Ecosystem Disturbance and Recovery Tracker (eDaRT) Data Product

“eDaRT 2.11, with MMI for CAL FIRE and Incident Management, scenes 3xx, 4xx, 2010-2019”

Product User Guide Document

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Spatial Extent:	20 eDaRT Scenes sc3XXns, sc4XXss (see sect. 2.1)
Temporal Extent:	Detection period 11/01/2008 to 11/30/2019 (approximate, variable)

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Disclaimer

eDaRT products described here are prepared for distribution by the U.S. Department of Agriculture, Forest Service (USFS), and are derived from a research prototype remote sensing algorithm developed in partnership between UC Davis Center for Spatial Technologies and Remote Sensing (CSTARS) and USFS Region 5 Remote Sensing Lab. The products are currently in continuous development, and therefore they are provided only as an example for experimental use by remote sensing researchers and/or for evaluation purpose. Accuracy may vary. Products may be: developed from sources of differing accuracy, resolution, or availability, more or less accurate at certain scales, based on modeling or interpretation, or incomplete while being created or revised. Users are encouraged to contact the developers to ensure that the assumptions behind and limitations of the data are appropriate for intended use. Using eDaRT products for purposes other than those for which they were created may yield inaccurate or misleading results. *The USDA Forest Service or University of California make no warranty, expressed or implied, including the warranties of merchantability and fitness for a particular purpose, nor assumes any legal liability or responsibility for the accuracy, reliability, completeness or utility of these geospatial data, or for the improper or incorrect use of these data*. The Forest Service reserves the right to correct, update, modify, or replace eDaRT products without notification.

1 eDaRT algorithm: a general overview

Disturbance information was generated using the Ecosystem Disturbance and Recovery Tracker (eDaRT) — an image analysis system prototype jointly developed by the *USFS Region 5 Remote Sensing Lab* and *UC Davis Center for Spatial Technologies and Remote Sensing (CSTARS)* (Koltunov et al., 2019; Koltunov et al., 2015; Koltunov & Ramirez, 2012, 2014; Koltunov et al., 2009). The eDaRT system is generally designed to process up to all available historic Landsat imagery (normally at 8 or 16 day step, per satellite, depending on cloud/snow cover), which increases the likelihood and accuracy of detection of subtle or short-lived disturbances and provides more current information than disturbance mapping algorithms/products based an annual change detection. However, to increase performance, images with little useful information (such as winter images in for some areas, or high-cloud/snow cover images)

1.1 'eDaRT scene' is an independently processed ROI

The eDaRT system operates on a scene-by-scene basis. The term *scene* in this document always refers to ***eDaRT scenes*** **defined as an analyst-defined *rectangular geographic ROI processed by* eDaRT independently of other ROIs.** eDaRT scenes should not be confused with Landsat WRS-based image tiles that are often called 'scenes', too.

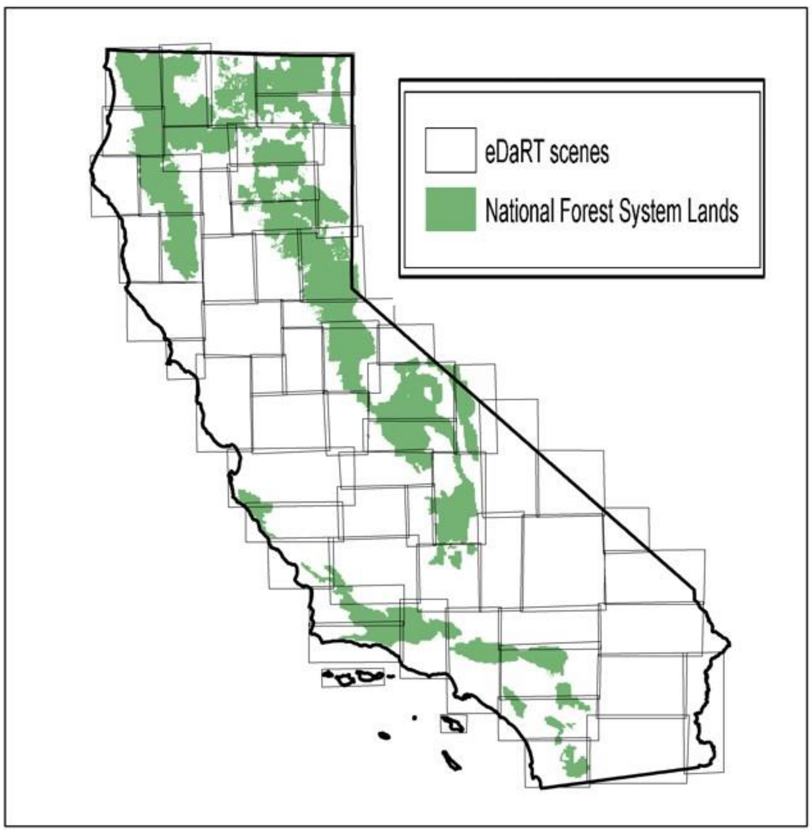

Figure 1: California scenes (fixed ROIs) independently monitored by eDaRT in regional applications (adapted from Koltunov et al. 2019).

1.2 eDaRT Events as a Representation of Pixel's Disturbance History

Although eDaRT outputs include disturbance status snapshots at every processed image, the primary outputs of the system are **disturbance events.**

> **Disturbance Event** is defined as an event at its onset of a significant and persistent loss of green vegetation cover and or health that is not explained by normal phenological development and environmental influence.

Figure 2 further illustrates the concepts of eDaRT events.

Disturbance Events detected for the pixel divide the time series into segments of "undisturbed" development. Every event is associated with the timing and the magnitude of loss w.r.t. recent baseline. After an Event is detected, the next event will be detected relative to a new baseline.

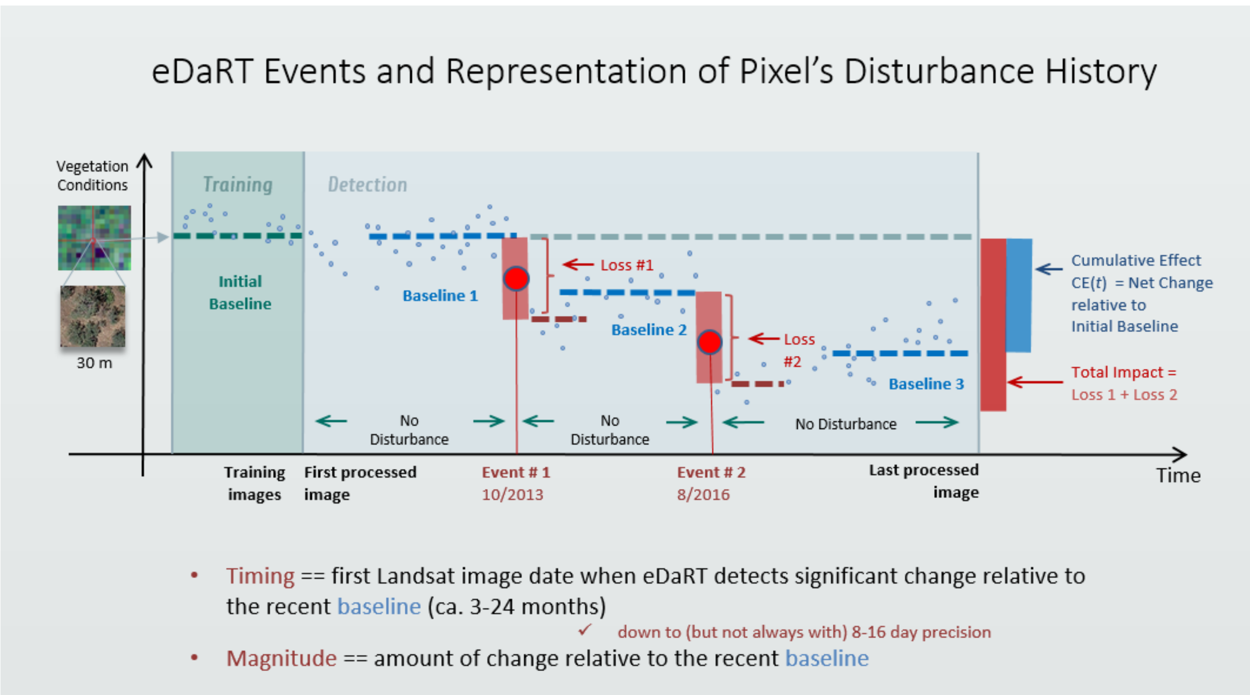

Figure 2: Disturbance Events detected for the pixel divide the time series into segments of "undisturbed" development.

1.3 Detection algorithms

Disturbance events and recovery status are estimated using two anomaly detection algorithms, called "detectors" hereafter, applied to a set of Landsat bands, vegetation indexes, and transformation outputs that are commonly known to reflect canopy greenness, abundance, and moisture content.

- Detector #1 (sect. 1.3.1) detects anomalies relative to a user-defined baseline period by empirically estimating the reference (no-anomaly) value at a 30x30 m Landsat pixel using past values at that pixel and the evolution of other pixels from the same baseline land cover class. At each image it thus provides a snapshot of the cumulative disturbance/regeneration effect relative to the baseline.

- Detector #2 (sect. 1.3.2) analyzes the time series of residuals (unmodeled part of the signal) from the first detector and identifies regime change events that are specific to that pixel.

The outputs from the two detectors are combined (details omitted) to yield disturbance event-candidates across time series. To ensure that the anomalies are representative of a true ecological change (and not noise in the image or other factors), a forward filter evaluates temporal consistency of the detected event-candidates in up to 12 post-event observations and normally accepts the event when the change signal persists in an algorithmically defined proportion of observations (e.g. 7 out of 12).

Event dates correspond to the Landsat image date where the first detection occurred. The confidence of a detected disturbance event ("SC" in Figure 3) represents a constrained Z-transform that combines standardized residuals (also termed z-scores) resulting from the above regime change analysis by Detector 2 (or of cumulative effect analysis by Detector 1; details omitted) for three vegetation indexes: NDVI, NDII, and NBR.

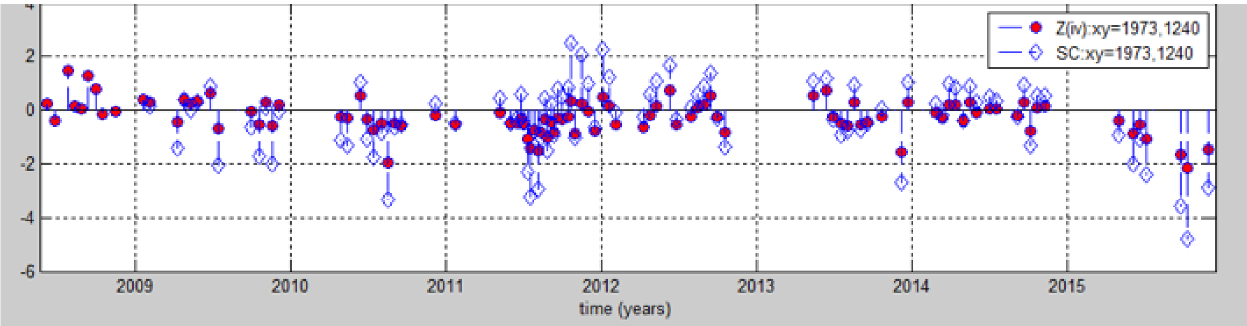

Figure 3: Each red point is the Detector 1 Z-score (the difference between the expected value of the band from the baseline time period and the observed value, divided by the standard deviation). Each blue diamond represents a multivariate z-score (SC)

1.3.1 Detector 1: Estimation of anomalous departure from reference ecosystem conditions

The landscape change detection methodology in eDaRT is based on an enhanced version of Dynamic Detection Model (DDM) approach (Koltunov et al., 2009; Koltunov & Ustin, 2007, Koltunov et al. 2015a), adapted for Landsat image time series processing (details in Koltunov et al. 2019).

For each pixel at a spatial location (pixel) *s* and time *t*, the eDaRT anomaly detection block based on DDM estimates cumulative changes in the multispectral intensities relative to a baseline period that are inconsistent with the hypothesis of a normal ecosystem development process. The eDaRT defines anomaly in ecosystem development relative to the dominant changes that are actually observed in the Landsat image at time *t* for the landscape class to which a pixel *s* belongs. The baseline period is set interactively for individual runs based on multiple criteria, including the objectives of a specific application, cloud/snow cover, and the algorithm-based constraints.

As defined by this method, for any given vegetation pixel, normal development does not necessarily mean "steady growth" or "stable health" during any given period of time, although this is the most typical scenario. Moreover, sometimes a pixel can be flagged as disturbed by eDaRT because the overall increase in canopy abundance or health is smaller than expected under normal circumstances, indicating that this pixel may have been disturbed. Conversely, an *actual* and significant reduction in canopy cover is not always an indicator of a disturbance event, but could be due to natural dynamics of the tree population within a 30x30 pixel area, e.g. background mortality or a phenological response to environmental factors (e.g. early senescence). Disturbances detected by eDaRT can be due to damage to overstory or understory, or both. Overstory disturbances are significantly more likely to be detected, and the Morality Magnitude Index that quantifies canopy cover loss is specifically trained to minimize the understory signal by selecting vegetation indices and leveraging their seasonality to enhance their sensitivity to conifers in particular.

1.3.2 Detector 2: Time Series Event Extraction (TSEE)

Detector 2 detects regime changes in the time series of the DDM standardized residuals of bands and vegetation indexes for each pixel that represent the unmodeled part of the background signal that is specific to that pixel. This is implemented using a median filter that compares the signal with a recent stable 10- to 20-observation baseline period.

Because this algorithm needs to accumulate a stable baseline period for regime change detection, when two detectable disturbance events are not sufficiently separated in time, only the earlier disturbance event can be accurately dated, whereas the later event, if detected, will have a delayed date. As a result, for example, there cannot be more than one detected event per 160 days for a given pixel. See also section "Known Limitations" below and discussion in Koltunov et al. (2019).

2 Information specific to this application or delivered dataset

2.1 Input data, Training period, and Detection (Inspection) period

A detailed summary of eDaRT major meta-parameters is given in section 2.4 "Major Meta-Parameters of eDaRT Application".

To generate the product described in this document, Landsat 5, 7 and 8 images were used (subject to constraints in sect 2.4 (Satellites_Used, Landsat7_Use_Period). Images representing the initial baseline conditions were selected from years in Training_Period (varies between scenes) depending, in particular, on the image quality and seasonal coverage.

The Detection (a.k.a. Inspection) period (Fig. 2), in which Landsat images were inspected by eDaRT, was selected to be approximately the same for each year for all eDaRT scenes included in this dataset, as defined by Season_Processed, Detection_Period_Start, Detection_Period_End. During the Detection period, all available dates were processed, subject to constraints depending on image availability and cloud/snow cover.

Remember: eDaRT does not map disturbances that occurred before the end of the Training period in a scene. Training period is considered a baseline for subsequent change detection. See also section "Known Limitations" below for additional information on this and other limitations. Additional information is available in Koltunov et al. (2019).

2.2 Where Are Disturbances Mapped?

The most accurate detections (in descending order of accuracy) in eDaRT are in Forest (best), Shrub, and Grass. However, eDaRT disturbances are mapped for all landcover types, EXCEPT as specified by parameter No_Detection_for_Landcover_Classes in sect 2.4. These classes are based on the National Land Cover Database (NLCD)-2006 land cover map dataset (https://www.mrlc.gov/).

These classes are assumed static, i.e. ignored areas are the same for all products, regardless of the dates these products might represent.

2.3 Known Limitations

- Disturbance events that occurred in a scene before the end of the scene's Baseline period are not shown in eDaRT outputs. A disturbance event that occurred during/after the Baseline period and before the start of the Inspection period, if the event was detected, is assigned the timing of the first inspection image or a later image.
- **The disturbance events detected by eDaRT can include various types and causes** of **disturbance,** including fire, vegetation treatments, e.g. partial stand and understory clearing, tree mortality and ecosystem stress, and other events. Please note that regardless of the type, these events are mapped as a single generic class "disturbance event", when Disturbance_Impact_Classifier=OFF (sect 2.4). The end user is advised to use ancillary datasets to differentiate disturbance types, such as 'mortality', 'harvest/treatement', 'fire', etc.
- **Important Notice about Product Validation Status:** This experimental product may not have been validated in a statistical sample from each delivered scene. Tests in conifer-dominated Sierra Nevada conditions (Koltunov et al. 2019, Haunreiter et al. 2018) showed that eDaRT was able to routinely detect fire, harvest, and mortality down to ~1-5% loss of vegetation cover and with ~90% reliability. Disturbances with canopy cover loss of 30% had effectively 100% chance of detection, and 1% canopy loss was detected with ~20% probability. Although based on our general understanding of factors affecting algorithm performance we reasonably expect a similar performance in other areas of California, we cannot guarantee any particular levels of this product's accuracy. Detection sensitivity and accuracy is known to vary spatially and temporally, with both random and systematic effects. In general, most false positives (FP) are found on the land cover class boundaries (due to image misalignment effects), in sparse forests, and in the regions with undetected snow cover or/ cloud edges.
- **Seasonal Constraints:** The Inspection period was constrained to Season_Processed (sect 2.4) of each year, to reduce the number of images with high snow or cloud cover or phenological changes that can produce undesirable results. Consequently, the timing of some events may be delayed, normally up to 6 months, due to the need to accumulate a sufficient number of images confirming the event. For the same reason, some events may show their detected timing as the previous year.
- More generally, pixels disturbed at the same time on the ground can have different detection time in eDaRT outputs, due to Landsat data gaps, persistent areas of haze or smoke, or other factors causing delayed detection.
- **Additional limitations may apply due to custom application of the eDaRT algorithm/software. Users are advised to consult with developers regarding the potential significance of these and other limitations for the intended use of eDaRT products.**

2.4 Major Meta-Parameters of eDaRT Application

eDaRT PARAMETER NAME	VALUE	COMMENT
Algorithm	eDaRT 2.9 (MMI-1.0β)	optimized in eDaRT 2.11 system
Satellites_Used	Landsat 5, 7, 8	same for all scenes
Landsat7_Use_Period	2012 - until Landsat 8 is available	same for all scenes
Training_Period	2006-2008	specific date depend on: scene
Detection_Period_Start	late 2008	specific date depends on: scene, pixel
Detection_Period_End	2019	specific date depends on: scene, pixel
Season_Processed	'05-01 11-30'	same for all scenes, each year
Date _of_1st_Available Valid Observation	2008-2009	specific date depends on: scene, pixel
Early_Detection_Mode	ON	Disturbances can be detected in the very first inspected image
Disturbance_Impact_Classifier	OFF	N/A
Best_Detection_for_Landcover_Classes	Forest (best), Shrub, Grass	NLCD classes (https://www.mrlc.gov/): 41 Deciduous Forest 42 Evergreen Forest 43 Mixed Forest 51 Dwarf Scrub* 52 Shrub/Scrub 71 Grassland/Herbaceous
No_Detection_for_Landcover_Classes	'nlcd-mod'	Ignores NLCD classes: *Unclassified, Water, Snow-Ice, Barren, Planted-Cultivated* [0 11 12 31 81 82]
Yearly_Products_Range	2006-2019	same for all scenes (may starts earlier for some scenes)

Additional information available upon request.

2.5 eDaRT Scenes Included

20 scenes total:

sc301ns, sc302ns, sc303ns, sc304ns, sc305ns, sc306ns, sc307ns, sc308ns, sc309ns, sc401ss, sc402ss, sc403ss, sc404ss, sc405ss, sc406ss, sc407ss, sc408ss, sc409ss, sc410ss, sc411ss.

3 Event detection file summary (ENVI format)

3.1 Files: *EVTY_*.bsq

3.1.1 Description

Band #N is an approximate time of the Landsat image in which a disturbance event #N was detected.

3.1.2 Number of bands

Variable, up to 10 (floating point, 32 bits)

3.1.3 Values

The time value is in the units of *decimal years*, e.g. 2017.142371. The EVTY value is calculated by simply dividing the Matlab's internal "serial date number" for the Landsat image by 365.242, the average number of days a year. To approximately, up to 1-2 day accuracy, calculate the Julian day (i.e. day of the year), one should multiply **the fractional part of the value** by 365.242 and round the result toward the smaller integer. Using Matlab R2013a, **the exact date string** can be obtained using Matlab's datestr() function, e.g.: datestr(EVTY*365.242, 'yyyy/mm/dd')

Example:
If EVTY= 2009.642944, then datestr(EVTY*365.242) yields the correct Landsat image date: 2009.08.21; however floor(0.642944*365.242) == floor(234.83) == 234. In 2009, Julian Day 234 is "2009.08.22"

inf (infinity) == processed, but event was not detected (inf in Band #1 means "undisturbed")

NaN == not processed/ignored due to irrelevant land cover type (as per LCM)

Band name format example for scene named "sc12a_v01":

time: event #1 [sc12a_v01],
time: event #2 [sc12a_v01],
time: event #3 [sc12a_v01],
time: event #4 [sc12a_v01],
time: event #5 [sc12a_v01]

3.2 Files: *EVYY_*.bsq

3.2.1 Description

Band #N is the integer *year* of the Landsat image in which a disturbance event #N was detected.

3.2.2 Number of bands

The same as in EVTY*.bsq (floating point, 32 bits)

3.2.3 Values

The time value is in the units of *years*.

3.3 Files: *EVpTY_*.bsq (if delivered)

3.3.1 Description

Time of the “possible” (unconfirmed) event. The likelihood of false positives is significantly higher for unconfirmed events.

3.3.2 Number of bands

1 (floating point, 32 bits)

3.3.3 Values

The time value is in the units of *decimal years* (the same as *EVTY*.bsq, see section 3.1.3).

3.4 Files: *nEV_*.bsq

3.4.1 Description

The number of disturbance events detected for a processed pixel over the inspection time period

3.4.2 Number of bands

1 (signed integer, 16 bits)

3.4.3 Values

-3 == always unavailable (cloud/snow/no Landsat data)

-2 == unknown, non-processed (e.g. too cloudy during baseline period)

-1 == not processed/ignored due to irrelevant land cover type (as per landcover (LCM) map used)

non-negative integer == number of disturbance events detected for a processed pixel

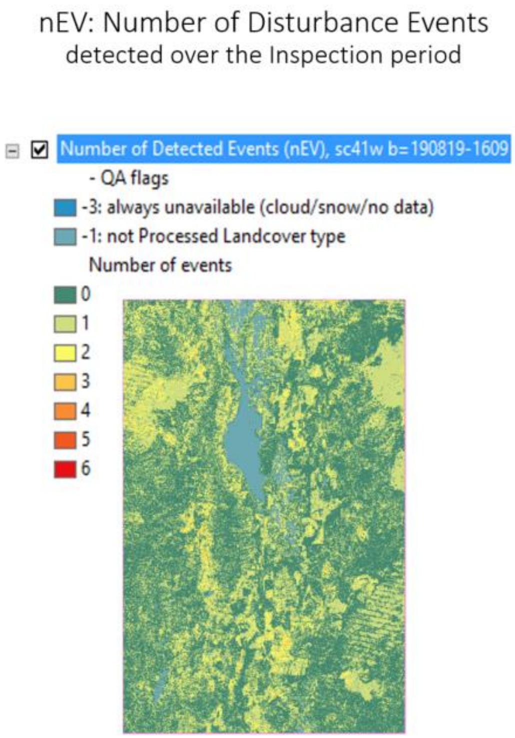

Figure 4: nEV: Number of detected disturbance events, per pixel

3.5 Files: *ConfEV_*.bsq

3.5.1 Description

Band # N is a relative confidence (Z-score*10) for the N-th disturbance event

3.5.2 Number of bands

The same as in EVTY*.bsq (signed integer, 16 bits)

Band name format example for scene named "sc12a_v01":

Conf_x10: event #1 [sc12a_v01],
Conf_x10: event #2 [sc12a_v01],
Conf_x10: event #3 [sc12a_v01],
Conf_x10: event #4 [sc12a_v01],
Conf_x10: event #5 [sc12a_v01]

3.5.3 Values

Confidence values corresponding to disturbances: 20-127

Special values: -1, 0, 1, 2

-1 == not processed/ignored due to irrelevant land cover type (as per a landcover (LCM) map used)

0 == processed, but event was not detected (0 in Band #1 means "undisturbed")

1 == always unavailable (cloud/snow/no Landsat data)

2 == unknown, non-processed (e.g. too cloudy during baseline period)

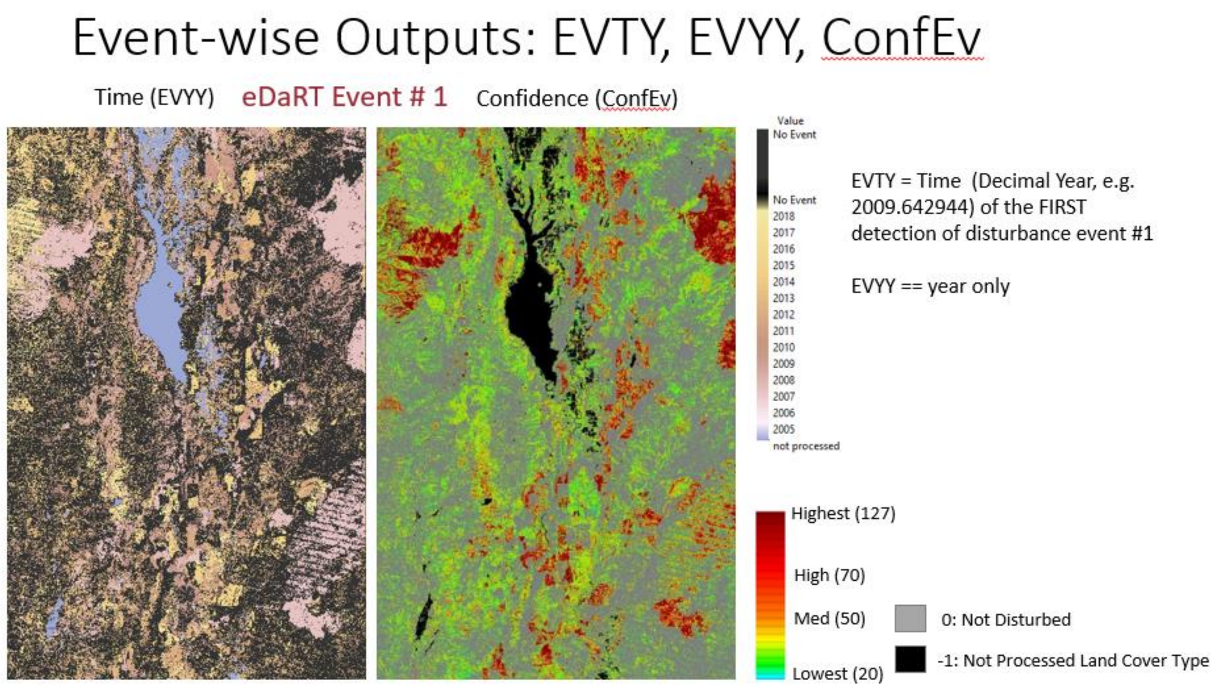

Figure 5: Event-wise Products: Event Timing and Confidence

3.6 Files: evty*_PerYear.bsq

3.6.1 Description

Event times by year. The consolidated version of EVTY_*.bsq with multiple bands, where each band represents the *final* event time of a given year of events. Depending on when the Detection period began, the first year may not be complete. For example, if the Detection period started in August 2008, then the band representing 2008 will only contain event times from August to Dec 31. Drawing evty_PerYear for adjacent scenes might result in unexpected breaks for the early years, unless the same start of the Detection period was used for all scenes (as per section 2).

3.6.2 Number of bands

Normally, equals the number of years processed (including both, Training and Detection periods) for the scene (floating point, 32 bits). When multiple scenes are delivered, the annual bands are usually the same across scenes, even though the Detection periods are different for different scenes.

3.6.3 Values

See *EVTY_*.bsq for values

3.7 Files: MMI*_PerYear.bsq

3.7.1 Description

The eDaRT Mortality Magnitude Index (version 1.0β) represents the modeled tree live canopy cover loss (as % of pixel's 900m^2 area) that corresponds to the first event detected per year. The MMI values were estimated using a non-linear statistical model based on eDaRT outputs and Landsat vegetation indices, and other predictors and trained with a sample of actual mortality events in California. The canopy cover loss in the training sample pixels was assessed by map analysts using multidate high resolution imagery. The resulting model was applied to all events for all years for all Sierra Nevada scenes.

Important Notes and Limitations:

- MMI product is *an experimental product in development*, and it has not been extensively validated across diverse California landscape. This work is underway. Initial small-scale tests for a conifer-dominated sample of *ca*. 600 mortality events detected by eDaRT showed 13% RMSE. A manuscript describing MMI development is in preparation.
- MMI values were calculated ONLY where eDaRT detects a disturbance event. The probability of eDaRT detecting a tree mortality event, as function of tree canopy cover loss, was assessed by Koltunov et al. (2019).
- MMI is generally computed for all disturbance types, but values for disturbance of type FIRE, HARVEST/TREATMENT, and STRESS, should be ignored until after further validation occurs. For FIRE disturbance, the MMI values may be more representative of the BURN SEVERITY (in terms of total vegetation canopy loss, rather than tree canopy cover loss), see example in the Figure 6 below.
- MMI values for pixels with multiple events within 1-2 years of each other should be utilized with caution.

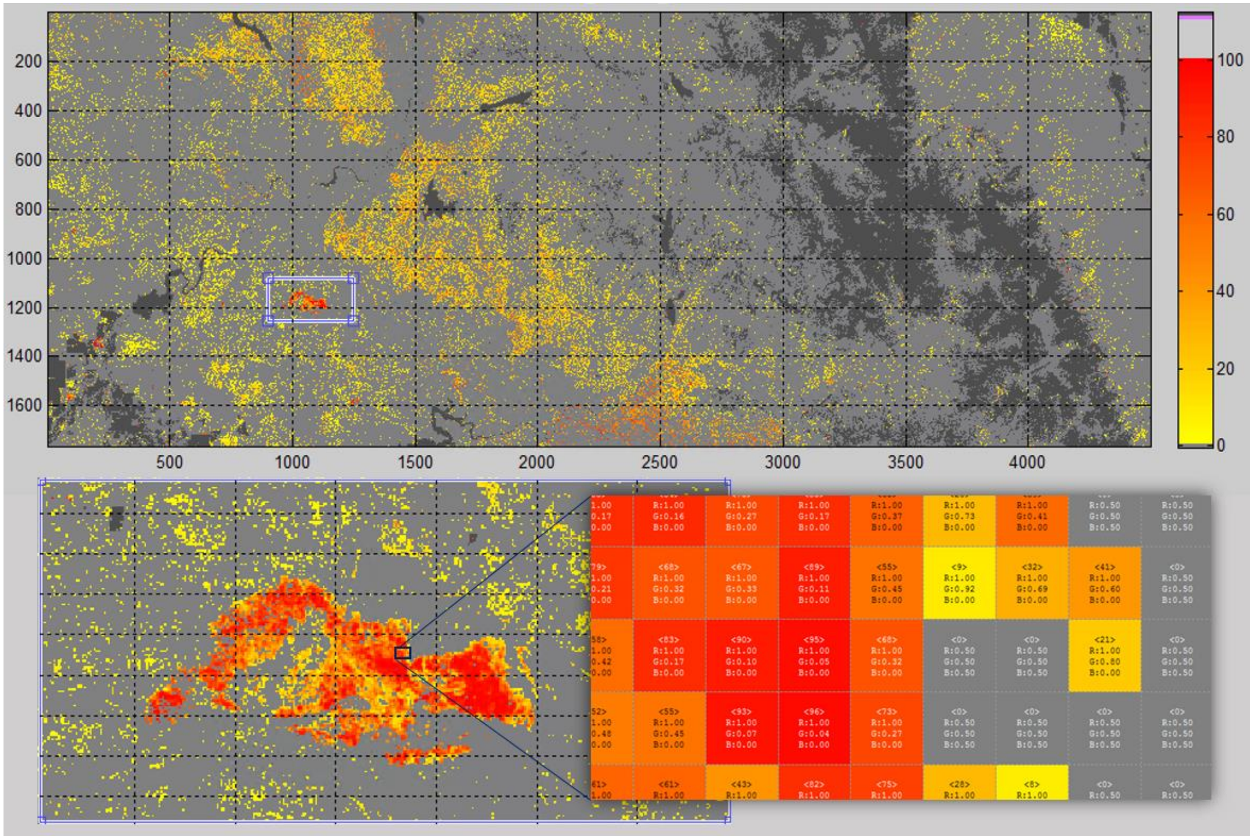

Figure 6: MMI values are calculated for all types of disturbance, and for FIRE BURNS they are more representative of relative BURN SEVERITY than of tree canopy loss.

3.7.2 Number of bands

Normally, equals the number of years processed during Detection period for the scene (unsigned integer, 8 bit). The first year of the Detection period typically contains missing values due to the offset between the timing of the event and the window prior to that required to search for images to calculate MMI.

3.7.3 Values

0 = either A) eDaRT did not detect an event (and thus the canopy cover loss should be assumed 0), or B) eDaRT detected disturbance for which the MMI-modeled tree canopy loss is at or near 0)

1-100 -- % canopy loss successfully estimated by the MMI model for the corresponding eDaRT disturbance event

101-109 – currently unassigned

111 = eDaRT event was detected, but MMI was NOT calculated due to lack of valid baseline observations for the model. Thus, it should be interpreted as disturbance of *unknown* magnitude.

112 - Not processed/ignored by eDaRT due to any of the reasons below (corresponding to values -1, 1, 2, in *ConfEV_*.bsq files (sect 3.5)):

a) not processed/ignored due to irrelevant land cover type (as per a landcover (LCM) map used),
b) always unavailable (cloud/snow/no Landsat data),
c) unknown, non-processed (e.g. too cloudy during baseline period).

3.8 Multiband Annual Files: conf*_PerYer.bsq, confsum*_PerYear.bsq

3.8.1 Description

The consolidated version of *ConfEV_*.bsq with multiple bands, where a given band represents the confidence/intensity of the final event detected for a given year. For example,

- band 'conf_sc301ns_2014' in file *conf_sc301ns_PerYear.bsq* contains the confidence/intensity value for the *final* event that occurred in 2014.
- band 'confsum_sc301ns_2014' in file *confsum_sc301ns_PerYear.bsq* contains the sum of confidence values of all events that occurred in 2014. This is more appropriate to represent the 'total damage' of the year than conf_sc*.* files.

In general, there is no more than 1 event per year for a given pixel. Thus although the confsum-files are generally preferable to conf-files, the difference is expected to be extremely minor for most datasets.

3.8.2 Number of bands

= the number of years, as in evty*_PerYear. (signed integer, 16 bits)

3.8.3 Values

See *ConfEV_*.bsq for values

3.9 Single-band Annual Files: [scene_id]_Yearly\confsum*.bsq, [scene_id]_Yearly\conf*.bsq, [scene_id]_Yearly\evty*.bsq, [scene_id]_Yearly\mmi*.bsq

As in the above sections, but each year is a separate file. The confsum-files are generally preferable to conf-files, but the difference is expected to be extremely minor for most datasets.

3.10 Optional Data

3.10.1 MMI summed over most recent-5year period (per year): scene_id]_Yearly\mmi_sum5*.bsq

The same as annual MMI files, but values in each yearly file represent the cumulative canopy cover loss over the previous 5 years. For example file mmi_sum5_sc305ns_2016.bsq is the sum of MMI values for years 2012 through 2016

3.10.2 in [scene_folder]\aux_data\

- NLC Landcover Raster map clipped to scene extent (LCM_nlcd_[scene_id]_v4.dat)
- Scene Boundary shape file: sc_boundary\[scene_name.*]

References

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[2] Koltunov, A., and C. Ramirez. (2012). Toward near real time automated monitoring of anomalous sub-annual scale changes in natural ecosystem development. In ForestSAT 2012 Conference CD-ROM. September 11-14, 2012, Corvallis, OR, USA

[3] Koltunov, A., and C. Ramirez. (2014) “The Ecosystem Disturbance and Recovery Tracker (eDaRT) system prototype for high-fidelity near-real time ecosystem monitoring”, In: ForestSAT 2014, Trento, Italy, Nov. 2014

[4] Koltunov, A., C. Ramirez, and S. L. Ustin (2015). eDaRT: the Ecosystem Disturbance and Recovery Tracking system prototype supporting ecosystem management in California. In 2015 NASA Carbon Cycle and Ecosystems Joint Science Workshop, April 19-24, 2015, College Park, MD, USA.

[5] Koltunov, A., C. Ramirez., S.L. Ustin, M. Slaton, E. Haunreiter. (2019) "eDaRT: The Ecosystem Disturbance and Recovery Tracker system for monitoring landscape disturbances and their cumulative effects", In: Special Issue on Time Series Analysis with High Spatial Resolution Imagery, *Remote Sensing of Environment*, v238, 111482. https://doi.org/10.1016/J.RSE.2019.111482

[6] Haunreiter, E., A. Koltunov, C. Ramirez., M. Slaton, K. Evans, T. Kohler, L. Young, S.L. Ustin,. (2018) "Validation and preliminary assessment of the Ecosystem Disturbance and Recovery Tracker (eDaRT) performance in forests of the Sierra Nevada, California", Poster Presentation, ForestSAT Conference, Baltimore, MD, USA, 1-5 October 2018.