Observing Earth from space

Resource booklet for Tū’desē’cho Wholistic Indigenous Leadership Development
produced by Arctic PASSION

Climate change observation funded by the European Union

Climate change is affecting the Arctic faster than other parts of Europe. As part of the Arctic, Europe wants to co-create new knowledge together with those who know the Arctic best: the local and Indigenous Peoples' Communities.

Arctic PASSION aims to develop a better system, called the 'Pan-Arctic Observing System of Systems – pan-AOSS', for monitoring the Arctic.

This system will enhance scientific and community-based monitoring, incorporating Indigenous and Local knowledge. It also seeks to improve data access and sharing, ensuring long-term usability.

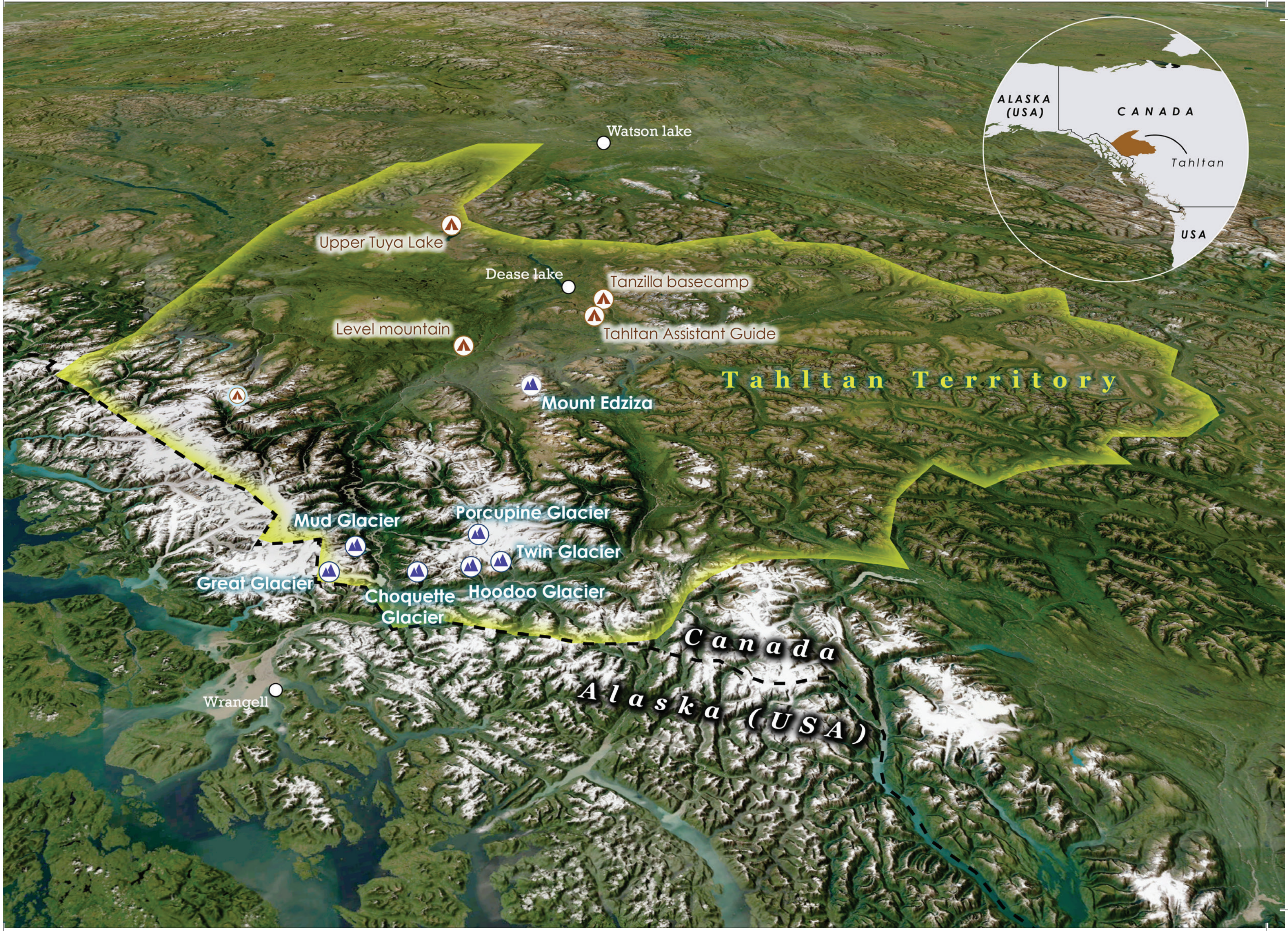
Partnering with Snowchange, Tū'desē'cho Wholistic Indigenous Leadership Development (TWILD) is creating a database of Indigenous Knowledge to track climate change impacts on the land, plants, animals, water, and fish, aiding in future sustenance hunting and fishing. TWILD's Tene Mehodihi youth program will use drone footage to measure glacier ice extent and compare it with historical data to illustrate ice loss around the Sheslay River headwaters. You will also map disturbances from recent forest fires in lower elevations to understand wildfire history in Tahltan territory.

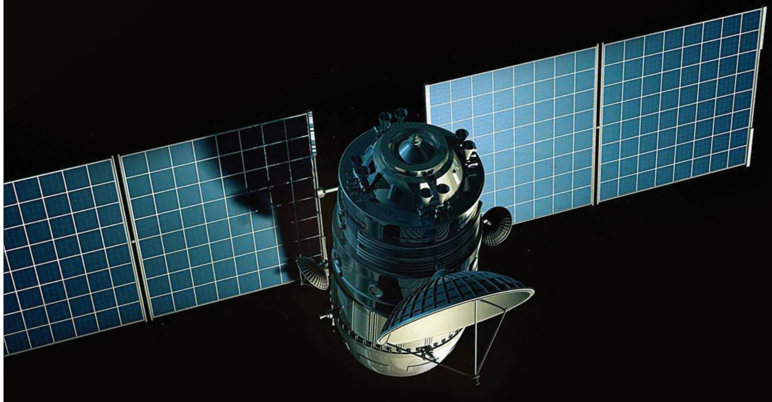
Our project aims to support your observations by sharing how scientists monitor changes in glaciers and wildfires, including aerial photos and satellite imagery.

In this booklet, you will find the following:

- Natural Colour satellite image
- False colour satellite image
- Mud Glacier 1985 – 2022
- Great Glacier 1982-2022
- Choquette Glacier 1985-2022
- Hoodoo-Twin Glaciers 1985-2022
- Porcupine Glacier 1985-2022

As well as theoretical background information on disturbance maps for wildfire observations.


ALASKA (USA)
CANADA
Tahltan
USA
Watson lake
Upper Tuya Lake
Dease lake
Tanzilla basecamp
Tahltan Assistant Guide
Level mountain
Tahltan Territory
Mount Edziza
Mud Glacier
Porcupine Glacier
Twin Glacier
Great Glacier
Choquette Glacier
Hoodoo Glacier
Canada
Alaska (USA)
Wrangell

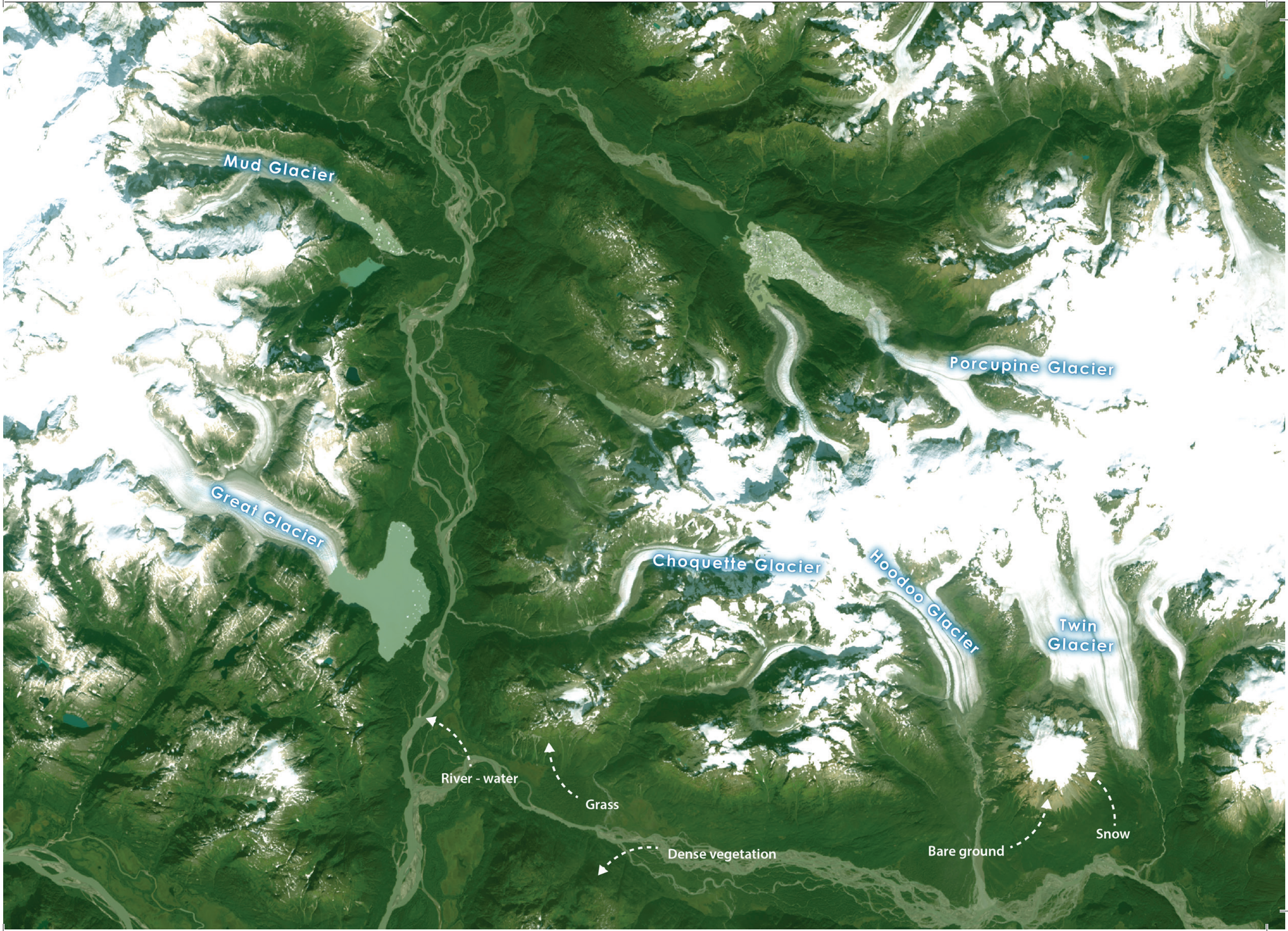


Detecting glaciers using satellites is like taking super detailed photos from space!

Satellites orbit high above Earth and use special cameras and sensors to capture images and data of the surface. Scientists look at these images to find glaciers by spotting large areas covered in ice and snow. They can also measure the temperature and see how the glaciers move over time. This helps scientists understand how glaciers are changing, which is really important for studying our planet's climate and water supply. So, satellites are like space detectives, keeping an eye on Earth's icy parts!

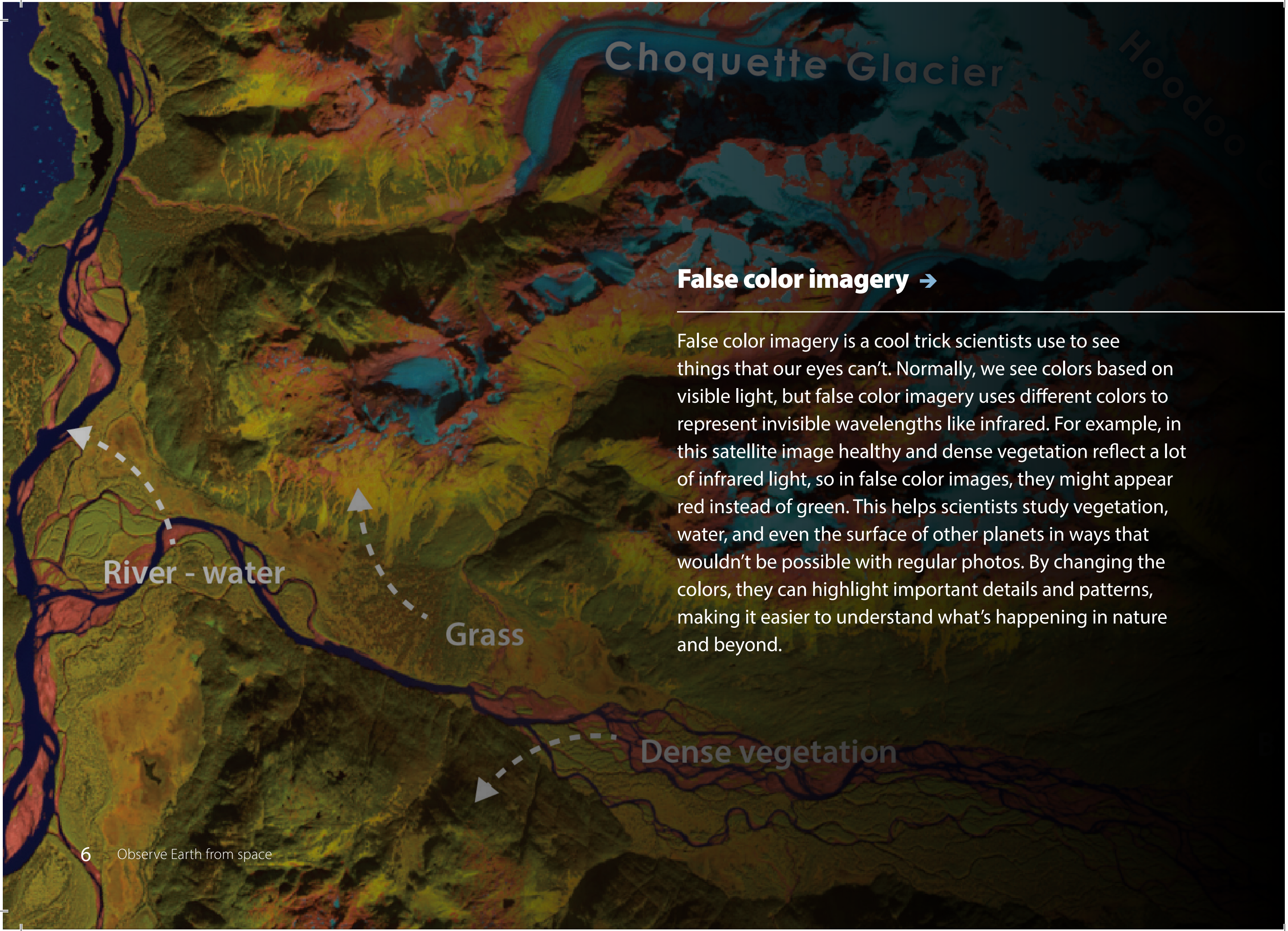
Natural color imagery →

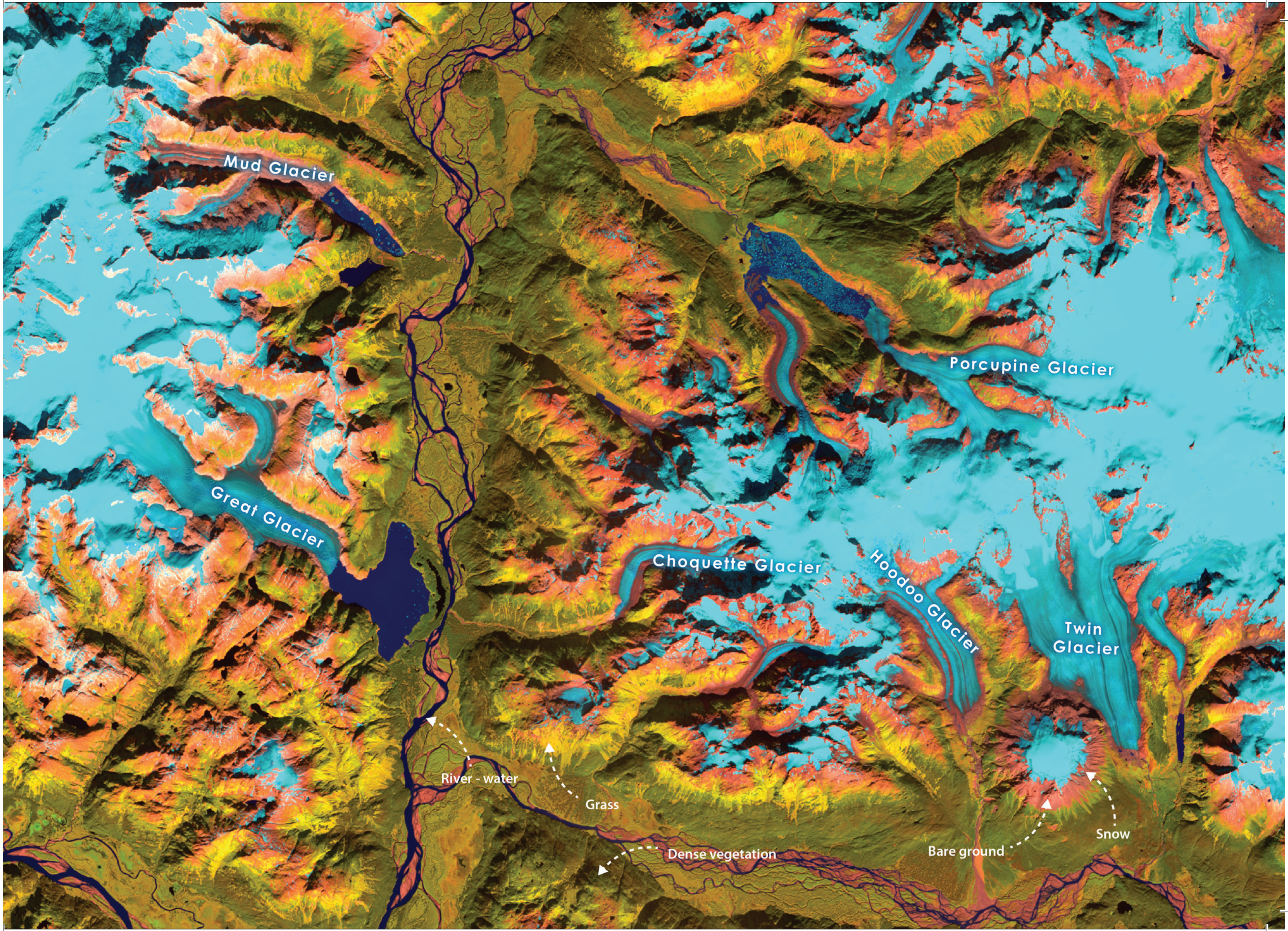
Natural color imagery is like seeing the world through a satellite's eyes, just as we would see it with our own. Satellites capture images using the same colors our eyes can see: red, green, and blue. When these images are combined, they create a true-to-life picture of Earth's surface. This helps scientists and researchers observe landscapes, cities, forests, and oceans in a way that's familiar and easy to understand. It's like taking a giant, super-detailed photo from space, showing us the natural colors of our planet exactly as they appear in real life.


Mud Glacier
Porcupine Glacier
Great Glacier
Choquette Glacier
Hoodoo Glacier
Twin Glacier
River - water
Grass
Dense vegetation
Bare ground
Snow

False color imagery →

False color imagery is a cool trick scientists use to see things that our eyes can't. Normally, we see colors based on visible light, but false color imagery uses different colors to represent invisible wavelengths like infrared. For example, in this satellite image healthy and dense vegetation reflect a lot of infrared light, so in false color images, they might appear red instead of green. This helps scientists study vegetation, water, and even the surface of other planets in ways that wouldn't be possible with regular photos. By changing the colors, they can highlight important details and patterns, making it easier to understand what's happening in nature and beyond.




Mud Glacier
Porcupine Glacier
Great Glacier
Choquette Glacier
Hoodoo Glacier
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River - water
Grass
Dense vegetation
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Monitoring Glaciers from Above

Have you ever wondered how scientists keep track of the massive rivers of ice called glaciers?

One cool way they do it is by using a method called "geodetic monitoring" which involves taking pictures and measurements from high above the glacier.

Step 1: Capturing Images

First, scientists use airplanes or satellites to take detailed photographs or laser scans of the glacier's surface. They do this at different times, maybe a few years apart. The images show the shape and height of the glacier's surface.

Step 2: Creating 3D Maps

Next, they use special computer programs to turn those images into 3D maps of the glacier's surface. It's like creating a virtual model of the glacier!

Step 3: Comparing the Maps

By comparing the 3D maps from different years, scientists can see how the glacier's surface has changed over time. If the surface has gotten lower, it means the glacier has lost some of its ice.

Step 4: Calculating the Changes

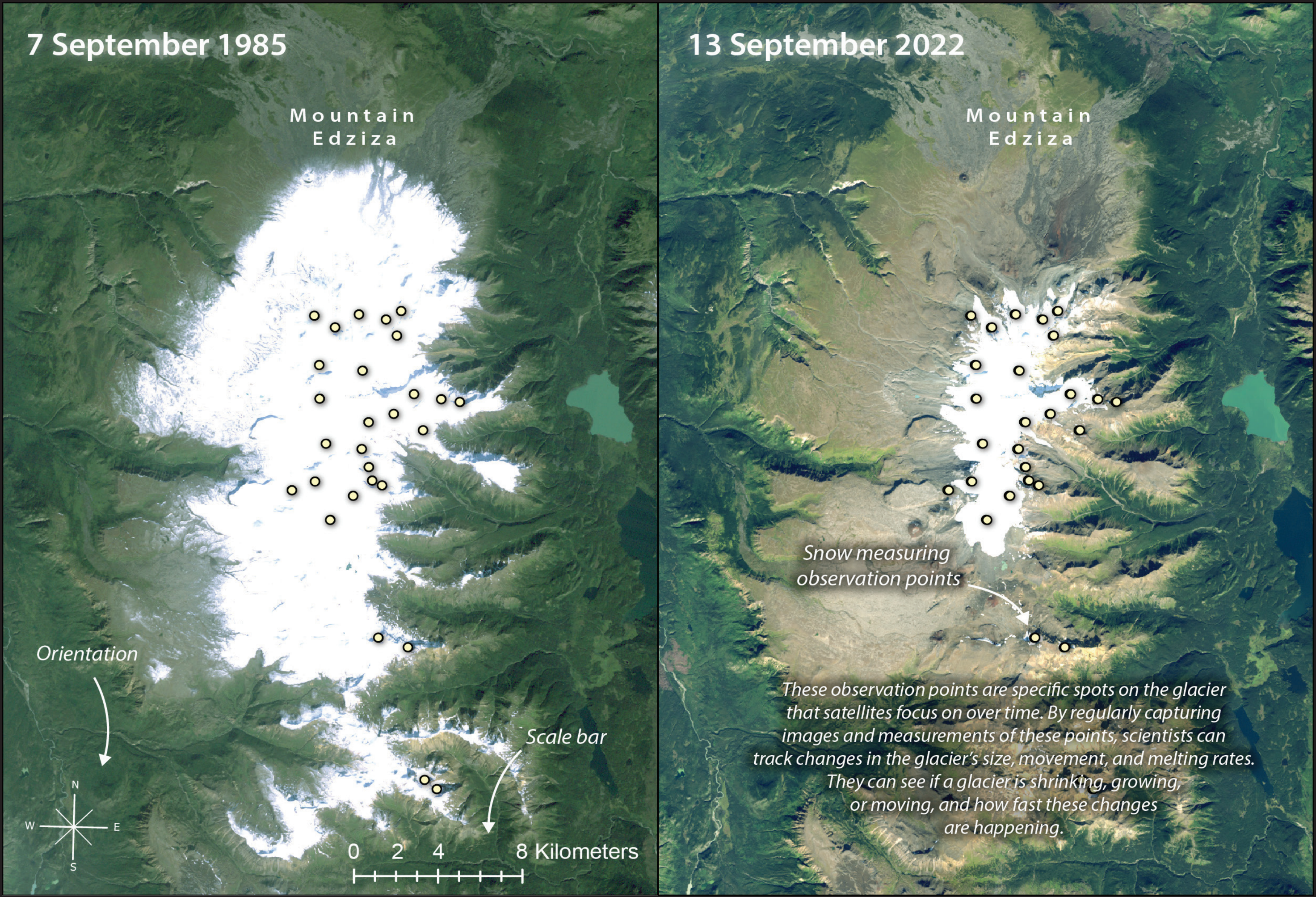
Using math, scientists can calculate exactly how much ice the glacier has lost or gained. They do this by measuring the difference in height between the maps and then converting that to a volume of ice.

This geodetic method is really useful because it gives scientists a complete picture of what's happening to the whole glacier. However, it does require special equipment and a bit of guesswork about how dense the ice is.

By monitoring glaciers from above, scientists can better understand how they are being affected by climate change and how that might impact the rest of the planet.

Here are satellite images for the glaciers you will be monitoring, with photos taken in 1985 and in 2022. Can you spot the differences between the two images?

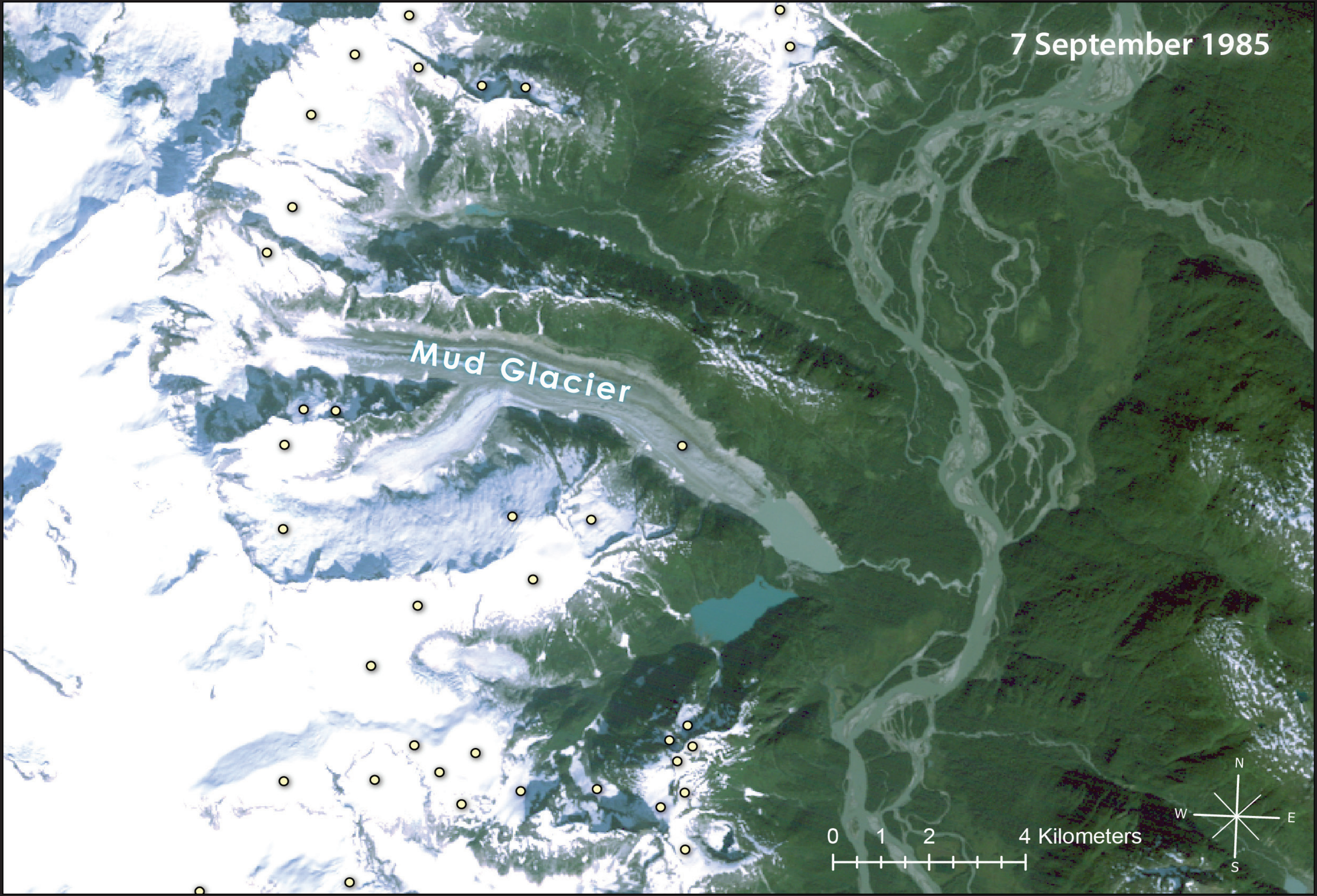
Credits: ESRI, NASA, USGS, Earthstar Geographics, NGA, CGIAR, NLS, OS, NMA



7 September 1985

13 September 2022

These observation points are specific spots on the glacier that satellites focus on over time. By regularly capturing images and measurements of these points, scientists can track changes in the glacier's size, movement, and melting rates. They can see if a glacier is shrinking, growing, or moving, and how fast these changes are happening.


7 September 1985
Mud Glacier
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4 Kilometers
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13 September 2022
Mud Glacier
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W
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S


7 September 1985
Snow observation points via satellites
Great Glacier
Stikine river
Scale bar
0 1 2 4 Kilometers
Orientation
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13 September 2022
Great Glacier
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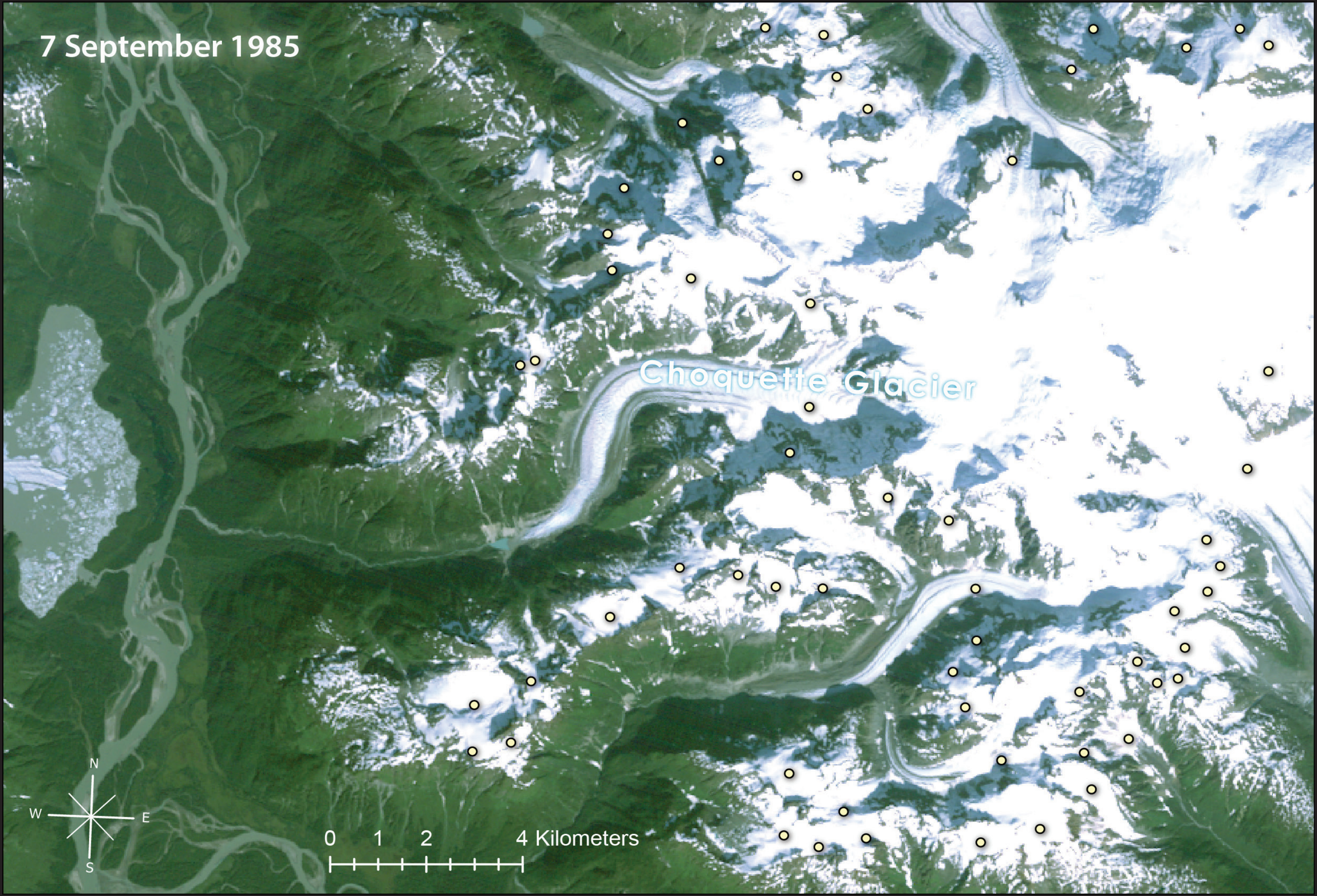
7 September 1985
Choquette Glacier
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13 September 2022
Choquette Glacier
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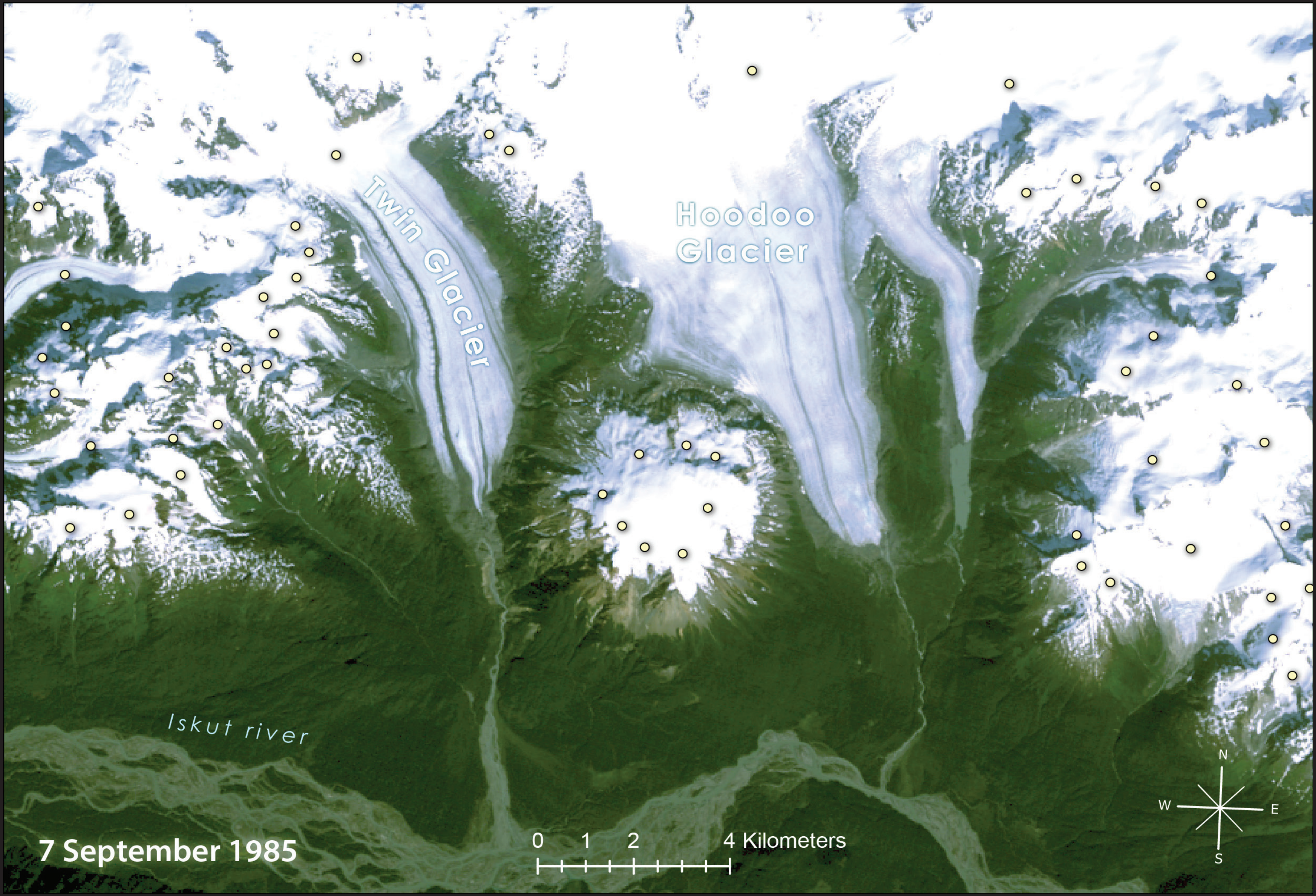

Twin Glacier
Hoodoo Glacier
Iskut river
7 September 1985
0 1 2 4 Kilometers
N
W
E
S


Twin Glacier
Hoodoo Glacier
Iskut river
13 September 2022
0 1 2 4 Kilometers
N
W
E
S


7 September 1985
Porcupine Glacier
0 1 2 4 Kilometers
N
W
E
S

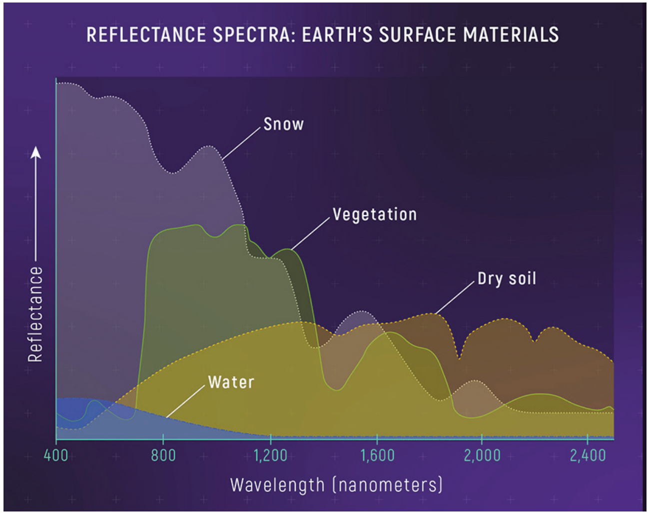
13 September 2022

Observe Earth from space

Observing the Earth from above allows us to understand aspects that are invisible from the ground.

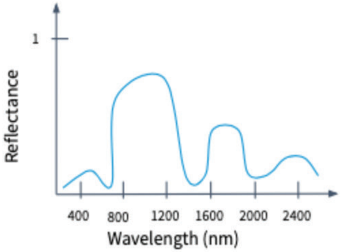
One key aspect is how much sunlight different objects reflect, known as reflectance. Reflectance varies by material and sunlight angle; for instance, soil, plants, and water reflect sunlight differently, as do various types of vegetation like forests and wheat fields. This variation helps us distinguish different colors.

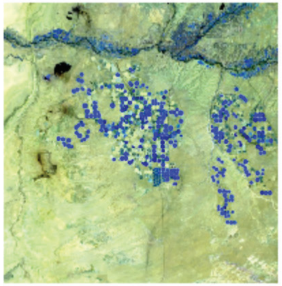
As plants change over time, their reflectance also changes. By measuring reflectance from space, we can identify soil, water, snow, ice, or vegetation in an area and assess the health, growth, and abundance of plants.



NASA, ESA, Leah Hustak (STScI)

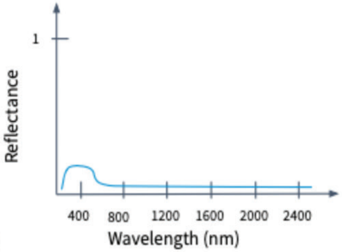
Vegetation

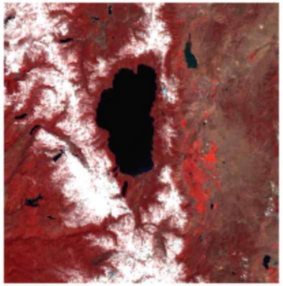




Center pivot irrigation, NASA Landsat, 2020
swir2 - swir1 - nir

Water

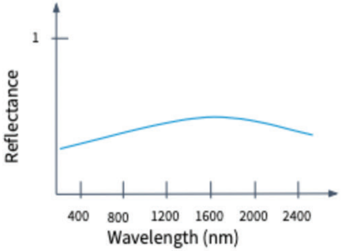




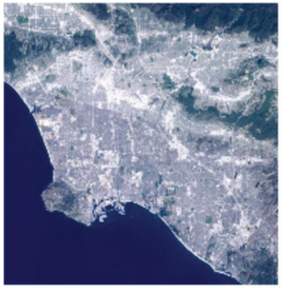
Lake Tahoe, NASA Landsat, 2020
nir - red - green

Descartes Labs Inc

Urban areas

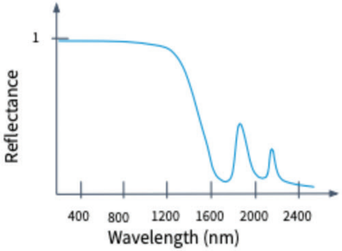


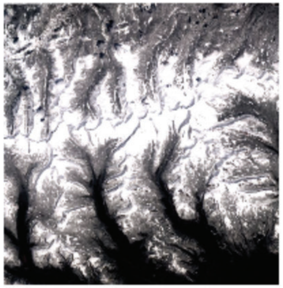
*Note: spectral signatures have been generalized



Los Angeles, NASA Landsat, 2020
red - green - blue

Snow





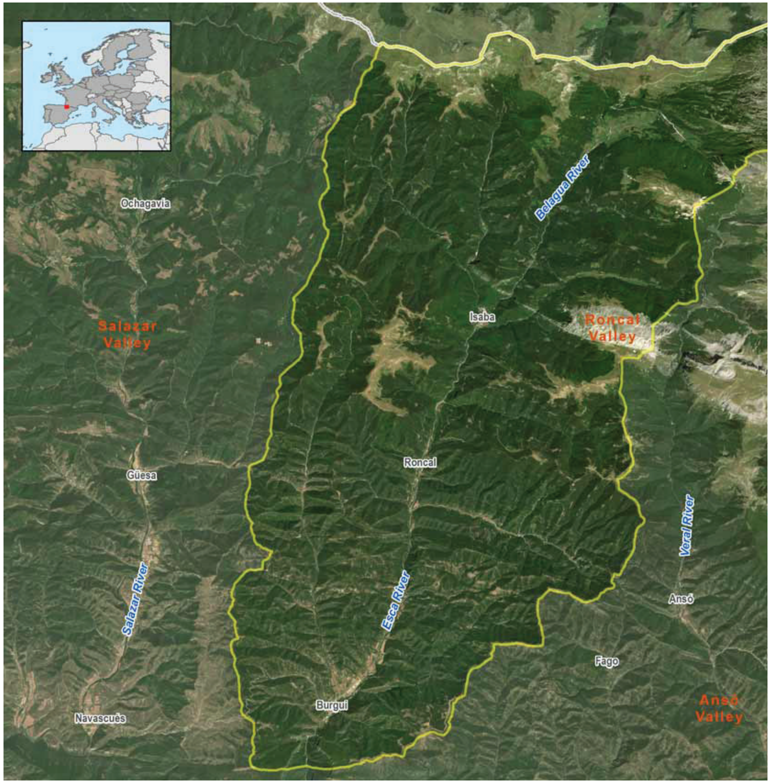
The Uintas, NASA Landsat, 2020
red -green - blue

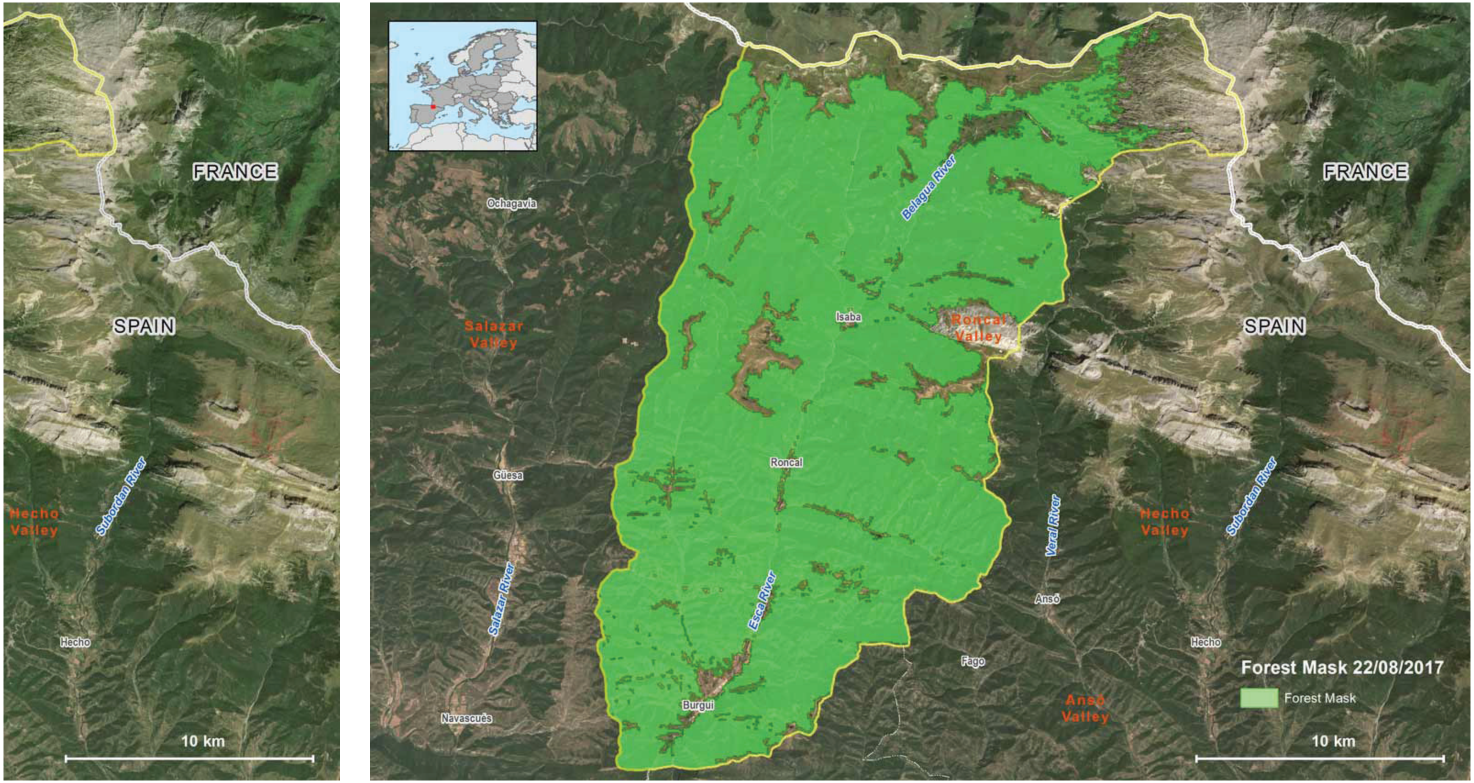
What we want to observe

The complexity of what we want to observe affects the difficulty of doing so.

For example, detecting changes in the number of trees (forest change) is easier than identifying forest degradation due to natural or human causes. Tracking forest changes, like deforestation and recovery, has been ongoing since the 1980s and 1990s with Landsat data. Today, we have global and country-specific maps showing yearly deforestation rates.

However, we still lack complete information on forest degradation. Now, with more detailed satellite images, we can create time series to monitor areas over time. This helps us spot small changes in deforestation and degradation and send alerts when changes occur. For more information on satellite observations, visit the My Sustainable Forest webpage, which offers well-documented products, application examples, videos, and webinars.





Roncal Valley of the Pyrenees (Navarra, Spain) – The forest mask locates the forested area

MySustainableForest, ESA

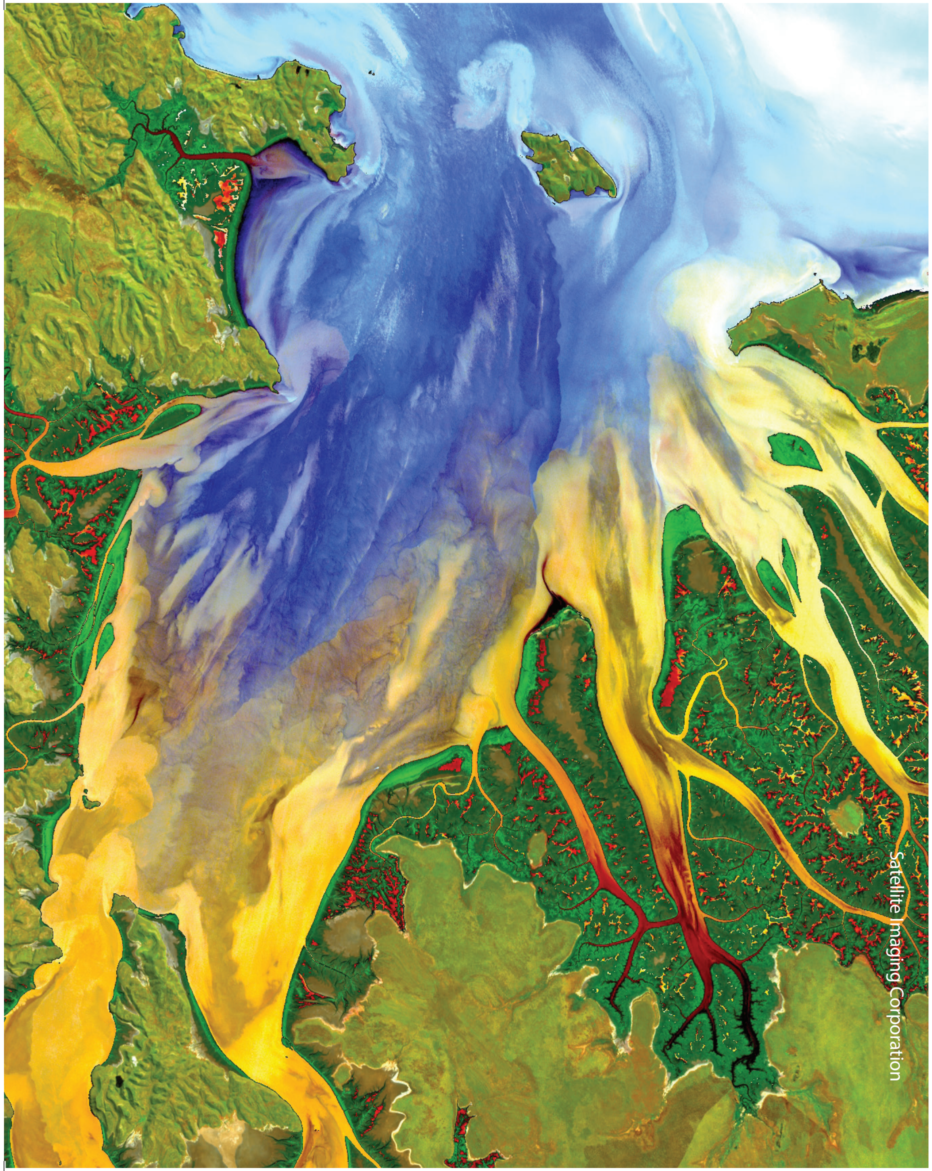
Disturbance or degradation

“Forest disturbance” refers to natural events causing the loss of tree cover or biomass, such as storms, fires, droughts, insect infestations, and disease outbreaks. It can also include human activities like logging that harm the forest. Disturbances are usually one-time events with short-term effects, often part of the natural forest cycle. “Forest degradation,” however, primarily involves long-term negative effects caused by human activities, resulting from one or more disturbances.

Examples of large-scale forest disturbances include:

- Windthrow in a Picea abies forest (a)
- Massive ice storm damage in 2014 (b)
- Forest fires in the sub-Mediterranean (c-d)
- Dieback of Fraxinus excelsior caused by the fungal disease *Hymenoscyphus fraxineus* (e)
- Forest management after a disturbance, such as salvage logging (f)

Earth-Science Reviews vol 235, a) A. Marinšek, b) L. Kutnar, c-d) K. Eler, e) J. Kermavnar, f) L. Kutnar


Satellite Imaging Corporation

Our eyes: multispectral sensors on satellites

Since the 1980s, Landsat missions have used satellites to monitor changes on the Earth's surface. These satellites have sensors that measure surface reflectance in specific parts of the electromagnetic spectrum. Selecting the right channels is crucial and complex, resulting in each satellite having a unique combination of channels.

Technological advancements have led to the development of hyper-spectral sensors, which measure a large number of wavelengths across broader spectral channels, simplifying the challenge of channel selection. Besides measuring different parts of the electromagnetic spectrum, these sensors also feature high spatial resolution, allowing them to observe smaller areas of the surface.

Highly accurate measurements of Earth's thermal energy obtained by Landsat 5

How deep to observe the surface: the spatial resolution

Observing the Earth's surface in detail relies heavily on technology.

Capturing small details is just the first step; the real challenge lies in storing, managing, and processing this data to extract useful insights.

- Very high-resolution (VHR) sensors can detect small changes with great detail, capturing images with pixels smaller than 4 meters. However, these images cover smaller areas, making it costly and time-consuming to survey large regions with VHR sensors.
- Medium to coarse resolution sensors, with pixels larger than 60 meters, are more cost-effective and faster for surveying large areas but lack the ability to detect small environmental changes.
- High-resolution satellite systems offer a compromise, providing clear images with sufficient detail while efficiently covering larger areas. Advances in technology, especially artificial intelligence (AI), are helping to address many of the challenges in processing this vast amount of data.

EOS Data Analytics

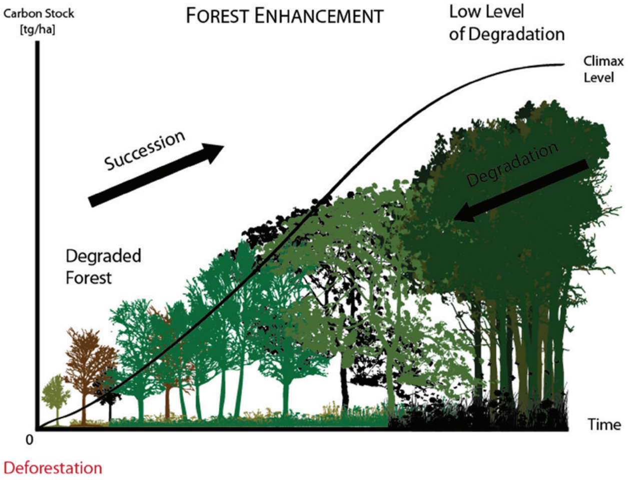
Medium-resolution (30m/pixel) image from Landsat 8 OLI and TIRS displaying the general landscape features of a relatively vast area

Methods for Forest Degradation Mapping

There are two main methods for mapping forest degradation using optical image data:

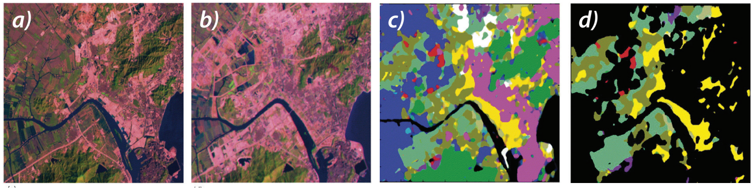
1. Image-to-image change detection
2. Time series analysis-based change detection

Image-to-image change detection involves comparing at least two images: one taken before and one after a degradation event. The initial image marks the start of the monitoring period, while the final image marks the end. This method is widely used for mapping forest degradation, as it compares the spectral signatures (patterns of light reflection) of the land surface in images from two different times to identify changes. To focus exclusively on forest areas, a forest mask is used to exclude other land types, such as agricultural fields, which can change significantly in one growing season and could lead to false results. These masks must be up-to-date and can be created from the same Earth observation data used for change detection or sourced from other data.



Forests, Morales-Barquero *et al.*

Forest succession curve



Researchgate, D.Li

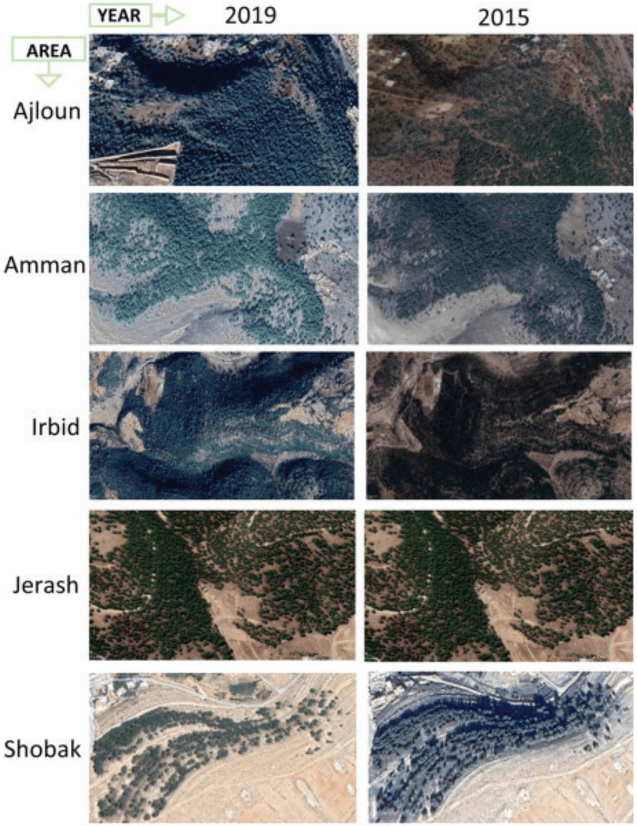
Change detection result and changed area: (a) 1992, (b) 1996, (c) change detection results and (d) changed area masking (in black).

How to identify changes

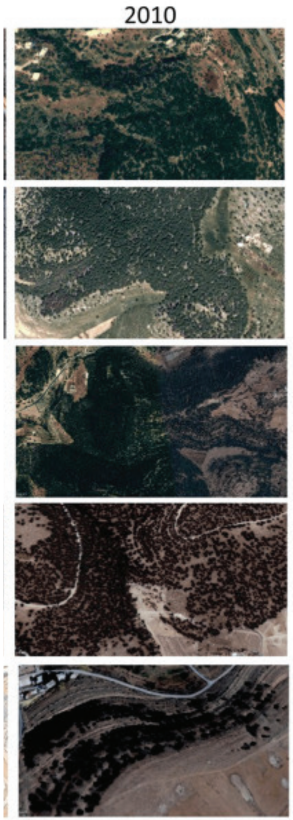
No matter which method we use, we end up with images captured in different spectral channels.

To identify changes in features like burned areas, we can either compare surface reflectance values in different parts of the electromagnetic spectrum directly or use indices. Using indices has a major advantage: they highlight changes by integrating data from different spectral bands. Changes in surface characteristics affect the spectral reflectance curve differently along the spectrum.

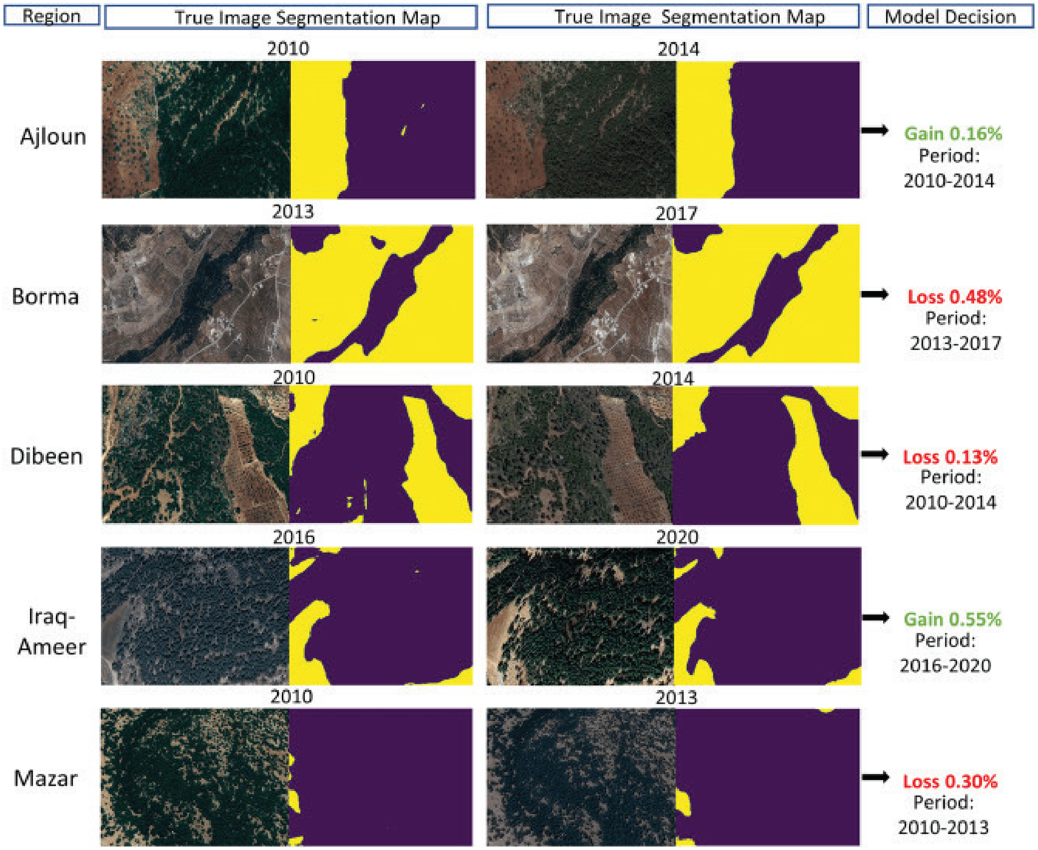
A great example of using indices is the Normalized Difference Vegetation Index (NDVI), widely used to measure vegetation health and density. NDVI is calculated using data from the red and near-infrared bands. If there is much more reflected radiation in the near-infrared wavelengths than in the visible wavelengths, the vegetation in that pixel is likely dense and could contain a forest. NDVI is directly related to the photosynthetic capacity and energy absorption of plant canopies. Other indices used for detecting changes and degradation in vegetation and forests include the Normalized Burn Ratio (NBR), Enhanced Vegetation Index (EVI), and Soil-Adjusted Vegetation Index (SAVI). The best way to identify changes depends on the specific feature of interest, as different features have optimal indicators that work best for them.



Representative sample images of the major forest regions in Jordan over ten years



Ecological Informatics vol 70, Alzu'bi & Alsmadi



Ecological Informatics vol 70, Alzu'bi & Alsmadi

Sample results of deforestation monitoring in five forest regions

Attributing the origin or cause of changes

Satellites can show us that changes have occurred on the Earth's surface, but they can't determine the cause of these changes just by looking at the reflectance data.

To figure out the cause, we need to understand how different factors can alter the spectral reflectance curve of the surface. We classify changes based on how indicators like the NDVI (Normalized Difference Vegetation Index) or NBR (Normalized Burn Ratio) change between two dates. The best indicator for detecting changes is identified through a combination of knowledge about the process and testing results. These indicators can be used in detection algorithms in two ways:

1. **As a threshold:** Detection results show changes in unique colors when displayed as a composite image
2. **To define a more standard classification procedure**

The chosen method significantly affects the quality and quantity of disturbance estimates. Even within the same environment, different methods might produce varying change maps, making the selection of the right method crucial. There are many methods available, each with its own level of flexibility and availability. For example, in the image-to-image change detection method, reviews have identified up to 10 different categories of detection algorithms developed over the last 50 years.

Land use 1999

Land use 2013

Land use change (Hatched)

Government of Queensland

Shifting the Goalposts: Land Use Change in Queensland

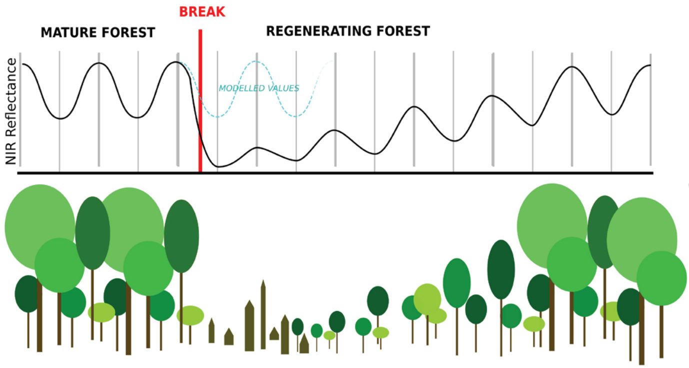
Toward a Near-time monitoring of degradation/disturbances

Another method for detecting changes in forests is Time Series Analysis-based Change Detection.

Unlike the image-to-image method, this approach requires a continuous series of images taken over a period of time, necessitating regular coverage of the area of interest. Time series analysis closely examines how images evolve over time and typically comprises three components:

1. **Long-term trend:** Indicates the overall direction of change.
2. **Seasonal component:** Reflects changes occurring at different times of the year.
3. **Residual component:** Includes unexpected changes that are not part of the long-term trend or seasonal variations.

Depending on the study focus, one or all of these components may be significant. To apply this method effectively, these components must be separated and the time series smoothed using mathematical techniques. For monitoring forest degradation, isolating the residual component is crucial to distinguish it from random noise. In different forest regions, understanding the seasonal component is also pivotal for assessing disturbances accurately.



EU 2022, Jonas Viehweger

Near-real time disturbance detection using time series looks for breaks from modelled seasons patterns in forest reflectance

Use disturbance maps for wildfires

Disturbance maps are like treasure maps for understanding wildfires.

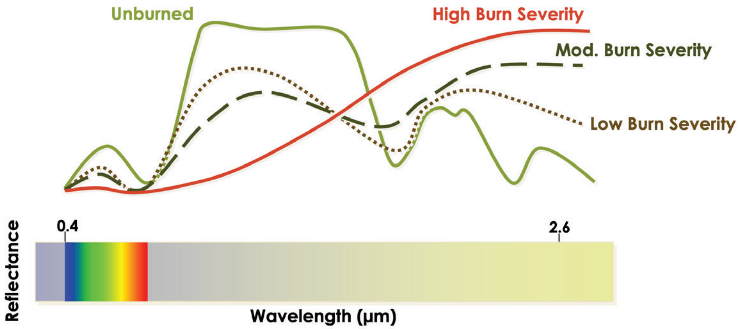
Scientists use disturbance maps to understand and manage wildfires better. These maps show areas where wildfires have caused changes in the landscape.

By comparing images taken before and after a wildfire, scientists can see exactly where the fire burned and how severe it was. This information helps them plan for future wildfires, figure out which areas need replanting or other restoration efforts, and study how wildfires affect the environment. Disturbance maps are essential tools for keeping forests healthy and safe.

Scientists study areas burned by fires by analyzing how the surface reflects light before and after a fire.

Healthy vegetation reflects a lot of green light that our eyes can see, but after a fire, the landscape turns brown or black, with reduced reflectance. Even though our eyes can't see it, satellites can detect these changes in near-infrared light (which is just beyond what we can see).

Exploiting Spectral Response Curves



Healthy Vegetation vs.
Burned Areas

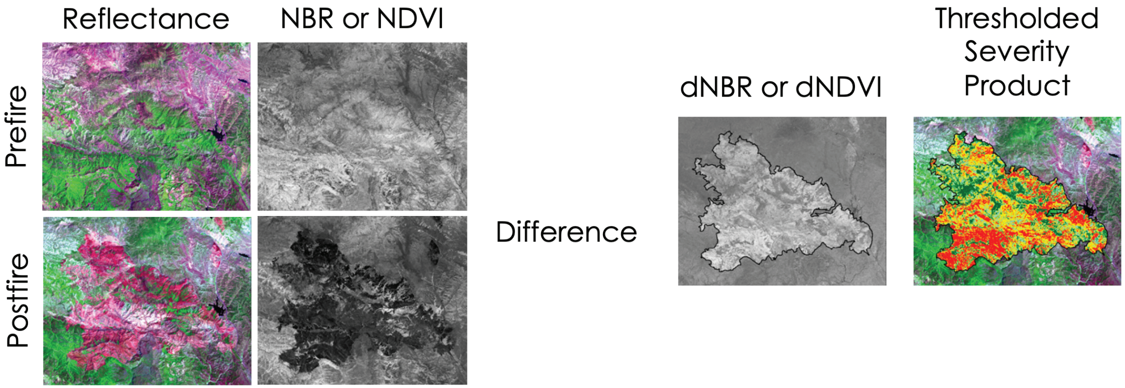
NASA Applied Sciences

Two important indices, NDVI and NBR, help scientists identify burned areas by comparing reflectance in visible and near-infrared light.

These indices show where fires have affected vegetation. Scientists also use fire detection data from satellites, which spot fires by sensing unusually high temperatures. By combining these tools, scientists can create maps that show where fires have burned and how severe the damage is, helping them manage and restore forests more effectively.

NBR *(Normalized Burn Ratio)*
NBR = (NIR-SWIR) / (NIR + SWIR)
dNBR = Prefire NBR – Postfire NBR

NDVI *(Normalized Difference Vegetation Index)*
NDVI = (NIR – RED) / (NIR + RED)
dNDVI = Prefire NDVI = Postfire NDVI



Burn severity mapping

References

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Spectral Signatures, https://blog.descarteslabs.com/a-look-into-the-fundamentals-of-remote-sensing, accessed 18.06.2014.

Forest mask: Roncal Valley, Navarre, Spain. Copernicus Sentinel-2A (2018) (acquired on 22/08/2017, GSD 10.0 m) provided by the European Space Agency. https://mysustainableforest.com/outputs/sample-cases/, accessed 18.06.2014.

The effects of large-scale forest disturbances on hydrology – An overview with special emphasis on karst aquifer systems. November 2022 Earth-Science Reviews 235(1):104243, DOI:10.1016/j.earscirev.2022.104243, LicenseCC BY-NC-ND 4.0.

Enhanced Image Western Australia, Satellite Imaging Corporation. https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/landsat-8/, accessed 18.06.2014.

High-resolution (0.5m/pixel) image from Kompsat 3 where you can distinguish each individual tree. EOS Data Analytics. https://eos.com/blog/spatial-resolution/, accessed 18.06.2014.

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