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Trends in research on global climate change: A Science Citation Index Expanded-based analysis

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ABSTRACT

This study was conceived to evaluate the global scientific output of climate change research over the past 18 years and to assess the characteristics of the research patterns, tendencies, and methods in the papers. Data were based on the online version of Science Citation Index Expanded from 1992 to 2009. Articles referring to climate change were assessed by distribution of source countries, source institutes, paper titles, author keywords, KeyWords Plus, abstracts, and the most cited articles in these years. By synthetic analysis of the four kinds of keywords, it was concluded that the items "temperature", "environment", "precipitation", "greenhouse gas", "risk", and "biodiversity" will be the foci of climate change research in the 21st century, while "model", "monitoring", and "remote sensing" will continue to be the leading research methods. A novel method, "phylogeography", may have a strong application potential in the near future.

1. Introduction

Climate change refers to an alteration in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer (IPCC, 2007). Climate change reflects abnormal variations in the Earth's atmosphere and subsequent effects on other parts of the planet, such as on crop lands, reducing the annual yield (Challinor et al., 2007), and the melting of polar ice leading to a rise in sea level and flooding of low-lying countries and the plains that provide food (Wassmann et al., 2004). The oceans are growing more acidic because of CO_2 absorption, which makes it harder for animals like corals and clams to build and maintain their shells and skeletons (Hoegh-Guldberg, 1999). Moreover, climate change can result in higher future ozone levels over polluted areas (Nolte et al., 2008). At the end of the nineteenth century, Svante Arrhenius and Arvid Högbom suggested that temperature might be affected by greenhouse gases (Heimann, 2005). In an early study, there were arguments about whether the Indian climate had changed (Lockyer, 1910). Hubert Horace Lamb (1913–1997) was among the first to alert the scientific community to the natural vagaries of climate over recent centuries and millennia, and to point to their possible effects on human societies (Kelly, 1997). The first and now iconic examples documenting global climate change were the precise measurements of the concentration of CO_2 in the atmosphere made at the mountain station on Mauna Loa, Hawaii, by Charles David Keeling (1928–2005) (Heimann, 2005). This work prepared the ground for the public and political acceptance of the threat that would, in 1992, result in the United Nations Framework Convention on Climate Change — the international community's initial response to this pressing environmental problem (Kelly, 1997). Climate change has become a major scientific, political, economic, and environmental issue during the last decade (Hoegh-Guldberg, 1999; Walther et al., 2002; Watson, 2003; IPCC, 2007). Scientific articles on climate change have demonstrated a rapid increase in quantity over the past several decades, and a number of papers presenting the latest research achievements have been published in authoritative scientific journals such as *Nature* (Walther et al., 2002; Harte et al., 2004; Thomas et al., 2004) and *Science* (Crowley, 2000; Watson, 2003; Lobell et al., 2008). Global warming, greenhouse gases, and limitations on CO_2 emissions are at the top of the political agenda. With the international environmental treaty – the Kyoto Protocol (Bohringer, 2003) – some countries have committed to reducing their anthropogenic greenhouse gas emissions, namely CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride, by at least 5% below 1990 levels, during the commitment period 2008 to 2012. James Hansen of America's National Aeronautics and Space Administration, the first scientist to warn about global warming more than two decades ago, concluded that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm in order to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted (Hansen et al., 2008).

Despite the high growth rate of publications, there have been few attempts to gather systematic data on the global scientific production of research on climate change, except for a scientometric study by Stanhill (2001). Garfield (1970) indicated that a recent research focus should be reflected in its publication output. A common research tool for this

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analysis is the bibliometric method, which has already been widely applied in many disciplines of science and engineering (Braun et al., 1995; Ho, 2008; Li et al., 2009a). The Science Citations Index Expanded (SCI-EXPANDED), from the Institute of Scientific Information (ISI) Web of Science databases, is the most important and frequently used source for a broad review of scientific accomplishment in all fields (Ugolini et al., 2001; Li et al., 2009b). Conventional bibliometric methods often evaluate research trends by the publication outputs of countries (Braun et al., 1995), research institutes (Xie et al., 2008), journals (Colman et al., 1995), and research fields (Ugolini et al., 1997), as well as by citation analysis (Li and Ho, 2008). However, merely depending on changes in the citations or publication counts of countries and organizations cannot completely reveal the developmental trends or future orientation of a research field. More information, closer to the research itself, such as paper titles (Li et al., 2009b), author keywords (Ugolini et al., 2001), KeyWords Plus (Qin, 2000), and abstracts (Zhang et al., 2010) have been introduced.

In this study, a traditional bibliometric method, analysis of language, source country, source institute, and the most cited papers was used to describe the latest advances in climate change research. Moreover, an innovative method – word cluster analysis of selected topics in the combination of paper titles, author keywords, KeyWords Plus, and abstracts (Li et al., 2009a; Mao et al., 2010) – was applied to map the global research trends during the period 1992–2009. Findings from these investigations can help researchers to realize the breadth of climate change research and to establish future research directions.

2. Materials and methods

The data were based on the online version of SCI-EXPANDED. According to Journal Citation Reports (JCR), this indexed 7387 major journals with citation references across 174 scientific disciplines in 2009. However, a limitation is that most abstracts before 1991 are not included in SCIE. “Climate change”, “climate changes”, “climatic change”, and “climatic changes” were used as the keyword to search titles, abstracts, and keywords from 1992 to 2009. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Articles from Hong Kong were not included in China. All articles referring to climate change during the past 18 years were assessed according to: type of publication, characteristics of publication outputs, distribution of outputs in journals, publication outputs of source country, source institute, and analysis of paper titles, author keywords, KeyWords Plus, and abstracts.

The words in titles and abstracts were separated, and then conjunctions and prepositions such as “and”, “of”, “in”, and “on” were discarded, as they were meaningless for further analysis. Keywords were defined as comma-separated items of one or more words. All keywords (1992–2009), both those reported by authors and those attributed by ISI as well as the words in titles and abstracts, were identified and separated into 3 six-year periods, and then their ranks and frequencies were calculated in order to thoroughly and precisely analyze the variations of trends. Different words with identical meaning and misspelled keywords were grouped and considered as a single keyword. A word cluster analysis combination of the words in titles, author keywords, KeyWords Plus, and words in abstracts was used in the analysis (Li et al., 2009a; Mao et al., 2010).

3. Results and discussion

3.1. Characteristics of publication outputs

From this study, 16 document types were found in the total 41457 publications during the 18-year study period. Article was the most-frequently used document type comprising 74% of the total production. Only 30843 original articles were used for further analysis as relevant citable items. Ninety-eight percent of the journal articles were published in English. Twenty other languages also appeared; the most frequent were French (0.62%), German (0.46%), Russian (0.19%), Spanish (0.17%), and Chinese (0.17%). This reflects the limitation of evaluation of climate change research in SCI-EXPANDED, most papers in which are in English.

Climate change research developed rapidly over the last century (Fig. 1), from 1 article in 1907 to 862 articles in 2009 with “climate change”, “climate changes”, “climatic change”, and “climatic changes” as the search keywords in titles only. World academic publications had a notable growth after the 1990s. There are some papers related to climate change published before 1907, but due to the limitation of SCI-EXPANDED and the methods used here, they are not included in our discussions.

Based on the classification of subject categories in JCR 2009, the publication output data of climate change research was distributed into 154 SCI subject categories during 1992–2009. Subject categories containing more than 5000 articles were environmental sciences (7022; 23%), multidisciplinary geosciences (22%), meteorology and atmospheric sciences (18%), and ecology (17%). From 1992 to 2002, environmental sciences, meteorology and atmospheric sciences, and multidisciplinary geosciences held primacy; however since 2002 the number of articles in ecology grew quickly and ranked second in 2009 (Fig. 2). This indicates the recent emphasis on the impact of climate change in ecology (Hoegh-Guldberg, 1999; Walther et al., 2002).

Articles were published in a wide range of 2023 journals. In this particular research field, *Geophysical Research Letters* published the most articles (921; 3.0%), while *Climatic Change* ranked second with 891, *Global Change Biology* ranked third with 788, and *Journal of Climate* ranked fourth with 659. Close on *Journal of Climate*'s heels was *Journal of Geophysical Research-Atmospheres* with 649. The percentage of the top journal was not high, which indicates the breadth of article distribution in climate change research as well as the broad interest in climate change from various research angles. This phenomenon also appears in other research areas, such as *Atmospheric Environment* (8.7%) in atmospheric simulation (Li et al., 2009a), *Journal of Geophysical Research-Atmospheres* (9.5%) in aerosol (Xie et al., 2008), and *Water Research* (19%) in biosorption technology for water treatment (Ho, 2008).

Of the 30606 articles with author addresses, 21425 (70%) were single country articles and 30% were internationally collaborative articles. To a certain extent, the number of research articles reflected

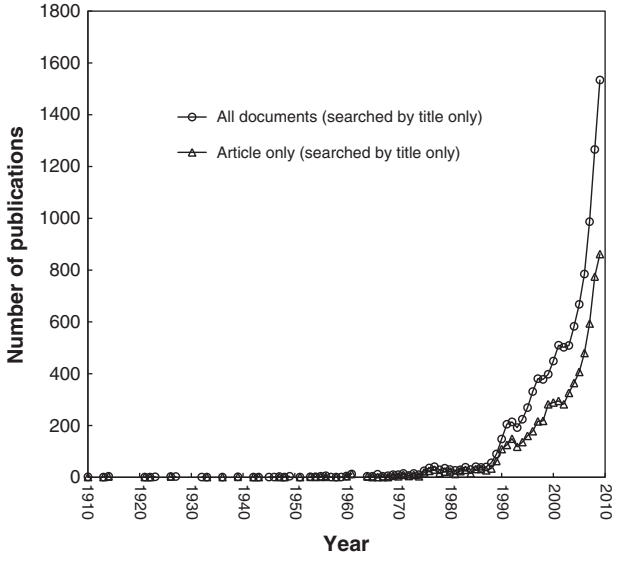

Fig. 1. World SCI-EXPANDED journal publications with climate change, climate changes, climatic change, or climatic changes in titles during 1900–2009.