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Benefits of the free and open Landsat data policy

Zhe Zhu[a,*], Michael A. Wulder[b], David P. Roy[c], Curtis E. Woodcock[d], Matthew C. Hansen[e], Volker C. Radeloff[f], Sean P. Healey[g], Crystal Schaaf[h], Patrick Hostert[i,n], Peter Strobl[j], Jean-Francois Pekel[j], Leo Lymburner[k], Nima Pahlevan[l], Ted A. Scambos[m]

[a] Department of Natural Resources and the Environment, University of Connecticut, Storrs, CT 06269, USA
[b] Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, 506 West Burnside Road, Victoria, British Columbia V8Z 1M5, Canada
[c] Department of Geography, Environment & Spatial Sciences and Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI 48824, USA
[d] Department of Earth and Environment, Boston University, Boston, MA 02215, USA
[e] Department of Geographical Sciences, University of Maryland, College Park, MD 20740, USA
[f] SILVIS Lab, Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 35706, USA
[g] US Forest Service, Rocky Mountain Research Station, Ogden, UT 84401, USA
[h] School for the Environment, University of Massachusetts, Boston, 100 Morrissey Blvd, Boston, MA 02125, USA
[i] Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany
[j] European Commission Joint Research Centre, 21027 Ispra, Italy
[k] Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia
[l] Science Systems and Applications, Inc., 10210 Greenbelt Rd., Lanham, MD 20706, USA
[m] Earth Science Observation Center, CIRES, University of Colorado Boulder, Boulder, CO 80303, USA
[n] Integrative Research Institute on Transformation of Human-Environment Systems (IRI THESys), Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

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ABSTRACT

The United States (U.S.) federal government provides imagery obtained by federally funded Earth Observation satellites typically at no cost. For many years Landsat was an exception to this trend, until 2008 when the United States Geological Survey (USGS) made Landsat data accessible via the internet for free. Substantial increases in downloads of Landsat imagery ensued and led to a rapid expansion of science and operational applications, serving government, private sector, and civil society. The Landsat program hence provides an example to space agencies worldwide on the value of open access for Earth Observation data and has spurred the adaption of similar policies globally, including the European Copernicus Program. Here, we describe important aspects of the Landsat free and open data policy and highlight the importance and continued relevance of this policy.

1. Introduction

Since the launch of Landsat-1 in 1972, the Landsat program has occupied a unique niche and today represents the longest running terrestrial satellite record. While perturbed in early years by changes in operational responsibilities, the original ambitions of the Landsat program have largely been met or exceeded (Goward et al., 2017). The U.S. Landsat archive is held at the United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center and contains > 5.6 million acquisitions sensed by Landsat-1 through Landsat-8 (Dwyer et al., 2018). For many years, as described in the Land Remote Sensing Policy Act of 1992 (15 U.S.C §§5601), Landsat data could be sold, but the cost to the user community could not exceed the cost of fulfilling user requisitions. In 2008, the USGS adopted a free and open Landsat data policy (Woodcock et al., 2008), which led to a substantial increase in the use of Landsat data that has been beneficial to many segments of society (Roy et al., 2014; Wulder et al., 2012; Wulder et al., 2019). Free and open access has greatly benefited operational applications, scientific studies, and discoveries informed by analyses of large numbers of Landsat images. For example, global mapping of annual forest change has been achieved using all available Landsat observations from 2000 to 2012, reporting a net forest loss of 1.5 million km^2 (Hansen et al., 2013). Similarly, the location and persistence of global surface water extent have been mapped using three million Landsat images acquired from 1984 to 2015, finding both > 180,000 km^2 of new permanent water bodies and a loss of nearly 90,000 km^2 (Pekel

* Corresponding author.
E-mail address: zhe@uconn.edu (Z. Zhu).

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et al., 2016). Other global maps, including of human settlements (Pesaresi et al., 2016) and land cover (Chen et al., 2015; Gong et al., 2013) have been generated using large amounts of Landsat data. The spatial detail and temporal range of Landsat data is routinely utilized at local levels and many continental, national, and regional projects have been implemented (Wulder et al., 2019).

2. Landsat Science Team perspectives

The free and open Landsat data policy has periodically come under scrutiny (Landsat Advisory Group, 2012; Popkin, 2018). Indeed, as of 2018, the U.S. federal government is seeking to “explore how putting a price on Landsat data might affect scientists and other users” (Popkin, 2018). The possibility of a policy change away from free and open access has raised uncertainty and a high level of concern in the remote sensing and stakeholder communities. Based upon insights gleaned from our participation on the USGS-NASA Landsat Science Team, we assert that the free and open data policy is key to the ongoing success of the Landsat program. We, therefore, present several illustrations that highlight the benefits of the free and open Landsat data policy and the continued relevance of the policy.

2.1. Relationship between cost and use

The first and most obvious evidence for the value of the free and open Landsat data policy is the rapid increase in Landsat data ordering and use after the policy was enacted in 2008. Fig. 1 shows annual statistics of the price, number of downloads, and number of publications related to Landsat data. Prior to 2008, costs for an individual Landsat Multispectral Scanner (MSS) image varied from $20 USD (1972–1978) to $200 USD (1979–1982), increased from approximately $3000 to $4000 USD for a Landsat Thematic Mapper image (1983–1998), and was $600 USD for an Enhanced Thematic Mapper Plus (ETM+) image (1999–2008). As a result, from 1972 to 2008, no > 3000 Landsat images were *ever* sold in a given month (Wulder et al., 2012). In contrast, nearly one million images were downloaded in 2009, the first full year of free and open access (Fig. 1, the first gray circle on the left), and there has been a 20-fold increase of annual data downloads in 2017 (compared to 2009), the most recent year for which complete information is available (Fig. 1, the last gray circle on the right).

In addition to the new data policy, the mode of data distribution has also changed. Early Landsat data costs included the cost of copying the digital imagery to media and postage to customers, costs that no longer occur as users download imagery for free via the internet. Arguably, except in developing countries with poor internet connectivity (Roy et al., 2010b), the increase in Landsat data usage post-2008 could partially be due to the ease of internet-based browsing and delivery of Landsat imagery. Similarly, at the same time when the charge for data was lifted, the USGS also added certain higher-level processing (e.g., orthorectification), which reduced the need for some preprocessing steps making Landsat data more attractive for users. However, the sharp and exponential increase in the post-2008 use of Landsat illustrated in Fig. 1 exceeds gains attributable to advances in internet capacity for that period. Furthermore, the USGS statistics do not include data access from secondary platforms, such as Google Earth Engine or Amazon Web Services that started hosting Landsat data after 2008, and so the actual increases are greater than those illustrated in Fig. 1.

Also evident in Fig. 1 is how the price affected the use of Landsat data for scientific and academic research. The annual number of publications with “Landsat” in the title, abstract, or keyword started to decline when the image price was raised to $4000 USD in 1983, with < 400 publications per year from 1986 to 1999. The annual number of publications started to increase after 1999 when the price was reduced to $600 USD. After 2008, the number increased rapidly, reaching almost 1600 in 2017. The Landsat free and open data policy thus corresponds to a more than four-fold increase in the annual number of publications. Furthermore, the rapid rise in the number of publications is expected to continue given the high number of downloads in recent years and typical lag times from analysis to publication of one to three years. This increase in Landsat related publications highlights the opportunity for innovation that has resulted from the open data policy, as well as the expansion in applications and Landsat derived information products. It also reflects the scientific community's uptake of Landsat data for understanding and managing the planet's resources.

2.2. Economic benefits of open access Landsat

Based on the 2014 White House-led assessment of national programs for civil Earth observations, Landsat is one of the most critical U.S. systems, third only to the satellite-based GPS system and the

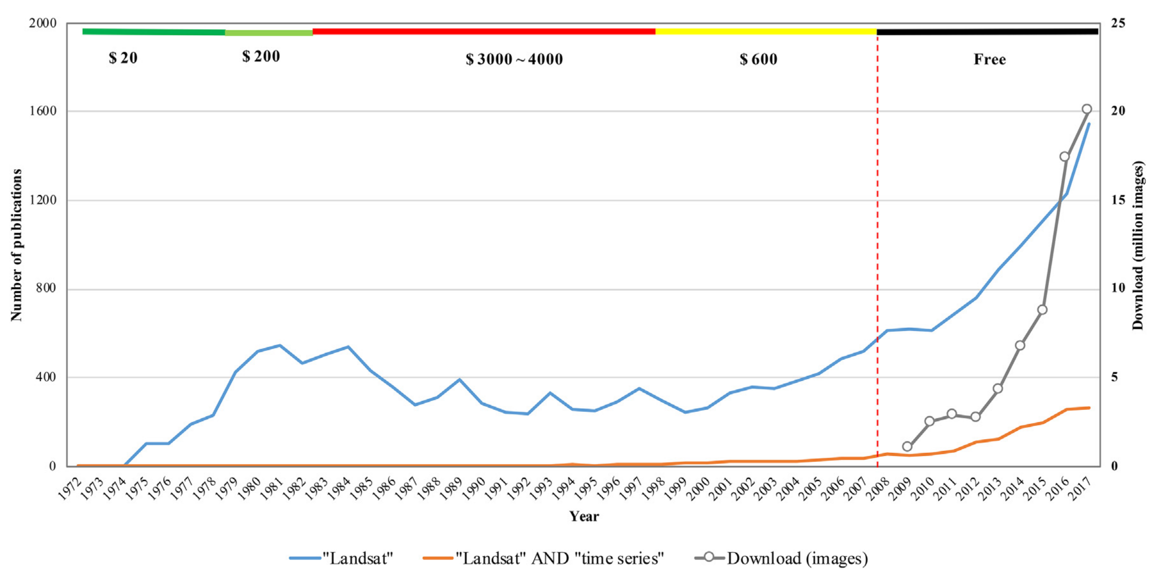

Fig. 1. Landsat image cost (top color bar, values from Wulder et al., 2012), number of downloads of Landsat images from the U.S. Landsat archive (gray line), and the number of annual publications from 1972 to 2017 in the Scopus database that have “Landsat” (blue line) or “Landsat” AND “time series” (orange line) in their title, abstract, or keywords. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

National Weather Service satellites (National Science and Technology Council, 2014). Given that the U.S. government does not currently charge for Landsat data, the imagery have a high intrinsic value to Landsat users and stakeholders. For example, a recent user survey revealed that U.S. Landsat data users have gained 1.8 billion USD in benefits from the 2.38 million images they downloaded prior to the survey (Loomis et al., 2015). The National Geospatial Advisory Committee (National Geospatial Advisory Committee Landsat Advisory Group, 2014) analyzed sixteen economic sectors (e.g., agriculture, water consumption, wildfire mapping) where the use of Landsat data lead to productivity savings, and estimated the economic benefit of Landsat data for the year 2011 as $1.70 billion for U.S. users plus $400 million for international users. Many of the sixteen economic sectors are directly associated with U.S. federal, state and local government activities (e.g., risk assessments, mapping and monitoring activities). In addition, the open data policy is particularly beneficial to government, university, and commercial research groups and organizations that have limited budgets.

2.3. Enabled the Landsat Global Archive Consolidation

The U.S. Landsat Global Archive Consolidation (LGAC) program repatriates Landsat data that are not in the U.S. archive from international cooperator ground stations, which have downlinked unique data for their reception regions (Wulder et al., 2016). In return, these data are reprocessed and made available at no cost to the international ground stations and the global user community. The LGAC initiative began in 2010 and has acquired, reconciled, and ingested large amounts of recoverable data into the U.S. Landsat archive, making historic Landsat data more accessible to users and increasing the temporal frequency and spatial coverage of the Landsat archive substantially (Fig. 2). Research that focuses on large areas and long time series has greatly benefitted from the resulting more complete and publicly available archive.

The success of the LGAC was ensured by the Landsat free and open data policy. International cooperators supplying data to the LGAC were ensured that their data were freely available from the U.S. archive, and that their data would be subject to future reprocessing under the Landsat collection scheme implemented by the USGS (Dwyer et al., 2018).

2.4. Tightened international partnership and increased data compatibility

The opening of the USGS Landsat archive in 2008 served as a catalyst for replication by other national and multi-national observation programs (e.g., the Copernicus Program of the European Union) to also make collected data free and open access. The subsequent demand, also including from non-experts, has spurred efforts to render satellite data from multiple providers interoperable through common standards, cross-calibration, and development of harmonized products (Claverie et al., 2018; Helder et al., 2018; Roy et al., 2016; Zhang et al., 2018) also known as 'Analysis Ready Data' (ARD). The Committee on Earth Observing Satellites (CEOS) encourages and facilitates the delivery of ARD by space agencies to improve the interoperability of increasing volumes of medium resolution multi-spectral optical wavelength imagery (Dwyer et al., 2018). For example, the European Sentinel-2A and -2B satellites have sensing capabilities that are similar to those of Landsat-8 (Drusch et al., 2012; Loveland and Dwyer, 2012) and together these sensors provide near weekly cloud-free global monitoring (Li and Roy, 2017). Interoperability will enable the rapid development of algorithms and processes that use data from different sensors and enable the use of these data in self-informing and complementary ways (Wulder et al., 2015).

Landsat and Sentinel-2 data, due to ongoing program alignment based on joint developments and integrated science activities, are increasingly assimilated to meet science needs and support emerging applications (see Section 2.6) which each mission alone could not fulfill. The resulting "virtual constellation" of satellites (Wulder et al., 2015), is a prominent example for a "system of systems", called for also in the recent U.S. Decadal Strategy for the Earth Observation from space (National Academies of Sciences, Engineering, and Medicine, 2018). Such systems will be difficult if not impossible to design and operate without free and open data sharing.

2.5. Stimulus for non-federal cloud computing archives

The free and open data policy has coincided with the expansion of cloud computing. Several commercial cloud computing services now host large volumes of Landsat data, and provide programming interfaces and processing capabilities in support of broad-scale mapping projects (Gorelick et al., 2017; Ma et al., 2015). While cloud-based image collections cannot replace a formally curated, permanent archive, they allow less-established institutions to conduct mapping projects by substantially reducing local computing needs, enable sharing of algorithms (e.g., Kennedy et al., 2018), and provide scalable computing resources that can greatly reduce map production and updating times. Reintroduction of a Landsat fee would jeopardize the continued availability of Landsat data in these non-federal open archives, particularly of newly acquired Landsat data.

2.6. New opportunities

Free and open access to the Landsat archive continues to support emerging applications, including those based on very large assemblages of data, both in space and time. In particular, the use of Landsat data for time series analyses has increased substantially since 2008 (Fig. 1). Landsat time series advance remote sensing science and applications in several ways. For instance, land cover classifications can be improved

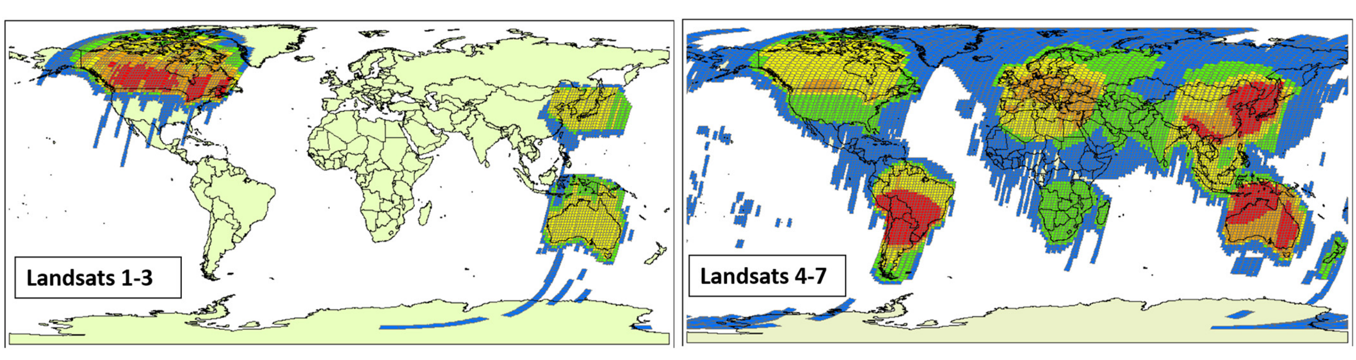

Fig. 2. Status of Landsat Global Archive Consolidation (LGAC) as of June 30, 2018 (adapted from https://landsat.usgs.gov/landsat-global-archive-consolidation-lgac accessed on November 27th, 2018). The graphic illustrates the number of images added to the USGS Landsat archive via the LGAC initiative for each path/row scene.

and informed by insights from time series (i.e., presence, type, and timing of change) (Wulder et al., 2018); to improve the precision of the type and timing of landscape change (Zhu, 2017); and by enabling near real-time monitoring of natural resources (Hansen et al., 2016). The aggregation of long and consistent time series into analysis ready data cubes (Roy et al., 2010a; Lewis et al., 2017; Dwyer et al., 2018) and the ability to integrate them with other geospatial data has demonstrated further innovative and ambitious applications (Sagar et al., 2017).

3. Conclusion

As stated by the 2013 National Research Council: "*The economic and scientific benefits to the United States of Landsat imagery far exceed the investment in the systems*" (National Research Council, 2013). Landsat's tremendous economic value has been consistently affirmed. The Landsat free and open policy has spurred the adoption of similar policies around the globe for Earth Observation satellites, including the European Copernicus Program. Furthermore, international initiatives and private sector increasingly rely on Landsat data (Wulder et al., 2019). For example, the United Nations Framework Convention on Climate Change (UNFCCC) specified the Reducing Emissions from Deforestation and forest Degradation (REDD+) mechanism partly based upon what could be monitored using Landsat (De Sy et al., 2012). Such institutionalization and reliance on Landsat are based upon access to the historic archive (providing baseline, change, and trends), expectations of measurement continuity (facilitating planning, operationalization, and investment), and, increasingly, to provide leverage to other analogous Earth Observation programs of international space agencies and commercial operators.

The importance of Landsat data as a national and global resource is difficult to overstate, and as evidenced here, we maintain this importance hinges on the free and open Landsat data policy. The U.S. is a world leader in the provision of Earth Observation remote sensing data, science and applications, and the free and open Landsat data policy underpins and maintains this leadership position. The Landsat program has demonstrated the combined importance of satellites with ground systems in gathering, processing, and disseminating data across multiple satellite missions (Goward et al., 2017). Open access to Landsat and other data, such as Sentinel-2, is becoming the norm and is needed to maximize the societal benefit from satellite data, allowing Earth Observation data to play an important and necessary role in science supported policy development.

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