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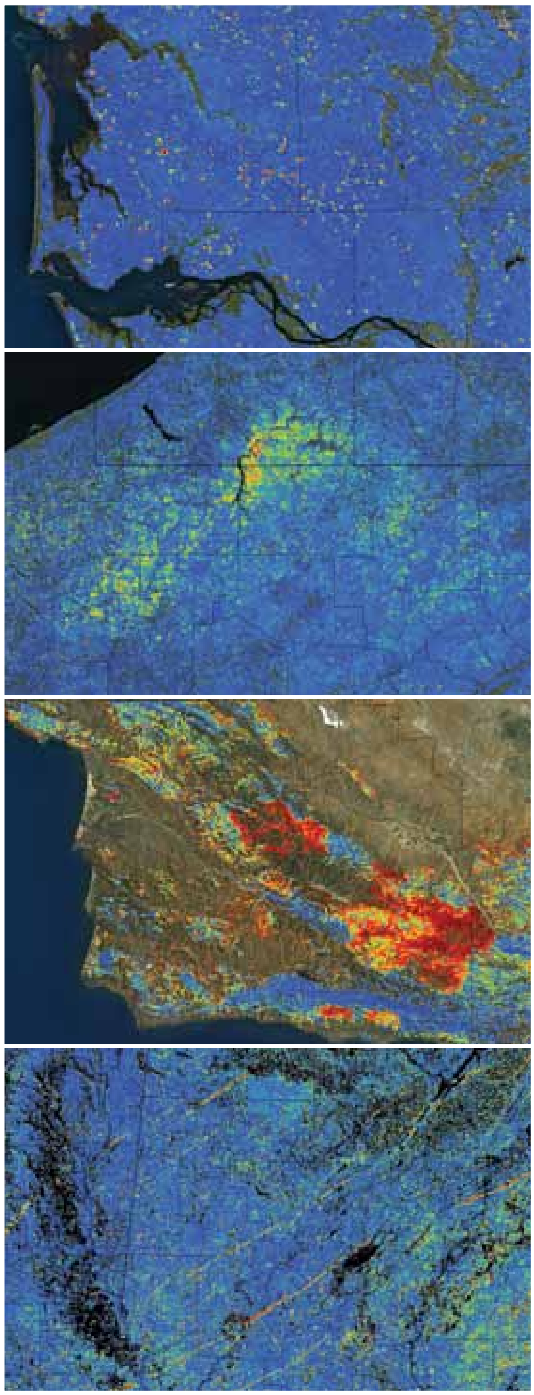
Highlights of Satellite-Based Forest Change Recognition and Tracking Using the *ForWarn* System

Steven P. Norman, William W. Hargrove, Joseph P. Spruce, William M. Christie, and Sean W. Schroeder



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COVER IMAGES: Top to bottom: (1) Clear cut logging near the mouth of the Columbia River in Oregon and Washington shows up as red and orange. This map documents logging during the 12 months prior to July 19, 2013; (2) Minor to severe Gypsy Moth defoliation occurred near the New York-Pennsylvania line during early July, 2013; (3) Southern California—areas mapped as shades of red and yellow signify the departure from the long-term maximum vigor and reveal the variable, but long-lasting impacts of several fires; (4) Northern Alabama after April 2011—a distinctively striped pattern reveals the tree and foliage losses from multiple tornadoes and illustrates the decline in forest vigor across the region during 2011.

For more information about *ForWarn*, visit the project's website at:
http://forwarn.forestthreats.org.

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Abstract

Satellite-based remote sensing can assist forest managers with their need to recognize disturbances and track recovery. Despite the long standing availability of raw imagery, the systematic delivery of spatially continuous, ready-to-use, processed products has evaded us until recently. The web-based *ForWarn* system moves us a step forward by generating forest change maps at high frequency in a format that is usable to forest managers, planners, and the public. The *ForWarn* system shows change in the Normalized Difference Vegetation Index derived from moderate resolution imagery according to a range of baseline normals. Expectations of normal derive from previously observed changes in seasonal leaf phenology; this adjustment is critical for forests dominated by deciduous vegetation that vary in greenness through the year. After these seasonal adjustments are made behind the scene, the remaining forest change that *ForWarn* users see may result from an array of climatic and disturbance causes. These include insects and disease, wildland fire, wind, hail, human development, drought, or variation in the timing of spring and fall. This publication outlines the data and methods that underlie this technology, and provides examples that illustrate selected capabilities of this system for coarse-scale forest monitoring.

Keywords: Disturbance, monitoring, phenology, recovery, remote sensing.

Introduction

Forest conditions can change rapidly from violent storms, severe fire or human development, but they can also change gradually from the progressive effects of altered disturbance regimes, slow-acting stress, or the cumulative impact of multiple factors (fig. 1, 2). Forest monitoring is difficult because we want to know about rapid change as soon as it occurs, while not neglecting the slower changes that can easily go unnoticed.

Satellite-based monitoring has long been used to monitor rapid and gradual forest change, but not as systematically as it could be. Regular, high frequency observations that are corrected for the confounding effects of clouds would provide meaningful insights into how background conditions change naturally with climate variation and across seasons. This is important for the accurate recognition of change.

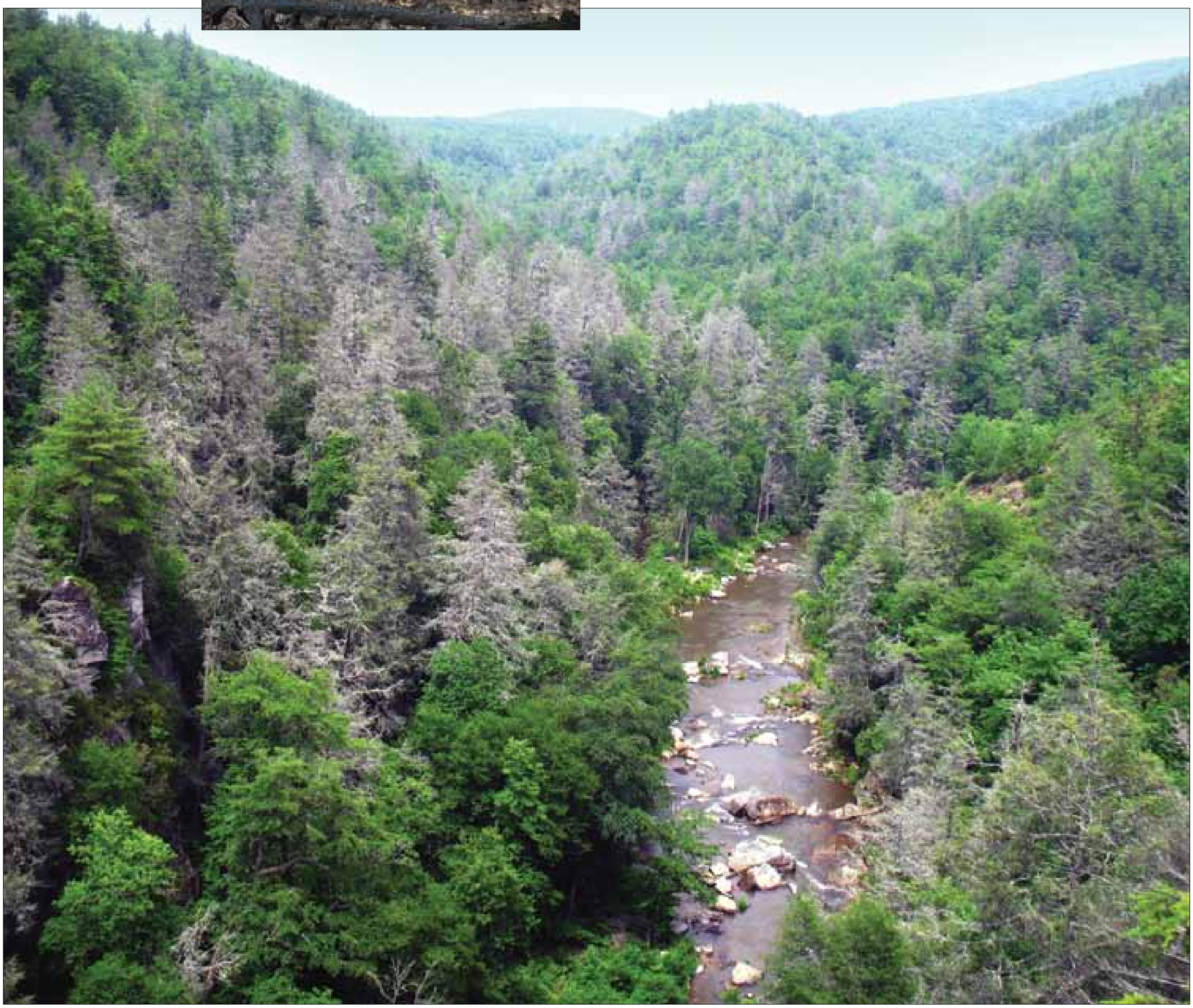
Diagnosing the cause or causes of change is the subsequent challenge. Fortunately, forest change assessment efforts can build on pre-existing efforts. Thanks to Federal and State programs, we have specialized knowledge of wildfires, insects and diseases, and climatic stress. What these efforts lack is an overarching system for integrated monitoring, assessment, tracking and communication for those who need this information.

The highlights of forest change presented in this document reveal the capabilities of an important part of just such a system: a satellite-based change recognition and tracking system that leverages insights derived from these complementary, but specialized efforts.

US DOI Fish and Wildlife Service

Figure 1—(top) Coastal forests after a severe hurricane and repeated fires in the Great Dismal Swamp National Wildlife Refuge, Virginia.

Figure 2—(bottom) Forests in decline from the non-native hemlock woolly adelgid, Linville Gorge State Park, NC.



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The Technology

The National Early Warning System (EWS) is a coordinated effort to bring cutting-edge monitoring and assessment technologies and forest professionals together (Hargrove and others 2009[1]). Today, technological advances allow us to systematically detect and track forest disturbances from space in near-real time, and a network of professionals is required to accurately interpret observations and communicate conditions to those who can take action, as appropriate. The core technology, *ForWarn*, is a satellite-based change recognition and tracking system developed by the Forest Service, USDA's Threat Assessment Centers,[2] and NASA Stennis Space Center, with substantive involvement by the U.S. Geological Survey, Department of Energy's Oak Ridge National Laboratory, and the University of North Carolina, Asheville's National Environmental Modeling and Analysis Center.

ForWarn provides a strategic national overview of potential forest change which directs attention to places where forest behavior seems unusual or abnormal. These insights can help focus ground and aircraft observation efforts (such as those conducted by the Forest Service's National Insect and Disease Detection Survey program or post-disturbance response efforts). Operating since January 2010, *ForWarn* generates national disturbance maps covering the conterminous United States every eight days, even throughout the winter. It detects all types of forest disturbances, including insects, disease, wildfires, frost and ice damage, tornadoes, hurricanes, blow-downs, harvest, urbanization, and landslides. It also detects drought, flood, and other extreme climate effects and tracks early and delayed vegetation development during spring and fall.

ForWarn uses the Normalized Difference Vegetation Index (NDVI) to measure vegetational vigor, or relative "greenness." NDVI measures the degree to which solar radiation is differentially absorbed across red and infrared wavelengths due to the chlorophyll in plants. Reflectance data are obtained from the MODIS[3] sensors aboard NASA's Terra and Aqua satellites;

[1] Hargrove, W.W.; Spruce, J.P.; Gasser, G.E.; Hoffman, F.M. 2009. Toward a national early warning system for forest disturbances using remotely sensed canopy phenology. Photogrammetric Engineering & Remote Sensing. 75: 1150-1156. http://www.treesearch.fs.fed.us/pubs/33669. [Date accessed: May 15, 2013]

[2] The Eastern Forest Environmental Threat Assessment Center (EFETAC) is located in Asheville, NC, and the Western Wildland Environmental Threat Assessment Center (WWETAC) is in Prineville, OR.

[3] Moderate Resolution Imaging Spectroradiometer.

these satellites provide a daily record of the condition of vegetation, when the view is not obstructed by smoke or clouds. The data are available at a nominal spatial resolution of 250 m, which translates to a map cell size of about 13 acres, or 5.4 ha (the equivalent to about 9 football fields each). While seemingly coarse compared to the dozens to hundreds of individual trees that normally exist within a single hectare of forest, finer resolution data do not exist at high frequency, and even with moderate resolution, this database grows by billions of data points each year.

ForWarn works by comparing current conditions with the "normal greenness" that would be expected for healthy, undisturbed vegetation growing at a location during a given time of year. Locations that are currently less green than expected are marked as potentially disturbed (as indicated by shades of red, orange, and yellow on figure 3a and 3b on pages 6–7). Unfortunately, clouds can act to decrease the current observed greenness, mimicking the actions of forest disturbance agents. *ForWarn* overcomes this problem by relying on a moving 24-day window of daily satellite observations that nearly always provides a cloudless view. The moving window advances forward in eight day time steps. *ForWarn* also includes maps and time series graphs of raw NDVI values since 2000. Assessing forest change requires a historical baseline or multiple historical baselines of varying durations to determine how "normal," healthy vegetation should appear. *ForWarn* utilizes three baselines—(1) the prior year, (2) the maximum value of the last three years, and (3) the entire period of record. The maximum greenness value is kept from each of the 46 different 8-day time periods per year. Several of the forest change highlights in this document illustrate the insights that come from having a range of baselines for comparison.

Forest change maps generated using *ForWarn* are available to anyone via the Forest Change Assessment Viewer, a Web-based tool that is accessible at http://forwarn.forestthreats.org/fcav/. New, near-real time maps are available at this Web site, as well as an archive of forest change products since 2000.

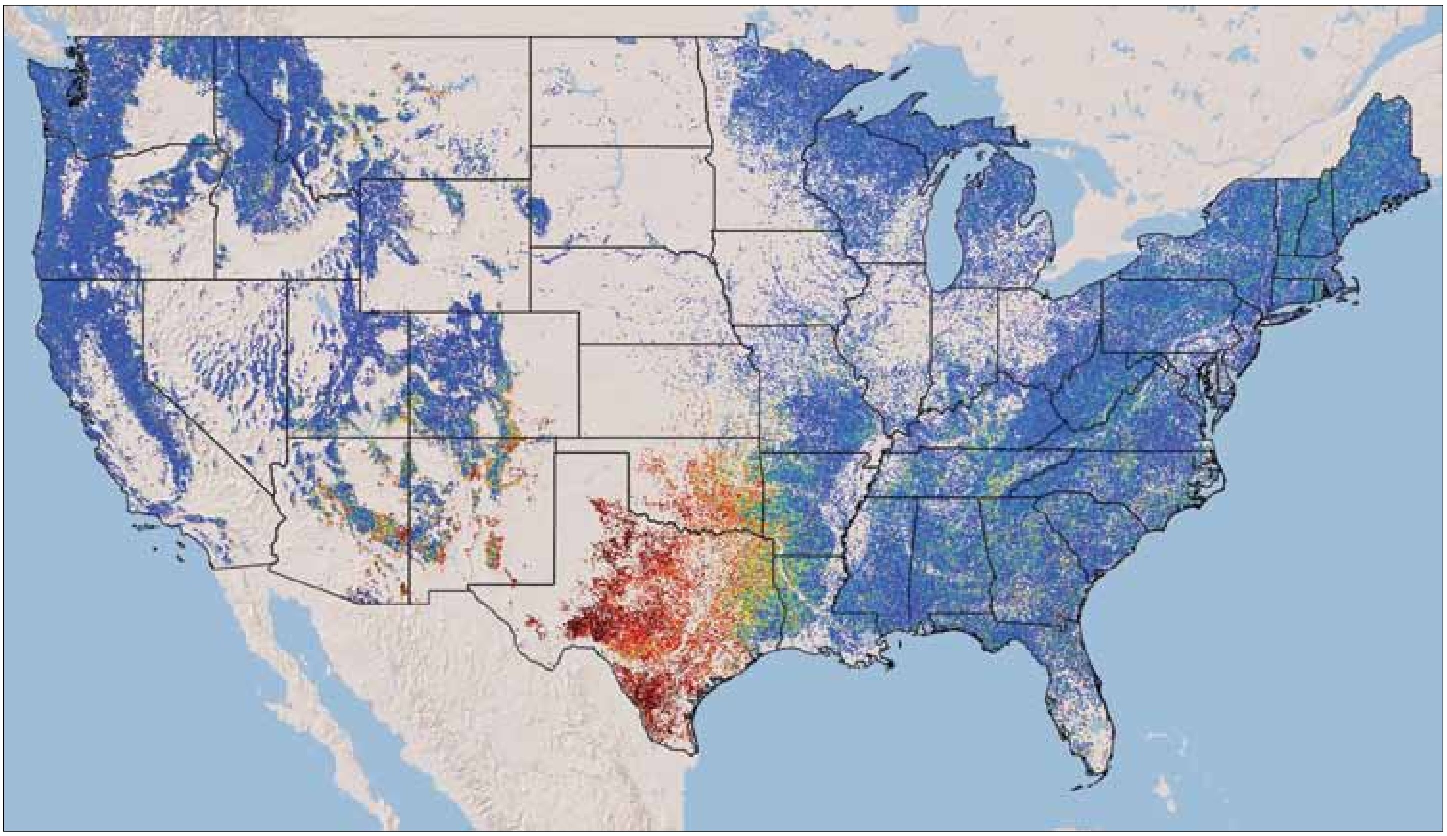


Figure 3a—Map of the United States showing the state of forests as of August 28, 2011 compared to the same 24-week period of 2010. Note the extensive red anomaly in western Texas and surrounding States that corresponds to extreme drought. Blue indicates that much of the Northeast and West were similar to or more productive than in 2010.

Colors refer to departure from historical conditions based on the NDVI. Extreme loss of vegetation productivity is shown by shades of red while areas in shades of dark blue have healthier or heavier vegetation cover than they did in the past.

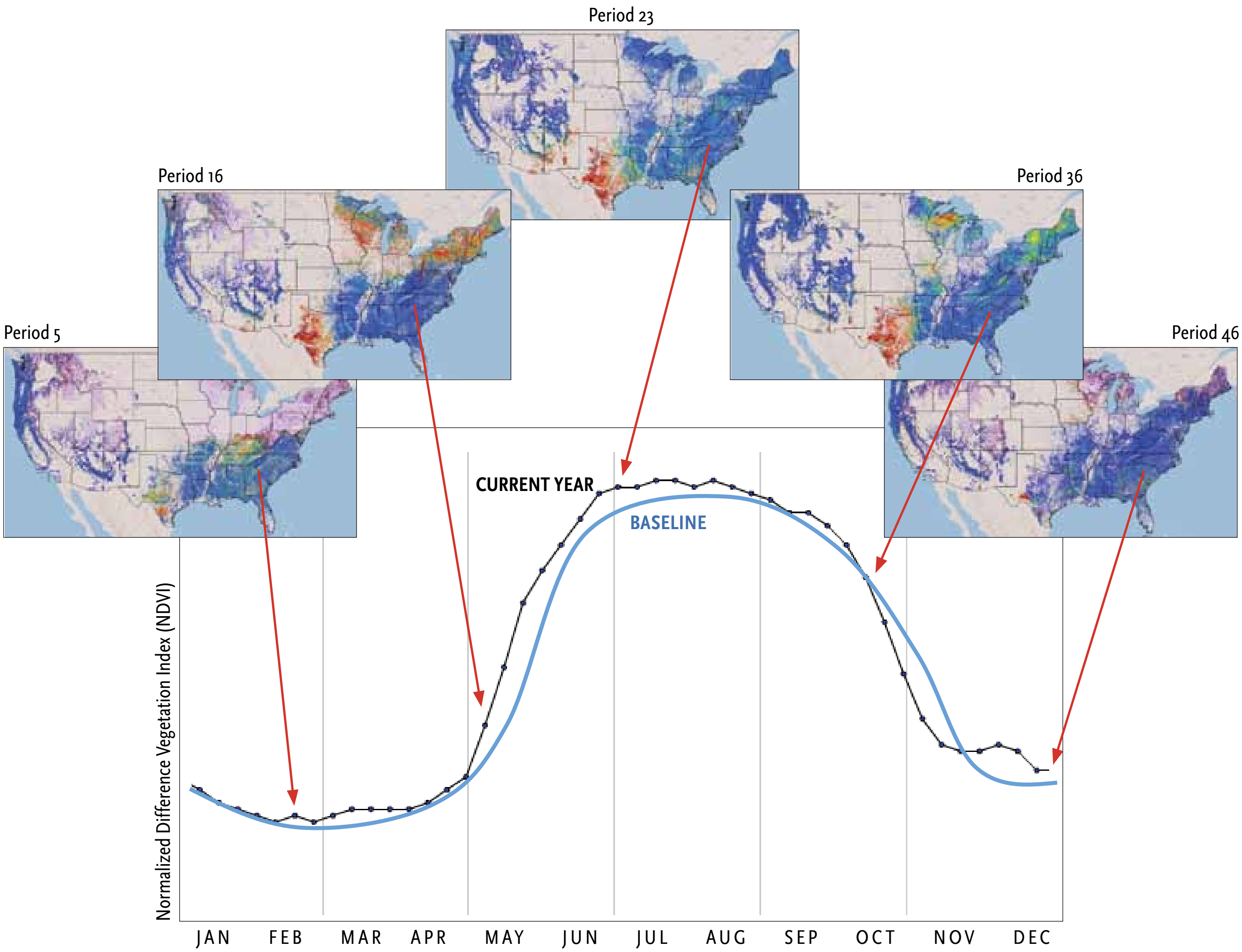


Figure 3b—An annual NDVI curve for one site in North Carolina compared to a hypothetical baseline curve. Every year, forty-six change maps are produced for each combination of current conditions with the 1, 3, and all year baselines which provide different seasonal expectations of normal.

Overview of Forest Changes

Recent years have experienced remarkable forest disturbances and climate anomalies across the United States. Their co-occurrence has tested *ForWarn's* ability to detect disturbances during drought, and to map climate stress despite disturbance. For example, in 2011, extreme drought dominated much of the south-central and south-eastern United States. This drought was particularly strong in Texas where western portions of that State experienced extreme and prolonged drought that led to a sharp decline in rangeland productivity and a record outbreak of wildfires. Large fires also occurred from the ponderosa pine forests of eastern Arizona to the peaty forests of the Coastal Plain of Florida, North Carolina, and Virginia in areas that were and were not experiencing drought. Despite causing a directionally similar decline in greenness, *ForWarn* successfully distinguished wildfire from drought by mapping the relative severity of the decline.

Earlier in 2011, spring was delayed across much of the United States by cool temperatures or an abnormally heavy snowpack. In the Southeast, the spring of 2011 brought one of the most notable tornado outbreaks in memory. Researchers used *ForWarn* to map tornado scars from these tornado outbreaks across northern Mississippi, Alabama, Tennessee, and Georgia. In contrast, 2012 experienced a remarkably early spring across the East due to early warm temperatures with fewer, yet still destructive tornadoes. *ForWarn* successfully detected these storm effects during both years.

ForWarn has also detected defoliating insects across the United States. Particularly noteworthy examples of detected defoliation include the bald cypress forests of Louisiana; the ponderosa pine forests of South Dakota; the pine and fir forests of Montana, Idaho, and Washington; the northern hardwood forests of northwestern Pennsylvania; and the hemlock-dominated forests of the Central and Southern Appalachians.

Heavy Snowpack

Winter snowpack has a major influence on spring flooding and water supplies, and snowpack can vary considerably from year to year. While *ForWarn* does not directly measure snowpack depth, it maps changes in snow cover compared to historical cover.[1] Heavy snowpacks can lower satellite-based measurements of NDVI either by temporarily obscuring evergreen vegetation or by delaying the spring greenup of deciduous grasses, herbs, shrubs, or trees. This snow-obscuring effect likely explains differences between December 2010's high elevation forest anomalies in the Sierra Nevada and that of 2011 (fig. 4 on page 10).

In high elevation and northern portions of the Northeast, spring was delayed by below average winter temperatures and the lingering heavy snowpack, despite March and April having normal to above-average temperatures[2] (fig. 5 on page 11).

[1] For archival maps of snow cover and modeled snowpack, see the National Weather Service's National Operational Hydrologic Remote Sensing Center Web site located here: http://www.nohrsc.nws.gov.

[2] Monthly temperature and precipitation departures from average for the United States are available on NOAA's climate monitoring Web site: http://www.ncdc.noaa.gov/oa/climate/research/cag.

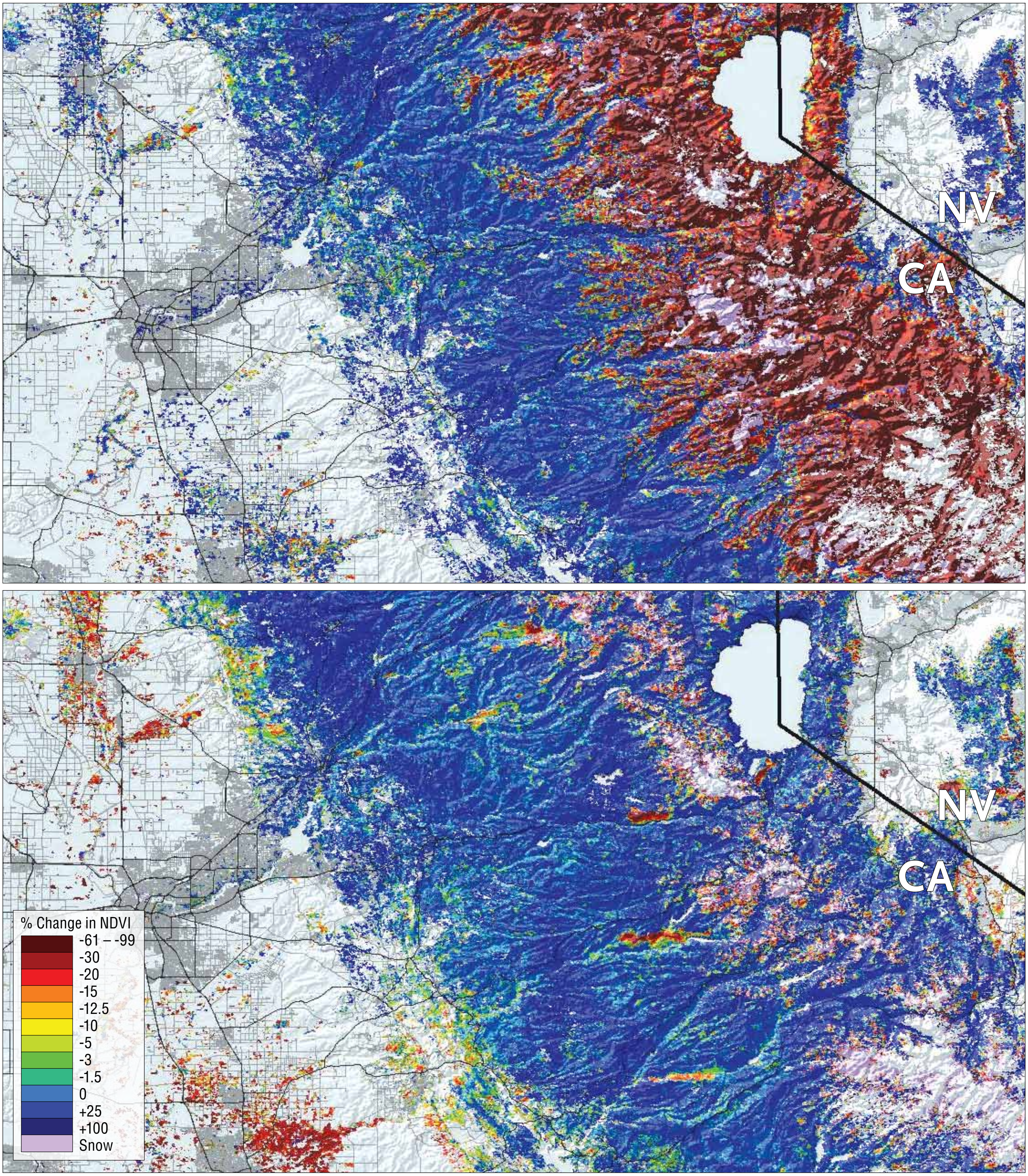
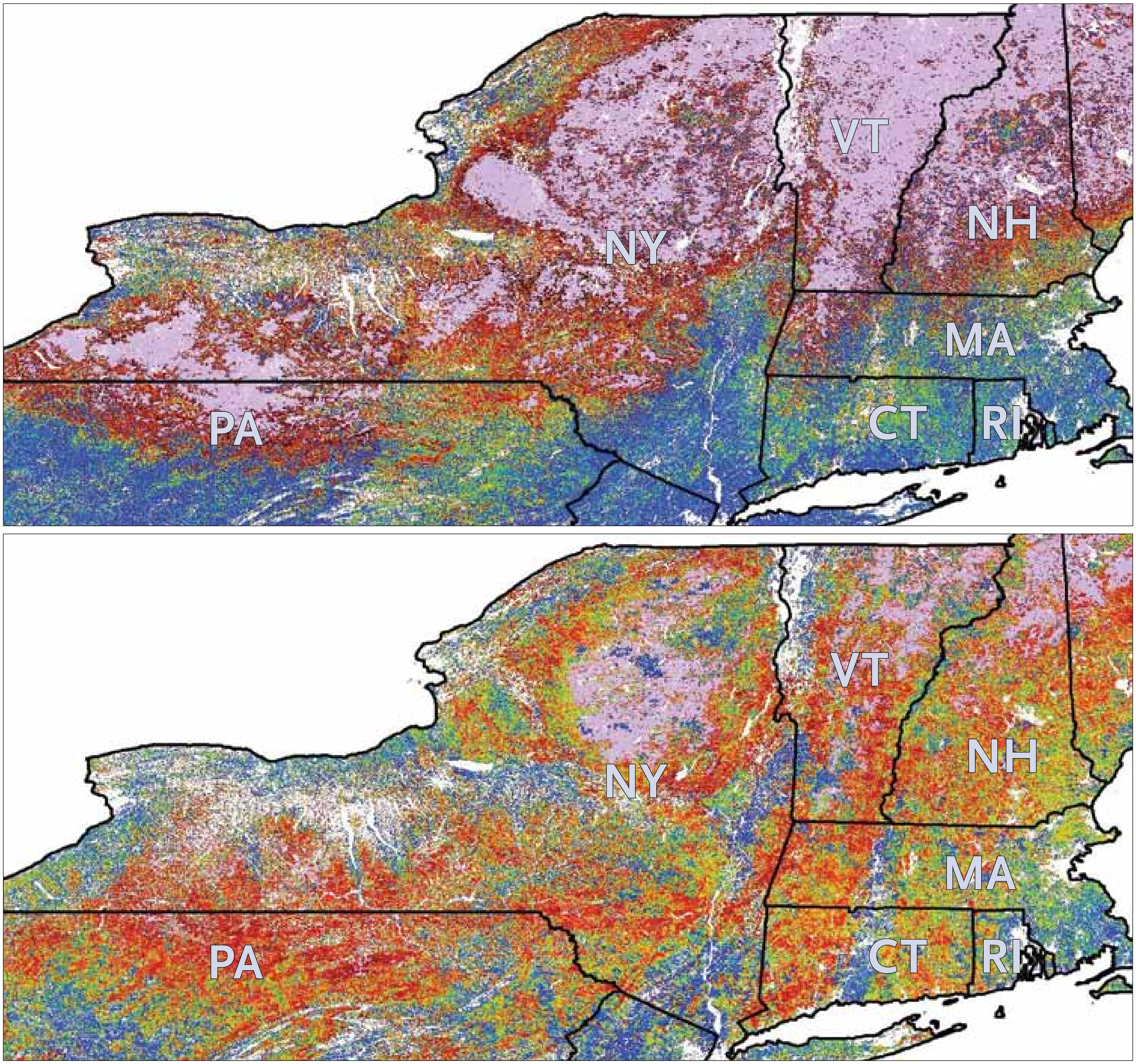


Figure 4—High elevation snowpack anomalies varied greatly in the central Sierra Nevada between December 2010 (top) and December 2011 (bottom), as shown by differences in red based on an 8-year normal. Areas in blue are at the long-term maximum NDVI, while areas in dark red are over 61 percent less. The California-Nevada State line cuts through Lake Tahoe in the upper right corner of the map; the city of Sacramento is shown in grey at center left.



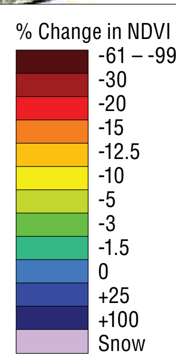


Figure 5—In late March 2011 (top), extensive snow cover remained in the higher elevations of the Northeast and contributed to lower than average levels of forest vigor. Five weeks later, by early May (bottom), snow still lingered in the Adirondacks and northern New England, as shown in pink and dark red; spring greenup was still delayed over extensive portions of the Northeast relative to the 8-year historical baseline, as shown in red, orange, and yellow.

Early Frost

The end of the growing season can be gradual or sudden in response to nuances of temperature and precipitation. In the Northeast, fall's onset is sensitive to the first frost. Progressively lower nighttime temperatures can lead to an extended fall, but unusually cold days or a series of cold days can lead to a rapid decline in observed NDVI measurements. These spatial and year to year differences are evident in *ForWarn*.

The first severe frost in northern Minnesota, Wisconsin, and Michigan varies among years. In 2011, northeastern Minnesota experienced freezing temperatures on September 14, and the temperature dropped several degrees more the following night. In contrast, during 2010, widespread frost occurred on October 2, and a broad, killing frost occurred at the end of the month.[1] While mid-September frosts have occurred there in the past, 2011's cold temperatures were reached relatively early (fig. 6).

[1] RAWS climate data are from Meander, MN. See http://www.raws.dri.edu/.

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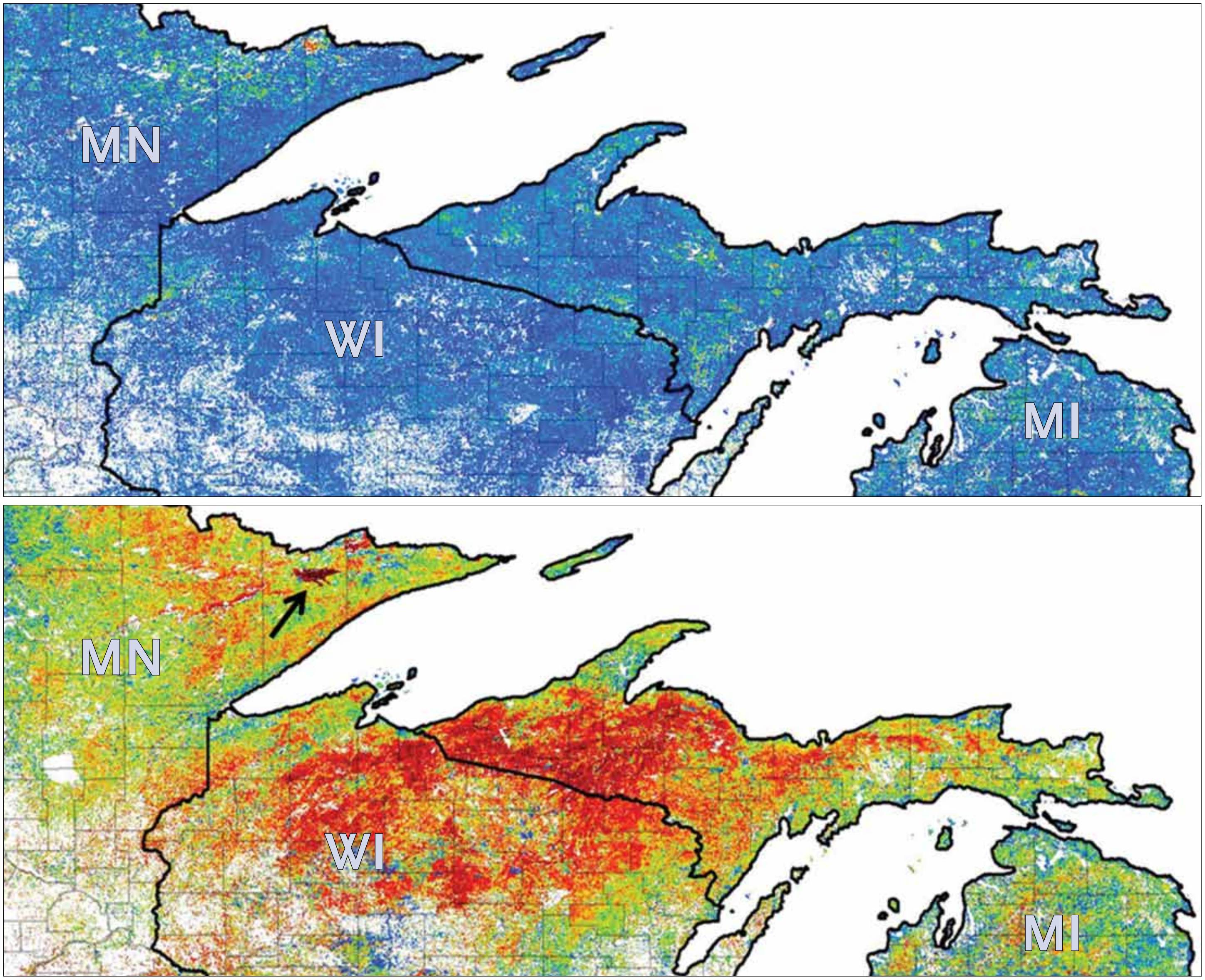
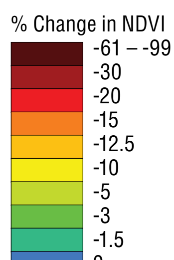
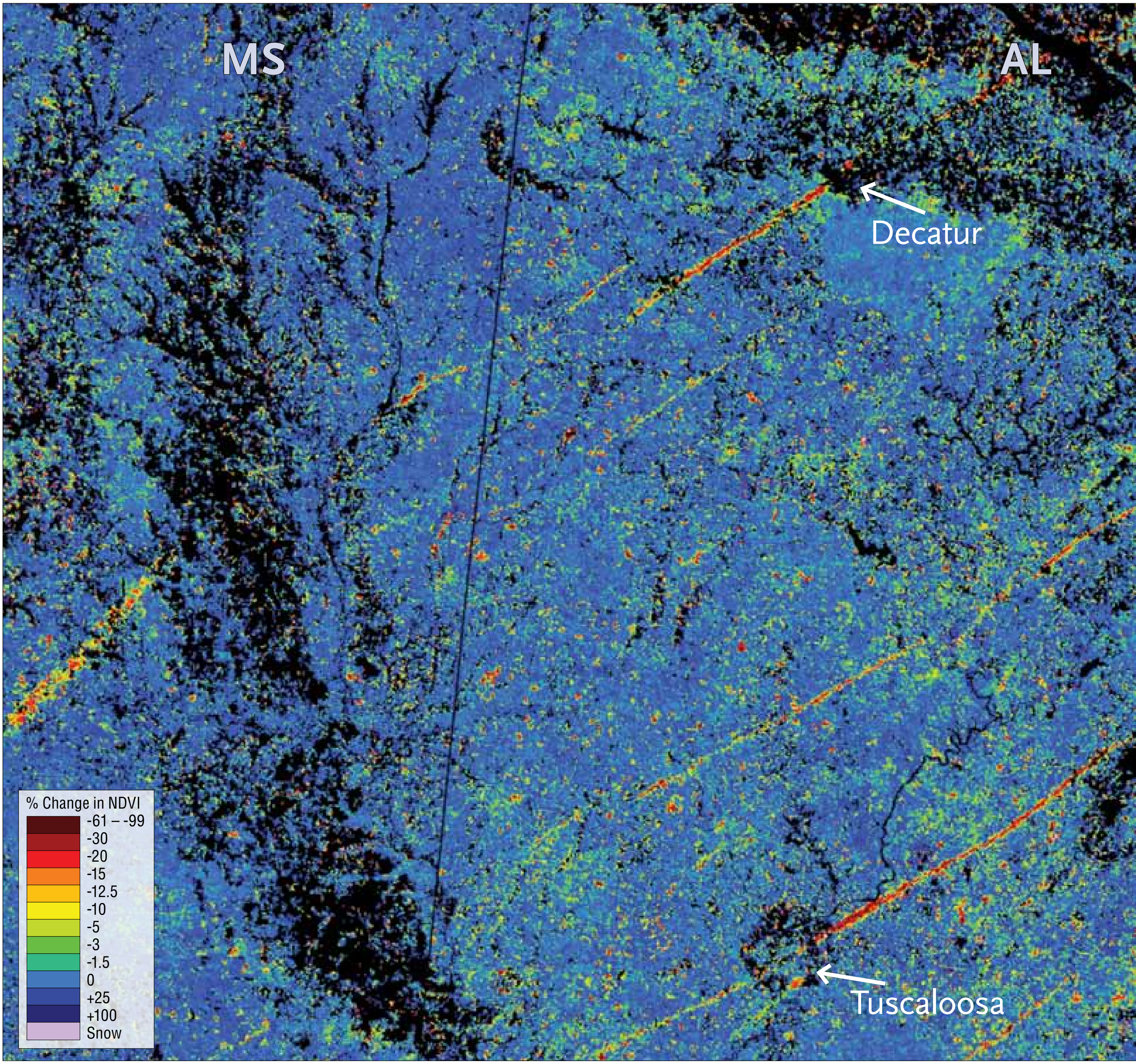


Figure 6—Immediately prior to a hard mid-September frost in 2011, the forests of the Upper Midwest experienced fall much like they did during 2010 (top; ending September 13). However, in the weeks following, a strong forest change anomaly developed over northeastern Minnesota, northern Wisconsin, and the upper peninsula of Michigan (bottom; ending October 15). The dark patch in extreme northeastern Minnesota (indicated by the black arrow) is the Pagami Creek wildfire that made a major run shortly after the NDVI values were collected for the top image. See figure 14 for more detail on this wildfire. The photograph on the left shows the effects of a spring frost on greenup. ForWarn *captures frost effects in both spring and fall.*



Tornadoes and Hail



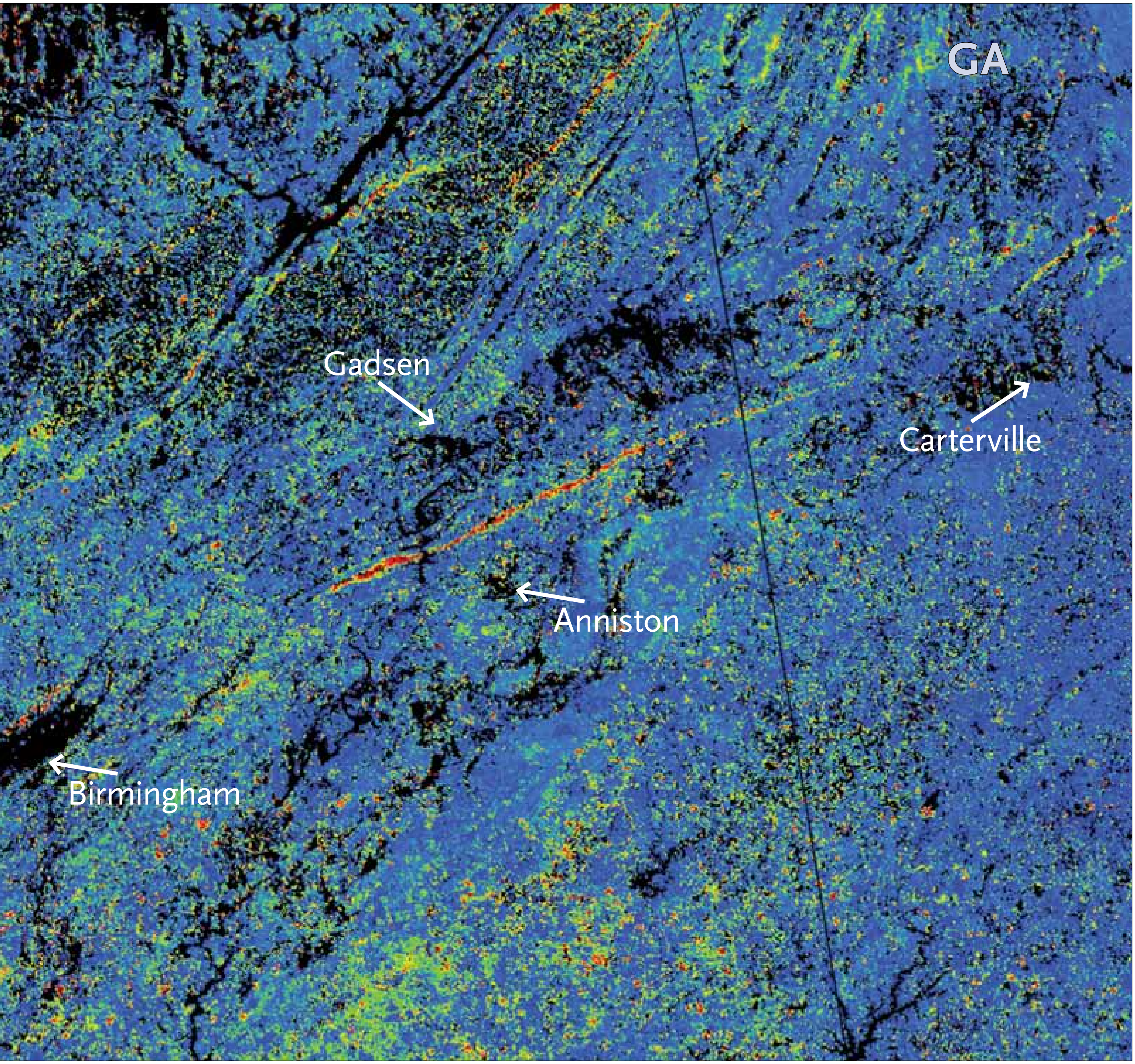


Figure 7—Forests of northern Mississippi (left), Alabama (center), and Georgia (right) were severely scarred by tornadoes in April, 2011. In this image from June 1, note the parallel, northeastern-trending yellow and red streaks that reveal the location and intensity of these storms. Blue areas have similar vigor as 2010 and were unaffected by these storms. Black areas are nonforest, such as fields or developed areas.

The spring of 2011 will be remembered for its multiple outbreaks of destructive tornadoes. According to the National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center, there were about 1,612 tornadoes during 2011, with a record number occurring during late spring and summer. Despite advanced meteorological warning systems now in place in the United States, tornadoes caused 549 fatalities in 2011—the fourth highest death toll since 1875.[1] While the media focused on storms that hit in or near high population areas such as Tuscaloosa, AL, Joplin, MO, and Springfield, MA, these storms had a notable impact on National, State, and private forests.

Across the eastern United States, storms uprooted or damaged hundreds to thousands of trees. The southeastern States of Mississippi, Alabama, and Georgia were hit especially hard (fig. 7 on pages 14–15). *ForWarn* systematically documented the effects of these tornadoes on urban forests and in remote areas that received less or no media attention. *ForWarn* has monitored these areas to document recovery (fig. 8). This combination of near-real time disturbance detection and post-disturbance monitoring suggests that ephemeral defoliation from strong wind or hail is both detectable and widespread (fig. 9).

1 Only 1917, 1925, and 1936 were higher and only 1925 experienced substantially more fatalities. Web site address: http://www.noaanews.noaa.gov/2011_tornado_information.html [Date accessed: May 15, 2013].

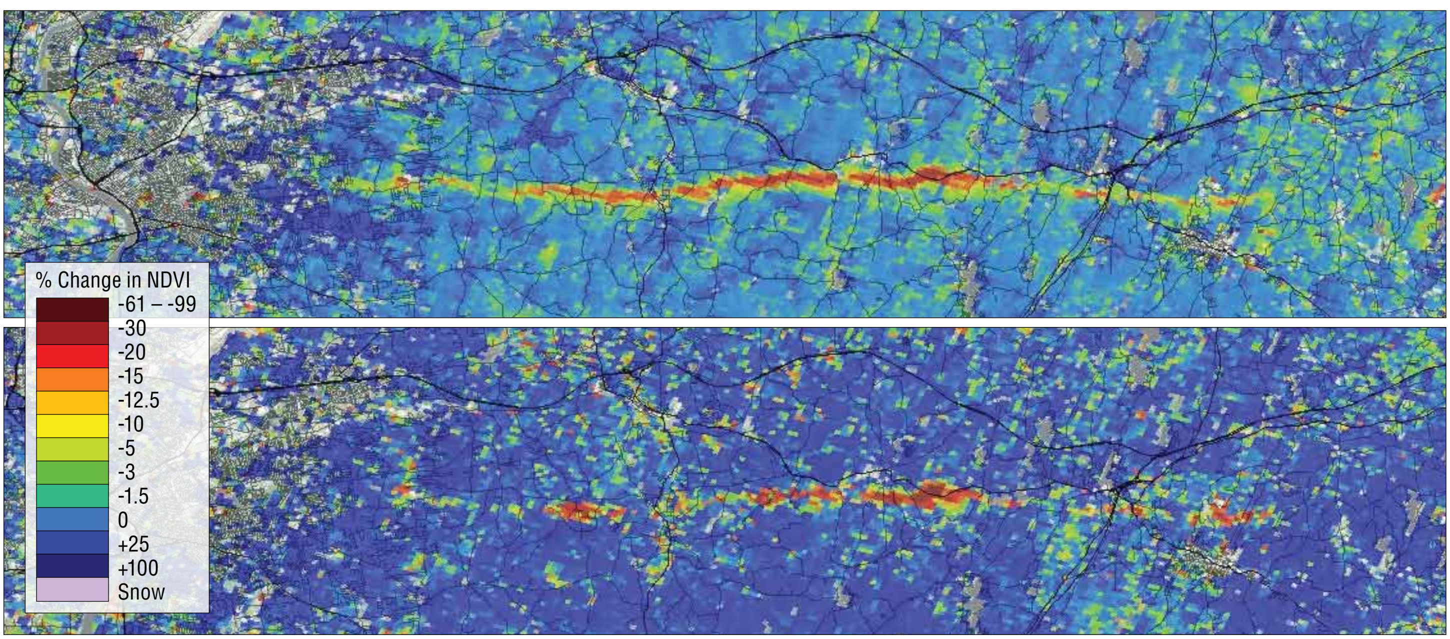


Figure 8—A severe tornado touched down in southeastern Springfield, MA (gray area on left) on June 1, 2011, then carved a path through nearly 30 miles of State and private forest. The areas in red show an extreme reduction in greenness compared to the prior year's condition during mid-June (top), and then six months later in mid-December (bottom) after the unaffected or marginally affected deciduous trees lost their leaves. This persistent forest change suggests that many of the trees damaged or destroyed were evergreen conifers that recover slowly.

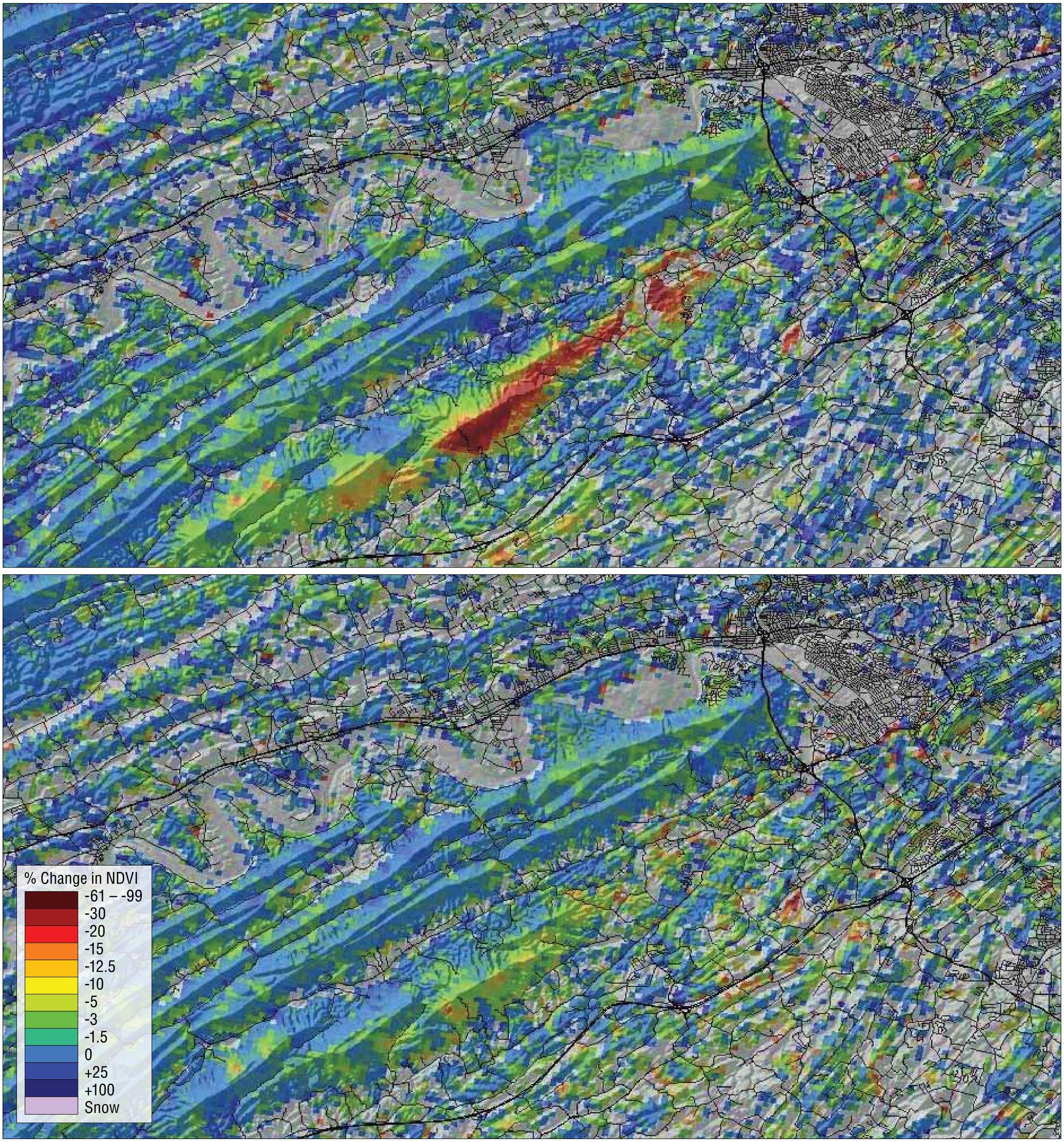


Figure 9—Full-fledged tornadoes are typically well documented by NOAA and subsequent recovery efforts, but the severe storms of April 2011 caused localized short-term effects that were not widely recognized. These images from June 1 (top) and July 3 (bottom) show change anomalies along a forested ridge southwest of Kingsport, TN (in the northeastern corner of the images), where a linear area of wind or hail-induced defoliation recovered after a few months time. In the past, monitoring efforts overlooked such ephemeral disturbances, but ForWarn's *continuous, high-frequency approach to monitoring makes such detections possible.*

Hurricanes

Despite being an active hurricane season in the Atlantic, only two storms made landfall in the United States in 2011. Hurricane Irene was a Category 1 hurricane when it came ashore in coastal North Carolina on August 27 (fig. 10). A week later on September 4, Tropical Storm Lee came ashore in Louisiana; it fanned severe wildfires in Texas without bringing moisture, and then continued northward to bring heavy rains and flooding to the Northeast where soils were already saturated from Irene.

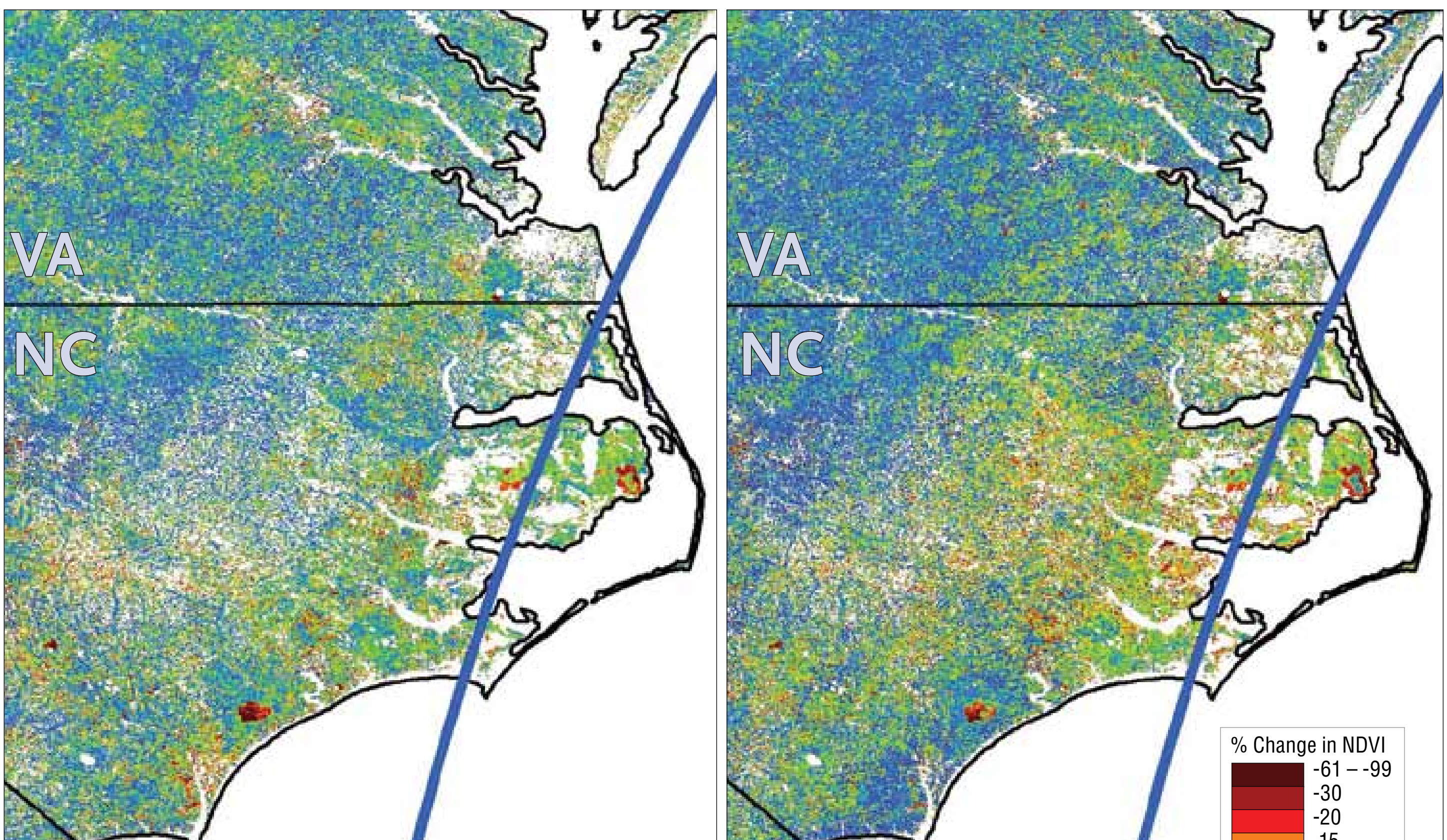


Figure 10—This image pair from coastal North Carolina and southeastern Virginia shows changes associated with Hurricane Irene that made landfall on August 27, 2011. The hurricane's path is shown by the bold blue line. The dark red spots reveal the effects of wildfires burning since spring. In the pre-Irene image (left), shades of green and yellow show the effects of drought on vegetation. Irene brought damaging winds that defoliated trees, but also much needed rain. By the end of September (right), the effects of the storm reduced vegetational vigor in the hardest hit areas of extreme eastern North Carolina while helping the interior forests recover, as shown by the increase in blue, particularly in Virginia.

Drought

Near-record drought plagued the South Central United States during the greater part of 2011, leading to billions of dollars of crop and livestock losses and extensive wildfires. The drought was associated with persistent La Niña conditions in the tropical Pacific, which typically reduce precipitation across the southern tier of the United States. The effects of this severe drought on the forests of Texas were particularly significant, where an estimated half a billion trees succumbed[1] (fig. 11).

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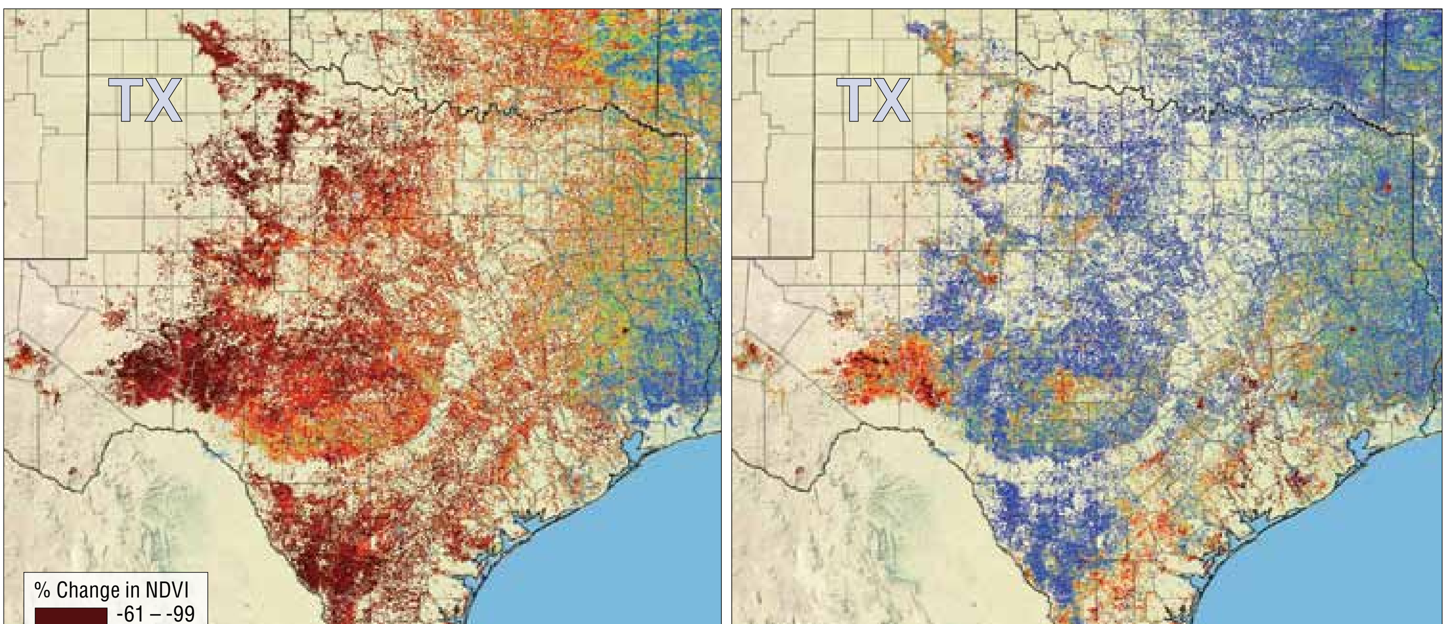
[1] This estimate of tree death from the 2011 drought was made by the Texas Forest Service based on field observations and estimates of tree cover from Forest Inventory and Analysis (FIA) statistics.



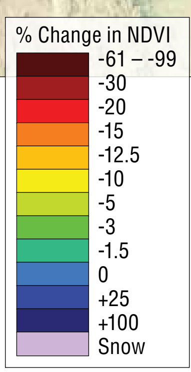


Figure 11—Throughout much of 2011, moderate to severe drought afflicted forests across the south central United States. By the end of summer, the cumulative effects of drought and wildfires were pronounced across much of Texas (below left). Four months later, despite continued drought, forests began to resemble their 2010 condition (as shown in blue) with the prominent exception of west-central Texas that was hit especially hard (below right). Uncolored regions north of Mexico are nonforested rangeland, cropland, or other developed areas.

Wildfires

Wildfires impact the character of a large portion of U.S. forests, but their distribution and specific impacts are not consistent from year to year. The pattern of fire during 2011 sharply differed from recent years in large part due to the extreme drought. Texas was hit especially hard, but notable wildfires occurred across the Nation, including the massive Wallow Fire in Arizona (fig. 12), the Honey Prairie Complex in Georgia (fig. 13 on page 22), the Pagami Creek Fire in Minnesota (fig. 14 on page 22), and the lingering effects of a range of fires in southern California (fig. 15 on page 23). Using *ForWarn* to map forest change shows fire severity immediately after the fire and during subsequent months and years.

Figure 12—In June of 2011, the Wallow Fire burned over half a million acres in east-central Arizona, much of it on the Apache-Sitgreaves National Forests. A substantial portion of the burn was of high severity, killing millions of trees outright. Looking south-southwest over the Escudilla Mountain Fire Lookout Tower (A), the effects of the high-severity fire are clear. This observed severity is consistent with the ForWarn *map from July (B) showing that same area within the Escudilla Wilderness. The severity of the entire fire is shown as of September 13, 2011 (C). Note that the fire's effect on vegetation is highly variable within the boundary of the fire (outlined in black) and that some areas outside the fire perimeter have a reduction in NDVI from drought or some other disturbance.*

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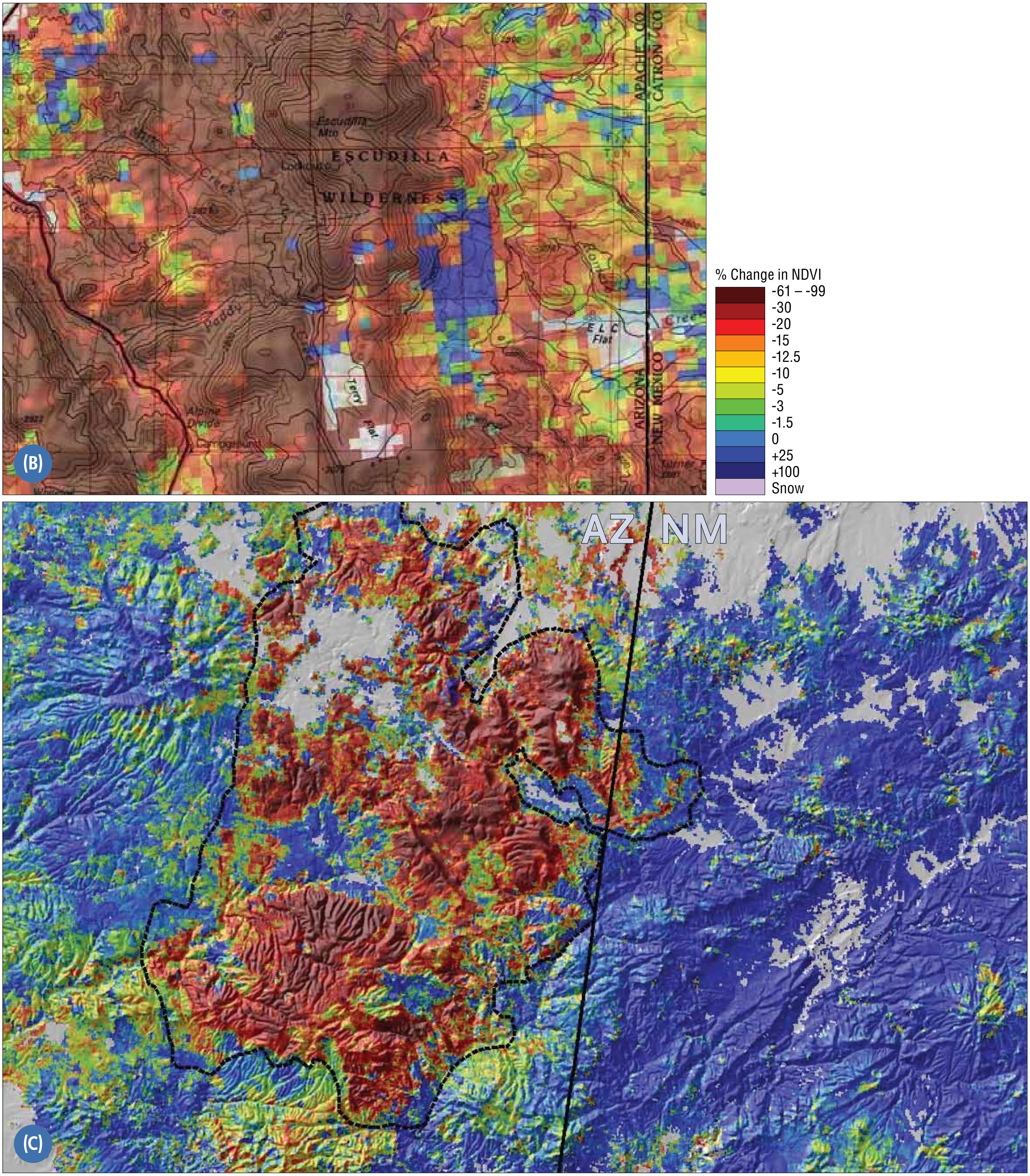
(B)
Escudilla Mtn
ESCUDILLA
WILDERNESS
APACHE CO
CATRON CO
ARIZONA
NEW MEXICO
Terry Flat
Alpine Divide Campground
E L C Flat
% Change in NDVI
-61 – -99
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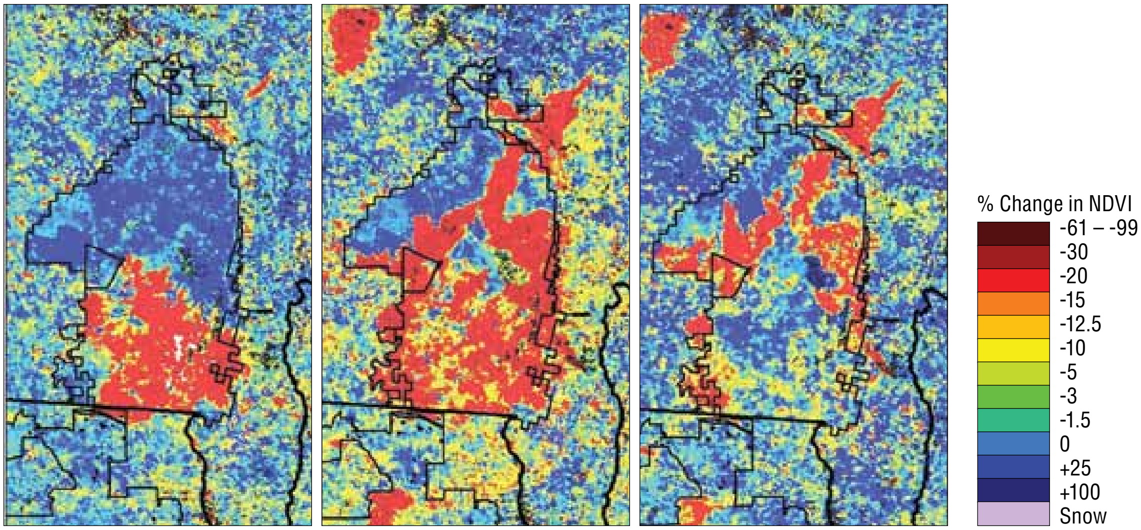

Figure 13—Georgia's Okefenokee Swamp National Wildlife Refuge near the Georgia-Florida State line burned in 2007 and again in 2011. This rapid recovery of fuels reflects the importance of sprouting vegetation. This image sequence from the summer of 2011 illustrates the vegetative resilience in the region. By June 17, wildfire, as shown in red, had spread northward through about half of the Refuge (left). By July 19 (center), fire had progressed north, and a new fire became evident northwest of the Refuge. By August 20 (right), vegetation in the area that had burned in May and June had recovered to the long-term baseline NDVI, as shown in blue. This fire burned over 300,000 acres.

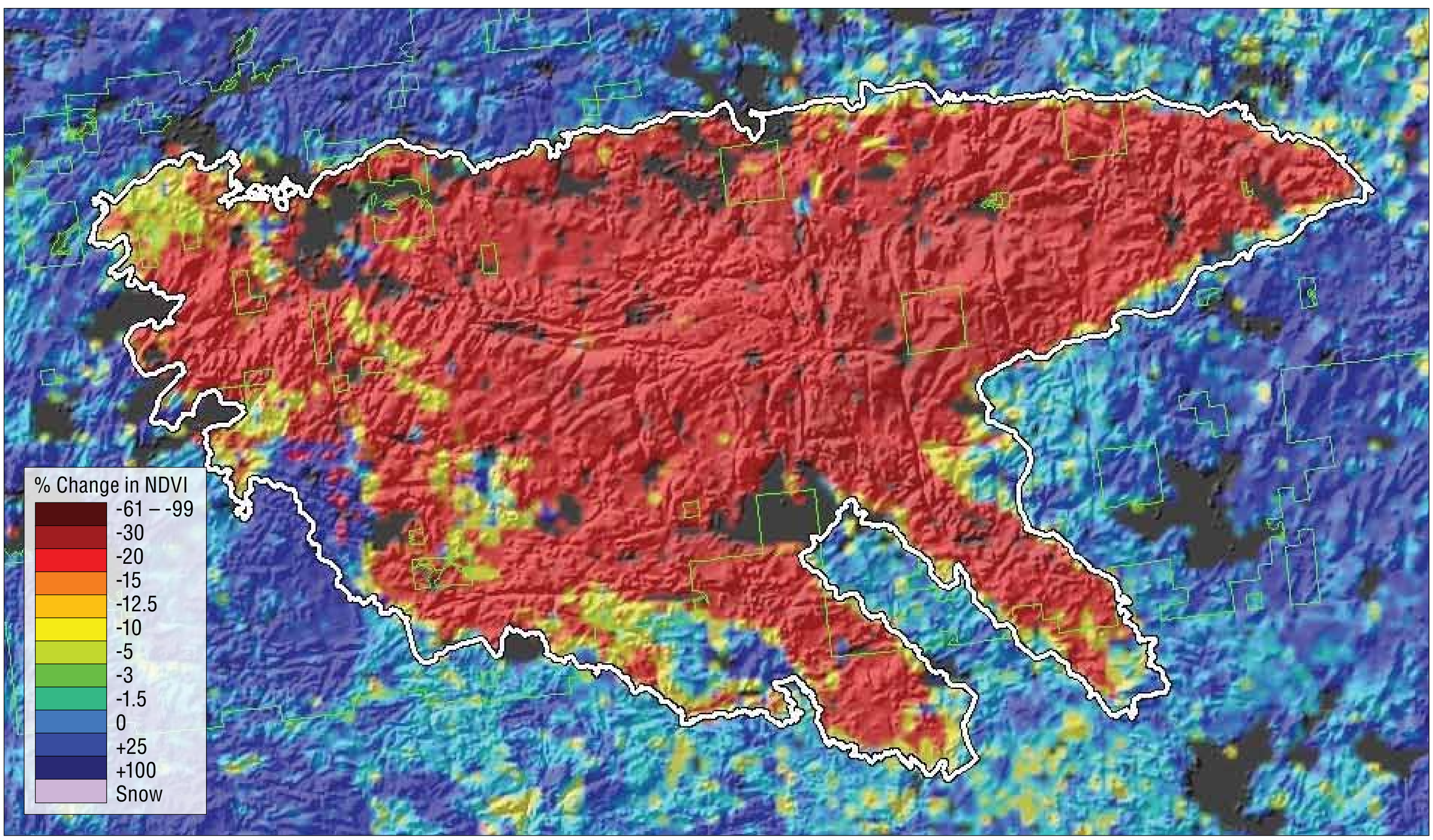

Figure 14—In September 2011, the Pagami Creek Fire burned over 92,000 acres at the heart of the Boundary Waters Canoe Area Wilderness of the Superior National Forest, Minnesota. Fire severity was particularly high over a vast area, as most of the area burned in just a few days time during extreme fire weather. The fire started among the lakes in the upper left corner of the image (lakes are shown as dark gray). Then, it rapidly spread toward the east and southeast. Note the irregular southern fire perimeter that includes a "fire shadow" on the leeward side of a lake where water interrupted the southeastward spread of fire. This fire is visible on figure 6.

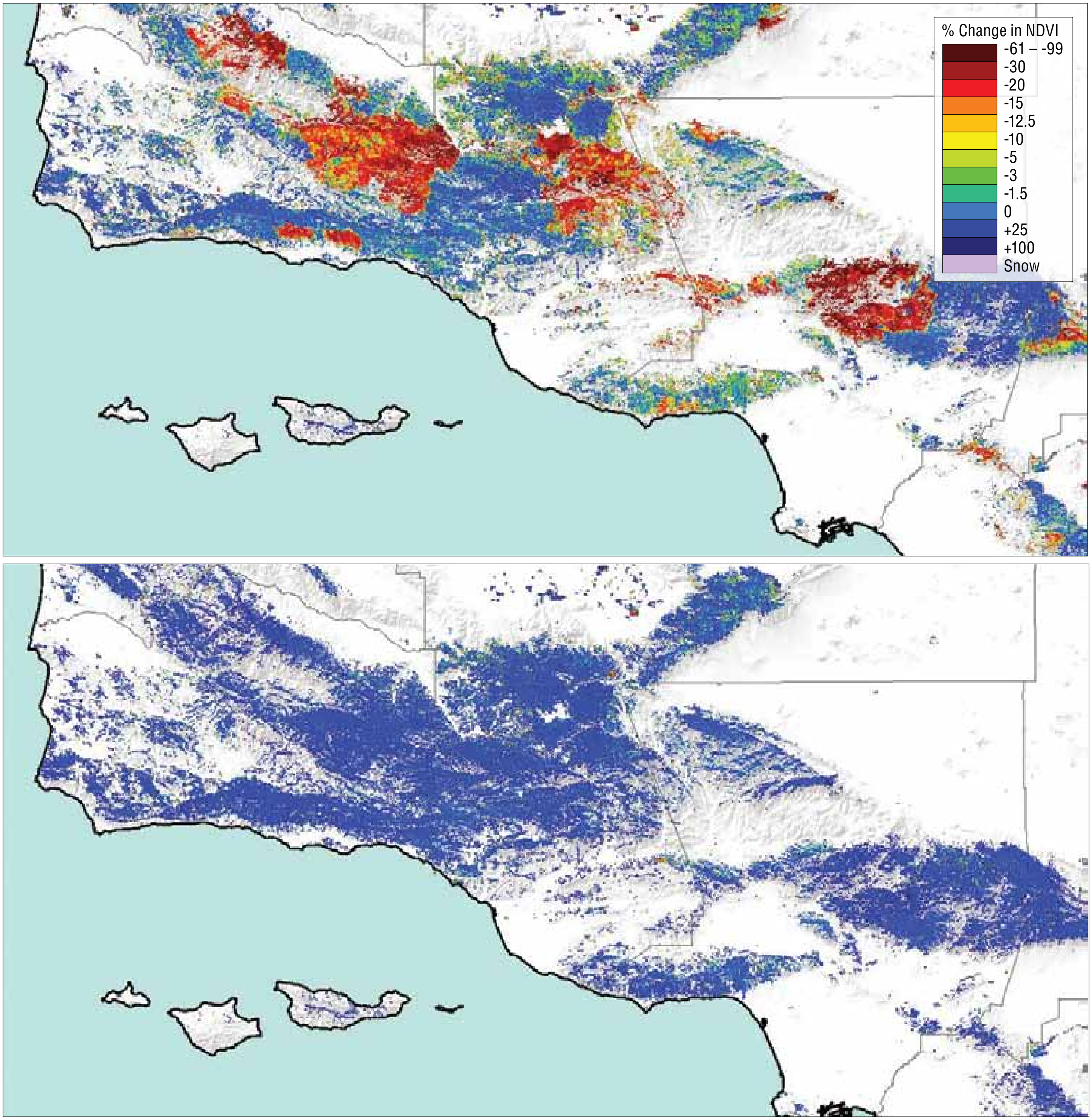

Figure 15—A comparison of two different baselines for the same date provides a perspective on change for southern California. This image pair from September 21, 2011 shows change in NDVI relative to the 2003-2010 baseline (top) and change relative to 2010 (bottom). The decline in greenness from numerous wildfires is clear in the top image (as evidenced by the red and yellow areas), but as no new fires occurred during 2011, blue occurs everywhere in the image with the prior year (2010) baseline (bottom). Dark shades of blue reflect rapid post-fire recovery. Having multiple baseline conditions to explore both disturbance and recovery provides powerful monitoring insights for understanding long-term fire effects and ecological resilience.

Insect Defoliation

Over their evolutionary history, trees have had to contend with a wide array of insects and pathogens, but outbreaks can be symptomatic of fundamental environmental change, such as the emergence of previously minor or non-existent causes. The spread of nonnative insects and pathogens provides many examples of the critical need for systematic field and remotely sensed monitoring. Nonnative species include Gypsy Moths, the hemlock woolly adelgid, the beech scale insect responsible for beech bark disease, the pathogen responsible for sudden oak death, and the emerald ash borer. The effects of native insects and pathogens are also important to track, as their distribution and impacts are often influenced by broad-scale factors, such as warming temperatures, fire exclusion, and stand management. Remotely sensed monitoring is particularly useful when efforts are undertaken to control spread or minimize impacts during or after outbreaks. Shown here are examples highlighting a range of pest activities detected during 2011 from the States of Utah (fig. 16), Washington (fig. 17), Pennsylvania (fig. 18 on page 26), and Tennessee (fig. 19 on page 27).

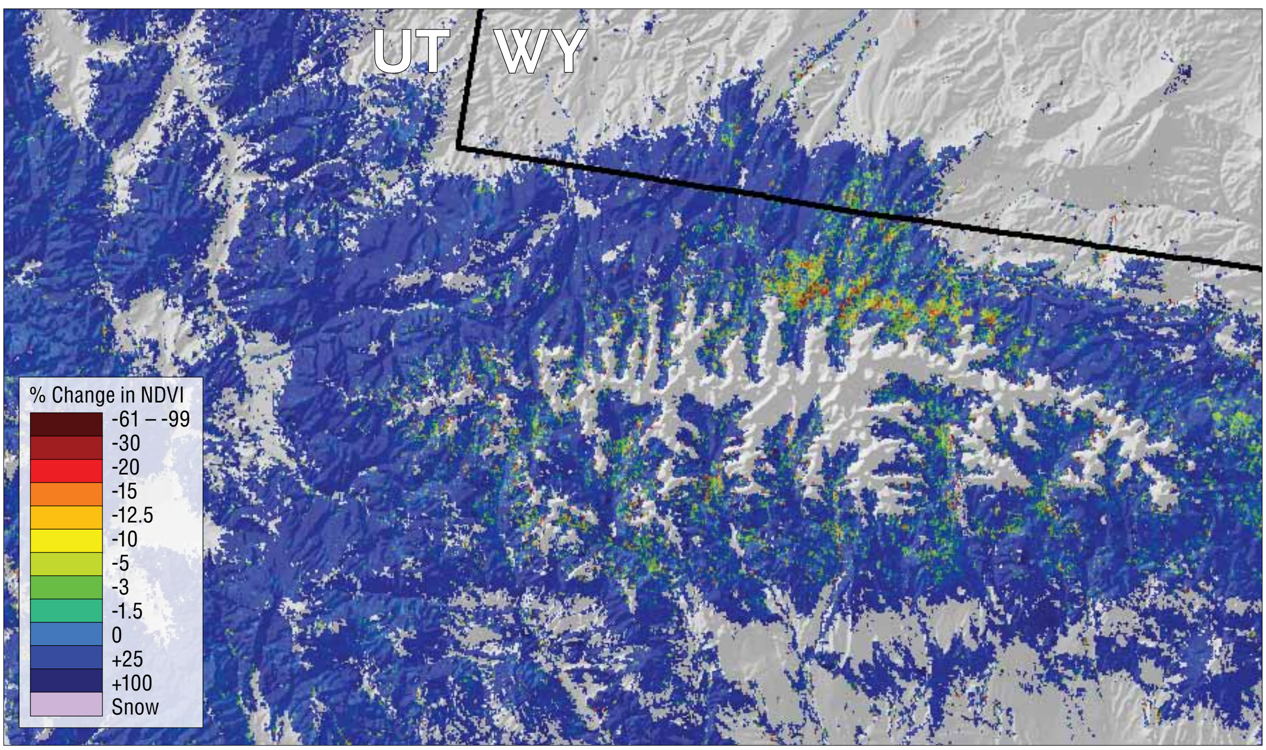

Figure 16—This image shows a high concentration of anomalies in green, yellow, and red on the north slope of the Wasatch Range in the Wasatch National Forest, Utah on September 13, 2011 compared to the previous year. The highest elevations of the Wasatch Mountains (to the right of center) are shown without color, as they lie above treeline. Most of the region's forest is blue, meaning it is similar to that of the same satellite image collection period of the prior year. According to aerial detection surveys, the north slope of the Wasatch has experienced repeated mountain pine beetle outbreaks in recent years, but they usually occur at lower elevations. These affected forests are dominated by lodgepole pine.

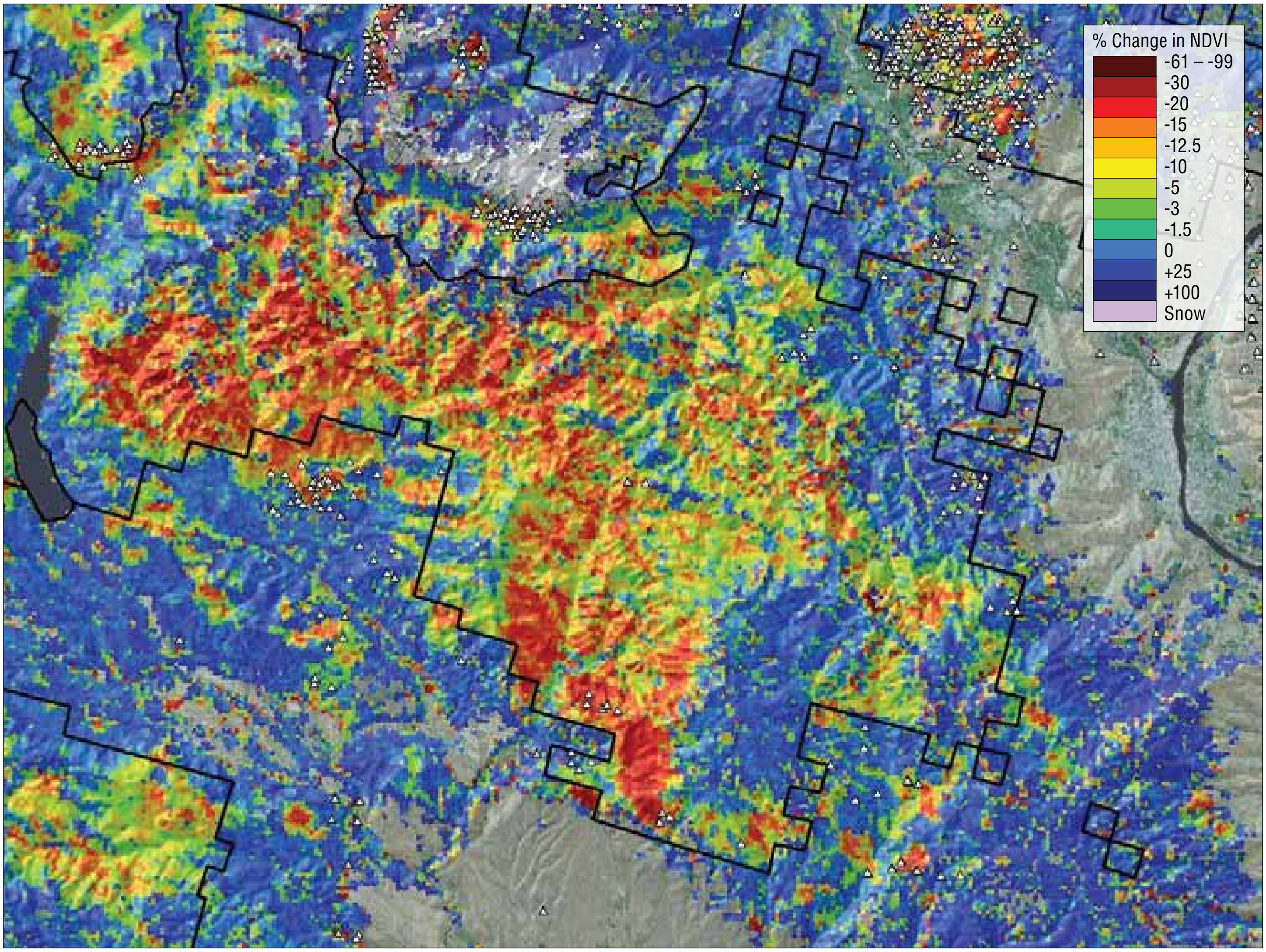

Figure 17—A sizable portion of Washington's Wenatchee National Forest departed from normal, as shown in yellow, orange, and red for the all-year baseline for September 13, 2011. While such declines in NDVI often result from tree death due to wildfires, no large fire occurred in the primary area of decline. On this map, satellite-based fire detections are shown by white triangles. These detections were made by the same MODIS sensors and satellites used by the ForWarn system, but they are provided by the Active Fire Mapping Program of the Forest Service Remote Sensing Applications Center, or RSAC (see http://activefiremaps.fs.fed.us/). Rather than from fire, much of this decadal decline in NDVI was probably caused by the cumulative effects of defoliating insects on tree mortality, particularly spruce budworm, given mapped attributions by aerial mapping surveys conducted by the Forest Health mapping program.

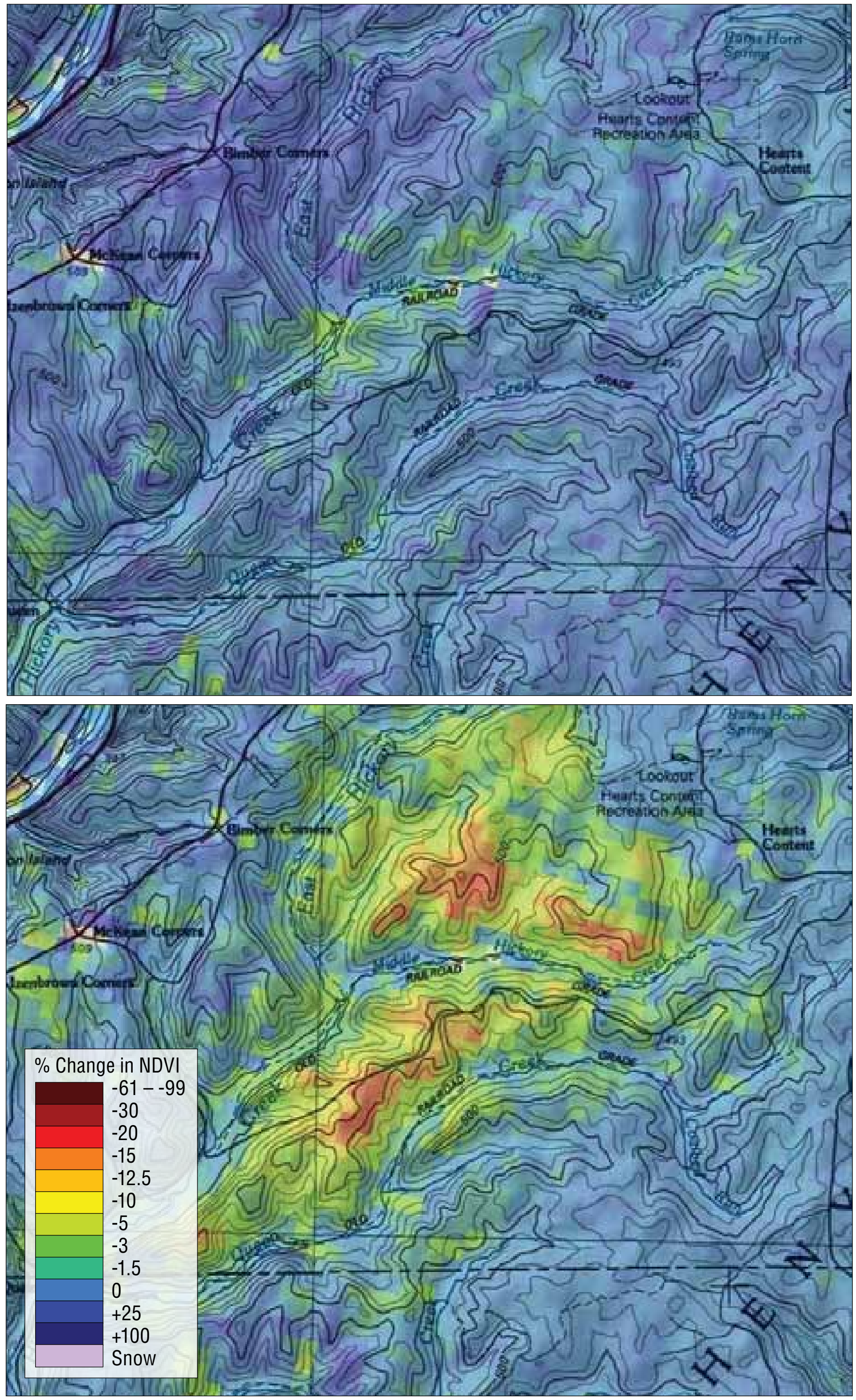

Figure 18—Detecting insect defoliations near the end of the growing season is challenging as loss of greenness is rapid and fall varies from year to year simply from nuances of temperature and precipitation. ForWarn *compares existing conditions to the same window of time for baseline years to minimize the effects of seasonal change. The success of this approach is demonstrated by this fall webworm detection in the Hickory Creek Wilderness Area of the Allegheny National Forest, Pennsylvania. The image shows minimal indications of defoliation in mid-August 2011 (top), but that by mid-September extensive areas of defoliation of variable intensity appear (bottom). This anomaly persisted into November when the seasonal norm became leafless.*

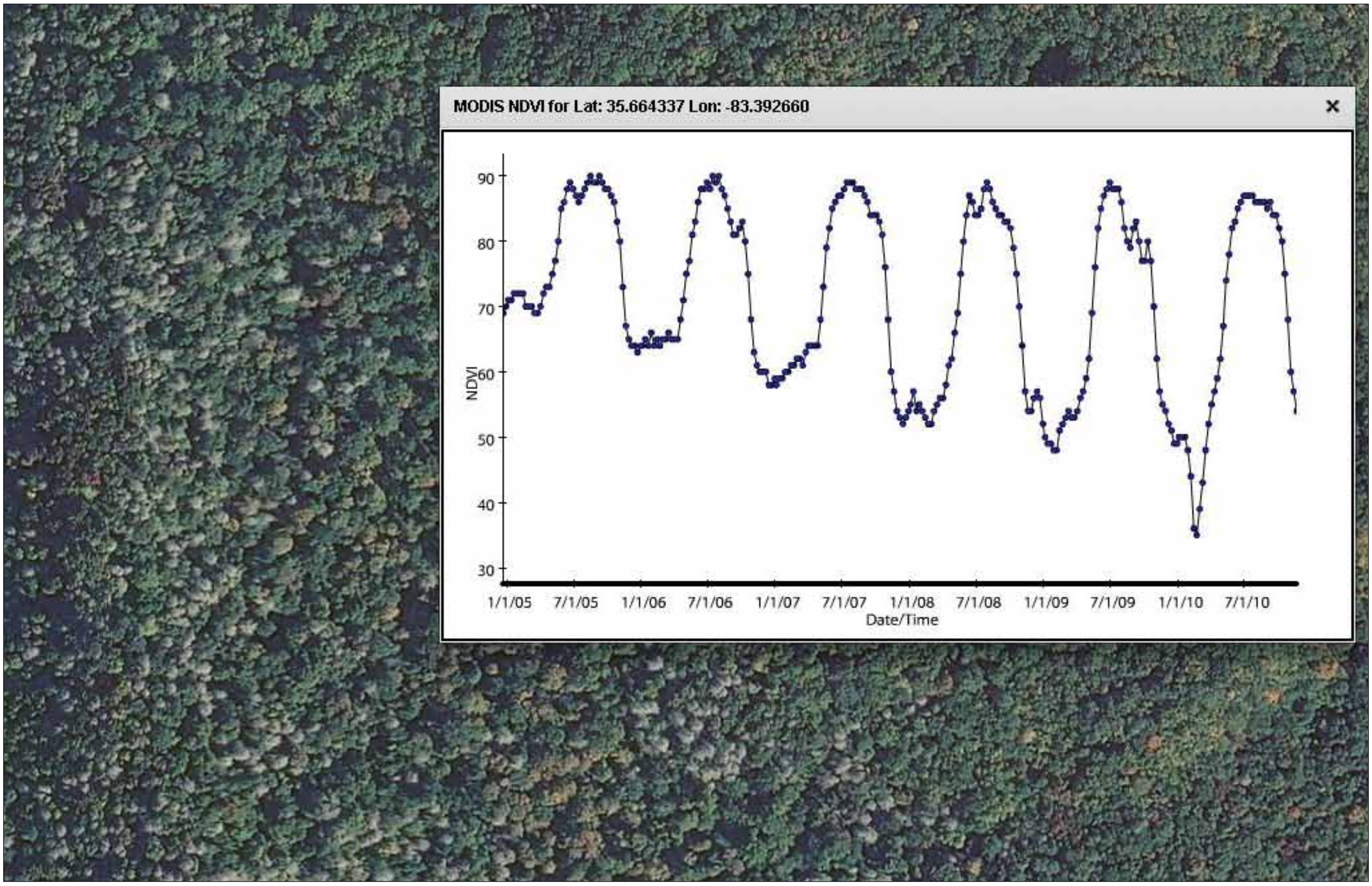

Figure 19—The grey canopies in the background image are hemlocks that have succumbed to the hemlock woolly adelgid. ForWarn *captured the rapid and widespread mortality of these evergreen trees by this invasive insect across the southern Appalachians in recent years. The time trace of 8-day NDVI from 2005-2010 (see inset graph) shows how winter NDVI has progressively fallen for this area in Great Smoky Mountains National Park east of Gatlinburg, TN. This decline is due to the selective mortality of the evergreen component of this stand, which is most apparent during the winter months. The sudden drop in early 2010 was caused by a wet snow that covered branches and understory vegetation for weeks.*

Development and Deforestation

Conversion of forest to nonforest uses is a localized phenomenon across much of the United States. Urbanization is often the primary cause of this change, as forests are broken up into smaller parcels for homes and roadways (fig. 20). Other areas are deforested for gas well development or strip mining (fig. 21). Tracking where this change is taking place is important for resource managers, as fragmented forests impact plant and wildlife habitat and water supplies. The variable baselines within *ForWarn* provide insights into the pattern and rate of land cover change.

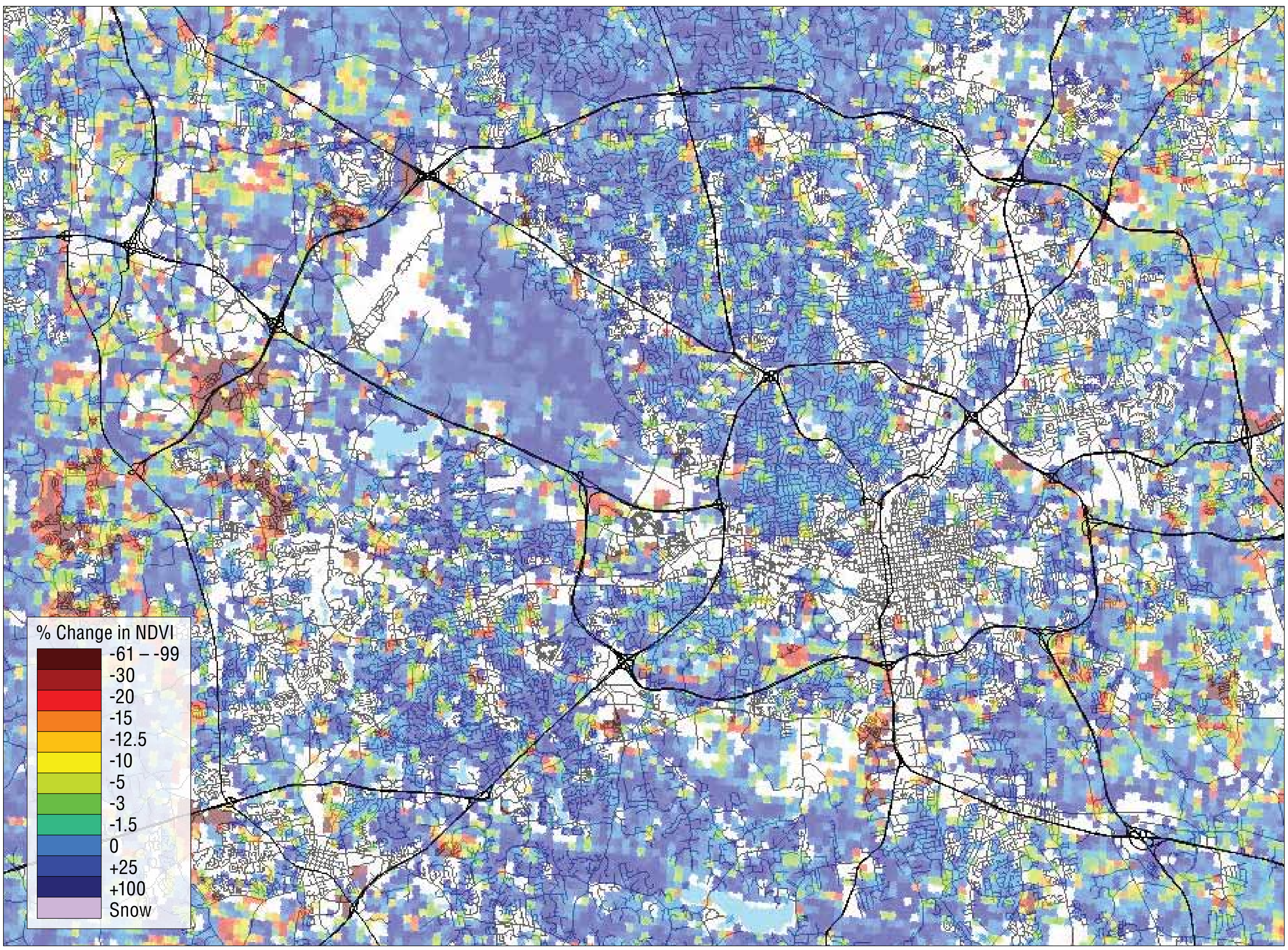

Figure 20—Substantial forest area has fallen to development in the periphery of many urban areas over the last decade. This image shows deforestation in the periphery of Raleigh, NC (center-right of image) as yellow to red anomalies. Blue areas have not changed during the last decade. This reveals that scattered forest patches have been converted south and east of downtown, and that sizable areas have been converted west of the city along the outer highway belt.

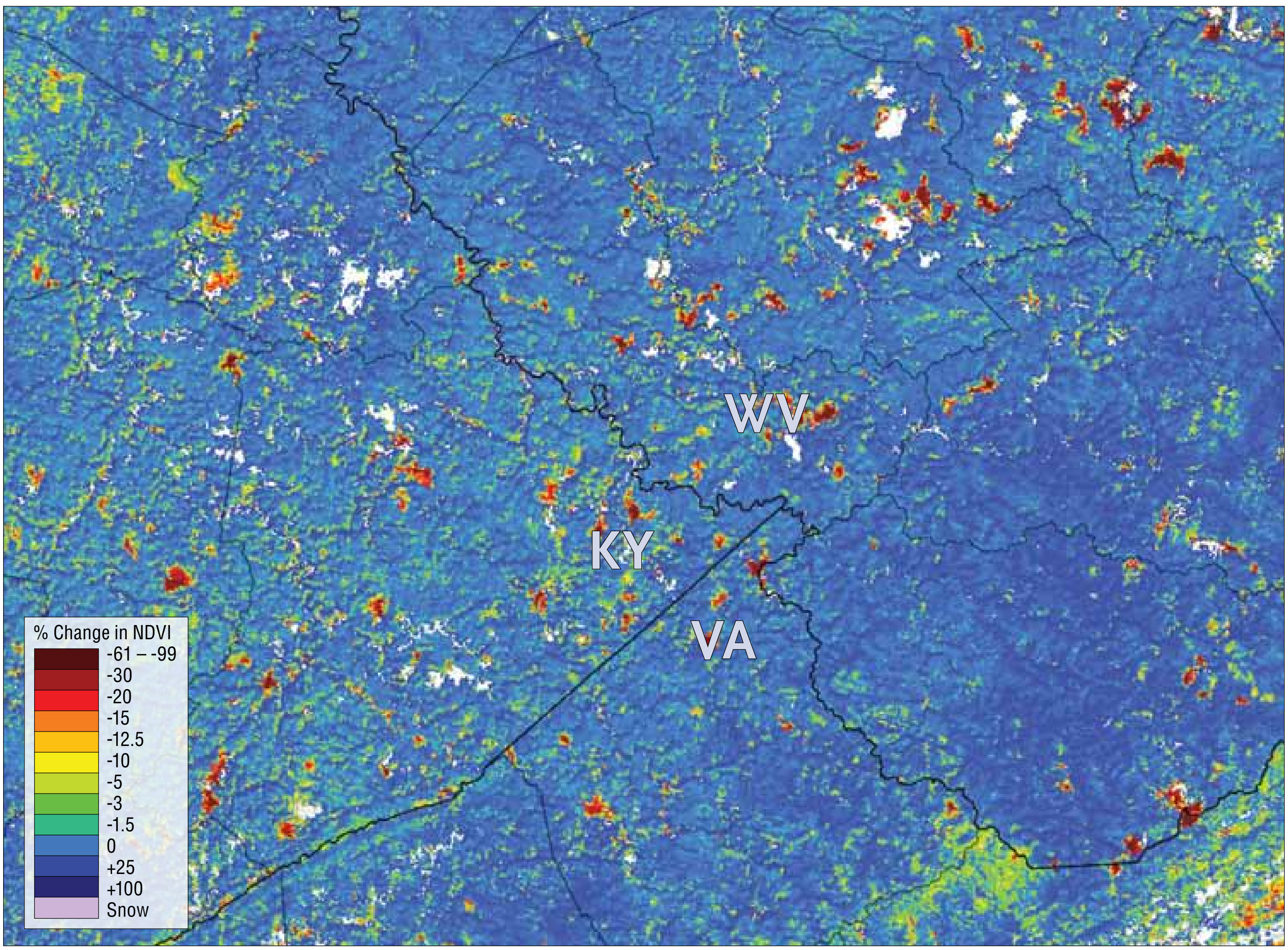

Figure 21—Deforestation for strip mining is common practice in the coal fields of eastern Kentucky and West Virginia. Red and orange patches in this image show areas where vegetation has been removed for this purpose over the last decade.

Summary

ForWarn HAS SUCCESSFULLY DETECTED DIVERSE CLIMATE AND disturbance effects on forest vegetation. Climate effects include delayed spring greenup in the East, an early fall in the Midwest, the effects of an exceptionally severe drought in Texas, and an unusually heavy snowpack in the West. Despite variation in the climate-affected background condition, *ForWarn* successfully detected a range of local disturbances. These disturbances included the effects of tornadoes and windstorms in spring, variations in the severity of wildfires, the complex effects of a hurricane and tropical storm during regional drought, and defoliation and mortality from insects. *ForWarn* also detected deforestation associated with urbanization and mining among other drivers of forest change.

ForWarn's near-real time and broad spatial approach to monitoring allows managers to systematically follow the progression of long-duration disturbances and recovery as readily as ephemeral disturbances that are detectable for only part of the growing season. This flexibility empowers forest managers and researchers to understand the condition and dynamics of forests across the United States.

Norman, S.P.; Hargrove, W.W.; Spruce, J.P. [and others]. 2013. Highlights of satellite-based forest change recognition and tracking using the *ForWarn* System. Gen. Tech. Rep. SRS-180. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 30 p.

Satellite-based remote sensing can assist forest managers with their need to recognize disturbances and track recovery. Despite the long standing availability of raw imagery, the systematic delivery of spatially continuous, ready-to-use, processed products has evaded us until recently. The web-based *ForWarn* system moves us a step forward by generating forest change maps at high frequency in a format that is usable to forest managers, planners, and the public. The *ForWarn* system shows change in the Normalized Difference Vegetation Index derived from moderate resolution imagery according to a range of baseline normals. Expectations of normal derive from previously observed changes in seasonal leaf phenology; this adjustment is critical for forests dominated by deciduous vegetation that vary in greenness through the year. After these seasonal adjustments are made behind the scene, the remaining forest change that *ForWarn* users see may result from an array of climatic and disturbance causes. These include insects and disease, wildland fire, wind, hail, human development, drought, or variation in the timing of spring and fall. This publication outlines the data and methods that underlie this technology, and provides examples that illustrate selected capabilities of this system for coarse-scale forest monitoring.

Keywords: Disturbance, monitoring, phenology, recovery, remote sensing.

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