

# U.S. Geological Survey Development of a Landsat-based Fire Disturbance ECV

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**Abstract – The United States Geological Survey (USGS) is the steward of the Landsat archive which includes satellite imagery dating back to 1972. The United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change have specified requirements to systematically observe atmosphere, ocean, and land characteristics, or Essential Climate Variables (ECVs). The Global Climate Observing System has developed formal specifications for ECVs that are technically and economically feasible for systematic ECV observation. Fire Disturbance is one of the 14 Terrestrial ECVs, and is defined as “burned area” supplemented by “active fires” and “fire radiated power” (FRP) measurements. Landsat’s temporal resolution and sensor characteristics make it suitable for mapping burned area, but not suitable for monitoring active fires or FRP. In this paper, we describe the development of a database for calibration, verification, and validation of a Landsat-based burned area ECV, along with the algorithms to be tested against that database.**

**Keywords:** Landsat, remote sensing, fire, disturbance, ECV, burned area.

## 1. INTRODUCTION

The Global Terrestrial Observing System (GTOS), Global Climate Observing System (GCOS), World Meteorological Organization (WMO), and the Committee on Earth Observation Satellites (CEOS) all support consistent global land observations and measurements. To accomplish this, GCOS defined Essential Climate Variables (ECVs) as measurements of atmosphere, oceans, and land characteristics that are technically and economically feasible for systematic observation and are needed to meet the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) requirements (GCOS 2010). Fire disturbance is one of the terrestrial ECVs, and is defined as “burned area” with the supplemental variables of “active fire” and “fire radiated power” (FRP) (Csiszar, Arino et al. 2009). This information is important to climate and carbon modeling as these three variables are critical for estimating biomass consumption, and carbon, trace gas, and aerosol emissions.

GCOS has established requirements for burned area measurements to be detected with optical sensors with a

spatial resolution of 250-meters or less. Burned area would ideally be collected on a weekly basis, but with the day burned identified. Active fires and FRP require mid- and thermal-infrared spectral channels with a wide dynamic range to avoid sensor saturation (Global Observing Systems Information Center (GOSIC) 2010). Active fires and FRP are not needed at such a fine spatial resolution as burned area; the GCOS requirements suggest 1 km.

The United States Geological Survey (USGS) is the steward of the Landsat archive, satellite imagery which dates back to 1972. This long-term archive provides a potential basis for deriving long-term, global-scale, accurate, timely and consistent measurements of many of the terrestrial ECVs. Landsat 5 Thematic Mapper (TM) has a 30-meter spatial resolution, and a 16-day temporal interval (U.S. Department of the Interior 2010). Although not in compliance with the temporal requirements of the Fire Disturbance ECV of weekly summaries of burned area with the day of burn identified, Landsat is far superior in its spatial resolution (30 meter) than the 250-meter resolution requirement. With the opening of the Landsat archive and the Landsat Data Continuity Mission, data are available for deriving burned area using consistent data with nearly global coverage, and over a time period that is suitable for climate-change analysis.

The USGS is researching algorithms to support the automated derivation of burned area from Landsat data. In support of this, a calibration and validation dataset has been developed over the state of Colorado for the years 2000-2009. This paper discusses the dataset development and the algorithms that will be tested against that dataset for burned area ECV production.

## 2. DATABASE DEVELOPMENT

Landsat 5 TM data for the years 2000-2009 were downloaded for the 16 path-row footprints shown in Figure 1. The imagery was required to be less than 70% cloud covered, but no other restrictions were placed on the data. All images were atmospherically corrected using the ENVI 4.7\*\*\* Landsat Calibration utility (ITT Visual Information Solutions 2009).

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Reported fire locations were gathered from all available federal sources. This information was in both point and polygon format. The federal sources included: the FireCode System (U.S. Department of Agriculture and U.S. Department of Interior 2010), Federal Wildland Fire Occurrence Database (U.S. Department of Interior 2010), ICS-209 Interagency Management Situation Report (IMSR) data (National Interagency Fire Center 2010), Monitoring Trends in Burn Severity (MTBS) (USDA Forest Service and U.S. Geological Survey 2010), GeoMAC (U.S. Department of Interior and U.S. Department of Agriculture 2010), the LandFire Reference Database, (U.S. Department of Agriculture and U.S. Department of Interior 2010), and the National Fire Plan Operations and Reporting System (NFPORS) (DOI-USDA 2010). Additionally Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire (U.S. Department of Agriculture 2010) were acquired for 2001 – 2009, and MODIS Burned Area data (Justice, Giglio et al. 2002; Justice 2010) were acquired for the years 2000 through 2009.

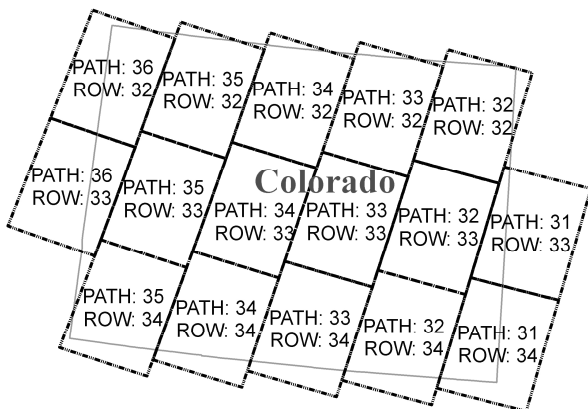


Figure 1. Landsat path-row footprints covering the state of Colorado.

The federal reported fire locations were loaded into a geodatabase and examined against the Landsat imagery using ESRI ArcMap 10<sup>\*\*\*</sup> (ESRI 2011). The reported fire locations were used by interpreters to quickly determine which images to search for fire scars. In addition, polygon data, although limited in quantity, aided in training interpreters to distinguish fire scars from other types of disturbances. Only fires reported to be 10 acres or greater were included in this process, as fires less than 10 acres were difficult to consistently identify in Landsat images. In addition, any records identifying prescribed burns as “piles” in the federal data sources were not included, even if they

<sup>\*\*\*</sup> The use of trade, firm, or industry names in this paper is for identification purposes only and does not imply endorsement by the U.S. Government.

exceeded 10 acres in size, due to the difficulty of identifying pile burns on Landsat scale images.

The Landsat images were displayed as false color images, typically as bands 7, 4, 1 (R,G,B) combinations, but other band combinations were used at the interpreter’s discretion. If a fire scar was visible in the Landsat imagery, based on the date and location of a reported fire, and a polygon did not already exist from a federal data source that closely matched the fire scar, then a perimeter was manually digitized around the fire scar and attributed with the source information. If a polygon existed from federal data sources that closely matched the fire scar observed on the image it was retained and not manually digitized. Digitizing was performed at a scale of 1:24,000. If a given fire was identified in multiple data sources, the attributes of the perimeter were updated to indicate all data sources the fire was reported in. If multiple perimeters existed for a given fire, priority was given to GeoMAC and MTBS perimeters, followed by LandFire perimeters and historical field records. This process was completed for all years, 2000 through 2009.

The Normalized Burn Ratio (NBR) (Roy, Boschetti et al. 2006) was calculated for all the images in 2008, 2009, and some months in 2007 using Equation 1.

$$NBR = (Band4 - Band7) / (Band4 + Band7) \quad (1)$$

Where Band4 = Landsat TM band 4  
Band7 = Landsat TM band 7.

The year 2008 was examined for additional unreported fires using the calibrated and NBR images. Each image was visually examined at 1:50,000 scale. If a fire scar greater than approximately 10 acres was visible, its perimeter was digitized. The final database developed includes perimeters for reported fires for 2000 through 2009 and all fires identifiable on Landsat imagery for 2008.

### 3. Algorithms

In order to efficiently produce a globally consistent ECV product, the process to identify a burned area must be automated. For this effort, several indices, including NBR and Differenced Normalized Burn Ratio (dNBR), Tasseled Cap (TC), and Disturbance Index (DI); and algorithms, including Vegetation Change Tracker (VCT), Landtrendr, and MODIS Burned Area Algorithm will be evaluated against the database as described above.

#### 3.1 Disturbance Indices

##### 3.1.1 Normalized Burn Ratio (NBR)

The NBR (Key and Benson 2006) was developed to provide the best distinction between burned and unburned areas. The NBR Equation (see Equation 1) outputs values between -1.0 and 1.0. Burned areas have NBR values approaching 1;

however, many other disturbed areas may also have high NBR values, such as disturbed agricultural fields. Thus this ratio is not a straight forward indicator of burning in all areas and may introduce confusion.

### **3.1.2 Differenced Normalized Burn Ratio (dNBR)**

The dNBR (Key and Benson 2006; Miller and Thode 2007) is a change analysis method where NBR is derived from pre- and post-fire images. The pre-fire NBR values are then subtracted from the post-fire NBR values producing a Differenced Normalized Burn Ratio. Areas with little change should have values close to zero, while values which have been changed by a fire will be larger. One challenge with this process is identifying the most appropriate pre-fire and post-fire images. The goal is to minimize non-fire change as much as possible between the images, thus allowing the changes the fire produced to show clearly.

The dNBR index is used extensively by the MTBS project for both "Initial Assessments" and "Extended Assessments" (USDA Forest Service and US Geological Survey 2010). Initial Assessments are based on data acquired at the first opportunity after the fire and are used especially in ecosystems that exhibit rapid post-fire vegetation response as in herbaceous and some shrubland systems. Extended Assessments are based on satellite imagery acquired during the growing season following a fire, to include secondary fire effects such as latent tree mortality.

### **3.1.3 Tasseled Cap Transformation and Disturbance Index**

The Tasseled Cap transformation (Kauth and Thomas 1976; Crist and Cicone 1984) originated for identifying physical crop characteristics, reduces Landsat 5 TM data to 3 bands, Brightness, Greenness, and Wetness. Visual inspection by USGS did not indicate a strong connection between the TC values and fire scars within the Colorado study area. However, a Disturbance Index (DI) can be derived from the three TC bands (Healey, Cohen et al. 2005) and stand-replacing disturbances are more visible with this index than with the individual TC bands in some ecosystems.

## **3.2 Disturbance algorithms**

### **3.2.1 Vegetation Change Tracker**

The Vegetation Change Tracker (VCT) uses a set of Landsat images, ideally one per year during the growing season (Huang, Goward et al. 2010). It has been fine-tuned for forests, and detects changes relative to a set of reference, undisturbed forest pixels. VCT has shown its usefulness in identifying changes in a variety of forest ecosystems, although it has had varying success rates identifying disturbances in non-forested areas (Huang, Goward et al. 2009; Li, Huang et al. 2009; Huang, Goward et al. 2010).

### **3.2.2 LandTrendr**

Landsat-based detection of Trends in Disturbance and Recovery or LandTrendr (Cohen, Yang et al. 2010; Kennedy,

Yang et al. 2010) is based around the recognition that change is a continual process which operates at a variety of rates on the landscape. It also uses a set of yearly Landsat images which are radiometrically calibrated to a base scene. LandTrendr extracts spectral trajectories of land-surface change through time and uses characteristics of those trajectories to determine the type and severity of change as well as post-disturbance recovery patterns.

### **3.2.3 MODIS Burned Area Algorithm**

The MODIS Burned Area Product is generated using an algorithm (Justice, Giglio et al. 2006) which tests pixels for burned characteristics on an iterative basis using images collected daily. It looks for persistent evidence of fire effects over time. Landsat is more limited in the number of images collected, with a given satellite re-imaging every 16 days. Therefore, this type of processing algorithm wouldn't be effective for use with Landsat data without additional modifications.

## **4. ECV Development**

Combinations of the most promising indices and algorithms described above will be tested for their abilities to discriminate burned areas. These results will be evaluated with the database of historic fires over the state of Colorado from 2000 to 2009. The reported fire location datasets will also be analyzed to ascertain if there are any essential and appropriate supplemental fire location sources useful for mapping burned area with Landsat data. The most effective method(s) will be further developed in the effort to generate a Fire Disturbance (Burned Area) ECV based on Landsat data over time, and at a near global-scale.

## **5. Summary**

A Landsat-based burned area ECV will provide a product with much finer spatial resolution than required by the GCOS ECV specifications. This will benefit both the climate-modeling community, as well as land management agencies. Due to coverage gaps, Landsat's revisit interval, and cloud cover, a Landsat-based burned area ECV may not meet the temporal burned area requirements outlined by GCOS in all areas. Incorporating additional information from other sensors and data sources may be required in certain places.

## **REFERENCES**

- Cohen, W. B., Z. Yang, et al. (2010). "Detecting trends in forest disturbance and recovery using yearly Landsat time series: 2. TimeSync -- Tools for calibration and validation." *Remote Sensing of Environment* **114**(12): 2911-2924.
- Crist, E. P. and R. C. Cicone (1984). "A Physically-Based Transformation of Thematic Mapper Data---The TM Tasseled Cap." *IEEE Transactions on GeoScience and Remote Sensing* **GE-22**(3): 256 - 263.

- Csiszar, I., O. Arino, et al. (2009). Fire Disturbance: assessment report on available methodological standards and guides. Essential Climate Variables. Rome, Italy, United Nations Food and Agriculture Organization, Global Terrestrial Observing System. **Assessment of the status of the development of the standards for the Terrestrial Essential Climate Variables: 38.**
- DOI-USDA (2010). "National Fire Plan Operations and Reporting System (NFPORS)." 2010, from <http://nfpors.cr.usgs.gov/NFPORS/NFPORS-111/viewer.htm> <http://www.nfpors.gov/>.
- ESRI (2011, 1/13/2011). "ArcGIS 10, What's New in ArcGIS 10." Retrieved 1/13/2011, 2011, from <http://www.esri.com/software/arcgis/arcgis10/index.html>.
- GCOS (2010). WMO/IOC Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update). Global Climate Observing System. P. Mason and A. Simmons. Geneva, Switzerland, World Meteorological Organization. **GCOS-138 (GOOS-184, GTOS-76, WMO-TD/No. 1523): 186.**
- Global Observing Systems Information Center (GOSIC) (2010). "GCOS Terrestrial ECV: ECV T13 Fire Disturbance." 2011, from <http://gosic.org/ios/MATRICES/ECV/TERRESTRIAL/ECV-GCOS-TERRESTRIAL-Fire-Disturbance.htm>
- Healey, S. P., W. B. Cohen, et al. (2005). "Comparison of Tasseled Cap-based Landsat data structures for use in forest disturbance detection." Remote Sensing of Environment **97**(3): 301-310.
- Huang, C., S. N. Goward, et al. (2010). "An automated approach for reconstructing recent forest disturbance history using dense Landsat time series stacks." Remote Sensing of Environment **114**(1): 183-198.
- Huang, C., S. N. Goward, et al. (2009). "Dynamics of national forests assessed using the Landsat record: Case studies in eastern United States." Remote Sensing of Environment **113**(7): 1430-1442.
- ITT Visual Information Solutions (2009). ENVI User's Guide, Preprocessing Utilities.
- Justice, C. (2010). "MODIS Active Fire & Burned Area Products." from <http://modis-fire.umd.edu/>.
- Justice, C., L. Giglio, et al. (2006). "MODIS Fire Products: Algorithm Technical Background Document." Version 2.3, 1 October 2006. from [http://modis-fire.umd.edu/Documents/atbd\\_mod14.pdf](http://modis-fire.umd.edu/Documents/atbd_mod14.pdf).
- Justice, C. O., L. Giglio, et al. (2002). "The MODIS fire products." Remote Sensing of Environment **83**(1-2): 244-262.
- Kauth, R. J. and G. S. Thomas (1976). The Tasseled Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by LANDSAT. Symposium on Machine Processing of Remotely Sensed Data. West Lafayette, IN, The Laboratory for Applications of Remote Sensing, Purdue University. **Agriculture/Forestry: 13.**
- Kennedy, R. E., Z. Yang, et al. (2010). "Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr -- Temporal segmentation algorithms." Remote Sensing of Environment **114**(12): 2897-2910.
- Key, C. H. and N. C. Benson (2006). Landscape Assessment (LA) Sampling and Analysis Methods. USDA Forest Service General Technical Report, USDA Forest Service: 1-55.
- Li, M., C. Huang, et al. (2009). "Assessing rates of forest change and fragmentation in Alabama, USA, using the vegetation change tracker model." Forest Ecology and Management **257**(6): 1480-1488.
- Miller, J. D. and A. E. Thode (2007). "Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR)." Remote Sensing of Environment **109**(1): 66-80.
- National Interagency Fire Center (2010). "ICS-209 Interagency Management Situation Report (IMSR)." Retrieved 1115, 2010, from <http://fam.nwcg.gov/fam-web/>.
- Roy, D. P., L. Boschetti, et al. (2006). "Remote Sensing of Fire Severity: Assessing the Performance of the Normalized Burn Ratio." Geoscience and Remote Sensing Letters, IEEE **3**(1): 112-116.
- U.S. Department of Agriculture and U.S. Department of Interior (2010). "FireCode System." Retrieved 0420, 2010, from <https://www.firecode.gov/>.
- U.S. Department of Agriculture, F. S., Remote Sensing Applications Center (2010). "MODIS Fire Detection GIS Data." Cumulative MODIS fire detections 2001-2010. 2010, from <http://activefiremaps.fs.fed.us/gisdata.php>
- U.S. Department of Agriculture F. S. and U.S. Department of Interior USGS (2010). LandFire Reference Database, LANDFIRE 1.1.0.
- U.S. Department of Interior (2010). "WILDFIRE Wildland Fire Information, Federal Wildland Fire Occurrence Data." Retrieved 05/20, 2010, from <http://wildfire.cr.usgs.gov/firehistory/data.html>.
- U.S. Department of Interior and U.S. Department of Agriculture (2010). "GeoMAC; Geospatial Multi-Agency Coordination, Wildland Fire Support." Retrieved 0420, 2010, from <http://www.geomac.gov>.
- U.S. Department of the Interior, USGS. (2010). Landsat: A Global Land-Imaging Project: 1-4, Fact Sheet 2010-3026. <http://pubs.usgs.gov/fs/2010/3026/pdf/FS2010-3026.pdf>
- USDA Forest Service and U.S. Geological Survey (2010). "Monitoring Trends in Burn Severity (MTBS)." from <http://mtbs.gov/>

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