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Applications and impacts of Google Earth: A decadal review (2006–2016)

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ABSTRACT

Since Google Earth was first released in 2005, it has attracted hundreds of millions of users worldwide and made a profound impact on both academia and industry. It can be said that Google Earth epitomized the first-generation of Digital Earth prototypes. The functionalities and merits that have sustained Google Earth's lasting influence are worth a retrospective review. In this paper, we take the liberty to conduct a bibliometric study of the applications of Google Earth during 2006–2016. We aim first to quantify the multifaceted impacts, and then to develop a structured understanding of the influence and contribution associated with Google Earth. To accomplish these objectives, we analyzed a total of 2115 Scopus publication records using scientometric methods and then proceed to discussion with a selected set of applications. The findings and conclusions can be summarized as follows: (1) the impact of Google Earth has been profound and persistent over the past decade. Google Earth was mentioned in an average of 229 publications per year since 2009. (2) Broadly, the impact of Google Earth has touched upon most scientific disciplines. Specifically, during 2006–2016, Google Earth has been mentioned in 2115 publications covering all of Scopus's 26 subject areas; (3) the influence of Google Earth has largely concentrated in GIScience, remote sensing and geosciences. The extended influence of Google Earth has reached a wider range of audiences with a concentration in fields such as human geography, geoscience education and archaeology.

1. Introduction

Digital Earth is a vision popularized by former US Vice-President Al Gore's speech (Gore, 1998) aiming to create a digital representation of the Earth's physical and social environments (Cragliaet al., 2012). Earth's environments encompass not only the static structures and properties but also the dynamic geo-processes and human activities. As the volume and complexity of information grow exponentially with the scale and level of detail at which the Earth is to be represented, a complete and perfect digital replica of the Earth might not be achievable in the near future. Indeed, the advent of the 'Big Earth Data' era are bringing many challenges and opportunities to Digital Earth's development (Guo et al., 2017). New frameworks, methods and theories, such as spatial cloud computing (Yang et al., 2011, 2013) and Big Data analytics (Baumann et al., 2016), are needed to support utilization of 'Big Earth Data'. Digital Earth has been established as a key research area. From 1998 to 2015, there has been 11,061 research articles related to Digital Earth published in recognized international journals (Liu et al., 2017).

Efforts toward computer realization of the Digital Earth vision has been thriving since the early 2000s in both academia and industry. Various terminologies such as "Google Earth", "Virtual Globe", "Virtual Earth", "Digital Earth" and "Digital Globe" have become the norm in the literature. A bibliometric research was conducted to quantify how frequently each of these key terms were cited in the literature (Blaschke et al., 2012). The results showed that "Google Earth" and "Virtual Globe" appeared most frequently in the ISI Web of Science database from 2005 to 2010 (Blaschke et al., 2012).

NASA World Wind and Google Earth are among the first generation of virtual globes. World Wind is an open-source virtual globe first developed by NASA in 2003 for use on personal computers and then further developed in concert with the open source community since 2004. Google Earth was released in June 2005. Although Google Earth came out a little later, it has received far more public attention and generated much greater impacts, as supported by the finding that the total number of ISI-indexed papers on Google Earth is nearly six times of that on Microsoft Virtual Earth, NASA World Wind and ESRI/ArcGIS Explorer combined together (Yu and Gong, 2012). It was said that Google Earth (Fig. 1) typified the first generation of virtual globes which achieved many but not all the elements of this vision (Goodchild

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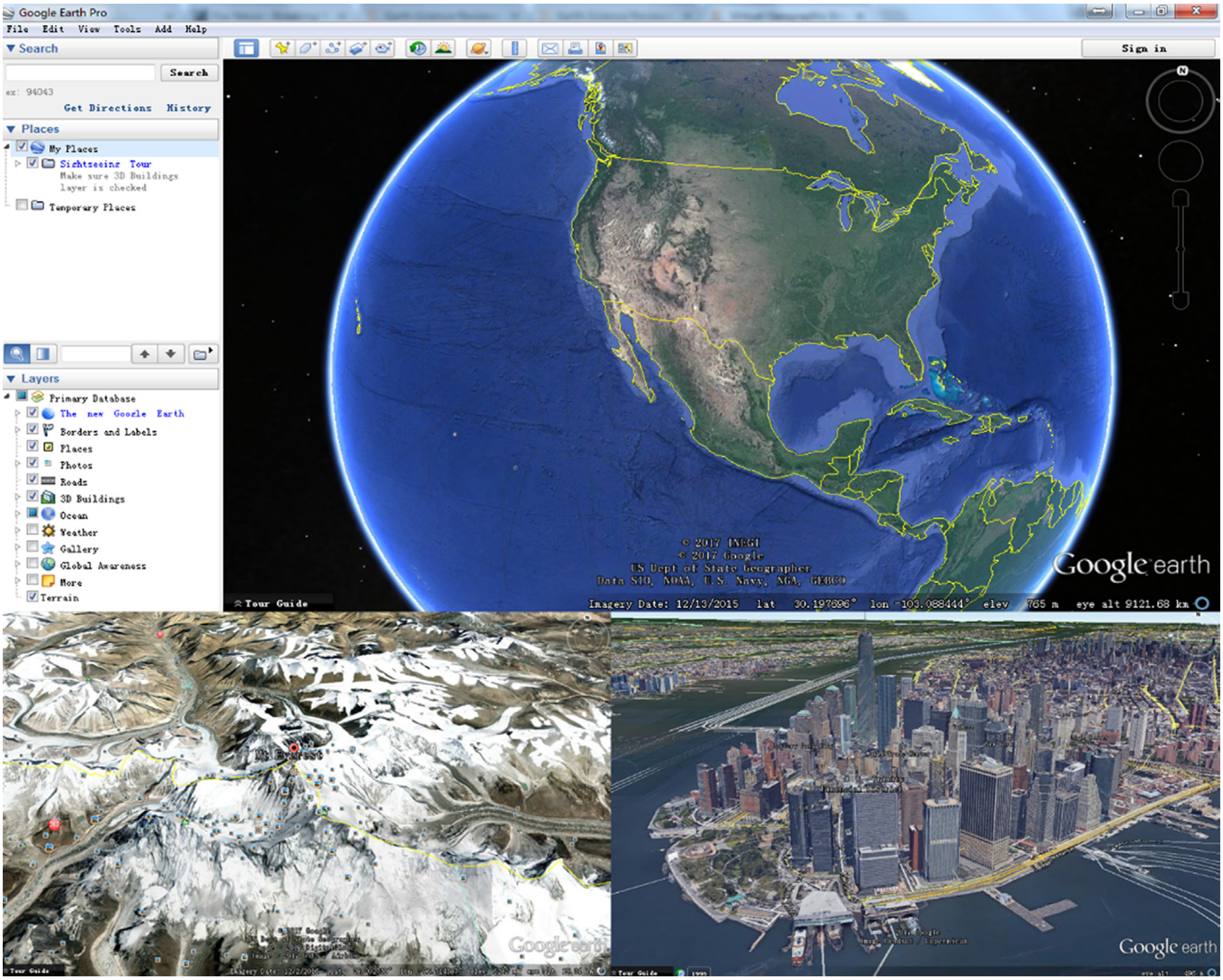

Fig. 1. Visualization of multisource geospatial data on Google Earth.

et al., 2012).

By 2006, Google Earth had already proved effective in many applications such as relief efforts (Nourbakhsh et al., 2006), lake mapping (Shen et al., 2006) and health geography research (Curtis et al., 2006), and had made an enormous impact on GIS by making GIS accessible for people without GIS expertise (Goodchild, 2006). By 2007, Google Earth had been downloaded more than 100 million times (Goodchild, 2007). In the meantime, it started to influence international relations and global representation, exemplified by intervention in the humanitarian crisis in Darfur (Patterson, 2007) and the terrorist attack in Mumbai (Bratton, 2009). Although Google Earth has no analytic functions and was not designed to replace professional GIS software, its mashup and data dissemination capability could be an asset to geographers in the era of NeoGeography and Web 2.0 (Hudson-Smith et al., 2009), which was termed "the new era for geo-information" (Li and Shao, 2009). Moreover, there has even been unexpected implications arising from the opening up of a global inventory of satellite imagery to the public, for example, remodeling the paradigms of archaeological investigation (Kennedy, 2011; Myers, 2010; Luo et al., 2014) and geoscience education (Bodzin, 2008; Monkkonen, 2008; Blank et al., 2016).

Three years after the launch of Google Earth, Goodchild (2008) retrospectively analyzed the functionalities of Digital Earth with reference to the applications of Google Earth. Goodchild (2008) identified four use cases which differed from conventional GIS use cases, including visualization, ease of use, interoperability and mashups, and modeling and simulation. Gore envisioned a future computer system that has the capability to "display an unprecedented amount of information about our planet and a wide variety of environmental and cultural phenomena", from which Goodchild (2008) drew the first and to some extent most important use case of Digital Earth, i.e., visualization. Google Earth offers such extreme ease of use that even a "young child" can learn to manipulate and make use of in 'ten minutes'. The third use case 'interoperability and mashups' resonates with Gore's notation that Digital Earth" is 'a multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced information'. Last but not least, Gore also dreamed of a Digital Earth" that can be used to 'project future states of the planet's surface, interpret the data that we are collecting about our planet and assist policy making', which Goodchild (2008) summarized as 'modeling and simulation'.

At a time when Google Earth had already been routinely used in Earth science research, Yu and Gong (2012) comprehensively reviewed the development of Google Earth from an Earth scientist perspective. A comparison of Google Earth and other virtual globes revealed that Google Earth was mentioned in the literature nearly six times more frequently than any other virtual globes. Yu and Gong (2012) summarized the merits and limitations of Google Earth and offered recommendations for improving and augmenting the functions to better serve Earth science applications. By combining the use cases of Goodchild (2008) and Stensgaard et al. (2009), Yu and Gong (2012)