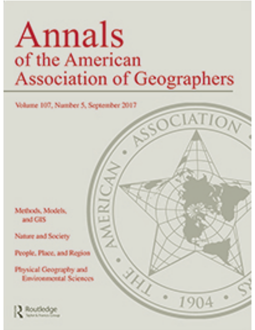

Annals of the American Association of Geographers

ISSN: 2469-4452 (Print) 2469-4460 (Online) Journal homepage: http://www.tandfonline.com/loi/raag21

Production, Property, and the Construction of Remotely Sensed Data

Luis F. Alvarez León & Colin J. Gleason

To cite this article: Luis F. Alvarez León & Colin J. Gleason (2017) Production, Property, and the Construction of Remotely Sensed Data, Annals of the American Association of Geographers, 107:5, 1075-1089, DOI: 10.1080/24694452.2017.1293498

To link to this article: http://dx.doi.org/10.1080/24694452.2017.1293498

Published online: 04 Apr 2017.

Submit your article to this journal

Article views: 170

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=raag21

Download by: [University of Massachusetts, Amherst] **Date:** 21 August 2017, At: 09:18

Check for updates

Production, Property, and the Construction of Remotely Sensed Data

Luis F. Alvarez León * and Colin J. Gleason[†]

*Sol Price Center for Social Innovation, Sol Price School of Public Policy, University of Southern California
[†]Department of Civil and Environmental Engineering, University of Massachusetts, Amherst

Remote sensing, particularly satellite imaging, is widely used in scientific, government, and public applications. One of the reasons it is so highly valued is the perception of its fundamental objectivity and neutrality. Yet like all data, satellite imagery is a product of human action. Elements such as specific technologies, strategic priorities, and privileged interpretations influence the availability and applications of remotely sensed data. We therefore argue that careful examination of the epistemological, social, and political dimensions of these data is a crucial, yet relatively underdeveloped task, especially in the scientific literature. We conduct such an examination through the property regimes (or property rights regimes) framework developed by Schlager and Ostrom. Property regimes are the arrangements by which rights over particular goods are allocated, as well as the roles to which these rights are assigned and the rules that regulate this process. This framework is especially useful in revealing the large contextual variation in the production, use, and appropriation of particular goods, in this case remotely sensed data. Understanding remotely sensed data through the property regimes that govern them emphasizes the political and economic dimensions of this valuable resource and reveals its embeddedness in the world it intends to capture from afar. Thus, we show that to have a better grasp on the role of remotely sensed data in science, policy, and society, users must acknowledge the property regimes and other political interventions that are here shown to be indeed fundamental to their construction. *Key Words: critical remote sensing, geography, Landsat, property regimes, remote sensing, satellite data.*

遥感, 特别是卫星图像, 在科学、政府与公共应用中广泛使用。其之所以高度受到重视的原因之一, 便是认为它根本上具客观性与中立性。但如同所有的数据一般， 卫星图像亦是人类行为的产物。诸如特定技术, 策略性优先顺序, 以及偏好的诠释等因素, 皆影响了遥感数据的可及性与应用。我们因此主张, 仔细检视这些数据的认识论、社会与政治面向, 是关键但相对而言尚未充分发展的工作, 特别是在科学文献中。我们透过施拉格尔与奥斯特罗姆建立的财产制度（或产权制度）架构, 执行上述检视。财产制度是特定商品权分派的安排， 以及这些权力被指派的角色和规范此依此一过程的规则。此一架构在揭露生产、使用和应用特定产品的大型脉络差异中特别有用， 于本案例中则是遥感数据。透过管理遥感数据的财产制度理解遥感数据, 强调此一可贵资源的政治与经济面向, 并揭露其植基于自身企图从远处捕捉的世界中。我们从而显示, 为了更佳理解遥感数据在科学、政策与社会中的角色, 使用者必须认识到此处所揭露的作为其发展基础的财产制度及其他政治介入。 *关键词： 批判性遥感, 地理, 陆地卫星, 财产制度, 遥感, 卫星数据。*

La percepción remota, en particular el escaneo satelital, se usa por doquier en aplicaciones científicas, gubernamentales y públicas. Una de las razones por las que esta tecnología es tan altamente apreciada es la apreciación que se tiene sobre su fundamental objetividad y neutralidad. No obstante, como todos los datos, la imaginería satelital es un producto de la acción humana. Elementos tales, como las tecnologías específicas, las prioridades estratégicas e interpretaciones privilegiadas determinan la disponibilidad y las aplicaciones de datos obtenidos por percepción remota. Por eso nosotros argüimos que es crucial un examen cuidadoso de las dimensiones epistemológicas, sociales y políticas de estos datos, tarea relativamente subdesarrollada, especialmente en la literatura científica. Nosotros llevamos a cabo tal examen a través del enfoque de regímenes de propiedad (o regímenes de los derechos de propiedad) desarrollado por Schlager y Ostrom. Los regímenes de propiedad son las disposiciones mediante las cuales se asignan derechos sobre bienes particulares, lo mismo que los roles sobre los cuales se asignan estos derechos y las reglas que regulan el proceso. Este esquema es especialmente útil para revelar la gran variación contextual en la producción, uso y apropiación de bienes particulares, que en este caso son los datos obtenidos por percepción remota. Entender datos de percepción remota a través de los regímenes de propiedad que los gobierna enfatiza las dimensiones políticas y económicas de este valioso recurso, y revela su carácter embridado dentro del mundo que la percepción remota intenta capturar desde lejos. Así, pues, indicamos que, para agarrar mejor el papel de los datos percibidos de manera remota en ciencia, política y sociedad,

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

Annals of the American Association of Geographers, 107(5) 2017, pp. 1075–1089 © 2017 by American Association of Geographers
Initial submission, March 2016; revised submission, October 2016; final acceptance, December 2016
Published by Taylor & Francis, LLC.

los usuarios deben reconocer los regímenes de propiedad y otras intervenciones políticas que aquí se muestran como ciertamente fundamentales para su construcción. *Palabras clave: percepción remota crítica, geografía, Landsat, regímenes de propiedad, percepción remota, datos satelitales.*

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

Since the dawn of the age of aviation, remote sensing of the earth has been a critical scientific and strategic tool. Remote sensing has moved beyond its beginnings in aerial photography to incorporate increasingly sophisticated sensors, both airborne and spaceborne, that enable understanding of the earth system that simply would not be possible without them. Broadly, remote sensing can be classified into two modes of operation: active remote sensing and passive remote sensing. In both modes, a sensor records the energy emitted by a target. Passive remote sensing functions like a standard camera and captures solar insolation or other electromagnetic energy as reflected by a target, and most passive sensors include the ability to detect wavelengths of light well outside the visible spectrum. In active remote sensing, this energy originates with the sensor itself and is reflected by a target before returning to the sensor (e.g., radio or light detection and ranging; radar and lidar, respectively).

Regardless of the type of sensor employed, the advent of modern remote sensing has been a boon for scientific understanding of the earth. Scholars the world over with access to remotely sensed data have been able to improve precipitation forecasting (Bevis et al. 1992; Kummerow et al. 2000; Stephens et al. 2002; Hijmans et al. 2005), quantify global carbon stocks in forests (Houghton et al. 2001; DeFries et al. 2002; Saatchi et al. 2007; Le Toan et al. 2011), track changes in sea ice extent and glacier retreat (Reynolds et al. 2002; Zwally et al. 2002; Rignot and Kanagaratnam 2006; Smith et al. 2015), better understand ocean circulation (Ducet, Le Traon, and Reverdin 2000; Reynolds et al. 2002), and quantify surface water hydrology (Gleason and Smith 2014; Gleason, Smith, and Lee 2014; Pavelsky 2014; Roy et al. 2014), among numerous other applications. These studies have been highlighted for their impact on the scientific community (via their high citation counts or novelty) and express just a part of the breadth of remote sensing. In all of these studies, however, there is very little (indeed almost no) discussion about the political, legal, and administrative dimensions that shape the production of the satellite data used and how this production can affect the use and application of these data.

It is our goal in this article to draw attention to the multiple mediations that intervene in the production process of remotely sensed data. In doing so we question the common view of remotely sensed imagery as the end results of a fundamentally objective process, which follows a Cartesian dualist view of science and data in general. This mode of scientific inquiry that informs most remote sensing research follows a realist ontology premised on the existence of a world independent from human thought. In such an ontology, there is no room for the consideration of remotely sensed data as nonobjective: Data are just data as recorded by a satellite. This ontology has been expressed through paradigms such as the "view from nowhere" proposed by Nagel (Avramides 2006) and the "God's eye point of view," criticized as untenable by Putnam (1981). Both of these positions establish fundamental objectivity stemming from the separation between observer and observed or subject and object. These paradigms are premised on the possibility of a point of view that achieves objectivity and neutrality through detachment from the observer's own positionality. Sankey (2012) characterized this mode of inquiry as "scientific realism," which he considers to be a special case of "metaphysical realism." In scientific realism, according to Sankey, "scientific inquiry leads to knowledge of the truth about observable and unobservable aspects of a mind-independent objective reality" (31).

Alternate Conceptions of Geospatial Data

We here invoke a broader context of social constructionist arguments that call into question the immutability, objectivity, and neutrality of knowledge. For example, social studies of science, knowledge, and technology have advanced a range of explorations of the historical and contextual conditions behind these related phenomena whose development or present form is often considered natural, inevitable, or given: from probability (Hacking 1990) to the practice of science in laboratories (Knorr-Cetina 1981; Latour and Woolgar 2013) to missile guidance technologies (MacKenzie 1990) and geographic information systems (GIS; Pickles 1995). These contributions have shown both the social conditions in which knowledge is created and how these social conditions affect the very substance of the knowledge itself. A useful illustration of this perspective in the field of geography is

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

found in the work of Barnes. In exploring the construction of regression and correlation analysis and their role in geography's quantitative revolution, Barnes (1998) located in the works of Bloor and Latour complementary sources of insight into the social construction of scientific knowledge:

> [Bloor's work] shows over and over again that rationalist justifications for mathematical truths do not hold up. Ideas thought to be sealed from the social and the cultural turn out at critical points to depend upon them. . . . Though Bloor is persuasive in the abstract about both the problems of rationalism and the general influence of social interests on knowledge, he is less helpful in marking the often contorted and convoluted processes, material and nonmaterial, involved in both fixing that knowledge and generating those initial social interests. Here Latour's work is germane. Whereas Bloor is concerned with providing a complete analysis of events once all the dust is settled, cleaning and tidying them up with forensic precision, care and patience, Latour is mainly interested in events while the dust is still flying. For it is then that the various networks of resources, allies and actors that are responsible for all the commotion, and which for Latour are the stuff of both science and society, are best glimpsed. (206–07)

Whereas these debates have become influential in the humanities and social sciences, they have not had the same resonance in natural sciences. This article aims to address this by contributing to a conversation in the specific context of remote sensing. It does so by building on the insights generated by scholars in the critical GIS literature and linking them with the literature on property regimes, particularly through the work of Schlager and Ostrom (1992). We here argue that remote sensing, like other types of geographic data and the knowledge derived from them, should be interrogated with attention to their mediating mechanisms. As Cosgrove (2008) pointed out, these mechanisms involve both human and computer interventions: "Even the remote sensed image is a product of colouring choices applied by the mapmaker to pixels received by the cartographic studio in numerical, digitized form" (162). Kwan (2016) cogently noted this effect in the production of geographic knowledge: "As the algorithmic mediation of the knowledge production process increases, the precise ways in which data are generated, processed, and analyzed tend to become increasingly invisible to and detached from researchers" (281). To shed light on these interventions and their downstream effects in the production and application of knowledge, we must turn to ways of understanding remotely sensed data that highlight their embeddedness within particular sociotechnical contexts.

As a bridge between social and natural sciences that emerged out of debates between these perspectives, the critical GIS literature has developed sophisticated critiques of the scientific realism prevalent in geographic information science (GIScience) and remote sensing (Curry 1994; Sheppard 1995; Schuurman 2000). Throughout a growing number of perspectives (e.g., critical GIS, critical cartography, feminist GIS, public participation GIS [PPGIS]; Elwood 2010), geographers have continuously reengaged in creative ways with the epistemic frameworks and political interventions opened by geographic technologies such as GIS, digital mapping, geovisualization, and big spatial data (Elwood 2010). More recently, in the context of data-driven geography, Kwan (2016) made a strong case that researchers should recognize the potentially significant influence of algorithms in the generation of geographic knowledge. Her proposition to foreground the algorithmic (instead of the data) component of the knowledge generation process is in line with the call put forth in this article toward critically examining the technologies of mediation involved in the generation of remotely sensed imagery.

Remote Sensing Reimagined

In the field of remote sensing, as in much of the physical sciences, the predominant ontology continues to be informed by a Cartesian dualism. Despite a seeming epistemological consensus arising from this, however, different uses of remotely sensed data have developed particular understandings of truth, accuracy, and objectivity. One example of this is strategic remote sensing, which starkly contrasts with scientific remote sensing in terms of its objectives, methods, and politics. Whereas objectivity of observation is one of the core claims of scientific remote sensing (via its dualism), strategic remotely sensed data are produced through a different lens: Capturing visual evidence of activities beyond "friendly" territory through devices such as spy satellites and drones has long been a key state activity that is undeniably intrusive. Strategic remote sensing embraces this intrusiveness and justifies it on the grounds of state security and stability, whereas scientific remote sensing asserts that this intrusion does not affect the validity of their results despite, for example, collecting the exact same kind of images as a spy drone to understand climate effects over the exact same "enemy" territory.

The contrast in logics of acquisition and use in strategic remote sensing versus scientific remote sensing illustrates a key argument of this article: The same remotely sensed data can be endowed with different claims and qualities depending on who obtains it, how, and for what purposes. From this perspective, remotely sensed data can be considered, for example, either objective and value free or intrusive and value laden (and therefore less objective), depending on the intent of the user and their political relation to spaces where data are collected. As suggested earlier, though, neither approach accurately captures the range of sociotechnical mediations in the data generation process or the knowledge claims that can be derived from remotely sensed imagery.

Regardless, the tension between objectivity and intrusion could provide a starting point to further explore the sociotechnical—and consequently political—dimensions of remote sensing images. This spirit has not reached the widespread scientific remote sensing community, but it has been theorized that "[s]uch developments [critical inquiries] will create a *context for the discipline that differs greatly from the recent past, in which the field was seen as the province of specialists largely detached from such issues*" (Campbell 2007, 608, italics added). Another example in this vein comes from Gleason and Hamdan (2017), who argued that using remote sensing to generate data they would not normally be able to access for political reasons (river discharge data in their case) is in fact explicit political interventionism regardless of the motivation of the study. Gleason and Hamdan still generated these data but acknowledged their inherently political act. It is exactly this "context for the discipline"—one that has not yet been fully characterized or reached the scientific remote sensing community and that rejects a dualist Cartesian ontology—that we investigate here.

Our goal in this article is to examine a range of remotely sensed data from different sources through a framework that addresses its production, property, and circulation. Although these issues have been peripheral to scholarship on remote sensing, we here argue that they are key to understanding the political, economic, and epistemological constructions of this technology and the data it generates. This article aims to contribute to both the critical GIS and remote sensing literatures through an explicit and unprecedented inspection of the rights, roles, and rules of remotely sensed data. Shedding light on these underexamined aspects of remote sensing data can help us better understand its impact in society, as well as how its claims to knowledge are structured in a range of contexts. We conduct this examination through the perspective of property regimes, which allows us to focus on the diverse legal and political arrangements that develop around individual data repositories in each particular context. Through this lens we show how these arrangements influence how the data can be used, the value it can produce, as well as how (and by whom) that value may be appropriated and how remotely sensed data can influence, enable, or limit particular practices and applications while challenging or reinforcing specific conceptions of scientific objectivity. We focus this exploration on the property regimes of three remotely sensed technologies that are frequently used both in scientific and popular settings: Landsat, la Systeme Pour l'Observation de la Terre (SPOT), and Google Earth.

The article proceeds in the following manner. In the next section we introduce the concept of property regimes and explain its usefulness to analyze the differentiated construction of remotely sensed data. We then briefly summarize the particular contexts of production, distribution, and use of each of the three examples of remotely sensed imagery (Landsat, SPOT and Google Earth) and apply the property regimes framework to each of these three cases to answer questions such as these: How are these data produced? Whose property are they? Who can extract value from them? Finally, we discuss how these property regimes differ from one another and how all interface with the Cartesian neutrality of scientific remote sensing, offering a view of the subject grounded in property regimes that we hope is legible to remote sensing scientists and geographers alike.

Property Regimes

Although the concept and practices of property are in continuous transformation and are highly contingent on specific sociohistorical contexts, there are certain understandings that have acquired lasting influential standing. One such notion is the eighteenth-century Blackstonian ideal of the right of property as a "sole and despotic dominion" (Blackstone 1893), which itself can be traced at least as far as sixteenth-century conceptions developed by early modern English lawyers (Blomley 2016). In this conception of property, all rights pertaining to a

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

particular good are assigned to an individual or group, who retain absolute control over it. Closer looks at the workings of property, however, have eroded this monolithic notion by drawing light to the multiplicity of ideas and practices of property in the real world. Heller (2000), for example, identified the standard trilogy of property as articulated by private, commons, and state property. Finding this trilogy constraining, he proposed updating it by developing what he called three productive approaches: constructive, integrative, and definitional.

The constructive approach identifies emerging problems in the real world and creates new conceptions of property suitable to analyze them (e.g., the anticommons in post-Soviet Russia). The integrative approach brings together existing approaches and combines their insights to produce new conceptions of property (e.g., the liberal commons, which combines aspects of private and commons property). Finally, the definitional approach traces existing metaphors at the base of conceptions of property (e.g., the enduring "bundle of rights") and reworks them or substitutes them for more fitting ones.

Heller's exercise points to the flexible and shifting boundaries of our understandings of property and how they need to be continuously challenged and expanded to address the changing real-world problems or growing complexity. For this reason, the tide in property studies has shifted from fixed categories of property toward more adaptable conceptual schemas that enable a wider range of analysis (Hsu 2002). We find Schlager and Ostrom's property rights regime to be particularly useful for a number of crucial reasons: It does not contain any set categories of property but rather relies on the linkages built through the allocation of rights to particular actors. This allows the unbundling of property rights as well as a comprehensive analysis that can address configurations of rights, rules, and actors involved in the process of creating, allocating, and exploiting property.

In this regard, we find it a schema that takes the sole focus away from objects and turns it toward the articulation of social relations embedded in sociotechnical systems. As Blomley (2016) eloquently put it, "Rather than merely the objects of ownership, property must be thought of as an organized set of relations between people in regards to a valued resource. As such, it provides a crucial grammar for many of the most consequential relations of social and political life" (593). Due to its flexibility and capacity to address the articulation of social relations, the property rights regime devised by Schlager and Ostrom (1992) stands as a particularly capable tool for understanding that "crucial grammar" provided by property relations.

According to Schlager and Ostrom (1992), property rights regimes are ways of organizing different bundles of property rights over a given good. In the schema introduced by these authors, the bundles of property rights can be analyzed from the perspective of the rules that delineate particular rights and the roles or positions created in this process. Schlager and Ostrom explained that that these rights are the product of mainly two types of rules, each addressing a level of action: operational and collective choice. They pointed out that distinguishing between operational and collective choice–level rules and rights is critical, as this is "the difference between exercising a right and participating in the definition of future rights to be exercised" (Schlager and Ostrom 1992, 251).

Operational rules define actors' rights over a particular resource. One example of an operational rule is the type of plant that is allowed in a community garden. Collective action rules, on the other hand, refer to the rights of some actors to define other actors' rights over that resource. An example of this is the right to regulate use patterns of a resource such as a water reservoir. A third level of action involves constitutional-level rules, which is where collective choice–level rules are defined. Schlager and Ostrom (1992) developed a conceptual schema that centers on operational and collective action rules and identifies the rights defined by such rules. These potential configurations, along with the actors involved in the allocation of rights, constitute the property rights regimes that can arise in any particular situation. Table 1 contains these property regimes as they result from the two rights within the operational level of action (access and withdrawal) and the three rights within the collective choice level of action (management, exclusion, and alienation).

The rights organized in Table 1 can then be assigned to a series of roles. This process simultaneously defines the relationship between roles and to the good in question. Schlager and Ostrom's (1992) schema identifies four roles in total. Out of these, only one role is limited to the operational level (authorized user), whereas three roles have incremental rights at the collective choice level (claimant, proprietor, and owner). These roles, the rights that are assigned to them, and their levels of action are reproduced in Table 2.

This schema has the advantage of providing an alternative to monolithic "all or nothing" conceptions of

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

Table 1. Rights and levels of action

Right	Level of action	Definition
Access	Operational	The right to enter a defined physical property
Withdrawal	Operational	The right to obtain the "products" of a resource (e.g., catch fish, appropriate water, etc.)
Management	Collective choice	The right to regulate internal use patterns and transform the resource by making improvements
Exclusion	Collective choice	The right to determine who will have an access right, and how that right may be transferred
Alienation	Collective choice	The right to sell or lease either or both of the above collective-choice rights

Source: Made by authors with information from Schlager and Ostrom (1992, 250–51).

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

property, as well as going beyond the three traditional ideal types of property: state, private, and common (Heller 2000). Through this schema of property rights regimes it is possible to identify a multiplicity of configurations that correspond to specific arrangements in the context of particular goods. This in turn increases the understanding of how goods can be managed and the political negotiations involved in this process.

In this article we take Schlager and Ostrom's schema as a point of departure but prefer the term property regimes to property *rights* regimes, to signal the extension of our analysis from the allocation of rights over particular goods to the broader technological and political context of the construction of different kinds of remotely sensed data. We also extend this approach to a different kind of goods, informational goods, which have particular technological and operational characteristics that influence the definition of rules and the exercise of rights over them. Thus, in developing the arguments in this article, in addition to analyzing the roles, rules, and rights in each property regime, we pay close attention the structuring functions of specific technologies in each remote sensing platform (Landsat, SPOT, and Google Earth).

We argue that deploying the framework of property regimes in this way can provide new insights into the discursive and material construction of particular goods (e.g., remotely sensed data), as well as the production, circulation, and appropriation of knowledge and value from them. We advance the framework of property regimes to explore questions about remotely sensed data rarely considered by its users despite their political, economic, and epistemological significance: Who produces this good, who can use it, and who can claim ownership over it? How are these claims advanced? What are the rules or agreements that validate said claims? Who are the actors that intervene in this process of claim and validation? What are the relationships between them?

To address these questions, it is necessary to understand the power dimensions pervading the relationships between actors involved in the production and use of remotely sensed data. These relationships are closely aligned with the definition of rules about the allocation of rights and the roles created in this process. The politics of property rights do not emerge fully formed in a vacuum, however, but are themselves influenced by the social, political, and economic standing of actors; the existing asymmetries of power between them; their access to technological means of control and distribution; and the legal framework at a particular time or place.

In the case of remotely sensed imagery, much of the access and use is structured through electronic interfaces that manage the distribution of content, the authorization of users, and the processing of payments, if required. We argue that these interfaces and the transactions structured and enacted by them are crucial to understanding the formation of property regimes around particular kinds of remotely sensed data. Elements such as the process of user navigation, the formats in which the data

Table 2. Roles and rights in a property regime

Role/right and (level of action)	Access (operational)	Withdrawal (operational)	Management (collective choice)	Exclusion (collective choice)	Alienation (collective choice)
Authorized user	X	X			
Claimant	X	X	X		
Proprietor	X	X	X	X	
Owner	X	X	X	X	X

Source: Reproduced by authors with information from Schlager and Ostrom (1992, 250–52).

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

are offered, the spatiotemporal ranges allowed for public download, and the methods of payment for data sets—far from being technical details—constitute expressions of the political construction of remotely sensed data and profoundly affect who can use it, what can be done with it, and how the value and knowledge generated from it can be distributed.

The property regimes analysis presented in this article understands remotely sensed data as fluctuating between two types of goods: (1) public good and (2) toll or club good. This requires explanation and represents an innovative extension of Schlager and Ostrom's (1992) schema, which has been primarily used to analyze the management of common pool resources such as fisheries, pastures, and other environmental goods. Ostrom (2003) defined common pool resources as those "characterized by difficulty of exclusion *and* subtractability of resource units and … threatened by overuse leading to congestion or even destruction of the resource" (239). Public goods, on the other hand, are less susceptible to congestion and destruction from overuse and thus have low subtractability and low excludability (Ostrom 2003).

Remotely sensed data, like much digital data, have low subtractability of use but are excludable in principle (and increasingly in practice through licensing and other technical controls). Goods that are excludable but have low subtractability are referred to as club or toll goods (Ostrom 2010). Examples of this are theaters and computer software. They have low subtractability because consumption by one party does not necessarily prevent consumption by another. They are also excludable, however, because it is inexpensive to exclude unauthorized individuals from using them. The low subtractability of remotely sensed data combined with the specific degree of excludability enacted by each particular data repository make remote sensing data fit both the categories of toll (when it has high excludability) and public (when it has low excludability) goods, depending on the characteristics of each case. This highlights the need to understand the property regimes of goods in specific cases. In the following section we illustrate this approach by examining three remotely sensed data sets: The first is Landsat, run and operated jointly by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS), two U.S. government agencies. The second is SPOT, produced and managed in part by the French government, with strong private-sector involvement. The third is Google Earth, a product made and owned by a private firm, Google, that uses satellite data from various sources, including Landsat.

Remotely Sensed Data

In this section we provide a synthesis of three different types of remotely sensed data and their property regimes by highlighting the specific technical and political conditions of their production, distribution, and use. We have selected these three cases due to the range of technical and institutional contexts they represent, as well as their importance as sources of remotely sensed imagery. Our aim is to illustrate how these contexts enable constructions of data that are distinct not only in technical aspects but also in their political and epistemological dimensions. We argue that this differentiated construction of remotely sensed data subsequently affects its potential to create and allocate scientific, economic, strategic, and other kinds of value.

Landsat

The iconic Landsat program has been in continuous operation since 1972. The images collected by this family of multispectral satellites (capturing wavelengths of light beyond the visible spectrum in multiple discreet channels or "bands") constitute an astounding archive of Earth-imaging data at numerous spatial resolutions (although the past several Landsat missions have been 30-resolution) and with practically uninterrupted spatial and temporal coverage. Perhaps the most important advantages of Landsat data are its near infrared (NIR) band of information, reasonable temporal repeat (about fourteen days for most latitudes), and moderate (30 m) spatial resolution. Landsat data are particularly good for the study of vegetation, as plants reflect a high percentage of NIR light (they also reflect green light and absorb red and blue light), therefore allowing detection of chlorophyll and thus analysis of plant health and production. The NIR band is also excellent at detecting open water, as water reflects almost no NIR light and therefore appears very dark in Landsat scenes. Note that NIR information is collected by numerous satellite platforms because of this utility. When combined with the deep temporal history of the Landsat family of satellites, Landsat images form a peerless data archive for study of the earth system for which there are few alternatives. The Landsat program is administered jointly by NASA and the USGS, two scientific agencies of the U.S. government. The widespread use and recognition of the Landsat program has made many of its users aware of its institutional provenance.

The production and distribution of Landsat data by these agencies is governed by the public nature of unclassified government information in the United States. This is further specified in the Land Remote Sensing Policy Act of 1992, which funded Landsat 7 and established the guidelines for distribution and commercialization of remotely sensed data produced by the U.S. government. In this Act, remotely sensed data are outlined as major benefits "in studying and understanding human impacts on the global environment, in managing the Earth's natural resources, in carrying out national security functions, and in planning and conducting many other activities of scientific, economic, and social importance" (§2, Art. 1) as well as in the national interest of the United States (§2, Art. 2). Furthermore, this Act established that "the Nation's broad civilian, national security, commercial, and foreign policy interests in remote sensing will best be served by ensuring that Landsat remains an unclassified program that operates according to the principles of open skies and nondiscriminatory access" (§2, Art. 10).

Landsat data are stored at USGS's Earth Resources Observation and Science Center (EROS) and acquired from either of two USGS portals: Glovis (https://earthexplorer.usgs.gov/) or Earth Explorer (http://glovis.usgs.gov/distribution/). These sites also serve as the distribution portals for all other public domain satellite imagery in the United States. According to the USGS, "There are no restrictions on the use of data received from [EROS] ... unless expressly identified prior to or at the time of receipt" (USGS 2013). Thus, the USGS sees Landsat data as open, public, and unrestricted, a position that is consistent with its policies as the science arm of the Department of the Interior: "It is the policy of the USGS to conduct its activities and to make the results of its scientific investigations available in a manner that will best serve the whole public, rather than the interest or benefit of any special group, corporation, or individual" (USGS 2012).

Once an account is established, Glovis and Earth Explorer each have visual search tools that let users select a region of interest and query the metadata for the available imagery covering that region. This allows users to see what images are available, when they were captured, the percentage of cloud clover in those images, and any quality issues that might be evident with a particular image. Once desired images are selected, these are then "ordered" from the USGS's EROS Data Center for download to the user's machine. Depending on the number of requests for a particular scene, images are either immediately available for download or must be transferred from a data reel to digital format at EROS. Interestingly, the USGS provides the source code for the Glovis portal, the software of which is in the public domain and available to anyone at http://glovis.usgs.gov/distribution/. This allows advanced users additional access to the remotely sensed data and serves as an additional mechanism for transparency.

Once data are acquired from the USGS, a user needs the capability to view and analyze Landsat images. First, users need to unzip the multiple layers of compression applied to the images by the USGS for their practical download. Once the images have been decompressed, a user needs to view them. Unlike other photos, Landsat images contain information from seven discrete bands of the electromagnetic spectrum and cannot be viewed with standard photo viewing software. Most commonly, proprietary software is used for viewing and analysis (e.g., ENVI, ArcGIS, and IDRISI programs), although some limited capability open source software exists (e.g., QGIS). Once the data have been downloaded and opened with a software application, users can then analyze and manipulate the data as they see fit, as they have access to the raw reflectance values for each pixel in a scene.

SPOT

The SPOT program was led by the Centre national d'études spatiales (CNES), the French space agency, and launched by a consortium of European governments in the mid-1980s. CNES was to end its role in the SPOT program by 2015 when SPOT 5 was decommissioned and deorbited, but Airbus Defense & Space (Airbus DS) launched SPOT 6 and 7, continuing the legacy of the project. Airbus DS has long been a commercial partner of SPOT, and SPOT data have always been only commercially available for purchase (most recently via Airbus DS at http://www.geo-airbusds.com/geostore/), despite being a publicly funded initiative. Although it restricts widespread access, the commercial nature of SPOT enables this program to offer users a high degree of control over the imagery they receive. This is reflected in the ability to provide users with on-demand images; unlike Landsat, whose sensing path cannot be controlled by users, SPOT can be "pointed" at a particular region at a user's request.

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

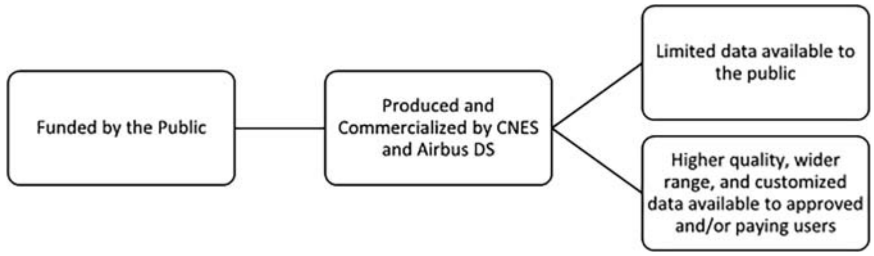

Figure 1. The process of generating and accessing la Systeme Pour l'Observation de la Terre remotely sensed data. *Source:* Drawn by authors with information from the Centre national d'études spatiales and Airbus Defense & Space. CNES = Centre national d'etudes spatiales; DS = Defense & Space.

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

SPOT data allow for similar scientific investigations as enabled by Landsat and also require specialized (and usually proprietary) software to view and manipulate. SPOT's 20-m multispectral sensor is similar to Landsat TM data and also has an NIR band, but its spatial resolution is slightly finer and its historical archive is smaller. Despite its comparative advantages in some respects, one of the consequences of the commercial nature of SPOT has been to limit its widespread uptake by the scientific community. This is reflected in the number of scientific papers using SPOT data, which is dwarfed by those using Landsat data, despite the similar characteristics of the two sensors.

SPOT hosts a variety of sensors with varying spatial resolutions, and these products are available at different prices. We requested a price list from Airbus DS on 29 June 2015 and received the December 2014 price list for imagery. Images are priced per square kilometer and range from €0.70 for 20-m multispectral data to €8.40 for 1.5-m color stereo imagery. Thus, the finer the spatial resolution, the more expensive the data. Compared to Landsat TM, SPOT offers similar spectral resolution but much enhanced spatial resolution (SPOT 6 and 7 have spatial resolution of 6 m). Although this feature, compounded with the ability to of users to "point" the sensor, provides SPOT with advantages in the marketplace, its property regime is not limited to commercial distribution. Although it is technically not public like Landsat data, some SPOT data are available free of cost. Data from satellites SPOT 1–3 collected between June 1986 and December 1998 in 10-m panchromatic and 20-m multispectral resolutions have been provided to EROS for "approved federal users" free of charge (see https://lta.cr.usgs.gov/SPOT_Historical). Although these data are considered public, they only appear in the list of available images once a user has logged into the system.

Authorized users can in turn acquire the rights to these data for internal and derivative uses including commercial use. They are precluded from distributing and commercializing the images as such, however, except for small extracts (without metadata) used for promotional purposes that include the corresponding acknowledgments of ownership. According to the agreements distributed by Airbus DS, the default jurisdiction for the intellectual property rights assigned is French law (http://www.intelligence-airbusds.com/legal-information/). There is, however, an explicitly defined exception that applies to customers in North America, whose use of SPOT data is governed by U.S. law due to the location of Airbus DS's U.S. subsidiary in Virginia (https://northamerica.airbus-group.com/north-america/usa/Airbus-Group-Inc/about-us/Contact-Us.html).

According to a 23 January 2014 press release, CNES will also release archived SPOT images that are at least five years old and coarser than 10 m in spatial resolution free of charge to the general public, citing continued public investment in the satellite given that CNES (a public agency) developed and launched SPOT 1–5. This arrangement allows Airbus to continue to charge for recent and high-resolution imagery while making the publicly funded SPOT archive available for noncommercial uses. These data are available via the Theia Land Data Center, a French national agency, to any international user (https://www.theia-land.fr/en). Similar to the Glovis portal, Theia users are able to see available imagery and query metadata without an account but must register with the site to download data. At the time of writing, only SPOT-archived images of France and Belgium have been processed and are available to the public. A schematic overview process of generating and accessing SPOT data is depicted in Figure 1.

Google Earth

Google Earth represents a fundamentally different sort of remote sensing than either SPOT or Landsat.

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

Google acquires imagery from a suite of different sensors (e.g., the Landsat, GeoEye, and Digital Globe satellites) and stores these on its cloud servers, allowing users to display these images on their machines via the Google Earth software application. Only true color (RGB) images are available for display, and the images that are displayed are not available to be downloaded and analyzed on a local machine. Thus, users can never really acquire images via Google Earth; they can simply look at them. This is an important distinction from the satellite data providers previously discussed. Google Earth also offers a temporal slider, allowing users to display images at different times provided that images exist in the Google servers. Google Earth imagery is available for display to any user with Internet access, allowing users to verify the presence or absence of certain features or note changes on the land surface over time. The inability to process imagery on a local machine or display information from electromagnetic spectra other than the visible, however, limit the applicability of Google Earth imagery for scientific purposes.

Google Earth Engine, a new application of Google Earth, is a processor that stands to revolutionize the field of remote sensing as well as the distribution of remotely sensed data. This application allows users to utilize the entire Landsat archive on Google's supercomputer cloud clusters. This means that every Landsat scene ever captured can be processed in the span of minutes (for a small area). The limitation, though, is that the user can never actually acquire the data, which resides on Google's servers. This presents an alternative to the property regime of Landsat data, which is on the open end of the spectrum, in terms of formal rights, but requires relatively high levels of knowledge and technical capabilities to use. Google Earth Engine's property regime, on the other hand, trades the right of withdrawal for increased access by lowering the technical barriers through easy processing but creating a dependency from authorized users toward its proprietary online platform.

The fact that Google Earth Engine aggregates data from different providers and makes it widely accessible complicates the construction of its property regime, as only some of the rights in the bundle of rights for each data set might have been allocated to Google for distribution through this product. For example, in the case of Landsat data, the owner is the public and the U.S. government has the role of proprietor that facilitates the data to Google without restrictions on commercialization. Google's inclusion of Landsat data in Google Earth Engine implies the construction of a new property regime for this data set. In the following section we discuss in greater detail the specific features of the property regimes involved in the creation and distribution of remote sensing data by the three platforms that are the focus of this study: Landsat, SPOT, and Google Earth.

Discussion

How, then, can the property regimes just discussed inform the dualist understandings of scientific remote sensing? Examining specific configurations of property regimes foregrounds the social and technical relations involved in the discursive and material construction of remote sensing: from considering the remote sensor as a physical presence in the space where data are collected to examining remotely sensed imaging as a product of interactions between actors differently endowed with differential rights as well as power. This in turn provides a framework to consider political relations between actors involved in the production, distribution, and multiple uses of the data, as well as the spaces where this process takes place.

To conduct this analysis, it is necessary to shift the understanding of remote sensing from neutrally acquired "raw" data and instead consider them political, technical, and epistemological constructions governed by specific arrangements contingent (among others) on time, place, institutional frameworks, and technological systems. Each of the three data sets presented here is constructed differently and endowed with varying characteristics that enable their appropriation and use by specific sets of actors. We here argue that this is important and should be interrogated because said actors can use these data to produce different kinds of value and advance claims of scientific and political truth that rely to a great degree on the perceived objective nature of remote sensing technology.

Increased awareness of the property regimes shaping the construction of remote sensing imagery can help users conduct a more self-reflexive use of these data. This, in turn, can enhance the production of knowledge by addressing important political and social considerations involved in the creation and distribution of satellite imagery such as sovereignty, invasiveness, objectivity, access to information, and control over natural and informational resources, as in the cases of upstream and downstream cross-border hydrological

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

data. As della Dora (2012) and Parks (2009) both suggested, the emergence of products such as Google Earth raises questions about the control exercised by states and private corporations in the production of "visual capital" as well as who the beneficiaries of such production and the knowledge derived from it are.

In the case of Landsat, the combination of public funding, public access, and operating principles of "open skies and nondiscriminatory access" (Land Remote Sensing Policy Act, §2, Art. 10) articulate a property regime where Landsat data are produced by the U.S. government but owned by the public and distributed with very few restrictions for reproduction, creation of derivative works, public performance, display, and distribution. Although there are no copyright restrictions to Landsat data (and other products considered government works) in the United States, these can be enforced by the U.S. government outside of its territory. Although Landsat data are unclassified, with few restrictions to use and access, it is important to consider that this particular construction might already be the result of a previous filtering process whereby certain data considered classified might have been removed and placed in a much more restrictive category governed by a different property regime (Johnson 2007).

Because Landsat data are considered unclassified works of the U.S. government, their property regime allocates the full bundle of rights to the public (which includes rights of access and withdrawal, management, exclusion, and, crucially, alienation). In practice, this bundle of rights is difficult to implement, as the exercise of any rights by the public beyond access and withdrawal (i.e., management, exclusion, and alienation) would require highly coordinated large-scale collective efforts. For these reasons, the U.S. government has taken the role of proprietor of Landsat data and exercises the rights of access and withdrawal, management, and exclusion (but not alienation, which is in theory reserved to the public). In this case, the U.S. government can grant access to any user but can reserve the right of exclusion in specific circumstances or outside of its territory.

NASA and the USGS are the parts of the U.S. government entrusted with managing access and thus they can be considered the claimants under this property regime. In this arrangement, unless an individual or organization is deemed unauthorized and explicitly barred from accessing Landsat data, it is assumed that they are authorized users with rights of use and withdrawal. Because there can be a large number of authorized users (which, in principle, can be coterminous with the public), there is in this property regime a considerable overlap between the roles of owner (the public as such) and authorized user (members of the public not explicitly barred from access). These two roles are separated by the right to alienation that, although practically impossible to exercise in this case, is solely assigned to the public, who is the owner of this good.

In the property regime of SPOT data, user access is mediated by monetary transactions, where the relationship between a French government agency (CNES) and a private company (Airbus DS)—the joint owners of the data—determines the types of rights that can be allocated to different users, the limitations of those rights, and applicable rules governing them. These rights are allocated through commercial contracts that depend principally on the type of product purchased and the corresponding spatial and temporal resolution. This arrangement influences the characteristics of SPOT remotely sensed data, as it incentivizes the development of comparative advantages for monetary gain on this publicly funded, but commercially distributed data, which contrast with publicly available data sets, such as Landsat.

The mismatch between SPOT's public funding, the designation of only part of its archive as public, and its technical and commercial restrictions on availability complicate the notions of free and public that can be attached to this type of data, as there are institutional and technical barriers that enforce a selection process of authorized users. For the publicly available part of the archive, the owner of the data, SPOT Image Corporation/Airbus DS, has allocated rights of access, withdrawal, management, and exclusion to at least one proprietor, the USGS. This proprietor then makes these data available through its Earth Explorer interface. In this case there is no identifiable claimant, as the USGS can exclude authorized users from access, but there is no intermediary actor who only has rights of management but not rights of exclusion.

The property regime for SPOT is an arrangement that tries to serve both the publicly funded nature of the SPOT program and its commercial aims. A combination of technical controls and contractual negotiations has secured limited public distribution of these data with the aim of maximizing the revenue stream from its direct commercialization. Unlike Landsat, SPOT's "pointing" feature enables customers to produce tailor-made data sets to suit their needs, which highlights the relationship between the incentives and

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

relations in this data set's property regime and the production of remote sensing data endowed with particular technical characteristics.

In the case of Google Earth, the integration of multiple data sets, each with its own property regime, into an online remote sensing platform is both an important innovation in remote sensing as well as indicative of the reconfiguration of access and use of information in the Web. Google's main innovation with Google Earth and now Google Earth Engine has been to bring satellite imagery into widespread distribution and lower the barriers for its use and manipulation. Its continued use by the media to illustrate natural disasters and other news stories is evidence of its widespread appeal. This comes with a trade-off, however, where Google has substituted users' ability to acquire the data from each particular source with an access pipeline that, although practical and user-friendly, is governed by a property regime built around the commercial goals of this company, rather than a mandate for public access or scientific work. This example, in conjunction with the examination of Landsat and SPOT data in their own regard, shows that it is insufficient to consider the openness or property of information as isolated, one-dimensional criteria. In today's increasingly complex informational environment, of which remote sensing is a growing part, it is necessary to examine the multiple articulations of rights around informational goods and the social and political relations enabled by them.

For example, whereas Landsat data in and of themselves remain under the property regime described earlier, when they are brought into Google Earth Engine their access and distribution become simultaneously governed by a new property regime. This property regime regulates the access to Landsat data through the Google platform, which has different technical and informational barriers to access, which are designed following the commercial goals of Google rather than the public and scientific goals of NASA or the USGS, the claimants of Landsat data sets outside of Google Earth Engine. Thus, in this case Google is the owner of the platform that makes the information available but not the owner of the information it provides. When it comes to Landsat data, Google could more appropriately be considered a new claimant, because it can allocate rights to access and withdrawal and has management rights but does not seem to have exclusion rights and cannot have alienation rights over the imagery (because this is in the public domain).

The preceding discussion has examined the complex assemblages of political, social, and technological forces that constitute the property regimes of three remotely sensed data sets. How, then, might these considerations be brought to bear on contemporary scientific remote sensing? First, our property regimes analysis calls into question the notion of the "fundamental neutrality" of remotely sensed (or any other kind of) data, and in this we agree with a wealth of scholars in the social studies of science, knowledge, and technology who have long advocated this position (Gitelman 2013).

Of our three cases, only Landsat comes close to approaching this kind of objectivity, with full property rights allocated to the public. Even in this most open of remotely sensed data sets, however, the fact is that Landsat was launched exclusively to serve the interests of the U.S. government (Land Remote Sensing Policy Act of 1992, §2, Art. 2 and 10), and these data are provided to the public at the discretion of the government. Thus, although full property rights are currently allotted to the public, both in the United States and abroad, this can be subject to policy changes. After all, Landsat satellites represent several hundred million dollars' worth of government property orbiting the Earth at 700 km, and control of the spacecraft ultimately dictates control over the data. This is more easily understood in SPOT, which can be pointed to a target and thus invokes ideas of more active spacecraft control and selective availability. Thus, whereas SPOT's property regime is congruous with these ideas, Landsat is taken for granted as publicly available.

Remote sensing is a powerful tool that has truly enabled a paradigm shift in the scientific understanding of the world, and we certainly do not advocate that scientific investigation be postponed or its impact somehow lessened because of ignorance of the property regimes that govern its data. We also do not advocate that users abandon using remote sensing to study politically and economically sensitive activities. Rather, our analysis reveals that users of remotely sensed data should explicitly acknowledge the conditions that have enabled them access to the data and that the data are not "value-free." In strategic remote sensing, for example, spy satellite users or drone pilots enjoy exclusive access and thus privileged information enabled by property regimes deliberately designed to produce these selective informational goods. The perception of the open-access and ultimately dualist nature of remote sensing would seem to render such informational asymmetries moot in scientific remote

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

sensing, however. After all, if everyone can access the data, then are they not truly neutral? The property regimes just outlined answer with a resounding "no" and show that even if these data are open access, they are still privileged.

The property regimes of the data sources examined here, and by extension all remote sensing platforms, show that such scientific work must be carried out by first acknowledging the legal, political, and technical relations that allowed the scientist to access the data and next allowed the data to be created in the first place. We live in a complex and interconnected world, and the political, social, and economic conditions enabling satellite images of that world bear consideration before they are used. Incorporating into scientific work a self-reflexive attitude with respect to the production and provenance of satellite data would be an important step toward improving the conditions of production and circulation of knowledge in the world within and outside academia. In the realm of academic publishing, we are seeing a similar type of awareness—in this case of the high barriers of access to knowledge and its storage silos—that has a material effect on the means of distribution through the creation of open access venues and mounting pressures on scientific publishers.

Conclusions

Remotely sensed data are a key resource to scientific and strategic endeavors and include an expanding number of applications. By applying Schlager and Ostrom's (1992) schema of property (rights) regimes to three commonly used remote sensing data sets (Landsat, SPOT, and Google Earth), this study presents an effective lens to analyze what has been an underexamined dimension of remotely sensed data: the scientific dualism that underlies much scientific remote sensing. By expanding the focus of property regimes to examine the increasingly important role of technological interfaces in the allocation of rights to informational goods, we questioned the dualist premise of remote sensing through an analysis of the political, social, and technological embeddedness of remotely sensed data. We find that these data should not be assumed to be "raw," fundamentally objective, and detached from the observer but rather both a product and a part of contextually specific political negotiations and sociotechnical systems. Although this process is always informed by existing social relations and their corresponding power asymmetries, it simultaneously creates new conditions of possibility for the production and appropriation of value of particular goods. By asking questions such as who owns a particular data set or who can access and use it, our examination reveals that the allocation of rights and the conditions this creates are crucial to the production and multiple constructions of remotely sensed data. The rights, roles, and rules involved in the property regimes of remote sensing shape the possibilities of its use in a variety of contexts, enable claims for its scientific and strategic authority, and structure the production and appropriation of value through this informational resource.

By downloading remotely sensed data, a user participates in a chain of events and political decisions that ultimately affect the conclusions drawn from the data. We argue that scientists must acknowledge this in their work, especially when using remote sensing to access areas of the globe where they would not be allowed physical access. Currently, such acknowledgment happens seldom outside of the use of remote sensing for explicit activism. We do not argue that remote sensing as it exists now should cease or that previous and future remote sensing work conducted under a dualist paradigm is somehow invalid, as such a premise would be hypocritical for one of the authors. Rather, we conclude that the scientific remote sensing community must be made aware of these property regimes and should add explicit acknowledgment of their privileged position in any remote sensing study.

ORCID

Luis F. Alvarez León http://orcid.org/0000-0001-9888-4921

References

Avramides, A. 2006. Thomas Nagel: The view from nowhere. In *Central works of philosophy*, ed. J. Shand, 227–45. New York: Acumen.

Barnes, T. J. 1998. A history of regression: Actors, networks, machines, and numbers. *Environment and Planning A* 30 (2): 203–23.

Bevis, M., S. Businger, T. A. Herring, C. Rocken, R. A. Anthes, and R. H. Ware. 1992. GPS meteorology: Remote-sensing of atmospheric water-vapor using the

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017

Global Positioning System. *Journal of Geophysical Research-Atmospheres* 97 (D14): 15787–15801.

Blackstone, W. 1893. *Commentaries on the laws of England in four books*. Vol. 1. Philadelphia, PA: Lippincott.

Blomley, N. 2016. The territory of property. *Progress in Human Geography* 40 (5): 593–609.

Campbell, J. B. 2007. *Introduction to remote sensing*. New York: Guilford.

Centre National D'Etudes Spatiales (CNES). 2014. CNES's SPOT World Heritage programme to provide free SPOT satellite archive imagery over five years old for non-commercial uses. 23 January. https://presse.cnes.fr/en/cp-8193 (last accessed 8 March 2017).

Cosgrove, D. 2008. *Geography and vision: Seeing, imagining and representing the world*. London: I. B. Tauris.

Curry, M. R. 1994. Image, practice and the hidden impacts of geographic information systems. *Progress in Human Geography* 18 (4): 441–59.

DeFries, R. S., R. A. Houghton, M. C. Hansen, C. B. Field, D. Skole, and J. Townshend. 2002. Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s. *Proceedings of the National Academy of Sciences of the United States of America* 99 (22): 14256–61.

della Dora, V. 2012. A world of "slippy maps": Google Earth, global visions, and topographies of memory. *Transatlantica: Revue d'études américaines American Studies Journal* 2 (October): 1–21.

Ducet, N., P. Y. Le Traon, and G. Reverdin. 2000. Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and-2. *Journal of Geophysical Research-Atmospheres* 105 (C8): 19477–98.

Elwood, S. 2010. Thinking outside the box: Engaging critical geographic information systems theory, practice and politics in human geography. *Geography Compass* 4 (January): 45–60.

Gitelman, L. 2013. *Raw data is an oxymoron*. Cambridge, MA: MIT Press.

Gleason, C. J., and A. N. Hamdan. 2017. Crossing the (watershed) divide: Satellite data and the changing politics of international river basins. *The Geographical Journal* 183 (1): 2–15.

Gleason, C. J., and L. C. Smith. 2014. Toward global mapping of river discharge using satellite images and at-many-stations hydraulic geometry. *Proceedings of the National Academy of Sciences of the United States of America* 111 (13): 4788–91.

Gleason, C. J., L. C. Smith, and J. Lee. 2014. Retrieval of river discharge solely from satellite imagery and at-many-stations hydraulic geometry: Sensitivity to river form and optimization parameters. *Water Resources Research* 50 (12): 9604–19.

Hacking, I. 1990. *The taming of chance*. Cambridge, UK: Cambridge University Press.

Heller, M. A. 2000. Three faces of private property. *Oregon Law Review* 79 (2): 417–34.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25 (15): 1965–78.

Houghton, R. A., K. T. Lawrence, J. L. Hackler, and S. Brown. 2001. The spatial distribution of forest biomass in the Brazilian Amazon: A comparison of estimates. *Global Change Biology* 7 (7): 731–46.

Hsu, S.-L. 2002. Two-dimensional framework for analyzing property rights regimes. *UC Davis Law Review* 36 (January): 813.

Johnson, J. 2007. Google's view of D.C. melds new and sharp, old and fuzzy. *The Washington Post* 22 July, Technology. http://www.washingtonpost.com/wp-dyn/content/article/2007/07/21/AR2007072101296.html (last accessed 31 March 2017).

Knorr-Cetina, K. 1981. *The manufacture of knowledge*. Oxford, UK: Pergamon.

Kummerow, C., J. Simpson, O. Thiele, W. Barnes, A. T. C. Chang, E. Stocker, R. F. Adler, et al. 2000. The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. *Journal of Applied Meteorology* 39 (12): 1965–82.

Kwan, M.-P. 2016. Algorithmic geographies: Big data, algorithmic uncertainty, and the production of geographic knowledge. *Annals of the American Association of Geographers* 106 (2): 274–82.

Land Remote Sensing Policy Act of 1992, Pub. L. No. 102–555, H.R.6133. https://www.congress.gov/bill/102nd-congress/house-bill/6133/text?q=%7B%22search%22%3A%5B%22HR6133%22%5D%7D&resultIndex=6 (last accessed 15 March 2017).

Latour, B., and S. Woolgar. 2013. *Laboratory life*. Princeton, NJ: Princeton University Press.

Le Toan, T., S. Quegan, M. W. J. Davidson, H. Balzter, P. Paillou, K. Papathanassiou, S. Plummer, et al. 2011. The BIOMASS mission: Mapping global forest biomass to better understand the terrestrial carbon cycle. *Remote Sensing of Environment* 115 (11): 2850–60.

MacKenzie, D. A. 1990. *Inventing accuracy: A sociological history of nuclear missile guidance*. Cambridge, MA: MIT Press.

Ostrom, E. 2003. How types of goods and property rights jointly affect collective action. *Journal of Theoretical Politics* 15 (3): 239–70.

———. 2010. Beyond markets and states: Polycentric governance of complex economic systems. *The American Economic Review* 100 (3): 641–72.

Parks, L. 2009. Digging into Google Earth: An analysis of "Crisis in Darfur." *Geoforum* 40:535–45.

Pavelsky, T. M. 2014. Using width-based rating curves from spatially discontinuous satellite imagery to monitor river discharge. *Hydrological Processes* 28 (6): 3035–40.

Pickles, J. 1995. *Ground truth: The social implications of geographic information systems*. New York: Guilford.

Putnam, H. 1981. *Reason, truth, and history*. Cambridge, UK: Cambridge University Press.

Reynolds, R. W., N. A. Rayner, M. T. Smith, D. C. Stokes, and W. Q. Wang. 2002. An improved in situ and satellite SST analysis for climate. *Journal of Climate* 15 (13): 1609–25.

Rignot, E., and P. Kanagaratnam. 2006. Changes in the velocity structure of the Greenland ice sheet. *Science* 311 (5763): 986–90.

Roy, D. P., M. A. Wulder, T. R. Loveland, C. E. Woodcock, R. G. Allen, M. C. Anderson, D. Helder, et al. 2014. Landsat-8: Science and product vision for terrestrial global change research. *Remote Sensing of Environment* 145:154–72.

Saatchi, S. S., R. A. Houghton, R. C. Dos Santos Alvala, J. V. Soares, and Y. Yu. 2007. Distribution of aboveground live biomass in the Amazon basin. *Global Change Biology* 13 (4): 816–37.

Sankey, H. 2012. *Scientific realism and the rationality of science*. Farnham, UK: Ashgate.

Schlager, E., and E. Ostrom. 1992. Property-rights regimes and natural resources: A conceptual analysis. *Land Economics* 68 (3): 249–62.

Schuurman, N. 2000. Trouble in the heartland: GIS and its critics in the 1990s. *Progress in Human Geography* 24 (4): 569–90.

Sheppard, E. 1995. GIS and society: Towards a research agenda. *Cartography and Geographic Information Systems* 22 (1): 5–16.

Smith, L. C., V. W. Chu, K. Yang, C. J. Gleason, L. H. Pitcher, A. K. Rennermalm, C. J. Legleiter, et al. 2015. Efficient meltwater drainage through supraglacial streams and rivers on the southwest Greenland ice sheet. *Proceedings of the National Academy of Sciences of the United States of America* 112 (4): 1001–06.

Stephens, G. L., D. G. Vane, R. J. Boain, G. G. Mace, K. Sassen, Z. E. Wang, A. J. Illingworth, et al. 2002. The Cloudsat mission and the A-train: A new dimension of space-based observations of clouds and precipitation. *Bulletin of the American Meteorological Society* 83 (12): 1771–90.

U.S. Geological Survey (USGS). 2012. U.S. Geological Survey: Information policies and instructions. http://www.usgs.gov/laws/info_policies.html (last accessed 20 February 2017).

———. 2013. Earth Resources Observation and Science (EROS) Center: Data citation. http://eros.usgs.gov/about-us/data-citation (last accessed 20 February 2017).

Zwally, H. J., B. Schutz, W. Abdalati, J. Abshire, C. Bentley, A. Brenner, J. Bufton, et al. 2002. ICESat's laser measurements of polar ice, atmosphere, ocean, and land. *Journal of Geodynamics* 34 (3–4): 405–45.

LUIS F. ALVAREZ LEÓN is a Postdoctoral Researcher at the Sol Price Center for Social Innovation, Sol Price School of Public Policy at the University of Southern California, Los Angeles, CA 90089. E-mail: alva373@price.usc.edu. His research focuses on the political, economic, and geographic dimensions of information, innovation, and technology.

COLIN J. GLEASON is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Massachusetts–Amherst, Amherst, MA 01003. E-mail: cjgleason@umass.edu. His research covers fluvial hydrology, fluvial geomorphology, remote sensing, ungauged basins, arctic hydrology, and the global water budget.

Downloaded by [University of Massachusetts, Amherst] at 09:18 21 August 2017