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**Communication**

# Limitations and utilisation of Monitoring Trends in Burn Severity products for assessing wildfire severity in the USA

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**Abstract.** The Monitoring Trends in Burn Severity project is a comprehensive fire atlas for the United States that includes perimeters and severity data for all fires greater than a particular size (~400 ha in the western US, and ~200 ha in the eastern US). Although the database was derived for management purposes, the scientific community has expressed interest in its research capacity. As with any derived data, it is critical to understand inherent limitations to maximise the utility of the dataset without compromising the inferences. The classified severity product in particular is of limited use to research due to a lack of both consistency in developing class thresholds and empirical relationships with ecological metrics. Here we review the products available and their development process, and characterise and quantify the limitations of the classified burn severity data product based on the use of highly variable and subjective classification thresholds. We suggest a framework for overcoming these limitations by developing a more robust classified product that will support ecological management and applications. This framework utilises field data to develop consistent, ecologically based thresholds that incorporate existing ecoregion classifications from LANDFIRE or other fire management frameworks already widely integrated into planning efforts.

**Additional keywords:** dNBR, Landsat, MTBS, RdNBR.

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## Introduction

Wildfire burn severity maps reveal immediate fire effects and long-term ecosystem changes applicable to many management needs, including fire planning and mitigating post-fire watershed effects (Robichaud *et al.* 2007). Focusing on fire planning, the Monitoring Trends in Burn Severity project (MTBS, www.mtbs.gov) evolved from the joint National Park Service (NPS) and United States Geological Survey (USGS) Burn Severity Mapping project developed to map and monitor wildfire effects across national parks from remotely sensed data (Eidenshink *et al.* 2007). Two primary products of the initial effort were the Composite Burn Index (CBI), a field methodology for quantifying total fire effects at the spatial resolution of Landsat reflectance data, and the Normalised Burn Ratio (NBR), a spectral index that differentiates between healthy green, dry senesced and charred vegetation (Key and Benson 2006). Subsequent research produced a differenced NBR (dNBR) from pre- and post-fire scenes more strongly correlated with 1-year post-fire field measurements of burn severity than the single, post-fire NBR scene for some ecosystems; although considerable uncertainty remains over the nature of the biophysical responses detected by dNBR (Lentile *et al.* 2009). A relative version of dNBR (RdNBR) accounting for pre-fire fuel heterogeneity was more accurate in delineating higher degrees of fire effects in ecosystems with lower fuel loads (Miller and Thode 2007; Cansler and McKenzie 2012). MTBS retrospectively mapped NBR, dNBR and RdNBR for wildfires in the United States dating back to 1984 and classified dNBR into thematic severity maps. Additionally, some prescribed and agricultural fires were mapped because the burn scars were visible on the Landsat scenes. There is a ~2-year lag for inclusion of new fires into the database.

The research community has increased its focus on larger-scale assessment of burn severity in recent years, including analysing trends and patterns (e.g. Miller *et al.* 2009; Lannom *et al.* 2014; Cansler and McKenzie 2014) and relating burn severity to biophysical phenomena and management practices (e.g. Smith *et al.* 2007; Wimberly *et al.* 2009; Kolden and Abatzoglou 2012; Hicke *et al.* 2013; Morrison and Kolden 2015). Robustness of such studies is dependent upon MTBS product accuracy; because MTBS was developed specifically for management needs and has not undergone systematic, field-based evaluation to quantify individual fire accuracy for scientific purposes (e.g. including error bars in analyses), most of these studies used MTBS protocols to develop their own equivalent data products with field-based accuracy assessments. However, given the widespread availability of the MTBS dataset, reproducing its methodology on a case-by-case basis seems counter-productive to the development of a broadly transferable tool. Here, we review sources of error in the MTBS products that affect research accuracy and robustness of results, including:

- Areas of no detectable change are included in MTBS fire perimeters.
- The phenology offset is not applied to continuous spectral indices (i.e. dNBR and RdNBR).

- Subjective, highly variable classification thresholds are used to map classified burn severity.
- Classification thresholds are neither ecologically quantified nor field validated.

We consequently propose a framework for improving utility of the MTBS products based on identifying ecologically based classification thresholds tied to the LANDFIRE project.

## Data products and limitations

The two primary MTBS spatial data products are polygon fire perimeters and four burn severity raster datasets (i.e. continuous NBR, dNBR and RdNBR indices, and a five-class, thematic map of burn severity) (Sparks *et al.* 2015). Because polygon perimeters often include unburned patches within the fire, errors of commission usually exceed errors of omission, leading to true area burned overestimations of 16–35% (Kolden and Weisberg 2007; Kolden *et al.* 2012; Sparks *et al.* 2015). Notably, excluding unchanged areas within wildfires in analyses of relationships to external drivers (e.g. climate) has been demonstrated to improve relationships (Abatzoglou and Kolden 2013).

The NBR, dNBR and RdNBR continuous data rasters are created through a semi-automated process following best practice to select pre- and post-fire Landsat scenes, including anniversary dates to minimise phenological differentiation, maximal solar angle to reduce shadows and cloud-free scenes to maximise data coverage (Key 2006). The result is a unitless index correlated with a variety of ground-observed and quantified fire effects metrics, such as vegetative cover, char, ash and organic soil consumption with variable significance and strength ranging from high to relatively low (Lentile *et al.* 2006*a*; Eidenshink *et al.* 2007). Prior efforts have concluded that the sensitivity and accuracy of these indices for representing fire effects is highly variable by ecosystem (Lentile *et al.* 2006*a*, 2009; French *et al.* 2008). Following best practice, MTBS calculates an 'offset value' for both dNBR and RdNBR derived from a relatively homogenous area of unburned vegetation outside the fire perimeter that represents the phenological difference between pre- and post-fire scenes (Key 2006). Ideally, this offset value should be applied to normalise dNBR and RdNBR for phenological differences between fires across space and time. However, MTBS does not automatically apply the offset value to dNBR and RdNBR products; it is assumed that users will apply the offset themselves, but this step is rarely noted as being performed in the literature.

In contrast to the semi-automated process producing the spectral indices, the thematic burn severity classifications are developed on a per-fire basis and are the most subjective MTBS product. As described in detail in Eidenshink *et al.* (2007), an analyst visually interprets maps and dNBR histograms and subjectively assigns threshold values to delineate each of the five primary classes: Increased greenness, Unchanged, Low, Moderate and High burn severity. Although this approach produces a thematic map that is useful for achieving a general sense of the spatial burn severity pattern, it lacks both the empirical foundation and the accuracy necessary for quantitative assessment of trends and patterns that should be expected for a scientific framework.

Three primary concerns exist for using the classified burn severity products based on these subjective and highly variable thresholds. First, the classified product was created from dNBR. This index can be less sensitive than other approaches (e.g. RdNBR or spectral mixture analysis) to variability in fire effects at both higher burn severities and in ecosystems where the pre-fire live vegetation density is lower, resulting in lower classification accuracy (Roy *et al.* 2006; Hudak *et al.* 2007; Miller and Thode 2007; Kolden and Rogan 2013).

Second, a distribution analysis of MTBS thresholds applied to individual fires during the development of the dataset demonstrates their subjectivity. Fig. 1 displays the classification thresholds for every MTBS fire from 1984 to 2010 (obtained from the individual fire metadata files) delineated by Geographic Area Coordination Center (GACC) boundaries. These distributions demonstrate that (1) the High severity classification threshold is the most variable and (2) there is considerable overlap of thresholds between fires, meaning that a specific dNBR value (e.g. 200) could be classified as Low, Moderate or High severity on three different fires within the same region.

Third, and perhaps most critical, MTBS threshold values are not empirically field validated to objective ecological metrics, but based on limited analyst interpretation (Eidenshink *et al.* 2007). For example, if a user interested in wildlife habitat wished to assess specific amounts of tree mortality or loss of canopy cover following fire, ecologically based thresholds would define this on a per-ecoregion basis (e.g. a dNBR threshold of 500 might be associated with a specific conifer type experiencing 80% tree mortality or greater based on field data from numerous fires). A few studies have regressed continuous dNBR values with such ecosystem metrics; however, these relationships may be site specific and were not applied by MTBS to the thematic classifications (Lentile *et al.* 2009). Current thresholds assigned to each MTBS fire lack this ecological association, and are not comparable across fires for empirical analysis. The Increased Greenness and Unchanged classes are nationally consistent, but the other three severity thresholds discriminating Unchanged from Low, Low from Moderate and Moderate from High, are highly variable (Fig. 1).

One assessment of the effects of arbitrary thresholds is through comparison to classifications based on specific (i.e. not aggregated), field-validated biological or physiological metrics that have defined units (e.g. change in canopy cover, biomass consumed or tree mortality). Few studies have utilised multiple fires across an ecoregion to identify such thresholds (e.g. Lentile *et al.* 2006*b*; Holden *et al.* 2009; Miller *et al.* 2009; Cansler and McKenzie 2012). Cansler and McKenzie (2012) identified ecologically based dNBR and RdNBR thresholds for their Washington State study area based on over 600 field validation plots, defining Low severity as 0–19% tree mortality, Moderate as 20–59% and High as 60–100%. A comparison of their severity classification (from ecological thresholds) to the MTBS classification (from subjective thresholds) reveals substantial differences across example fires within the same region (Fig. 2). The most pronounced differences are in the Low and High severity classes, where MTBS classified an average of 123% more area burned at Low severity and 43% less area burned at High severity compared with Cansler and McKenzie (2012) for two example fires.

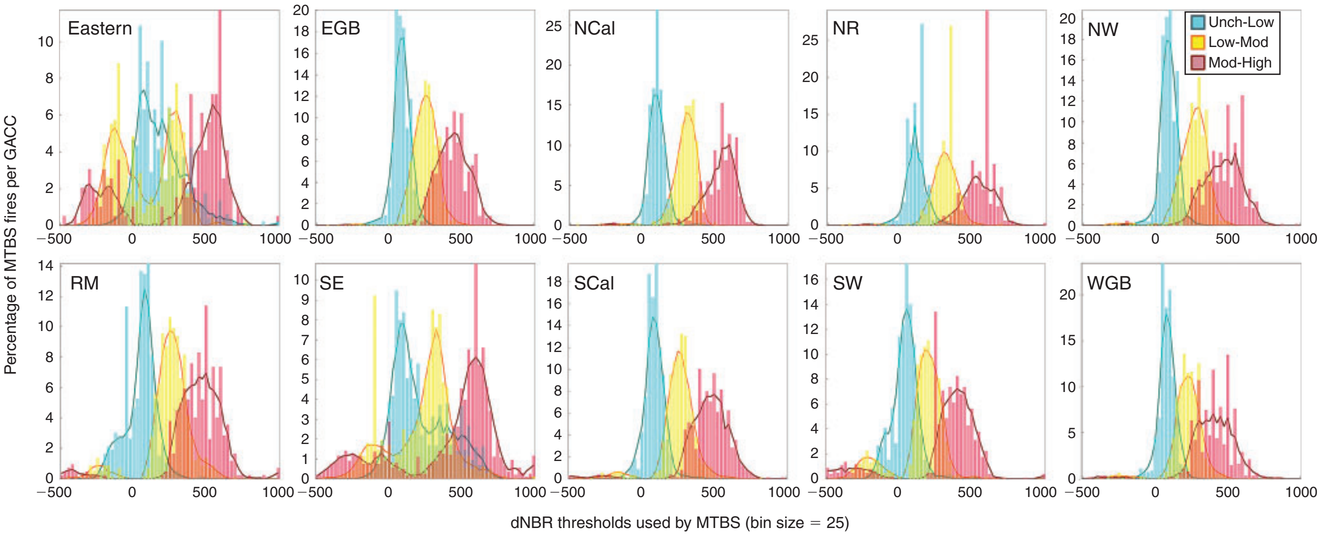


**Fig. 1.** Histogram examples of the wide distribution of classification thresholds for the 10 contiguous US Geographic Areas Coordination Center (GACC) regions: Eastern, Eastern Great Basin (EGB), Northern California (NCal), Northern Rockies (NR), North-west (NW), Rocky Mountains (RM), Southern (SE), Southern California (SCal), South-west (SW) and Western Great Basin (WGB). The differenced Normalised Burn Ratio (dNBR) values for each threshold represent the value used by Monitoring Trends in Burn Severity (MTBS) to split between two classes: Unchanged to Low (cyan), Low to Moderate (yellow) and Moderate to High (red). Bin size is 25; the *y*-axis represents percentage of MTBS fires with thresholds in that bin for the specific GACC.

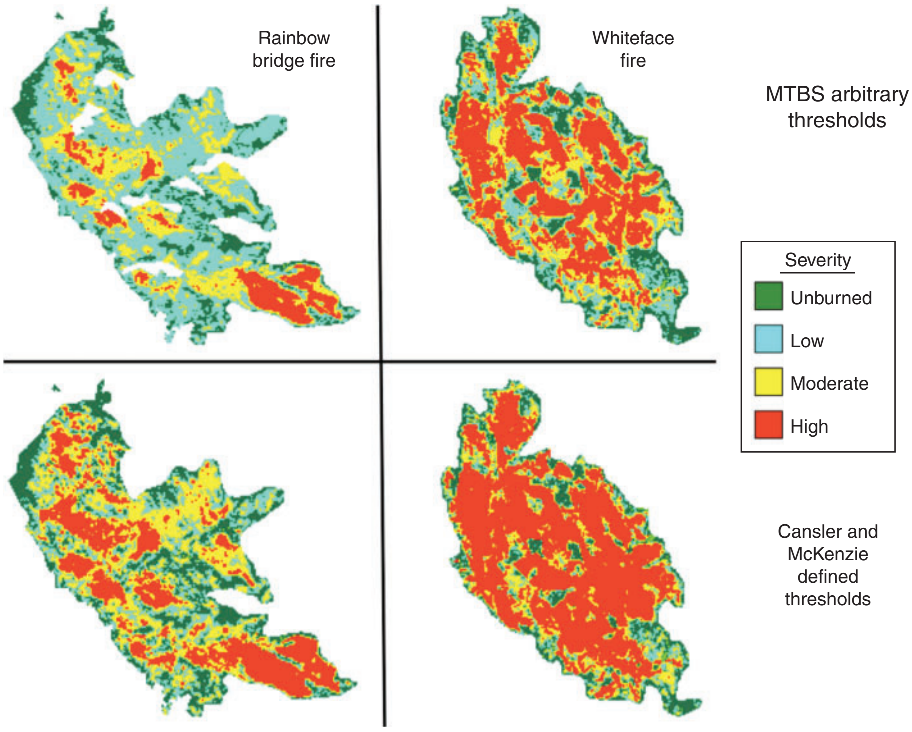


**Fig. 2.** Example of differences in the classified burn severity maps between arbitrary thresholds assigned by Monitoring Trends in Burn Severity (top) and the ecologically based thresholds (bottom) identified by Cansler and McKenzie (2012) for two fires in the North Cascades region of Washington State.

## A framework for developing a robust, classified MTBS product

Several steps can be taken to utilise MTBS data in a consistent, ecologically linked, and scientifically defensible manner. First, areas of no detectable change can be removed from within fire perimeters to represent true area burned (e.g. Abatzoglou and Kolden 2013). Second, the phenology offset value should be applied to the dNBR

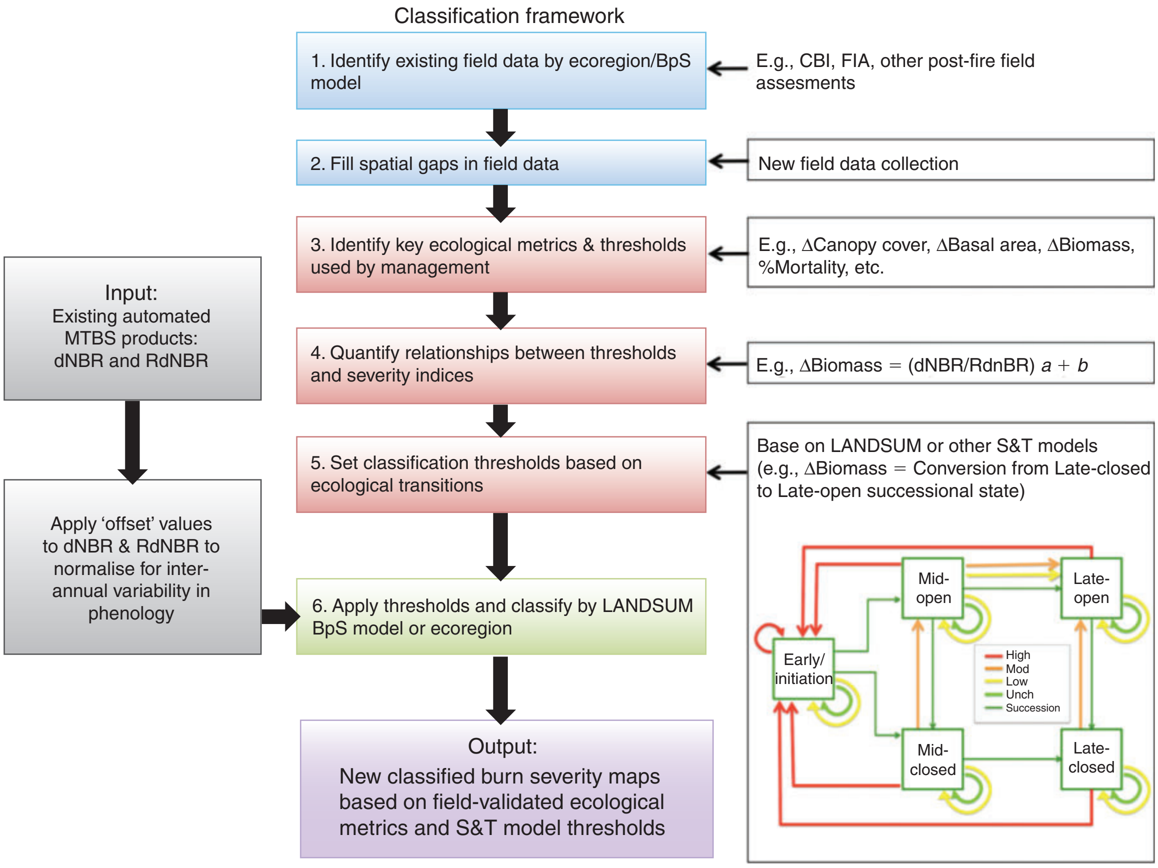


**Fig. 3.** Suggested framework for developing a national set of thresholds congruent with existing LANDFIRE products (Rollins 2009) and based on ecological State-and-Transition (S&T) model approaches such as LANDSUM (Keane *et al.* 2006). These thresholds could be applied to create a more consistent and accurate Monitoring Trends in Burn Severity classified severity product that is linked to ecological thresholds.

and RdNBR spectral indices, particularly when comparing multiple fires.

Finally, classified data must be made consistent and comparable across space and time by identifying classification thresholds based on empirical ecological metrics. This alignment of class thresholds and ecological metrics could occur at broad ecoregion levels, but we suggest that such an effort would align well with the LANDFIRE project objectives (Rollins 2009; Ryan and Opperman 2013), particularly if thresholds were defined for the finer-scale Biophysical Settings (BpS) models used as the basis for LANDFIRE product development, as was implemented by Miller and Safford (2012). Such thresholds could subsequently apply to other LANDFIRE products, such as Existing Vegetation Type, which is widely used for management purposes as it represents current conditions (Rollins 2009; Nelson *et al.* 2013). The rationale for this framework is that fire regime characteristics are defined by BpS model, where burn severity is a fire regime characteristic. Once these thresholds are defined nationally for each BpS model, re-classification of raw dNBR and RdNBR outputs could then create new classified MTBS products (Fig. 3).

Such products (both the thresholds and re-classified data) would require identifying key ecological metrics critical to land management planning; for example, percentage change in canopy cover, basal area or biomass (Miller *et al.* 2009). Metrics will likely vary across ecoregions depending on ecosystem goods and services of interest. Potential routes to defining thresholds include drawing from the ecosystem vulnerability and resilience literature (e.g. Smith *et al.* 2014) or using the framework of State and Transition models (e.g. LANDSUM successional pathway modelling within LANDFIRE, Keane *et al.* 2006), where severity thresholds for each BpS model are defined by what magnitude of change results in a transition to a new successional state (Fig. 3). Thus, the final product would ideally include a cross-walk table to identify ecological metrics used in classification and provide alternative thresholds for classification based on other metrics that users could apply to the raw dNBR or RdNBR data.

Field data are the foundation of such a development process. Although several regional datasets exist, two existing US-wide data sources could be utilised to minimise new and expensive field data acquisitions: (i) CBI and GeoCBI plots used to field validate dNBR throughout the US (Key and Benson 2006; De Santis and Chuvieco 2009) and (ii) the Forest Inventory and Analysis (FIA) programme (Bechtold and Patterson 2005). CBI is a unitless, aggregated measure of field burn severity;

however, both CBI and FIA protocols include unit-based measurements of fire-induced tree mortality, canopy cover and other ecological information. Whereas CBI plots are generally installed 1 year post-fire, FIA plots are re-sampled at regular (~5 year) intervals, such that any FIA plots burned in the intervening period could be utilised to help define thresholds. Following Cansler and McKenzie (2012), specific ecological thresholds could be identified for the most critical metrics from all field plots within a BpS region, and relationships modelled between ecological metrics and spectral indices. Following our earlier example, if 80% tree mortality is required for a forested stand to be suitable habitat for a critical bird species, tree mortality per CBI or FIA plot would be modelled from RdNBR and the RdNBR value where tree mortality equals 80% could be used as a threshold for High burn severity in that BpS model. As with land cover classifications (e.g. the National Land Cover Dataset), the accuracy would be included. As there are several metrics and thresholds that could potentially be of interest to users, we suggest that national workshops identify and document priorities per BpS (similar to the LANDFIRE development process) to facilitate the development of robust classification schemes.

## Conclusion

The development of the MTBS national burn severity atlas helped facilitate operational monitoring of trends and patterns in wildfire effects and burn severity, but its use for robust scientific analysis and application is currently limited by a lack of accuracy and field-based validation of the most widely used product: the thematic maps of classified burn severity. The thresholds used for classification are widely variable by region, and overlap considerably, with the greatest variability and uncertainty in the threshold that delineates High severity; unfortunately, this is the class that is often of the greatest interest to land managers. The framework we propose for developing ecologically based thresholds could standardise land management planning efforts and integrate MTBS with the widely used LANDFIRE suite of products, thus improving and streamlining the application of new landscape burn severity science to management practices.

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