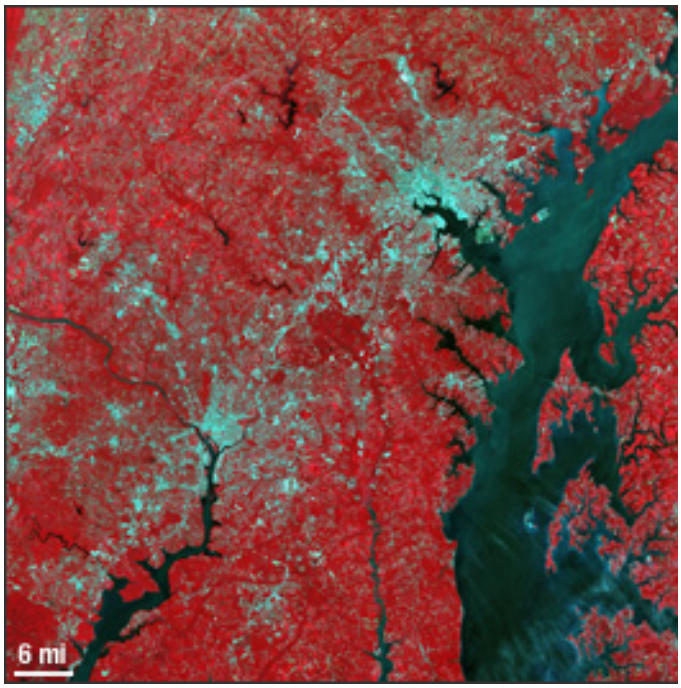
How are satellite images different from photographs?

Many of the satellite images we see have very different colors than the ones we are used to seeing with our own eyes.

Why do satellite images look so different?

Below are two pictures of the exact same location. The picture on the left is a "true color" image, this means that the picture shows objects in the same colors that your eyes would normally see. The picture on the right is a "false color" image, this means that the colors have been assigned to three different wavelengths that your eyes might not normally see.



Landsat 7 images of Washington D.C., Baltimore and the Chesapeake Bay area in Maryland. A true color image using ETM+ bands 3,2 and 1 is on the left and a false color image using ETM+ bands 4,3 and 2 is on the left.

To better understand this concept, it might be helpful to first study electromagnetic radiation. All objects emit radiation, albeit in various amounts and at differing wavelengths. Radiation travels in a wave-like manner and the distance between wave peaks is known as the wavelength. When organized by wavelength and frequency, these emissions collectively form the electromagnetic spectrum.

- NASA's Landsat Program. The Landsat 7 Compositor

http://landsat.gsfc.nasa.gov/education/compositor

References

- National Science Content Standards (*National Research Council*)
- Virtually Hawaii (http://satftp.soest.hawaii.edu/space/hawaii)
- Remote Sensing Tutorial (*by Dr. Nick Short*)
- The World As Seen By Butterflies *(courtesy of University of Derby UK)*
- Remote Sensing Library Piece
- World of Beams (http://bc1.lbl.gov/CBP_pages/educational/WoB/home.htm)
- USGS: Earthshots (http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents)

What is the Electromagnetic Spectrum?

You probably know that you should wear sunscreen at the beach because of dangerous ultraviolet rays, but do you know what ultraviolet rays are? Can you see them? Maybe you've also heard about infrared sensors used for detecting heat. But what is infrared?

Ultraviolet rays and infrared are types of radiant energy which are outside of the human range of vision. The diagram below shows the entire electromagnetic spectrum from high frequency, short-wavelength gamma rays to low frequency, long-wavelength radio waves. Humans can only see a very small part of the electromagnetic spectrum, the visible spectrum (think of a rainbow).

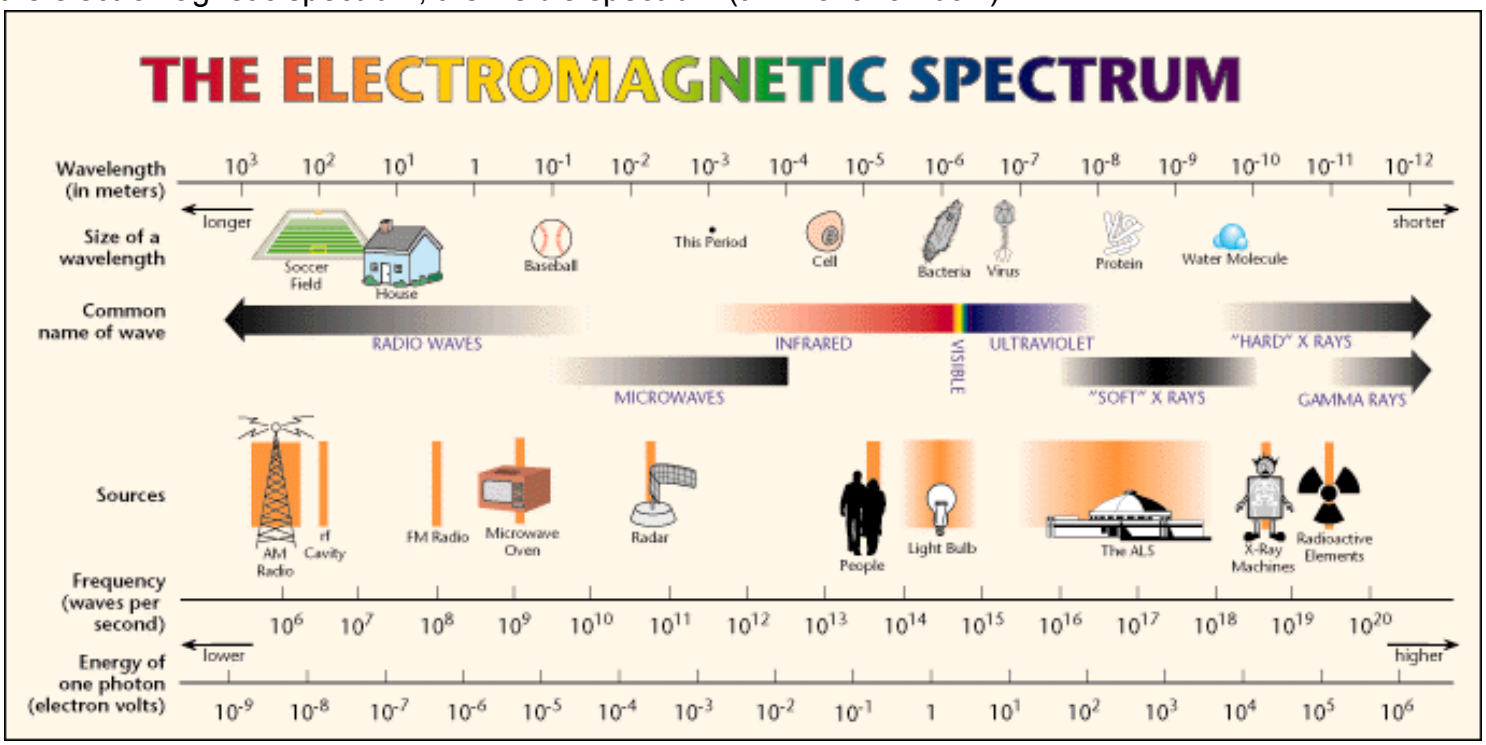


Image taken from World of Beams

Many insects are able to detect wavelengths that humans are not able to see. Bees, for example, can detect three colors: ultraviolet, blue, and yellow, but not red. The ability to see red is actually rare for all insects. The butterfly is an exception to this rule. Butterflies are believed to have the widest visual range of any animal. Various species of butterfly can detect wavelengths anywhere from 310 nm to 700 nm. To humans, male and female butterflies may look the same, but butterflies are able to identify each other easily because of ultraviolet markings on their wings. Butterflies and insects are also attracted to ultraviolet nectar of certain flowers. The photos below other simulate how humans, bees, and butterflies see the same flower.

- NASA's Landsat Program. The Landsat 7 Compositor

http://landsat.gsfc.nasa.gov/education/compositor

Himalyan balsam (policeman's helmet)- Impatiens glandulifera

Human Vision

Bee Vision Simulation

Butterfly Vision Simulation

Images taken from The World as Seen by Butterflies

Think:

- What light can a human detect, but not a bee?
- What light can a bee detect, but not a human?
- Is there any light the human or bee can detect, but not the butterfly? How can you tell?

The ability to detect light beyond the visible spectrum is not only helpful to insects. Humans can benefit from seeing non-visible wavelengths as well. How is this if we can only see visible light?

- NASA's Landsat Program. The Landsat 7 Compositor

http://landsat.gsfc.nasa.gov/education/compositor/

Humans cannot see light past the visible spectrum, but satellites are able to detect wavelengths into the ultraviolet and infrared. Satellites, like Landsat 7, fly high above the earth, using instruments to collect data at specific wavelengths. These data can then be used to build an image. Satellite instruments are able to obtain many images of the same location, at the same time. Each image highlights a different part of the electromagnetic spectrum.

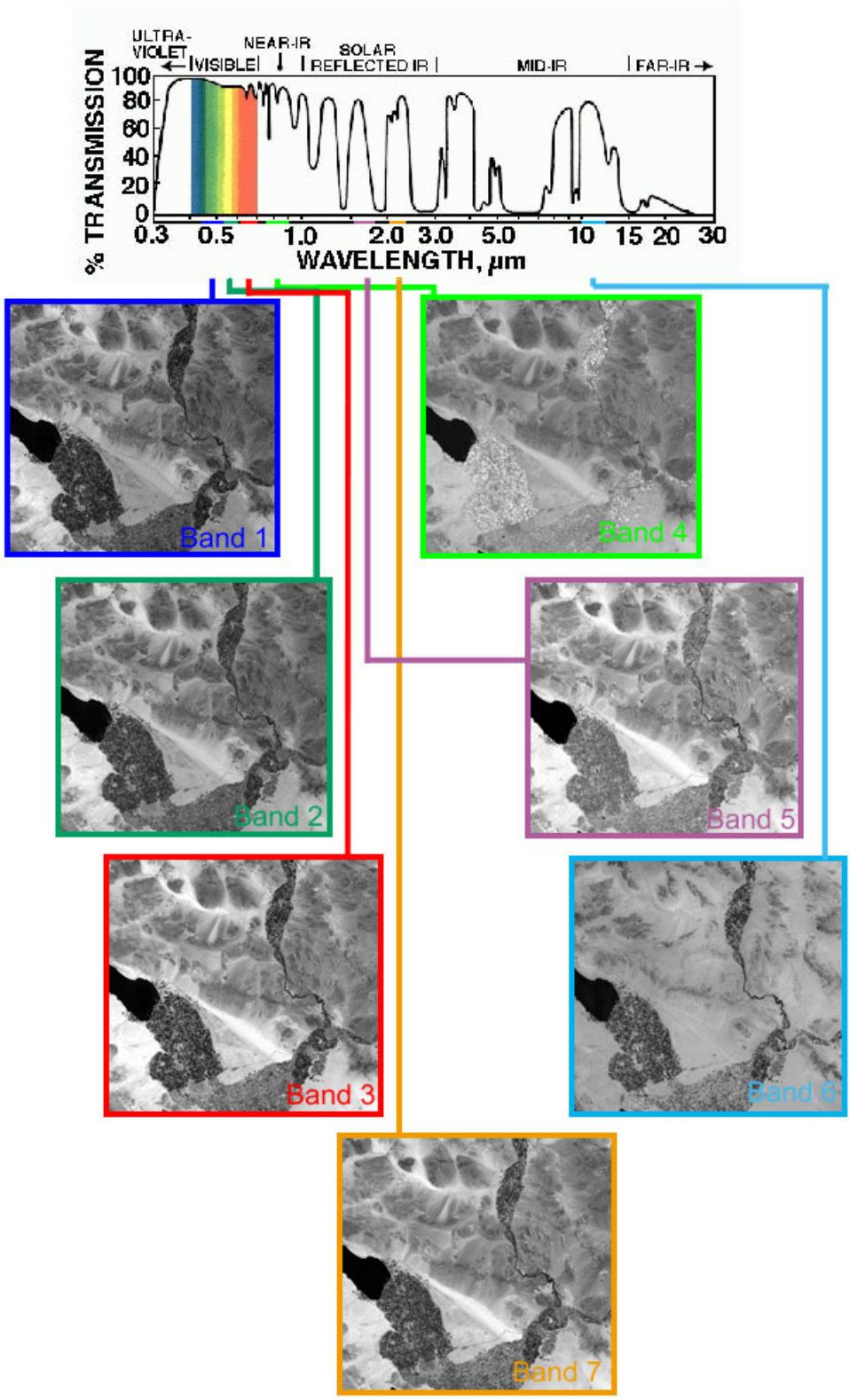
The Landsat 7 satellite uses an instrument that collects seven images at once. Each image shows a specific section of the electromagnetic spectrum, called a band. Landsat 7 has seven different bands. The table below shows the seven bands of Landsat 7.

Spectral sensitivity of Landsat 7 Bands.

Band Number	Wavelength Interval	Spectral Response
1	0.45-0.52 µm	Blue-Green
2	0.52-0.60 µm	Green
3	0.63-0.69 µm	Red
4	0.76-0.90 µm	Near IR
5	1.55-1.75 µm	Mid-IR
6	10.40-12.50 µm	Thermal IR
7	2.08-2.35 µm	Mid-IR

- NASA's Landsat Program. The Landsat 7 Compositor

http://landsat.gsfc.nasa.gov/education/compositor/

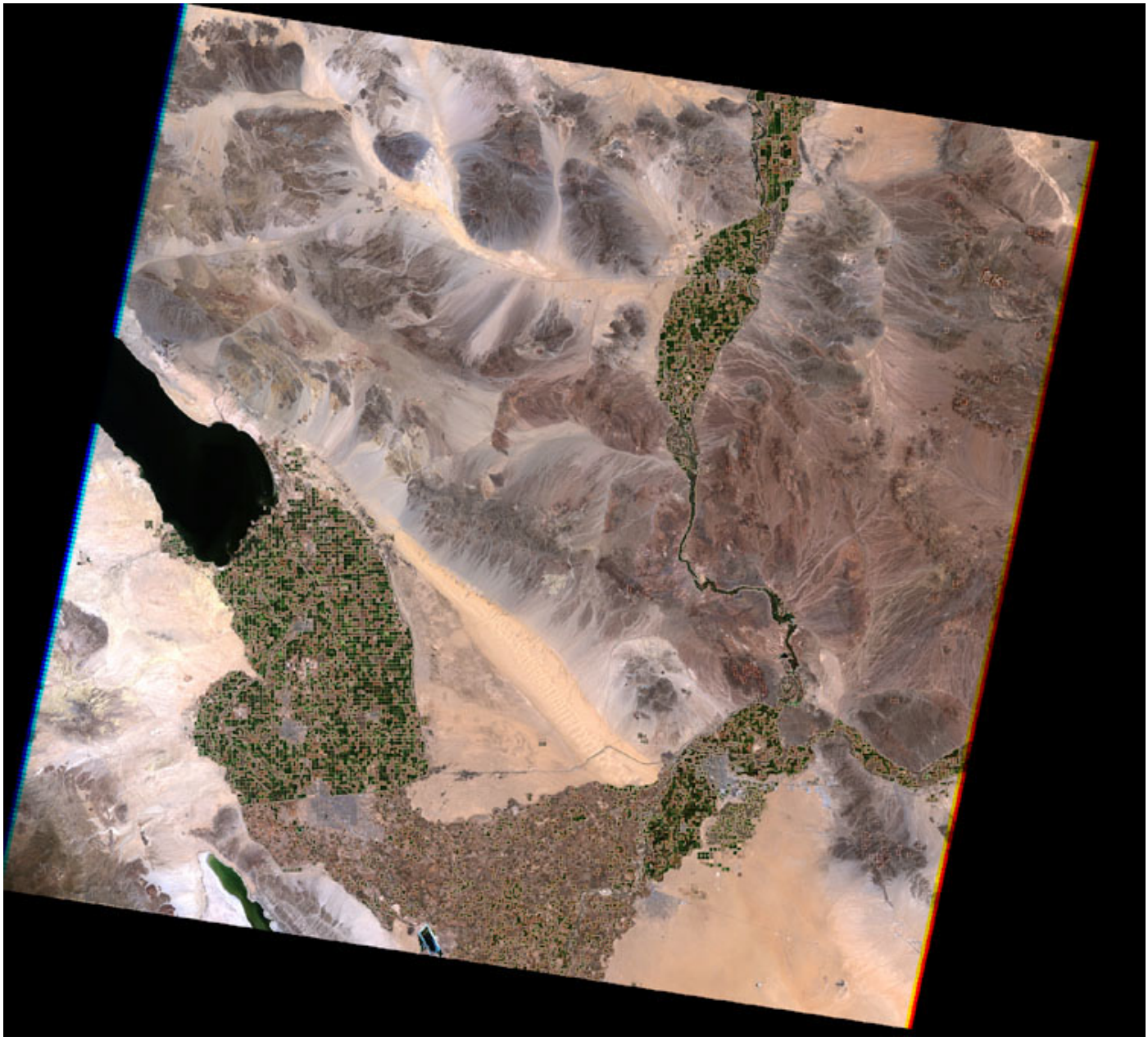


Electromagnetic Spectrum Image from Virtual Hawaii.

- NASA's Landsat Program. The Landsat 7 Compositor

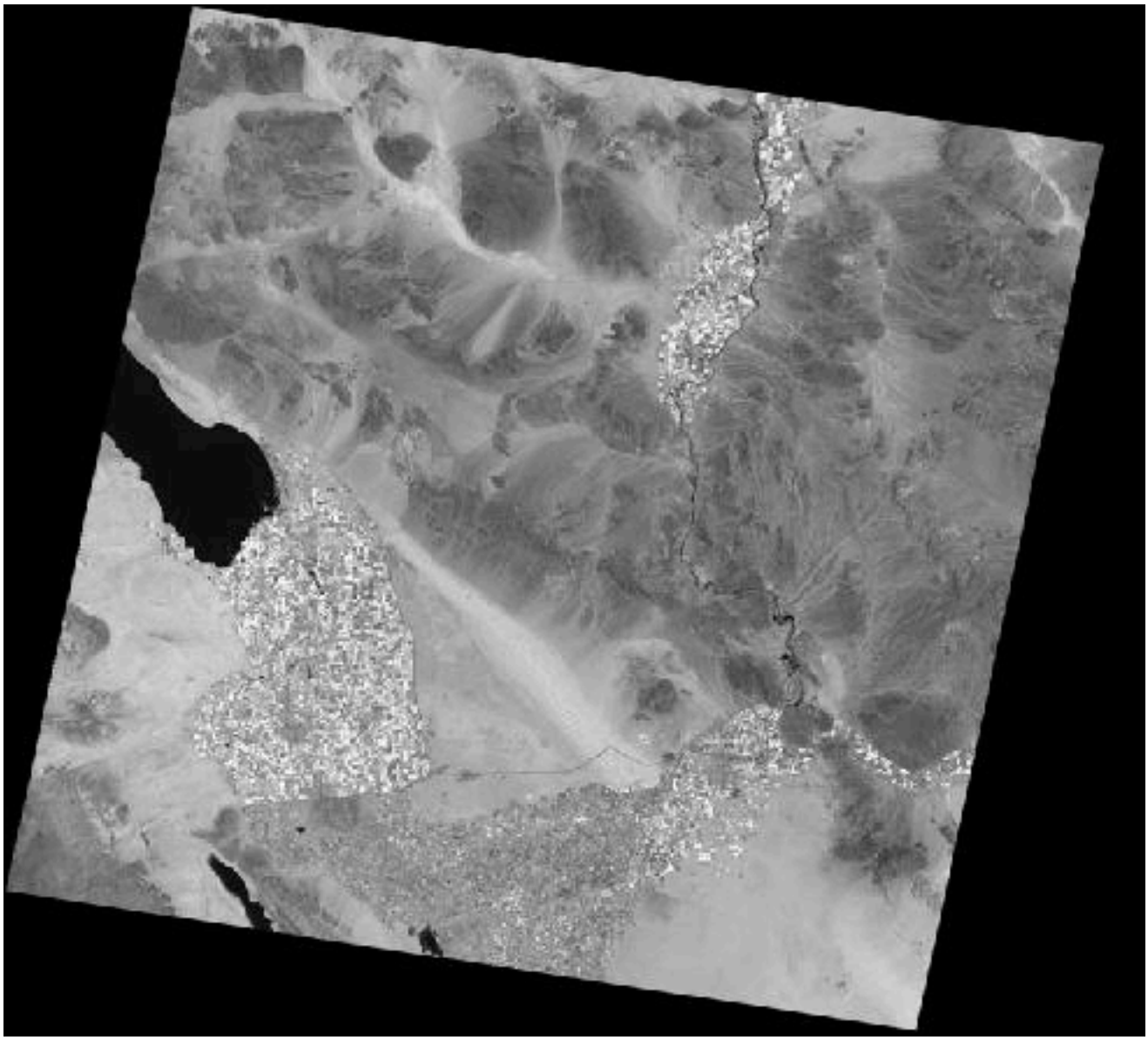
http://landsat.gsfc.nasa.gov/education/compositor/

All of the images on the previous page were obtained by Landsat 7 at the same time, and at the exact same location. If you look closely at the images, you will see that they do not all look the same. Light and dark spots in the images appear in different places. This is because different objects on earth (plants, soil, water, etc.) reflect different wavelengths of light. The bright spots on the images show where a lot of light is being reflected.



The image above is a "true color" image of the desert around the Salton Sea and Imperial Valley in Southern California. The American/Mexican border is clearly visible.

- NASA's Landsat Program. The Landsat 7 Compositor
http://landsat.gsfc.nasa.gov/education/compositor/



In this Band 4 image, the light areas indicate strong reflection of wavelengths between 0.76 and 0.90 µm; the darker areas do not strongly reflect in those wavelengths. What do you think the light areas are?

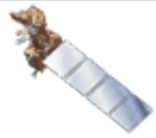
- NASA's Landsat Program. The Landsat 7 Compositor

http://landsat.gsfc.nasa.gov/education/compositor/

Landsat 7 Band Number	Applications
1	coastal water mapping, soil/vegetation discrimination, forest classification, man-made feature identification
2	vegetation discrimination and health monitoring, man-made feature identification
3	plant species identification, man-made feature identification
4	soil moisture monitoring, vegetation monitoring, water body discrimination
5	vegetation moisture content monitoring
6	surface temperature, vegetation stress monitoring, soil moisture monitoring, cloud differentiation, volcanic monitoring
7	mineral and rock discrimination, vegetation moisture content

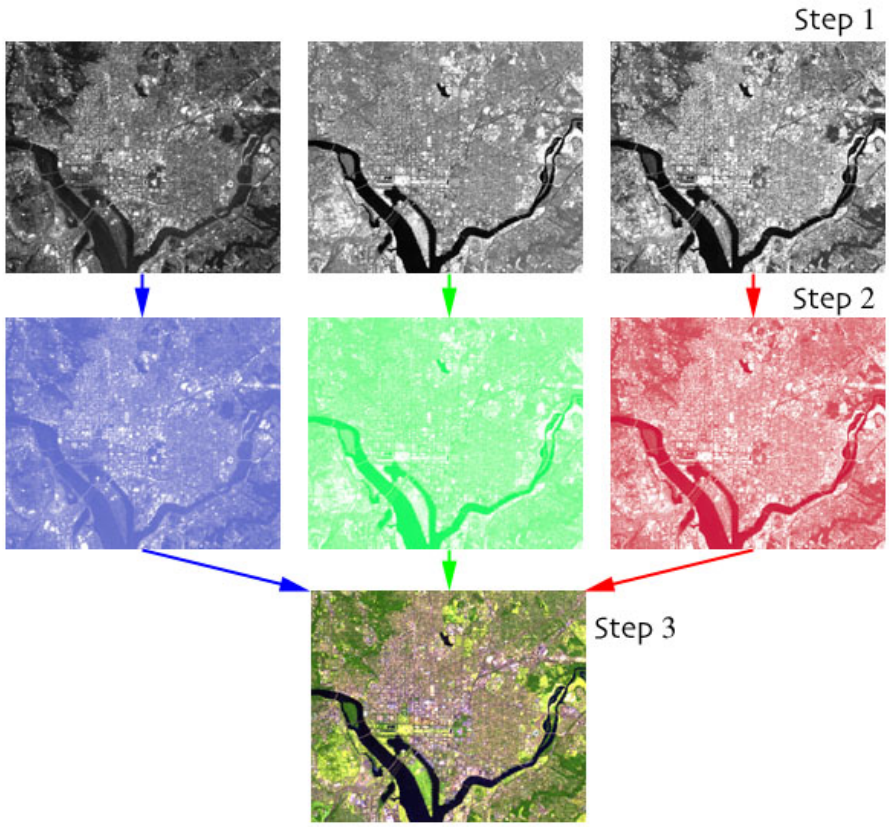
For more details see: Lillesand, T. and Kiefer, R., 1994. *Remote Sensing and Image Interpretation*. John Wiley and Sons, Inc., New York, p. 468.

How are color satellite images created?



Satellites acquire images in black and white, so how is it possible to create the beautiful color images that we see on television, in magazines, and on the internet? Computers provide us with the answer.

Remember that images created using different bands (or wavelengths) have different contrast (light and dark areas). Computers make it possible to assign "false color" to these black and white images. The three primary colors of light are red, green, and blue. Computer screens can display an image in three different bands at a time, by using a different primary color for each band. When we combine these three images we get a "false color image".



To really understand a false color image, we must know which band was assigned to each of the three colors.

- NASA's Landsat Program. The Landsat 7 Compositor

http://landsat.gsfc.nasa.gov/education/compositor/

Think:

- Why can a false color image only display three bands at a time?
- Why do we call colored satellite images "false color images"?
- Why is it important to know which band was assigned to each color in "false color" images?

- NASA's Landsat Program. The Landsat 7 Compositor
http://landsat.gsfc.nasa.gov/education/compositor/

How do primary colors mix to represent reflection?

RGB = NRG

Landsat 7 images are color composites, made by assigning the three primary colors to three bands of the Enhanced Thematic Mapper (ETM+) sensor. These images are not color photographs, they are "false color" images (green fields won't necessarily look green in the image).

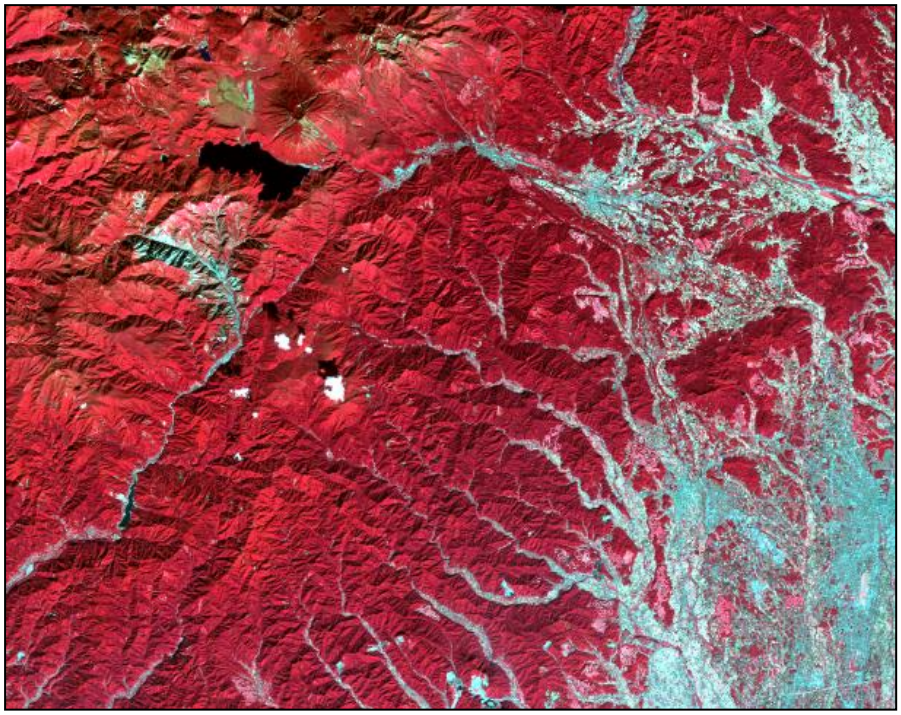
One common way that primary colors are assigned to bands can be easily remembered using the mnemonic -

RGB = NRG (Red, Green, Blue = Near Infrared, Red, Green, or "energy")

Red = Near IR (ETM+ band 4)

Green = Red (ETM+ band 3)

Blue = Green (ETM+ band 2)



This image uses Landsat ETM+ Bands 4,3,2. The image depicts an area just north of Tokyo, Japan.

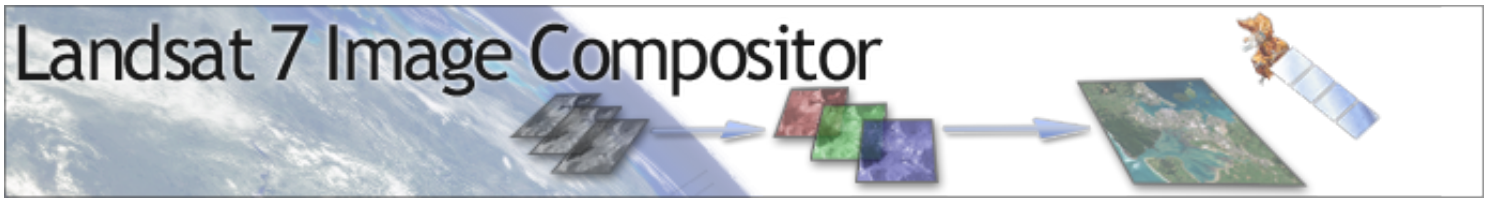
- NASA's Landsat Program. The Landsat 7 Compositor

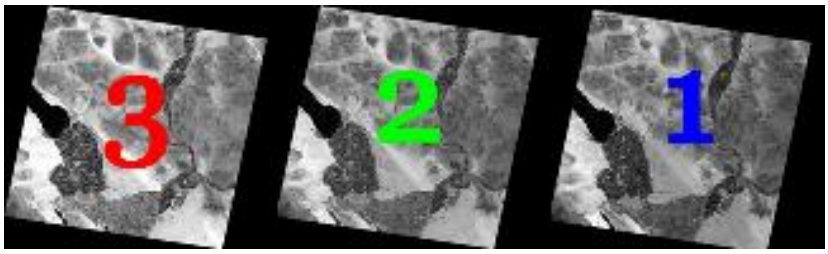
http://landsat.gsfc.nasa.gov/education/compositor/

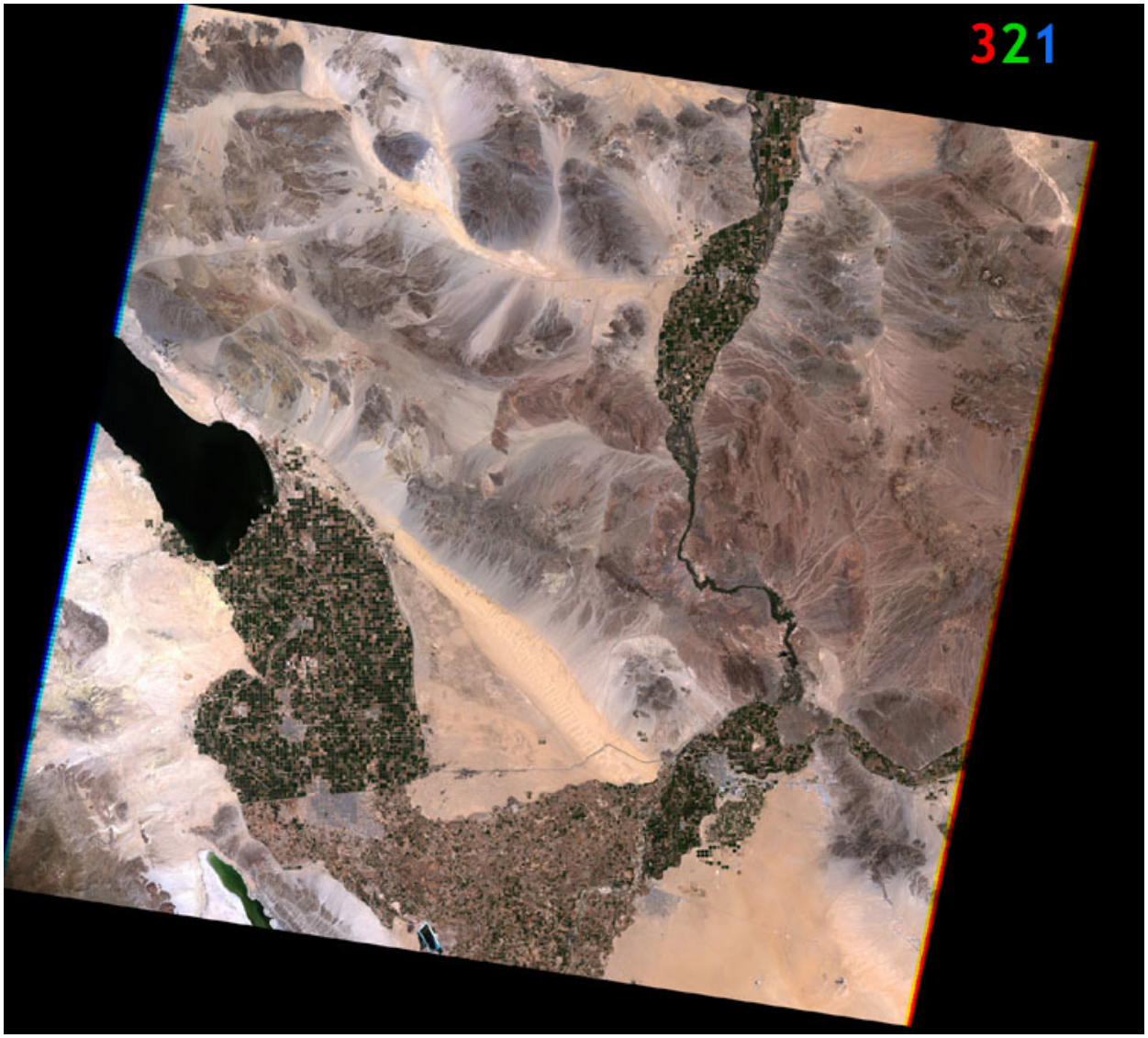
This common band combination makes vegetation appear as shades of red, because vegetation reflects a lot of near infrared light. The brighter the red, the healthier the vegetation. Soils with little or no vegetation will range from white (for sand) to greens and browns, depending on moisture and organic matter content. Water will range from blue to black. Clear, deep water is dark, and sediment-laden or shallow water appears lighter. Urban areas look blue-gray. Clouds and snow are both white.

This assignment of colors is only one of many possible combinations. Any combination of bands can be represented by red, green, and blue. In the following activity you will have the opportunity to manipulate the seven bands of Landsat 7.

- NASA's Landsat Program. The Landsat 7 Compositor
http://landsat.gsfc.nasa.gov/education/compositor/







- NASA's Landsat Program. The Landsat 7 Compositor

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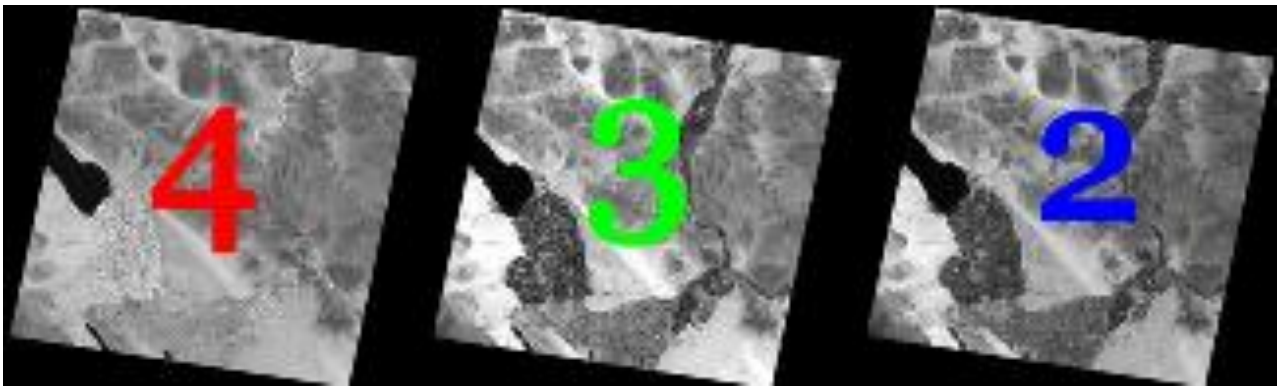

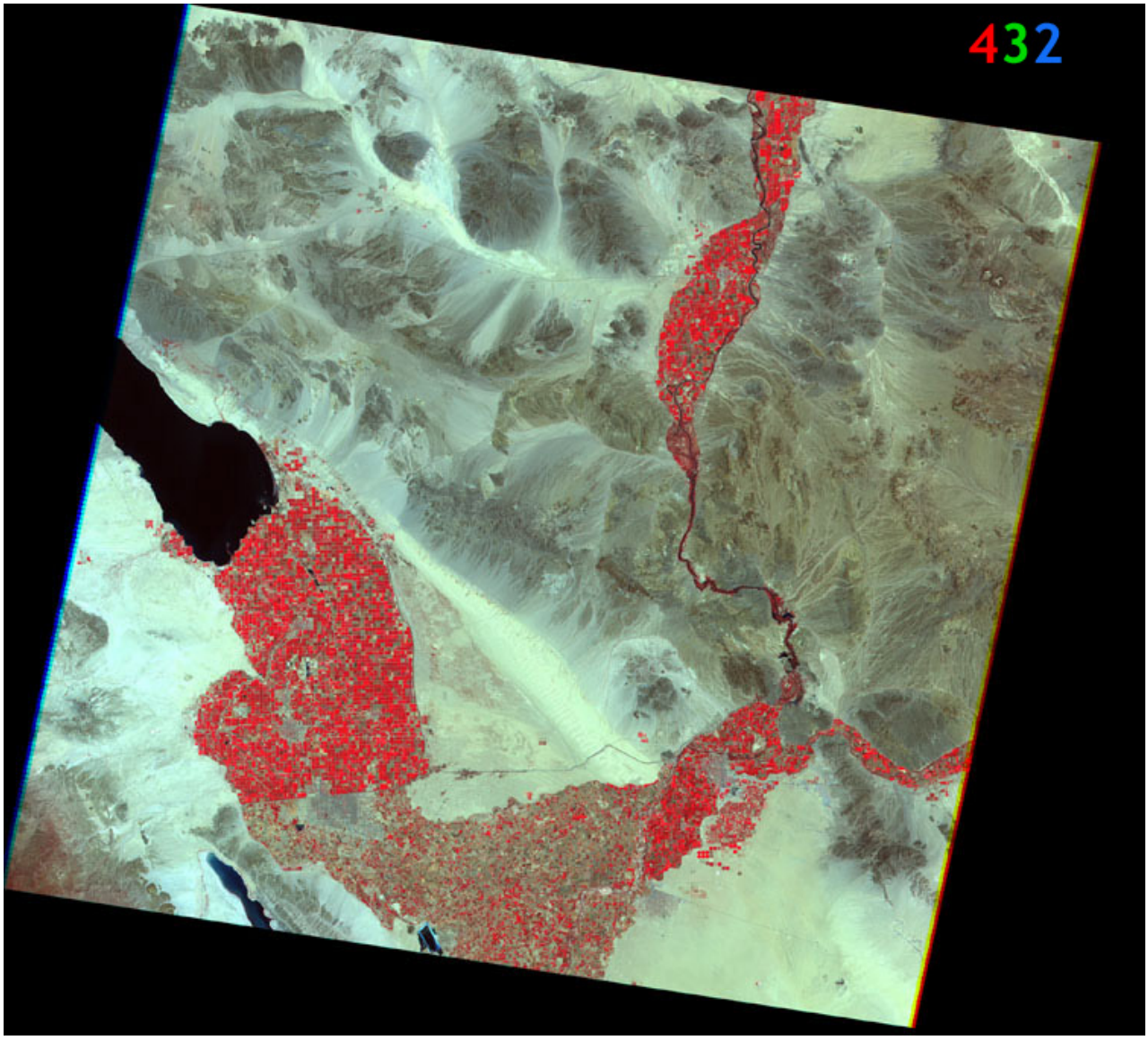

- NASA's Landsat Program. The Landsat 7 Compositor
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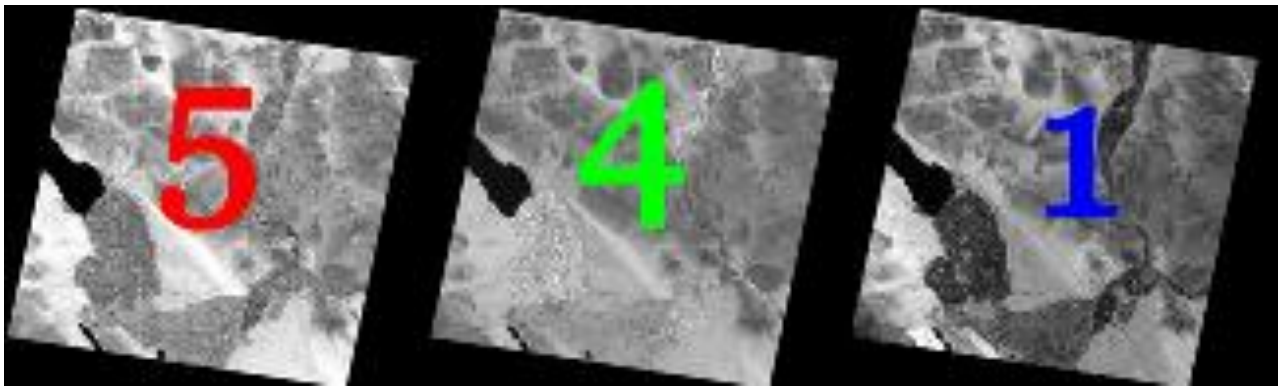

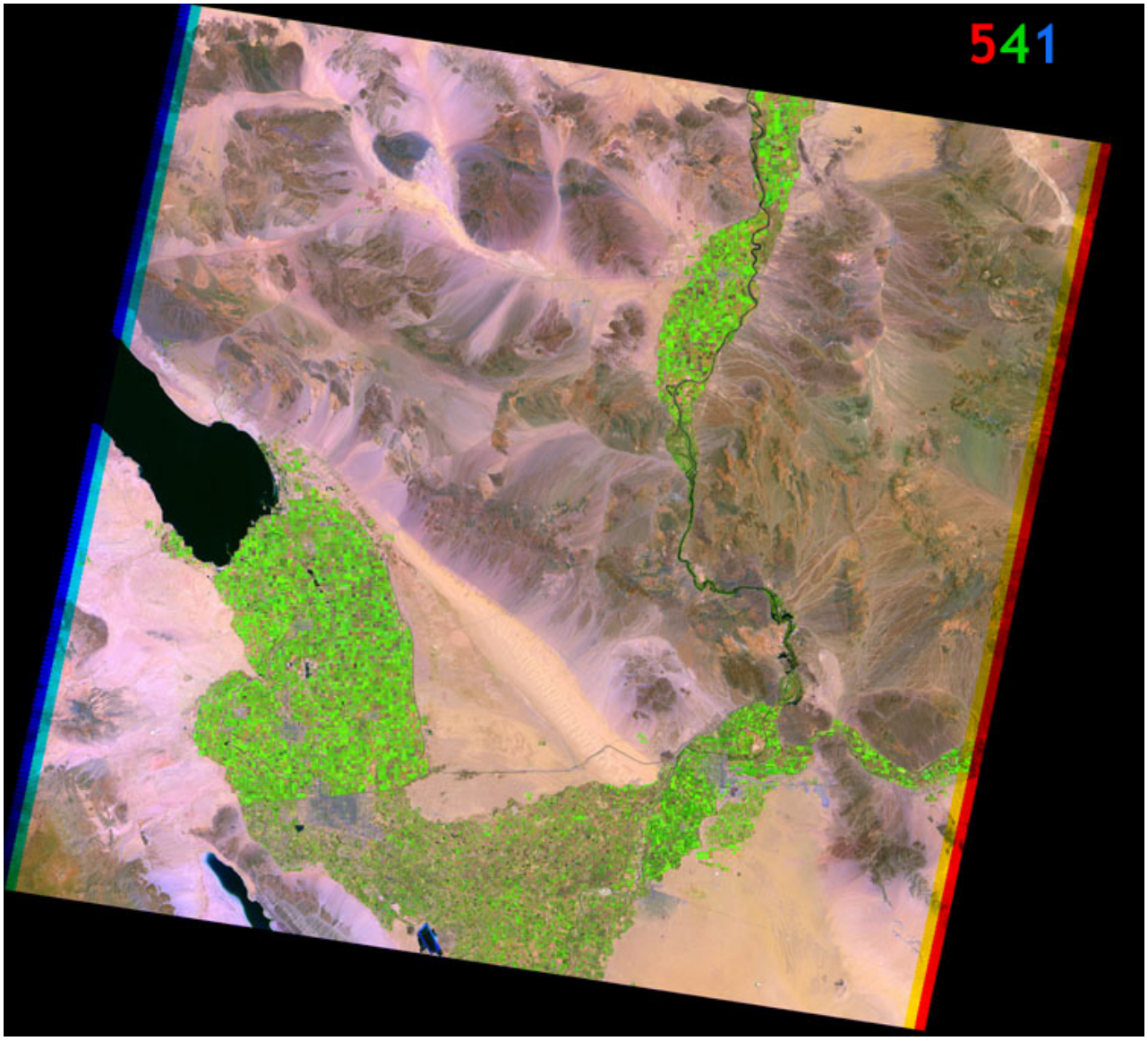

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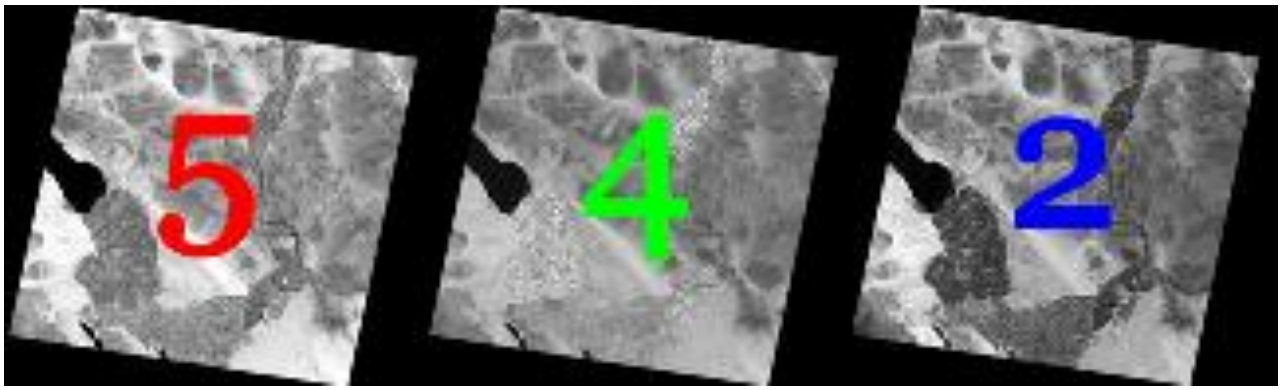

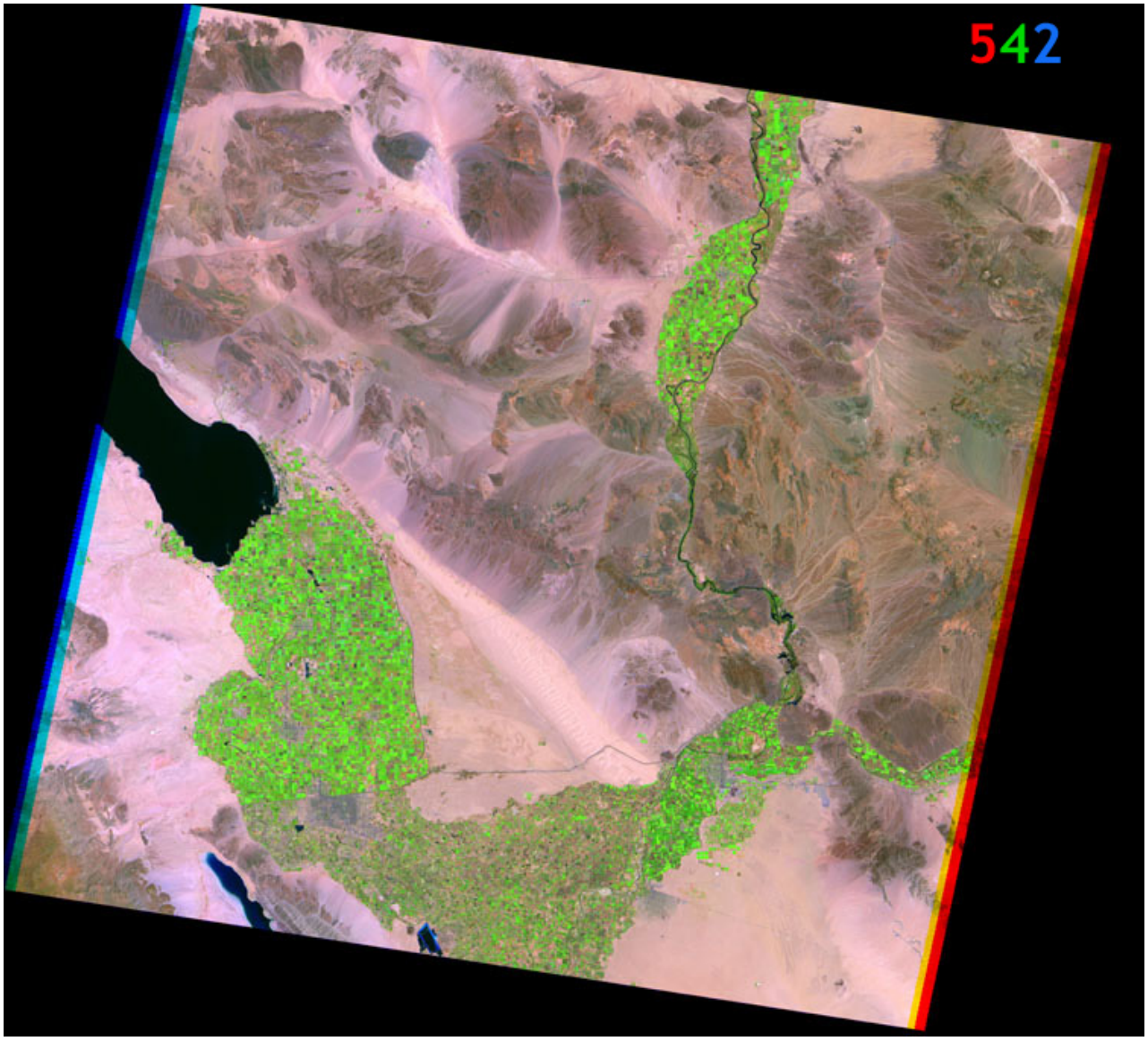

- NASA's Landsat Program. The Landsat 7 Compositor
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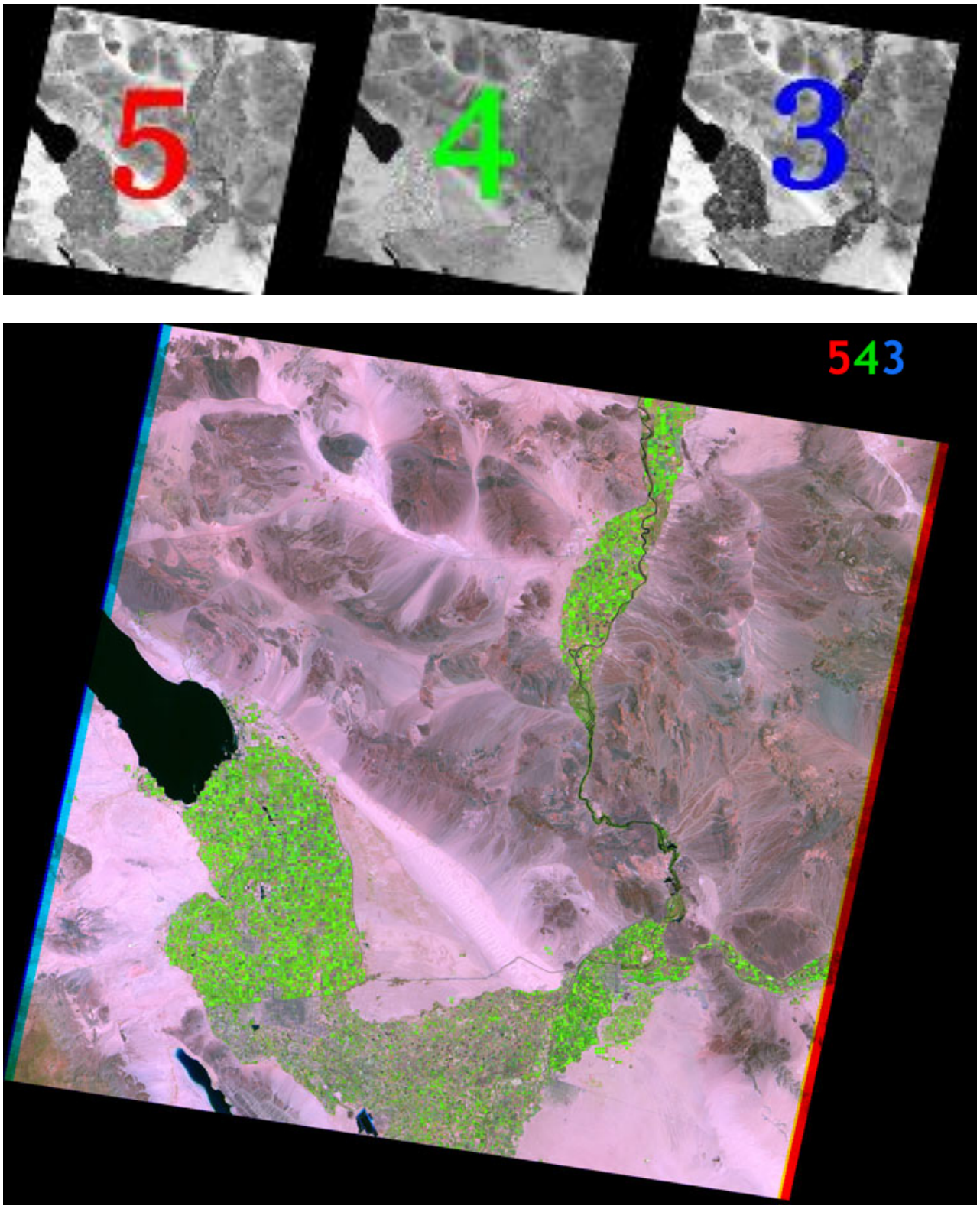

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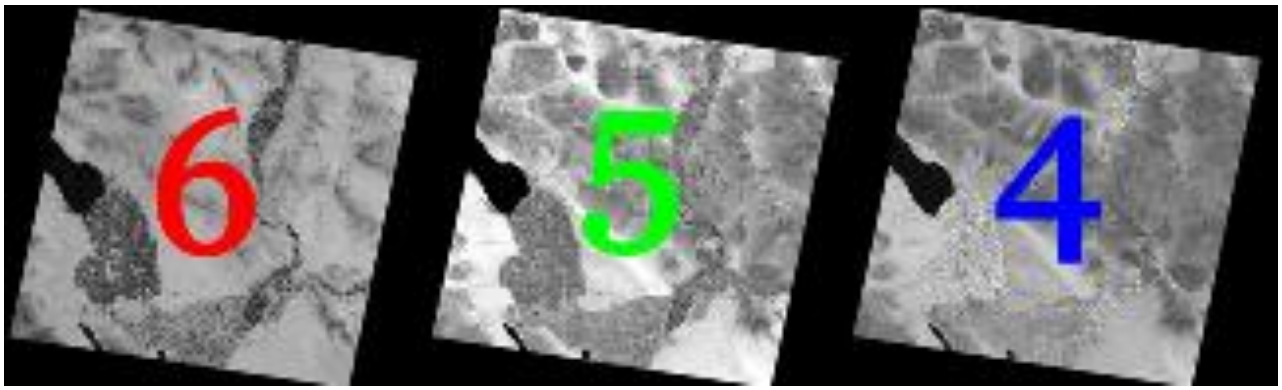

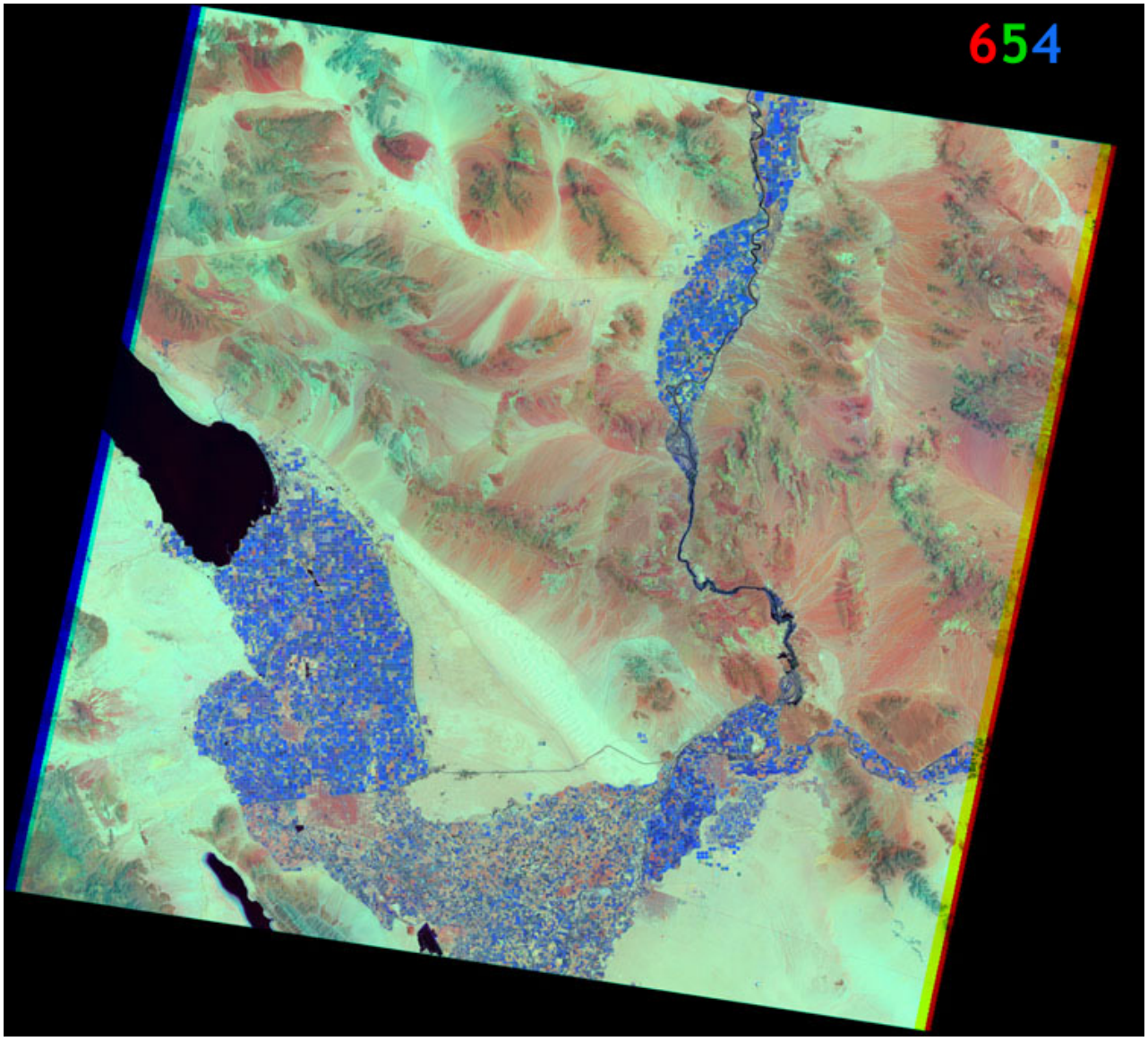

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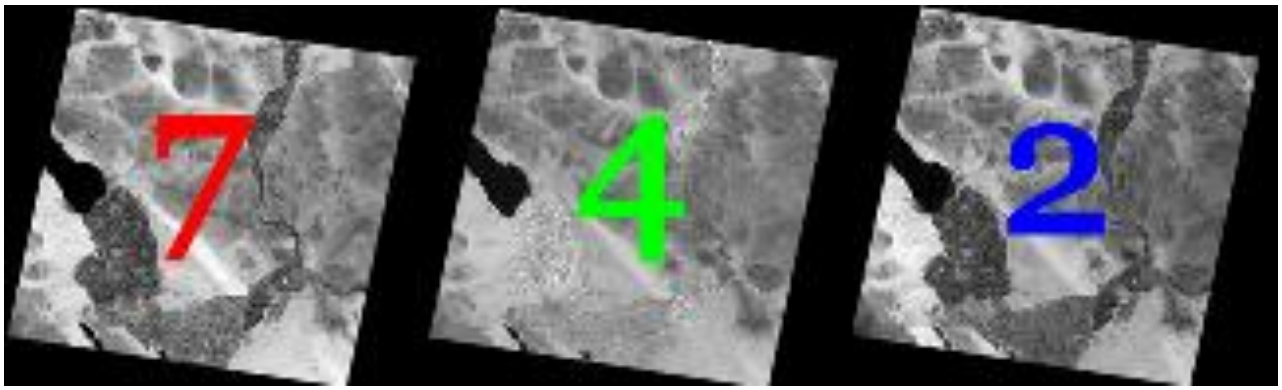

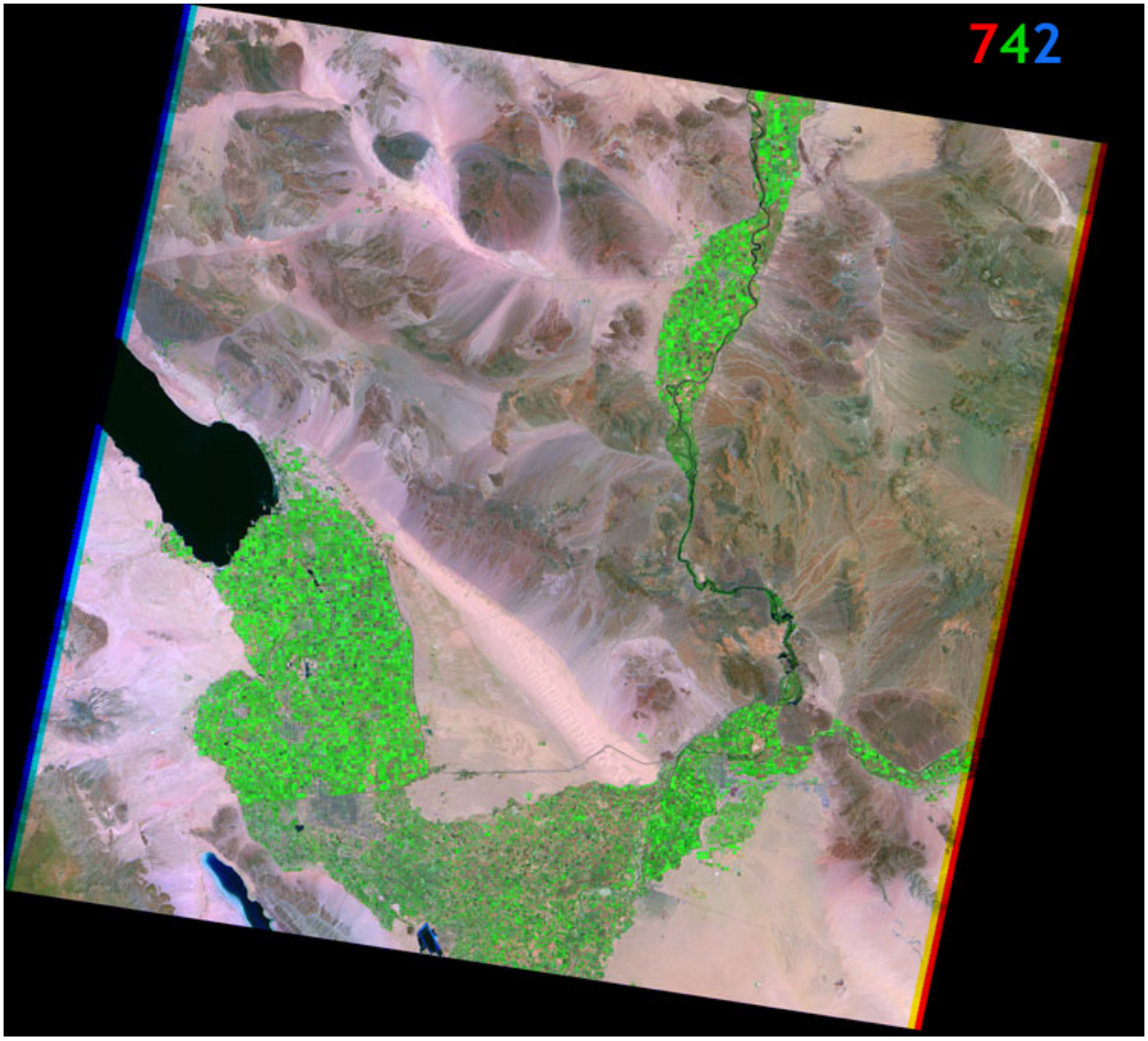

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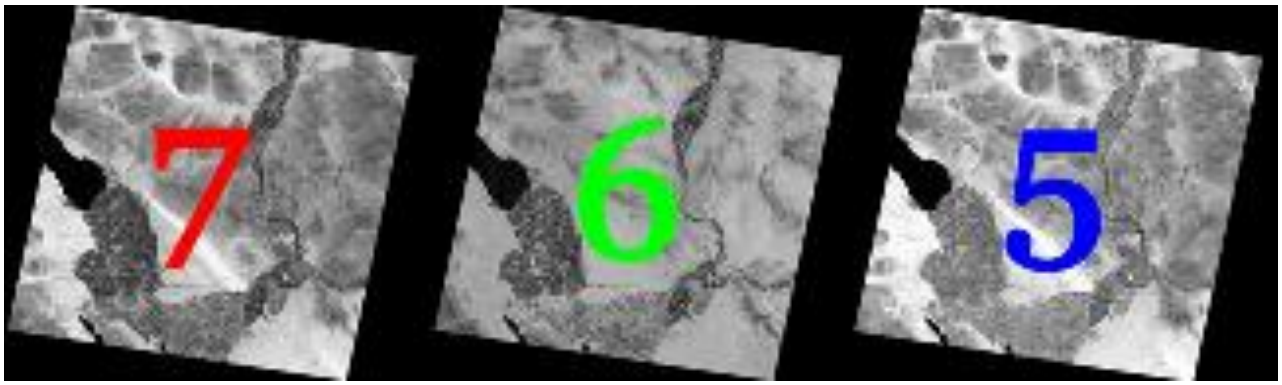

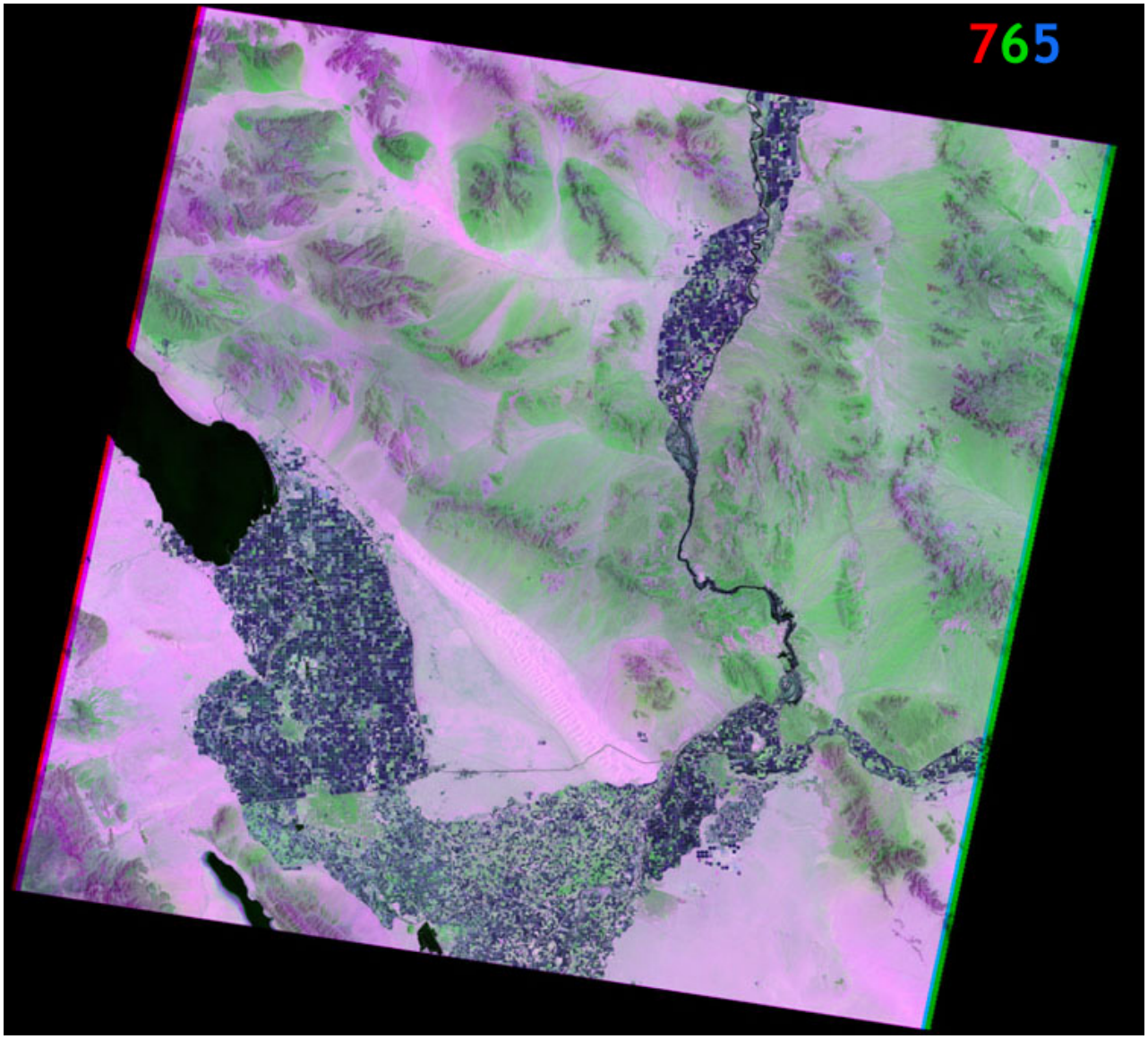

- NASA's Landsat Program. The Landsat 7 Compositor
http://landsat.gsfc.nasa.gov/education/compositor/

Applications of Landsat Data

False color satellite images can provide extremely valuable information about the world we live in. Just as butterflies benefit from their ability to detect invisible wavelengths, humans can benefit from the technology of satellite imaging.

Agriculture, Forestry and Range Resources	**Land Use and Mapping**	**Geology**	**Hydrology**	**Coastal Resources**	**Environmental Monitoring**
Discriminating vegetative, crop and timber types	Classifying land uses	Mapping major geologic features	Determining water boundaries and surface water areas	Determining patterns and extent of turbidity	Monitoring deforestation
Measuring crop and timber acreage	Cartographic mapping and map updating	Revising geologic maps	Mapping floods and flood plain characteristics	Mapping shoreline changes	Monitoring volcanic flow activity
Precision farming land management	Categorizing land capabilities	Recognizing and classifying certain rock types	Determining area extent of snow and ice coverage	Mapping shoals, reefs and shallow areas	Mapping and monitoring water pollution
Monitoring crop and forest harvests	Monitoring urban growth	Delineating unconsolidated rocks and soils	Measuring changes and extent of glacial features	Mapping and monitoring sea ice in shipping lanes	Determining effects of natural disasters
Determining range readiness, biomass and health	Aiding regional planning	Mapping volcanic surface deposits	Measuring turbidity and sediment patterns	Tracking beach erosion and flooding	Assessing drought impact

Agriculture, Forestry and Range Resources	Land Use and Mapping	Geology	Hydrology	Coastal Resources	Environmental Monitoring
Determining soil conditions and associations	Mapping transportation networks	Mapping geologic landforms	Delineating irrigated fields	Monitoring coral reef health	Tracking oil spills
Monitoring desert blooms	Mapping land-water boundaries	Identifying indicators of mineral and petroleum resources	Monitoring lake inventories and health	Determining coastal circulation patterns	Assessing and monitoring grass and forest fires
Assessing wildlife habitat	Citing transportation and power transmission routes	Determining regional geologic structures	Estimating snow melt runoff	Measuring sea surface temperature	Mapping and monitoring lake eutrophication
Characterizing forest range vegetation	Planning solid waste disposal sites, power plants and other industries	Producing geomorphic maps	Characterizing tropical rainfall	Monitoring and tracking 'red' tides	Monitoring mine waste pollution
Monitoring and mapping insect infestations	Mapping and managing flood plains	Mapping impact craters	Mapping watersheds	Coral reef health assessment	Monitoring volcanic ash plumes
Monitoring irrigation practices	Tracking socioeconomic impacts on land use	Chevron discovery	Mapping closed-basin ponds	Global coral reef mapping	Assessing carbon stocks
Bison management	Online mapping	Mega-lake discovery	Monitoring wetlands	Chesapeake Bay restoration	Cancer research
Crop production estimates	Cartographic discoveries	Soil carbon flux	Water management	Monitoring coastal erosion	Atmospheric modeling

Agriculture, Forestry and Range Resources	Land Use and Mapping	Geology	Hydrology	Coastal Resources	Environmental Monitoring
Quantifying burn severity	Mapping Antarctica		Wetland restoration	Coastal Studies	Mapping Rift Valley Fever risk areas
Fighting crop insurance fraud	Fighting hunger		Monitoring dam construction	Chesapeake Bay management	Assessing clear-cutting impacts
Forest trends in Madagascar	Urban sprawl and climate change		Groundwater discharge		Assessing impacts of industrial logging
Forest protection in Peru	Caribbean Island mapping		Bushfire impact on water yields		Mapping urban heat islands
Better Estimate of Boreal Forest Loss	Tropical forest clearing for development				Landsat, Potholes, and Climate Change
Crop water stress	Exploring ancient Mexico				Disaster aftermath
Crop water demand	Landsat Image Mosaic of Antarctica				African environmental change
Rice production monitoring	Kansas Map				Cyclone Nargis' impact on Burma
Demise of Papua New Guinea forests					Fire prevention in Spain
Monitoring conservation tillage					Surveying mangroves
North American forest disturbance					Greek fires

Agriculture, Forestry and Range Resources	Land Use and Mapping	Geology	Hydrology	Coastal Resources	Environmental Monitoring
Forest damage caused by Hurricane Katrina					Glacier monitoring
Sumatran deforestation					Algea monitoring

- NASA's Landsat Program. The Landsat 7 Compositor
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