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Landsat and Beyond: Sustaining and Enhancing the Nation's Land Imaging Program

National Research Council
Space Studies Board

COMMITTEE: Jeff Dozier, Carlos del Castillo, Jack Fellows, Kass Green, John Jensen, Dennis Lettenmaier, Berrien Moore III, Diane Pataki, David Schimel, Walter Scott, Bill Townsend, Howard Zebker, Mary Lou Zoback

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The future of Landsat is uncertain.

- "Landsat 9 will ensure data continuity," but the Senate is "highly skeptical of either a hosted payload or international partner" and it should be accomplished for "approximately $650 million."*
- The House of Representatives intends that "…no funds should be spent [by NASA] in pursuit of a new land imaging system for USGS."**

Washington, DC, June 18, 2013
From Landsat 8

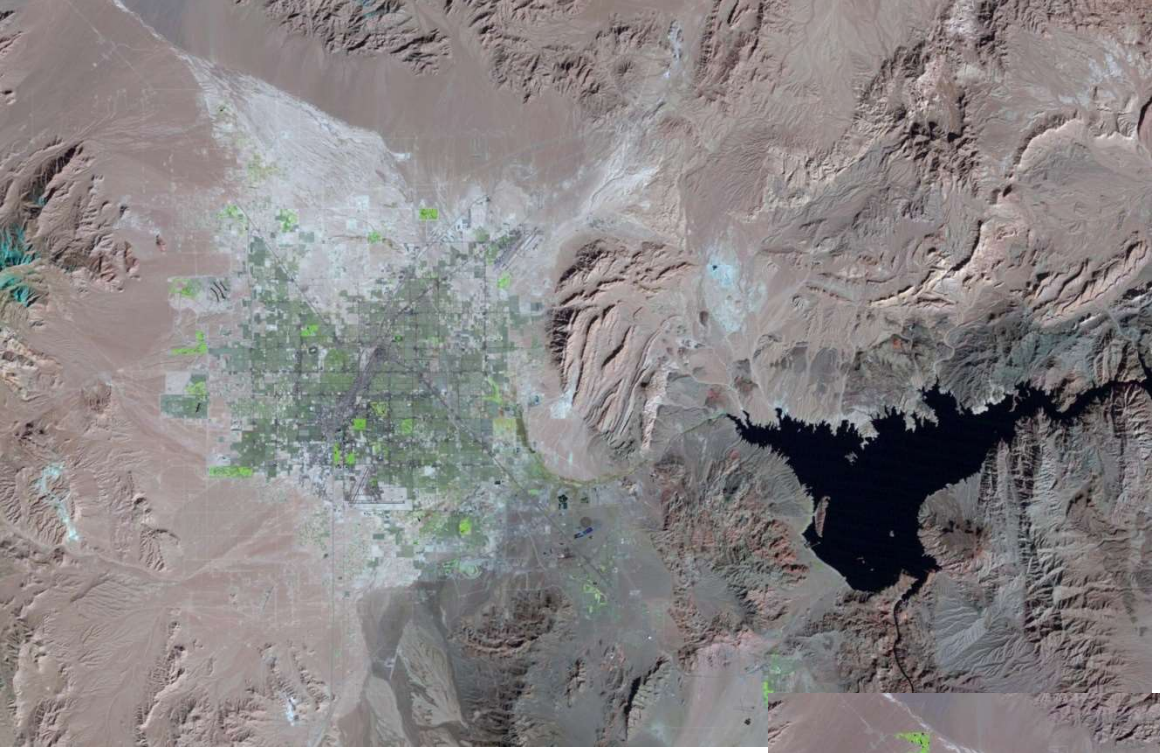
*Departments of Commerce and Justice, and Science, and Related Agencies Appropriations Bill, 2014, Report 113-78. http://www.gpo.gov/fdsys/pkg/CRPT-113srpt78/pdf/CRPT-113srpt78.pdf

** Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2014, Report 113-171. http://www.gpo.gov/fdsys/pkg/CRPT-113hrpt171/pdf/CRPT-113hrpt171.pdf

Statement of Task (Paraphrased)

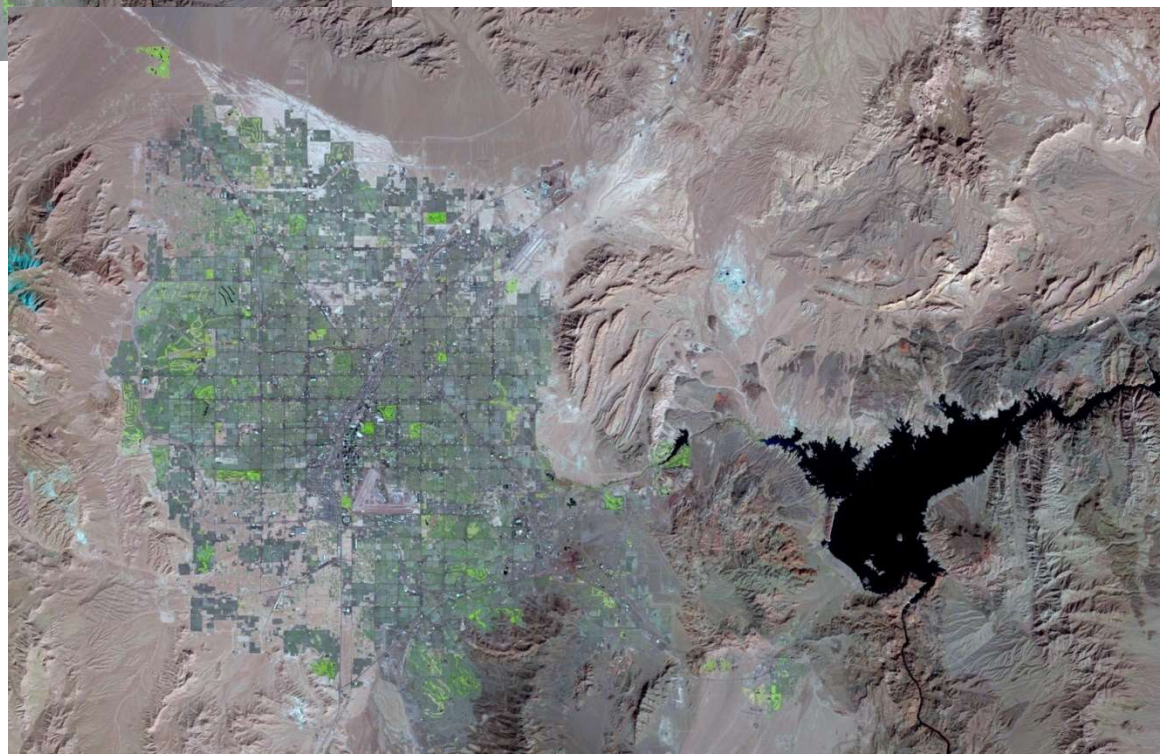
- Assess the needs and opportunities to develop a national space-based operational land imaging capability.
- Task 1: Users' needs for data and service requirements for land imaging
- Task 2: Characteristics and critical program support areas expected of a sustained land imaging program
- Task 3: Critical baseline products and services
- Task 4: How to transition from single research-based missions to a sustained program.

The economic, intrinsic, and scientific benefits to the United States of Landsat imagery far exceed the investment in the system.

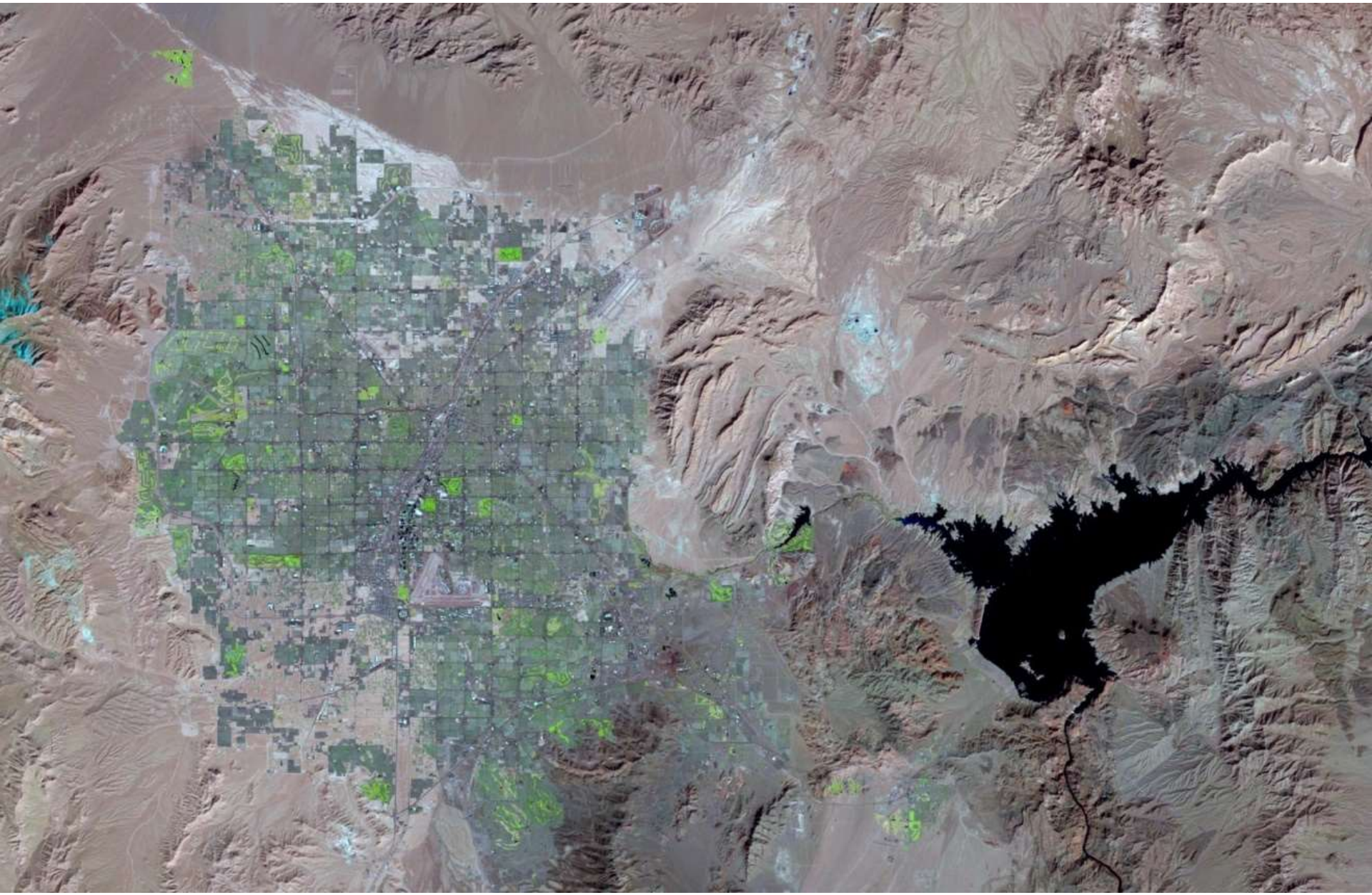


1990

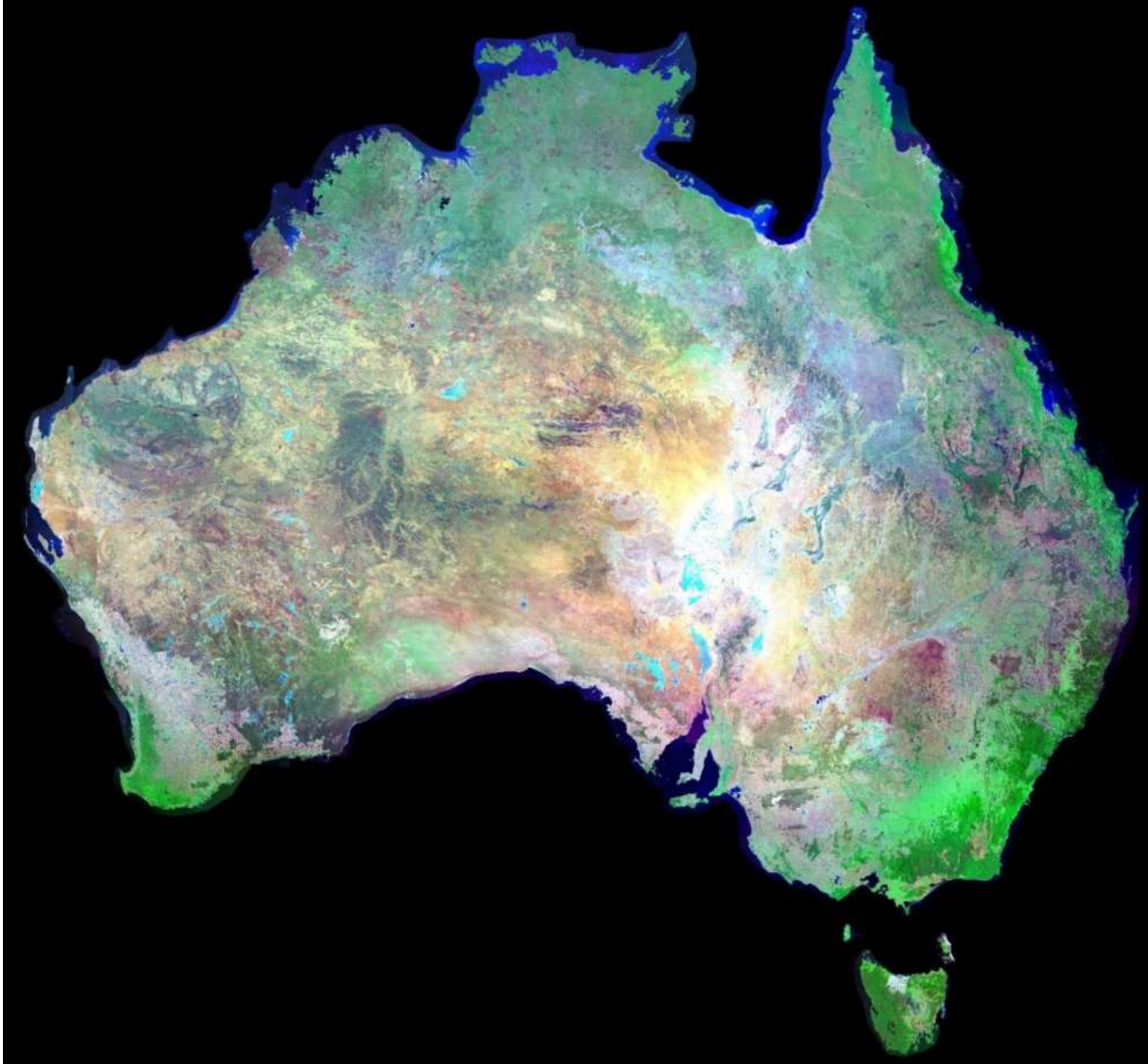
Documenting change: Las Vegas and Lake Mead



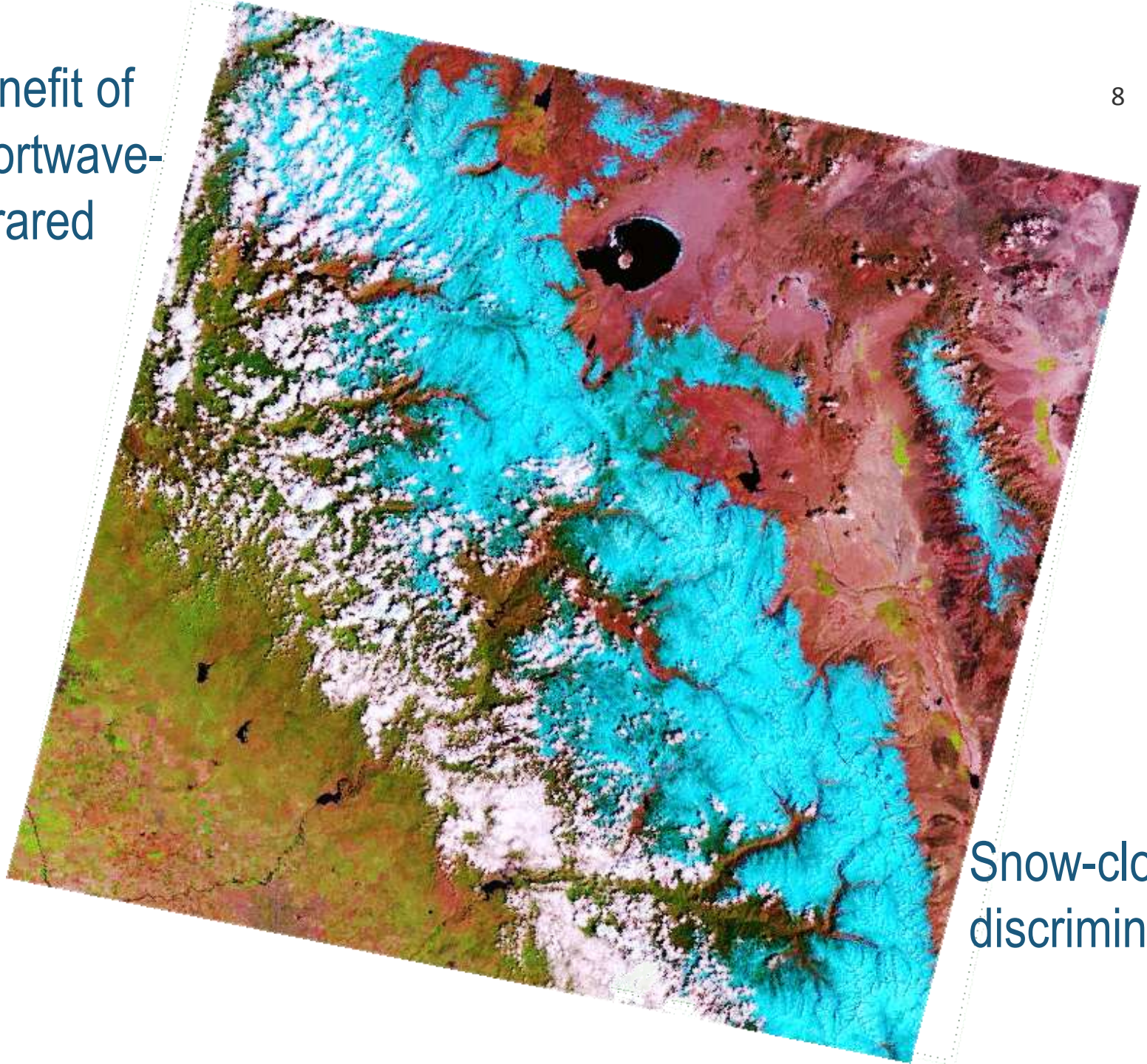
2010



Global carbon estimates



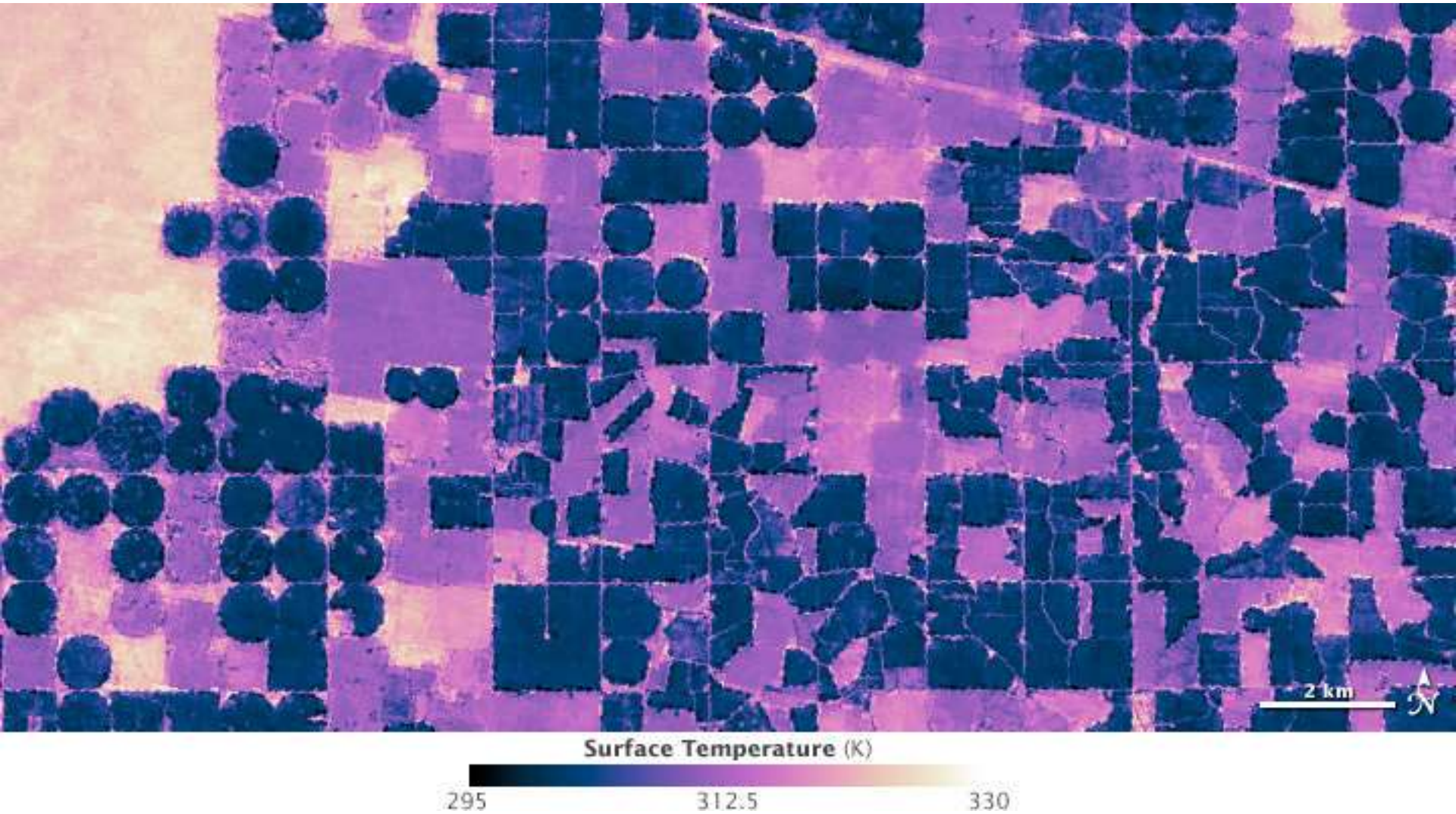
Benefit of shortwave-infrared



Snow-cloud discrimination

Space-based land imaging is essential to U.S. national security as it is a critical resource for ensuring U.S. food, energy, health, environmental, and economic interests.

Together visible/near-IR and thermal IR data can estimate evaporation



Establish a Sustained and Enhanced Land Imaging Program (SELIP)

- Build on the strengths of USGS and NASA
- Ensure continuous acquisition of data
- Establish other partnerships and data sources
- Include research and development

- The committee's primary recommendation is that the U.S. government should establish a Sustained and Enhanced Land Imaging Program with persistent funding to respond to current and future national needs. Such a program would:
  - Develop a plan for a comprehensive, integrated program that capitalizes on the strengths of USGS and NASA, maintains current capability and the existing archive, and enhances the program as technology enables new imaging capabilities and data products;
  - Ensure acquisition of land imaging data continuously from orbital platforms, and periodically from airborne platforms, to respond to the needs of producers and consumers of derived data products along with users who analyze imagery;
  - Establish partnerships with commercial firms and international land imaging programs to leverage enhanced capabilities;
  - Coordinate land imaging data buys across the U.S. government; and
  - Include a research and development component to improve data products based on core measurements and develop new measurement methods and consider evolving requirements.

Requirements and budget go together

- Balance science requirements with mission complexity and cost
- Final decisions with agency that has the budget

For the Sustained and Enhanced Land Imaging Program to be successful, the division of program responsibilities between USGS and NASA should be designated such that the agency responsible for balancing science requirements with mission complexity and cost is also provided with the necessary budget. Both agencies should participate in an iterative process to design missions that meet the needs of research and operational communities, but final decisions should be made by the agency that has been given the budget.

Continuity, but make land imaging a *program*

- Continuity is essential
- Keep track of and take advantage of innovations
- Monitor user needs
- Consider alternative implementations (more later)

The top priorities for the Sustained and Enhanced Land Imaging Program should be to assure that the core program provides for continuity of Landsat products and coverage on a secure and sustainable path.

The SELIP should take advantage of technological innovation in sensors, spacecraft, and data management and analysis to improve system performance, allow for new analyses that better exploit the data and meet future needs. Because future measurements will derive from both current and new technologies, new implementations of existing data products derived from a multispectral sensor should be able to be cross-calibrated with Landsat legacy products and be essentially interchangeable for scientific and operational purposes.

To better meet these primary goals, the committee recommends that the program should:

- Systematically monitor users and uses of Landsat data so that the program can evolve with changing user requirements.
- Consider alternative implementations that continue to enable the collection of global, moderate resolution data with the full range of spectral capabilities.

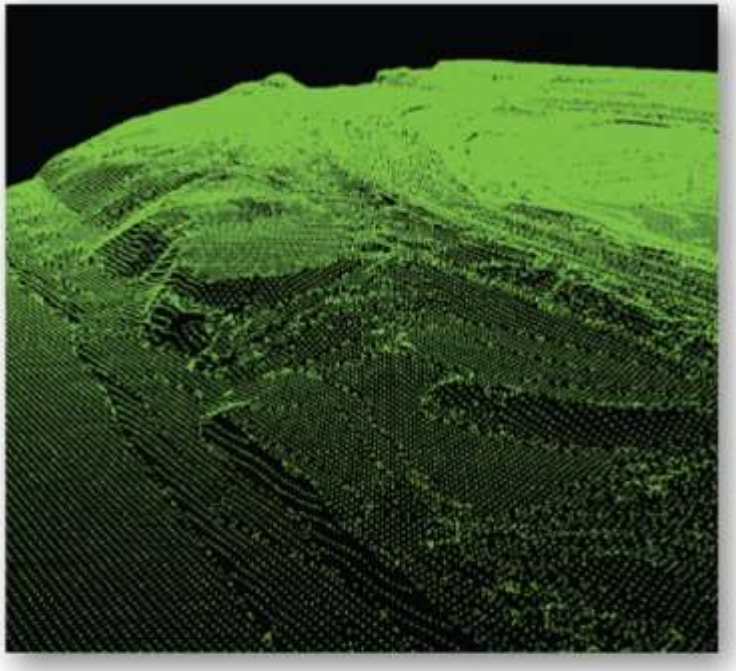
Enhancing a sustained land imaging program

- Landsat is necessary but not sufficient
- Integrate data from other sensors and sources
  - Fine resolution multispectral
  - LiDAR, SAR & InSAR, Hyperspectral

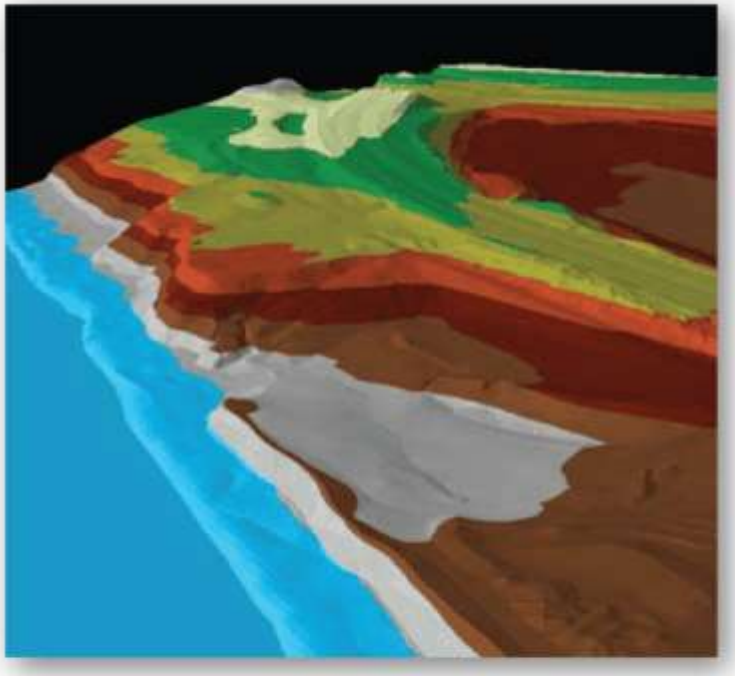
The committee recommends that the Sustained and Enhanced Land Imaging Program integrate measurements from commercial partners, spaceborne sensors recommended by the 2007 National Research Council report Earth Science and Applications from Space, and a variety of airborne sensors and acquisitions to provide the capability for analyses not possible with only moderate-resolution multispectral data. These measurements should include, but not be restricted to, the following:

- Airborne and spaceborne fine-resolution remote sensing data from public and commercial sources that can be used for detailed land use and land cover, urban infrastructure, transportation, hydrology, and disaster response;
- LiDAR data that can be used to extract precise digital surface and terrain models, building and vegetation height information, and vegetation canopy and internal structure information;
- Synthetic aperture radar (SAR) and interferometric SAR (InSAR) images at resolutions suitable for studies of deformation, elevations, and surface cover; and
- Hyperspectral data collection and information extraction capabilities for hydrology, ecosystem health and biodiversity, and soil science and mineralogy.

LiDAR Information Extraction



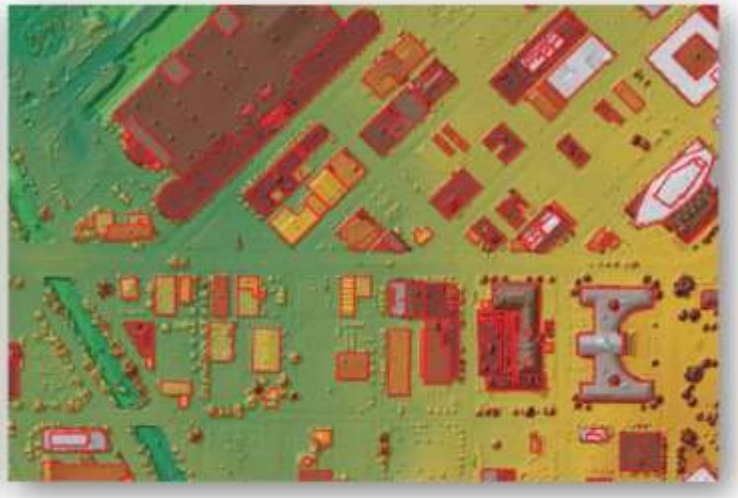
a. LiDAR-derived masspoints of an area near Monterey Bay, CA.



b. LiDAR-derived bare-Earth digital terrain model (DTM).

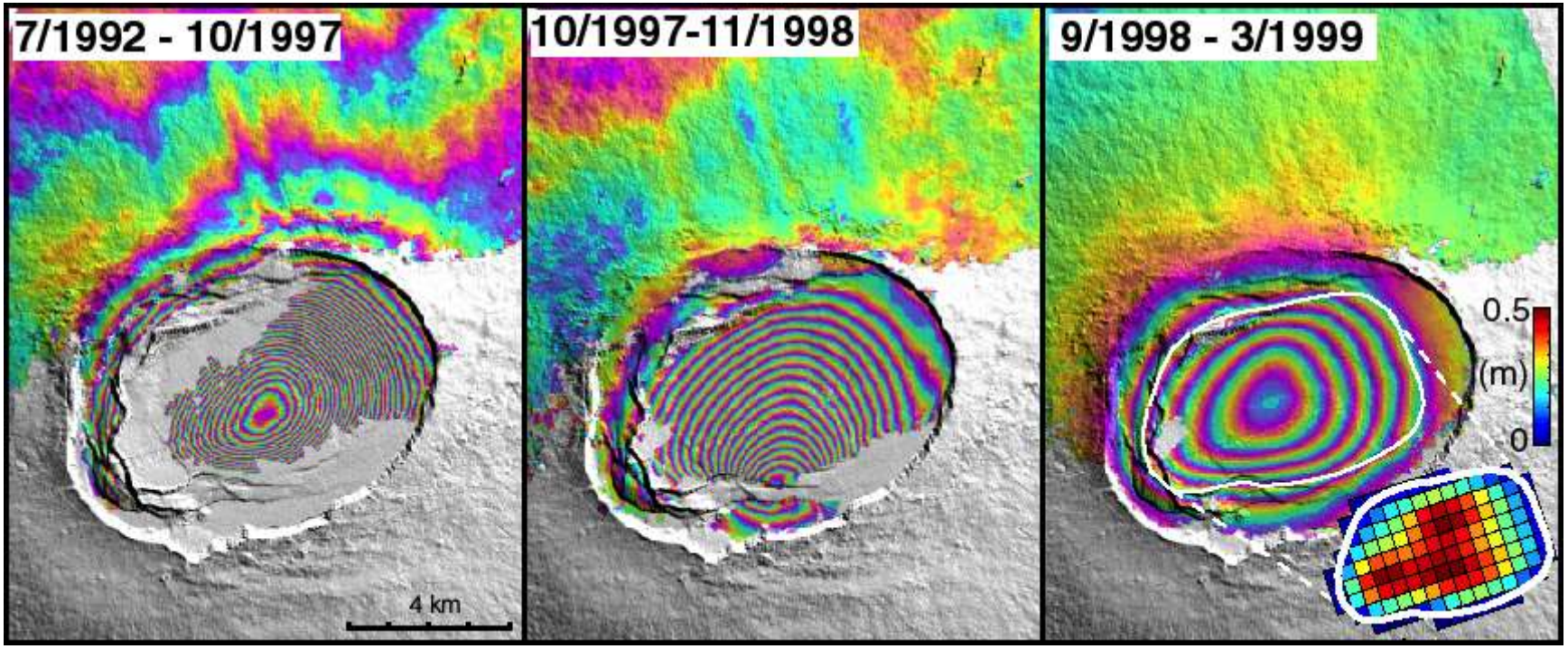
c. LiDAR-derived digital surface model (DSM) of Denver CO.

d. LiDAR-derived digital DTM.



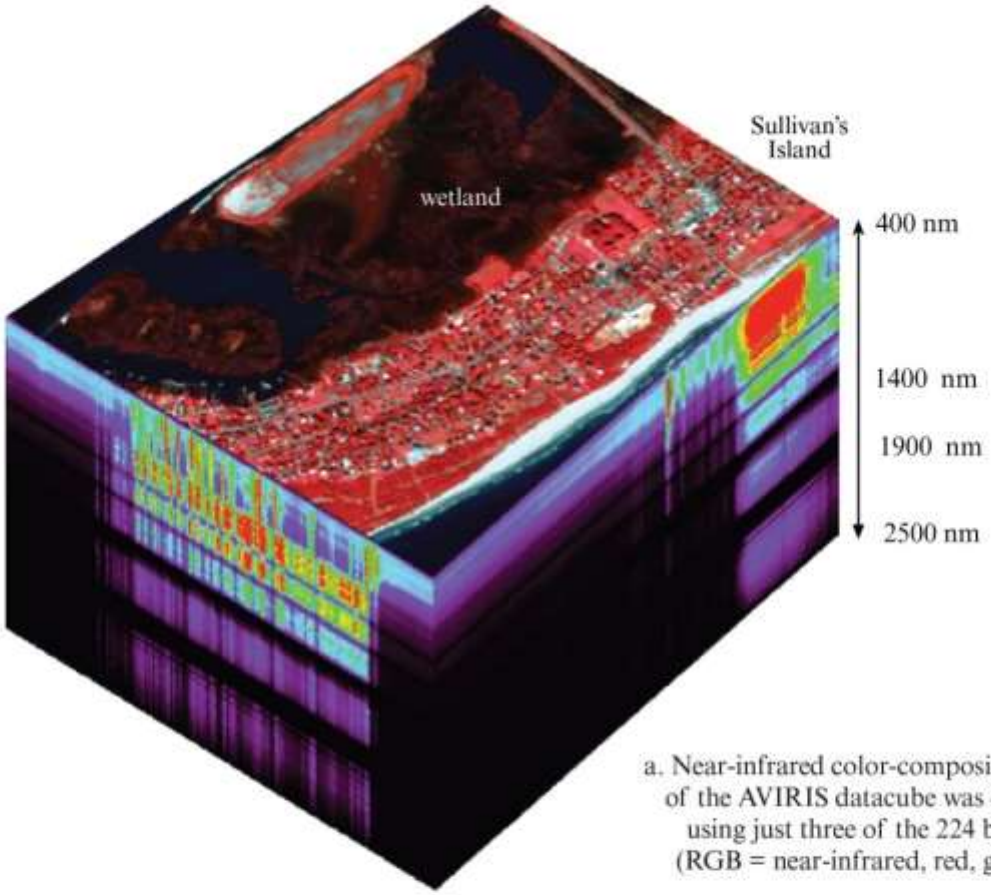
e. LiDAR-derived building footprints.

Interferometric synthetic aperture radar (InSAR)

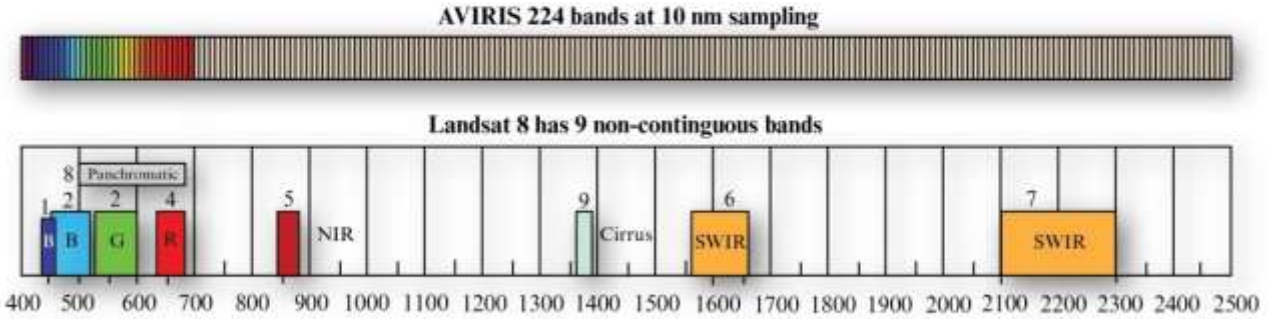


Elevation changes in the caldera of Fernandina Volcano, Galapagos Islands, caused by emplacement of a dike and faulting events. Inset on right shows inference of magma displacement.

Hyperspectral image cube

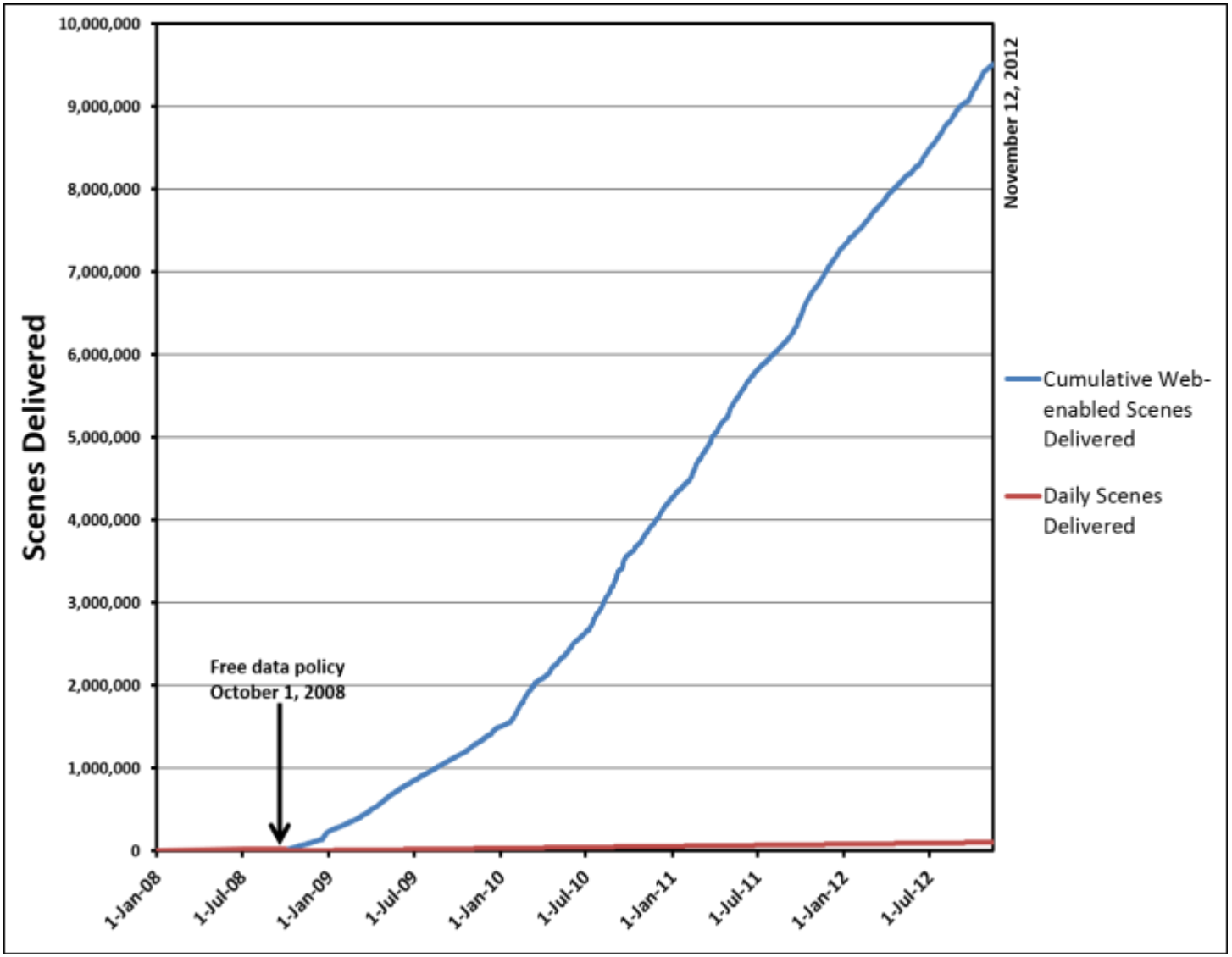


a. Near-infrared color-composite on top of the AVIRIS datacube was created using just three of the 224 bands (RGB = near-infrared, red, green).

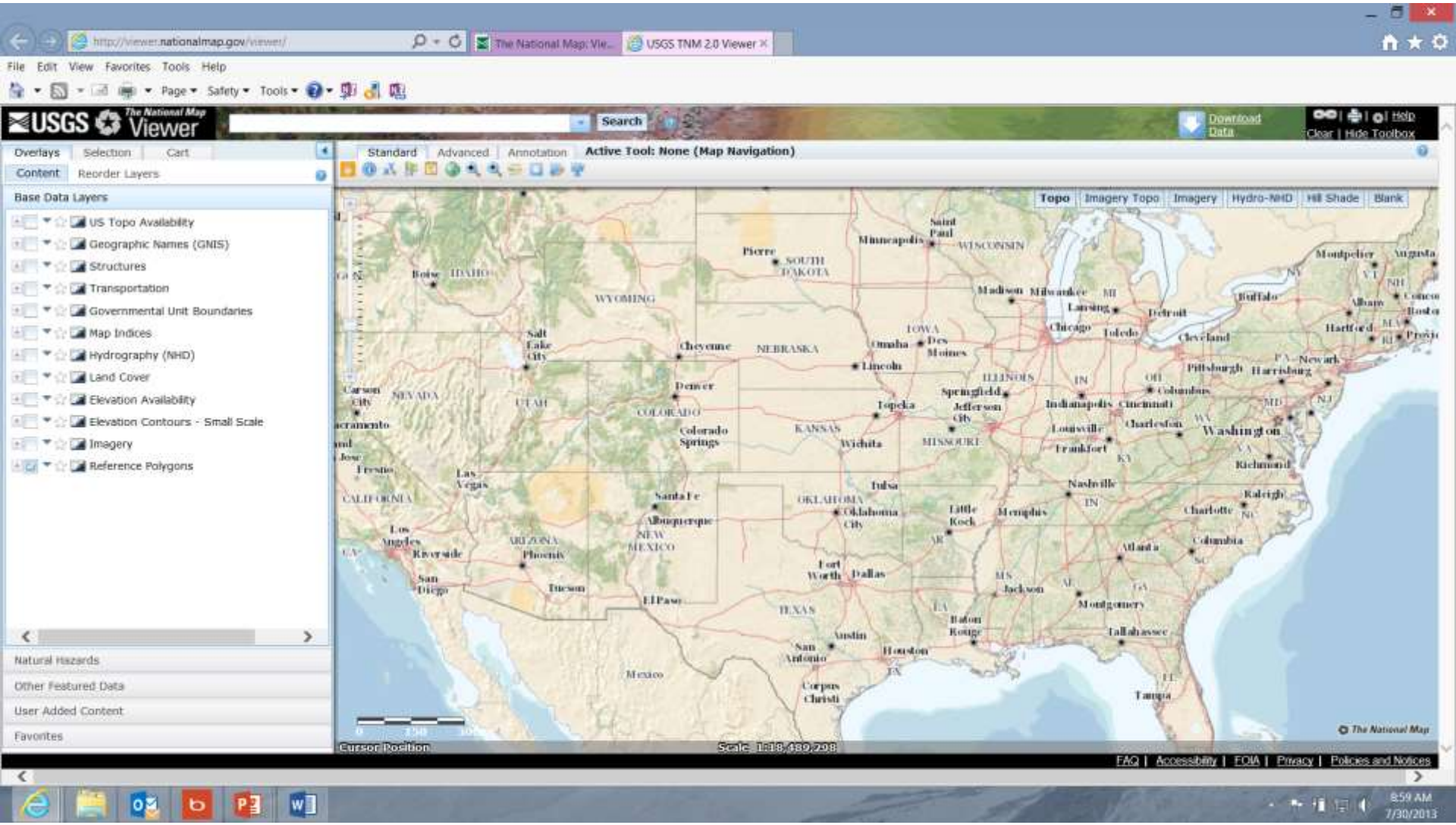


b. Comparison of 224 AVIRIS spectral bands at 10 nm sampling with the sensitivity of the nine Landsat 8 non-contiguous bands in the region from 400 to 2,500 nm.

Huge benefits of an open data policy to operations and science



Effective data distribution



Data systems: what else could be done

- Improve site navigation
  - GloVis? EarthExplorer? NationalMap? LandsatLook? WELD? . . .
- Availability of derived products as well as imagery
  - NLCD, LANDFIRE, surface reflectance . . .
  - Develop a systematic process for identifying new ones

USGS, as part of the Sustained and Enhanced Land Imaging Program, should continue to deliver derived products from imagery without explicit cost to the end users.

- Improve search capabilities and transparency to users, and
- Continue to interface with the private sector to improve access to public- and private-domain land imaging data products and services.

The Sustained and Enhanced Land Imaging Program should develop a systematic process for identifying and prioritizing a wider suite of products, including essential climate variables, . . .:

- Define criteria that government-provided authoritative data sets should meet, including such attributes as calibration, accuracy assessment, and validation, including ground truth;
- Define criteria for which products should be provided by the government and which should be provided by the private sector;
- Implement procedures for development, cost estimation, peer-review, and publication of algorithms that produce derived products; and
- Implement plans, procedures, and budgets for ongoing validation.

Costs for Landsats 1-8, in 2012 dollars

	Launch	Design Life (years)	Lifetime (years)	Original cost ($ million)	2012 cost ($ million)
Landsat 1	1972	1	5.5	$ 197 together	$ 841
Landsat 2	1975	1	6.0		
Landsat 3	1978	1	5.1	$ 50	$ 157
Landsat 4	1982	3	11.4	$ 538	$ 1,280
Landsat 5	1984	3	27.7	$ 573	$ 1,266
Landsat 6	1993	5	0.0	$ 518	$ 823
Landsat 7	1999	5	13.8	$ 800	$ 1,102
Landsat 8	2013	5		$ 931	$ 931

SOURCE: Originally compiled by Tony Morse, Spatial Analysis Group, LLC. 2012 costs calculated from http://www.bls.gov/data/inflation_calculator.htm, using year-by-year consumer price indices

“Opportunities”: what to do about cost?

- The Sustained and Enhanced Land Imaging Program will not be viable under the current mission development and management practices.
- Building an exact copy of Landsat 8 might seem to be the simplest approach for Landsat 9, but that approach is not likely to substantially lower the cost for the next mission.
- Nonetheless, options do exist to create a less costly, more robust Sustained and Enhanced Land Imaging Program.
  - Acquire satellites differently
  - Integrate with other data sources
  - Increase the swath width
  - Small satellite constellations

Example of one future alternative, preserves continuity and reduces life-cycle costs

- Start with Landsat 8 near clone
- As a block buy, fixed price
  - Landsat 9
  - Landsat 10
  - Landsat 11
  - Landsat 12
  - (all the same)
- Use a collaborative team approach
- Makes land imaging a *program*
- Similar to model for meteorological satellites
- Reduces cost for the program . . .
  - but not significantly for Landsat 9

But if the cost of Landsat 9 is the driver . . .

- A different approach, possibly riskier
  - Acquire constellations of small satellites on a fixed price basis as augmentation or replacement
  - Increase the swath width
  - Make use of small satellites for specific purposes
- Incorporate new technologies incrementally
- Share rides
- Use of commercial and international data when available may be necessary in any approach

The Sustained and Enhanced Land Imaging Program should create an ambitious plan to incorporate opportunities to improve land imaging capabilities while at the same time increasing operational efficiency and reducing overall program cost.

The program should consider a combination of the following to increase capabilities while reducing the costs for land imaging beyond Landsat 8:

- Shift the acquisition paradigm via block buys and fixed price contracting and by collaborating with commercial and international partners.
- Streamline the process by which satellites and sensors are designed, built, and launched using a single organizational unit approach (a collaborative team approach) consisting of both government employees and contractors working together as a fully integrated team.
- Identify foreign sources of land imaging data that complement the U.S. core land imaging requirements and seek formal data sharing agreements with their suppliers.
- Consider technological innovations such as increasing the swath width and employing constellations of small satellites.
- Incrementally incorporate new technologies that do not compromise core operational capabilities, such as by leveraging industry, international, and other technology development activities.
- Accommodate candidates for improved or new instruments on a small satellite for the purpose of demonstrating new technologies.
- Take advantage of opportunities to fly as a secondary payload or as a shared ride.

Backup slides

NRC Committee on the Implementation of a Sustained Land Imaging Program

- Jeff Dozier, University of California, Santa Barbara, *Chair*
- Carlos Del Castillo, Johns Hopkins University Applied Physics Lab (now at NASA Goddard Space Flight Center)
- Jack Fellows, EnviroGen International Foundation and G2Groups, Inc.
- Kathleen Green, Kass Green & Associates
- John Jensen, University of South Carolina
- Dennis Lettenmaier, University of Washington
- Berrien Moore III, University of Oklahoma
- Diane Pataki, University of Utah
- David Schimel, Jet Propulsion Laboratory
- Walter Scott, DigitalGlobe, Inc.
- William Townsend, Independent Aerospace Consultant
- Howard Zebker, Stanford University
- Mary Lou Zoback, Stanford University

Report Reviewers

- Mark Brender, GeoEye Foundation,
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- Joanne Gabrynowicz, University of Mississippi,
- George Hilley, Stanford University,
- Anthony C. Janetos, Boston University,
- Christopher O. Justice, University of Maryland,
- Thomas M. Lillesand, University of Wisconsin-Madison (professor emeritus),
- Emilio F. Moran, Michigan State University,
- John R. Schott, Rochester Institute of Technology, and
- A. Thomas Young, Lockheed Martin Corporation (retired).

Why was the NRC asked to carry out this activity?

- The Landsat series of research satellites has had a chaotic history, and responsibility has passed back and forth between several agencies and the private sector.
- The political history surrounding Landsat has also been chaotic.
- Even so, the data has been of great value to the nation for 40 years, and an operational need has emerged.
- A 2007 report from OSTP presented a vision for a space-based land imaging program, and the 2010 National Space Policy directed the USGS to take more responsibility for the future of land imaging data and research.
- On this basis, the USGS requested a study from the National Research Council.

Current Political Context

- **Congressional directives for the future of Landsat continue to change.**
- **The draft Senate FY 2014 Appropriations for Commerce, Justice , Science, and Related agencies issued these directives**
  - **Ensure data continuity.**
  - **No international partners or hosted payloads.**
  - **$650M mission cap.**

Land Imaging—The Committee commends NASA and its team for the recent successful launch of Landsat 8, and provides $30,000,000 for Land Imaging activities, which is the same as the budget request. However, the Committee is concerned about the administration's approach towards the follow-on Landsat 9 mission, for which funds requested in fiscal year 2014 are extremely low. The Committee is highly **skeptical of either a hosted payload or international partner** concept for Landsat 9. The Committee discourages NASA from spending an inordinate amount of time or funds on these alternate approaches, which already have been considered on multiple occasions over the past four decades and have only distracted and delayed the inherently governmental role in preserving the continuity of Landsat data. At the same time, **expectations that a Landsat 9 mission will cost a billion dollars** due to enhanced new instrumentation or other efforts at program resiliency **are equally unrealistic**. For this reason, the Committee expects a plan not later than 120 days after enactment of this act detailing how **Landsat 9 will ensure data continuity** in an era of increasingly scarce resources with an overall **mission cap of approximately $650,000,000**, a level substantially below that required for Landsat 8.

http://www.gpo.gov/fdsys/pkg/CRPT-113srpt78/pdf/CRPT-113srpt78.pdf

- The land imaging program of the future requires an overarching national strategy and long-term commitment.
- The continuity of Landsat imagery has never been ensured by a sustained government program.
- A satellite system with new requirements and technologies for each iteration is expensive
- **A sustained land imaging program will not be viable under the current mission development and management practices.**

•To best serve the needs of the United States, the land imaging program of the future requires an overarching national strategy and long-term commitment, including clearly defined program requirements, management responsibilities, and funding.
•The continuity of Landsat imagery has never been ensured through the development of a sustained government program. Instead, responsibility has been shifted from one organization to another over Landsat's 40-year history, resulting in persistent uncertainty for the future of this important asset.
•Building a satellite sequence with new requirements and technologies for each individual instrument is an expensive way to acquire land imaging data and inhibits the addition of new capabilities.

Findings of User Requirements

- Spatial resolution
  - 30 m except in the thermal band, which would have coarser spatial resolution.
  - Finer resolution (10-15 m), perhaps in a panchromatic band, was desired by some.
- Spectral requirements
  - Visible and near-infrared region (VNIR, 0.4-1.1 m).
  - Shortwave infrared region (SWIR, 1.2-2.8 m).
  - Thermal infrared region (TIR, 8-12 m, with some interest in 3.5-4.0 m).
  - Calibration sufficient to allow backwards-compatible comparisons of future image products to previous collections.
  - A larger dynamic range in the VNIR region to prevent saturation over snow and clouds; this requirement has been met in the Landsat 8 OLI, with its 12-bit quantization instead of 8.
- Coverage and repeat cycle
  - Ability to acquire and make available imagery anywhere on Earth, except perhaps for areas very near the poles, at approximately weekly frequency. The 705-km Landsat orbit, at 98° inclination, provides 16-day repeat. The temporal frequency is not necessarily to acquire weekly data but for cloud-free images.
  - Increased temporal frequency could be achieved with a slightly larger swath and consequently slightly larger off-nadir view angles at the edge (there was no objection to this among the users queried) .
- Data management and distribution
  - A free data policy, as is currently in place, provides huge benefits to the nation as well as the international user community by supplying imagery to operational programs critical to U.S. needs as well as spurring innovation in the private sector.
  - The USGS data distribution system is successful and effective but has opportunities to continue to improve with technological advances and to streamline methods for managing Landsat imagery and derived products.