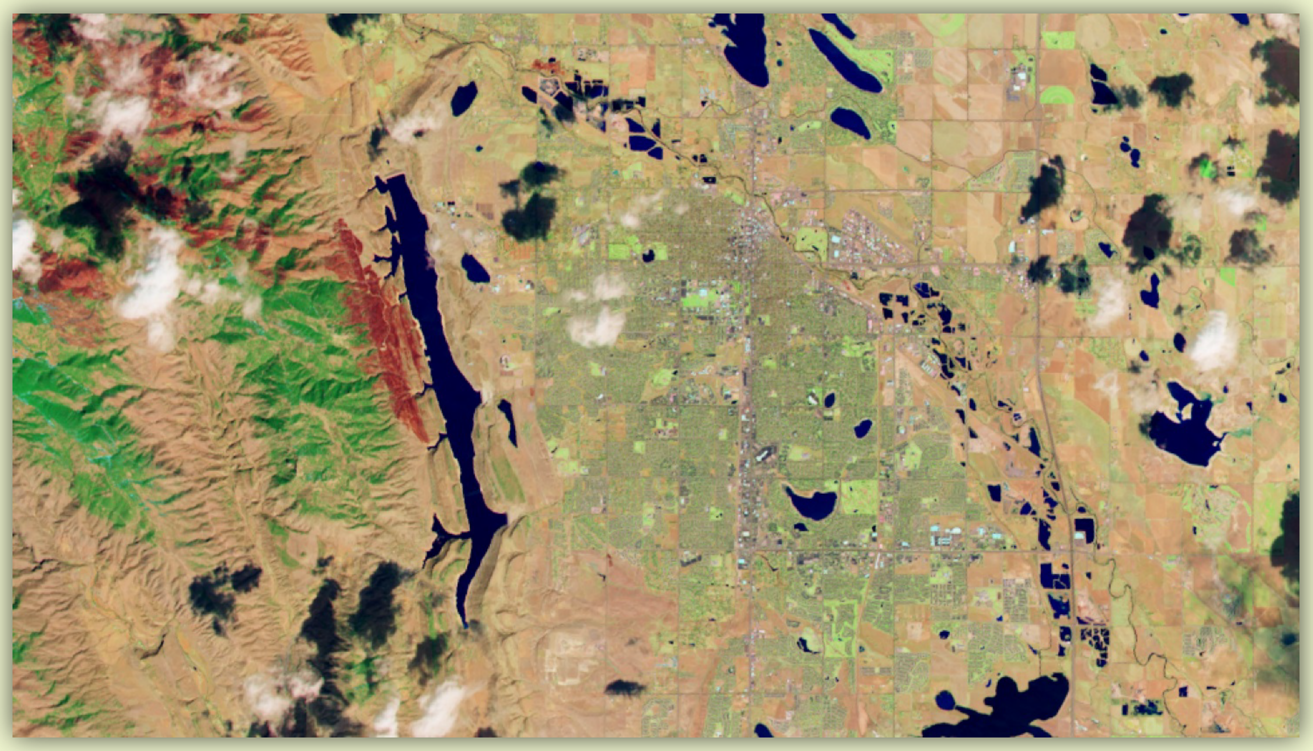
Users and Uses of Landsat 8 Satellite Imagery—2014 Survey Results

By Holly M. Miller



Open-File Report 2016–1032

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2016

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Suggested citation:
Miller, H.M., 2016, Users and uses of Landsat 8 satellite imagery—2014 survey results: U.S. Geological Survey Open-File Report 2016–1032, 27 p., http://dx.doi/org/10.3133/ofr20161032.

ISSN 2331-1258 (online)

Cover image: First image released from Landsat 8, collected over Fort Collins, Colo., on March 18, 2013, showing the Galena Fire burn scar in red.

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Acronyms and Initialisms

EROS	Earth Resources Observation and Science Center
ETM+	Enhanced Thematic Mapper Plus
GIS	geospatial information system
MSS	Multispectral Scanner
OLI	Operational Land Imager
SLC	scan-line corrector
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
USGS	U.S. Geological Survey

Executive Summary

In 2013, Landsat 8 began adding high quality, global, moderate-resolution imagery to the more than 40-year archive of Landsat imagery. To assess the potential effects of the availability of Landsat 8 imagery on users and their work, the U.S. Geological Survey (USGS) Land Remote Sensing Program (LRS) initiated a survey of Landsat users. The objectives of the survey were to

1. Characterize various Landsat user groups, such as United States (U.S.) and international users and Landsat 8 and non-Landsat 8 users;
2. Identify any differences among user groups in uses and preferences;
3. Measure the importance of and satisfaction with Landsat 8 attributes;
4. Assess the importance to users of the frequency of usable imagery; and
5. Determine any challenges in using Landsat 8.

The online survey was sent to 51,617 Landsat users registered with USGS in May 2014. Almost 13,000 people responded to the survey for a response rate of 25 percent (n = 12,966). Current Landsat users (users who had used Landsat in their work in the year prior to the survey) composed 89 percent of the sample (n = 11,549) and past Landsat users composed 11 percent (n = 1,417). The results reported here apply to current Landsat users registered with the USGS Earth Resources Observation and Science (EROS) Center.

Users from 161 countries responded to the survey. Of those, 19 percent were citizens or permanent residents of the United States and 81 percent resided in other countries. More than 70 percent of current users had used Landsat 8 in the year prior to the survey. The majority of Landsat 8 users (65 percent) were established users who used Landsat imagery regularly both before and after Landsat 8 imagery became available. The average current Landsat user was male, 36 years old, and highly educated, with 9 years of experience using satellite imagery or geographic information system (GIS) software. Landsat 8 users had, on average, two more years of experience than non-Landsat 8 users. Users were employed predominantly by academic institutions (65 percent), followed by private businesses (13 percent), Federal governments (10 percent), State and local governments (6 percent), and nonprofit organizations (6 percent).

Of the Landsat imagery obtained in the past year by current users, on average 31 percent came from a Landsat 8 sensor. An equivalent amount came from the Landsat 7 ETM+ sensor (33 percent); slightly less came from Landsats 4 and 5 TM sensors (27 percent). Much less came from Landsats 1 through 5 MSS sensors (5 percent). Overall, more than a third of users' work used Landsat imagery (38 percent). Of this work, on average, 37 percent of the work was operational. Landsat 8 users considered a greater proportion of their work operational than non-Landsat 8 users (39 percent compared with 29 percent). Environmental sciences and management were the most commonly selected primary applications (selected by 42 percent of users). Land use/land cover (23 percent) was the second most commonly selected primary application, followed by education (12 percent), agriculture (9 percent), and planning and development (6 percent).

Landsat 8 users were asked to rank the importance of certain attributes in determining whether to use Landsat 8 imagery in their work. The archive was ranked most important, followed by cost, spatial resolution, extent of coverage, data quality, and frequency of revisit. Users were asked how satisfied they were with these same attributes as they currently apply to Landsat 8 imagery. On average, users were most satisfied with lack of cost, extent of coverage, data quality, and the archive, but they were satisfied with all attributes.

Users were asked how often they needed Landsat imagery to meet various requirements for their primary application. The survey question specifically asked how often users needed usable

imagery, which differs from how often they would like the Landsat satellites to acquire an image. Users were asked to identify their needed frequency of usable imagery for the following levels:

1. Threshold level—the minimum frequency of usable imagery needed to be of any value to their primary application.
2. Breakthrough level—the frequency of usable imagery that would result in a significant improvement for their primary application of the imagery.
3. Target level—the frequency of usable imagery that would only provide a limited additional increase in the expected performance for their primary application.

To meet the threshold level, three-quarters of users needed usable imagery every 17 days or less frequently. At the breakthrough level, two-thirds of users (64 percent) needed a usable image every 5–16 days. The current constellation of two satellites (Landsat 7 and 8) is capable of meeting the threshold and breakthrough needs of most users at least some of the time, but a single satellite would be highly unlikely to do so. Two-fifths of users (40 percent) felt that usable imagery provided every 4 days or more frequently would meet their target level which the current Landsat constellation cannot provide. Landsat 8 users were significantly more likely than non-Landsat 8 users to need usable imagery more frequently to meet their target levels. Additionally, U.S. Landsat 8 users were significantly more likely than other Landsat users to need usable imagery more frequently in order meet both their breakthrough and target levels.

To explore the effect of the availability of Landsat 8 imagery on Landsat imagery use in general, established users (those who had consistently used Landsat imagery both before and after Landsat 8 imagery became available) using Landsat 8 imagery were asked about changes in the amount of Landsat imagery they used. The majority of established users using Landsat 8 imagery (60 percent) reported an average increase of 51 percent in the number of scenes obtained after Landsat 8 imagery became available. Landsat 8 users were asked if they had encountered challenges in using Landsat 8 whereas non-Landsat 8 users were asked if such challenges had played a role in why they were not using Landsat 8 imagery. Although many users did not encounter challenges when using or trying to use Landsat 8 data, slightly less than 30 percent did encounter issues with processing the data to a usable point. The most common issue reported was not being able to create or have access to a surface reflectance corrected product. Other challenges were related to the file sizes of images being too large to download, store, or analyze. There were no statistically significant differences between Landsat 8 and non-Landsat 8 users in terms of challenges encountered when using or trying to use the imagery, which indicates that users were not unduly discouraged by the challenges they may have encountered. When asked about potential consequences of not using Landsat 8, more than half of the non-Landsat 8 users did not report detrimental effects on their work from not using the imagery. Of those who did report detrimental effects, decreased quality of work, decreased scope of work, and increased time spent on work were the most common.

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Introduction

Landsat satellite imagery, which has been continuously collected since 1972, now composes an unparalleled archive of more than four decades of global moderate-resolution imagery. All Landsat data is received, processed, distributed, and archived by the U.S. Geological Survey's (USGS) Earth Resources Observation and Science (EROS) Center. As of June 2015, more than 5.8 million scenes were available in the EROS archive for users to download at no cost (U.S. Geological Survey, 2015). From 2008, when the imagery became available at no cost, until June 2015, more than 26 million scenes had been downloaded. Tens of thousands of users around the world use Landsat in applications that range from agriculture and water resources to urban planning and software development (Miller and others, 2013).

Previous research has documented the numerous uses and users of the imagery, as well as the substantial value of the imagery (for example, Morse and others, 2008; Miller and others, 2011, 2013; Forney and others, 2012; Landsat Advisory Group, 2012). However, during the last decade, changes in the imagery (the decommissioning of Landsat 5 and the launch of Landsat 8 in 2013) and imagery provision (imagery available online at no cost since 2008) have made it difficult to consistently assess the users and uses of Landsat. Each change brings with it potential shifts in the users and uses of the imagery, which in turn may suggest changes to how the imagery is provided as well as inform the development of future satellites.

The launch of Landsat 8 and subsequent provision of imagery from this satellite is the focus of this report. Landsat 8 imagery differs in several ways from Landsat 7 and other, earlier Landsat imagery (table 1). Although the spatial resolution of the multispectral imagery has remained the same, the spatial resolution of the thermal imagery is different (though most of the thermal data is resampled to 30 meters). Landsat 8 also has two thermal bands instead of one. Two new multispectral bands were added to Landsat 8: a coastal band for investigating water resources and coastal areas and a cirrus band for identifying high, thin clouds. The majority of the bands on the Landsat 8 sensors have changed slightly as well, meaning that they do not match exactly with data from previous sensors. Additionally, the bit depth of Landsat 8 images is greater than that of previous Landsat sensors, which results in higher quality data, but also substantially enlarges the file size of the images.

Table 1. Comparison of characteristics of selected Landsat sensors.

[MSS, Multispectral Scanner; TM, Thematic Mapper; ETM+, Enhanced Thematic Mapper Plus; OLI, Operational Land Imager; TIRS, Thermal Infrared Sensor; NA, not applicable; ~, approximately; MB, megabytes; GB, gigabytes]

Sensor characteristic	MSS (Landsats 1–5)	TM (Landsats 4,5)	ETM+ (Landsat 7)	OLI & TIRS (Landsat 8)
Multispectral imagery				
Spatial resolution	90 meters	30 meters	30 meters[1]	30 meters[1]
Number of bands	4	6	7	9
Thermal imagery				
Spatial resolution	NA	120 meters	60 meters	100 meters
Resampled spatial resolution	NA	30–60 meters	30 meters	30 meters
Number of bands	NA	1	1	2
All imagery				
Bit depth	8-bit	8-bit	8-bit	12-bit
File size	~25 MB	~170 MB	~250 MB	~1 GB
Known problems	Missing data	Missing data	Scan Line Corrector failure	Ghosting in thermal band 11

[1]Panchromatic band has a 15-meter spatial resolution.

To assess the potential effects of these differences in Landsat 8 imagery on users and their work, the USGS Land Remote Sensing Program initiated a survey of Landsat users. The objectives of the survey were as follows:

1. Characterize various Landsat user groups, including U.S. and international users and Landsat 8 and non-Landsat 8 users;
2. Identify differences among user groups in uses and preferences;
3. Measure the importance of and satisfaction with Landsat 8 attributes;
4. Assess the importance of the frequency of usable imagery to users; and
5. Determine any challenges in using Landsat 8, given differences in the imagery, as compared with earlier versions of Landsat imagery.

Methods

Sampling

The population of interest for this study comprised all people who had accessed Landsat images through EROS within the year prior to the survey; it did not include downstream and secondary users who are not registered with EROS. A list of 55,494 email addresses was provided by EROS. After duplicate and undeliverable email addresses were removed, 51,617 addresses remained. Because of the low time and cost barriers associated with contacting users by email and providing the survey exclusively online, we conducted a census of this population, rather than take a sample. One of the main reasons for a census approach was that more than half of the users (62 percent) on the list resided in countries where English is not an official language.

Because the survey was available only in English, we anticipated that there would be language barriers with some users. Every user needs some knowledge of English to navigate the web sites that provide access to Landsat imagery. However, because of the complexity of some of the questions on the survey, not all users may have been able to fully understand every question. A random sample would have limited the number of users contacted and thus potentially increased the effect of any existing language barriers on the response rate. A census ensured that everyone who had sufficient knowledge of English was afforded an opportunity to take the survey. The language barrier may have introduced some bias into the results, but it is very difficult to determine if this is the case for this survey effort. Although some open-ended questions allowed users to write responses, the small amount of writing limited any kind of proficiency analysis.

Survey

We launched the survey in May 2014 to all the users with valid email addresses on the EROS list. For continuity, the survey was very similar to surveys conducted in 2009 and 2012, though the use of Landsat 8 imagery (instead of all Landsat imagery) was emphasized. The survey was developed in conjunction with experts at the USGS Land Remote Sensing Program to ensure that the technical details were accurate and that the instrument would gather information that would inform the Land Remote Sensing Program's distribution of imagery and its future requirements. The 2009 and 2012 surveys were conducted entirely online and we followed the same model for the 2014 survey, using a modified Dillman method for contacting users by email (Dillman, Smyth, and Christian, 2014). Users received as many as six emails asking for their participation in the survey. The sender and subject line were varied with each email to decrease the chances of being caught in spam filters and to increase the chances of recipients opening an email. Each email contained a link to the survey unique to that recipient, which allowed individual users to enter and exit the survey as they wished while saving their answers. As soon as users clicked on the "Submit" button at the end of the survey, the survey was considered complete and they were sent no further emails.

An online survey is not appropriate for all populations, because commonly some members lack access to a computer, access to the Internet, an email account, or the technological skills necessary to complete a survey online. In this case, the population consisted of imagery users who must have access to a computer and the Internet to have accessed the imagery through EROS, who have an email account, and who must be at least somewhat technologically adept to use the imagery. Providing the survey online allowed asking only those questions relevant to each respondent through the use of automated logic patterns in the survey. Because there was no guarantee that all the users had used Landsat 8 imagery in their work in the year prior to the survey, we constructed a survey with questions tailored to Landsat 8 users and to users of other Landsat imagery. Aside from asking the respondents to focus on their Landsat 8 use or their Landsat use in general, these questions were identical in order to facilitate comparisons of the two user groups.

Analyses

We examined frequency data, chi-square analyses, and *t*-tests (as described in Ott and Longnecker, 2001). Because Landsat satellites are built and operated by the U.S. Government and U.S. users download the majority of imagery from EROS (Miller and others, 2013), the views of U.S. users were of particular interest. Significant differences between U.S. and international users, as well as between Landsat 8 and non-Landsat 8 users, are reported (refer to the following section on statistical significance and interpretation for what constitutes significance for these analyses). Where there are differences, chi-squares are reported for categorical variables and *t*-tests (two groups of users) or one-way analyses of variance (ANOVA; three or more groups) are reported to compare means computed from scale variables.

Statistical Significance and Interpretation

Owing to the large sample size, the statistical power of all tests is very high (close to or at 100 percent), which may lead to differences that are statistically significant but not meaningfully different (in other words, practically significant). To address this issue, we consider differences to be statistically significant at $p \leq 0.001$, rather than the more typical $p \leq 0.05$. Although this significance level may seem conservative, in these analyses, *p*-values are mainly used as guides to identify tests that may yield significant effect sizes; *p*-values greater than 0.001 are unlikely to yield significant effect sizes. Effect sizes are measurements of the amount of impact an independent variable has on a dependent variable (Murphy and Myors, 1998, p. 12) and are better indicators of meaningful differences than *p*-values. The effect sizes calculated for these analyses are phi (Φ; two groups) and Cramer's V (three or more groups) for chi-square analyses (from SPSS software) as well as Cohen's d_s for *t*-tests (calculated using Lakens, 2013) and partial eta squared (η_p^2) for ANOVAs (from SPSS software; table 2).

Cohen (1988, p. 25–27, 79–80) provides the following examples to assist in interpreting these effect sizes:

- A small effect = difference in mean height between 15- and 16-year-old girls,
- A medium effect = difference in mean height between 14- and 18-year-old girls, and
- A large effect = difference in mean height between 13- and 18-year-old girls.

Following Cohen's recommendations on the interpretation of effect size for behavioral and psychological studies (1988, p. 25), we consider statistically significant measures with small effect sizes or greater to indicate meaningful difference for this study (table 2).

To identify where differences are located within a given chi-square analysis, the significant adjusted standardized residuals (ASR) are reported. An ASR either above 2 or below –2 indicates a statistically significant difference. All statistical results are located in the footnotes to the text or tables.

Table 2. Guidelines for interpretation of effect sizes (from Cohen, 1988).

Effect size	Small effect	Medium effect	Large effect
Phi (Φ) and Cramer's V	0.10	0.30	0.50
Cohen's d_s	0.20	0.50	0.80
Partial eta squared (η_p^2)	0.01	0.06	0.14

Results

Response Rate

Almost 13,000 people responded to the survey for a response rate of 25 percent (n = 12,966), which is slightly lower than the average response rates for online surveys reported in several meta-analyses (for example, Sheehan, 2001; Lozar Manfreda and others, 2008; Shih and Fan, 2008). This number includes both completed surveys (n = 12,042) and partially completed surveys (n = 924). Partially completed surveys were included only if respondents had answered a key question about their preferences for the available frequency of usable Landsat imagery.

Because the response rate was not 100 percent, there is the possibility of nonresponse bias in the results. Nonresponse bias can occur when those people who did not respond to the survey are different in some way from those who did. A survey of those who did not respond helped to determine if nonresponse bias might exist. This short survey contained four questions: Landsat use in the past year; Landsat 8 use; new, established, or returning Landsat 8 user; and work sector (such as government, private business, or academia). A total of 2,473 individuals responded to the nonresponse survey. Results from this survey were compared to those of the respondent sample to determine differences. There were no statistically significant differences in the distribution of the four variables between respondents and nonrespondents. However, since the nonresponse survey was not completed by all nonrespondents, there may still be differences between respondents and nonrespondents that cannot be identified.

Response rates to individual questions are also of concern in statistical analyses. The percentage of missing data for any given question ranged from 0 to 33 percent. Although Lynch (2003) suggests that more than 10 percent missing data on any given question may be problematic, given the large sample size of this survey, the power remains very high for all results reported here. However, there is a chance that respondents who did not respond to certain questions would have responded differently than those who did respond, so where the percentage of missing data is more than 10 percent for a given question, that information is given in the text or in a footnote.

Types of Landsat Users

Current Landsat users (users who had used Landsat in their work in the year prior to the survey) composed 89 percent of the sample (n = 11,549) and past Landsat users composed 11 percent (n = 1,417). Past Landsat users were asked no further questions. The results reported here apply to current Landsat users registered with USGS EROS. Of the current Landsat users, 19 percent were citizens or permanent residents of the United States and 81 percent were from other countries (fig. 1). This distribution of users is very similar to the distribution in the original EROS list, which contained 21 percent U.S. users and 79 percent international users. Users from 161 countries responded to the survey. More than half (65 percent) were from countries where English is not an official language, slightly more than the percentage on the original EROS list (62 percent). Additionally, the distribution of survey respondents across 21 regions defined by the United Nations (2012) was very similar to the distribution of the EROS registered users across those regions. The difference between the percentages of respondents and EROS users was 0.5 percent or less for 17 of the 21 regions. Of the remaining four regions, three had differences of 1 percent and the fourth (Southeast Asia) had a difference of 3.2 percent. This indicates language barriers may not have played a large role in whether users chose to respond.

Landsat 8 users (those who had used Landsat 8 imagery, as well as imagery from other Landsat sensors, in the year prior to the survey) composed more than 70 percent of current users (fig. 1). The relatively recent availability of high quality Landsat 8 data led us to hypothesize that at least some of the Landsat 8 users would be new (they had never used Landsat imagery before Landsat 8 imagery became available). While around a fifth of the Landsat 8 users (19 percent) were new, established users (those who used Landsat regularly both before and after Landsat 8 imagery became available) were the majority of the users (65 percent; fig. 2). There was also a small group of returning users (those who had used Landsat in the past, but had not used Landsat for at least a year prior to Landsat 8 imagery becoming available, 16 percent).

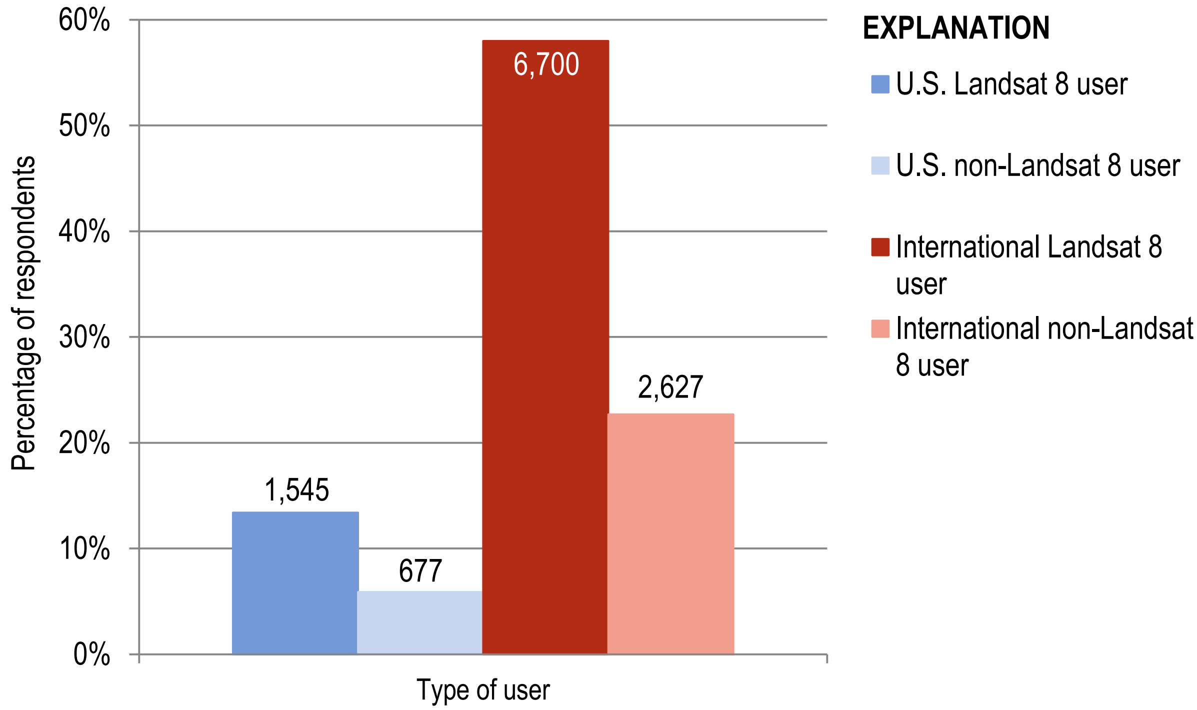

Figure 1. Current Landsat users by Landsat 8 imagery use and citizenship (n = 11,549).

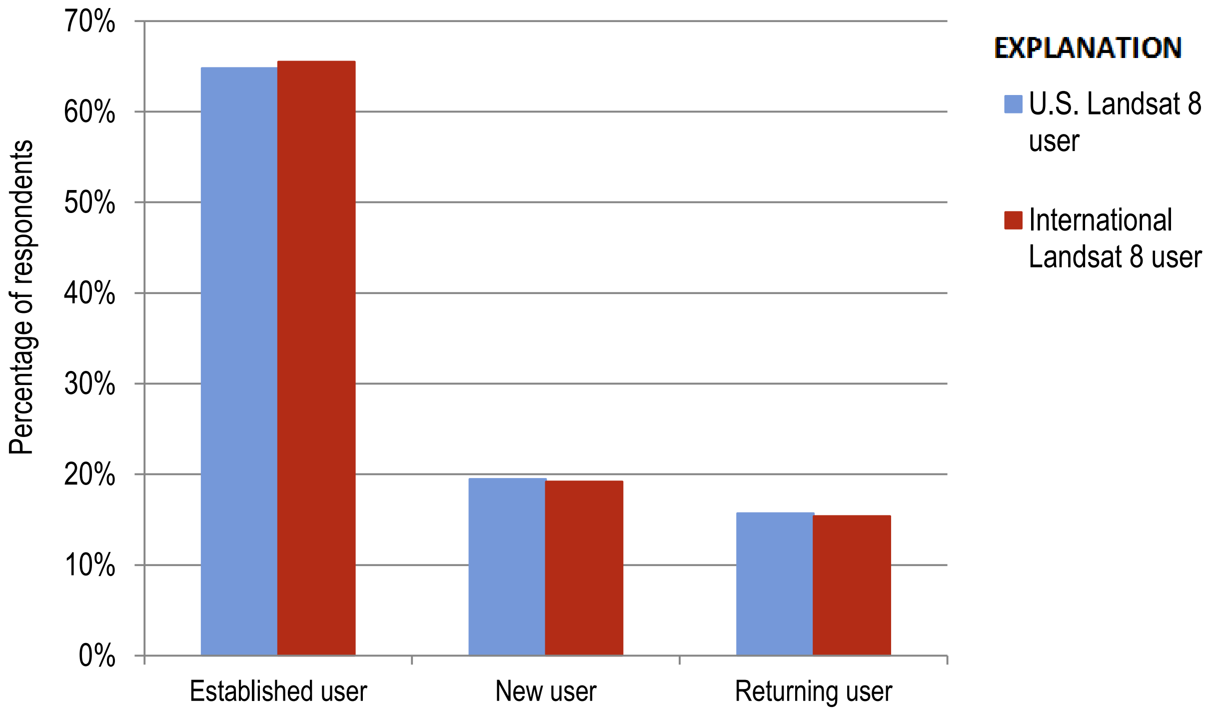

Figure 2. Status of Landsat imagery use among current Landsat 8 users (n = 7,452).

Demographics of Landsat Users

The average current Landsat user was male, 36 years old,[1] and highly educated. Three-quarters of the users were male and 50 percent had at least 18 years of education. Users had, on average, nine years of experience using satellite imagery, GIS software, or both. There were significant differences between user groups in both mean age and years of experience using satellite imagery or GIS software (table 3). U.S. users were significantly older (39 years) on average than international users[2] (35 years). Landsat 8 users had significantly more years of experience (9.2 years) than non-Landsat 8 users (7.1 years).[3]

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[1] 14 percent of eligible respondents did not answer this question.
[2] $t = -11.19$, $p < 0.001$, $d_s = 0.315$
[3] $t = -14.33$, $p < 0.001$, $d_s = 0.285$

Table 3. Demographic characteristics of current Landsat users.

Demographic	United States		International	
	Landsat 8 users (n ≥ 1,362)	Non-Landsat 8 users (n ≥ 627)	Landsat 8 users (n ≥ 5,479)	Non-Landsat 8 users (n ≥ 2,432)
Median level of education	Graduate or professional school (18 years)	Graduate or professional school (18 years)	Graduate or professional school (18 years)	Graduate or professional school (18 years)
Gender	72% male	68% male	78% male	72% male
Mean age	43 years	37 years	36 years	34 years
Mean years using satellite imagery or GIS software	10.5 years	7.6 years	8.9 years	6.9 years

University classes, degrees, or certificates were the most common source of training or education for remote sensing and GIS (69 percent), with another 22 percent of users either being self-taught or training on the job. The remaining users gained most of their training from public or private workshops (5 percent) or other types of education (2 percent). A lower percentage of Landsat 8 users selected university education and a higher percentage selected on-the-job/self-taught education than non-Landsat 8 users, but these differences were not significant (fig. 3).

The predominant sector was academic institutions (65 percent), followed by private businesses (13 percent), Federal governments (10 percent), State and local governments (6 percent), and nonprofit organizations (6 percent; fig. 3). Only 0.1 percent worked for indigenous groups, tribes, or nations, and 1 percent of users chose “other” because they worked for more than one sector or had recently retired (not shown in fig. 3). Landsat 8 users were less likely to be in an academic institution than non-Landsat 8 users and U.S. Landsat 8 users were more likely than other user groups to be working in the Federal government, but these differences were not significant (fig. 4).

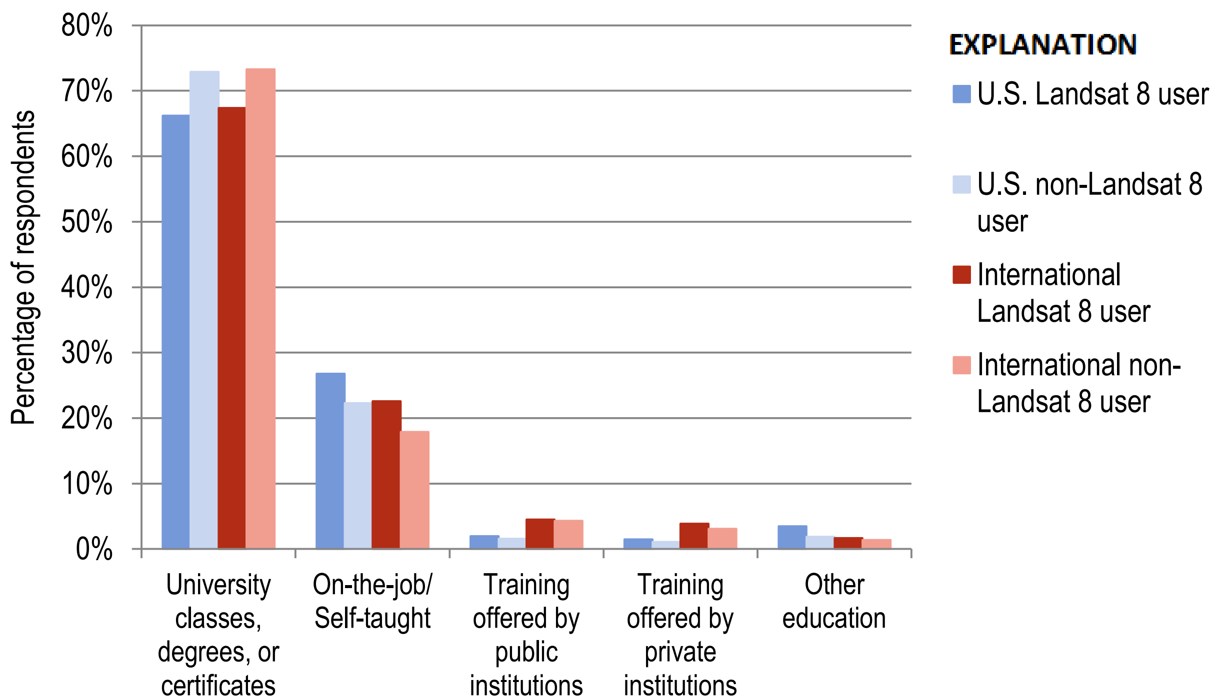

Figure 3. Sources of training or education for remote sensing and geographic information systems (GIS) among current Landsat users (n = 10,577).

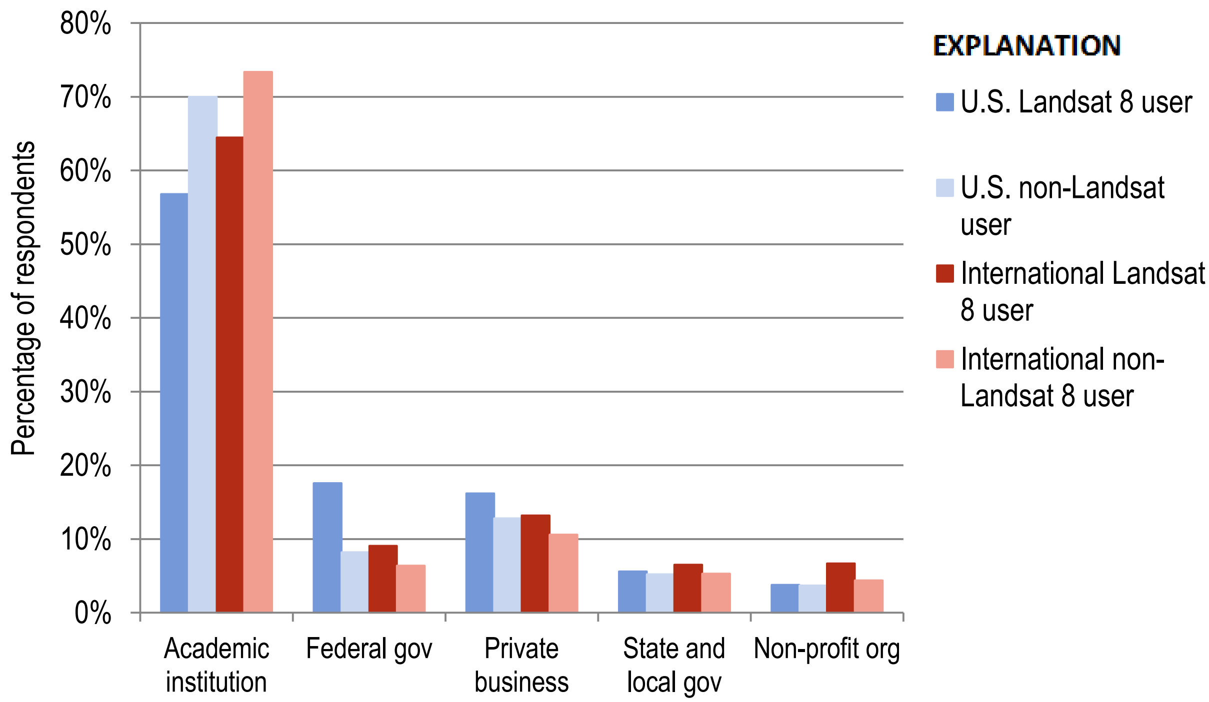

Figure 4. Sectors of current Landsat users (n = 10,540).

Use of Landsat Imagery

Of Landsat imagery obtained in the past year by current Landsat users, on average 31 percent came from a Landsat 8 sensor. An equivalent amount came from the ETM+ (33 percent) sensor on Landsat 7 with slightly less from TM (27 percent) sensors on Landsats 4 and 5. Much less came from the MSS (5 percent) sensors on Landsats 1 through 5. The remainder came from an unspecified Landsat sensor (3 percent).

Landsat 8 users used more OLI imagery on average than any other kind of Landsat imagery, but they still used imagery from all sensors (table 4). As would be expected, non-Landsat 8 users relied more heavily than Landsat 8 users on ETM+[4] (48 percent versus 27 percent) and TM[5] (37 percent versus 23 percent) imagery. They were also more likely than Landsat 8 users to not know which sensor produced the Landsat imagery they used[6] (7 percent versus 2 percent).

Table 4. Mean percentage of imagery from Landsat sensors used in the year prior to the survey among current Landsat users.

[OLI, Operational Land Imager; TIRS, Thermal Infrared Sensor; ETM+. Enhanced Thematic Mapper Plus; TM, Thematic Mapper; MSS, Multispectral Scanner; NA, not applicable]

Landsat sensor	United States		International	
	Landsat 8 users (n = 1,538)	Non-Landsat 8 users (n = 675)	Landsat 8 users (n = 6,518)	Non-Landsat 8 users (n = 2,619)
OLI (Landsat 8)	36%	NA	35%	NA
TIRS (Landsat 8)	10%	NA	9%	NA
ETM+ (Landsat 7)	25%	42%	27%	50%
TM (Landsats 4 and 5)	25%	40%	23%	37%
MSS (Landsats 1–5)	4%	6%	4%	7%
Unspecified Landsat sensor	<1%	12%	2%	6%
Total	100%	100%	100%	100%

Overall, more than a third of users' work used Landsat imagery (38 percent). U.S. users used Landsat imagery in less of their work than international users[7] (33 percent versus 40 percent; table 5). Of users' work which used Landsat, on average, 37 percent of the work was operational. Operational work was defined as continuous or ongoing work that either relies on the consistent availability of Landsat imagery or is mandated or required (for example, crop reports, routine mapping, monitoring). Landsat 8 users considered a greater proportion of their work operational than did non-Landsat 8 users[8] (39 percent versus 29 percent; table 5).

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[4] $t = 30.66$, $p < 0.001$, $d_s = 0.756$
[5] $t = 21.31$, $p < 0.001$, $d_s = 0.509$
[6] $t = 13.33$, $p < 0.001$, $d_s = 0.395$
[7] $t = -7.95$, $p < 0.001$, $d_s = 0.207$
[8] $t = -13.50$, $p < 0.001$, $d_s = 0.283$

Table 5. Mean percentage of Landsat imagery used in work and percentage of work which used Landsat imagery that was operational among current Landsat users.

Variable	United States		International	
	Landsat 8 users (n ≥ 1,308)	Non-Landsat 8 users (n ≥ 542)	Landsat 8 users (n ≥ 5,160)	Non-Landsat 8 users (n ≥ 1,960)
Percentage of all work that used Landsat	34%	32%	38%	43%
Percentage of work that used Landsat that was operational	32%	18%	41%	32%

Application Areas

The list of application areas originally developed for the 2009 survey (Miller and others, 2011) was modified slightly for subsequent surveys on the basis of responses to the 2009 survey. The 39 applications were collapsed into nine larger categories for the purposes of analysis (table 6).

Respondents were first asked to select their primary application of Landsat imagery from the list. Environmental science and management applications were the most commonly selected; almost half (42 percent) of users chose one of these primary applications. Land use/land cover (23 percent) was the second most common primary application, followed by education (12 percent), agriculture (9 percent), and planning and development (6 percent). U.S. users were more likely than international users[9] to select education[10] or services/goods[11] and less likely to select land use/land cover[12] or planning and development[13] as their primary application (fig. 5). Though a higher percentage of Landsat 8 users selected agriculture than non-Landsat 8 users, this difference was not significant overall.

Respondents were then asked to select as many secondary applications as they wished from the same list. For all users, environmental sciences (66 percent) and land use/land cover (42 percent) were the most common secondary applications, followed by planning and development (22 percent), agriculture (21 percent), and education (20 percent). There were no significant differences in secondary applications between U.S. and international users or between Landsat 8 and non-Landsat 8 users (fig. 6).

Land use/land cover is different from the rest of the applications because users can be working in environmental science, planning and development, or any number of other application areas in which land use/land cover analyses could be conducted. It was included in the applications list after pretesting indicated a substantial number of users would write it in the "other" category if it was not provided as an option. Of those who chose land use/land cover as their primary application, the most common secondary applications were environmental sciences (69 percent), followed by planning and development (31 percent) and education (22 percent) applications.

[9] Overall χ^2 = 205.35, Cramer's V = 0.134
[10] ASR = 9.9
[11] ASR = 7.4
[12] ASR = –6.3
[13] ASR = –5.0

Table 6. Applications of Landsat imagery among current Landsat users.

Category of application	Individual application
Agriculture	Agricultural forecasting
	Agricultural management/production/conservation
Education	Education: K–12
	Education: university/college
	Technical training (for example, workshops, short courses)
Energy	Energy (for example, oil, natural gas, coal)/metals/minerals development
	Alternative energy development (for example, wind, solar, geothermal)
Environmental sciences and management	Biodiversity conservation
	Climate science/change
	Coastal science/monitoring/management
	Cryospheric science (for example, sea ice, ice caps, glaciers)
	Ecological/ecosystem science/management
	Fish and wildlife science/management
	Fire science/management
	Forest science/management
	Geology/volcanology
	Range/grassland science/management
	Recreation science/management
	Water resources (for example, watershed management, water rights, hydrology)
Human needs	Emergency/disaster management
	Hazard insurance (for example, crop, flood, fire)
	Humanitarian aid
	Public health
Land use/land cover	Land use/land cover
Legal/security	Defense/national security
	Environmental regulation
	Law enforcement
Planning and development	Assessments and taxation
	Engineering/construction/surveying
	Rural planning and development
	Urban planning and development
	Urbanization
Services/goods	Art/media
	Cultural resource management (for example, archaeology, anthropology)
	Real estate/property management
	Software development
	Telecommunications
	Transportation
	Utilities

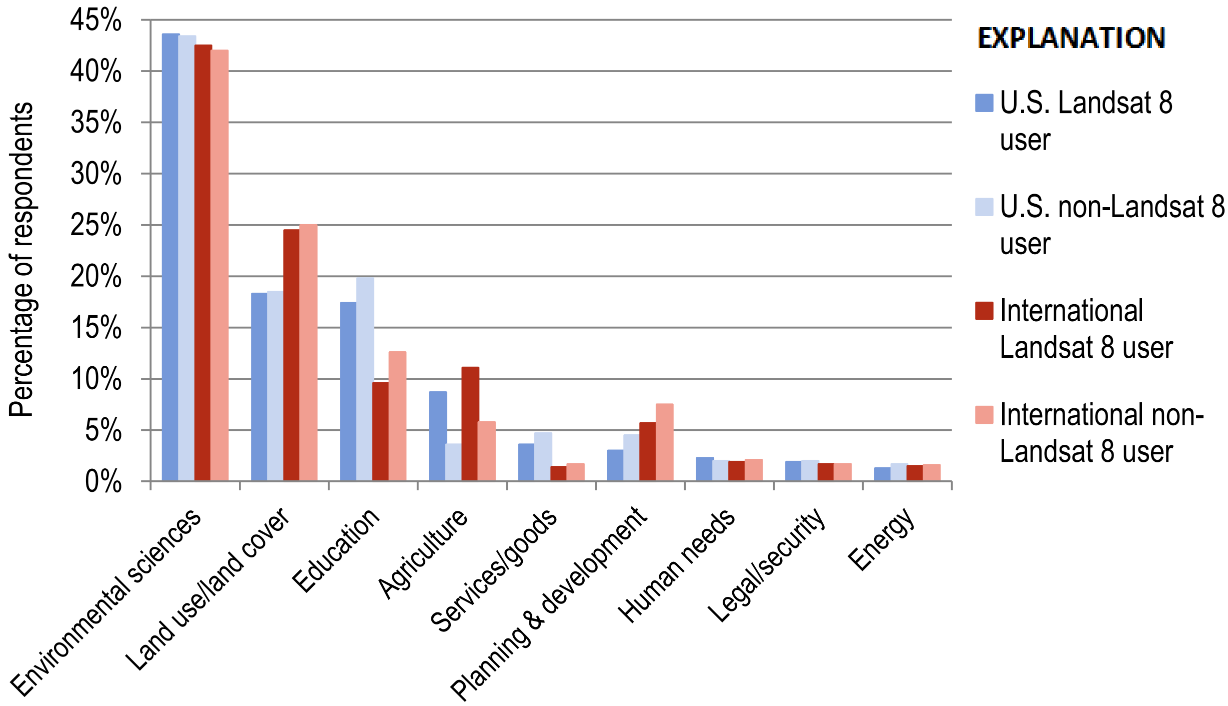

Figure 5. Primary applications of Landsat imagery in projects conducted in year prior to survey among current Landsat users (n = 11,379).

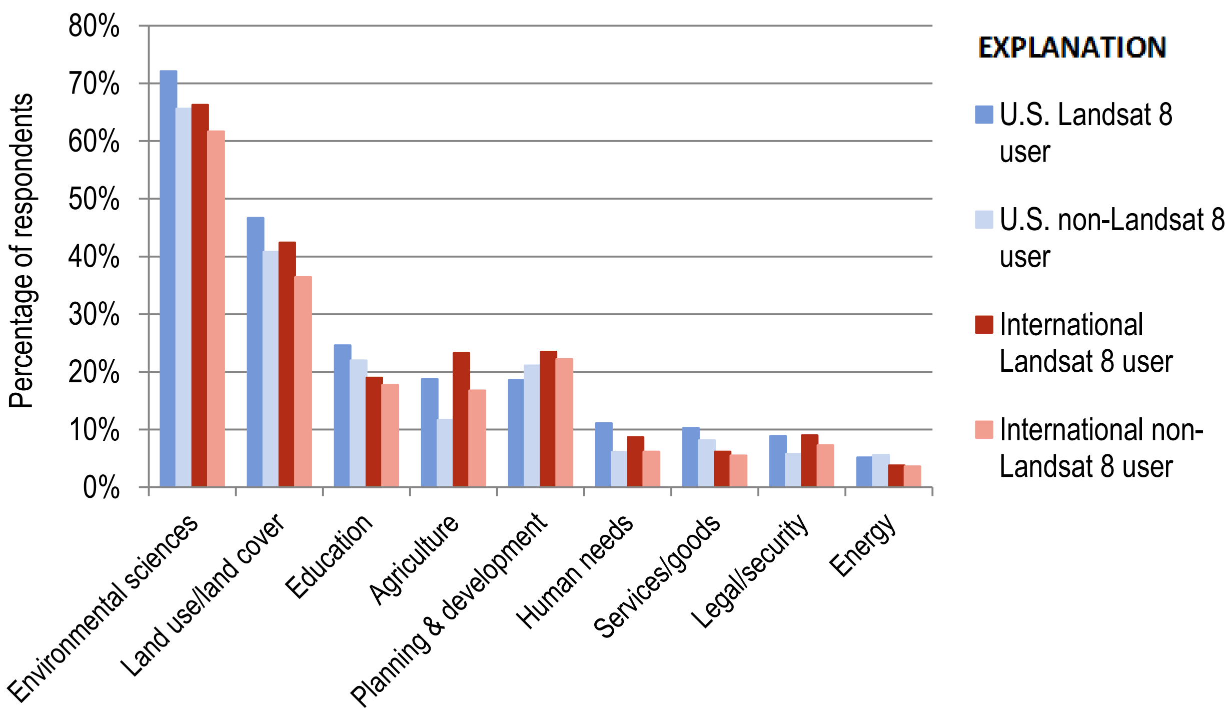

Figure 6. Secondary applications of Landsat imagery in projects conducted in year prior to survey among current Landsat users (n = 10,768).

Importance of and Satisfaction with Landsat 8 Imagery Attributes

Landsat 8 users were asked to rank the importance of certain attributes in determining whether to use Landsat 8 imagery in their work. Each respondent, in deciding to use Landsat 8 imagery in their work as opposed to other imagery, was asked to rank its three most important attributes. More than 60 percent of the users ranked the archive as important, followed by spatial resolution (41 percent), cost (38 percent), extent of coverage (34 percent), frequency of revisit (32 percent), and data quality (29 percent). A significantly higher percentage of U.S. users than international users ranked cost[14] as important to determining whether they use Landsat 8 in their work (fig. 7). To determine which attributes were ranked most important relative to each other, each rank was assigned a number of points (0 = not ranked, 1 = 3rd rank, 2 = 2nd rank, and 3 = 1st rank) and the mean for each attribute was calculated (table 7). The archive was most important, followed by cost, spatial resolution, extent of coverage, data quality, and frequency of revisit. U.S. Landsat 8 users ranked cost[15] on average more highly than international users.

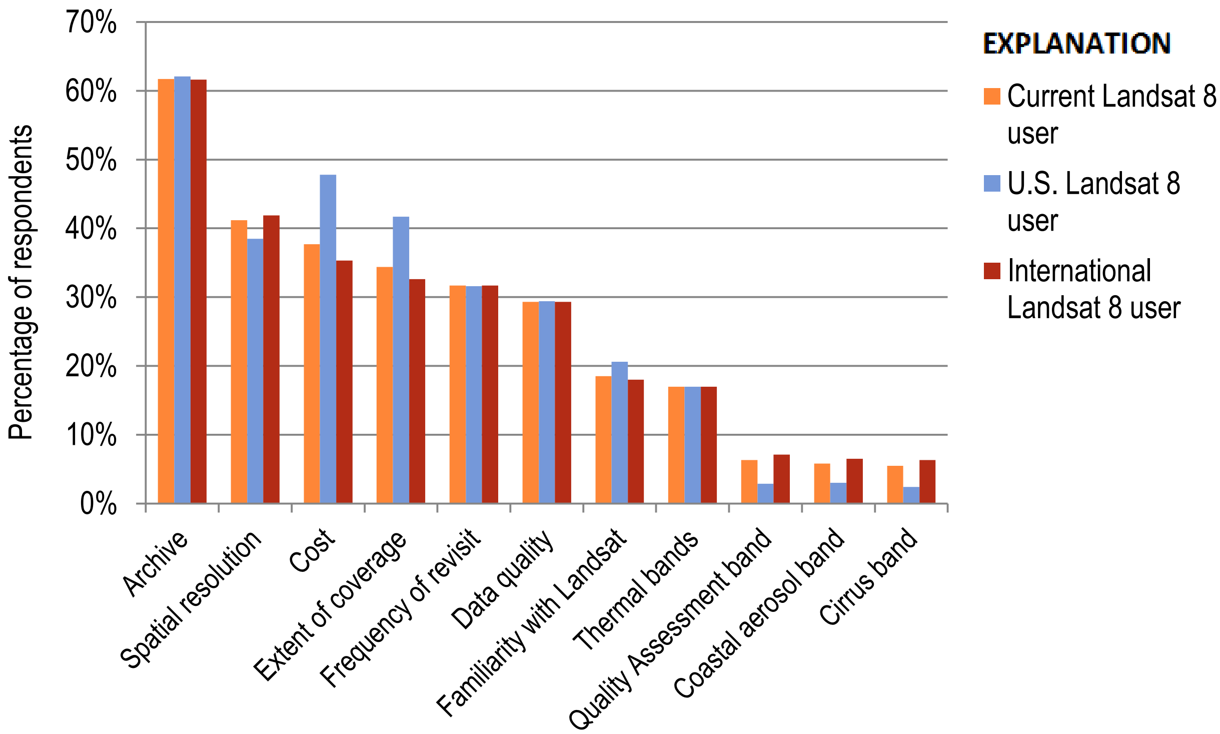

Figure 7. Percentage of current Landsat 8 users ranking Landsat 8 attributes as important (n = 7,464).

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[14] $\chi^2 = 78.91$, $p < 0.001$, phi = –0.103

[15] $t = 7.37$, $p < 0.001$, Cohen's $d_s = 0.224$

Table 7. Mean importance (range 0–3) of Landsat attributes ranked by Landsat 8 users.

Imagery	All Landsat 8 users (n = 7,464)	U.S. Landsat 8 users (n = 1,461)	International Landsat 8 users (n = 6,003)
Archive	1.40	1.39	1.41
Cost	0.86	1.08	0.81
Spatial resolution	0.81	0.75	0.82
Extent of coverage	0.65	0.77	0.61
Data quality	0.61	0.59	0.62
Frequency of revisit	0.55	0.57	0.54
Familiarity with Landsat	0.32	0.34	0.31
Thermal band	0.30	0.32	0.30
Quality Assessment band	0.11	0.05	0.13
Coastal band	0.11	0.06	0.13
Cirrus band	0.10	0.04	0.11

Users were also asked about their satisfaction with those same attributes as they exist today in Landsat 8 imagery.[16] On average, all respondents were satisfied with the attributes included in the survey (fig. 8). They were most satisfied with cost, extent of coverage, data quality, and the archive, and least satisfied with the coastal aerosol and cirrus bands. The lower satisfaction ratings on these two bands is most likely related to the fact that the bands were rated as important by less than 10 percent of users, indicating that many people do not rely on them. It is possible that some users do not have sufficient experience with the bands to accurately rate their satisfaction. U.S. Landsat 8 users were significantly more satisfied than international users with the archive,[17] cost,[18] data quality,[19] and extent of coverage,[20] though both U.S and international users were satisfied on average with all of the attributes.

Preferred Frequency of New Usable Landsat Imagery

The survey asked users how often they needed Landsat imagery to meet various requirements for their primary application.[21] The survey question specifically asked how often users needed *usable* imagery, which differs from how often they would like the Landsat satellites to acquire an image. This distinction is important because some images will not be usable owing to cloud cover. Although the current Landsat satellites acquire an image of a given location every 8 days, the chance of acquiring a cloud-free or mostly cloud-free image every time is very small.

[16] 19–33 percent of eligible respondents did not answer the satisfaction questions.
[17] $t = 11.61$, $p < 0.001$, Cohen's $d_s = 0.298$
[18] $t = 13.84$, $p < 0.001$, Cohen's $d_s = 0.359$
[19] $t = 10.31$, $p < 0.001$, Cohen's $d_s = 0.280$
[20] $t = 7.90$, $p < 0.001$, Cohen's $d_s = 0.222$
[21] 15–17 percent of eligible respondents did not answer the frequency of return questions. An additional 9–37 percent of eligible respondents provided unusable data. In total, 26–54 percent of the data for these questions is missing.

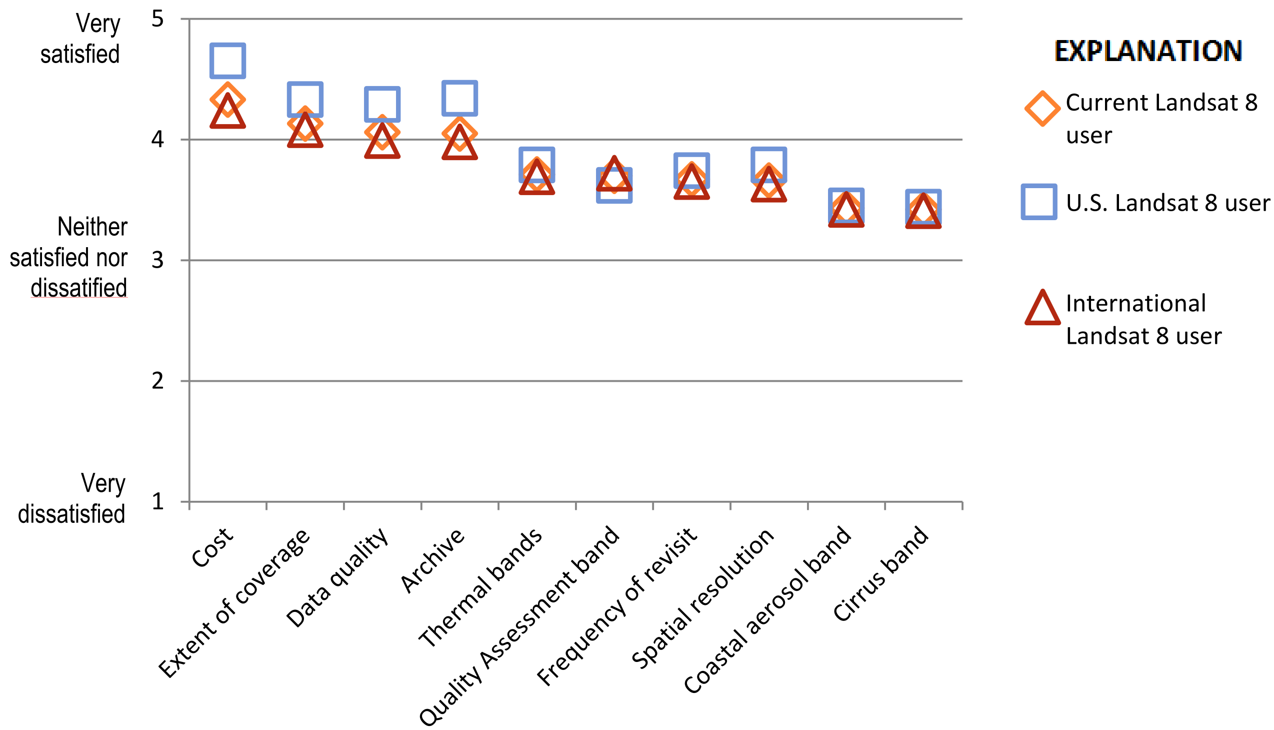

Figure 8. Mean satisfaction with Landsat 8 attributes among current Landsat 8 users (n ≥ 5,497).

Rick Allen (2010) at the University of Idaho found that there was a 45 percent probability of acquiring at least one 80 percent clear scene every 32 days in any given year from 2000 to 2009 over one particular location in southern Idaho. Allen notes that southern Idaho is not particularly cloudy and other regions, such as the Midwest, may have much lower probabilities. This analysis demonstrates that acquisition of imagery is not equivalent to usability of imagery.

On the survey, users were asked to identify their needed frequency of usable imagery for the following levels:

1. Threshold level—the minimum frequency of usable imagery needed to be of any value to their primary application.
2. Breakthrough level—the frequency of usable imagery that would result in a significant improvement for their primary application of the imagery.
3. Target level—the frequency of usable imagery that would only provide a limited additional increase in the expected performance for their primary application.

Few users (8 percent) required usable imagery every 8 days or more frequently to meet their threshold level (table 8). A sixth of users (17 percent) required usable imagery every 9–16 days and three-quarters of users needed usable imagery every 17 days or less frequently. These results indicate that the current constellation of two Landsat satellites is capable of meeting the threshold level needs of the majority of users.

For two-thirds of users (64 percent), the ideal provision of imagery at the breakthrough level was a usable image every 5–16 days (table 8). Few users (9 percent) required imagery every 4 days or more frequently to meet their breakthrough level. However, one-third of users needed usable imagery every 5–8 days to meet their breakthrough level. As discussed earlier, the current constellation of two satellites has the potential to meet these needs with the return of imagery every 8 days, but cloud cover reduces the probability of meeting those needs substantially. Just under one-third of users needed usable imagery every 9–16 days. Again, the current constellation is capable of meeting those needs some of the time, but a single satellite would be highly unlikely to do so. Allen (2010) found that a single satellite only had a 5 percent probability of acquiring usable imagery meeting his criteria of a usable scene every 32 days, compared with 45 percent for two satellites. For breakthrough levels, the current Landsat constellation is probably meeting the needs of 58 percent of the users and has the potential to meet the needs of another third of the users. U.S. users were more likely than international users to need usable imagery more frequently to meet their breakthrough level needs.[22] Specifically, U.S. users were more likely to need usable imagery every 5–8 days[23] and less likely to need it every 17 days or less frequently.[24]

Two-fifths of users (40 percent) felt that usable imagery provided every 4 days or more frequently would meet their target level (table 8). Another 24 percent selected 5–8 days for their target level. These results indicate that acquisition of imagery every 8 days, with the likelihood of a usable image every 16 days or less frequently, is not meeting the target needs of the majority of users.

Table 8. Percentages of Landsat users requiring usable Landsat imagery at certain intervals to meet a threshold level for primary application.

Usable imagery every	All users (n ≥ 5,068)	U.S. users (n ≥ 1,059)	International users (n ≥ 4,009)
		Threshold level	
4 days or more frequently	4%	1%	5%
5–8 days	4%	3%	4%
9–16 days	17%	17%	17%
17 days or less frequently	75%	79%	74%
		Breakthrough level	
4 days or more frequently	9%	10%	9%
5–8 days	33%	40%*	31%
9–16 days	31%	32%	31%
17 days or less frequently	27%	18%*	29%
		Target level	
4 days or more frequently	40%	40%	40%
5–8 days	24%	24%	23%
9–16 days	13%	12%	14%
17 days or less frequently	23%	24%	23%

* Indicates significant difference as demonstrated by an adjusted standardized residual ≥ 2.0 or ≤ –2.0.

Landsat 8 Use

Slightly more than 71 percent of the Landsat users registered with EROS were Landsat 8 users. There were no differences between Landsat 8 and other Landsat users in the desired number of days between available usable imagery for the threshold and breakthrough levels

[22] $\chi^2 = 59.72$, $p < 0.001$, Cramer's V = 0.104
[23] ASR = 5.3
[24] ASR = –7.3

(table 9). There were significant differences for the target levels between the two groups.[25] Landsat 8 users were significantly more likely than other Landsat users to need usable imagery every 4 days or more frequently[26] and less likely to need it every 17 days or less frequently[27] to be able to meet their target levels.

Table 9. Percentages of Landsat 8 and other Landsat users requiring usable Landsat imagery at certain intervals to meet specific levels for primary application.

Usable imagery every	All users (n ≥ 5,068)		U.S. users (n ≥ 1,059)		International users (n ≥ 4,009)	
	Threshold level					
	Landsat 8	Non-Landsat 8	Landsat 8	Non-Landsat 8	Landsat 8	Non-Landsat 8
4 days or more frequently	3%	5%	1%	2%	4%	6%
5–8 days	4%	3%	3%	3%	4%	4%
9–16 days	19%	14%	18%	15%	19%	13%
17 days or less frequently	74%	78%	78%	80%	73%	77%
	Breakthrough level					
	Landsat 8	Non-Landsat 8	Landsat 8	Non-Landsat 8	Landsat 8	Non-Landsat 8
4 days or more frequently	9%	10%	10%	10%	8%	10%
5–8 days	35%	26%	42%*	31%	33%	25%
9–16 days	30%	33%	31%	34%	30%	33%
17 days or less frequently	26%	31%	17%*	25%	29%	32%
	Target level					
	Landsat 8	Non-Landsat 8	Landsat 8	Non-Landsat 8	Landsat 8	Non-Landsat 8
4 days or more frequently	43%*	33%	44%*	28%	42%	34%
5–8 days	24%	23%	25%	22%	24%	23%
9–16 days	12%	14%	11%	14%	13%	15%
17 days or less frequently	21%*	30%	20%*	36%	21%	28%

* Indicates significant difference as demonstrated by an adjusted standardized residual ≥ 2.0 or ≤ –2.0.

Although no significant differences were found at any level between Landsat 8 and other Landsat users for international users, there were significant differences at the breakthrough level between the U.S. Landsat 8 users and other U.S. Landsat users.[28] U.S. Landsat 8 users were significantly more likely to need usable imagery every 5–8 days[29] in order meet their breakthrough levels than other U.S. Landsat users and less likely to be able to meet their breakthrough levels with usable imagery every 17 days or less frequently.[30] There were also significant differences between U.S. Landsat 8 users and other U.S. Landsat users for target levels[31] (table 9). U.S. Landsat 8 users were significantly more likely than other Landsat users to

[25] $\chi^2 = 59.94$, $p < 0.001$, Cramer's V = 0.109
[26] ASR = 6.2
[27] ASR = –6.6
[28] $\chi^2 = 15.03$, $p = 0.002$, Cramer's V = 0.115
[29] ASR = 3.3
[30] ASR = –3.2
[31] $\chi^2 = 35.19$, $p < 0.001$, Cramer's V = 0.182

need usable imagery every 4 days or more frequently[32] to reach their target levels and less likely to meet their needs with usable imagery every 17 days or less frequently.[33]

Sector

Overall, no significant differences were found between all users or international users in different sectors in the desired number of days between available usable imagery for all levels. There were significant differences for U.S. users for the breakthrough[34] and target[35] levels (table 10). U.S. Federal government users were more likely[36] and non-profit users were less likely[37] than U.S. users in other sectors to need usable imagery every 5–8 days to meet their breakthrough levels. U.S. Federal government users were less likely to need usable imagery every 17 days or less frequently[38] to meet their needs. To meet target levels, U.S. Federal government users were more likely[39] and U.S. state and local government users were less likely[40] than U.S. users in other sectors to need usable imagery every 4 days or more frequently. U.S. private[41] and state and local government users[42] were more likely and Federal government users[43] were less likely to need usable imagery every 17 days or less frequently to meet their target levels than U.S. users in other sectors.

[32] ASR = 4.7
[33] ASR = –5.2
[34] $\chi^2 = 37.30$, $p < 0.001$, Cramer's V = 0.107
[35] $\chi^2 = 32.67$, $p = 0.001$, Cramer's V = 0.103
[36] ASR = 4.6
[37] ASR = –2.5
[38] ASR = –3.5
[39] ASR = 3.3
[40] ASR = –2.8
[41] ASR = 2.1
[42] ASR = 2.7
[43] ASR = –2.3

Table 10. Percentages of U.S. Landsat users by sector requiring usable Landsat imagery at certain intervals to meet specific levels for primary application (n ≥ 1,020).

Usable imagery every	United States users				
	Threshold level				
	Academic	Federal government	State or local government	Private	Non-profit organization
4 days or more frequently	1%	1%	3%	1%	5%
5–8 days	2%	4%	2%	4%	0%
9–16 days	16%	23%	16%	19%	13%
17 days or less frequently	81%	72%	79%	76%	82%
	Breakthrough level				
	Academic	Federal government	State or local government	Private	Non-profit organization
4 days or more frequently	9%	10%	9%	13%	7%
5–8 days	37%	55%*	36%	39%	22%*
9–16 days	33%	26%	41%	28%	45%
17 days or less frequently	21%	9%*	14%	20%	26%
	Target level				
	Academic	Federal government	State or local government	Private	Non-profit organization
4 days or more frequently	39%	51%*	23%*	39%	31%
5–8 days	26%	21%	25%	19%	24%
9–16 days	11%	10%	13%	10%	24%
17 days or less frequently	24%	18%*	39%*	32%*	21%

* Indicates significant difference as demonstrated by an adjusted standardized residual ≥ 2.0 or ≤ –2.0.

Categories of Primary Applications

Overall, no significant differences were found between all users or international users in different categories of primary applications in the desired number of days between usable imagery for all levels. Significant differences were found for U.S. users. Categories of primary applications for which 30 or more U.S. users had also answered the frequency of usable imagery question were included in the analysis. Of the nine categories of primary applications, six fit these criteria and 93 percent of U.S. users were included in those six categories. The three categories of applications not included were energy, human needs, and legal/security.

There were significant differences between U.S. users with different categories of primary applications in the desired number of days between available usable imagery for the threshold level[44] (table 11). U.S. agricultural users were more likely to need usable imagery every 9–16 days[45] and less likely to need usable imagery every 17 days or less frequently[46] to meet their breakthrough levels than U.S. users in other applications.

[44] $\chi^2 = 33.70$, $p = 0.008$, Cramer's V = 0.100
[45] ASR = 3.4
[46] ASR = –4.0

Table 11. Percentages of United States Landsat users in categories of primary applications requiring usable Landsat imagery at certain intervals to meet specific levels (n ≥ 989).

Usable imagery every	Agriculture	Education	Environmental sciences	Land use/ land cover	Planning and development	Services or goods
			Threshold			
4 days or more frequently	2%	3%	1%	1%	0%	0%
5–8 days	5%	1%	3%	2%	0%	0%
9–16 days	29%*	11%	19%	14%	8%	10%
17 days or less frequently	64%*	85%	77%	83%	92%	90%
			Breakthrough			
4 days or more frequently	10%	8%	11%	8%	7%	4%
5–8 days	52%*	31%	42%	36%	23%	39%
9–16 days	22%*	41%*	32%	33%	50%*	25%
17 days or less frequently	16%	20%	15%*	23%	20%	32%
			Target			
4 days or more frequently	63%*	36%	42%	34%	19%*	19%*
5–8 days	21%	23%	27%	24%	34%	12%
9–16 days	8%	8%	11%	17%	9%	21%
17 days or less frequently	8%*	33%	20%*	25%	38%	48%*

* Indicates significant difference as demonstrated by an adjusted standardized residual ≥ 2.0 or ≤ –2.0.

There were also significant differences for the breakthrough levels for U.S. users[47] (table 11). U.S. agricultural users were significantly more likely than other U.S. users to need usable imagery every 5–8 days[48] to meet their breakthrough levels. Conversely, U.S. agricultural users[49] were less likely whereas education[50] and planning and development[51] users were more likely to need usable imagery every 9–16 days to meet their breakthrough levels. U.S. environmental sciences users were less likely than other U.S. users to need usable imagery every 17 days or more[52] to meet their breakthrough levels.

Significant differences also were found for target levels among different primary application U.S. users[53] (table 11). U.S. agricultural users[54] were more likely and planning and

[47] $\chi^2 = 46.03$, $p = 0.004$, Cramer's V = 0.118
[48] ASR = 2.7
[49] ASR = –2.4
[50] ASR = 2.2
[51] ASR = 2.0
[52] ASR = –2.5
[53] $\chi^2 = 78.69$, $p < 0.001$, Cramer's V = 0.159
[54] ASR = 4.5

development[55] and services/goods[56] users were less likely than other U.S. users to need imagery every 4 days or more frequently to meet their requirements. U.S. agricultural[57] and environmental sciences[58] users were less likely and services/goods[59] users were more likely than other U.S. users to need usable imagery every 17 days or less frequently to meet their target levels.

Effect of Availability of Landsat 8 Imagery

The majority of Landsat users (71 percent) had used Landsat 8 imagery in their work in the year prior to the survey. To explore the effect of the availability of Landsat 8 imagery on Landsat use in general, established users (those who had used Landsat imagery consistently both before and after Landsat 8 became available) using Landsat 8 were asked about changes in the amount of Landsat imagery they used. The majority of established users using Landsat 8 (60 percent) reported an increase in the overall amount of Landsat imagery used in their work (fig. 9); the average increase per user in the number of scenes obtained after Landsat 8 imagery became available was 51 percent. Significant differences were found between U.S. and international established users using Landsat 8 in the effects of the availability of the imagery on their use.[60] U.S. established users using Landsat 8 were more likely to have not changed their use[61] and less likely to have increased their use[62] of Landsat than international established users using Landsat 8.

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55 ASR = –2.4
56 ASR = –2.8
57 ASR = –3.5
58 ASR = –2.7
59 ASR = 3.6
60 $\chi^2 = 104.53$, $p < 0.001$, Cramer's V = 0.146
61 ASR = 9.9
62 ASR = –7.4

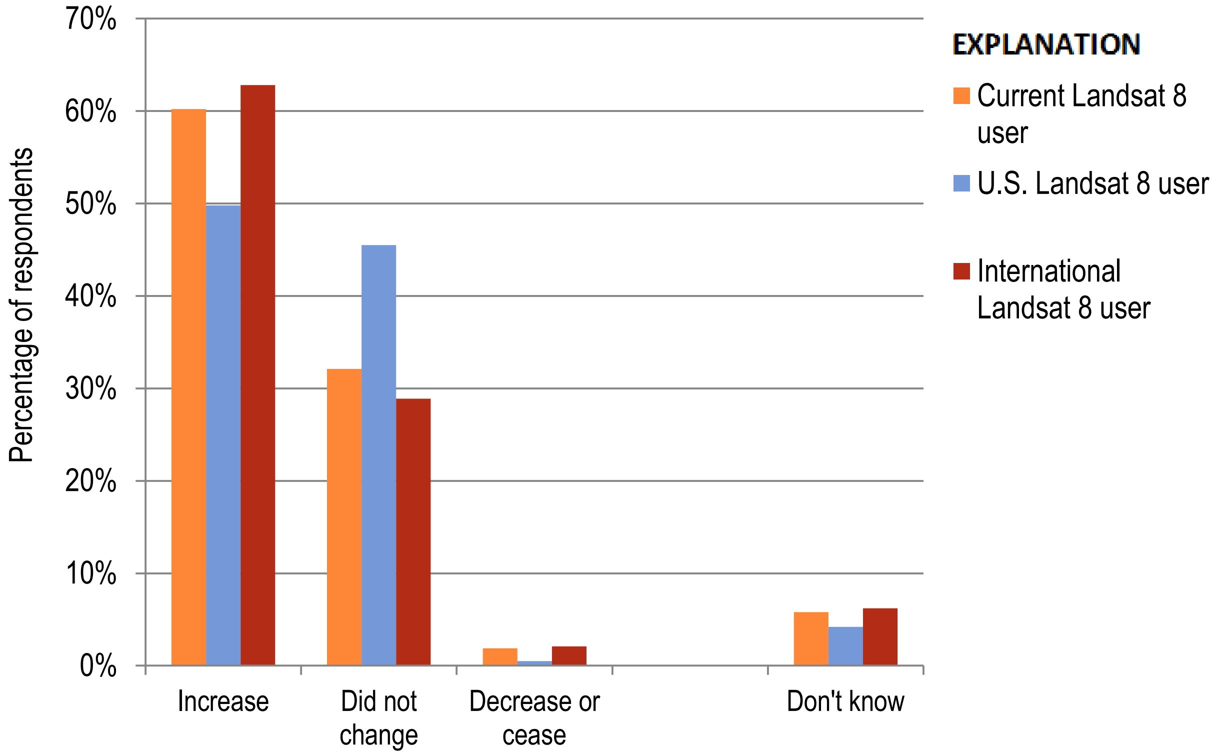

Figure 9. Effect of availability of Landsat 8 imagery on overall amount of Landsat imagery used among established users using Landsat 8 imagery (n = 4,920).

Landsat 8 imagery is higher quality than previous Landsat imagery; however, that quality means that the file size of each image is larger than those from other Landsat sensors. Additionally, at the time we surveyed users, USGS was not producing surface reflectance products for Landsat 8 scenes and the existing atmospheric corrections used for imagery from other Landsat sensors did not work for Landsat 8 imagery. To ascertain how much these potential problems affected the use of the imagery, Landsat 8 users were asked if they had encountered these challenges and non-Landsat 8 users were asked if any of these challenges had played a role in why they were not using Landsat 8 imagery. Although most users did not encounter any challenges to using or trying to use Landsat 8 data, just under 30 percent did encounter issues with processing the data to a usable point (fig. 10); the most common problem was not being able to create or have access to a surface reflectance product. Other processing issues were related to needing to change existing algorithms and systems to accommodate Landsat 8's different spectral bands and increased radiometric resolution. Most of the other challenges were related to file size, as the images were too large for some users to download, store, or analyze.

U.S. users were more likely than international users to say they had not encountered any challenges with using Landsat 8 data[63] (fig. 10). International users were more likely than U.S. users to have trouble downloading Landsat 8 imagery.[64] There were no statistically significant differences between Landsat 8 and non-Landsat 8 users in terms of challenges encountered using

[63] $\chi^2 = 130.24$, $p < 0.001$, phi = –0.126
[64] $\chi^2 = 150.65$, $p < 0.001$, phi = 0.136

or trying to use the imagery, which indicates that users were not unduly discouraged by the challenges they may have encountered.

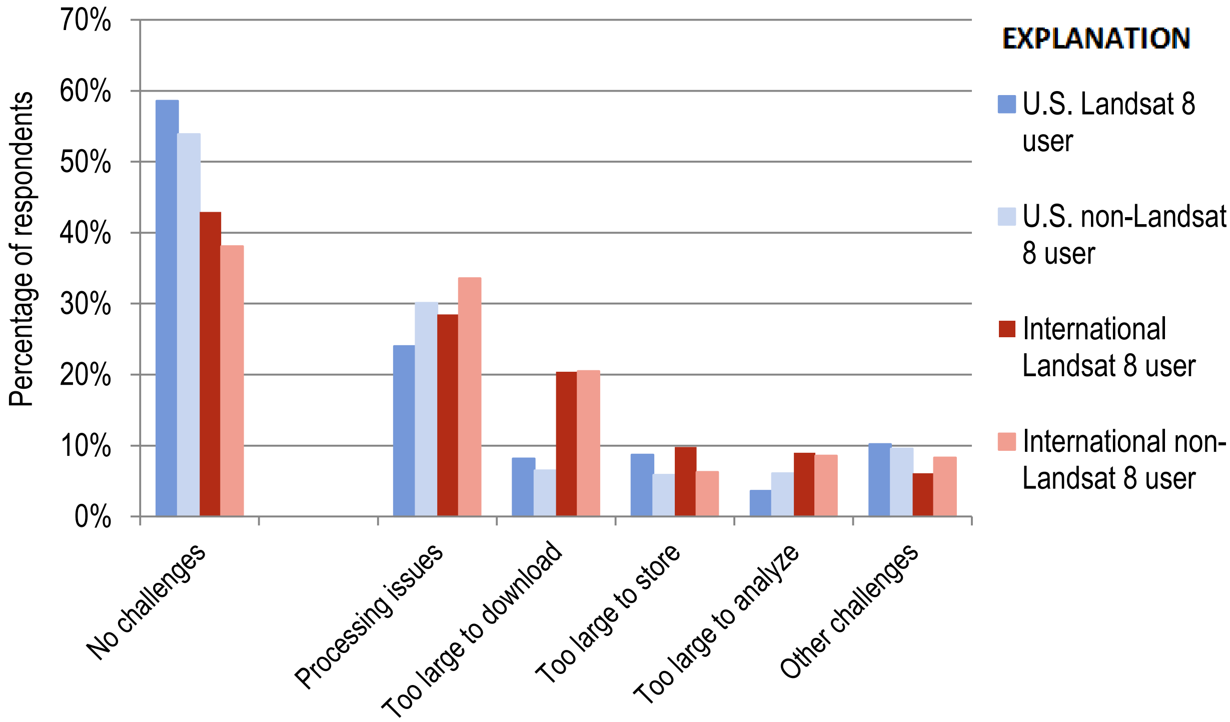

Figure 10. Challenges to using Landsat 8 imagery among current Landsat users (n = 8,185).

More than half of the non-Landsat 8 users did not experience any negative effects on their work from not using the imagery[65] (fig. 11). Of those who did see such effects, decreased quality of work, decreased scope of work, and increased time spent on work were the most common. U.S. non-Landsat 8 users were more likely than international non-Landsat 8 users to see no effect on their work from not being able to use the imagery[66] and less likely to report that their work had become more expensive.[67]

[65] 24 percent of eligible respondents did not answer this question.
[66] $\chi^2 = 36.42$, $p < 0.001$, phi = –0.121
[67] $\chi^2 = 28.75$, $p < 0.001$, phi = 0.107

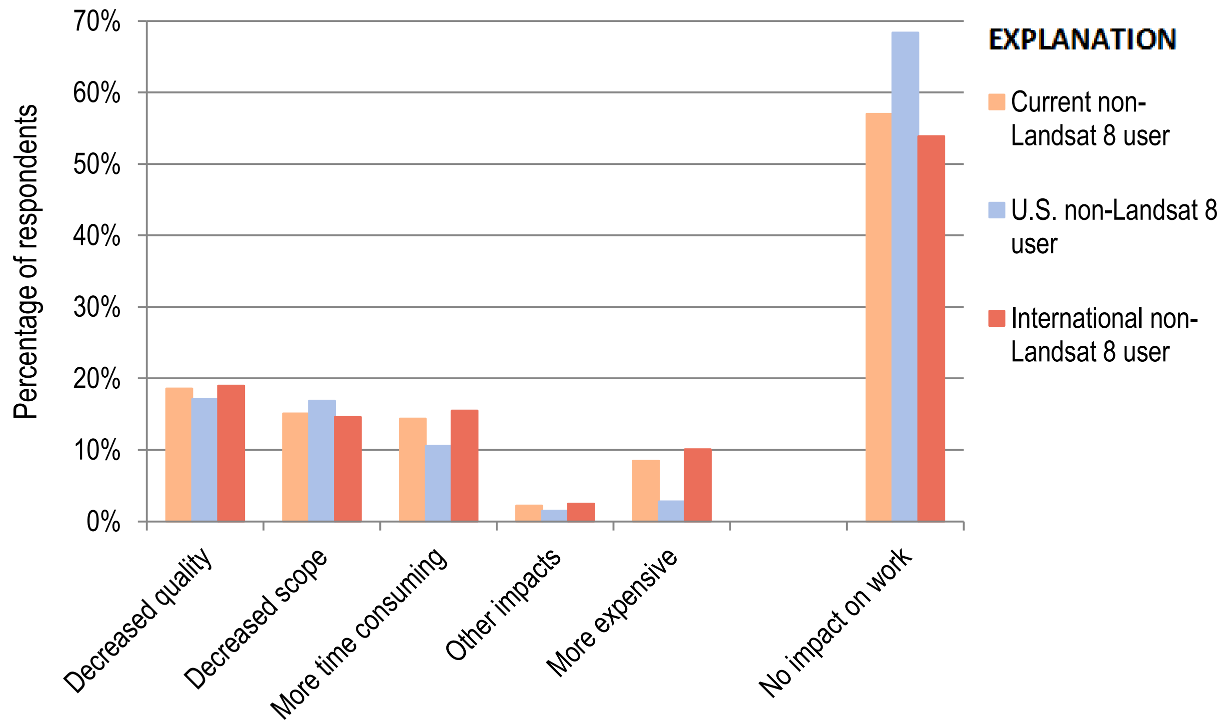

Figure 11. Effects on work of not using Landsat 8 imagery among current non-Landsat 8 users (n = 2,495).

Conclusion

After Landsat 8 imagery had been available for only one year, it already had been incorporated into the work of many users. Some of this use seems to have been driven by the need for new imagery. For example, Landsat 8 users conducted significantly more operational work and a higher percentage of Landsat 8 users selected agriculture as their primary application—an area typically requiring new imagery throughout each growing season. Landsat 8 users were also more likely to need usable imagery more frequently than non-Landsat 8 users. However, Landsat 8 users also ranked the archive of Landsat imagery the most important attribute of Landsat 8 imagery, indicating that historical imagery was also essential to them. Landsat 8 users seemed to be more experienced Landsat users, with more years of experience with remote sensing or GIS and a higher percentage indicating that their most common source of training or education for remote sensing or GIS was on-the-job training or self-education.

Though some users encountered challenges to using Landsat 8, the most common challenge was a lack of surface reflectance algorithms, which are now available. Other challenges were mostly related to the file size of the images, which made it difficult for some users to download, process, and store the data. New services which allow users to access and process Landsat 8 imagery in the cloud, such as the availability of the data at no cost on Amazon Web Services, have the potential to reduce some of the challenges related to file size.

Acknowledgments

This study was funded by the U.S. Geological Survey's (USGS) Land Remote Sensing Program. We would like to thank Eric Wood, Tom Loveland, and John Dwyer from the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota, for their invaluable help in constructing, reviewing, and testing the original 2009 survey instrument; and the numerous people who reviewed all of the surveys and provided constructive feedback, including members of the Landsat Science Team.

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Publishing support provided by:
Denver Publishing Service Center

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ISSN 2331-1258 (online)
http://dx.doi/org/10.3133/ofr20161032