

DEVELOP Students Battle Wildfires from Space Using NASA Earth Observations

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Thanks to NASA's investment in satellite remote-sensing platforms like Terra, Aqua, Landsats 1–7, and the Earth Observing-1 (EO-1) mission, wildfire monitoring capabilities have grown in spatial and temporal scale, and have provided the means by which to acquire more-accurate—and thus cost-effective and lifesaving—measurements.

Note: Please refer to the color pdf online version of *The Earth Observer* to properly view images in this article (eospsa.gsfc.nasa.gov/eos_homepage/for_scientists/earth_observer.php)

Introduction

Each year millions of acres of land are impacted by wildfire in the U.S. In 2011 alone, nearly nine million acres burned—an area larger than the state of Maryland. The high economic and human toll associated with wildfires calls for accurate monitoring before, during, and after fires. Multiple facets are involved in wildfire monitoring and management, including the enhanced understanding of environmental conditions that drive fires, monitoring the intensity and extent of fires, and predicting potential fire risks. NASA and its domestic and international partners have invested in satellite remote-sensing platforms like Terra, Aqua, Landsats 1–7, and the Earth Observing-1 (EO-1) mission, that have enabled wildlife monitoring capabilities to grow—i.e., improved spatial and temporal resolution. These new observations have provided the means to acquire more-accurate—and thus cost-effective and lifesaving—measurements. Employing instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) to track and monitor wildfires has given scientists, emergency managers, local governments, and decision makers an entirely new arsenal of tools to draw from as they battle these potential disasters.

The DEVELOP National Program, a component of NASA's Earth Sciences Applied Sciences Program, provides internships to students and young professionals with the goal of using NASA's Earth observations in real-world applied research projects. These research projects address various topics of national concern that are aligned with the Applied Sciences Program's main focus areas of disasters, Health & Air Quality, Ecological Forecasting, and Water Resources. Interns work on short-term (10-week-long) projects under the guidance of science advisors from NASA and partner organizations. Throughout the years, DEVELOP projects have focused on a variety of natural disasters, but a common thread running through many of the projects has been a focus on remote-sensing-based monitoring of wildfires. The interns have focused their research on the development of tools for local and regional agencies and decision makers to enhance their emergency management practices through the use of NASA Earth observations.

With the help of NASA's Earth science satellites and related technology, DEVELOP students have taken on such fire-related topics as pre- and post-fire land-surface conditions, fire extent and intensity, fuel loading and vegetation content, potential fire risk, and impacts upon local and regional air quality—all using space-based remote sensing. These projects have looked at fires around the globe, including the 2009 Station Fire in California, the 2010 Russian Federation fires, and the 2011 Possum Kingdom Lake and Bastrop Complex fires in Texas. Students have also investigated monitoring prescribed burns of agricultural fields and marshlands in Louisiana, and the associated air quality risks. Each of these will be discussed in some detail, following.

The 2009 California Station Fire

California consistently has one of the most active fire seasons within the U.S. each year. Several factors contribute to this, including fire suppression, fuel loading, and a climate that is often dry, warm, and windy. In 2009 California was ravaged by the Station Fire that destroyed over 160,000 acres in Los Angeles County and negatively impacted air quality in nearby areas. The Station Fire burned from August 26–October 16, 2009, a year that was ranked the tenth largest fire season in California history.

During the Summer 2010 term, a team of five DEVELOP students focused their research on applying NASA's Earth observations to assist land managers develop future

policy and decision-making tools. DEVELOP partnered with the U.S. Forest Service at the Angeles National Forest to use the Station Fire as a case study to enhance decision making for handling future fires in the region. The team used a suite of sensors and datasets, including Landsat's Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+), Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and MODIS, along with the U.S. Department of Agriculture (USDA)/U.S. Geological Survey (USGS)'s Landscape Fire and Resource Management Planning Tools (LANDFIRE) dataset and the National Oceanic and Atmospheric Administration (NOAA)'s Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model.

The team began by assessing the health of the land, using a rapid analysis of change in vegetative distribution by way of a land-cover classification and Normalized Difference Vegetation Index (NDVI) analysis. They selected Landsat images from before (August 6), during (September 7), and after (October 25) the fire for analysis. This allowed the team to identify vegetation loss due to the fires and, through multiple unsupervised classifications, create a time series of land-cover change, which demonstrated the impact of fire on vegetation extent—see **Figure 1**. The team also used Landsat imagery to improve the understanding of the impacts of a dry season on vegetation moisture content—an integral factor directly impacting ignition time, rate of spread, energy release, and production of smoke. Normalized Difference Moisture Index (NDMI) calculations were used to analyze average moisture values to characterize the environmental conditions leading up to the Station Fire—see **Figure 2**. Through use of NDMI from Landsat TM data, the team was able to analyze average moisture values for the study area and plot trends, providing a means of understanding the changes in live vegetation moisture content that preceded the fire.

Emissions from the Station Fire greatly impacted air quality in the local region, posing health risks and causing subsequent increases in respiratory illnesses, according to hospital data. Using the HYSPLIT model, the team ran forward and backward trajectories from multiple biomass burning sources at 24-hour intervals at multiple altitudes. This provided information on the extent and direction of smoke plumes from the Station Fire and allowed for better understanding of the geographic locations impacted by the fires—see **Figure 3**, next page.

The broad examination of so many factors relating to wildfire monitoring provides land and emergency managers a *synoptic* (i.e., large-scale) view of conditions, further enhancing their decision making process in a rapid manner—when time counts. Beyond the immediate benefits, this research was able to pioneer a vein of fire research at the DEVELOP office at NASA's Langley Research Center (LaRC).

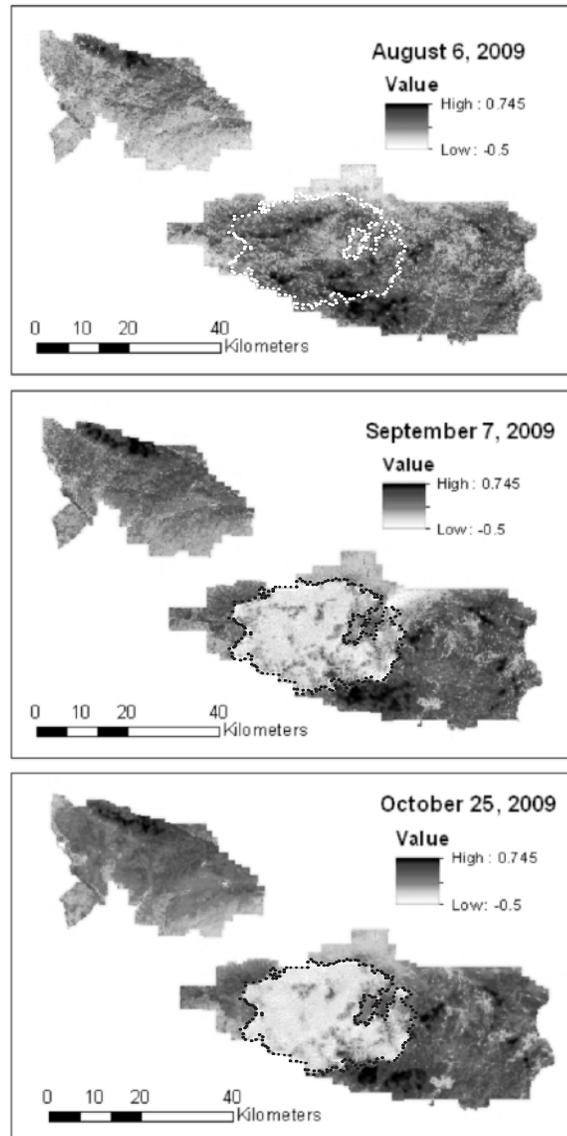


Figure 1. The three images above show the NDVI analysis of Landsat 5 TM data of the Angeles National Forest in California before [top], during [middle], and after [bottom] the Station Fire. There was a substantial decrease in vegetation health within the fire perimeter (dotted outline) associated with the fire. **Image credit:** DEVELOP National Program

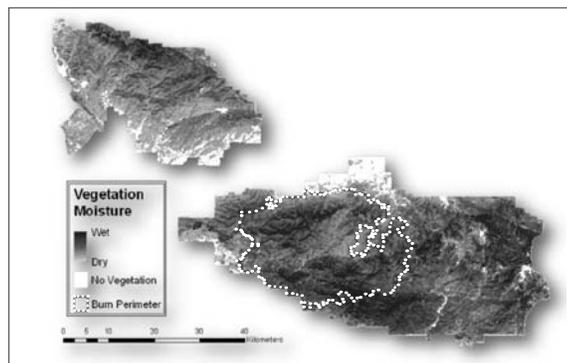


Figure 2. This image shows vegetation moisture conditions derived from Landsat 5's TM before ignition on August 6, 2009. The Station Fire burn scar has been outlined with a dashed line. Fire managers can use these maps to help assess potential fire risk. **Image credit:** DEVELOP National Program

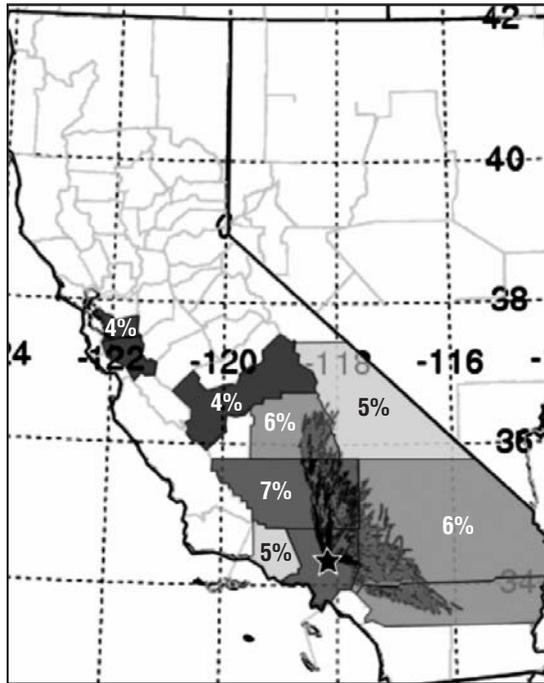


Figure 3. This image shows HYSPLIT trajectories for particulate matter originating from the Station Fire region (lines emanating from black star). Nearby counties are labeled with percent increase in hospitalizations due to respiratory health ailments during and after the fire compared to July 2009. **Image credit:** DEVELOP National Program

A team of DEVELOP students at LaRC focused their Summer 2011 research on investigating how these factors facilitated the disaster, and how data from NASA's Earth Observing System (EOS) could play a role in future forest-fire mitigation and response management.

The team began by analyzing the pre- and post-fire land conditions. Land-cover data were gathered from the Landsat 5 TM and Landsat 7 ETM+ instruments and were used to classify vegetated land cover and urban areas within the region. During the classification process the investigators made a very intentional effort to accurately identify the peat bogs that were the original source of the wildfires. To best use remote-sensing capabilities to assess another important factor in fire risk—moisture—the DEVELOP team ran a NDMI analysis that provided quantifiable data on soil moisture levels to identify areas of low moisture content and therefore higher fire risk. Three NDMI data layers were combined with a fourth layer depicting roadways in the area—an indicator of human activity. The result of aggregating these layers was a risk map for potential fires in the study area, thus establishing an effective method for land managers to use EOS data to enhance monitoring capabilities for areas susceptible to future fires—see **Figure 4** next page.

Due to the degraded air quality caused by the 2010 Russian fires and the associated impacts on respiratory health in the region, the team also generated methods to track and model smoke plumes from the fires. The team chose to approach this phase of their project by compiling Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), and MODIS aerosol optical depth (AOD) and visible imagery to identify smoke plume evidence. To better quantify their observations, the group used the HYSPLIT model to investigate the vertical distribution of particulate matter in the atmosphere and to study how the smoke plumes were likely transported locally and regionally. Information like this helps fire managers accurately predict where smoke plumes might impact communities. Health-care decision makers may also be able to identify relationships between reported cases of respiratory health ailments and known plume tracks.

At the conclusion of the project, the team created a tutorial for decision makers that provided training in the necessary steps to recreate this type of work and help facilitate the sustainable use in future fires. The Russian wildfire project also initiated the follow-on DEVELOP project that focused on the 2011 Texas wildfire season, discussed

Acknowledgements to the California Disasters Team: Malcom Jones [Christopher Newport University (CNU), *Team Lead*]; Joseph Reedy [Chadron State College]; Samiah Moustafa [University of Florida]; David Brundage [University of Tennessee at Knoxville]; and Kevin Anderson [University of Virginia (UVa.)].

The 2010 Russian Wildfires

During the summer of 2010 the Russian Federation saw a few localized peat bog fires erupt into a large-scale regional wildfire that scorched the landscape and caused severe deterioration in air quality across much of the eastern extent of the county. The draining of the peat bogs during the 1960s and the dismantling of the Russian National Fire Service in 2002 had already left the region vulnerable to a fire outbreak. A relentless heat wave only served to exacerbate the problem and created the perfect set-up for the massive wildfire outbreak that occurred. More than 196,000 hectares in the countryside near Moscow were scorched, causing an estimated \$15 billion in damage.

in the next section of this article. The methodologies used to study the 2010 Russian fires provided a foundation for the next team to build on.

Acknowledgments to the Russia Disasters and Public Health Team:

Derek Doddridge [George Mason University, *Team Lead*]; **Shalika Gupta** [University of California, Berkeley]; **Kenneth Hall** [CNU]; **Kathryn Morel**, [CNU]; **Raven Moreland** [UVA]; **Katie Overbey** [University of North Carolina]; **David Arczynski** [Walsingham Academy]; **Jonathan Wilson** [Brigham Young University, Idaho].

The 2011 Texas Wildland Fires

During the Fall 2011 term a group of four DEVELOP interns began work on one of the most ambitious fire-related projects undertaken by the program—the incredibly destructive 2010-11 Texas wildfire season, which burned nearly four million acres of land across the state. The project specifically focused on the fires near Bastrop County and the Possum Kingdom Lake. Excessive heat and prolonged drought (driven by La Niña conditions) made the region vulnerable to fire, and strong winds from Tropical Storm Lee helped to fan the flames, leading to a historic wildfire season that ignited over 26,000 separate fires resulting in the loss of over 5000 structures and the lives of four people.

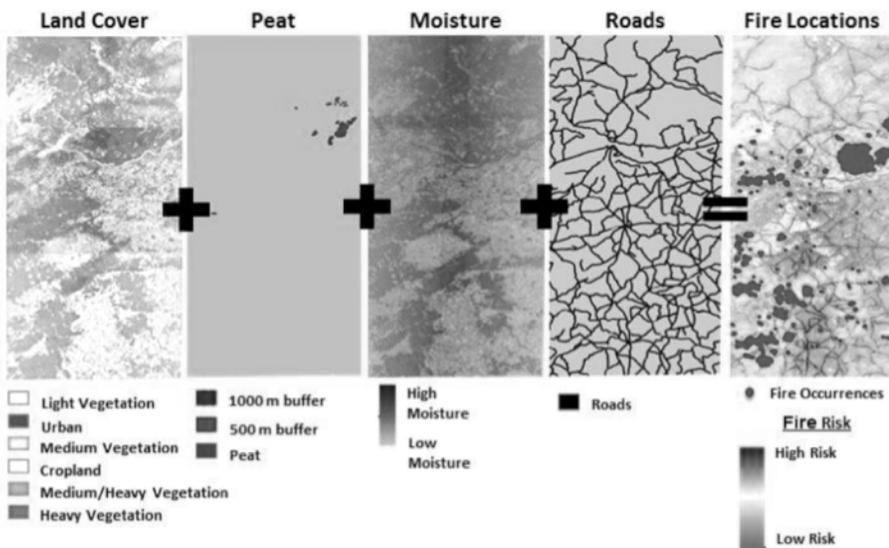
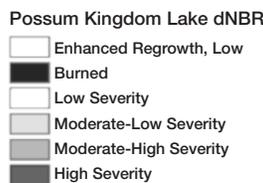


Figure 4. A potential fire-risk map [*far right*] with reported fire occurrences (gray dots) was created using four weighted layers [*left to right*]*—*land cover classification data, peat marsh locations and buffers, soil moisture, and roadways as an indicator of human activity*—*for the Russian Federation region. The three left images show data from Landsat 5 TM and Landsat 7 ETM+. **Image credit:** DEVELOP National Program.

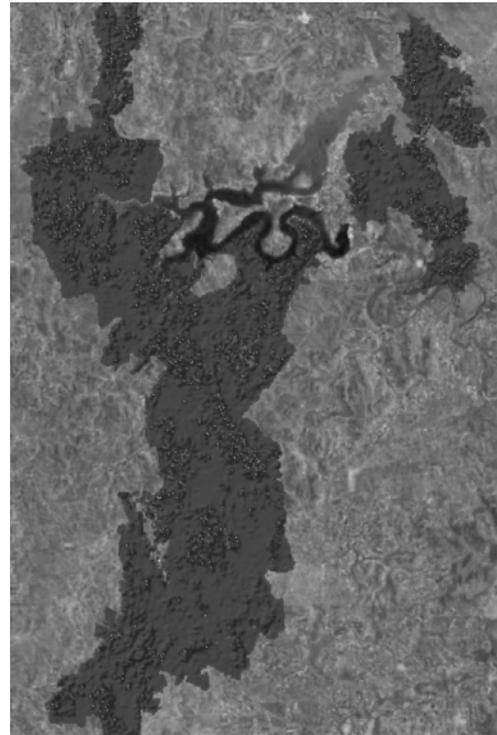
The DEVELOP research team partnered with the Texas Forest Service (TFS), which is responsible for directing all matters pertaining to forestry within the state. Prior to this project, the only Earth-observations that TFS used in their predictive risk was previously processed Advanced Very High Resolution Radiometer (AVHRR) and ground-based weather radar data. Daily maps of select fire weather and fire danger components were also produced, but these are done at the national level, and TFS desired to be able to conduct this type of analysis in-house to better address their unique concerns.

To enhance current TFS practices, the DEVELOP team began work on constructing burn extent and severity maps for the Bastrop County and Possum Kingdom Lake Fires. Using burn-scar imagery and calculating the difference Normalized Burn Ratio (dNBR) and Relative dNBR (RdNBR), the team was able to apply NASA Earth-observing assets to assist in fire monitoring during and after the wildfire events—see **Figures 5** and **6**. The team also calculated the NDVI of the local surface vegetation to investigate the impact of the drought on the local ecosystem and the magnitude of ecological changes the fires caused. Having determined that the drought had a major impact on the system, the team continued their investigation by analyzing soil moisture by conducting a NDMI for each of the study areas. All of these separate analysis techniques were then combined to generate a composite fire-risk map—see **Figure 7**—and

Figure 5. The dNBR created from Landsat 5 TM shows multiple levels of burn severity in the Possum Kingdom Lake for April–May 2011, indicating fire-induced ecological change levels. **Image credit:** DEVELOP National Program

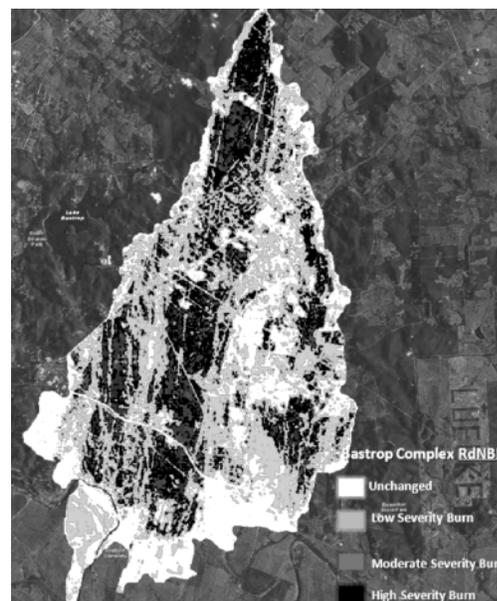


a time-lapse representation of the changing conditions of surface water resources during the duration of the fires. This type of information provided the TFS with a more timely and cost-effective aid for fire prediction and prevention.



dNBR for Possum Kingdom Lake (April 2011–May 2011)

Figure 6. Landsat 5 TM derived RdNBR displays four levels of burn severity in the Bastrop Complex fire, providing a more-robust and accurate means of monitoring burn severity than the dNBR. **Image credit:** DEVELOP National Program



in Louisiana has surpassed all other agriculture commodities in size for the state, and to maintain a high yield and maximum efficiency requires burning during the harvest period. Louisiana also contains approximately 30% of the total coastal marsh in the U.S., which is also periodically burned as an ecologically important management tool. Biomass burning produces particulate matter smaller than 10 μm in diameter (PM_{10}), which has been shown to have negative impacts on human health. To take steps towards alleviating some of these health concerns, the Louisiana Department of Agricul-

The DEVELOP team created tutorial demonstrating how to acquire the necessary data and conduct the proper analysis was created by for the TFS. During future fires, TFS can use this product to determine the best use of their resources.

The success of the 2011 Texas wildfire project lead to the development of a follow-on project that investigated the use of EOS data to monitor 2011 Texas fire season impacts on air quality in nearby metropolitan areas. The project also won the People's Choice Award in an online virtual poster session contest on IEEE's Earthzine website. To view a video created by the team, visit: www.earthzine.org/2011/11/10/using-nasa-earth-observations-to-assess-burn-severity-and-perform-risk-mapping-of-the-2011-texas-wildfires.

Acknowledgments to the Texas Disasters Team:

Kenneth Hall [CNU, *Team Lead*]; **Ande Ehlen** [CNU]; **Taylor Beard** [CNU]; **Myles Boyd** [Phoebus High School].

Prescribed Louisiana Sugar Cane and Marsh Burns (2008-2009 Burn Season)

Even when fires are prescribed—i.e., engineered by humans—they require proper management and monitoring. Each year across portions of sugar cane fields and marshes in Florida, Texas, and Louisiana are burned to remove approximately three-billion metric tons of excess biomass quickly and effectively. The sugarcane industry

ture and Forestry has put in place burning guidelines, but as yet these guidelines are only voluntary.

During the summer of 2010, a DEVELOP team at NASA's Stennis Space Center partnered with the Environmental Protection Agency (EPA) Region 6 Regional Haze Program, the University of Louisville, and Nicholls State University to investigate the use of Terra ASTER, Landsat TM, and Terra/Aqua MODIS data products for monitoring prescribed burns in coastal Louisiana and to examine the resulting air quality impacts.

The team began its work by developing methods to accurately identify fires and their spatial extent within the marshlands of Southern Louisiana—specifically, looking at Iberia and Cameron Parishes.

The investigators conducted NDVI analyses of Landsat and ASTER scenes to locate the burned areas in the sugarcane fields. (The scenes were subsetted and masked to show only the sugarcane fields in the study area.) Using the Fire Information for Resource Management System (FIRMS), MODIS point data were queried for fire locations that had over 50% confidence level and composited into images showing all fire points from 2005–2009 in Louisiana—see **Figure 8**. By mapping fire density information from the MODIS Rapid Response System, the team was able to show that the majority of the fires across the state were correlated with agriculture and marsh areas—see **Figure 9**, next page. The project also incorporated datasets from partner agencies, such as NOAA's Coastal Change Analysis Program (C-CAP) dataset, USDA's Geospatial Data Gateways land-cover dataset, USDA's 2009 Cropland Data Layer (CDL), and sugarcane statistics from the National Agricultural Statistics Service.

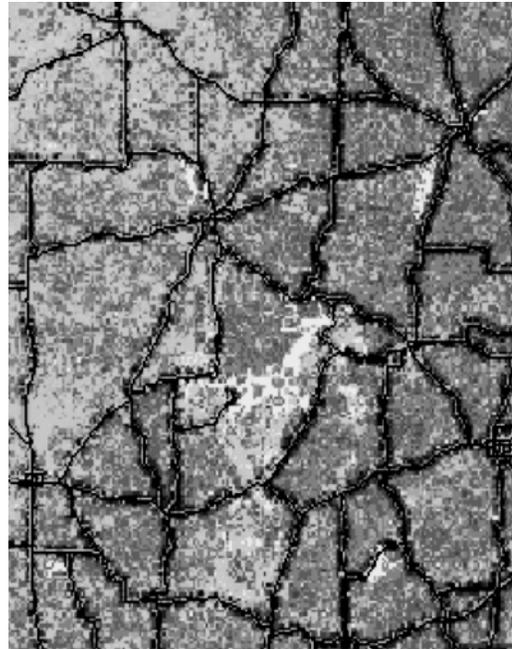


Figure 7. Risk assessment maps were created using RdNBR burn severity maps and four pre-fire risk factors (soil moisture, wildland-urban interface, fuel cover, and proximity to roads as an indication of human activity) for the Possum Kingdom Lake region. **Image credit:** DEVELOP National Program

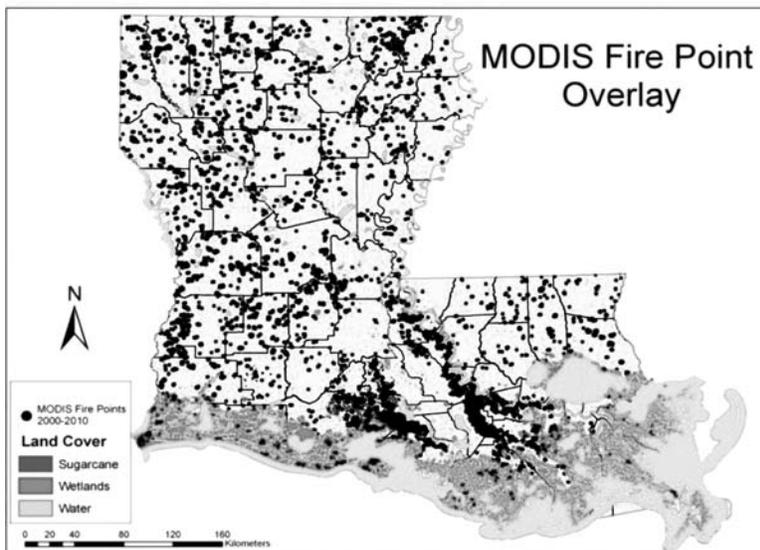


Figure 8. Using data from the MODIS Rapid Response System, active fire points (black dots) were compiled for the years 2005–2009, showing highest density near fields devoted to sugarcane cultivation and marshland. **Image credit:** DEVELOP National Program

Figure 9. MODIS Rapid Response System data provided a means to map fire densities, which helped visualize the high fire densities in the agricultural and marsh areas during the peak of the burning season. **Image credit:** DEVELOP National Program

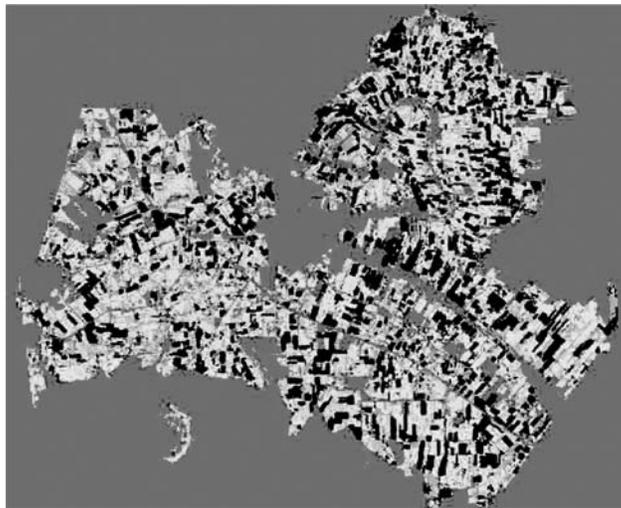
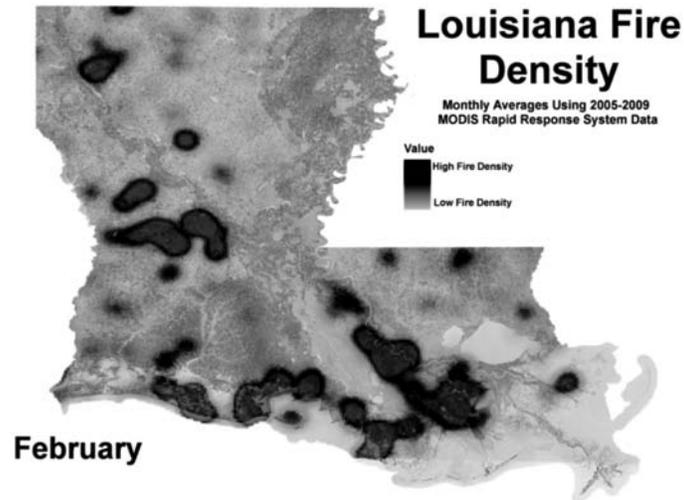


Figure 10. A burned-field detection analysis using ASTER data between September 1–November 4, 2009, shows that approximately 19,760 hectares of sugarcane fields were burned in Iberia Parish. **Image credit:** DEVELOP National Program

Once fire locations and extent were further refined using NDVI analysis on data from ASTER—see **Figure 10**—and Landsat 5 TM—see **Figure 11** next page—the team used algorithms to estimate emissions from the biomass burning to enhance decision making and future policy. Using a bottom-up methodology developed by Seiler and Crutzen, the project estimated pyrogenic emissions from biomass burning for each parish. They found that gaseous emissions produced by biomass burning in Louisiana are higher than previously estimated, and that Earth observations could clearly show monthly trends: Sugarcane fires occur mostly from October through December with a November peak, and marsh fires occur mostly during January through February.

The team's methods provide a means of using much-higher-resolution data than previously used, with results suggesting that biomass burning for the state of Louisiana may have been underestimated—information useful for Louisiana's decision and policy makers.

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Chad Robin [Florida State University, *Team Lead*]; **Robert Clark** [University of New Orleans (UNO)]; **Ross Reahard** [UNO]; **Jared Zeringue** [UNO].

Conclusion

When wildfires occur quick decisions must be made. To make those decisions, emergency managers require prompt, accurate information. The vantage point that space offers puts NASA Earth-observing satellites in a unique position to address this need. The DEVELOP National Program's work to address wildfire concerns has fostered many new users of NASA's Earth-observation data, and will assist decision makers in places like California and Texas during future fires. The training of a new generation of NASA science-literate decision makers continues this coming summer term as a new class of DEVELOP students take on a range of projects, including wildfire monitoring in places like North Carolina and Virginia.

Efforts to build capacity to use these national resources are imperative to enhancing future decision making and appropriate response to emergencies. The DEVELOP National Program addresses this need by training the next generation of scientists and policy makers in the use of Earth observations. DEVELOP is expanding the future capabilities for and benefits from NASA satellites to address societal concerns. With each project that partners with new organizations and agencies, the students are directly passing on knowledge and further expanding the user base for NASA Earth observations. As the “ambassadors” for the application of NASA’s Earth-science technology, DEVELOP students and young professionals are making an impact that far exceeds what might be expected from a relatively short, 10-week internship.



Figure 11. Landsat 5’s TM allowed for burn-scar detection in the coastal marshes in Cameron Parish, identifying approximately 23,160 hectares of marshland burned during the project’s study period. **Image credit:** DEVELOP National Program

For more information about the DEVELOP National Program, visit: develop.larc.nasa.gov.

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