Google Earth Application

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Released in 2005 by Google, Google Earth (GE) has become the most popular and successful virtual globe tool. GE has demonstrated its capacity for 3D global representation and visualization of geospatial data from local to global scales.

Google Earth scientometric analysis meta-analysis

1. Introduction

Released in 2005 by Google, GE has become the most popular and successful virtual globe tool and can effectively address the first challenge mentioned above [1]. Later, similar products, such as NASA World Wind (released in 2004), Microsoft Virtual Earth (released in 2005, now Bing Maps Platform), ESRI ArcGIS Explorer (released in 2006), and Cesium (released in 2012), emerged [1][2]. The concept of Digital Earth (Virtual Earth) was initially proposed by former U.S. vice president Al Gore in 1998 and was described as a computer-generated three-dimensional virtual globe with visualization functions that were easy to use, were interoperable, and could be used for modeling and simulation [3]. Among the virtual globe tools described above, GE has proved to be the most popular and has advantages in terms of visualization, ease of access to a wide range of geospatial data, and a unified coordinate system; however, it still lacks extendibility [1]. In recent years, GE was used for research on geomorphology [4][5][6][7], ecology [8][9][10][11], geology [12][13][14], the atmosphere [15][16], disasters [17][18][19][20][21][22], social science [23], and urban studies [24][25][26][27], and has served as an essential tool in studies of global environmental change. In addition, GE was also widely used in education, especially in the teaching of geography, because of its great ability to provide virtual visualizations of the Earth [28][29][30]. According to the reviews by Yu and Gong [1], Goodchild [3], and Liang et al. [2], the advantages of GE can be divided into six categories related to visualization and data exploration, data collection, validation, data integration and interoperability, simulation, and ease of use. Although the use of GE as a digital globe is thriving because it provides easy-to-use visualizations, GE also has many limitations, including inconsistent image quality, a limited capability for making quantitative measurements, a lack of analytical functionality, and the inability to support precise global spatial simulations [1].

2. Scientometric Analysis

We used“Google Earth” as keywords to retrieve relevant articles and review articles from the Web of Science (WoS) (https://www.webofscience.com/) core collection, including the SCIE (Science Citation Index Expanded) and SSCI (Social Sciences Citation Index), dated up to January 2021. After screening, 1334 articles related to “Google Earth” were obtained. Then the CiteSpace, a powerful bibliometric analysis software [31] was used to analyze document co-citations, keyword co-occurrences, and cooperative maps, thus enabling the exploration of knowledge base, structural frameworks, and research frontiers in research that is based on GE.

2.1 Statistical characteristics

In the case of GE, there were three main stages: stage one (2006–2008), which was a period of slow development; stage two (2009–2015), which was a period of rapid development; and stage three (since 2016), which is a period of proliferation. In stage one – prior to 2008 – the application of GE and related research developed slowly as GE was not yet fully explored and its functions were limited. For example, many vital functions (e.g., historical imagery and support for 3D imagery) were not introduced until after 2008 (https://en.wikipedia.org/wiki/Google_Earth). Later, GE gradually became more widely used: dozens of articles were published every year, and the mean increase of citations increased to about 300 times per year. This trend of increased use continued after 2016 and, in 2020, 231 papers on GE were published and there were 5115 citations.

A total of 1334 articles describing the use of GE were published in 547 journals relating to fields such as remote sensing, computer science, the environment, and GIS (**Figure 1**). The top ten journals were *Remote Sensing* (89), *The International Journal of Remote Sensing* (35), *Remote Sensing of Environment* (30), *Geomorphology* (22), *Computers and Geosciences* (19), *The IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* (19), *The Journal of Maps* (19), *The Journal of Applied Remote Sensing* (17), *PloS One* (17), and *Sustainability* (16). The publications referencing GE spanned a broad spectrum of journals. However, more than half of all journals (376) published just one article on GE, and only 22 journals published more than ten.

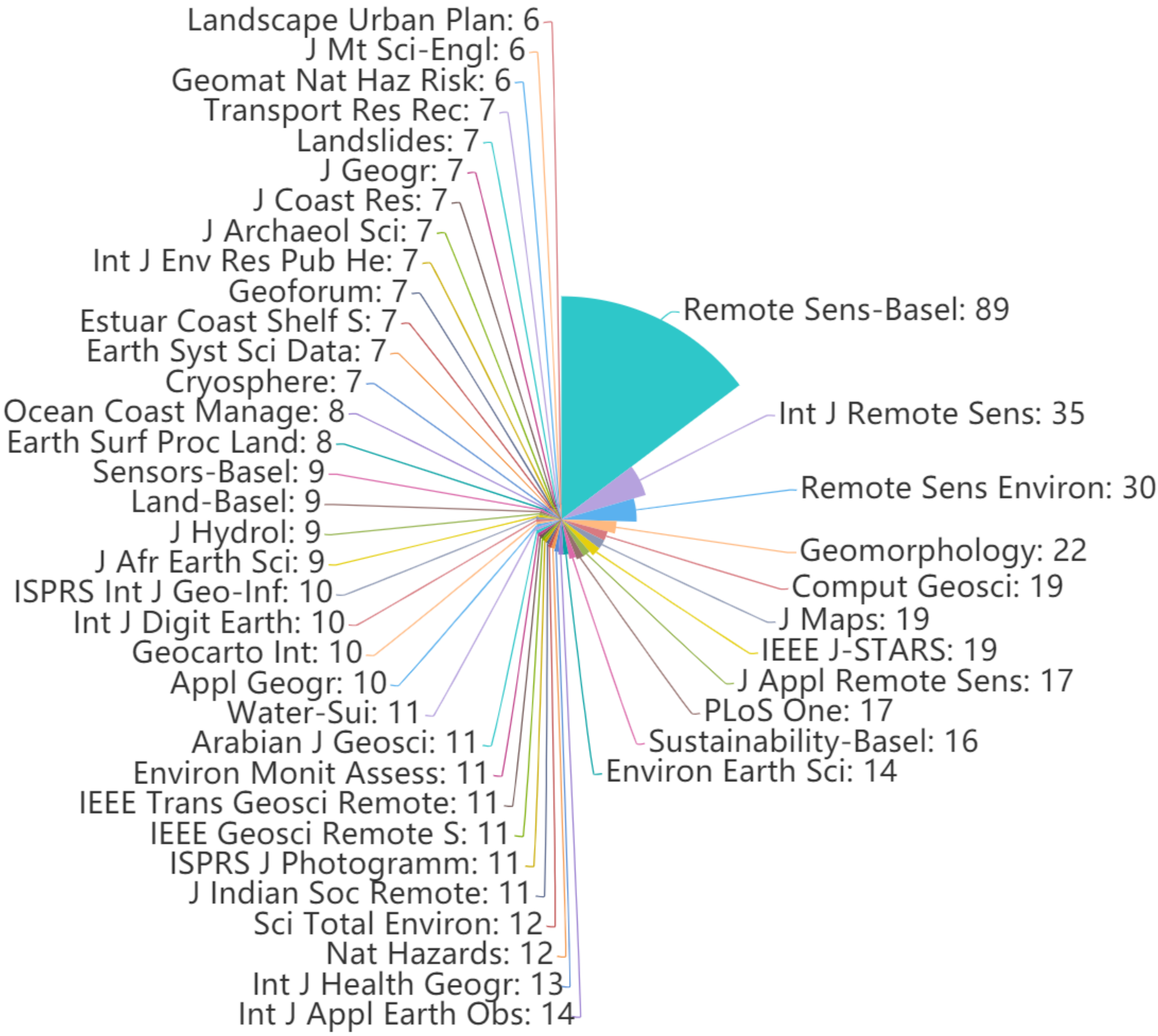

Figure 1. Journals in which papers related to GE were published

The GE publications found related to 102 different disciplines (**Figure 2**). The research areas with more than 100 related articles were in environmental sciences and ecology (415), remote sensing (295), geology (294), engineering (180), physical geography (162), imaging science and photographic technology (156), and water resources (108). These seven categories accounted for 62% of the total (**Figure 2**). In relation to the 102 disciplines, 48 research areas were found one or two times, and 66 were found fewer than ten times.

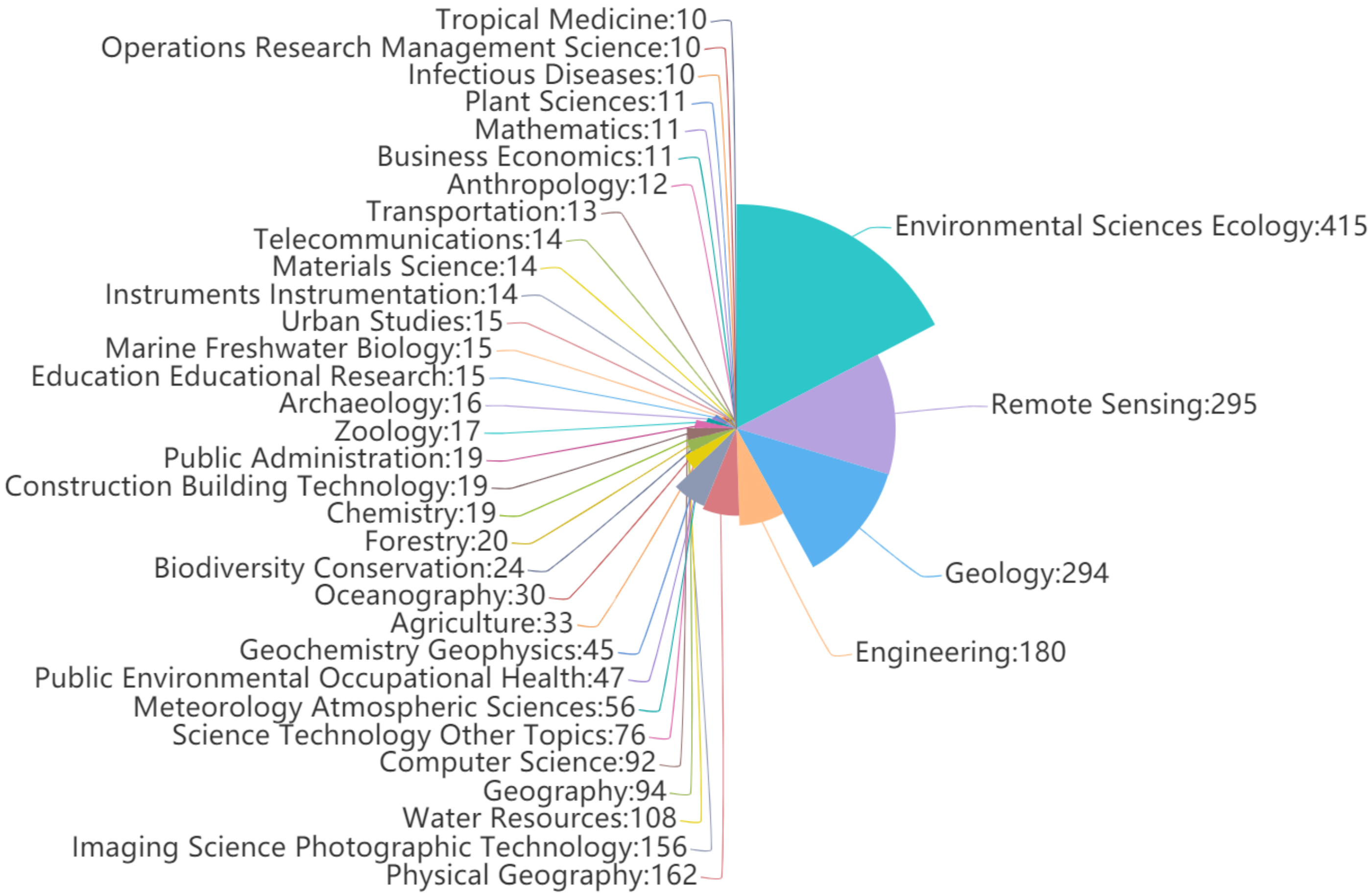

Figure 2. Research disciplines in which GE was applied

2.2 Subject structure analysis

Based on the analysis of keywords conducted on the literature related to GE (**Figure 3**), it was found that “high resolution” (referring to spatial resolution) had the highest frequency, with 1039 occurrences. GE provides free, easy, and stable high-spatial resolution satellite data of the whole globe. These data have good horizontal positional accuracy [32], but improvements to the consistency of the image quality are still required [1]. From **Figure 3**, it can be seen that the keywords with a large number of occurrences (larger areas in the figure) included “model”, “land cover”, “change detection”, “region”, “assessment”, “field”, “overall accuracy”, “estimated”, and “visualization”; these occur 743, 431, 412, 377, 356, 332, 307, 259, and 258 times, respectively. It can be observed from the keywords that 3D modeling based on the data provided by GE is one of the main ways in which GE was applied. That is, GE was the primary data provider for various land-cover observations. In addition, GE also served as a platform for displaying a wide range of geographic information, including information on water, forests, urban and other land cover types, vegetation indices, sample data, and other derived products. Sphere visualization is one of GE’s most distinctive techniques and enables GE to display heterogeneous data sets for use in academic communication. Thus, Earth system scientists can use GE as a tool to more easily conduct Earth system science research from a global perspective.

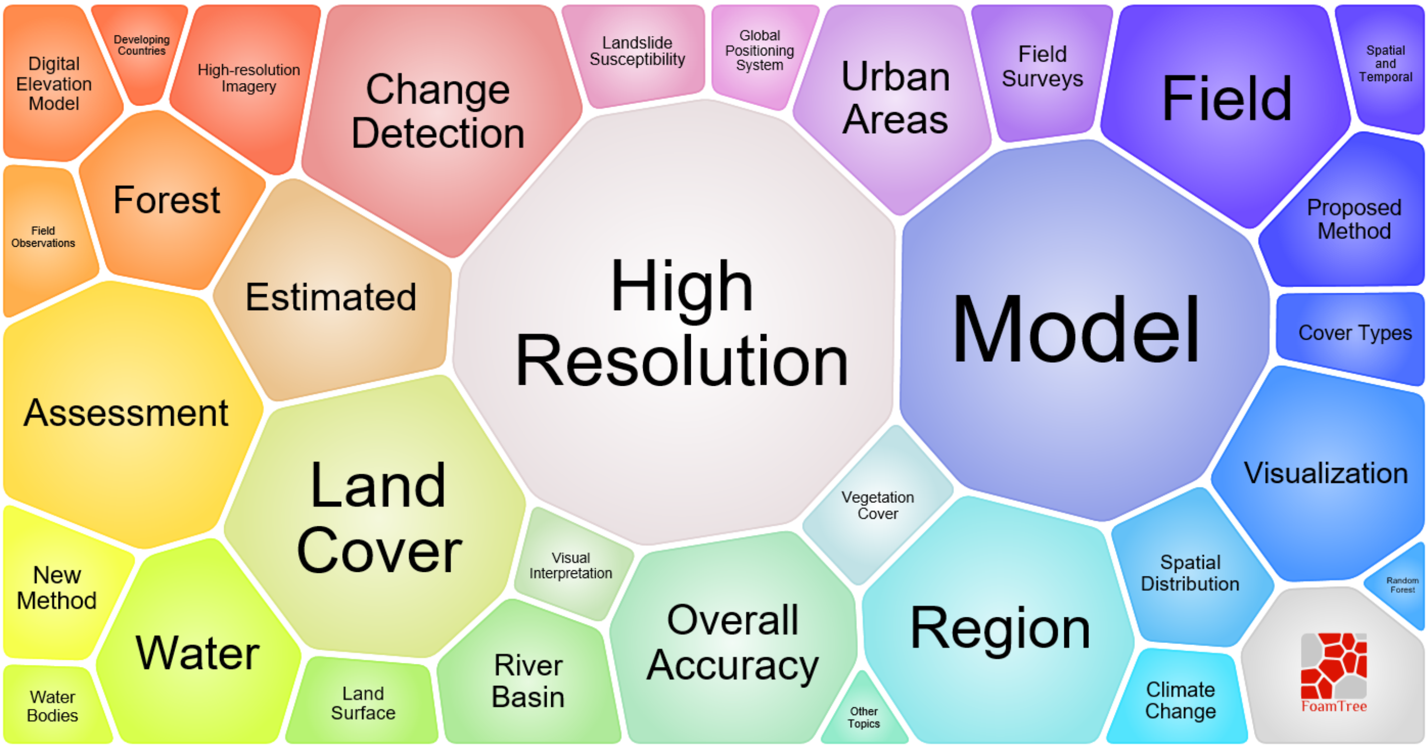

Figure 3. Keywords related to GE

As shown in **Figure 4**, during stage one (2006–2008), although the application of GE was then still in its infancy, many of the keywords used were consistent with future applications and included “Google Earth”, “GIS”, “model”, “Landsat”, “climate”, “China”, “time series”, and “remote sensing”. These keywords had a relatively high frequency, or betweenness centrality. In stage two (2009–2015), the application of GE entered a period of stable development. Again, many keywords that appeared during this period determined the primary research direction, and included “classification”, “land cover change”, “MODIS”, “change detection”, “accuracy”, “pattern”, “image classification”, “forest”, and “cover”. These keywords represented the main applications of GE during this period. In stage three (since 2016), the application of GE has boomed, and many new keywords were used. Among these new keywords, the ones that appeared most frequently were “CNN”, “neural network”, “soil”, “deep learning”, and “Sentinel”, which reflects the use of high-resolution images and artificial intelligence during this period.

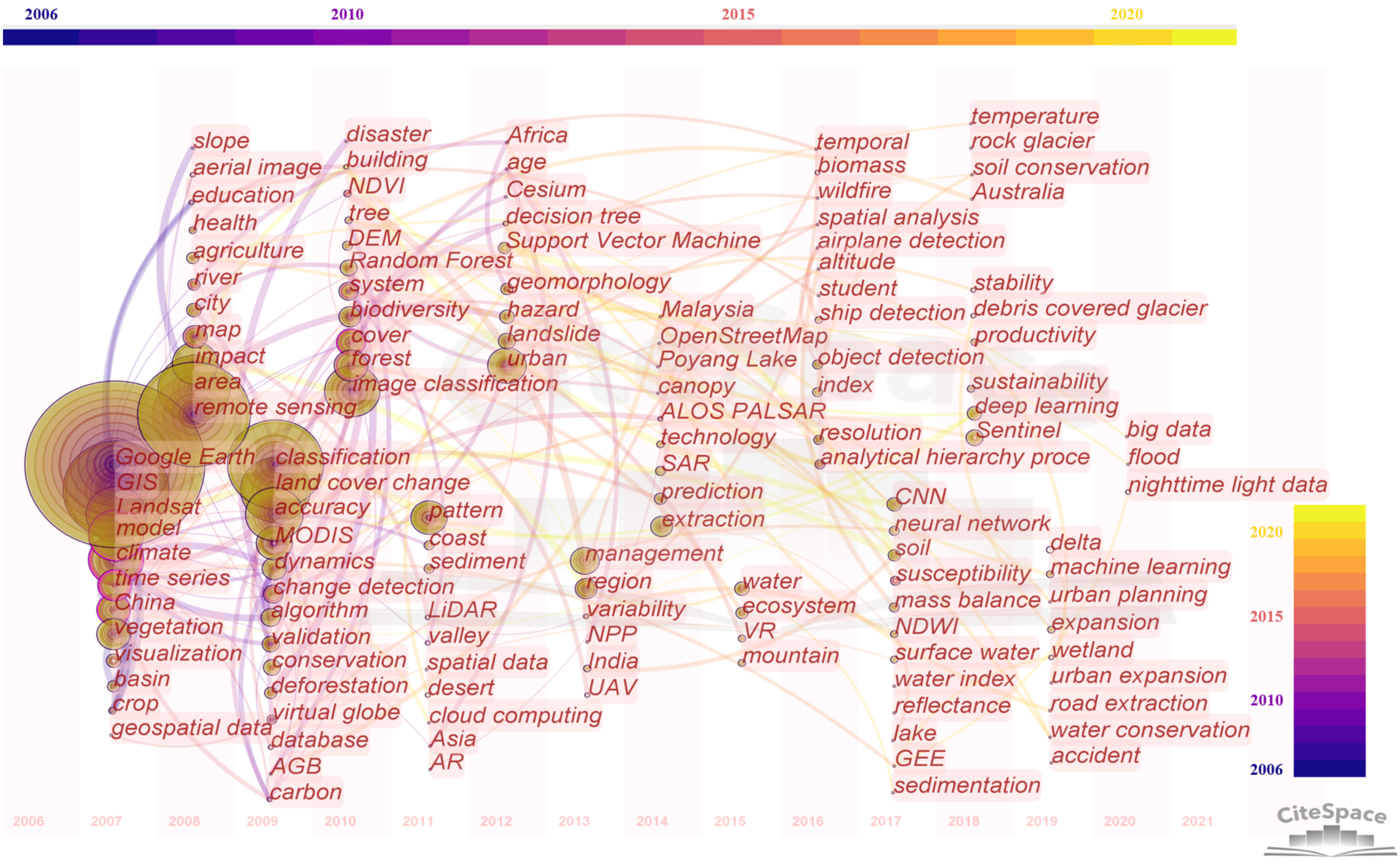

Figure 4. Co-occurrence keywords were used in relation to GE. The size of the node represents the frequency of the occurrence of the keyword, the connecting lines indicate the co-occurrence relationships for the keyword, and a purple outer circle indicates that the node is a key node (betweenness centrality > 0.1).

2.3 Research contribution analysis

Table 1 lists the cited papers that were found to correspond to the strongest citation bursts in GE articles. This list consists of papers that were important to the promotion, development and application of GE. In 2006, Butler [33] published a paper that described a systematic evaluation of the GE platform. He stated that GE was changing the world because it made the communication of spatial information between stakeholders and government agencies feasible. GE's data-sharing capability was an essential property for global climate change studies. Potere [34] verified the horizontal positioning accuracy of high-resolution GE imagery by selecting 436 control points in 109 cities worldwide. The results obtained using GE imagery were found to be sufficiently accurate for most urban research and the reliability of this imagery for use in subsequent applications was verified. Yu and Gong [1] published the first review of GE in 2012; this review examined the progress made in using GE, prospects for its use, and identified the merits and limitations of GE when applied to Earth science. This review was instructive in terms of the consideration of future applications of GE and the development of the virtual globe platform. Other important papers discussed new types of global geographic data [35][36][37][38] and image processing or accuracy assessment algorithms that had a significant impact on the application of GE [39][40] and Earth system science. Chang et al. [41] built a dengue surveillance system that was based on GE images and geographic information related to the incidence of dengue fever. This proved to be a successful GE application.

Table 1. GE papers with the strongest citation bursts

Article	Author	Year	Strength	Begin	End
The web-wide world [33]	Butler, D	2006	10.13	2008	2011
Google Earth as a virtual globe tool for Earth science applications at the global scale: progress and perspectives [1]	Yu, L	2012	9.92	2013	2017
Horizontal Positional Accuracy of Google Earth's High-Resolution Imagery Archive [32]	Potere, D	2008	6.74	2009	2013
MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets [35]	Friedl, MA	2010	6.14	2012	2015
Finer resolution observation and monitoring of global land cover: first mapping results with Landsat TM and ETM+ data [36]	Gong, P	2013	5.94	2015	2018
Deep Residual Learning for Image Recognition [39]	He, KM	2016	5.64	2018	2021
High-Resolution Global Maps of 21st-Century Forest Cover Change [37]	Hansen, MC	2013	5.61	2014	2018
Good practices for estimating area and assessing accuracy of land change [40]	Olofsson, P	2014	5.2	2017	2019
Global land cover mapping at 30 m resolution: A POK-	Chen, J	2015	5.12	2017	2018

based operational approach [38]					
Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries [41]	Chang, AY	2009	4.8	2012	2014

2.4 Cooperation network analysis

At the institutional level, Chinese scientific institutions have dominated the application of GE. The top ten scientific institutions in terms of the application of GE were the Chinese Academy of Sciences (101), the University of Chinese Academy of Sciences (39), Wuhan University (28), Beijing Normal University (17), Tsinghua University (13), Ghent University (12), China University of Geosciences (11), Beihang University (11), the University of California, Berkeley (10), and the Catholic University of Leuven (10). The number of published papers from Chinese scientific institutions was far greater than that from institutions in other countries.

At the national level, the number of publications was more concentrated. The top five countries published 1022 GE papers (including duplicates), which accounted for 51.8% of the total number of published papers. The top five countries were the USA (397), China (357), the United Kingdom (115), India (82), and Germany (71). In summary, the United States and China have dominated the application of GE, and have published a considerable number of related papers, as compared to other countries.

3. Current Insights

Virtual globes were in development for a long time, and, here, we describe several of the popular virtual globes that were first mentioned above. World Wind is a completely open-source virtual globe that is different from GE in that it is a software development kit (SDK) that provides a geographic rendering engine: users can build their own geospatial applications to solve problems specific to their own domains (https://worldwind.arc.nasa.gov/). Bing Maps (https://cn.bing.com/maps) and ArcGIS Explorer (https://www.esri.com/zh-cn/arcgis/products/arcgis-explorer) are more akin to web-maps or map-browsers, and mainly provide real-time navigation and positioning rather than 3D globe visualization. Cesium and OpenWebGlobe are open-source 3D geospatial virtual globes based on JavaScript and WebGL that support multiple scene modes (3D, 2.5D, and 2D). World Wind, Cesium, and OpenWebGlobe are superior to GE in terms of multi-dimensional visualization and extensibility, but do not have GE's ease of use and stable high-spatial resolution images. We used the same method used for GE articles to retrieve articles related to these virtual globes and found that the number of articles was far less than for GE: World Wind (18), Bing Maps (43), ArcGIS Explorer (3), Cesium (6) and OpenWebGlobe (0). The results found by Yu and Gong [1] confirmed this.

GE is a data fusion platform that has visualization as its primary function (**Table 2**). However, GE does not possess real-time modeling capabilities. Its use of the KML language means that there is great potential for the use of GE in geospatial studies in the future. The most significant limitation of GE is the lack of GIS analysis, which makes it difficult to improve the data preprocessing and analysis. GE can serve as a virtual world or "natural" earth; by using GE, users can observe global real-time changes or predict future conditions [1]. These functions could be improved by combining GE with cloud-computing technology. GE would then become a browser on which users would only need to initiate a request before receiving the processed results from the server [3]. Yu and Gong [1] envisioned that GE could generate artwork or statistical reports for use in scientific papers and reports. The reconstruction of historical relics and cities based on 3D/4D visualization techniques is also a trend. For some time now, studies were carried out on the application of GE as a geography teaching tool [29][42]. It is possible that GE could be made into an effective teaching tool by adding teaching content; GE would then greatly assist the development of geospatial thinking.

Table 2. Merits and limitations of GE

Merits	• Easy to use [1][2][3][43] • Easy visualization and availability of 3D models [1][3][2][43] • Freely accessible data collections [1][2][43] • Single coordinate system and KML, which help with the establishment of a perspective view of map/image layers and integration of multisource data sets [1][2] • Spherical visualization techniques are available [1] • Provides stable, high-spatial resolution global satellite data with good horizontal positional accuracy [1][43][32] • Good extendibility, but somewhat lacking compared to other virtual Earths [1][3]
Limitations	• Inconsistent image quality and inconsistent radiometric distortion [1][43] • Inadequate representation and tessellation of the Earth's surface [1] • Privacy issues [43] • Limited ability to display dynamic information [3] • Limited modeling and simulation ability [2][3] • Lack of GIS functions [1][2][3][43] • Lack of geospatial big data analysis capabilities [2]

The ideal virtual Earth that was described in Gore's speech had the capacity to model and simulate the global environment and to dynamically display the environment in real-time as well as the future. Such a virtual Earth would display the Earth's morphology using the advanced technologies of cloud computing, 3D and virtual reality (VR), and would have the capability to process big data. In this way, people would be able to observe global real-time (e.g., it will be very useful for Asian elephant's migration in China very recently [44]) or simulated future environmental changes using internet-connected devices, and scientists would easily be able to obtain details of environmental conditions or other geo-information at any place and time. Such a virtual Earth would meet the challenges proposed by Yu and Gong [1] and would be an effective tool for use in Earth system science.

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