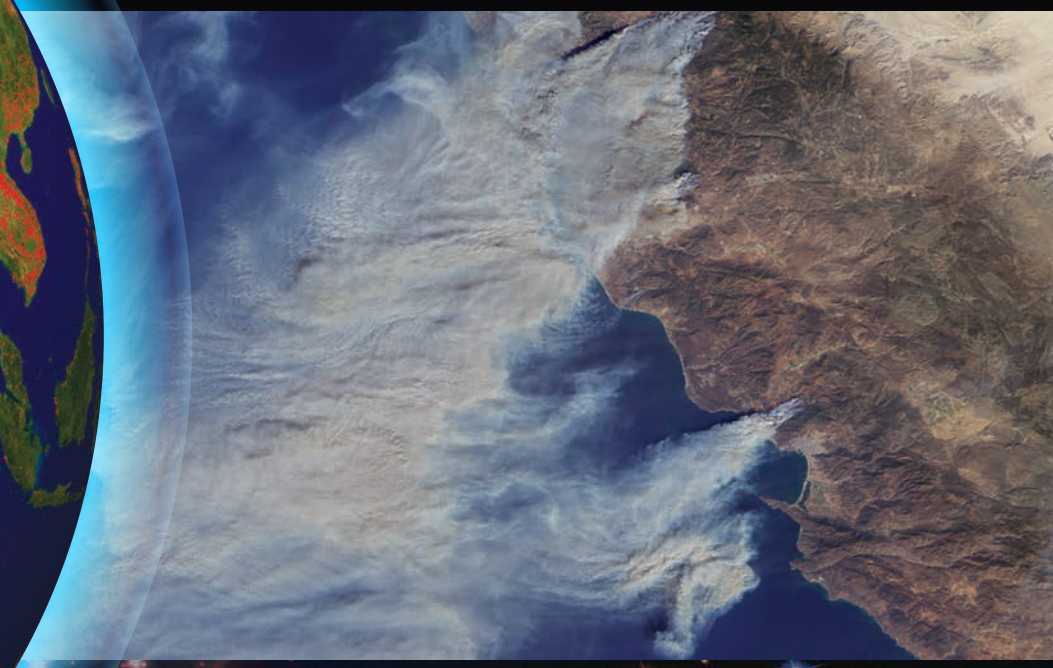
National Aeronautics and
Space Administration

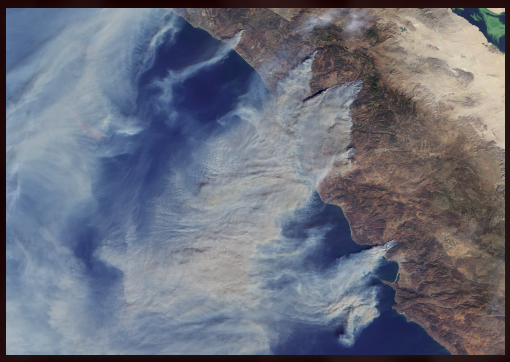
Understanding Earth
Biomass Burning



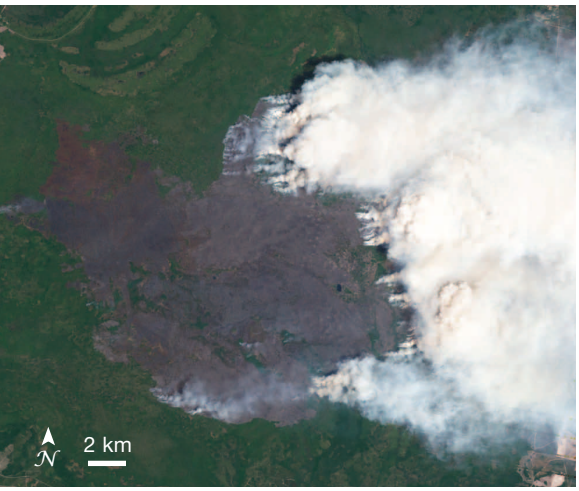
Understanding Earth | Biomass Burning

The Landsat 5 satellite captured this image on April 9, 2011, as fires burned in northern Mexico's Coahuila state. The fires—named El Bonito and La Sabina—were caused by lightning strikes in mid-March. By April 11, the fires had burned 245,000 acres (382 square miles). Lack of winter rain and frost left the plants dry and prone to fire. Lightning and strong, steady winds with gusts up to 70 miles per hour created the perfect conditions for a dangerous, fast-moving wildfire.

UNDERSTANDING EARTH:
Biomass Burning



On the cover: The Multi-angle Imaging SpectroRadiometer (MISR) instrument flying aboard the Terra satellite captured this image on October 26, 2003, as several massive wildfires burned across southern California.



Plumes of smoke billowed into the sky after lightning started the Honey Prairie Fire in the Okefenokee Swamp in southern Georgia. Nearly 61,850 acres (96 square miles) had burned when the Landsat 7 satellite captured this image on May 8, 2011. As fire helps restore the prairie's ecosystem, fire managers allowed the fire to burn until heavy rains put it out.

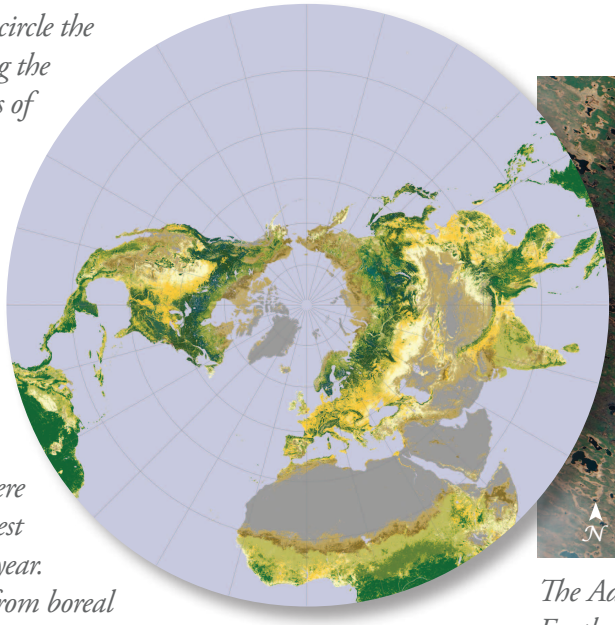
What is Biomass?

Biomass is living or once-living biological material. Strictly speaking then, all life is biomass. All plants and animals on Earth today will at some point die and decay—*ashes to ashes, dust to dust*. In most cases, however, when we use the term in this brochure, we are referring to vegetation—living or dead.

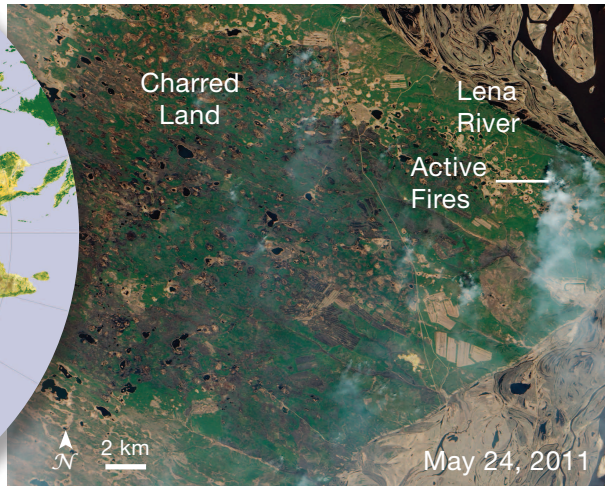
Biomass Burning

Biomass burning is the act of burning living, or once-living, biological material. Formerly believed to occur mainly in the tropics, Earth-observing satellites have revealed a global distribution of biomass burning. Although huge fires, often visible from space, occur in the savanna grasslands of Africa and South America and tropical forests in South America and Southeast Asia, they can take place wherever vegetation is abundant. *Boreal forests* for example—found at much higher latitudes—are major sources of biomass burning.

Biomass burning results from either: 1) natural processes, such as ignition by lightning strikes; or 2) anthropogenic (i.e., human-induced) activity, such as burning vegetation for agricultural land clearing and preparing existing fields for planting. Although natural and anthropogenic biomass burning can occur almost anywhere on the globe, the majority of biomass burning in the tropics stems from human causes, whereas in extra-tropical regions—such as boreal forests—natural causes are more common.



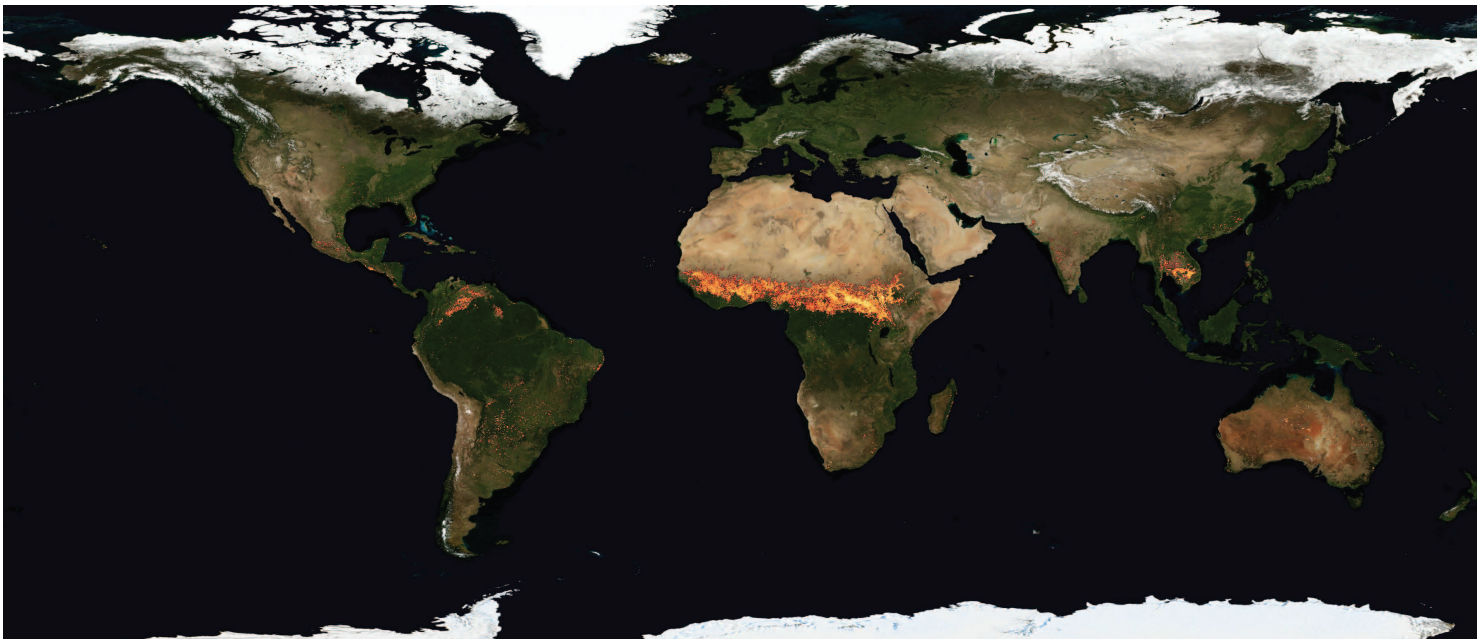
Boreal forests encircle the Arctic, occupying the northern reaches of North America and Eurasia. Depicted in dark green, boreal and other forest types cover large portions of the Northern hemisphere, where thousands of forest fires occur each year. Smoke plumes from boreal forest fires were the focus of study during NASA's ARCTAS field campaign mission. For more information about ARCTAS see page 9.



The Advanced Land Imager (ALI) on NASA's Earth Observing-1 (EO-1) satellite captured the image above just after fire swept through forests near Yakutsk, Russia. In this scene, charred land is visible, along with smoke from active fires still burning near the Lena River.

BURN FACT: *Slash-and-burn* is an agricultural practice aimed at preparing land to grow crops quickly and efficiently in areas that were once forested. Trees and other living ground cover are cut down, left to dry, and then burned, so the nutrient-rich ashes can fertilize new crops. The resulting deforestation, biodiversity loss, greenhouse gas emissions, and subsequent erosion all damage the environment. This practice is most common in Southeast Asia, Africa, and South America.

The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, aboard the NASA Earth-observing System's Aqua satellite, captured this image [right] of fires burning in the Amazon along the Madeira River near Porto Velho, Brazil on August 7, 2010. Typically, agricultural deforestation appears in spacecraft images as tan-colored "fishbone" patterns cut into the forests, often emanating from a road. Note the small hotspots shown in red along the fringes of deforested areas, which are most likely locations of active burning.



This image depicts the density of detected fires around the globe between January 1 and February 1, 2011. Each colored dot indicates a location where the MODIS instrument detected at least one fire. Color ranges from red where the fire count is lower to yellow, where the density of fires is large. MODIS detects fires by identifying locations where the surface appears anomalously bright in a particular infrared channel (observing at about four microns wavelength).

In Northern Africa south of the Sahara Desert, the landscape transitions into a sparse, semi-arid savanna known as the Sahel. Here, extensive agricultural-related biomass burning takes place each year for several months during the Northern Hemisphere fall and winter. People set fires to clear brush, burn off crop stubble, and renew pasture grasses. This image reveals the intensity of the Northern Africa fire season compared to other places on the globe during these months.

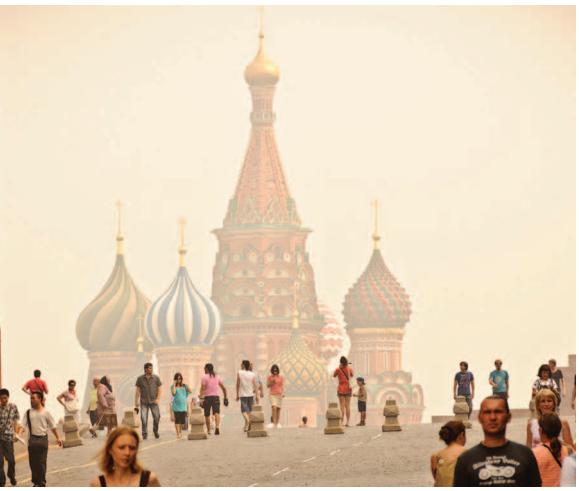
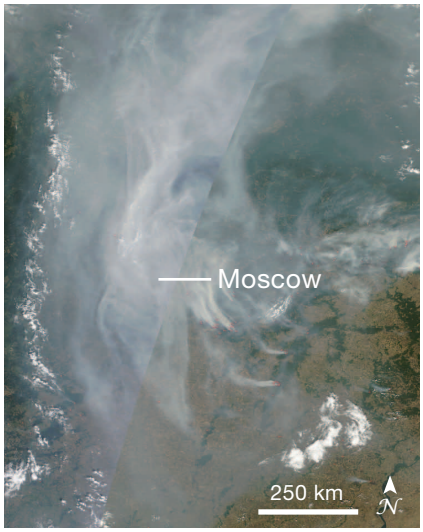


Photo credit: Christophe Chenevier

In August 2010, fires in western Russia produced dense smoke, affecting many urban areas including Moscow [above]. The fires—mainly southeast of the city—created hazardous air quality and reduced visibility to 0.01 miles (20 meters) in some places.

Wispy gray smoke blanketed western Russia [below] as fires continued to burn on August 9, 2010. This image, captured by MODIS aboard the Terra satellite, reveals smoke from fire locations southeast of Moscow.

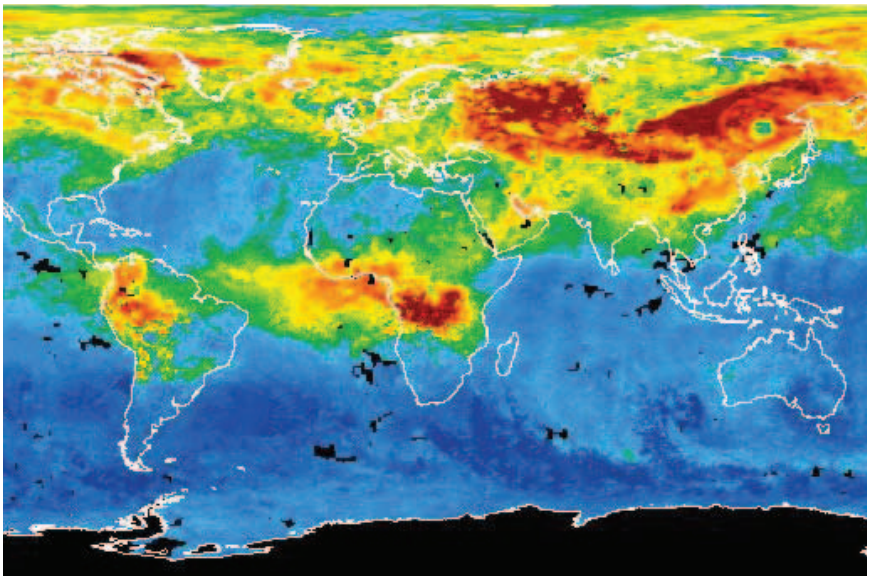


Changing Atmosphere and Ecosystems

When biomass is burned, copious amounts of gases and particulate matter are released, billowing smoke plumes can fill the sky, and entire ecosystems can change in seconds. These changes have both long- and short-term effects on Earth's atmosphere and climate system.

Biomass burning alters atmospheric composition—by releasing gases and particulate matter—affecting air quality and posing risks to human health and activity. Inhaling carbon monoxide, methane, nitrogen oxides, formaldehyde, and smoke particles can cause asthma and/or heighten other health issues.

Fire emissions include greenhouse gases, such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Greenhouse gases, together with other trace gases, lead to changes in atmospheric chemistry, such as the concentration of ozone (O_3)—another greenhouse gas. Increases in greenhouse gases (i.e., CO_2, N_2O, CH_4, O_3) affect Earth's energy balance and warm the Earth's surface, ultimately influencing Earth's climate system.



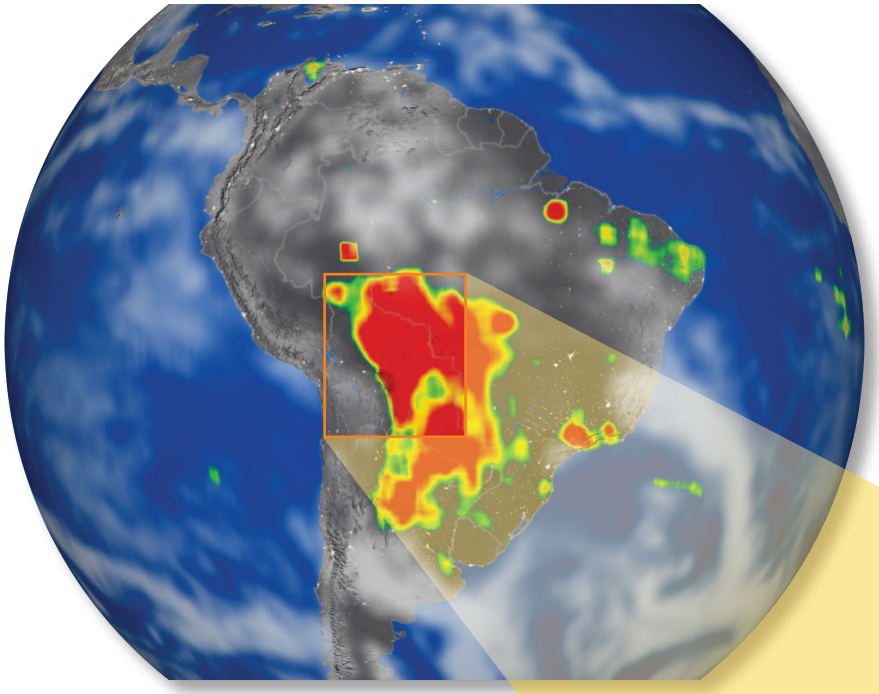
Fires produce carbon monoxide (CO) gas. This map shows the three-day global distribution of atmospheric CO from August 9–11, 2010 [highest concentrations in red], derived from observations by the Atmospheric Infrared Sounder (AIRS) instrument, flying aboard the Aqua satellite. The 2010 Russian wildfires—mainly temperate and boreal forest fires—produced high concentrations of CO across northern and central Asia. Other areas such as central Africa and western Canada, also show high concentrations likely caused by fire.

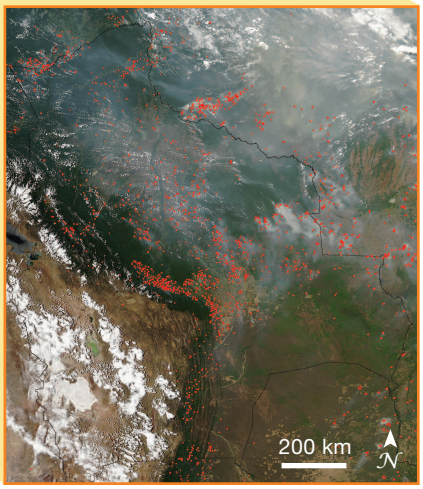
However, periodic forest fires are part of the natural cycle, and are actually beneficial. They clear out excessive brush and overgrowth, and return nutrients to the soil, helping maintain a healthy ecosystem.

Although biomass burning can have both positive and negative effects on a vegetated ecosystem, an increase in either natural or anthropogenic biomass burning events could have major repercussions for Earth's climate system. The warming of Earth's climate is expected to increase the number of warm spells, heat waves, and droughts in many regions of the world including southern and eastern Australia, eastern New Zealand, Europe, and the western United States. These changes are likely to increase the number of annual wildfires and health risks. Fortunately, scientists are able to study the location of fires and the effects of biomass burning from the vantage point of space, providing a vital global perspective on fires and how they are impacting Earth—our home.

Photo credit: Brady Smith, USDA Forest Service, Coconino National Forest.

In northern Arizona, firefighters monitor a prescribed burn in the Coconino National Forest on October 14, 2009. If natural fires are suppressed, forests and underbrush can become too dense, and when fire eventually does occur, it burns hotter and can destroy mature trees rather than just the less-well-established understory. Occasionally, Forest Service managers will prescribe burns to clear overgrowth, replenish soil nutrients, and help support biodiversity. One advantage of prescribed burns is that they can be scheduled when weather conditions pose a low risk of the fire going out-of-control.





Fires across central South America are responsible for high levels of nitrogen dioxide (NO_2)—a greenhouse gas and air pollutant produced by biomass burning. The image above shows NO_2 concentrations in the atmosphere detected by the Ozone Monitoring Instrument (OMI) aboard the Aura satellite on October 7, 2004. Red dots on the image to the right [inset], reveal active fires across Brazil and Bolivia on the same day, detected by MODIS on the Aqua satellite.

Photo credit: Wayne Clement, US Forest Service, Apache-Sitgreaves National Forests

This image, taken on June 4, 2011, reveals towering smoke clouds—named pyrocumulus clouds—produced by the Wallow Fire in Arizona. These clouds form when intense heat from the fires generates convection that propels air higher into the atmosphere.

The Wallow Fire

May 29, 2011–July 8, 2011

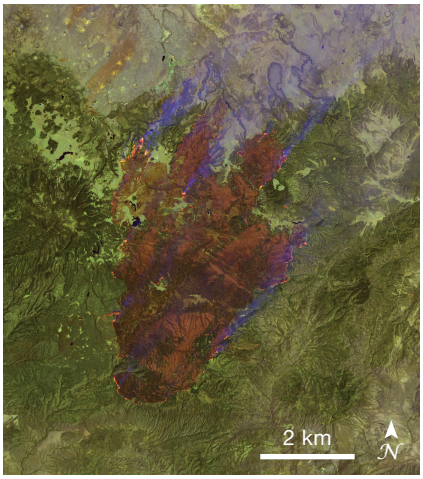
The Wallow Fire burned for nearly 41 days—984 hours—in eastern Arizona and later, portions of New Mexico before it was declared 100% contained. Nearly 540,000 acres (~843 square miles)—larger than the entire state of Idaho—were consumed by fire, making it the largest wildfire in Arizona history.

While firefighters, park officials, and community members alike worked to suppress the fire, NASA's Earth-observing satellites and instruments were busy helping out from space. Remote sensing satellite imagery is crucial for seeing the "big picture." Often times those responding on land are unable to survey and/or record the full extent of the fire and affected areas. Responders use daily satellite imagery to identify new fire locations and hotspots.

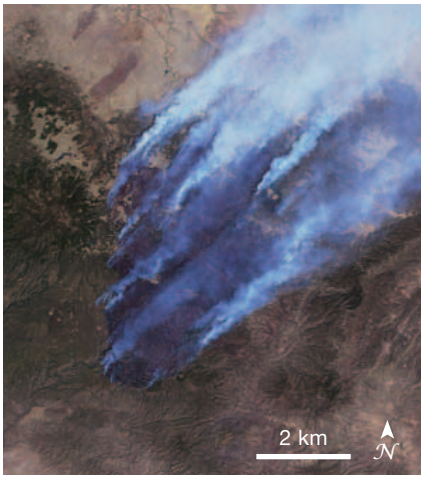
Not only do satellite images provide a unique overview of active fires from space, but they subsequently provide data used to differentiate between severely, moderately, or lightly burned land. Responders use these assessments to identify severely affected areas that may need to be stabilized. Once vegetation is burned, the soil becomes less efficient at absorbing water. As a result, even moderate rainfall can erode the soil, and trigger landslides and mud flows on steep terrain.

The three images below—each taken by a different satellite instrument—capture different aspects of the Wallow Fire in early June. In the Landsat 7 false-color image on the left, newly burnt land—shown in orange—continues to expand as fires burn around the edges. In comparison to the already scorched land, active fires appear tiny but are easy to identify by their glowing color and trailing blue smoke plumes. The Multi-angle Imaging SpectoRadiometer (MISR) instrument captured the center true-color image, revealing a wide band of opaque smoke stretching northeast from nearly ten individual fire locations in the green pine forests of the White Mountains. The border between Arizona and New Mexico is marked in the MODIS image on the right. It is easy to see how active fires—outlined in red—in one area can affect air quality in another.

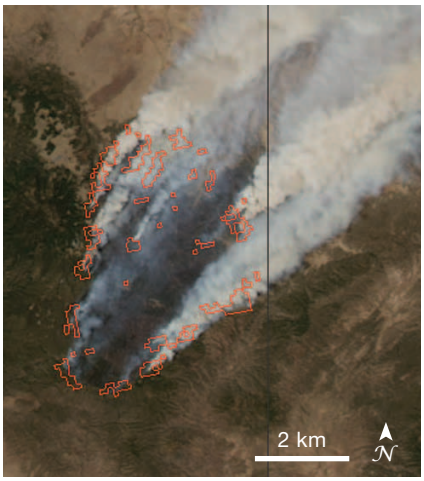
The cause of the Wallow Fire is still under investigation, but it is believed to have been started by human activity. Natural conditions such as low humidity and high wind can increase the intensity and extent of wildfires once they begin.



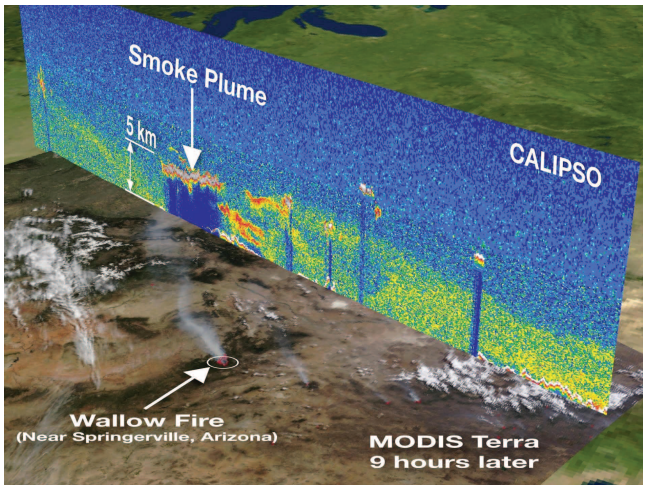
June 7, 2011—Landsat 7



June 7, 2011—MISR on Terra

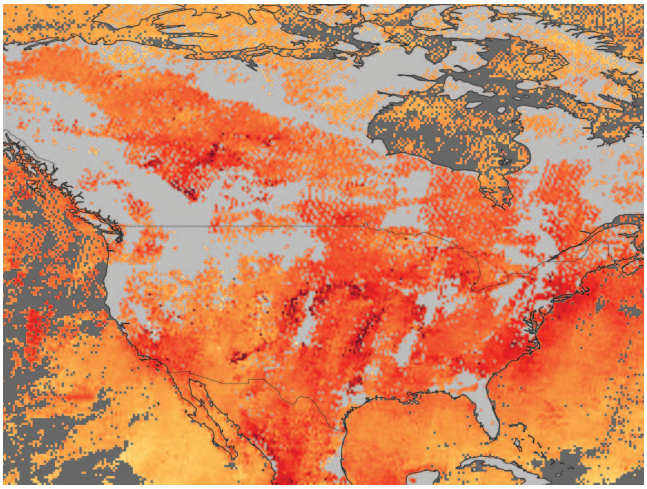


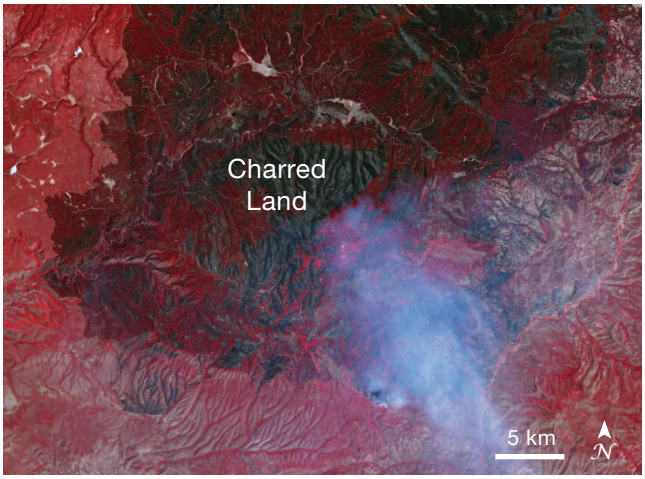
June 8, 2011—MODIS on Aqua



June 3, 2011—[left]The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite captured this vertical profile of the atmosphere near the Wallow Fire in Arizona. This atmospheric slice reveals the heights of various smoke plumes, the largest reaching an altitude of nearly 3 miles (5 kilometers) above the surface. The bottom image in this montage, taken by MODIS aboard Terra, shows the locations of individual fires to the west. Comparison of the CALIPSO and MODIS images indicates that the smoke plumes traveled northeast as they moved higher and higher into the atmosphere.

June 8, 2011—[right] Made with data from the Measurements of Pollution in the Troposphere (MOPITT) sensor on the Terra satellite, this map shows the abundance of atmospheric carbon monoxide (CO) on June 8, 2011. Dark red pixels reveal high amounts of CO flowing northeastward, directly from the fire location in eastern Arizona. Although much of the CO shown over the United States came from the Wallow Fire, some might have been produced by other fires, or could have originated as urban pollution.





June 21, 2011—[left] The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on the Terra satellite acquired this image on June 21, 2011. Even as firefighters were containing the biggest fire in Arizona history, work was already underway to restore the forest. The first step in planning a recovery is to assess how badly the forest was burned. False-colored satellite images like this one play a significant role.

Photo credit: pfly

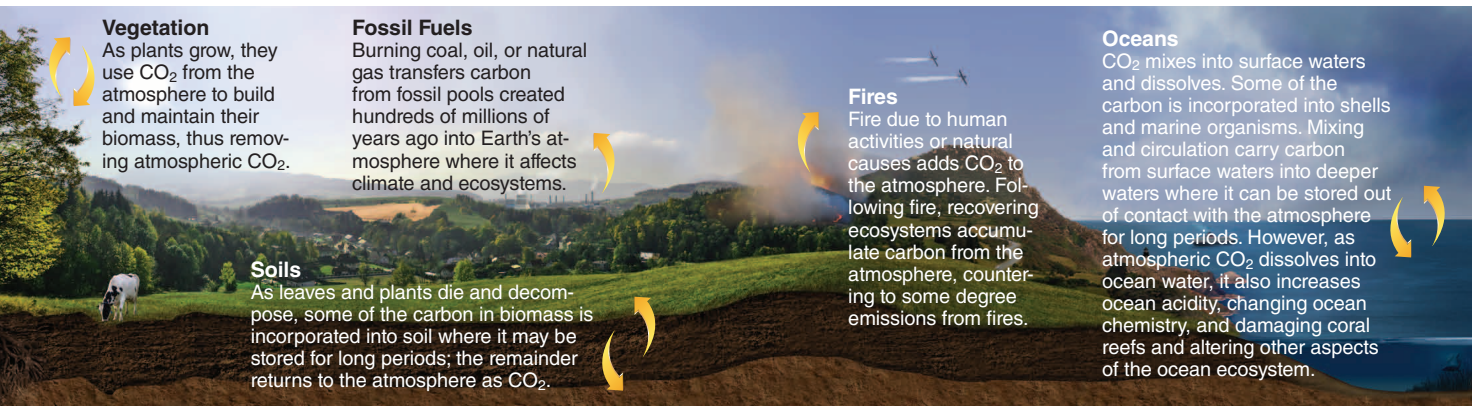
Organisms that break down dead plants and animals thrive on organic matter such as leaves, branches, bark, buds, and stems deposited on forest floors. By converting nutrients from living vegetation to enriched soil, decomposers help maintain the forest ecosystem. Old-growth forests like the one pictured above are valuable reservoirs of carbon. The organic matter accumulated on forest floors is rich in nutrients, but it also represents a major fuel source for forest fires. In healthy ecosystems, a balance is maintained by processes that include periodic fires and subsequent regrowth.

Understanding Earth's Intricate System

To assist in understanding Earth's intricate system, scientists often study changes in the cycle of a particular component, such as the cycle of water or carbon. For example, plants participate in the carbon cycle by "inhaling" carbon dioxide and converting it into organic plant matter as part of the process of photosynthesis. Animals then eat these carbon-containing plants (or they eat other animals that have eaten these plants) as a means of generating essential tissues needed for survival. Whether alive or dead, all biomass contains carbon. The continual exchanges of carbon between the biosphere, geosphere, hydrosphere, and atmosphere define Earth's carbon cycle. Carbon moves more quickly through some parts of the carbon cycle than others. Respiration, for example, is a rapid process compared to the lifetimes of trees, carbonate rocks, or fossil fuels.

Sprawling forests, extensive savanna grasslands, and vast oceans are all examples of carbon reservoirs. When forests and grasslands are growing, they absorb and store more carbon than they release, and serve as carbon "sinks." For this reason, forests and other largely vegetated areas play a major role in regulating Earth's climate. A large forest for example, absorbs carbon dioxide from the atmosphere, uses carbon to photosynthesize, and releases oxygen back into the atmosphere that animals (including humans) breathe to survive. When large forests and other vegetated areas are burned (i.e., biomass burning), the carbon stored within is released into the atmosphere, primarily as carbon dioxide—a greenhouse gas.

Sometimes carbon reservoirs are replenished with new vegetation; this is typically true for the savannas in Africa and South America during the annual growing seasons. New growth removes carbon dioxide from the atmosphere. However, not all carbon reservoirs are replenished, and large-scale fluctuations in these reservoirs affect the global carbon cycle, ultimately impacting Earth's climate system.



The Carbon Cycle

Scientists around the globe are developing new instruments for measuring and monitoring fire (i.e., biomass burning) from space as well as from aircraft. Efforts supported by NASA and other agencies will continue mapping fires and studying changes to the Earth system related to biomass burning.

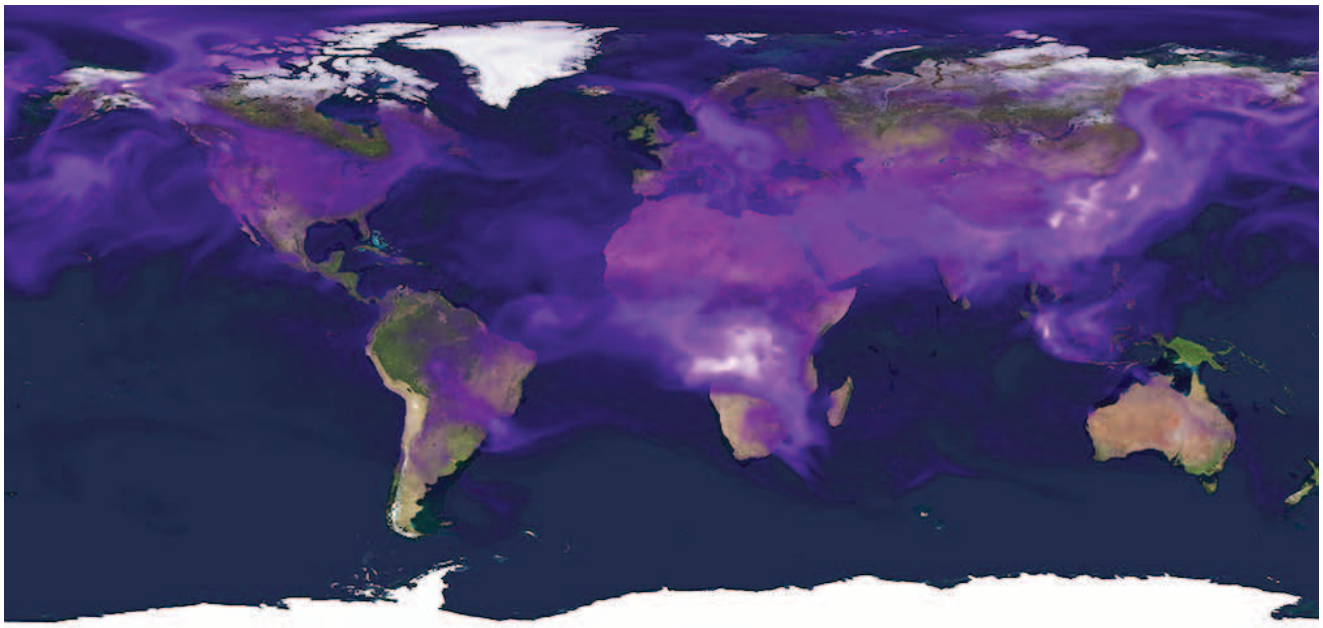
Future NASA Earth science missions including the Orbiting Carbon Observatory 2 (OCO-2) and NPOESS Preparatory Project (NPP) satellites will strengthen our understanding of global, short- and long-term change. OCO-2 will provide more accurate maps of global carbon dioxide (CO_2), which will improve our ability to identify and map carbon sources and sinks. Instruments aboard OCO-2 and NPP will enable scientists to maintain and extend existing datasets used for studying changes in Earth's climate.

The ARCTAS Mission

Given certain atmospheric circulation patterns, smoke plumes from boreal forest fires are sometimes carried into the Arctic, where they can warm the atmosphere, alter cloud formation processes, and darken icy surfaces, enhancing springtime melting. In 2008, over one hundred NASA scientists in collaboration with meteorologists, university scientists, and fire experts took part in an intensive field campaign tracking smoke plumes produced by forest fires at northern latitudes. The mission—Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)—took place during spring and summer months, obtaining thousands of measurements of the Arctic atmosphere and surface. Aircraft observations, along with data from NASA satellite and ground stations, were used to track smoke plumes from fires in North America and northern Eurasia into the Arctic.

Pilots supporting the ARCTAS campaign flew directly into billowing smoke plumes from active fires in northern Alberta and Saskatchewan to directly sample biomass burning particles. Numerous instruments, inside and out of the aircraft, were used to collect data on over one hundred different trace gases, as well as smoke particles to study the effects of biomass burning in the Arctic.

Results from the mission are helping scientists gain a better understanding of the effects northern latitude biomass burning events have on the Arctic environment once atmospheric circulations transport the plumes northward.



Black carbon particles are formed from the burning of biomass and fossil fuels and can linger in the atmosphere for days or weeks before being deposited on the land or ocean far away from their original sources. This map, generated using data from the Goddard Chemistry Aerosol and Transport (GoCART) model, illustrates the optical thickness of atmospheric black carbon aerosol on August 3, 2009 (lighter purple and white shades represent areas where aerosols interact with sunlight the most). The transport and deposition of black carbon has become an important topic related to climate change, as these particles absorb sunlight, and can cause increases in melting of ice surfaces or temperature in the atmosphere.

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NP-2011-10-250-GSFC (reprinted 2018)