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USGS Update on Landsat and Sustainable Land Imaging

National Academies of Sciences, Engineering and Medicine

Committee on Earth Sciences and Applications from Space

October 28, 2021

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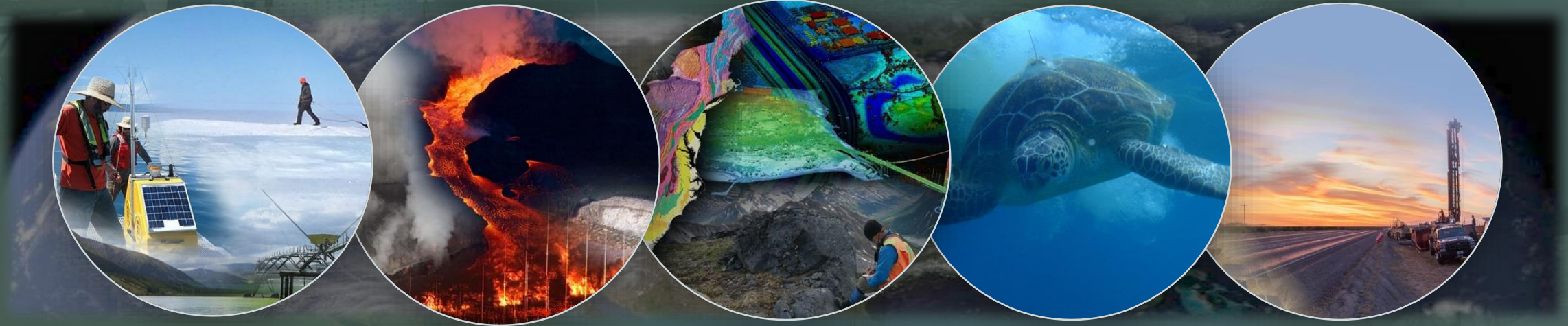
Program Coordinator
National Land Imaging Program
U.S. Geological Survey

USGS Mission Areas

Water Resources | Natural Hazards | Core Science Systems | Ecosystems | Energy and Minerals



Vision

- Lead the Nation in 21st-century integrated research, assessments, and prediction of natural resources and processes to meet society's needs.

Mission

- Monitor, analyze and predict current and evolving dynamics of complex human and natural Earth system interactions
- Deliver actionable intelligence at scales and timeframes relevant to decision makers.

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What is Landsat?

The world's longest continuously operated land remote sensing satellite series, and most widely used and cited land remote sensing data set, helping us understand and manage natural and human-induced landscape change via a multitude of land, water, and natural resource management applications.

Common Uses of Landsat data by Federal Agencies, States, and the private sector:

- Agriculture and Forestry
- Regional Land Use Planning
- Land Use/Land Cover
- Fire/Disaster Management
- Energy and Mineral Mapping
- Water Quality and Resources
- Global Change Science
- Flood Management
- National Security
- Ecosystem Monitoring
- Famine Early Warning
- Carbon Assessment
- Drought Monitoring
- Transportation Planning
- Calibration/Validation

Multi-spectral coverage in VNIR-SWIR-TIR
-> to map surface composition & temperature

15 / 30 / 100 meter spatial resolution
-> to resolve human-scale land dynamics

16-day revisit frequency (8-days w/ two satellites)
-> global, seasonal coverage

Broad area collection => 12,000+ square miles per image
-> 1200 images/day = 15 million square miles/day

Highly calibrated "science quality" data
-> to resolve long-term trends & retrieve biophysical variables

Free and Open Data policy since 2008
-> 30 million products distributed by USGS last year

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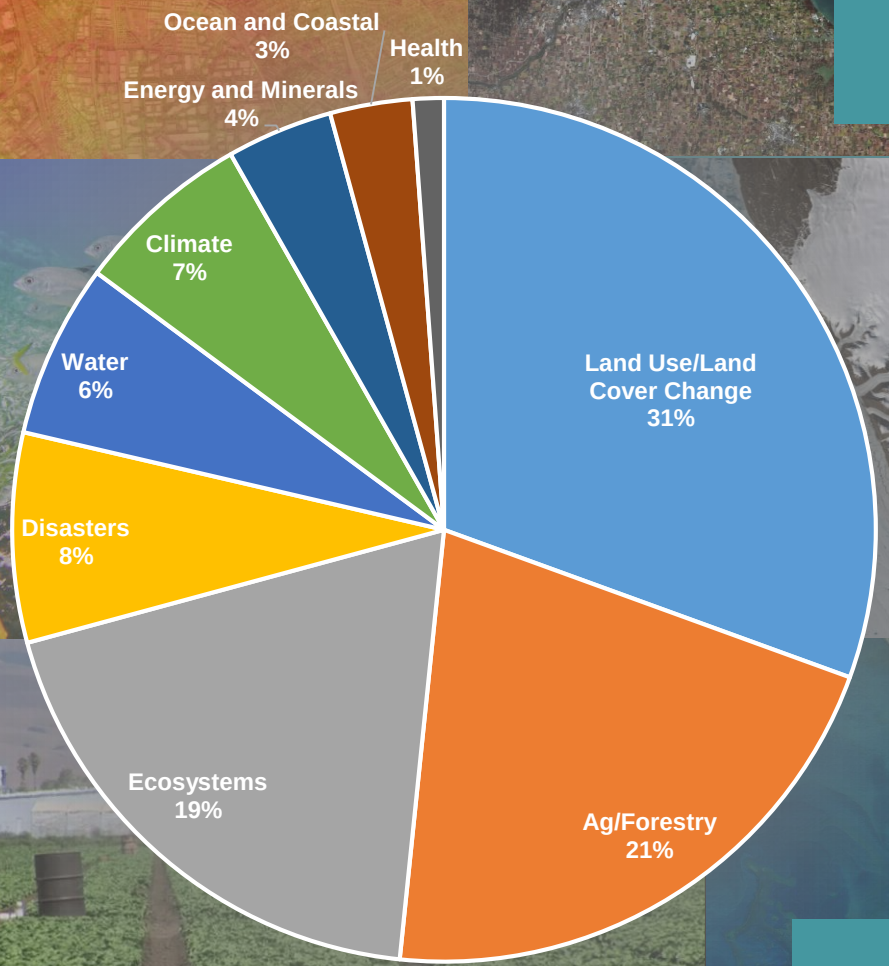
VNIR: Visible Near-Infrared SWIR: Shortwave Infrared TIR: Thermal Infrared

Landsat Applications



Landsat is the single most-used land imaging data set by U.S. Federal users and the 2nd highest satellite system in societal benefit impact (behind GPS)

- Federal Agencies (e.g. DOI, USDA, EPA, NASA, DOD, NOAA, State, USAID)
- State Agencies (planning, natural resources, Transportation)
- University Researchers and Educators
- International Organizations (e.g., UN agencies, GEO)
- Non Governmental Organizations (e.g., The Nature Conservancy, World Resources Institute, World Wildlife Fund, Resources for the Future)
- Commercial (e.g., Exxon-Mobil, MapBox, Descartes Labs, Esri, Gallo, L3Harris, ITT, MDA Federal, Planet)
- Foreign space agencies
- U.S. and foreign commercial satellite operators
- Cloud Service Providers (e.g. Amazon Web Services, Google Earth Engine)
- General Public

Supports Federal, state, local, tribal, academic, commercial, non-profit, and international use

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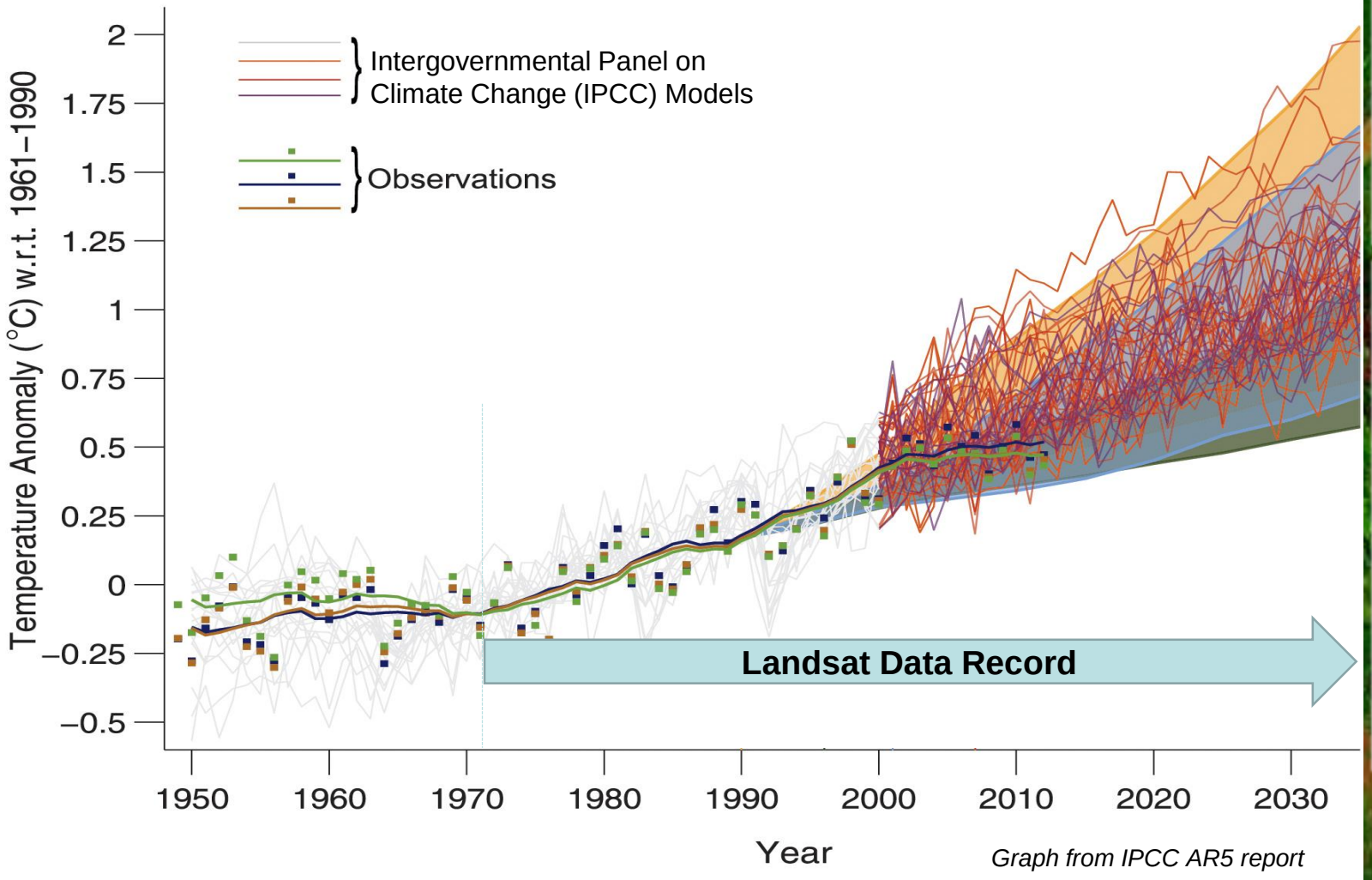
Landsat & Climate Change



Graph from IPCC AR5 report

"As the longest-running continuous satellite image dataset for land processes, Landsat data provide unparalleled witness to the enormous changes occurring on Earth since 1972."
(Kennedy, et al., Environmental Research Letters, 2014)

"The US Global Change Research Program identified Landsat as a critical observatory for climate and environmental change research due to the unbroken length of the Landsat record and its ability to monitor remote regions with surface features such as glaciers, rainforests, permafrost, and coral reefs."
(CRS Report on Landsat 9 and the Future of the Sustainable Land Imaging Program)

Landsat Data Record coincides with dramatic global temperature changes; sustaining it will ensure continued tracking of future global changes

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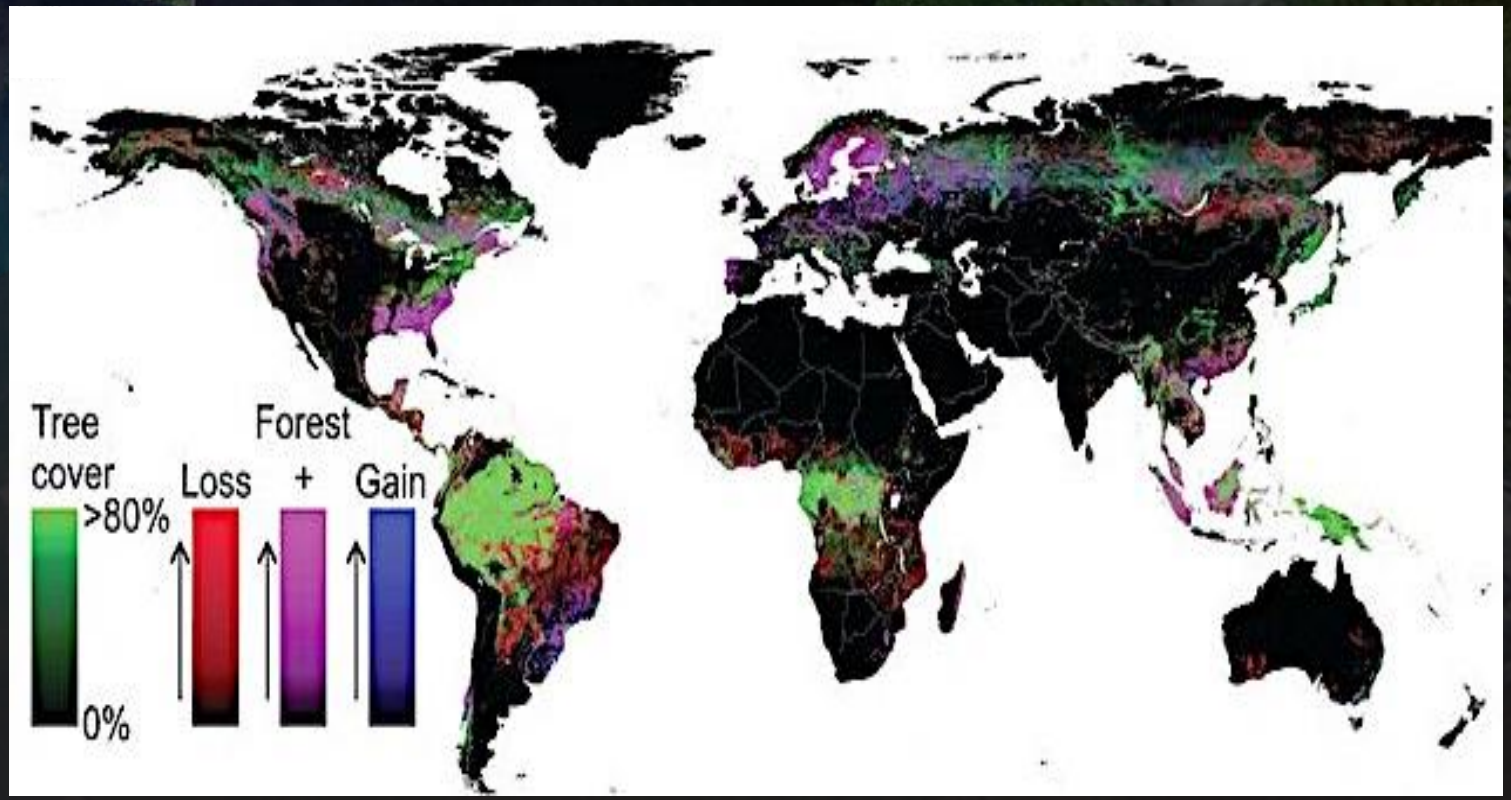
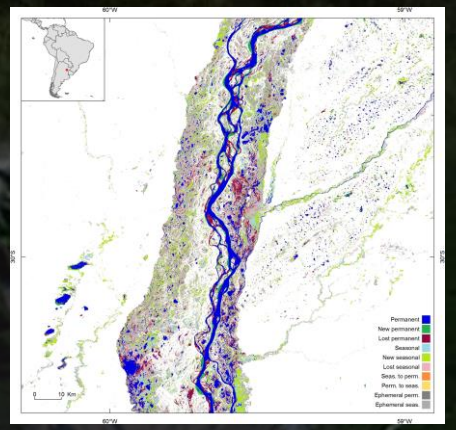
Landsat: the ‘Backbone’ of Earth Observation

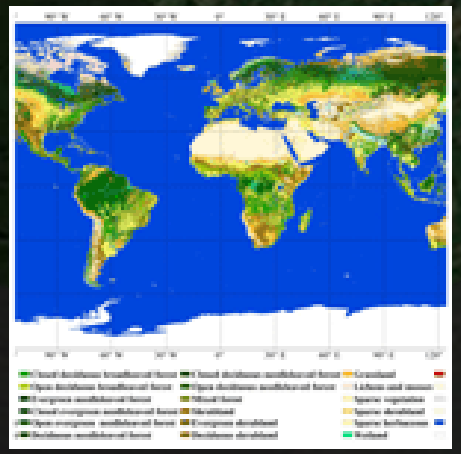
- Nearly five-decade record of land cover, land use, and vegetation condition
- **Large area** coverage for global, continental and regional land cover studies
- Landsat remains the most cited land remote sensing system in the peer-reviewed scientific literature—and the citation rate is increasing



Global Forest Change, Hansen et al., Science 2013



Global Surface Water Change, Pekel, et al., Nature 2016



Mapping Global Cropland, Phalke, et al, ISPRS 2020

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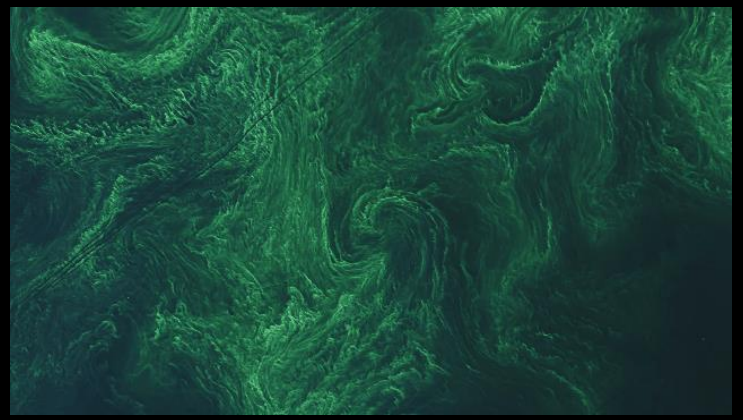
Landsat is Essential to Understanding Landscape Change

Celebrating 50 YEARS of Landsat 1972-2022

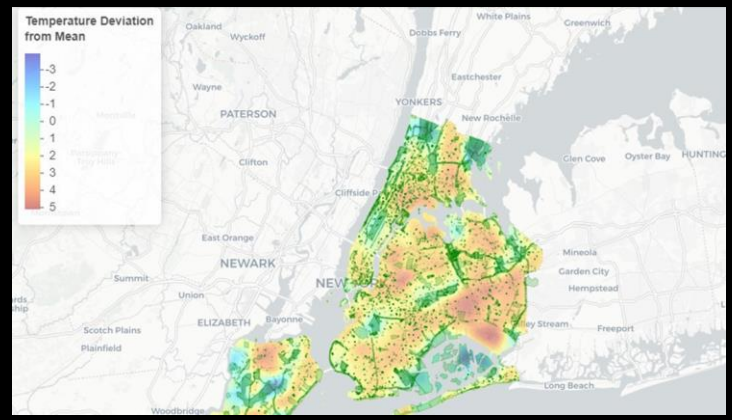
Applications of Landsat Data include:

- Impacts of Climate Change
- Quantifying Global Forest Change
- Managing Water Consumption, Management & Human Health
- Supporting Disaster Mitigation & Recovery Efforts

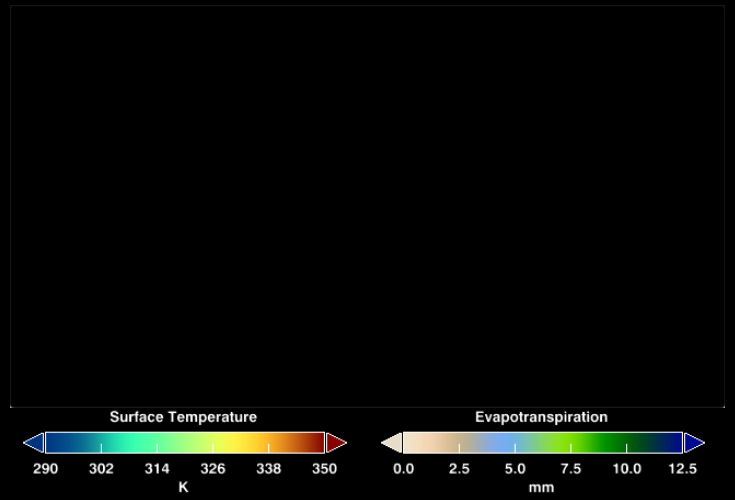
Harmful Algal Bloom - Lake Erie



Urban Heat Map - New York City

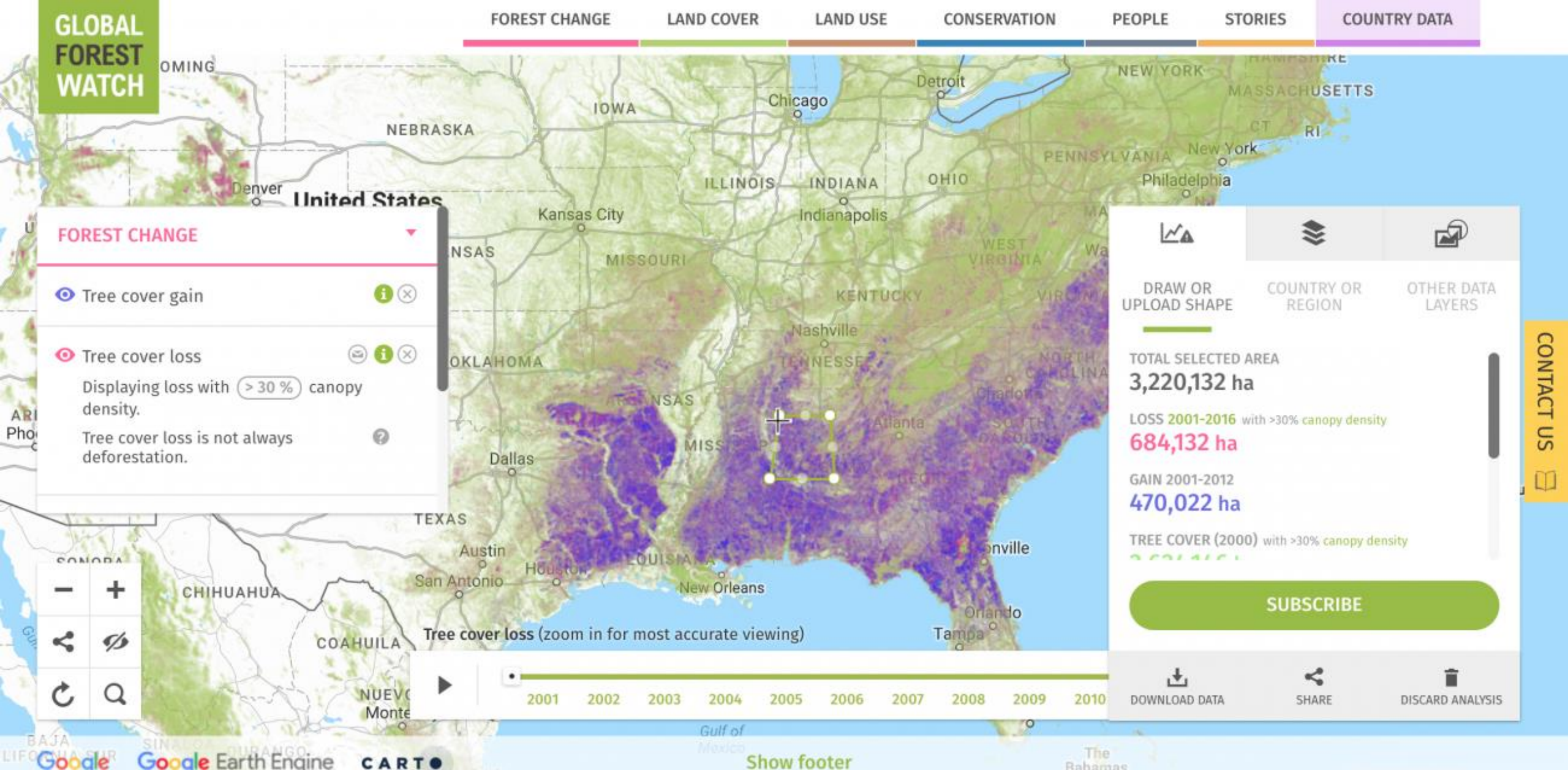


Irrigated Farm Lands - New Mexico



Tropical Forest Loss - South America

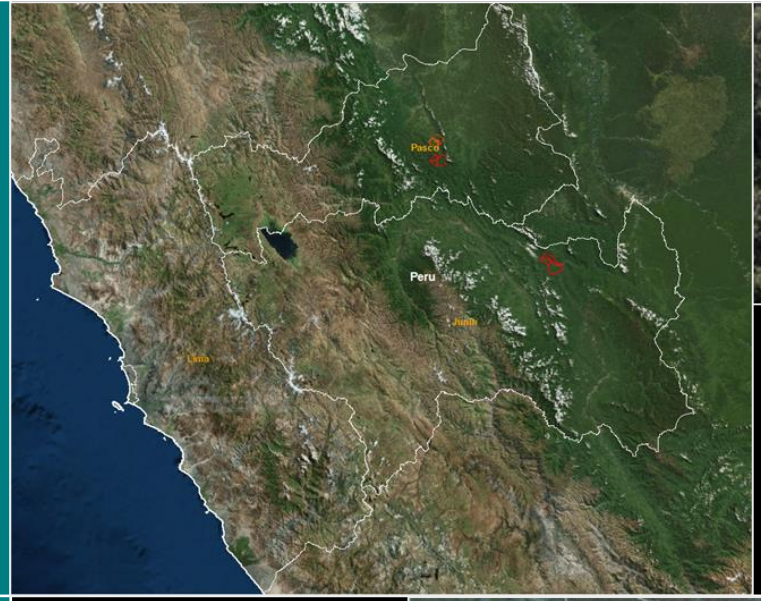
Disaster Recovery



- Global Forest Watch, aims to provide a "**near-real time**" view of deforestation (and reforestation) around the world
- Near-real time update of state of the world's forests using millions of Landsat images through Google's cloud computing and online access

Building National Forest Monitoring Systems

- Accounting of Carbon Emissions from *Deforestation* and *Forest Degradation*
- Setting *historical baselines* that inform policy
- Accessing Carbon Markets for *implementing sustainable forestry activities*



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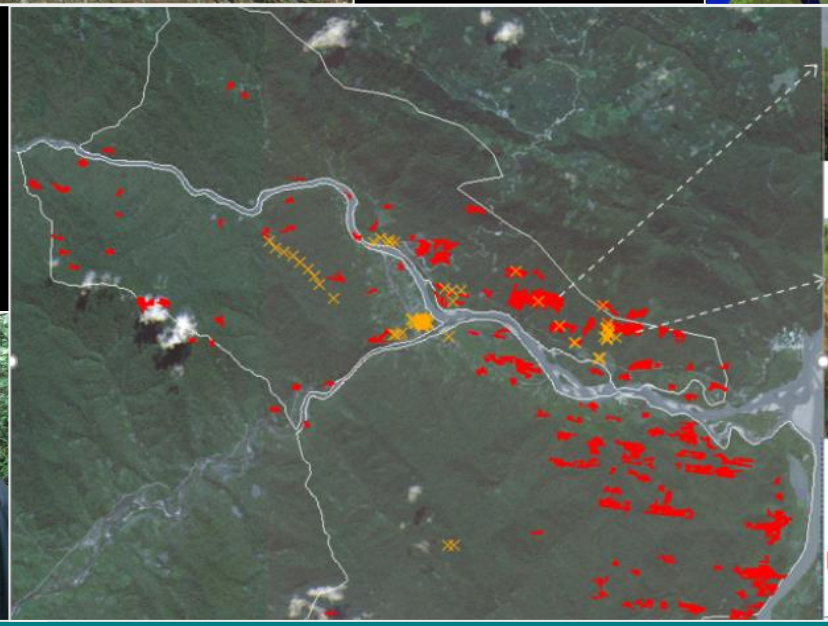
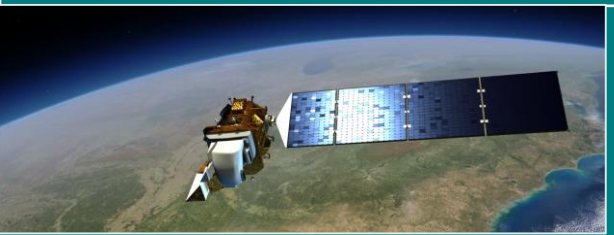
Early Warning Systems of Deforestation and Forest Disturbance

- Near real-time monitoring is necessary for better forest management
- Increase awareness and support law enforcement
- Empower local communities in monitoring and managing forest change

SilvaCarbon



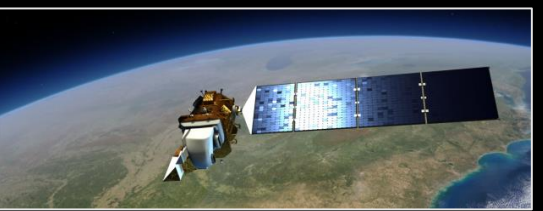


Supporting Global Forest Monitoring

- Landsat is the base satellite data for Global Monitoring Systems
- Global datasets support climate change mitigation actions

Understanding Amazon Deforestation Patterns

Landsat Gallery
https://landsat.visibleearth.nasa.gov/



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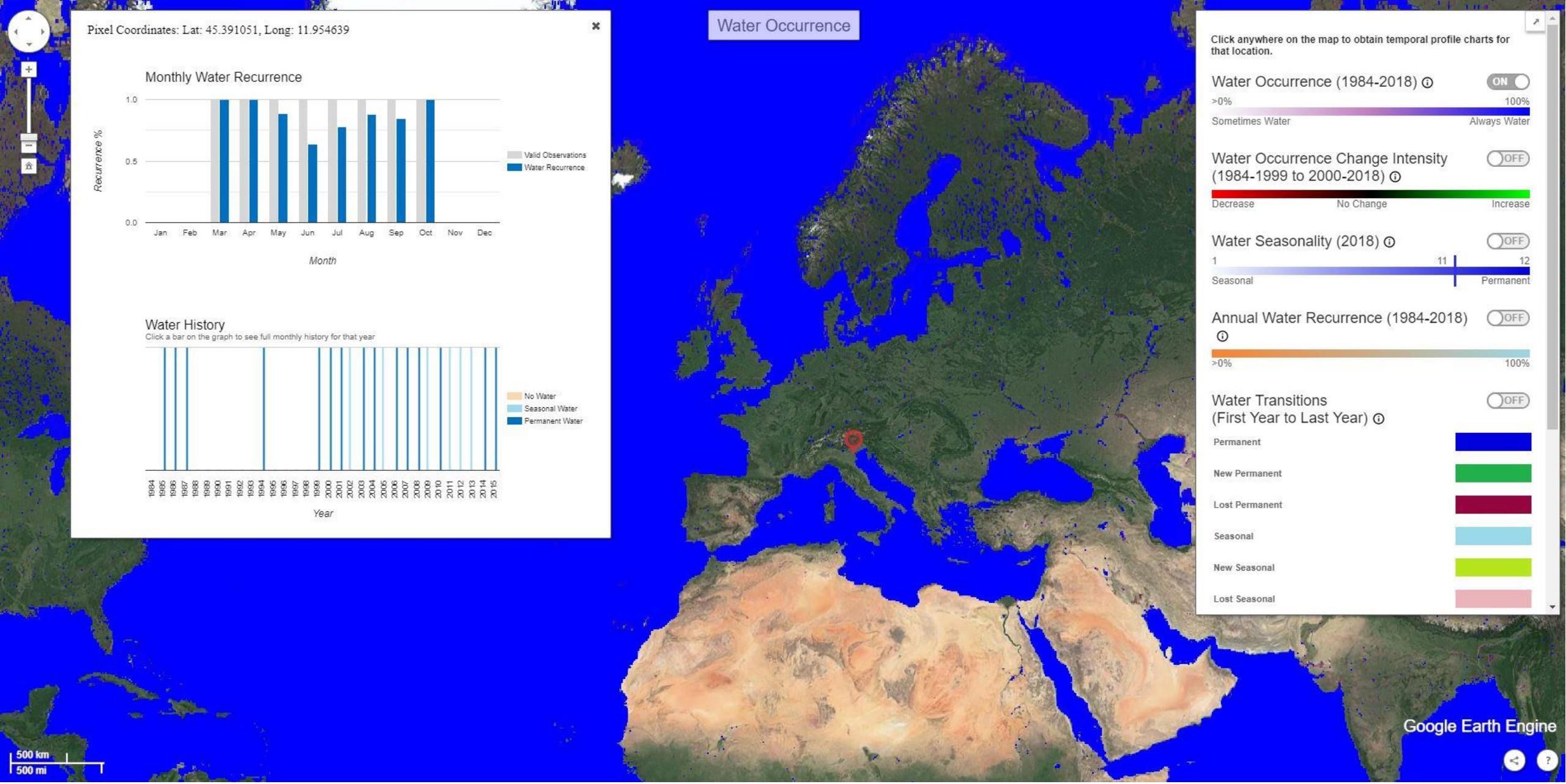
State of Para, Brazil
acquired June 4, 2000 - June 19, 2019
Landsat.visibleearth.nasa.gov


Google Earth Timelapse
Amazon Rainforest, Brazil
1984

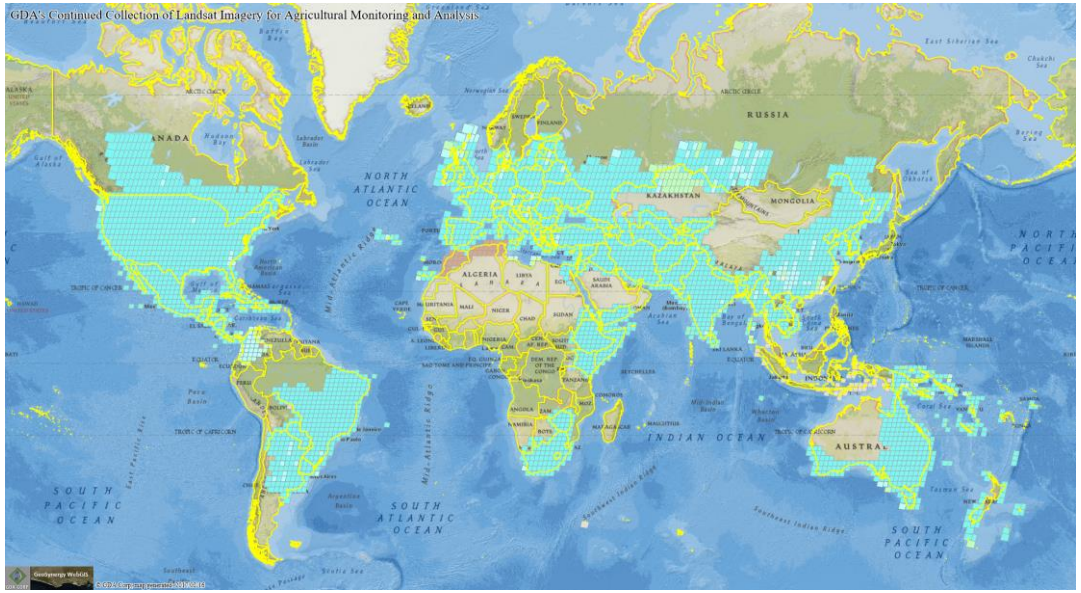


- Global Surface Water Explorer is a “virtual time machine” for global dynamic surface waters
- Map and compute statistics on the location, distribution, extent and changes of the word’s surface water using four million Landsat images

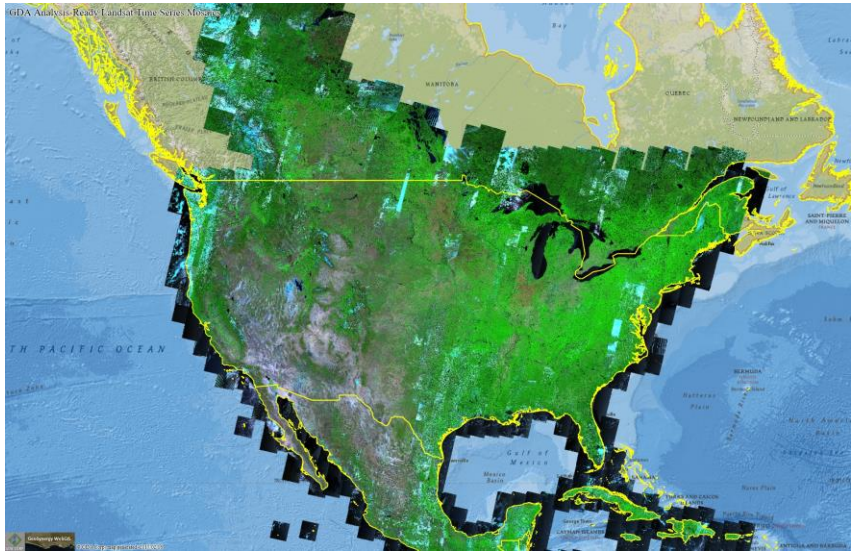

Google Earth Timelapse
Aral Sea, Kazakhstan - Uzbekistan
1984

Monitor and Forecast Global Crops

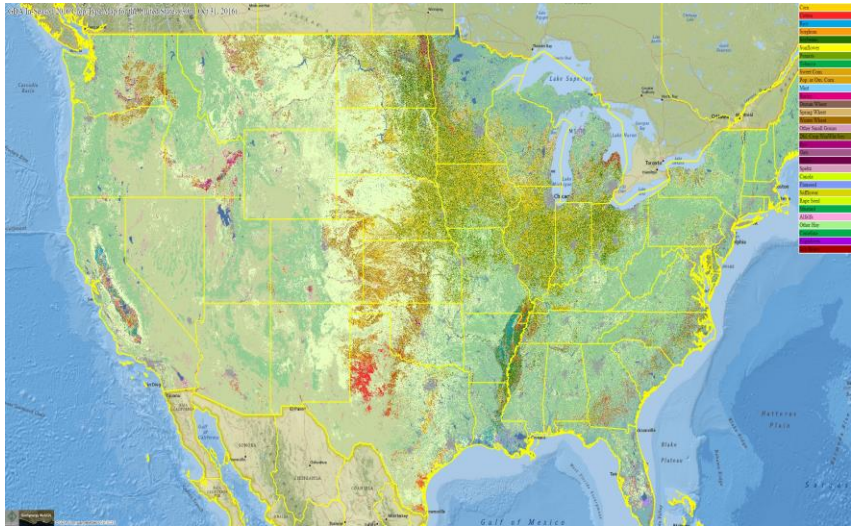
- Global crop mapping, monitoring, assessments, and forecasting.
- Use analysis-ready calibrated Landsat data for global crop analysis, supporting field-to-country assessments, and reducing more than 80 percent of the imagery data volume.



Landsat imagery coverage for global crop areas

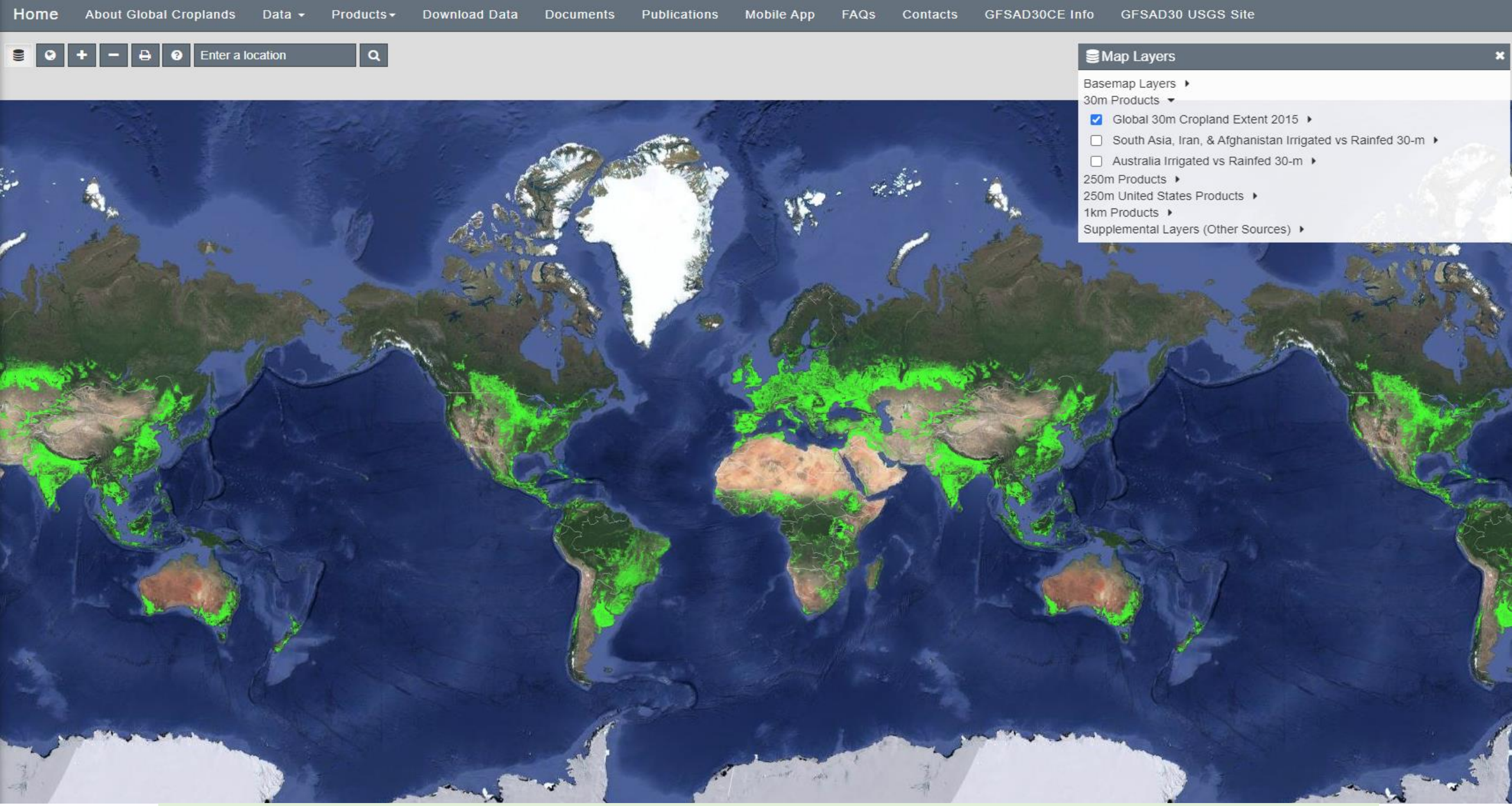


Analysis-ready Landsat data for the US

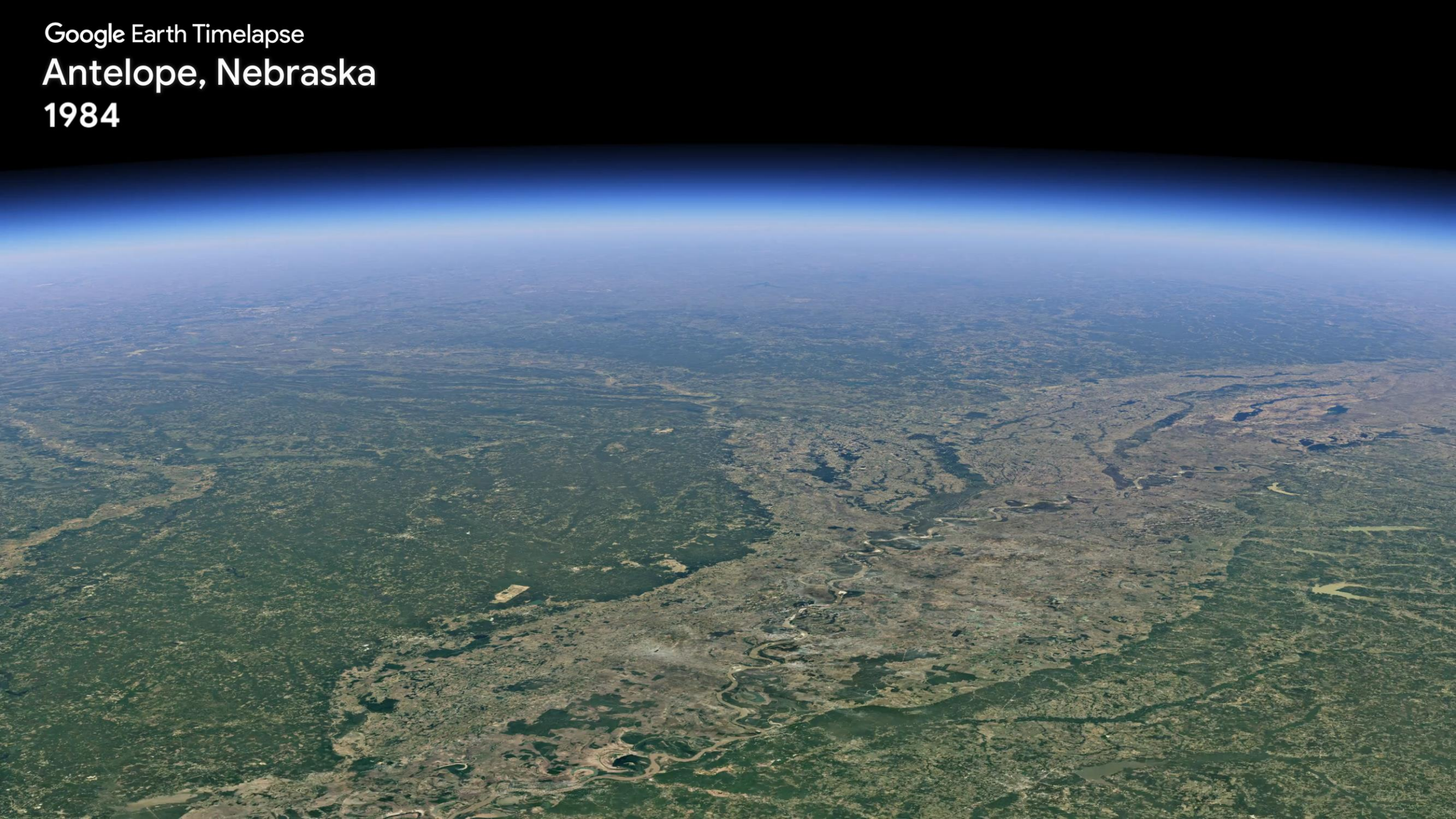


Crop map of the US

https://landsat.usgs.gov/landsat-in-action

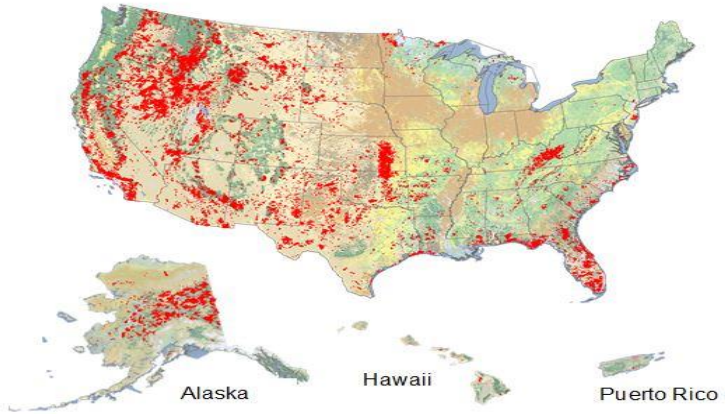


Use Landsat to map global cropland at 30m to support global food security and sustainability


Google Earth Timelapse
Antelope, Nebraska
1984

Landsat and Vegetation and Fire-Fuels Mapping

The Monitoring Trends in Burn Severity program uses Landsat to map burn severity, extent, and trends



The Burned Area Emergency Response program equips ground teams with Landsat-based burn severity maps immediately following fires to aid in remediation efforts

LANDFIRE team gathering field data in a remap prototype area of central Idaho

LANDFIRE uses Landsat to provide a common "all-lands" set of vegetation and wildland fire/fuels information, for strategic fire and resource management planning and analysis via 20+ national geospatial layers, databases, and eco-models

Landsat Operations Status

Landsat 8 (2013 -)

Collecting up to 740 new scenes per day; night and off-nadir imaging of volcano and fire imaging.

Landsat 7 (1999 -)

Collecting about 470 new scenes per day; latest fuel estimate projects operations through 2021.

Earth Resources Observation and Science Center (EROS)

Landsat Archive Operations

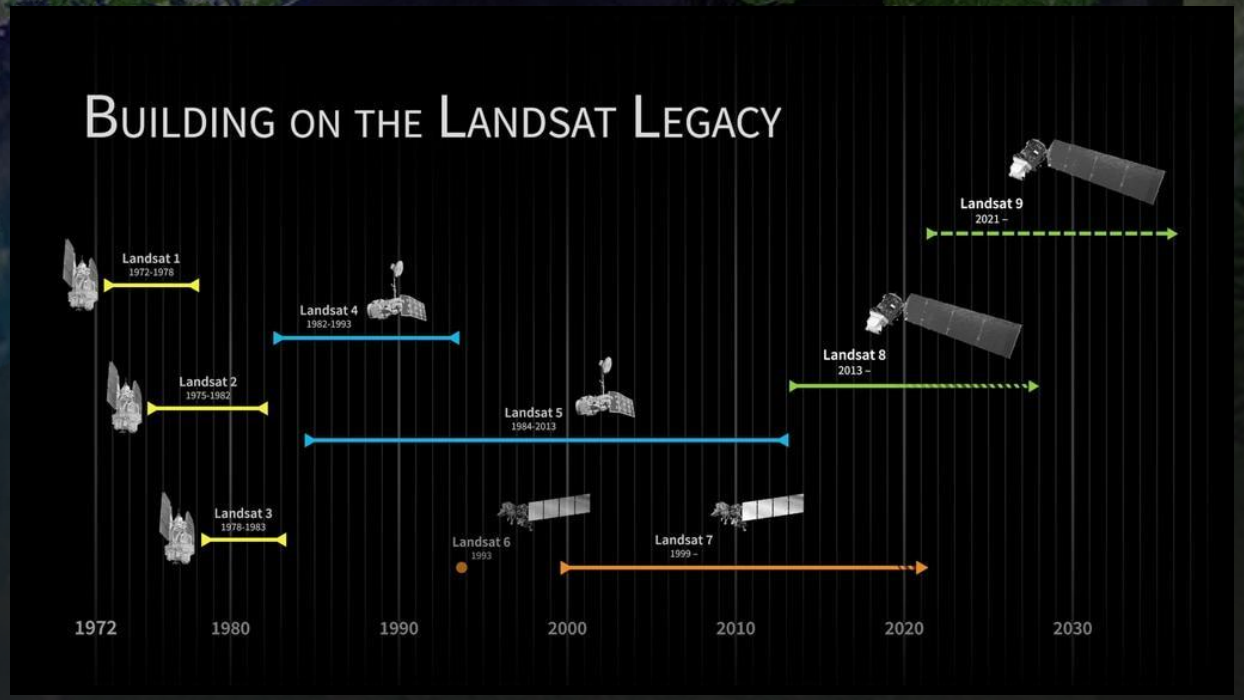
Nearly 10 million unique Landsat scenes available in the near 50-year archive, with well over 100 million downloads since Landsat data become freely available in 2008.

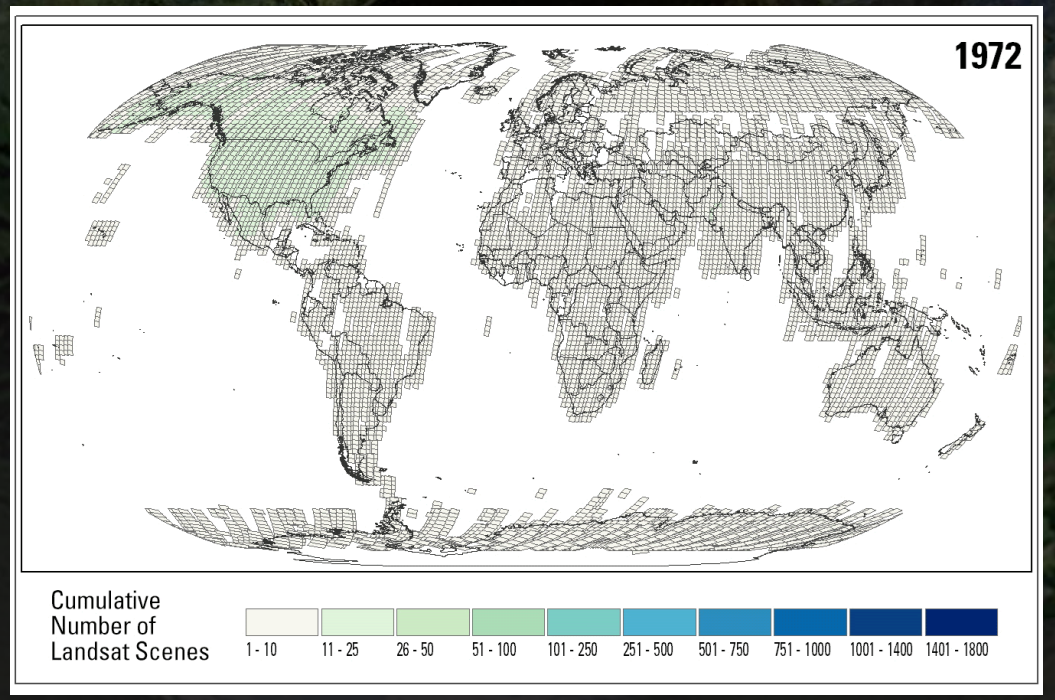
New “Collection 2” now available on the Amazon Cloud.

Sustainable Land Imaging (SLI)

A partnership between DOI/USGS and NASA to ensure sustained access to high-quality, global, land-imaging measurements compatible with the existing 49-year Landsat record for research and operational users

- NASA responsible for developing the space segment, launch and on-orbit check-out
- DOI/USGS responsible for developing the ground segment, flight and ground system operations





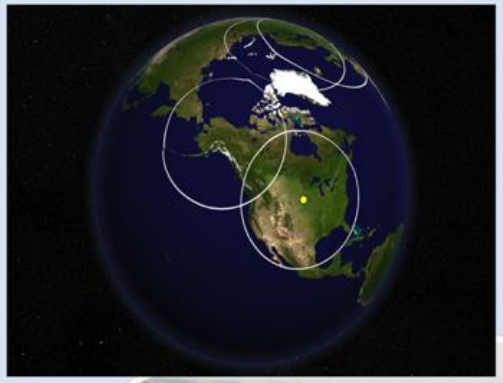
- Nearly five-decade record of land cover, land use, and vegetation condition
- Large area coverage for global, continental and regional land cover studies

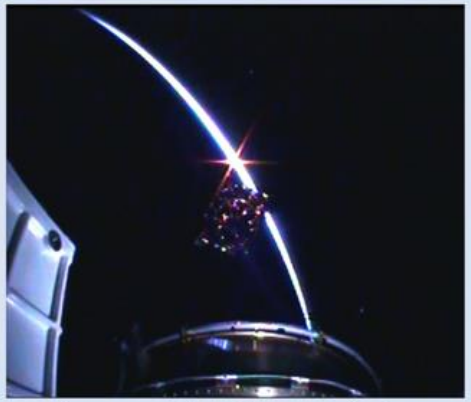
- Archive contains 300 billion km^2
- Adds 40 million km^2 per day

The Landsat 9 Project is jointly managed by NASA & USGS

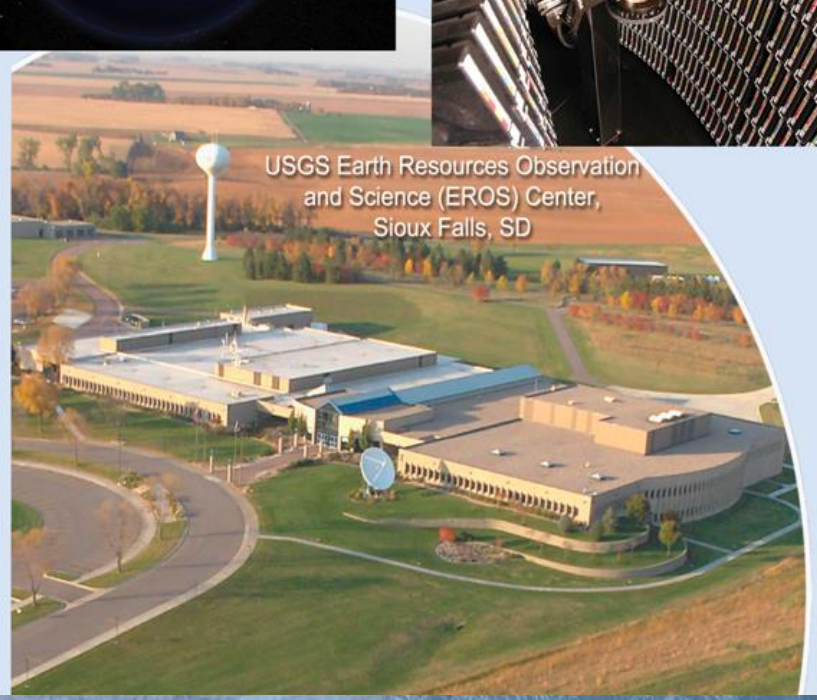
NASA manages mission development, builds and launches the satellite, and performs on-orbit checkout

USGS builds and manages the ground system, conducts mission operations, and processes and distributes the data





Landsat 8 integration, launch, and separation from rocket



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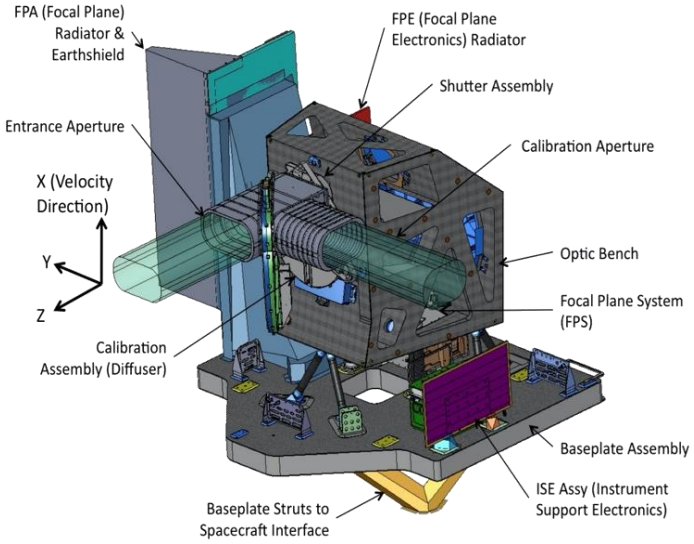
Landsat 9 Imaging Instruments

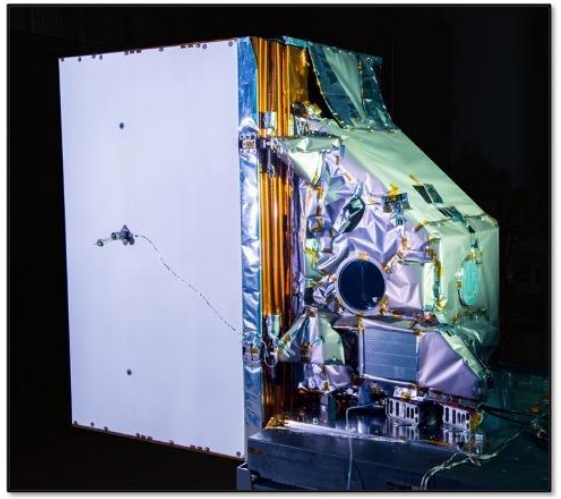
➢ Operational Land Imager 2 (OLI-2)

- Reflective band multispectral imager
- 8 VIS/NIR/SWIR bands w/ 30 m spatial resolution
- one panchromatic band w/ 15 m resolution
- Pushbroom sensor (Ball Aerospace)
  - » 4-mirror telescope
  - » Focal Plane Assembly (FPA) consisting of 14 sensor chip assemblies, passively cooled
- Absolute radiance uncertainty: <5%

➢ Thermal Infrared Sensor 2 (TIRS-2)

- Longwave imager for measuring surface temperature
- 2 spectral bands at 10.8 and 12 micrometers
- 100 m spatial resolution
- Pushbroom LWIR sensor (GSFC)
  - » 4-lens refractive telescope
  - » FPA consisting of three 2-d Quantum Well Infrared Photodetector (QWIP) sensor chip assemblies, mechanically cooled
- Absolute radiance uncertainty @ 300K <2%





Improvements to Landsat 9

- **Reliability**
  - The TIRS-2 instrument has been built to risk-class B
  - Upgraded flight operations systems for improved flight safety
  - TIRS-2 imagery will be available much sooner with a redesigned Scene Select Mirror encoder
- **Radiometric Improvement**
  - With changes to the spacecraft, the OLI-2 instrument will collect 14-bit data resulting in a 25% improvement in SNR for typical radiance targets
  - Optical TIRS-2 redesign has reduced the stray light contamination by ≈10x
  - Improved pre-launch OLI detector characterization/calibration
- **Improved User Access**
  - Unlike Landsat 8, Landsat 9 is designed from the start to collect all land imagery
  - Concurrent with Landsat 9 development, USGS EROS is developing near real-time (NRT) product availability (≈ <30 minutes) for acquisitions over CONUS

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Landsat 9 replaces Landsat 7, significantly improving global Landsat observations

Landsat 9

- Launched 9/27/21
- Deployed successfully
- On-orbit checkout underway
- Mission handover to USGS in January

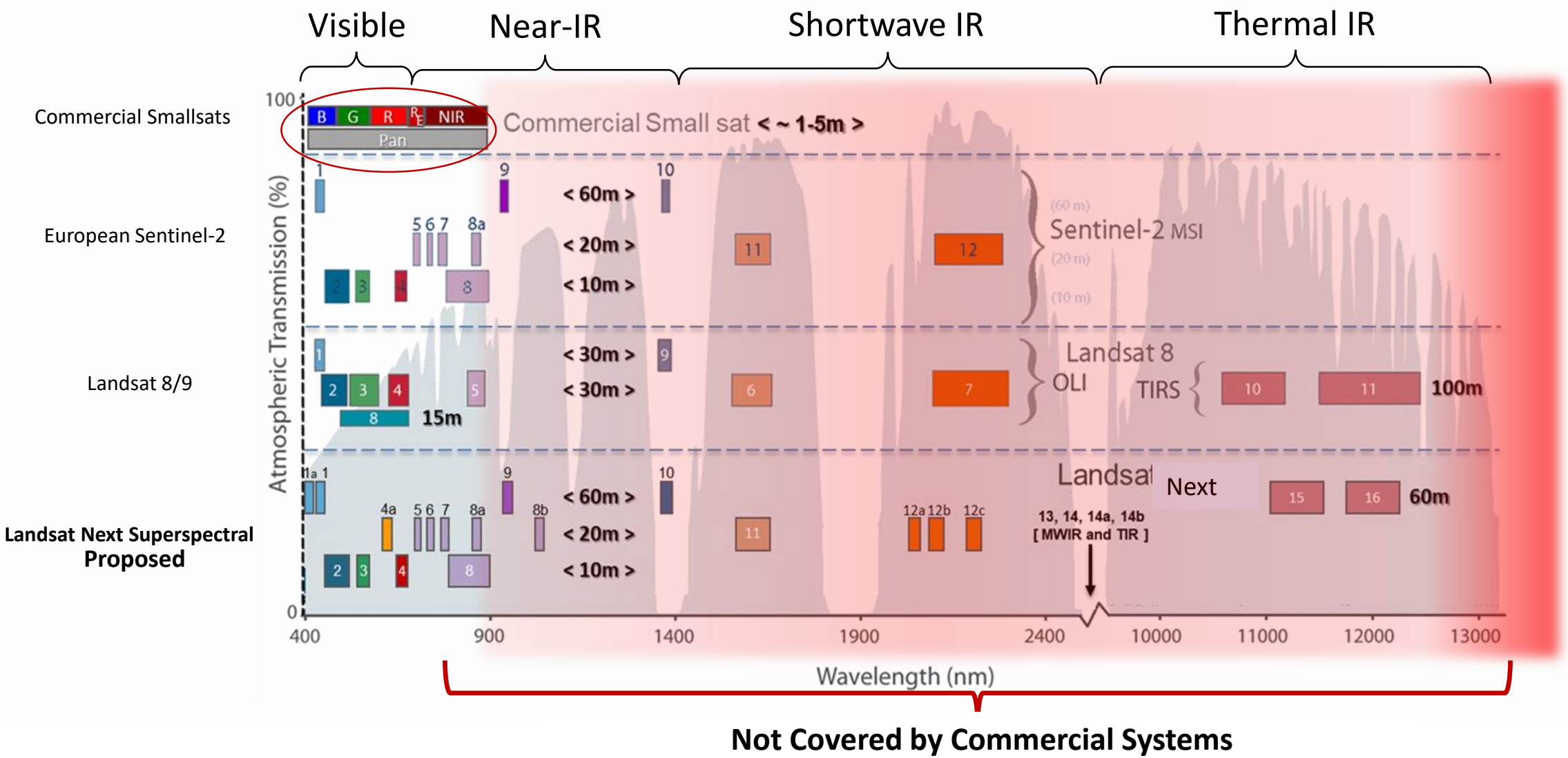

ULA

Landsat Next

- **Landsat Next**: Under the SLI agreement, the U.S. intends to implement a robust spaceborne, land imaging system to ensure continued collection of data for processing into useful and efficient information products for use by the wide range of interested science communities.
- **Mission Concept:** Collection of “superspectral” land observations featuring both richer spectral information and higher spatial resolution than Landsat 8 and 9 with improved temporal frequency.
- **Requirements:** Reflect the needs of users for:
  - **Improved temporal revisit** for monitoring dynamic land and water surfaces such as vegetation crop phenology, burn severity, water use and quality, coastal and wetland change, glacier and ice sheet dynamics.
  - **Improved spatial resolution** for agricultural monitoring, ecological monitoring, urban studies, water resources management and other applications.
  - **Synergy with European Sentinel-2** bands allowing easier merging of information products.
  - **Improved spectral resolution** to support new and evolving applications, including surface water quality, cryospheric science, geology, and agricultural applications including crop water consumption.
  - **Preservation of heritage performance**: spatial, geometric, radiometric, and Signal-to-Noise Ratio (SNR).

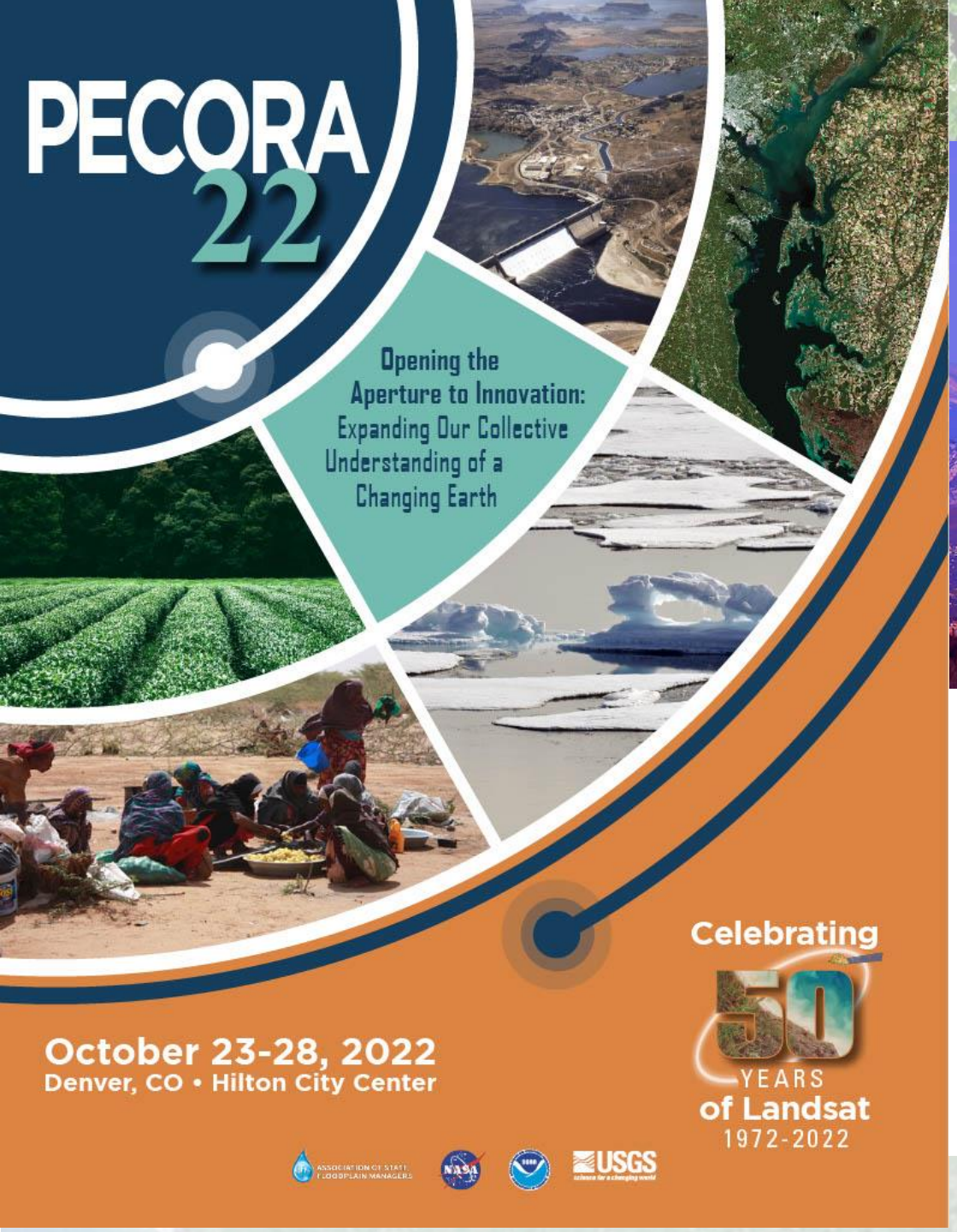
How are Landsat Data Unique?

Spectral Band Comparisons of Major Earth Observation Satellites



Landsat Next Current and Near-term Activities

- **NASA and USGS are working together to determine the Landsat Next mission concept**
  - Instrument study process underway
    - NASA Instrument Study RFP currently published: https://beta.sam.gov/opp/64c04ff25c094fbd92277604afa227ee/view
    - The intent of this study is to better inform the government as to the viability and risks associated with current instrument requirements and mission architecture options.
    - Instrument study contracts have recently been awarded
  - NASA/USGS Landsat Next Project Teams have been working together for over a year
  - Three Requests for Information released (Science Requirements/instrument concept/mission architecture, Instrument, Payload Interface/Data Storage)
  - Multiple space architectures under consideration
  - Ground system studies and architecture trades in progress
- **Target Launch Readiness Date: Late 2020s**
- **NASA Mission Concept Review (MCR) and Key Decision Point A for approval to proceed scheduled for early CY2022.**



Pecora-22: October 23-28, 2022

Denver, Colorado

- Our flagship land-imaging satellite applications conference, and a longstanding USGS-NASA partnership
- Highlights Landsat's 50th anniversary
- Conference will feature Landsat 9, Landsat Next and the many innovative developments in government and commercial land-imaging programs
- Website: pecora22.org **CALL FOR PAPERS NOW**

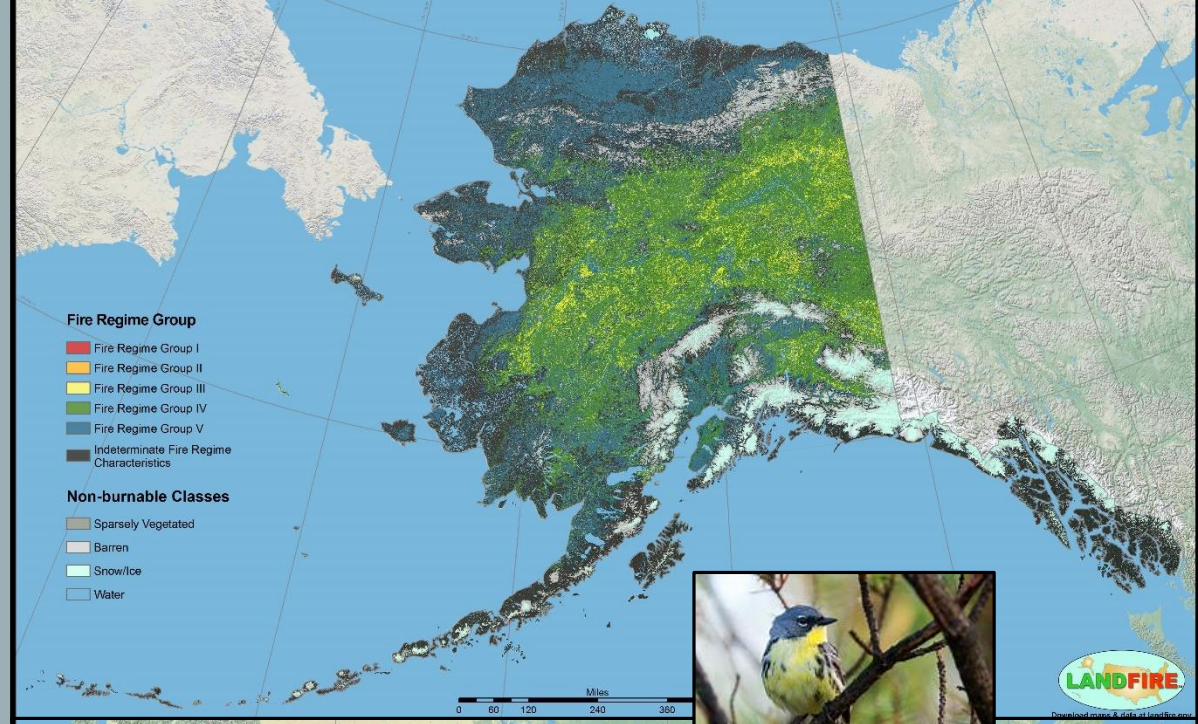
FIRE AS HAZARD & CRITICAL ECOSYSTEM DRIVER

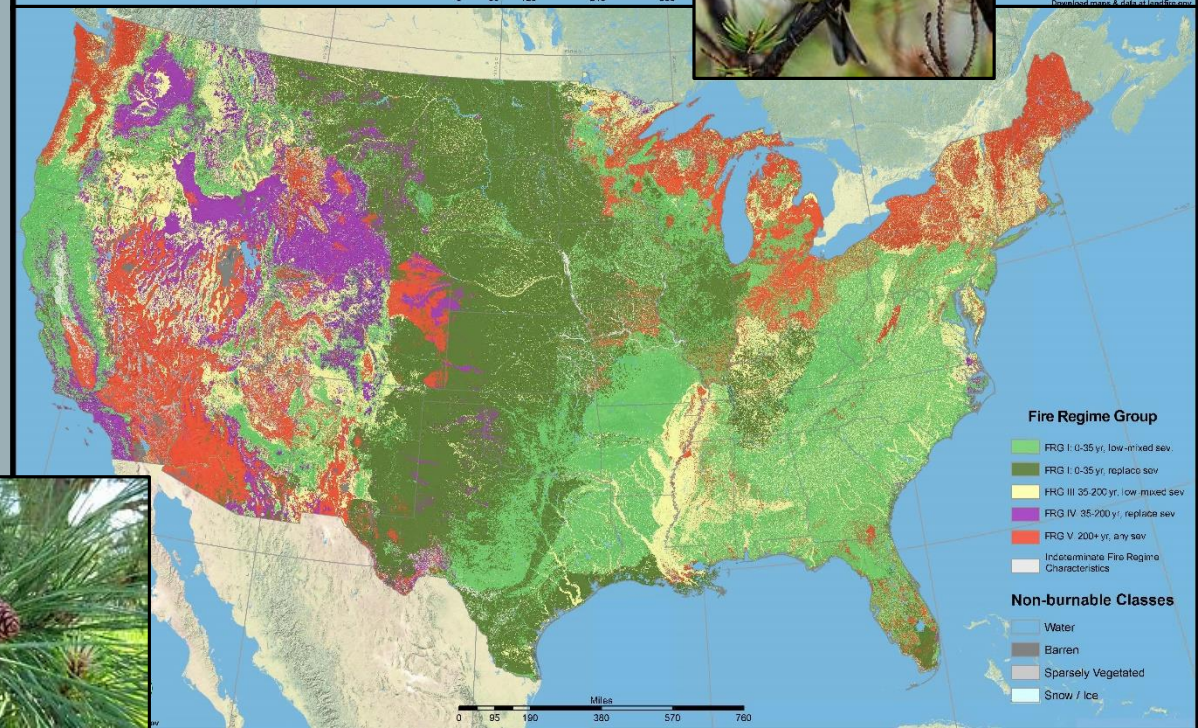
Why is Fire a Problem

- Climate Change
- Fire Adapted Invasive Species
- Insect & Disease Outbreak
- Fuel Accumulation
- Human Activity & Development in Wildlands

Fire as a Critical Ecosystem Driver

- Current vegetative communities evolved over the last 14,000 years
- Native Americans regularly used fire in many regions
- Many plant species depend upon fire to reproduce or as disturbance agents, wildlife depend on plant dynamics





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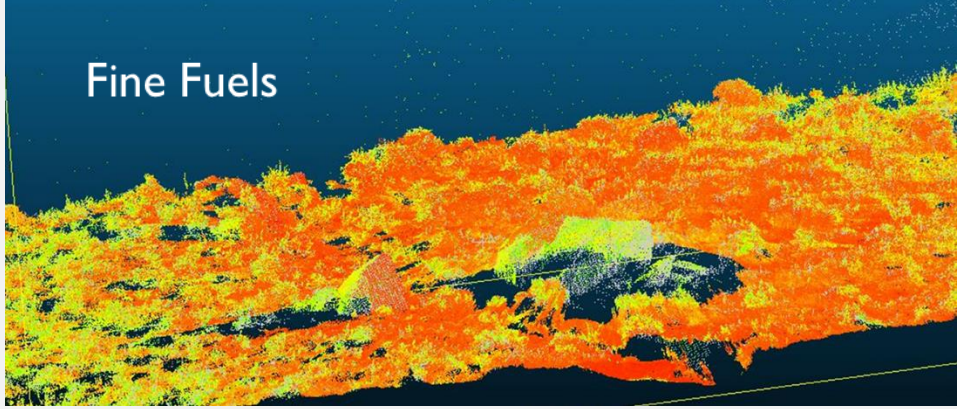
USGS WILDLAND FIRE SCIENCE STRATEGIC PLAN: 2021-2026



Priority 1: Produce state-of-the-art, actionable fire science: Provide scientific analyses, data, and tools that inform current and future fire and land management decision-making across the wildland fire cycle and promote understanding of fire-related and fire-responsive earth system processes and patterns.

Priority 2: Engage stakeholders in science production: Use a science co-production model throughout the fire-research life cycle to develop and maintain collaborations with actively and continually engaged stakeholders, and to ensure that end products and outcomes of research projects inform stakeholder needs and are relevant and useful for fire and land management decision making.

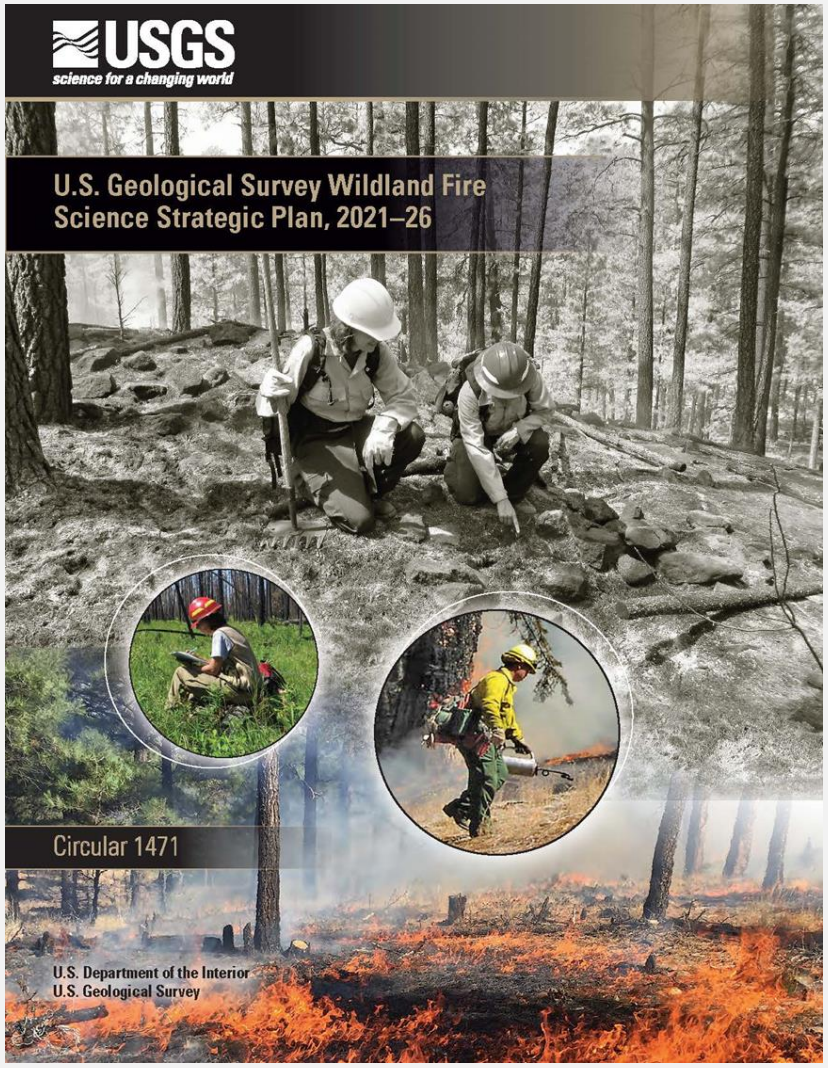
Priority 3: Effectively communicate USGS fire science capacity, products, and information: Strategically manage communications to effectively build awareness of and access to USGS wildland fire science among key external and internal stakeholders.

Priority 4: Enhance USGS organizational structure and advance support for fire science: Provide organizational structure and support that improves fire-science production, coordination, and cooperation within the USGS and with external partners.

USGS Wildland Fire Science Strategic Plan https://doi.org/10.3133/cir1471

USGS science for a changing world

PRIORITY 1: PRODUCE STATE-OF-THE-ART, ACTIONABLE FIRE SCIENCE



Goal 1: Improve understanding of the impacts of climate changes and other ecosystem stressors, and their synergistic interactions, on fire behavior, fire risk, and fire effects in natural systems and human communities.

Goal 2: Gain a better understanding of the relationships of fire and fire management to biodiversity conservation, ecosystem resilience, and post-fire recovery.

Goal 3: Conduct science to help protect human lives, livelihoods, property, and infrastructure.

Goal 4: Develop state-of-the-art tools and decision-support systems that enable land, fire, and emergency-managing bureaus and partners to obtain essential fire information.

FOUR MAIN GOALS FOR BUDGET, STRATEGIC PLAN IMPLEMENTATION

- Research within and between fire related programs/missions – integration for complex topics
- Enhance fire modeling, linked to other USGS models, collaboration with others
- Science applications at a landscape level – meets management needs
- Enterprise architecture that supports integrated science, adaptation to new technology, partnership with science producers and users

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USGS Fire Science
Wildland Fire Threat, Hazard, Risk & Mitigation

Before a Fire

Escaped Fire

Insects

Disease

Invasive Species

Drought

Climate Change

Human Caused Ignitions

Job Hazards

Ash

Smoke

Fire

During a Fire

Phases of Wildland Fire

After a Fire

Invasive Spp Response

Lost Vegetation & Organic Matter

Water Quality/Quantity & Supply Systems

Debris-Flows & Flooding

Wind Erosion

Forest & Rangeland Mgmt Pract

Prescribed Fire

Inv Spp Control

Fuel Breaks

Restore & Maintain Landscapes

Wildfire Prevention

Homeowner Actions

Create Fire-Adapted Communities

Fire Resistant Buildings

Community Wildfire Protection Plan

Landfire & WFDSS

Wildfire Suppression

Manage Fire for Resource Objectives

Improve Wildfire Response

Cultural Resources

Plants & Wildlife

Public Warning Systems

Human Health & Safety

Public Evacuation

Infrastructure

Integration with Other Hazards & Risks

Economic Costs Direct & Indirect

Ecosystem Services

Plants & Wildlife

Land Uses

Restore Vegetation

Inv Spp Control

Burn Severity Maps

BAER Plans

Public Warning Systems

Public Evacuation

Human Health & Safety

Infrastructure

Symbology

Threat/Hazard

Values at Risk

Mitigation

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USGS Science Resources to Support Management Before, During and After Fires

- Landfire - > 20 data products
  - https://www.landfire.gov/
- Monitoring Trends in Burn Severity
  - https://www.mtbs.gov/
- Invasive Species Maps
  - https://eros.usgs.gov/doi-remote-sensing-activities/2019/usgs/mapping-cheatgrass-sagebrush-ecosystem-western-us
- Burn Severity Mapping, USGS/USFS – status of requested post-fire maps and requesting new maps:
  - https://fsapps.nwcg.gov/mtbs/birch/requests/list
- Debris flow assessments:
  - https://landslides.usgs.gov/hazards/postfire_debrisflow/
- Streamgage Network:
  - https://www.usgs.gov/mission-areas/water-resources/science/usgs-streamgaging-network?qt-science_center_objects=4#qt-science_center_objects
- Hazard Data Distribution System – includes commercial satellite imagery (e.g., WorldView) obtained on fires:
  - https://hddsexplorer.usgs.gov/
- National Map data:
  - https://www.usgs.gov/core-science-systems/ngp/tnm-delivery/download?qt-science_support_page_related_con=0#qt-science_support_page_related_con
- Lidar 3DEP Data
  - https://www.usgs.gov/core-science-systems/ngp/3dep
- Landsat Data & Tools:
  - https://www.usgs.gov/core-science-systems/nli/landsat/data-tools
- 12-year Compendium of USGS Wildland Fire Science
  - https://pubs.er.usgs.gov/publication/ofr20191002
- USGS Fire Science Web Page:
  - https://www.usgs.gov/fire

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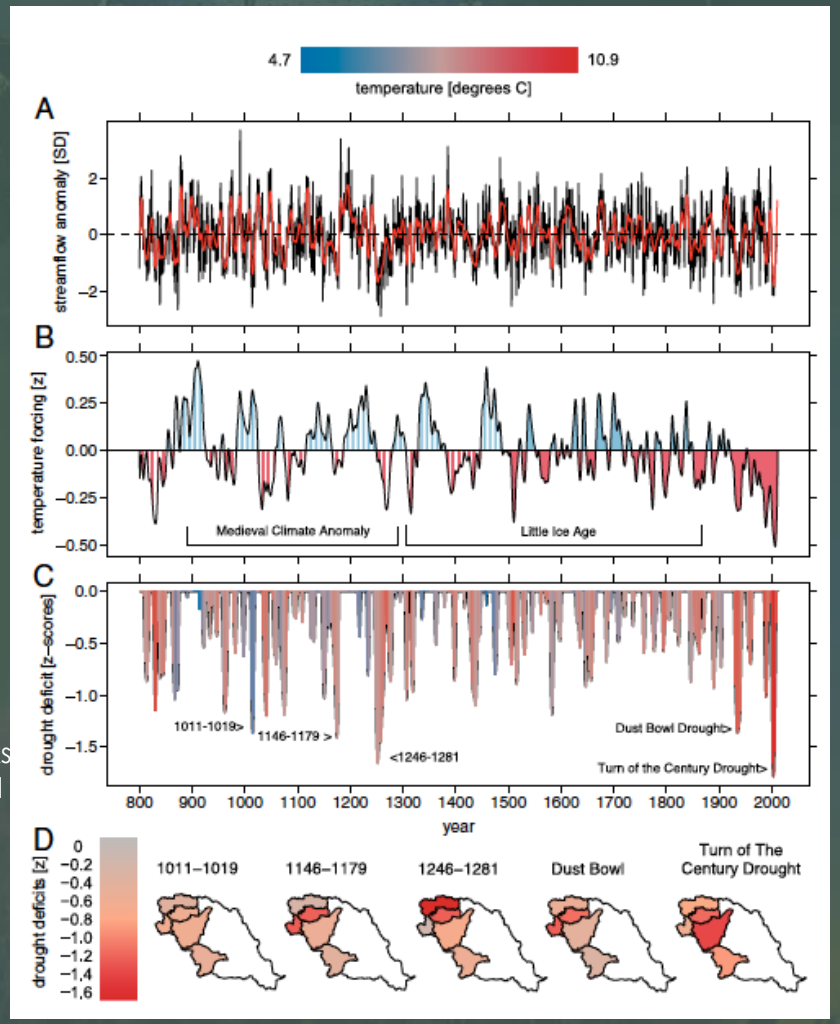
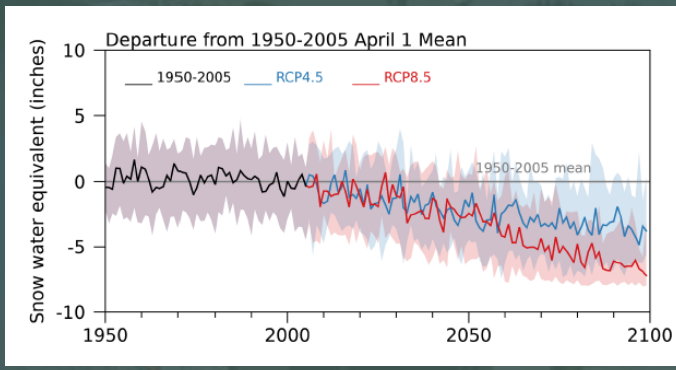
USGS climate science - Informing resource managers and the public on past, present, and future climate change

Documenting patterns and impacts of drought since 800 CE

Martin and others, 2020, Increased drought severity tracks warming in the United States' largest river basin.



Paleoclimate research helps us understand how natural patterns of climate variability interact with human modifications of the landscape to shape modern ecosystems.



Modeled changes in water stored in Yellowstone snowpack relative to 1950-2005 mean.
Hostetler & Alder, 2021. Greater Yellowstone Climate Assessment.

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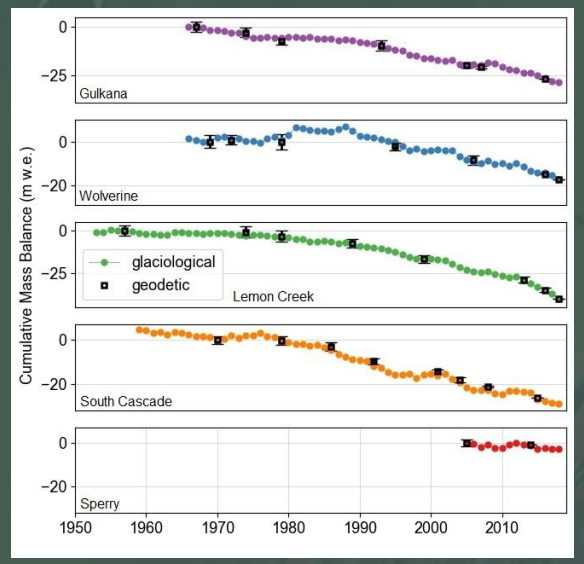
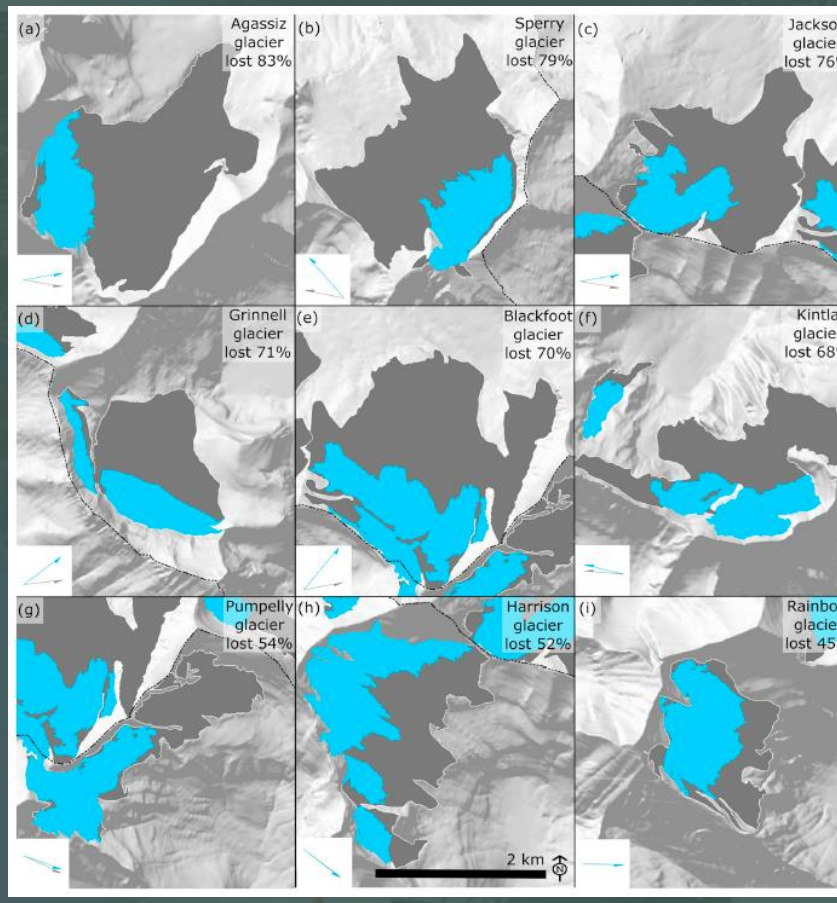
Integration of field, remotely sensed, and geologic observations to document glacier change

USGS researchers combine annual field measurements of glacier mass balance with satellite imagery, historic photos, and geologic evidence to examine patterns and drivers of glacier change since 1850 CE.



O'Neel and others, 2019. Reanalysis of USGS Benchmark glaciers: long-term insight into climate forcing of glacier mass balance.



Florentine and others, 2020. Parsing complex terrain controls on mountain glacier response to climate change.

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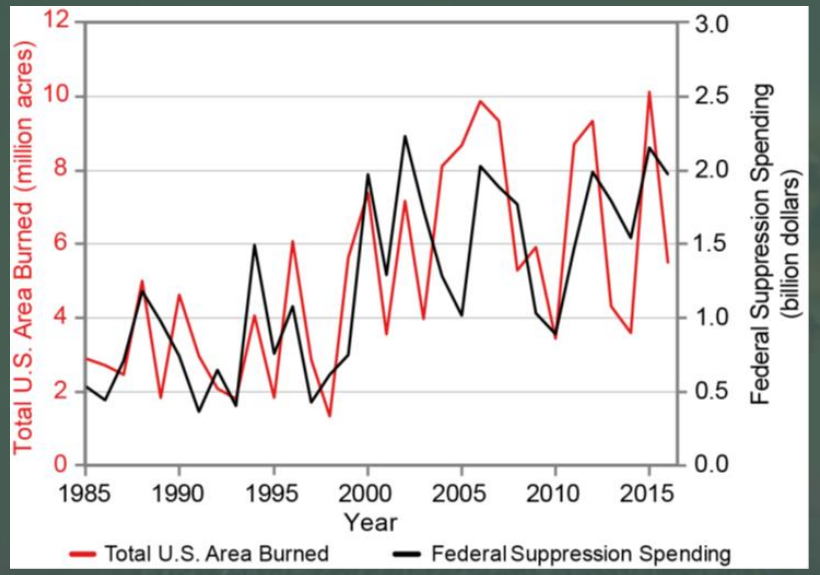
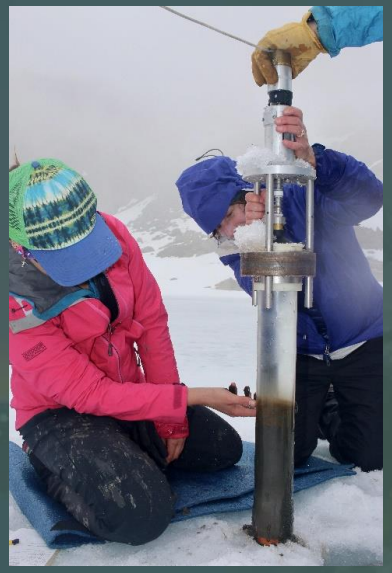
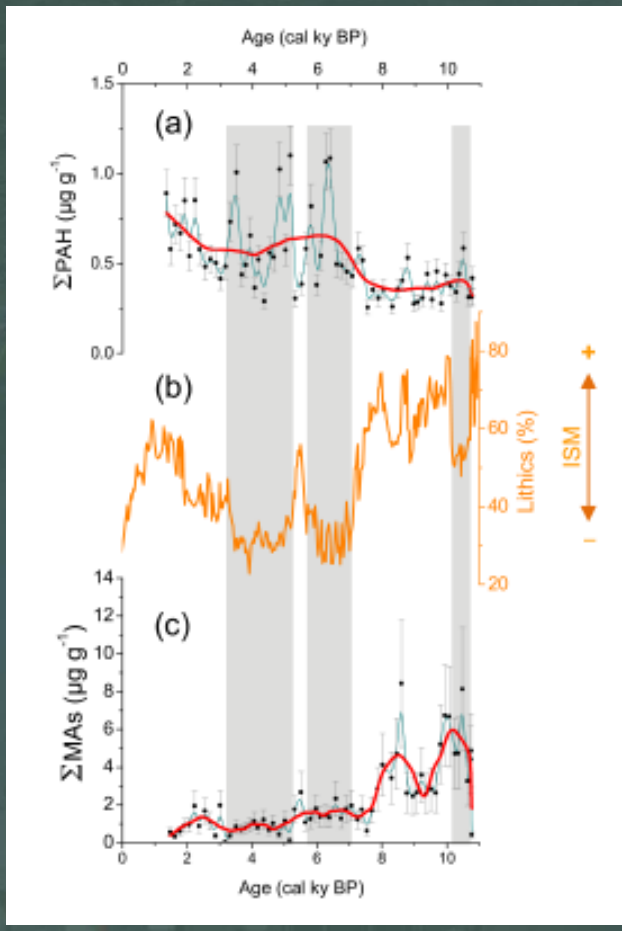
Fire history – paleo and modern observations enhance understanding of patterns and drivers of wildfire

USGS scientists conduct research to document the history, causes, and impacts of wildfire over decades to millennia. This supports efforts of forest and resource managers to develop sustainable management treatments under a changing climate.



US Fourth National Climate Assessment, 2018





Calegaro and others, 2018. Fire, vegetation, and Holocene climate in a southeastern Tebetan lake: a multi-biomarker reconstruction from Paru Co.