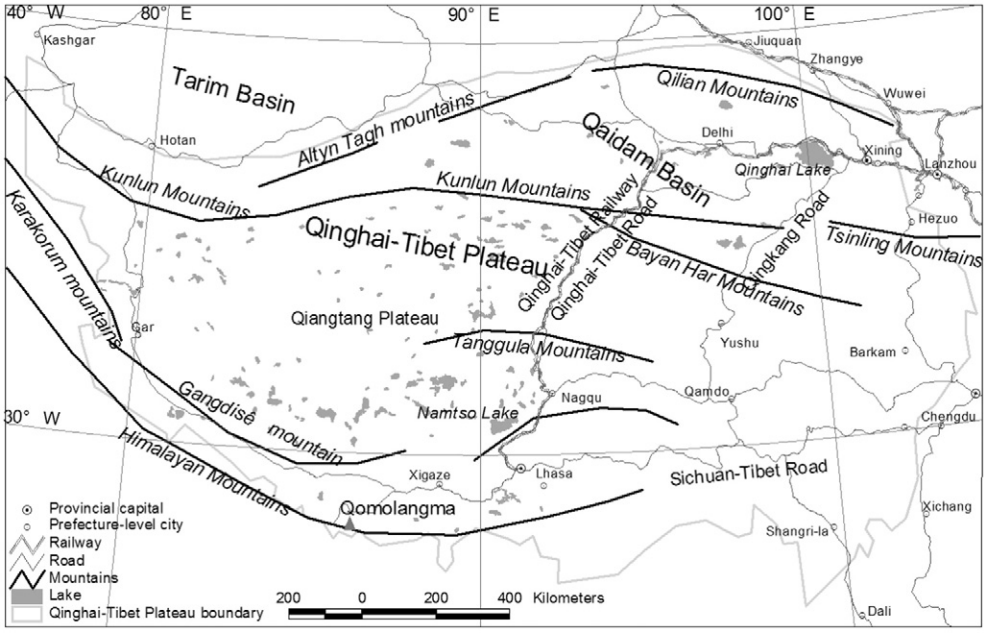

Fig. 1. Study area.

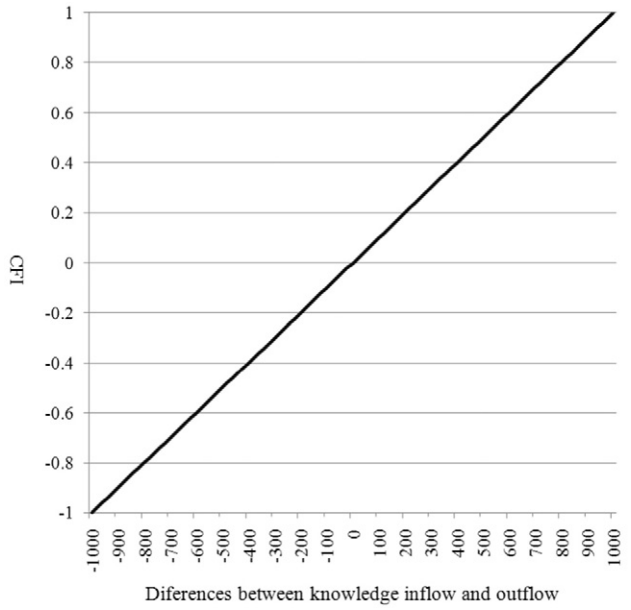

Fig. 2. Relationship among the CFI values and differences between $C_{a\to b}$ and $C_{b\to a}$.

was calculated (Fig. 2). The CFI values range from −1 to 1, which is non-dimensional. When the number of citations of one unit by the other unit is 0, the CFI reaches the endpoint value of −1 or 1. As the differences between $C_{a\to b}$ and $C_{b\to a}$ increase, the absolute values of the CFI increase accordingly, which represents a strict linear relationship. Thus, the CFI can provide a quantitative description of the knowledge flow based on the literature citations. A positive value indicates that the number of citations of unit *a* by unit *b* is more than that of unit *b* by unit *a*. Conversely, a negative value indicates that the number of citations of unit *b* by unit *a* is more than that of unit *a* by unit *b*. Therefore, the CFI can also represent the direction of the knowledge flow.

The CFI can be used to represent the interaction of the literature citations between two research units. For a given research unit, the index can be adjusted to measure the difference between the number of citations made by the research unit and the number of times that the research unit is cited. For a given research unit, such as a researcher, institution, or country, the number of publications and the number of citations of those publications (cited number) are highly sensitive to the unit size. Research units cannot be compared on absolute number of citations, as the size of these units must be considered. The adjusted index can normalize the absolute numbers of citations to allow for comparisons between research units. This adjusted index is defined as the Normalized Citation Flow Index (NCFI). The NCFI is described by the following formula:

$$NCFI = \frac{C_{out} - C_{in}}{C_{out} + C_{in}} \tag{3}$$

where C_{out} denotes the number of times a given research unit *a* is cited by all of the other research units in the given research areas during a given time period, which represents the knowledge output from unit *a*, and C_{in} denotes the number of times research unit *a* cites all of the other research units in the given research areas during a given time period, which represents the knowledge input to unit *a*. A positive NCFI value means that unit *a* has more knowledge output than knowledge input, whereas a negative NCFI value means that unit *a* has more knowledge input than knowledge output. The extremes of −1 and 1 indicate no knowledge output or no knowledge input, respectively.

4.3. Definition of "other-citations"

Self-citations typically refer to cited references that contain an author name that matches the name of one of the authors of a citing article. Here, the definition of the self-citations was expanded to the research unit, such as an author, institution, or country. In this study, the research unit is the country. Therefore, self-citations refer to cited references that contain an author affiliation country name that matches the author affiliation country name of a citing article. Correspondingly, other-citations is used here to refer to cited references that contain an author affiliation country name that is different from the author affiliation country name of a citing article. This represents the real knowledge flow statistics among countries at the country level.

4.4. Information extraction

In this study, for the sake of convenience of data gathering and analysis, the country name information of the articles was only extracted from the first author's affiliations. The place name dictionary is an important component of that information extraction. A place name directory was made before the information extraction. For example, Hong Kong and Macau were standardized into China. The UK, England, Scotland, Wales, and North Ireland were standardized into England. Then the country name of the first author's affiliations was extracted for each cited or citing article.

4.5. Spatial display using GIS tools

The CFI or NCFI values are linked with special research units. These units have spatial position attributions. Therefore geographical information system (GIS) tools can be used to display spatial distribution and

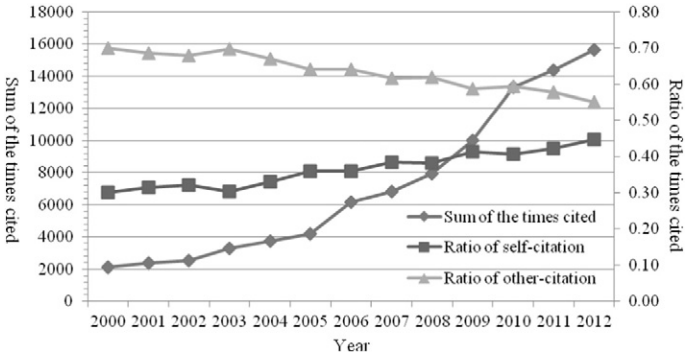

Fig. 3. Total number of citations and ratio of self-citations to other-citations.

Table 1
Top 20 countries or regions with high knowledge flows on the Qinghai-Tibet Plateau from 2000 to 2012.

Country name	Pubnum	Citedpapnum	Citedtime	Avecitedtime	Othcitedtime	Perothcited	Ctingtime	Othcitingtime	*h*-index	NCFI
France	210	184	8854	42.2	7806	88.16	3536	2488	49	0.517
USA	867	762	26,863	31	18,124	67.47	18,166	9427	79	0.316
Nepal	34	24	264	7.8	227	85.98	163	126	7	0.286
Taiwan	43	36	1368	31.8	1228	89.77	913	773	15	0.227
Austria	35	31	722	20.6	688	95.29	537	503	11	0.155
Canada	100	90	2634	26.3	2312	87.78	2363	2041	26	0.062
England	228	181	4675	20.5	3915	83.74	4380	3620	36	0.039
Australia	64	49	1498	23.4	1391	92.86	1414	1307	20	0.031
Belgium	23	17	297	12.9	256	86.2	286	245	8	0.022
Japan	275	233	3092	11.2	2111	68.27	3154	2173	29	−0.014
New Zealand	15	12	172	11.5	161	93.6	234	223	7	−0.161
Germany	216	185	3374	15.6	2517	74.6	4601	3744	31	−0.196
China	3994	2904	32,431	8.1	11,130	34.32	38,847	17,546	61	−0.224
Italy	67	54	932	13.9	735	78.86	1370	1173	19	−0.23
India	690	434	2960	4.3	1511	51.05	4015	2566	23	−0.259
Netherlands	34	23	351	10.3	285	81.2	579	513	10	−0.286
Switzerland	38	36	686	18.1	581	84.69	1174	1069	15	−0.296
Norway	35	24	194	5.5	165	85.05	476	447	7	−0.461
Korea	25	20	193	7.7	156	80.83	561	524	9	−0.541
Sweden	18	16	94	5.2	73	77.66	321	300	5	−0.609

Note: Pubnum: the total number of publication as first authors; Citedpapnum: the total number of papers cited as first authors; Citedtime: the total cited numbers; Avecitedtime: the average cited times per paper; Othcitedtime: the total cited number with other-citation; Perothcited: the percentage of the other-citation in the total cited numbers; Ctingtime: the total citing times; Othcitingtime: the total cited number with other-citation; *h*-index: Hirsch index; NCFI: Normalized Citation Flow Index.

knowledge flow networks on maps. The GIS tool used here was ESRI Arcview GIS 3.3.

5. Results

5.1. Basic statistical results

As described above, there were a total of 31,445 papers published from 2000 to 2012 that cited the 7448 papers that focused on the QTP. Certain papers were removed, either because they did not indicate author affiliations, or had zero cited records This left 5413 papers with effective cited records, and the total effective number of cited times was 92,468. The other-citations totalled 56,037, and self-citations totalled 36,431. There is a continuously increasing trend in the sum of the times a paper is cited (Fig. 3). The other notable characteristic is that the proportion of other-citations decreases and the proportion of self-citations increases continuously. Thus, these ratios converge at some point.

Table 1 presents the top 20 countries or regions with higher knowledge flows on the QTP for 2000–2012. China published 3994 papers, which was the highest for any country and represented 53.6% of the total. The reason for China's dominance in research on the QTP is obvious; the largest part of the region lies in China. The United States (USA), India, Japan, Germany, France, and Canada have the next highest numbers of published papers in descending order. Papers published in China were also cited the most. However, the USA had the highest number of other-citations, which indicates that the USA has the highest knowledge flow output to other countries or regions. The values of the *h*-index and NCFI were calculated for each country or region. The *h*-index is related to the number of published papers and the number of cited papers. A larger number of published papers typically displays a higher *h*-index. In contrast, the NCFI values are not related to the number of published papers. Although China, India, Japan, and Germany have more published papers, they have negative NCFI values, indicating that there is more input knowledge flow in these countries regarding QTP research. France has the highest NCFI (0.517) and Sweden has the lowest (−0.609). The NCFI is correlated with the average number of times the papers are cited, and the correlation coefficient is 0.77 for these 20 countries or regions.

For estimating the advantage of these newly developed indices, a correlation analysis was carried out among the new indices with the other established literature knowledge flow indices (Table 2). It can be seen that most of the indices are highly correlated with other indices. For example, the *h*-index has a significant correlation at 99% level with the total cited number with other-citation ($r = 0.9605$), the total cited numbers ($r = 0.8925$), the total cited number with other-citation

Table 2
Correlation coefficients among the literature knowledge flow indexes.

	Pubnum	Citedpapnum	Citedtime	Avecitedtime	Othcitedtime	Perothcited	Ctingtime	Othcitingtime	*h*-index	NCFI
Pubnum	1	0.9986*	0.8539*	−0.1345	0.5948*	−0.8275*	0.9667*	0.9426*	0.6133*	−0.0409
Citedpapnum	0.9986*	1	0.8782*	−0.105	0.6317*	−0.8218*	0.9399*	0.957*	0.6462*	−0.0176
Citedtime	0.8539*	0.8782*	1	0.21	0.9226*	−0.6936*	0.9517*	0.9593*	0.8925*	0.2366
Avecitedtime	−0.1345	−0.105	0.21	1	0.4492	0.3601	0.0063	0.0611	0.4794	0.7718*
Othcitedtime	0.5948*	0.6317*	0.9226*	0.4492	1	−0.4933	0.7635*	0.7995*	0.9605*	0.4245
Perothcited	−0.8275*	−0.8218*	−0.6936*	0.3601	−0.4933	1	−0.7895*	−0.7863*	−0.5468	0.2459
Ctingtime	0.9667*	0.9399*	0.9517*	0.0063	0.7635*	−0.7895*	1	0.9926*	0.7623*	0.06
Othcitingtime	0.9426*	0.957*	0.9593*	0.0611	0.7995*	−0.7863*	0.9926*	1	0.8177*	0.094
h-index	0.6133*	0.6462*	0.8925*	0.4794	0.9605*	−0.5468	0.7623*	0.8177*	1	0.4367
NCFI	−0.0409	−0.0176	0.2366	0.7718*	0.4245	0.2459	0.06	0.094	0.4367	1

* Correlation is significant at the level $p \le 0.01$; Pubnum: the total number of publication as first authors; Citedpapnum: the total number of papers cited as first authors; Citedtime: the total cited numbers; Avecitedtime: the average cited times per paper; Othcitedtime: the total cited number with other-citation; Perothcited: the percentage of the other-citation in the total cited numbers; Ctingtime: the total citing times; Othcitingtime: the total cited number with other-citation; *h*-index: Hirsch index; NCFI: Normalized Citation Flow Index.

Table 3
CFI values among the top 10 countries or regions with high knowledge flows on the QTP from 2000 to 2012.

Input countries / *Output countries*	China	USA	India	Japan	Germany	France	England	Canada	Italy	Australia
China	N/A	−0.401	0.371	−0.109	0.032	−0.650	−0.203	−0.039	0.110	−0.227
USA	0.401	N/A	0.638	0.314	0.400	−0.317	0.183	0.102	0.369	0.144
India	−0.371	−0.638	N/A	−0.013	−0.225	−0.760	−0.527	−0.264	0.315	−0.229
Japan	0.109	−0.314	0.013	N/A	0.434	−0.585	−0.241	−0.283	0.687	0.238
Germany	−0.032	−0.400	0.225	−0.434	N/A	−0.679	−0.189	−0.391	0	−0.377
France	0.650	0.317	0.760	0.585	0.679	N/A	0.299	0.311	0.438	0.380
England	0.203	−0.183	0.527	0.241	0.189	−0.299	N/A	−0.075	0.268	−0.100
Canada	0.039	−0.102	0.264	0.283	0.391	−0.311	0.075	N/A	0.196	0.250
Italy	−0.110	−0.369	−0.315	−0.687	0	−0.438	−0.268	−0.196	N/A	−0.086
Australia	0.227	−0.144	0.229	−0.238	0.377	−0.380	0.100	−0.250	0.086	N/A

($r = 0.8177$), the total citing times ($r = 0.7623$), the total number of papers cited ($r = 0.6462$) and the total number of publication ($r = 0.6133$) as first authors. But the NCFI is not correlated with most of the other indices. It only has significant correlation at 99% level with the average cited times per paper ($r = 0.7718$), which means that the NCFI has better independence. Compared with the other literature citation flow indices, the new indices can estimate both knowledge inflow and outflow.

5.2. Interactive CFI among countries with respect to literature citation on the QTP

Table 3 shows the CFI values for the top 10 countries with higher knowledge flows on the QTP. The sum of cited and citing paper numbers of these 10 countries represents more than 87% of the total knowledge flow. Therefore, the analysis of these countries can indicate the primary

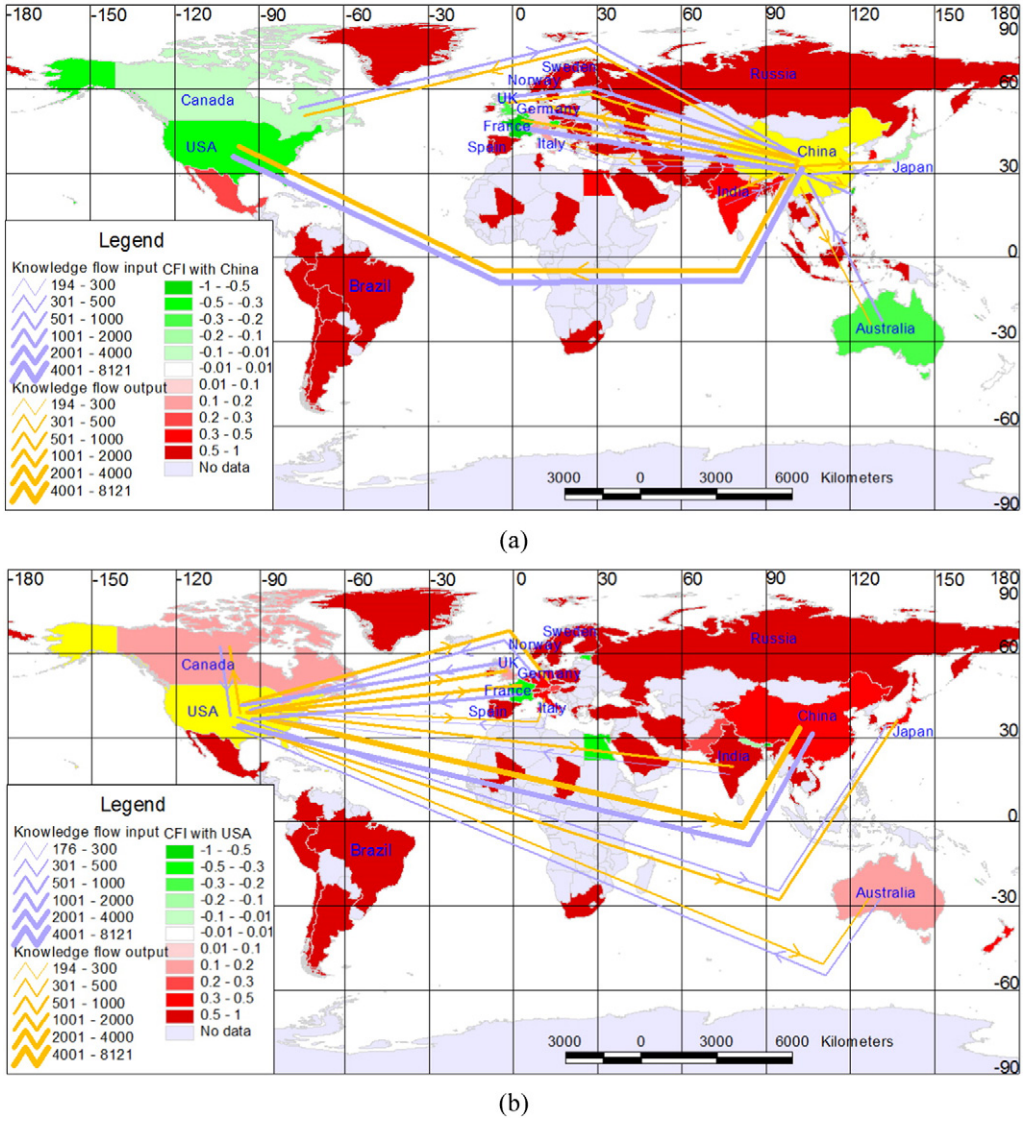

Fig. 4. Knowledge flows of China (a) and the USA (b) with the other countries or regions regarding the QTP from 2000 to 2012.

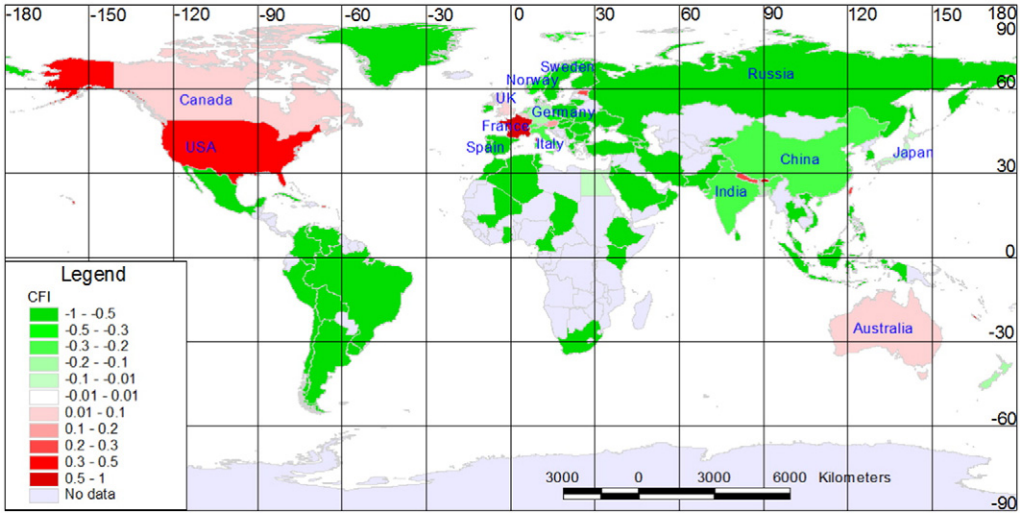

Fig. 5. NDCI of all countries or regions from 2000 to 2012.

characteristics of the interactive CFI among countries with respect to literature citation on the QTP. France has positive CFI values, as do nine other counties. France has the highest NCFI value of these 10 countries. After France, the USA exhibits the second-highest CFI value and has high NCFI value. In contrast, Italy, India, and Germany have mainly negative CFI values, and their NCFI values are also negative. Japan, England, and Australia have nearly equal positive and negative CFI values, and their NCFI values are close to zero. Although China has negative CFI values with six countries and positive CFI values with three countries, China exhibits a relatively lower negative NCFI value. This outcome results from the CFI of −0.401 between China and the USA. The sum of citing and cited paper numbers between these two countries represents 40.4% of the total amount forChina. Canada displays similar figures. Canada has positive CFI values with seven countries and negative CFI values with two countries. However, Canada's NCFI is close to zero. The knowledge flow between Canada and the USA represents 31.6% of the total amount, and the CFI between Canada and the USA is −0.102.

5.3. CFI values of China and the USA with other countries with respect to literature citation on the QTP

The CFI can be used to quantify the knowledge flow of one country with other countries or regions. Here, China and the USA are analyzed as an example. Fig. 4(a) illustrates China's knowledge flow regarding the QTP from 2000 to 2012 with other countries or regions. China has positive CFI values with most of the countries and regions (red). In addition, China has negative CFI values with several countries and regions, such as the USA, France, Canada, England, and Australia. Two types of lines can be used to connect two countries or regions. The line's colour and arrow indicate the knowledge flow's direction. The line's size indicates the amount of the knowledge flow. In Fig. 4, the orange lines indicate the knowledge flow output from China to other countries or regions, whereas the blue lines show the knowledge inflow to China from other countries or regions. The 10 countries and regions with the largest knowledge flows are represented in the map. The sum of the citing and cited paper numbers represents 88.2% of the total amount. Moreover, China has primarily negative CFI values with these countries and regions. As a result, China has more input knowledge flow than output flow, and the Chinese NCFI value is negative.

Fig. 4(b) illustrates the knowledge flow of the USA with the other countries or regions. The USA has positive CFI values with most countries and regions. Negative values are only observed for five countries: France, Nepal, Estonia, Egypt, and Bhutan. Only France is among the top 10 countries and regions with a larger amount of knowledge flow than the USA. Thus, the USA has more input knowledge than output knowledge flow and has a positive NCFI value.

5.4. NCFI of countries with respect to literature citation on the QTP

Fig. 5 presents a spatial distribution map of the NCFI values for all countries. Most countries or regions have negative NCFI values. In other words, most countries have more knowledge input flows than output flows with respect to the QTP literature. Only 11 countries or regions have positive NCFI values: the USA, France, Taiwan, England,

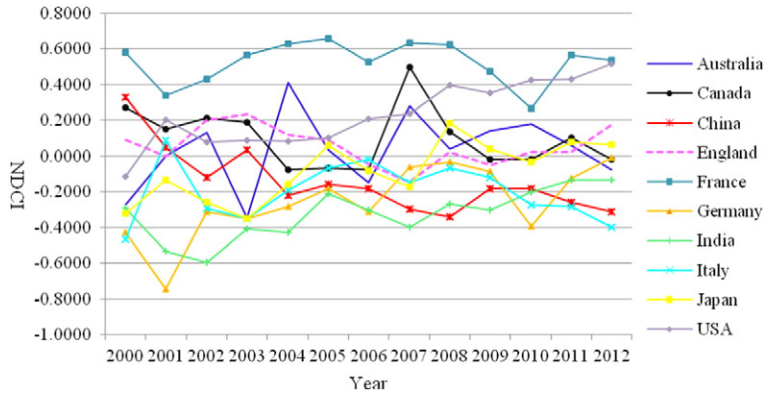

Fig. 6. Annual changes in the NDCI for the top 10 countries or regions with higher knowledge flows on the QTP from 2000 to 2012.

Table 4
Annual change trend of the top 10 countries with high knowledge flows on the QTP from 2000 to 2012.

Countries	Regression equation	*R*	Change trend
China	$y = -0.0362x + 0.1594$	0.80	Decreasing
USA	$y = 0.0452x - 0.1352$	0.92	Increasing
India	$y = 0.0259x - 0.4433$	0.66	Increasing
Japan	$y = 0.0341x - 0.295$	0.78	Increasing
Germany	$y = 0.0348x - 0.4752$	0.66	Increasing
France	$y = 0.0013x + 0.4782$	0.04	Stable
England	$y = -0.0134x + 0.2378$	0.43	Decreasing
Canada	$y = -0.0188x + 0.2463$	0.45	Decreasing
Italy	$y = -0.0116x - 0.1011$	0.26	Decreasing
Australia	$y = 0.0136x - 0.0483$	0.26	Increasing

Canada, Austria, Nepal, Australia, Bhutan, Estonia, and Belgium. The sum of the differences between output flows and input flows of these 11 countries or regions is 15,474. The magnitude of these differences is relatively large. The USA and France have a total difference of 14,015, which represents 90.5% of the total differences. In addition, the sum of the differences between output flows and input flows of the other 104 countries or regions is −15,474. The absolute amount of these differences is relatively smaller. The highest value is for China (6416); Germany is second, with a difference of 1227. There are more countries with negative NCFI values than countries with positive NCFI values.

The top 10 countries with high knowledge flows from 2000 to 2012 were selected to analyze the change tendency of the annual NCFI values (Fig. 6). There are substantial differences among these 10 countries (Table 4). China displays the largest decreasing NCFI trend for 2000 to 2012, which indicates that it has had more knowledge inflow recently. England, Canada, and Italy also exhibit decreasing NCFI trends. The USA has the largest increasing NCFI trend, which indicates that it has more knowledge outflow to other countries recently. Additionally, Germany, Japan, India, and Australia have increasing NCFI trends. France has a relatively stable change trend. According to Pearson's *r*, the USA, China, Japan, India, and Germany have persistent increasing or decreasing change trends, whereas the NCFI values of the other countries fluctuate significantly from 2000 to 2012.

The number of published papers during different periods may be the primary influence on the change trend of the annual NCFI values. Fig. 7 shows the number of published papers on the QTP for China, the USA, and France from 2000 to 2012. China published a small number of papers prior to 2000. More than 90% of the papers were published from 2000 onwards, and there is a rapidly increasing trend. The citation of literature requires a certain period of time. Thus, these papers have not been cited as much as older papers, as seen by the average number of citations (Table 1). However, the rapid increase in the number of publications inevitably results in a rapid increase in citing records. Therefore, China exhibits continuously decreasing NCFI values on the time scale.

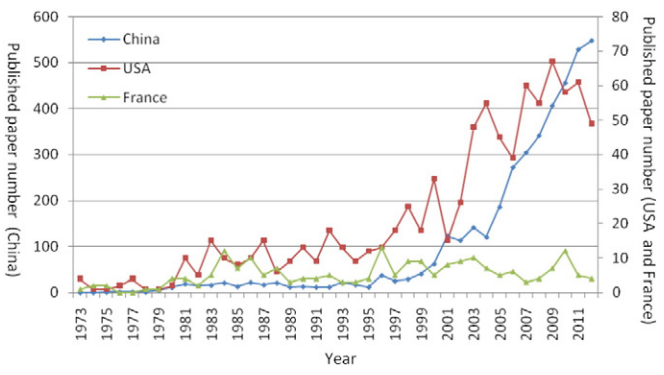

Fig. 7. Number of papers published on the QPT in China, the USA, and France from 2000 to 2012.

The USA had a stable number of papers published in the 1980s and 1990s. Additionally, the USA displays an increasing trend in this century. However, the rate of increase is not as rapid as that of China. The USA is the most important knowledge output flow resource for China. China's fast-increasing need for knowledge could explain the fast increase in the cited records of the USA, which results in the increasing trend of annual NCFI values for the USA. France exhibited a similar number of published papers during the 1980s, 1990s, and 2000s, resulting in France's relatively stable change trend.

6. Discussion

Few previous works have considered not only input but also output flow of knowledge. Preference indicators of cross-reference and cross-citation are representatives of the ratio indices (Schubert & Glänzel, 2006). The spatial diversity citation rank (SDCR) uses spatial diversity to measure the impact of authors in author citation networks (Wu, 2013). However, the new indices also attempt to measure both knowledge inflow and outflow between two research units or within a research unit itself. Compared with previous research, this study has developed indices with directional information regarding net knowledge flow by using positive and negative values. These indices are more suitable for GIS display and analysis, as seen in geospatial maps.

Any index can describe quantitative characteristics to a certain degree. However, it is difficult to represent all knowledge flow information using one index. The CFI and NCFI are normalized indices which can measure the ratio of net knowledge flows to total knowledge flow amount, and the CFI and NCFI can allow for comparisons among different research units. However, they cannot indicate the absolute amount of knowledge inflow and outflow. Therefore, the CFI or NCFI need to be used together with the other indices and then the knowledge flow can be described more comprehensively.

The CFI and NCFI were used to quantify knowledge flows of journal publications. However, there are many other formats which contribute to knowledge flow. One example might article-to-patent and patent-to-article flow. It would be interesting to apply CFI and NFCI analysis to this and other formats of knowledge flow.

7. Conclusion

The two new indices, CFI and NFCI, were shown to be able to measure knowledge flow (as represented by citation behaviour) among different research units, and further they can enable geospatial displays when considering country affiliation information. The indices can quantitatively describe knowledge inflow and outflow of citations simultaneously. In addition, the indices indicate the net knowledge flow direction. The test case analysis of knowledge flow characteristics of scientific articles published on the Qinghai-Tibet Plateau (QTP) can help researchers comprehend the characteristics and tendencies of international research in this region. These two indices can be linked with geographic units and spatially displayed and analyzed using GIS tools, which can promote the integration of GIS technologies in bibliometrics, and can enhance assessment of influence in knowledge flow.

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