Analysis of Non-Federal Landsat User Requirements
National Geospatial Advisory Committee
Landsat Advisory Group
June 2016

In 2015 the Department of the Interior requested that the Landsat Advisory Group (LAG) of the National Geospatial Advisory Committee provide advice on three tasks. This report provides the LAG response to Task 1: *LAG members to provide the Land Remote Sensing Program of the USGS with information about non-Federal data requirements that could include both LAG member input plus information obtained from non-Federal users contacted by LAG members.* The report first reviews the methods used to collect information on non-federal user requirements. A Survey Monkey (www.surveymonkey.com) questionnaire was created to elicit information from non-federal users. Next, the report briefly summarizes the results of the questionnaire. The final section of the report reviews what we believe to be the most important findings.

Methods

To collect information on non-Federal user requirements for Landsat imagery, a work group[1] of the LAG developed a short questionnaire, which was posted on Survey Monkey June 29th to August 10, 2015. The questionnaire was promoted at a few specific conferences (e.g. Esri User's Conference, Google Earth Engine Summit), through email lists, and through outreach efforts of LAG members. Respondents were not specifically chosen using a statistical design, but were self-selected after being notified about the questionnaire. While the results are not a representative sample of the whole Landsat non-federal user community, it provides a broad view of who is using the imagery and how[2].

The questions were as follows:

1. Please check your user organization type:
    - Commercial
    - State government
    - Local government
    - Academia
    - Not for Profit
    - International
    - Other
2. How did you hear about this questionnaire?
3. Please provide a brief overview of your organization's mission.
4. Please briefly describe the application or problem you are addressing or attempting to solve by using Landsat imagery.
5. Please rank the importance of the listed Landsat characteristics to your organization's decision making process:
    - Optical spatial resolution (30m multispectral & 15m panchromatic in Landsat 8)
    - Thermal spatial resolution (100m in Landsat 8)

[1] Julie Sweetkind-Singer, Joanne Gabrynowicz, Roberta Lenczowski, Kass Green, Rebecca Moore, John Copple, and Tony Willardson.

[2] In accordance with the Paperwork Reduction Act, the Office of Management and Budget (OMB) approved an Information Collection for the Non-Federal Landsat User Requirements Survey (OMB Control Number 1090-0011).

- Swath width (183 kilometers in Landsat 8)
- Spectral resolution – optical
- Spectral resolution – thermal
- Continuity with previous Landsat data
- Other

6. If you could add something new for Landsat 10 and beyond what would it be (e.g. add a specific band or more frequent revisit)?
7. Briefly explain why this added characteristic would be important to your organization.
8. What are you minimal requirements for the following Landsat characteristics?
    - Optical spatial resolution (in meters)
    - Thermal spatial resolution (in meters)
    - Swath width (in kilometers)
    - Repeat visit (in days)
9. What would be your optimal requirements for the following Landsat characteristics?
    - Optical spatial resolution (in meters)
    - Thermal spatial resolution (in meters)
    - Swath width (in kilometers)
    - Repeat visit (in days)
10. Please enter your contact information if you are available to provide additional information.

Results

A total of 285 respondents filled out at least one question of the questionnaire. This section of the report reviews the results of each question.

Question 1. Please check your user organization type.

Two hundred sixty respondents completed this question, with twenty-five declining to state their organization type. The question asked that respondents pick an organizational type from a list. Almost half (49%) of those answering picked "Academia," which is probably reflective of the distribution of the questionnaire through several academically focused organizations (e.g. AmericaView). Seventeen respondents chose "Other." While two of these respondents listed US federal agencies as their organization type, most of them listed international organizations such as the United Nations, the Australian government, or a European organization. Figure 1 summarizes the responses to Question 1.

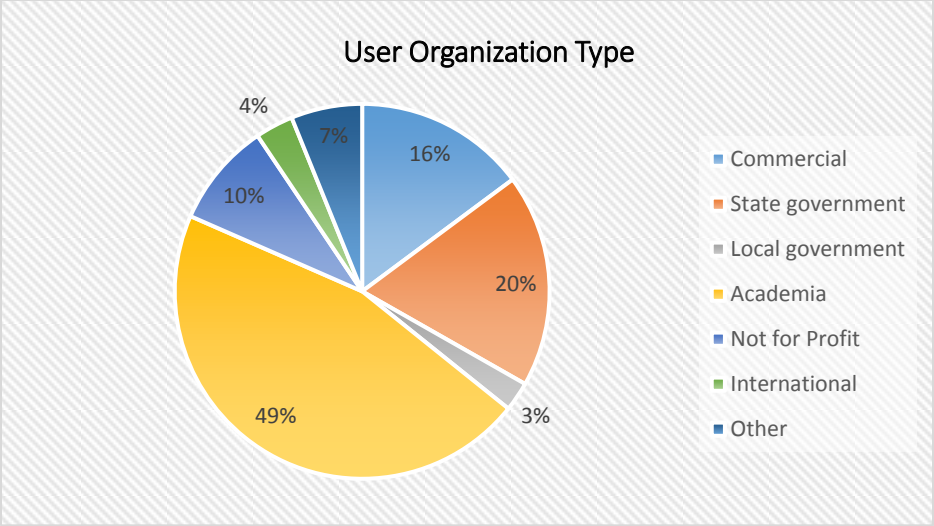

Figure 1. Summary of responses to Question 1.

Question 2. How did you hear about this questionnaire?

Two hundred seventy two respondents completed Question 2, which requested that respondents indicate how they heard about the questionnaire. They chose from a list of organizations that promoted the questionnaire at the behest of the Landsat Advisory Group members either through conferences, meetings, or list-servs. However, as illustrated in Figure 2, slightly over 40% of the respondents heard about the questionnaire from sources other than those listed. A further analysis of the "Other" category reveals that the questionnaire link was widely distributed by LAG members and their colleagues. Of the 102 "Other" responses to Question 2, 45% learned about the questionnaire through an email or from a colleague, and 21% responded to the questionnaire through a direct request from a LAG member (Figure 3).

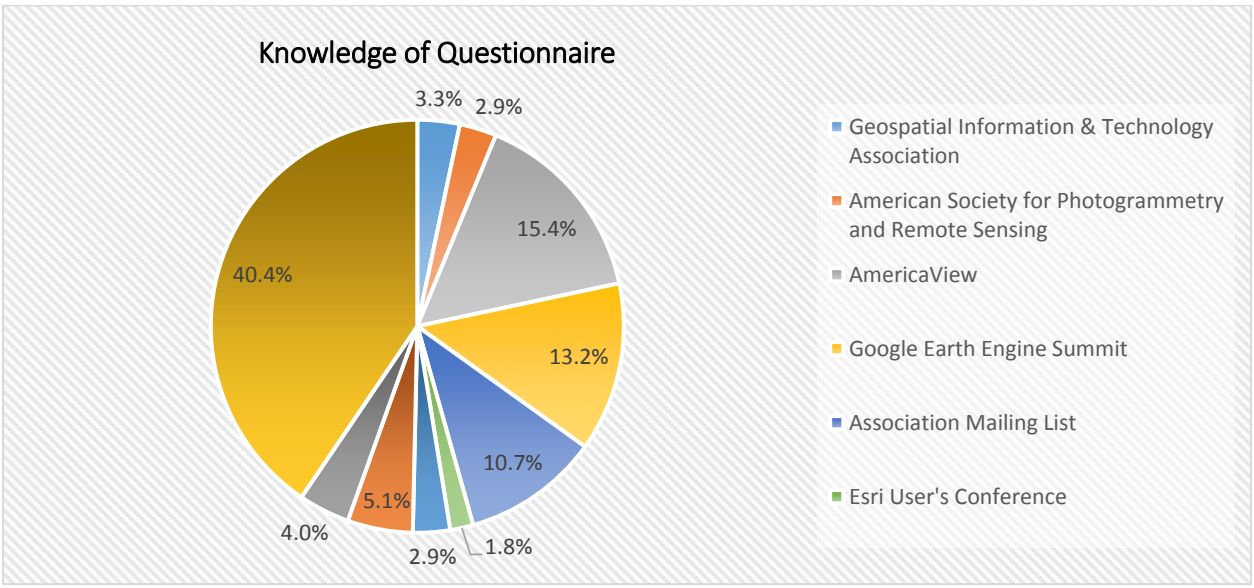

Figure 2. Summary of responses to Question 2.

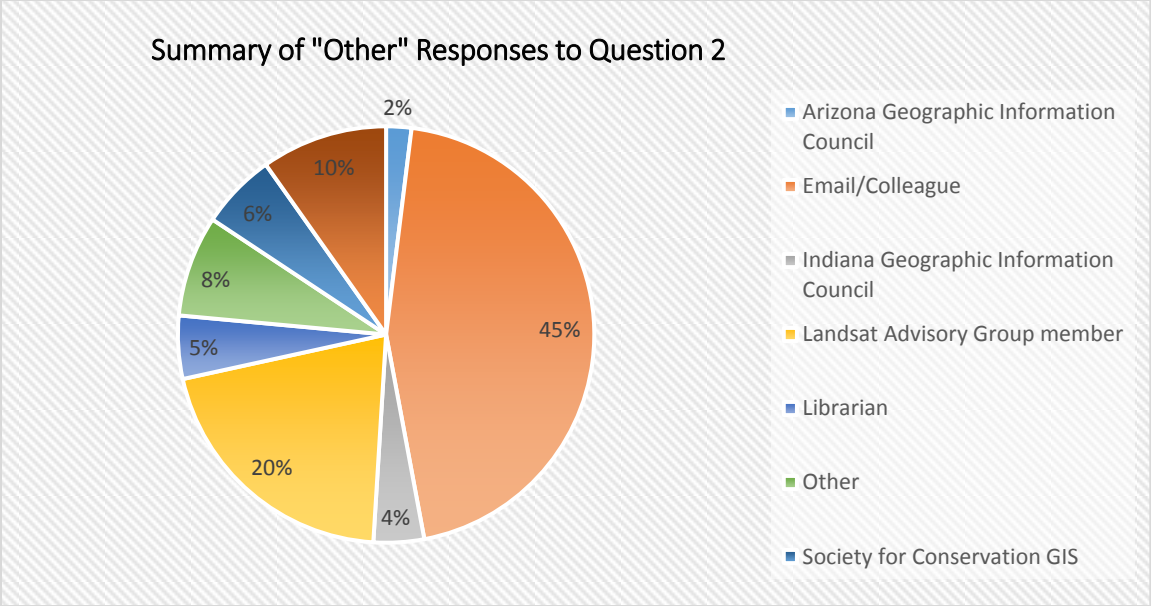

Figure 3. Analysis of "Other" answers to Question 2.

Question 3. Please provide a brief overview of your organization's mission.

Question 3 was answered by 264 respondents. The respondents answered the question by filling in an open text field. The answers were tabulated by creating subject categories that defined the organizational mission. More than one category was chosen if the answer warranted it. Tabulation allowed for more than one category to be chosen as the responses often covered multiple issues, therefore the numbers when aggregated do not add up the number of respondents. As illustrated in Figure 4, Landsat imagery is used in a wide variety of organizations spanning work from forestry to business to community outreach. The largest category of respondents at 34% said their mission was education and research. We know from Question 1 that 49% of the respondents come from academic institutions, but when asked about their organizational mission, only 34% mentioned this specifically.

The remaining 15% noted their research agenda rather than their educational mission. Hence, their responses were included in the other categories. A cluster of respondents was focused on environmental monitoring (12.5%), hydrology and water issues (10.6%), conservation (9.8%), and natural resource management (8.3%). GIS and remote sensing uses, agriculture, data collection and distribution, outreach and change detection (including climate change), land use/land cover, and mapping clustered around 5.6% or less of the missions. Business, ecosystems and forestry were the least mentioned missions reported.

The most used application for Landsat is in education and research, which supports all other applications noted by the respondents. It also points to the strong use of Landsat imagery in basic research and analysis of earth processes and systems. Respondents also indicated that Landsat imagery is used in unexpected ways, such as the mapping of poverty, analysis of human health issues, and improving nautical chart accuracy. This provides a value proposition for the imagery perhaps not imagined at the start of the Landsat program.

As expected, Landsat imagery is used to monitor ecosystems, the quality and quantity of forests, glacial retreats, and agriculture. Water is another major focus area, and is tied to many of the other organizational missions including agriculture, sea level rise, pollution, and evapotranspiration. Lack of water associated with drought suggest the use of the imagery when dealing with relevant policy issues around resource allocation and concerns about wildfires.

The responding groups noted that their work spanned the globe from a local focus on a specific lake to a state-wide view up to a country-wide interest and then to studying global forces at play in areas such as ecology and flooding.

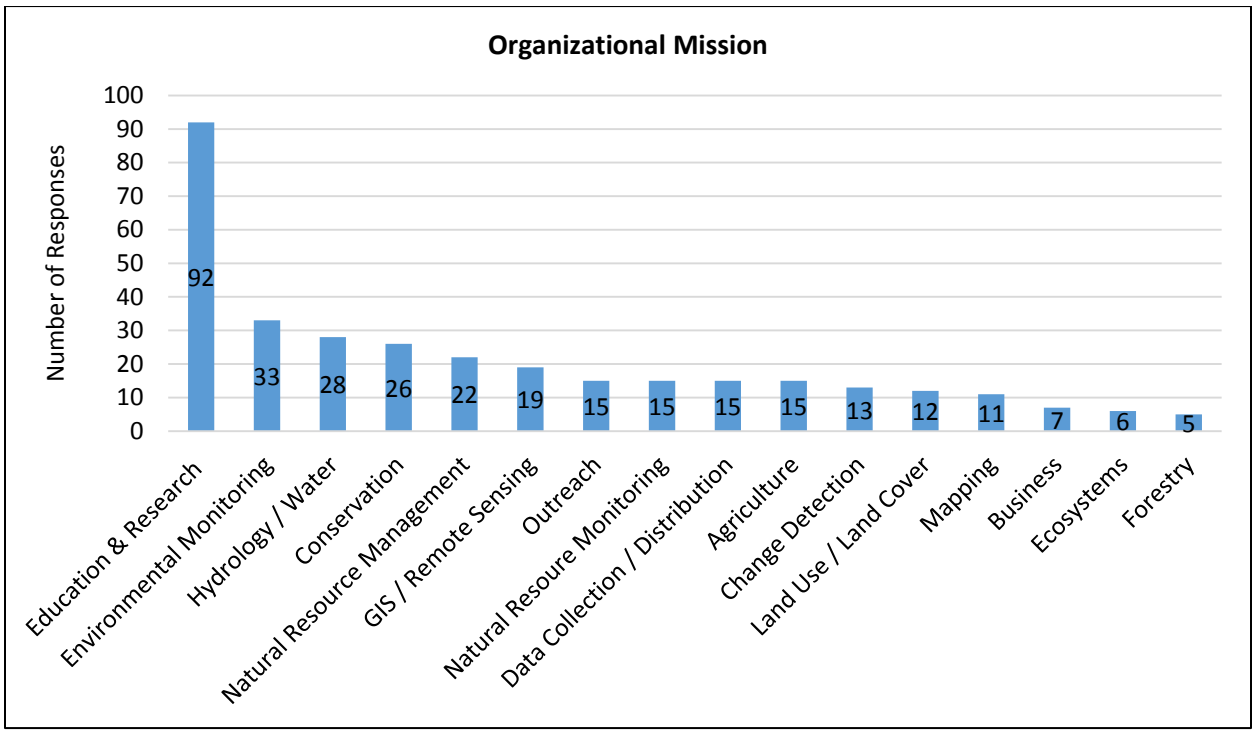

Figure 4. Categories of respondents' organizational missions.

Question 4. Please briefly describe the application or problem you are addressing or attempting to solve by using Landsat imagery.

Question 4 was answered by 266 respondents. The respondents answered the question by filling in an open text field. Many of the respondents listed multiple categories across a broad range of topics highlighting the wide range of uses for this imagery. Therefore, tabulation allowed for more than one category to be chosen reflecting the multiple issues. The numbers do not add up to 100% in order to equal the number of responses. The responses to Question 4 regarding applications or problems for which Landsat data are used overwhelmingly demonstrate that Landsat's value is in generating scientific data that is, in turn, used in applications. Most of the applications enable the understanding of a wide variety of natural phenomena that have a direct relationship to societal well-being. Looking at the data three macro categories emerge: land, water, flora. For land, these break down into land cover change and use; natural hazards; and urbanization, among others. For water, sub categories include hydrology, wetlands, snow and glacier mapping. The flora category includes agriculture, vegetation, and deforestation, among others. Many of the applications found in the data are cross-cutting and could apply to numerous categories in the questionnaire: natural hazards; mapping; and, education.

Figure 5 summarizes the responses to Question 4. The largest category of users at 39% were addressing issues concerned with land cover change and land use. This designation is quite broad with responses related to topics such as urban heat islands, monitoring food production in food insecure regions, neighborhood changes, and vegetation mapping. Imagery is being used, for example, to attempt to link land cover changes to socioeconomic and demographic neighborhood change. Numerous respondents linked land use to flooding and flood monitoring as well.

Twenty-two percent of respondents are studying water issues. Water quality emerged repeatedly for different reasons. Some of these include an early warning system for poor conditions, the monitoring of algal blooms, and how land cover changes impact water quality. Agriculture accounted for 13.5% of the replies. This well-known use includes crop-type detection, yield monitoring and consumptive water use. A cluster of respondents chose vegetation (10.5%), environmental monitoring (10.1%), forestry/deforestation (7.1%) and biodiversity (5.6%). Tropical forest health and the carbon impacts of deforestation were cited of examples in the forestry category. There were a variety of responses below the 5% level, which may be seen in the chart below.

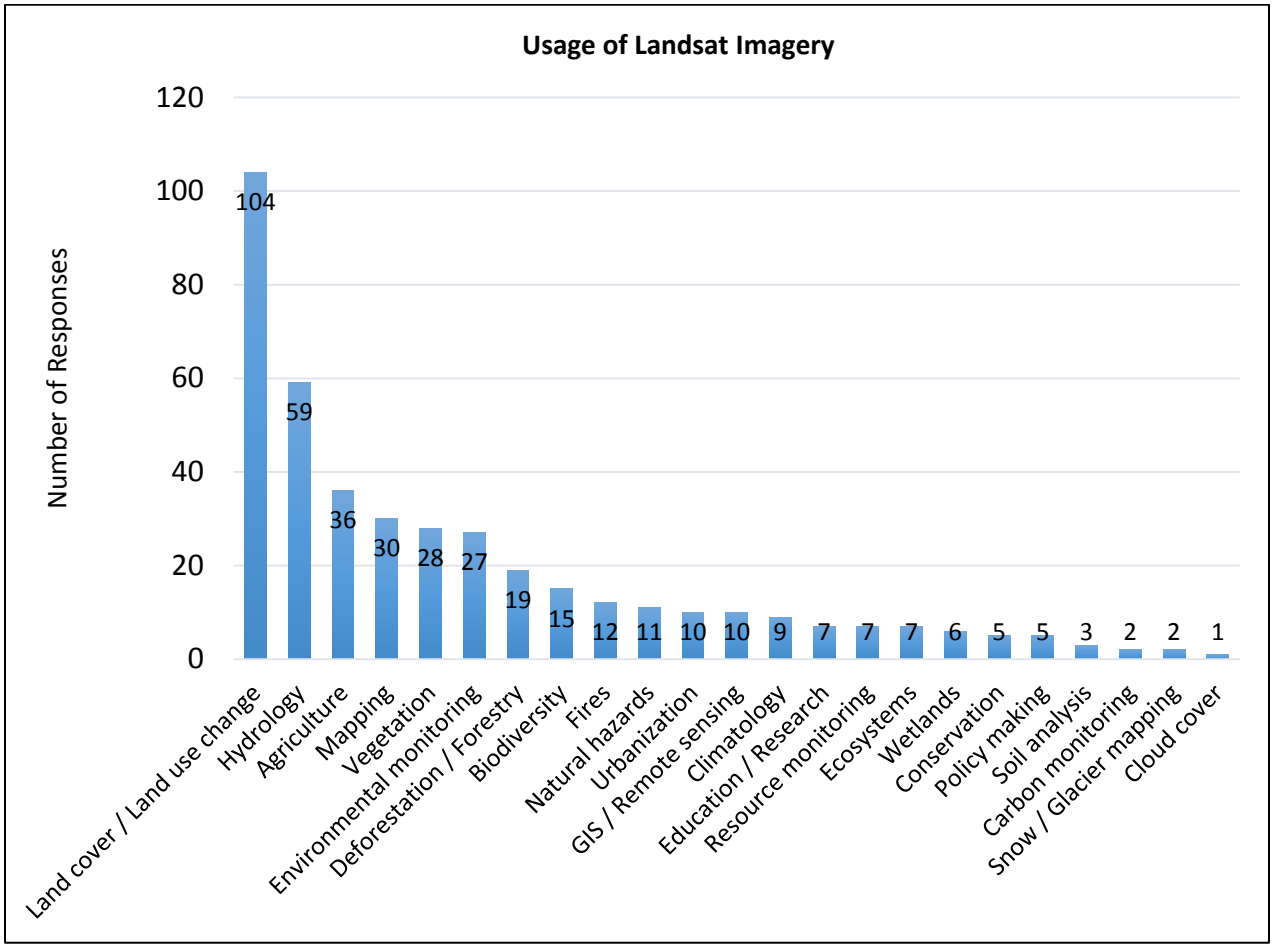

Figure 5. Categories of Landsat applications.

Question 5. Please rank the importance of the listed Landsat characteristics to your organization's decision making process.

Two hundred seventy two respondents answered Question 5. Respondents were asked to choose between seven Landsat imagery characteristics ranking them from most important to least important on an eight point scale with one being the most important and eight being the least important. The characteristics include: optical spatial resolution (30 meter multispectral & 15 meter panchromatic in Landsat 8), thermal spatial resolution (100 meter in Landsat 8), swath width (183 kilometers in Landsat 8), repeat visit, spectral resolution – optical, spectral resolution – thermal, and continuity with previous Landsat data. Respondents also had the option to choose "other," which 40 people did.

The "most important" category far beyond the rest with ninety-seven people choosing it at the highest rating was Landsat's optical spatial resolution. Continuity with previous Landsat data was the next most important with fifty-six respondents ranking it the highest. Repeat visit and spectral resolution – optical were about equal with ratings of thirty-seven and thirty-four respectively. Of least importance were thermal spatial resolution, spectral resolution – thermal, and swath width. The rating average breaks down as follows.

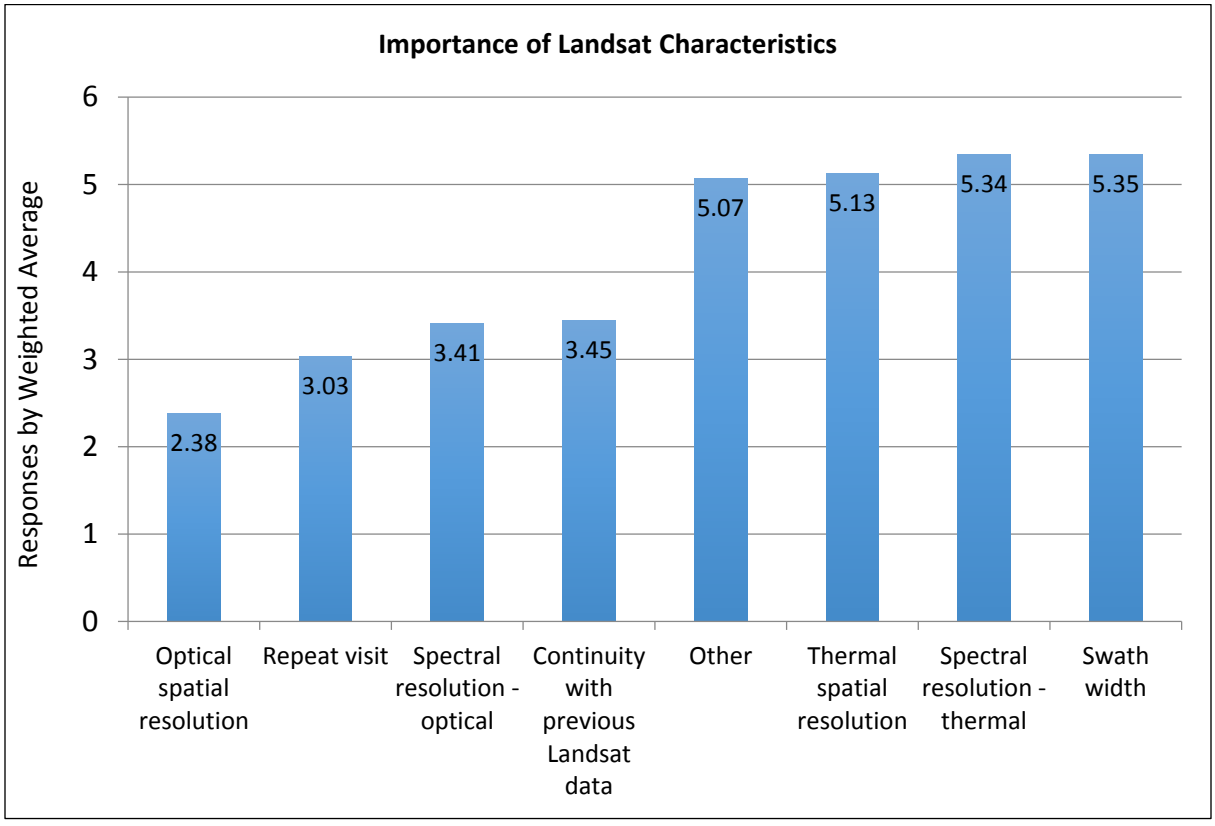

Figure 6. Importance of Landsat characteristics

The "other" responses were scattered although two characteristics were mentioned numerous times. Seven people mentioned that the most important characteristic was that the imagery was free. Making Landsat imagery free has greatly increased its use. For example, in the last ten years according to the Scopus database, Landsat imagery has been used as a data source in over 12, 420 publications, compared to the previous thirty years' number of 14,195 publications before Landsat was made freely

available in December 2005. Four respondents mentioned rapid download capabilities as a major benefit of the imagery. Other respondents mentioned calibration, geometric and radiometric accuracy of L1T products, panchromatic radiometric resolution, and atmospheric correction bands.

Question 6. If you could add something new for Landsat 10 and beyond what would it be (e.g. add a specific band or more frequent revisit)?

Questions 6 and 7 of the questionnaire, are highly correlated since the former asks what would you like and the latter asks why would you like it. Because one group of participants in the questionnaire was so dominant and because one response to both "what would you like" and "why that would be helpful" was also dominant, the analysis after compiling the counts was to determine if the trends for each distinct group of self-identifiers also showed the same preferences or if the size of the one group overwhelmed other responses.

Although there were 285 participants, for Question 6, only 213 submitted responses. For Question 7, only 209 offered an explanation. These questions were the most skipped.

If one examines the capability most desired by the largest groups, improved temporal resolution or more revisit opportunities typically tops the list and often garners close to a 50% preference. Improved spectral and improved spatial resolution are also typically the next desired new capabilities. The following graphics show the trends. When the population of a group drops below twenty, it can be difficult to assess whether such a small sample is representative of a group. (Note that counts of preference do not necessarily coincide with the counts of the respondent, since some respondents provided more than one preference for a new capability.)

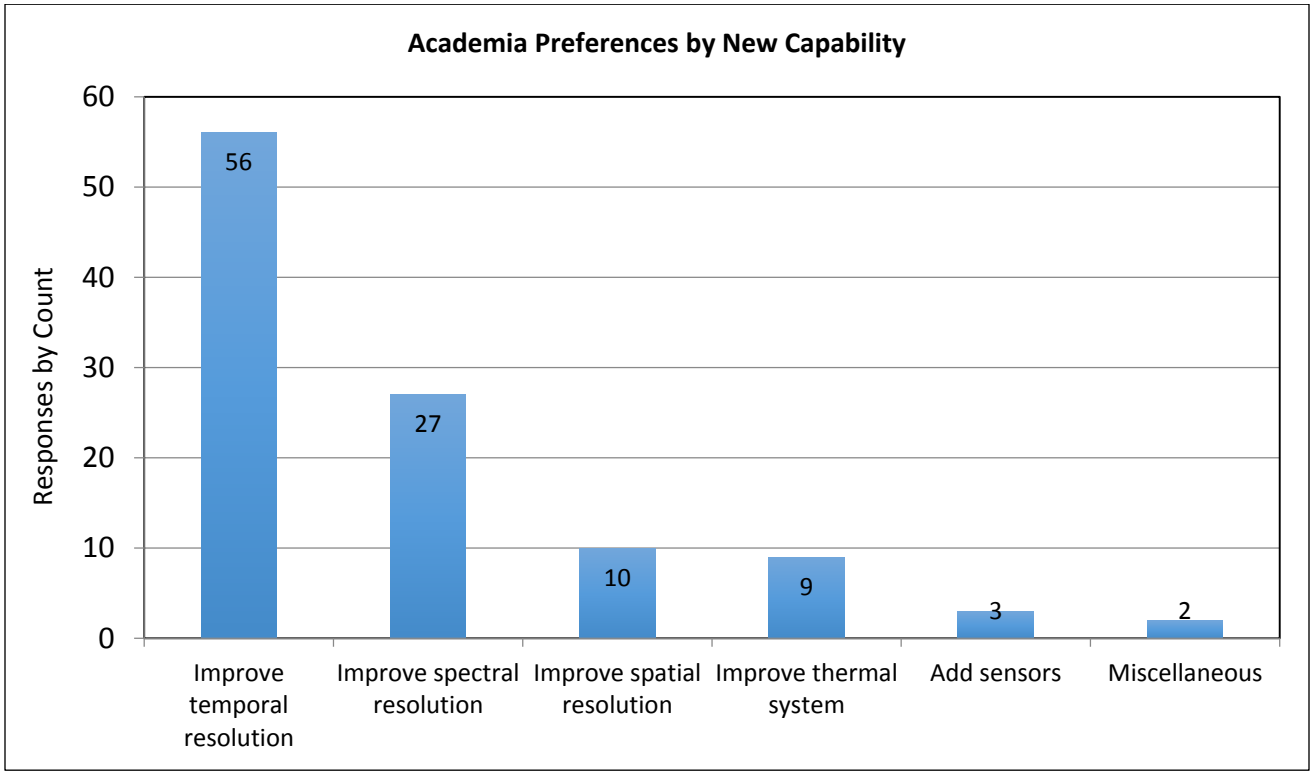

Figure 7. Academia preferences for new capabilities

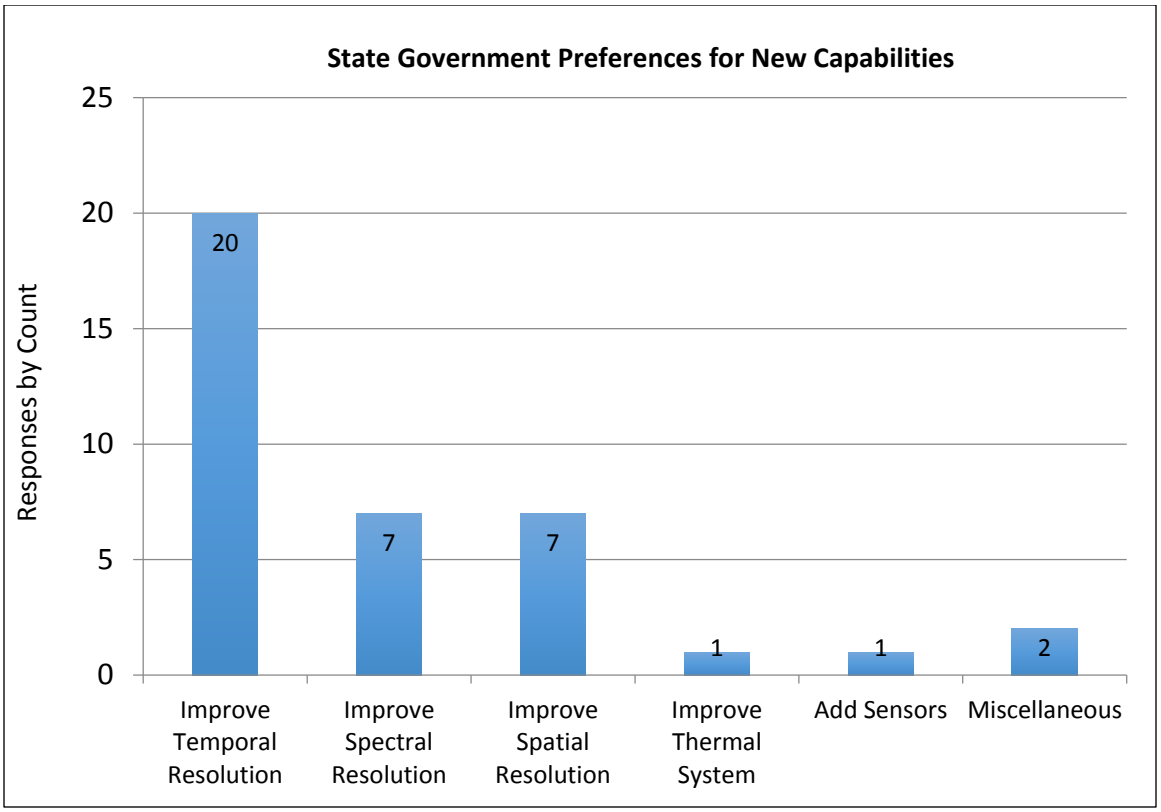

Figure 8. State government preferences for new capabilities

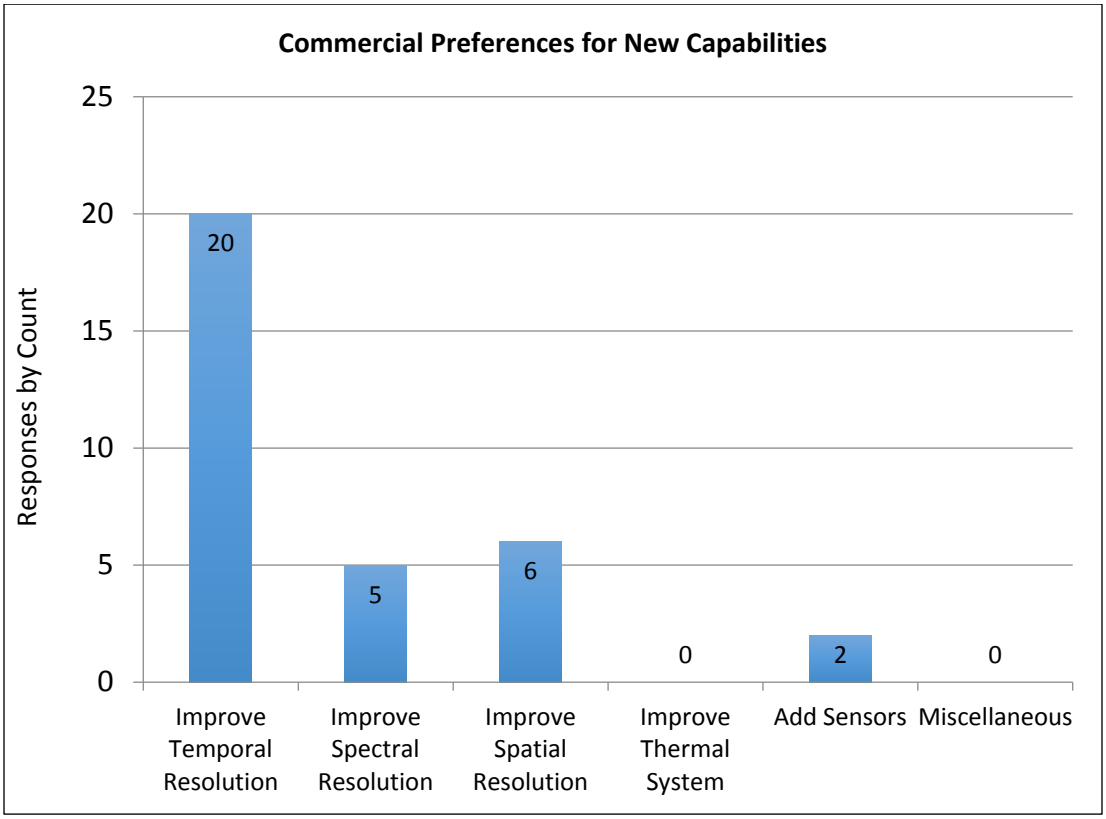

Figure 9. Commercial preferences for new capabilities

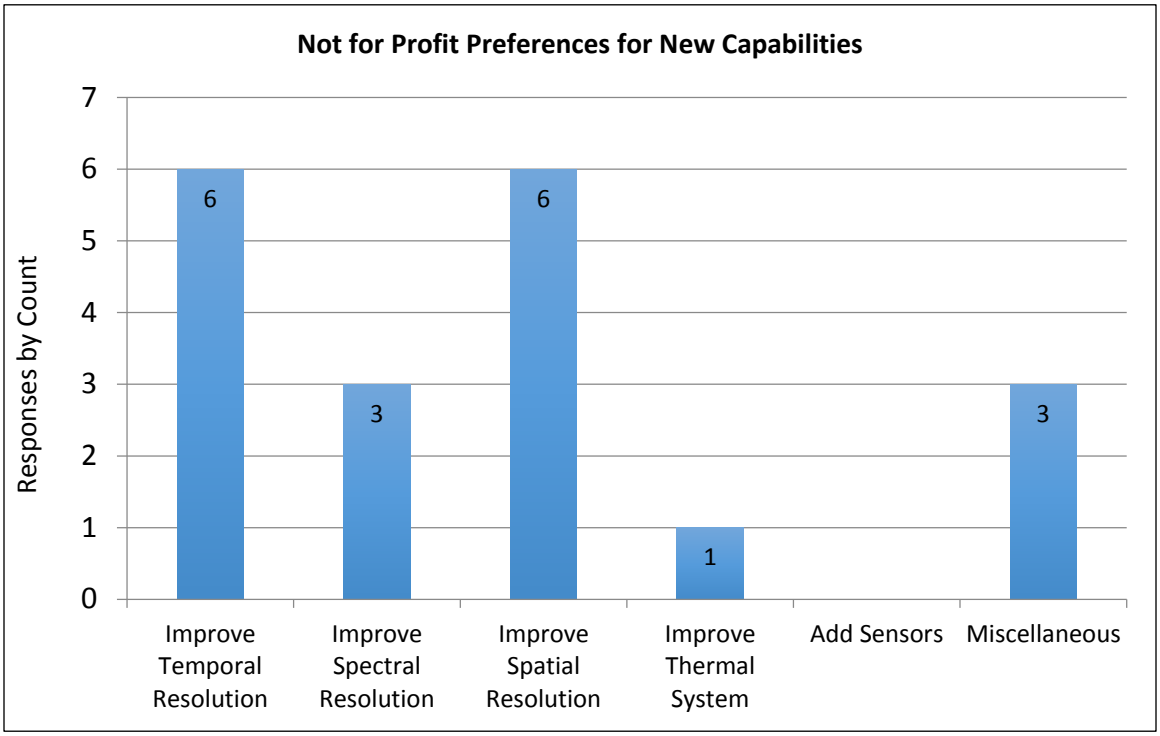

Figure 10. Not for profit preferences for new capabilities

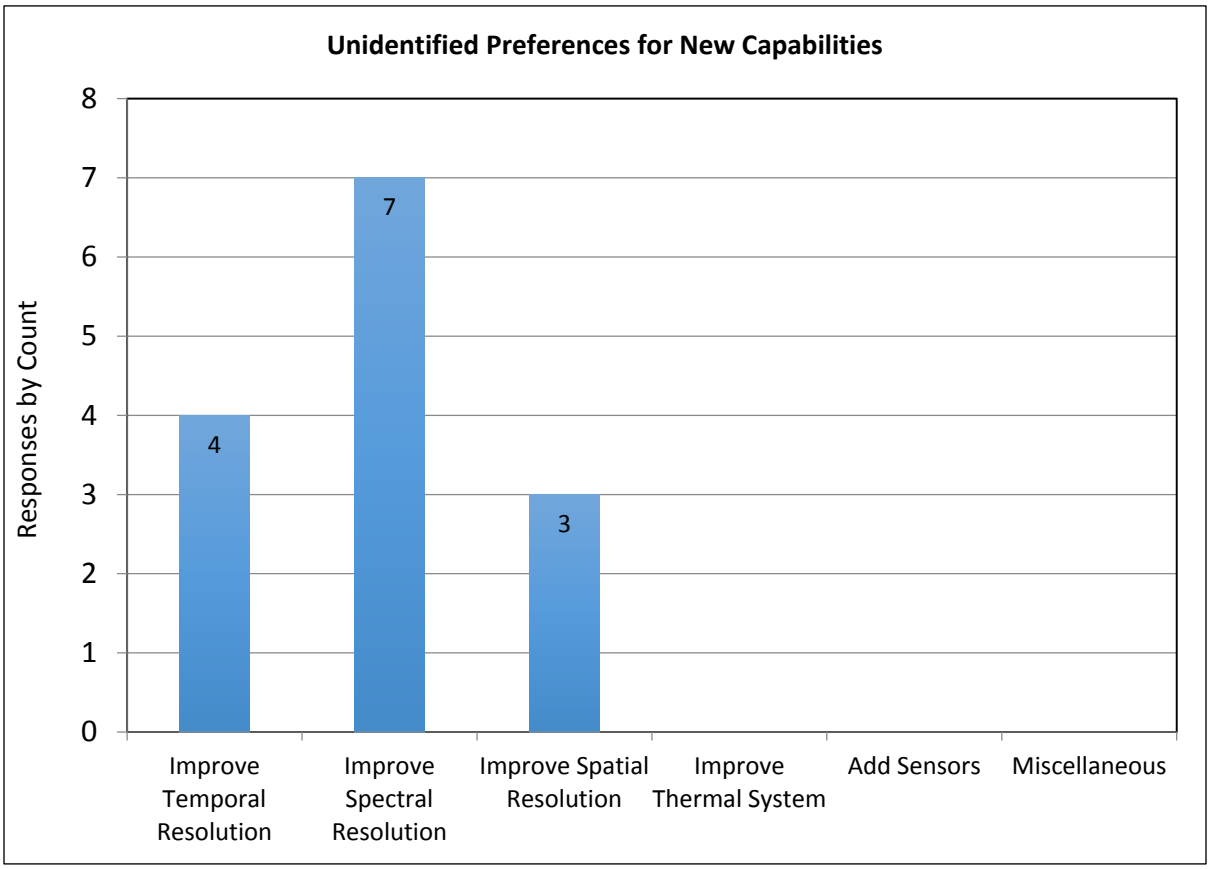

Figure 11. Unidentified preferences for new capabilities

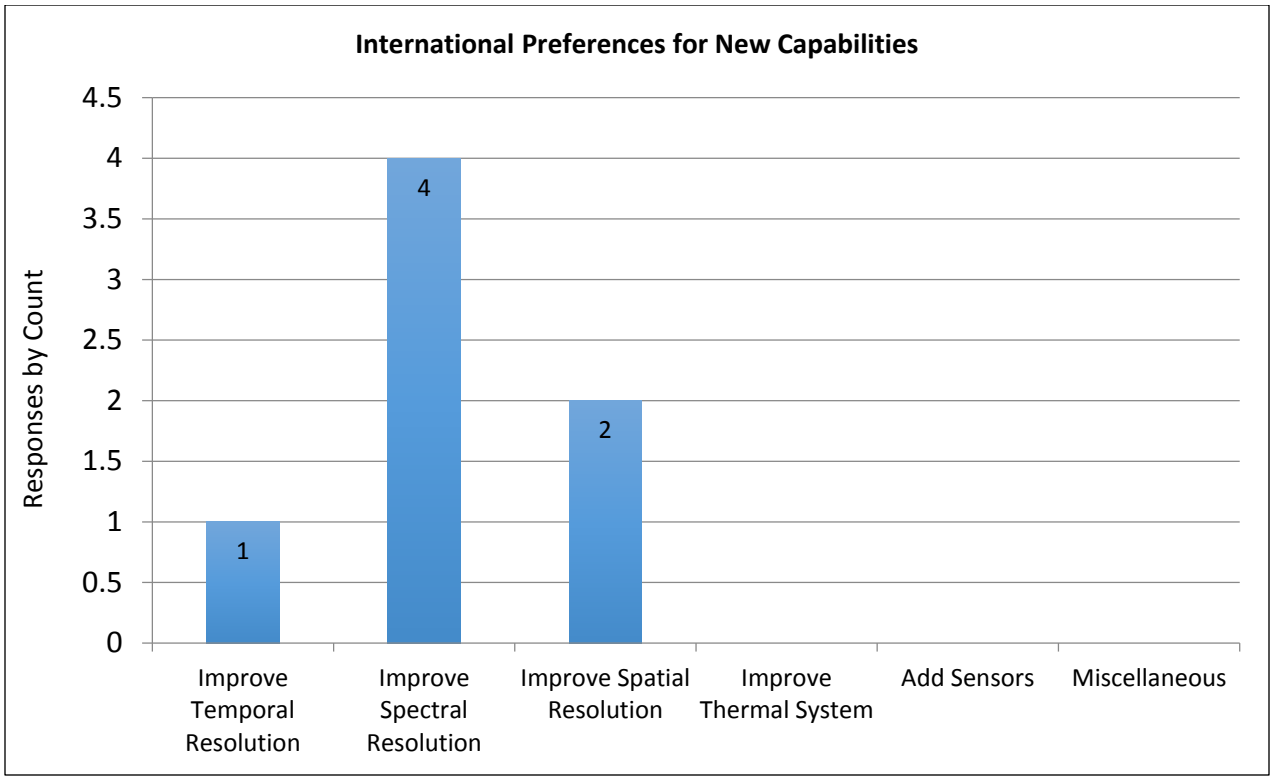

Figure 12. International preferences for new capabilities

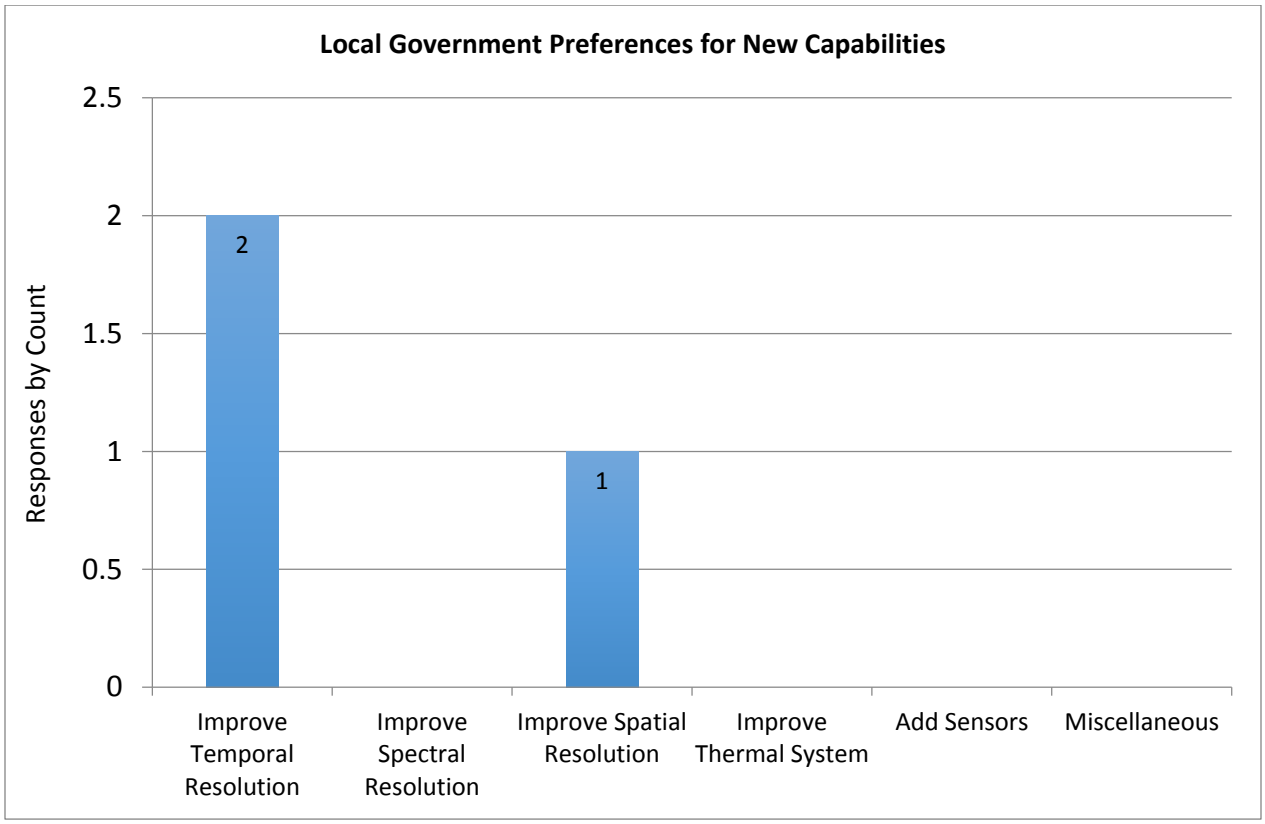

Figure 13. Local government preferences for new capabilities

Among the “miscellaneous” preferences were some capabilities that should not be ignored. Two respondents requested better cloud delineation and removal tools. In another response, related to tools, one individual suggested better website tools and service support. Two others needed real time access. Another was not quite that demanding but asked for improved data distribution.
To provide more detail about the general categories charted about, the following list addresses each with some additional detail about very specific characterization of the capability. Items in parentheses are subsets of the primary count.

Improve Temporal Resolution:	109
(More Satellites: 7)	
Improve Spectral Resolution:	53
(Hyperspectral: 4)	
(Spectrometer: 3)	
(Coastal need: 1)	
(Match Sentinel repeats in spatial: 2)	
Improve Thermal:	11
(Better Spatial Resolution: 7)	
(Additional Bands: 3)	
(Steerable Band: 1)	
Improve Spatial Resolution in Multispectral/Pan:	32
(Pan at 5 meters: 2)	
(Match Sentinel repeat in Spectral: 2)	
Add Sensors:	6
(Radar: 3)	
(L-Band Radar: 1)	
(Lidar: 2)	
Cloud delineation and removal:	2
Provide real time access	2
Improve Data Distribution:	2
Improve web site tools service:	1

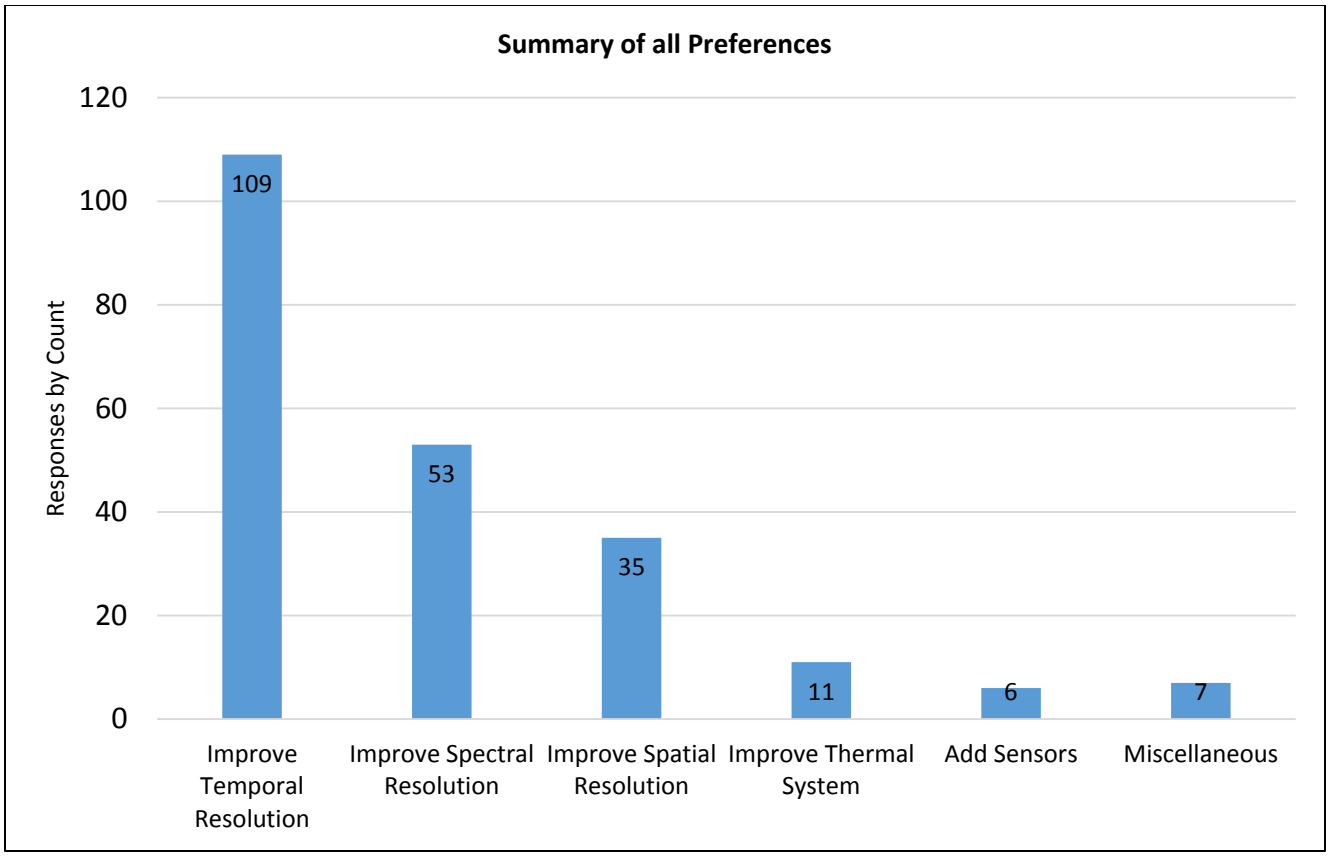

Figure 14. Summary of all preferences for Question 6.

Question 7. Briefly explain why this added characteristic would be important to your organization.

Just as the more populated identifier groups considered improved temporal resolution to be the most highly preferred new capability for Landsat 10, their reason why was also consistent: avoid clouds by having multiple opportunities within critical periods of time to receive at least one useable image.

The desire for improved spectral resolution was often based on having more bands within some particular ranges, not uniform widths across the whole spectrum. Many respondents, who had ranked improved spectral resolution as the preferred addition to Landsat 10, wanted to have better discrimination of the characteristics of certain object/feature types. By further looking through the questionnaire information, one could match those requests for specific spectral ranges to the specific research or application of the respondent.

Improved spatial resolution preference explanation was also closely aligned with those monitoring some types of change, often dynamic. With improved spatial resolution, the respondents anticipated improved detection of change at an earlier stage in a growing hazard or in remediation and recovery. Some sought better fusion with other available data collections both to improve understanding and to develop more robust observations. The majority of those who sought improved thermal data also wanted better spatial resolution. At the least, they requested spacing that aligned with the multispectral resolution, anticipating an identical footprint.

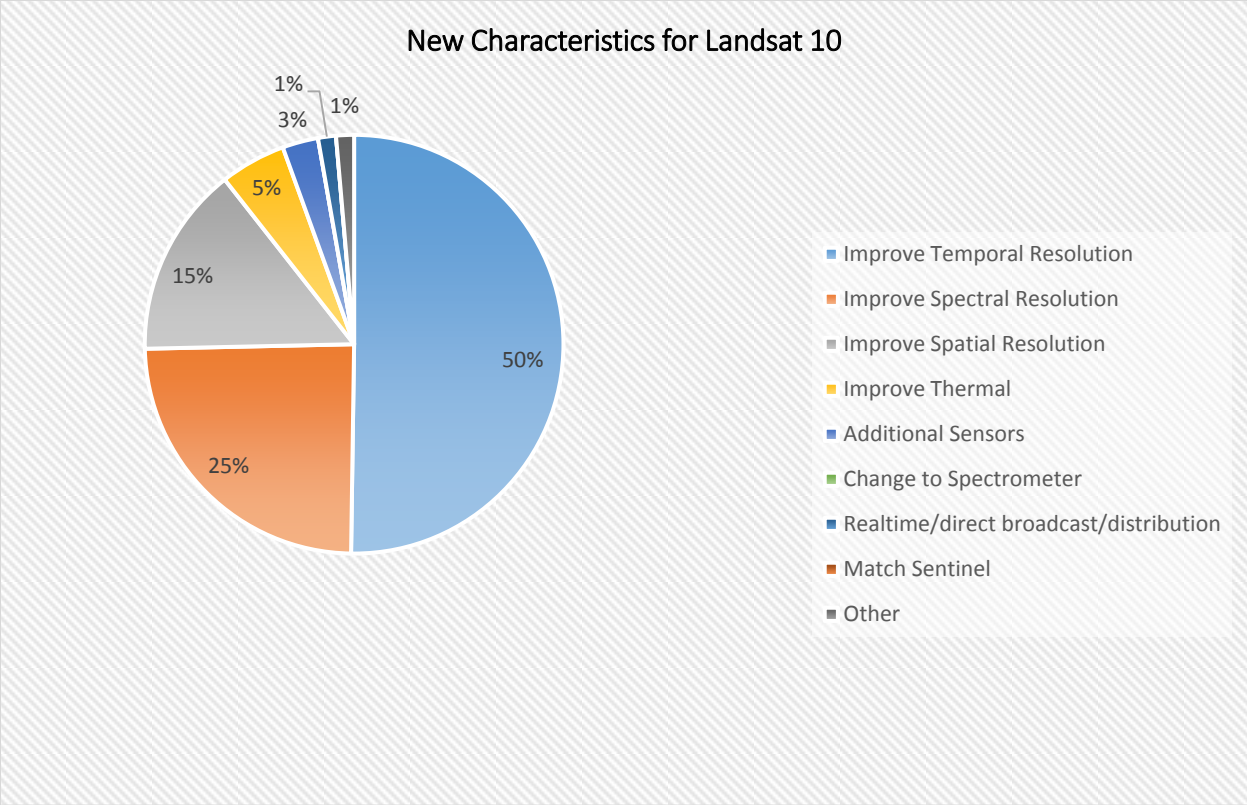

Figure 15. New characteristics preferences for Landsat 10 from Question 6.

If one examines the detailed distribution of "something new to add," the distribution looks like the pie chart above.

The reasons for wanting to improve the revisit time are not necessarily exclusive of each other. It was not simply that they wanted more images for the data archive. It was more likely that if the revisit time improved, users of the imagery were more likely to get a cloud-free view of their areas of interest. The pie chart below portrays the reasons given by respondents in a general way. Explanations provided in the earlier questions about the respondents' work or areas of interest correlate to these responses. Although in question 6, seven people had suggested adding more satellites from a range of two being synced to a swarm of thirty, no one articulated how those might be configured to address the reasons for needing more images.

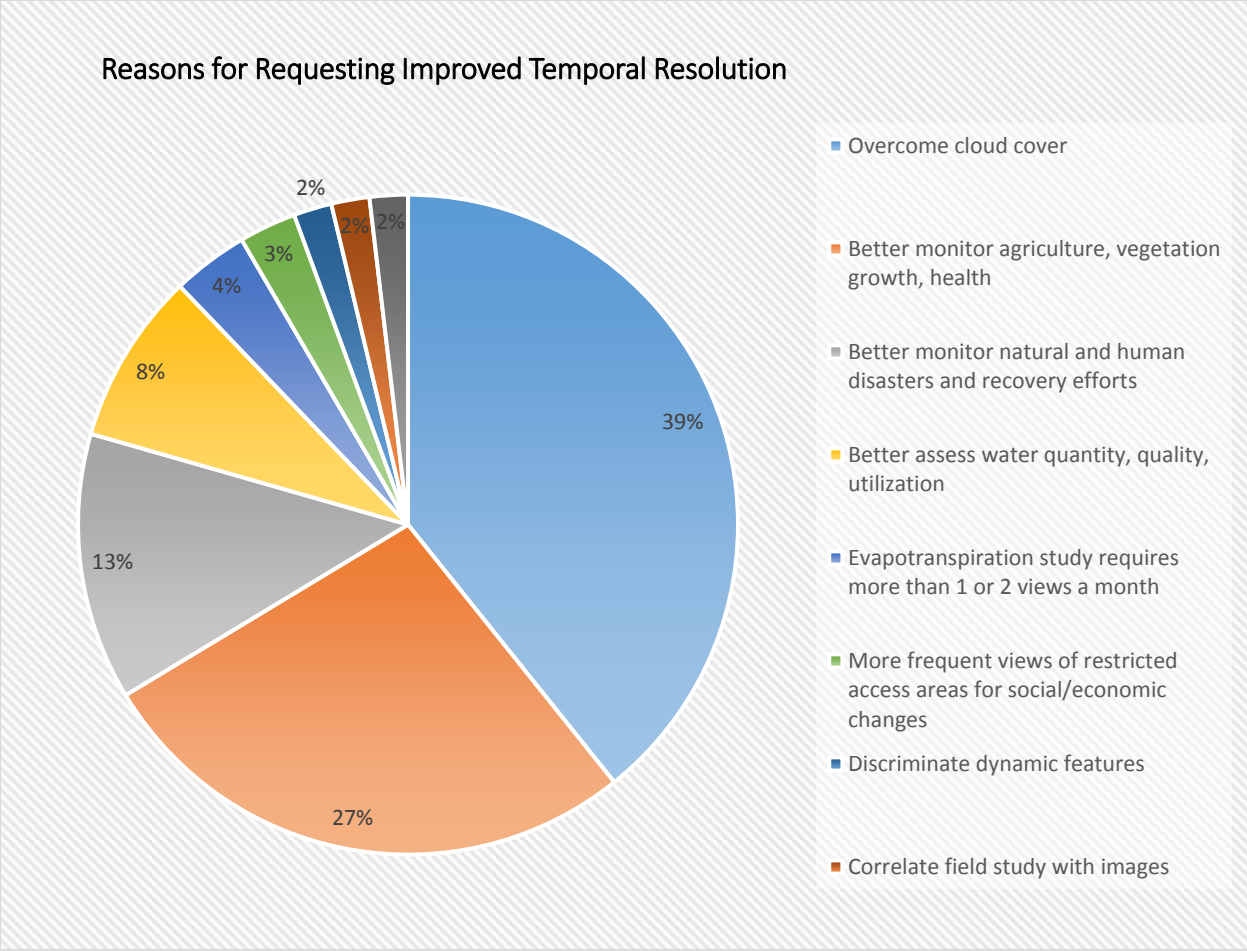

Figure 16. Reasons given for requesting improved temporal resolution.

A comparable look at the explanations for identifying the more dominant new capabilities will address improving spectral and spatial resolution, improving the thermal instrument, and adding new sensors follows.

Fifty-three individuals wanted improved spectral resolution. Some were quite specific as to their needs as represented on the chart below. Nine wanted more resolution in the Red Edge; eight of those were monitoring health and stress in the ecosystem and agriculture; one found that capability would be useful to distinguish algal from mineral turbidity in water. Six wanted finer resolution in the upper range for mineral and rock definition or for methane and water vapor detection. Four suggested that a hyperspectral capability would be superior to the current multispectral to allow better classification of minerals. Three respondents, not working together, recommended more resolution around 620, 680, and 705 nm that would allow detecting chlorophyll in water and its depth and would help detect cyanobacterial bloom in fresh and salt water.

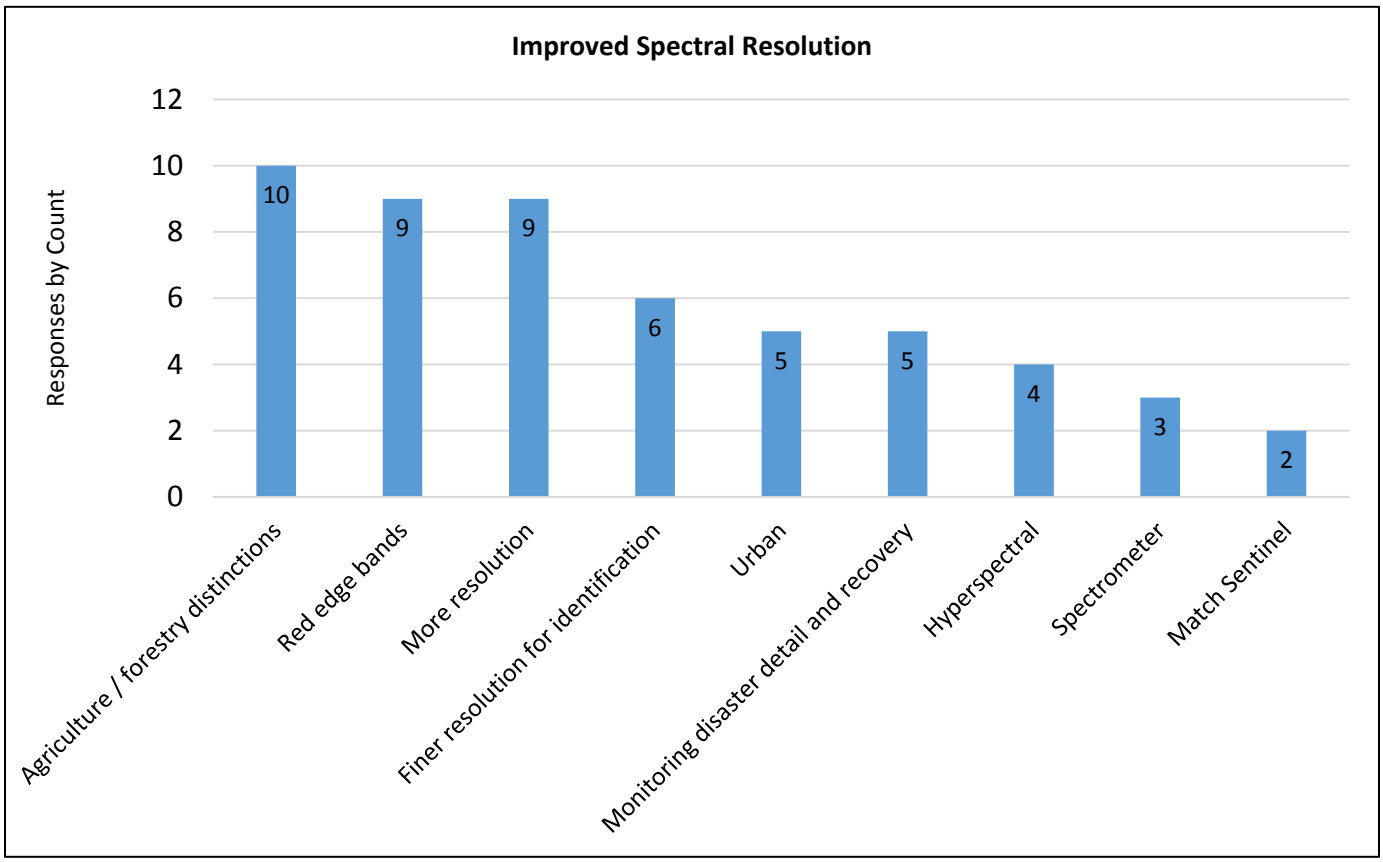

Figure 17. Reasons given for improved spectral resolution.

Thirty-two wanted improved spatial resolution with again some specific rationale. As shown in the chart below, four believed it would help distinguish vegetation types in land cover; three described how it could improve mapping and planning at the local level; others cited a need when they observe disaster recovery and the change that occurs is as resolution less than Landsat. Three were specific about using better spatial resolution for some hydrology challenges and in observing coastline areas. Three wanted the panchromatic spatial resolution to be better than 7.5 meters because they found the existing collections to be not useful and underutilizing a collection asset.

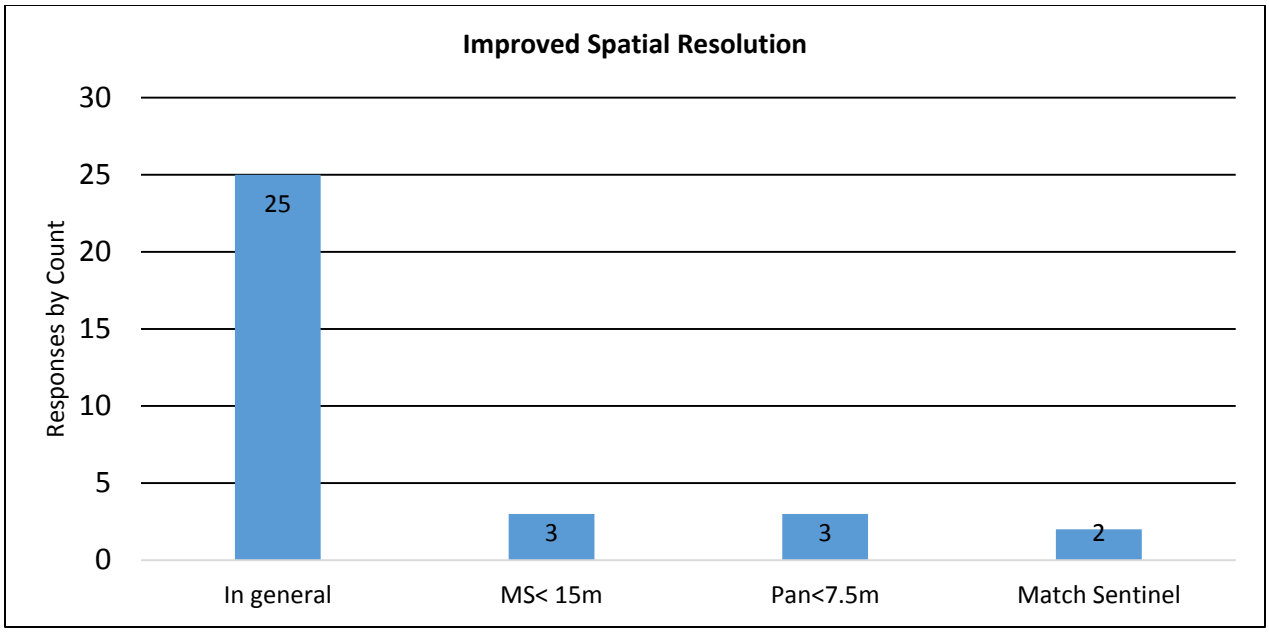

Figure 18. Reasons given for improved spatial resolution.

The eleven who described ways to improve the thermal collection fell into three categories. As noted in the chart below, seven asked for better spatial resolution. As a minimum they wanted the resolution to reflect the resolution of the multispectral collection. They explained that such a capability would improve the accuracy in calculating agriculture's water use, would support mapping active fires, and would address the emerging challenges understanding the impacts of urban heat islands. Three asked for an additional band so they could improve land surface monitory, support needed night time collections, and help trace groundwater discharge into surface water bodies. One asked for launching more than one instrument so that the additional instrument could be directed to specific items of interest, like tracking open ocean ship traffic or monitoring suspected illegal logging and burning.

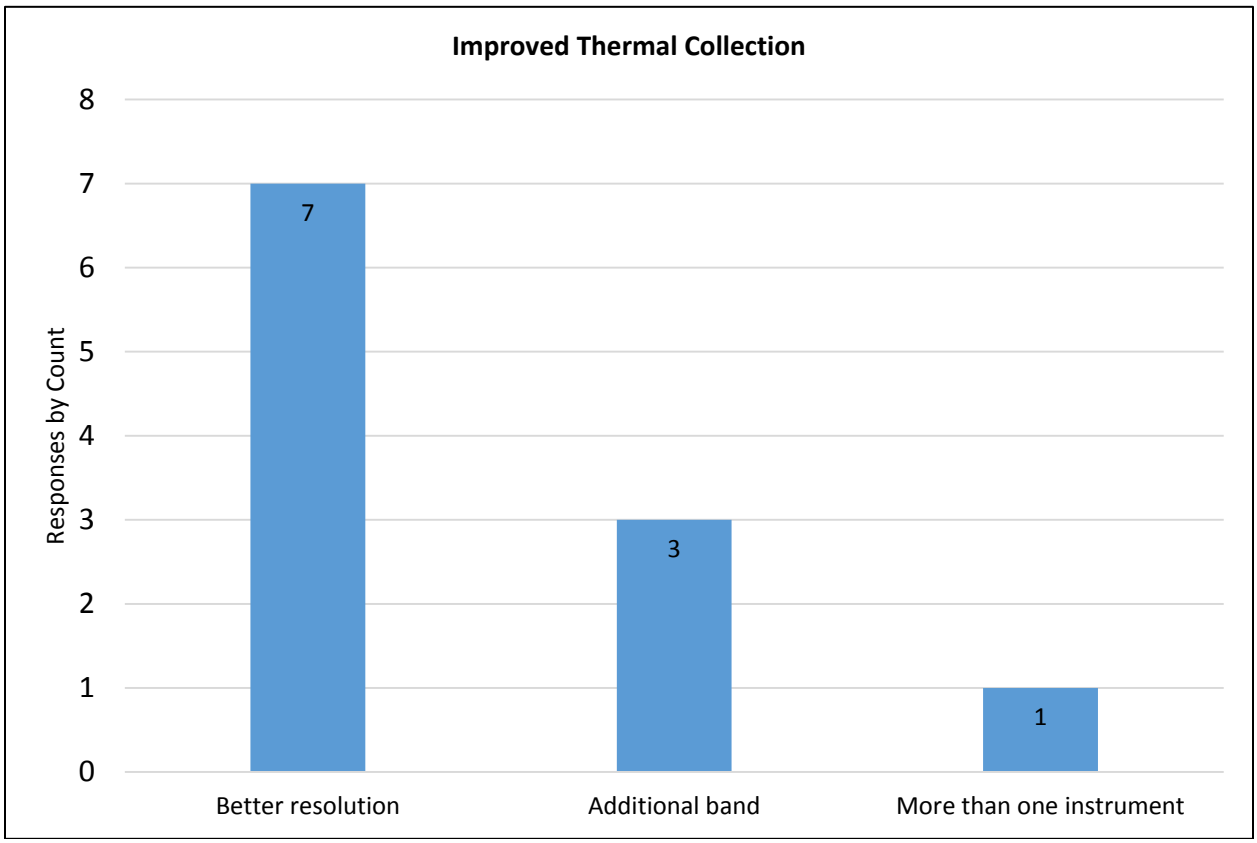

Figure 19. Reasons given for improved thermal collection.

Only six mentioned adding additional sensors to the Landsat 10 platform. Four would add radar to improve observation of terrain, through clouds and atmosphere. Of those one was explicit about having L-band radar for detecting soil moisture. Two were looking for LiDAR to help measure vegetation growth more accurately.

Three, when discussing improved spectral resolution, suggested consideration of the making Landsat 10 a spectrometer, noting that such an approach would dramatically improve discrimination between surface types and could add value to all other national and international optical systems. Two also asked that Landsat 10 be more like Sentinel, for both spatial and spectral resolution improvement. Those concern about both water quality and water quantity globally mentioned this would help when monitoring algal bloom.

Those requesting real time direct broadcast of a collection mentioned wanting a service like MODIS that is particularly helpful in crisis situations, whether natural or manmade disasters.

The responses to questions 6 and 7 offer much to consider. Some of the results may have been anticipated but understanding the subtleties in the rationale for the particular responses could be significant in the design and planning for Landsat 10. Some respondents may be thinking ahead, recognizing that many of the current issues addressed by Landsat will lead to even more complex situations in the future. They are wisely considering what must be addressed.

8. What are you minimal requirements for the following Landsat characteristics?

9. What would be your optimal requirements for the following Landsat characteristics?

- ***Optical spatial resolution (in meters)***
- ***Thermal spatial resolution (in meters)***
- ***Swath width (in kilometers)***
- ***Repeat visit (in days)***

Both Question 8 and 9 were structured as open text fields for each of the characteristics. Because the questions speak to the same Landsat characteristics, they lend themselves to a comparative analysis. Figures x through x compare the range of responses for each of the characteristics. In general, the majority of respondents listed existing Landsat 8 resolutions/swath width/repeat visit as their minimal requirement and then listed higher spatial resolutions, larger swath widths and more repeat visits for their optimal requirements.

As Figure 19 shows, 154 or 67% of the 229 total respondents to the query regarding their *minimal* multispectral spatial resolution, listed Landsat 4-8's 30 meter resolution as *minimal* with 47 respondents listing resolutions better than 30m as *minimal*. However, *optimal* resolutions listed were at the most 30 meters, with all of the 220 respondents listing 30 meters or less, and 81% of the respondents requesting spatial resolutions better than 30 meters.

Responses regarding minimal versus optimal thermal spatial resolutions were more mixed as illustrated in Figure 20. Forty-three percent of the 179 respondents listed Landsat 8's current 100 meter resolution as *minimal*. But an even higher percentage (53%) do not believe that the current resolution meets their *minimal* requirements. *Optimal* requirements for thermal spatial resolution are much higher than current Landsat 8 capabilities with 90% of the 182 respondents requesting at least 60 meter resolution, and 61 of the respondents requesting 30 meter resolution.

The pattern of responses concerning *minimal* (167 respondents) and *optimal* (163 respondents) swath width were very similar. However, as illustrated in Figure 21, 22% of the respondents believe that a wider swath width than that of Landsat 8 would be *optimal*.

Finally, respondents were asked to list their minimal and optimal revisit periods, and it is on this characteristic that the largest difference between current capabilities, and minimal and optimal requirements occurs. As Figure 22 shows 51% of the 211 respondents believe that the current revisit of 16 days is *minimal*. However, 38% believe that less than 16 days is a *minimal* requirement, and 86% percent of the 208 respondents listed that the *optimal* revisit period should be less than 10 days.

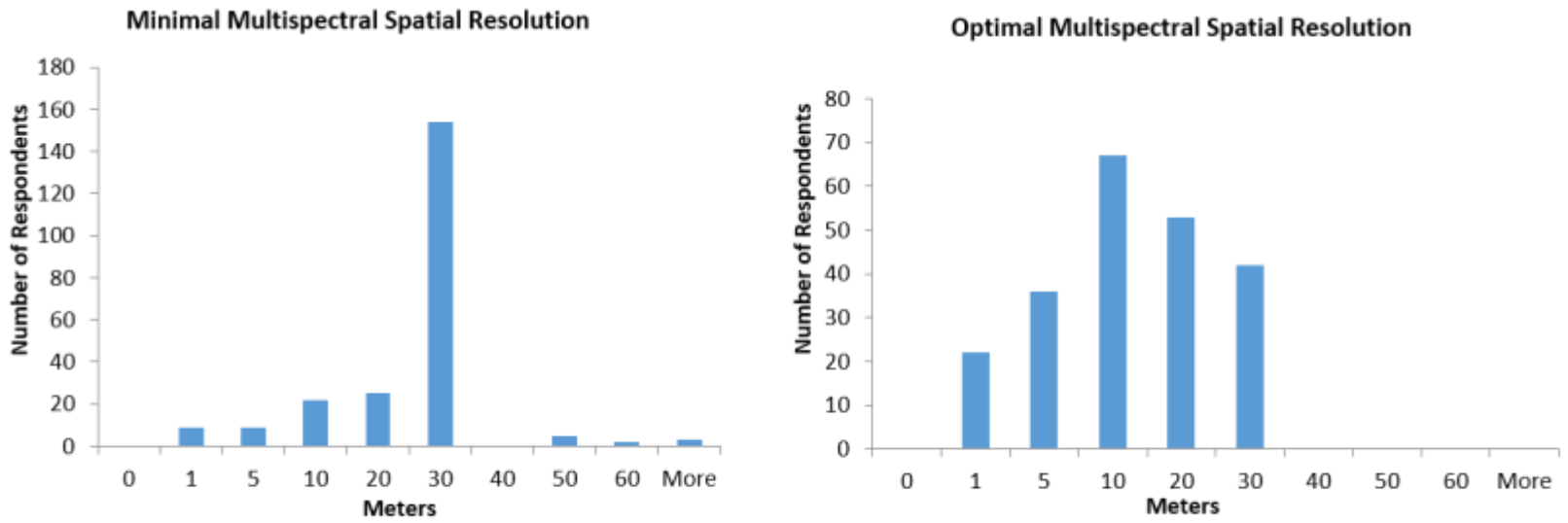

Figure 19. Comparison of minimal versus optimal optical spatial resolutions[3].

[3] Please note that the y axis are scaled differently in the two figures.

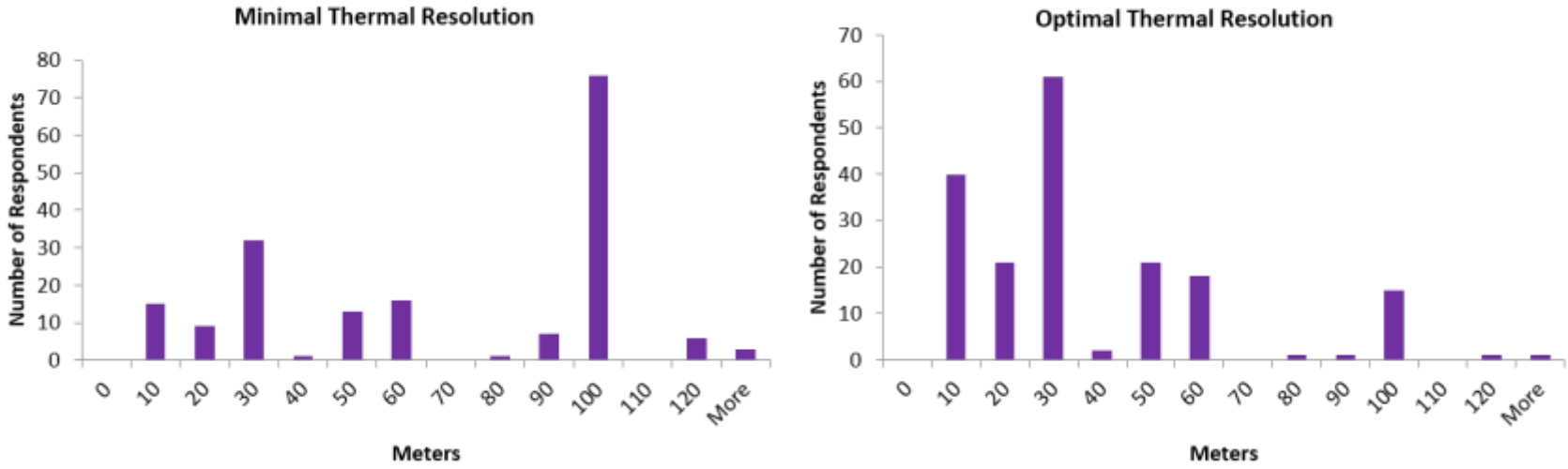

Figure 20. Comparison of minimal versus optimal thermal spatial resolutions[4].

[4] Please note that the y axis are scaled differently in the two figures.

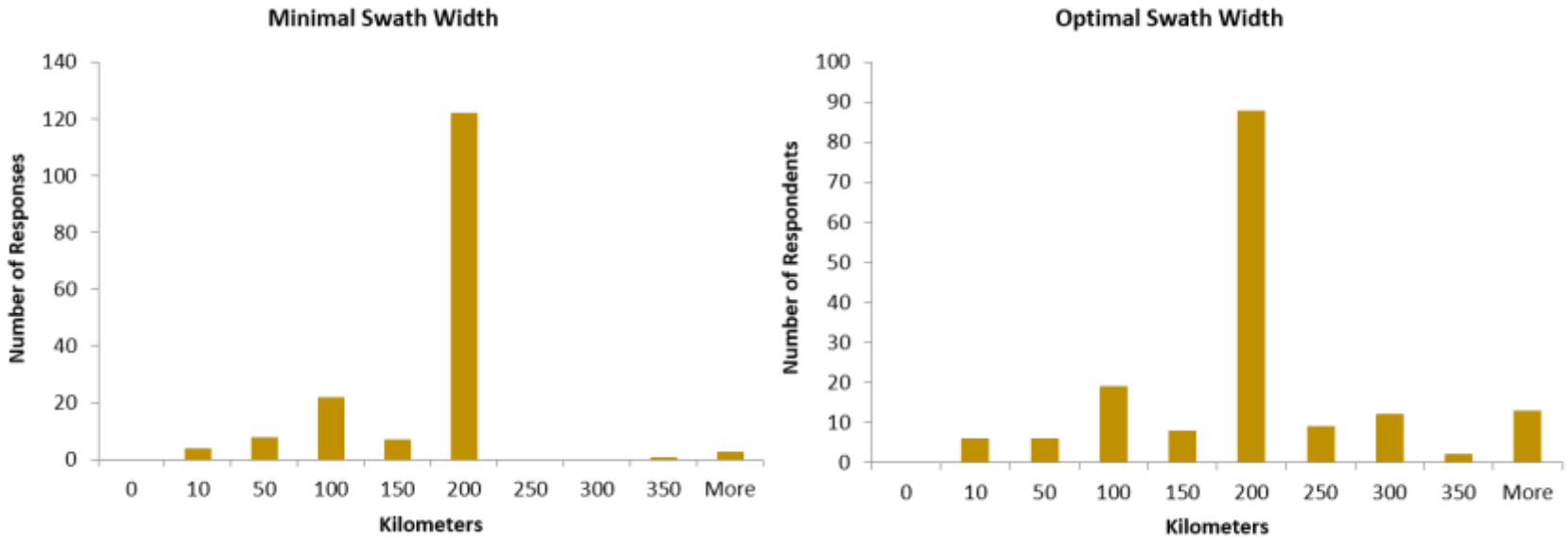

Figure 21. Comparison of minimal verses optimal swath width[5].

[5] Please note that the y axis are scaled differently in the two figures.

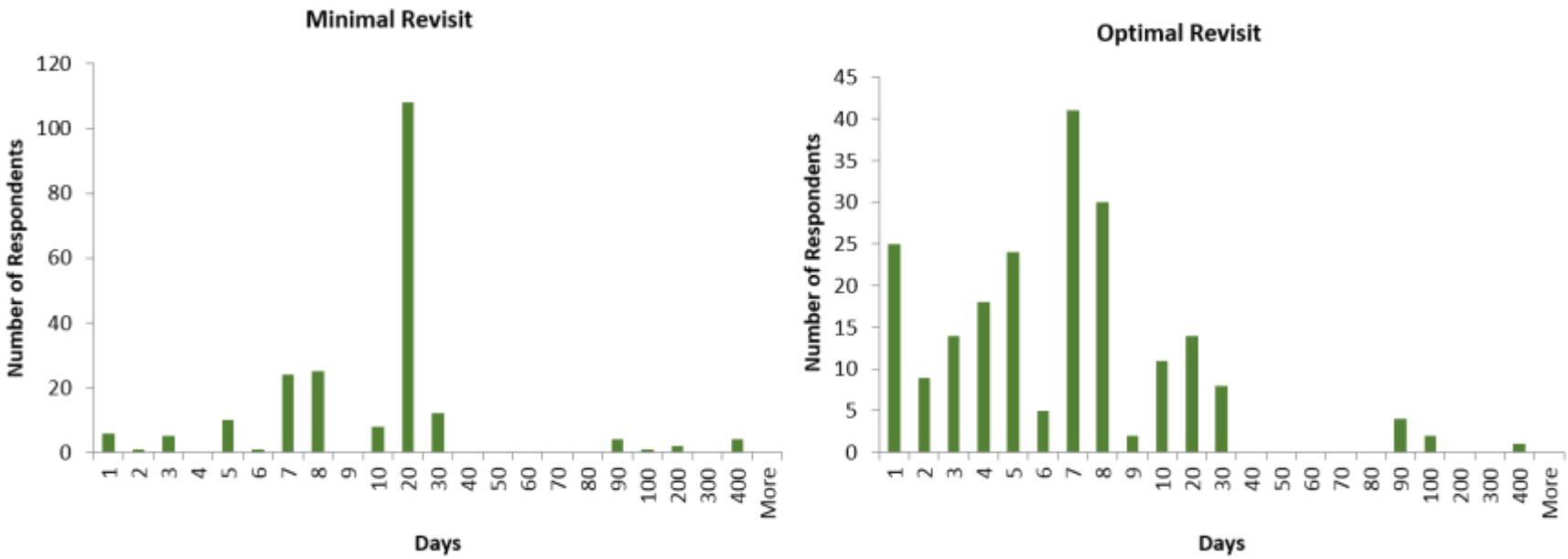

Figure 22. Comparison of minimal verses optimal revisit period[6].

[6] Please note that the y axis are scaled differently in the two figures.

Major Findings

- The explicit focus of this survey was to gather information on non-federal government users' requirements for Landsat 10 data and beyond. The largest population of respondents to the survey were from the academic sector, which is possibly tied to the heavy academic focus of many of the survey outreach efforts. However, all other user groups were well represented in the survey with multiple respondents from the state and local governments, non-governmental organization and international sectors.
- The uses of Landsat imagery by non-federal users continues to be broad and rich. While the largest use is for land cover and land use change analysis, other uses range from agricultural mapping to public health modelling to carbon monitoring. Landsat imagery serves a broad community for whom the data supplies foundational information, serving a myriad of applications, research and decision support.
- Even though the current Landsat optical spatial resolution and revisit period were considered the most important characteristics of Landsat imagery, 65% of the survey respondents believe that revisit time should be reduced and spatial resolution should be increased in future Landsat systems.
- Perhaps one of the most unanticipated results is the importance of improved temporal resolution to respondents. Improved temporal resolution was by far the most named improvement for the academic, state, commercial, and local government sector respondents. Thirty-eight percent of the respondents do not believe that the current Landsat temporal resolution meets their minimal requirements, and 86% believe that a revisit time of less than ten days would be optimal.