# Fire analysis report

## Introduction

This fire analysis report focuses on the Smokehouse Creek Fire Complex, a sequence of severe wildfires that occurred in the northernmost region in Texas that spread into parts of the Oklahoma Panhandle. The fire ignited on February 26th, 2024, in Hutchinson County, after a fallen utility pole pulled down a live power-line. On March 1st, it merged with the 687 Reamer Fire. In total, the fire burned 1,058,482 acres before it was fully contained on March 16. The fire killed 2 people and 15,000 cattle while leaving 11,000 people without power. More than 500 home or business structures along with the grasslands and prairies used by cattle ranchers and wildlife were also destroyed. In recent years, Texas has experienced an abnormal decrease in precipitation combined with hot and dry conditions during spring in Texas' northernmost (Panhandle) regions, thus leading to a higher-than-average wildfire frequency. This fire event was selected because it has extensive satellite coverage. In this fire severity assessment, multi-index composite approaches were used because compared to single-index approaches, multi-index composite approaches can account for diverse effects caused by different fires and assign different weights of importance to different effects. The objective of this analysis is to demonstrate how multi-index composite approaches can improve fire severity mapping in pre-Fire and Post-Fire dNBR Assessment, advanced Burn Index Assessment, Vegetation Health Multi-Index Analysis, Multi-Index Composite Fire Severity, and comparison with single-index approach.

## Methods

For this study, Sentinel-2 Sentinel-2 SR Harmonized satellite images were used. They have a spatial resolution of 10 m for blue, green, red, and near-infrared spectral bands with a revisit time of 5 or less days. The pre-fire period is February 1st to February 25th in 2024. The post-fire period is March 16th to April 6th in 2024. The Smokehouse Creek (Texas Panhandle) Fire Complex lasted from February 26th to March 15th, which is 21 days, therefore the pre and post fire periods also matched 21 days before and after. In order to ensure quality analysis, cloud, cloud shadow, and snow masks were applied to exclude irrelevant Sentinel-2 satellite images.

NDMI and NDWI detect moisture content change which can help denote moisture depletion in fire assessment. EVI and NDVI detect vegetation density which can help denote vegetation loss in fire assessment. BAI and BAI2 detect charcoal and ash signatures which can help denote direct burn evidence in fire assessment. MIRBI detects thermal changes which can help denote thermal signatures in fire assessment.

$$NDVI = \frac{NIR-Red}{NIR+Red}, \quad EVI = \frac{NIR-Red}{NIR+C_1 \times Red - C_2 \times Blue + L}, \quad NDMI = \frac{NIR-SWIR}{NIR+SWIR}, \quad NDWI = \frac{Green-NIR}{Green+NIR}$$

$$BAI = \frac{1}{(0.1-RED)^2+(0.06-NIR)^2}, \quad BAI2 = (1 - \sqrt{\frac{B06 \cdot B07 \cdot B8A}{B04}}) \cdot (\frac{B12-B8A}{\sqrt{B12+B8A}} + 1)$$

Burn detection thresholds were based on the normalized severity values calculated from composite indices. Values from 0 to 0.1 implies unburned, 0.1 to 0.3 implies low severity, 0.5 to 2 implies moderately-low severity, 0.5 to 0.7 implies moderately-high severity, and anything greater implies high severity.

The most weight--in other words, significance--was given to dNBR index which has 40% influence on the final severity calculation. The least weights were given to dEVI, postBAI, and postBAIS2 index values which only has 10% or 5% influence on final severity calculation. For confidence mapping, the original plan was to be strict and force dNBR to be greater than 0.1, dNDVI to be greater than 0.05, and postBAI to be greater than 50. This did not end up mapping nearly any "confident" pixels, therefore rules were loosened to condition confidence based on just dNBR greater than 0.1.

The dNBR index map in Fig. 1.3 matches the reported wildfire spread seen on official fire reports and news media.

# Results

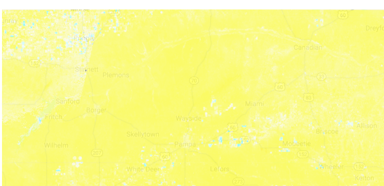

Fig. 1.1. Pre-fire NBR from Sentinel-2



Fig. 1.2. Post-fire NBR from Sentinel-2

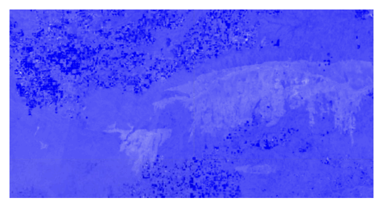

Fig. 1.3. dNBR from Sentinel-2

Fig. 2.1. Post-fire BAI map from Sentinel-2

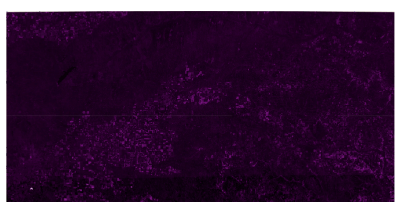

Fig. 2.2. Post-fire BAIS2 map from Sentinel-2

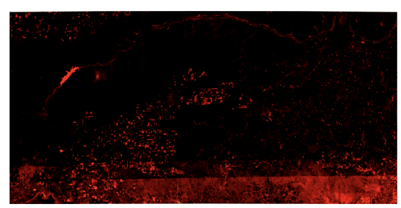

Fig. 2.3. Post-Fire MIRBI map from Sentinel-2

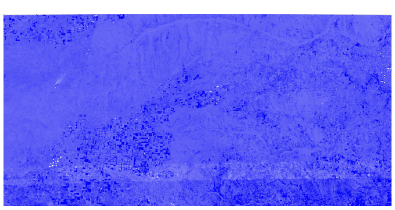

Fig. 3.1. dNDVI map from Sentinel-2

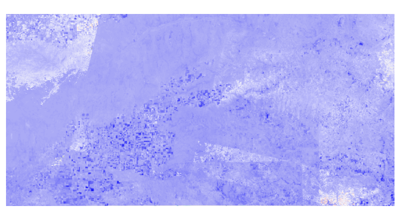

Fig. 3.2. dNDMI map from Sentinel-2

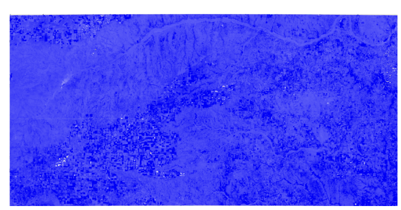

Fig. 3.2. dEVI map from Sentinel-2

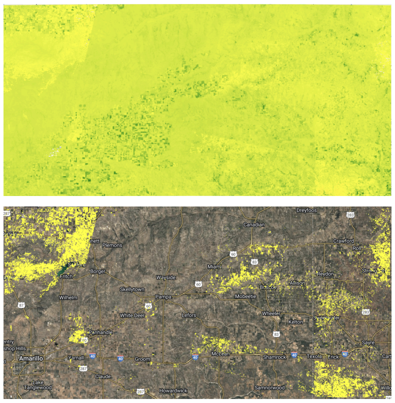

Fig. 4. Multi-index composite severity with classification from Sentinel-2

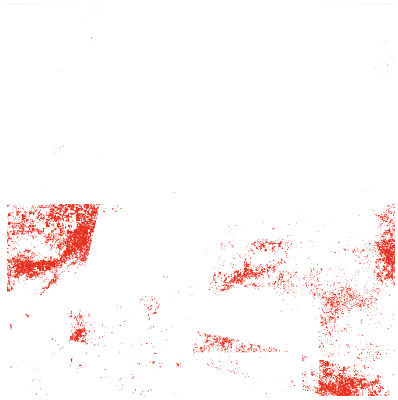

Fig. 5. Fire Detection confidence map from Sentinel-2

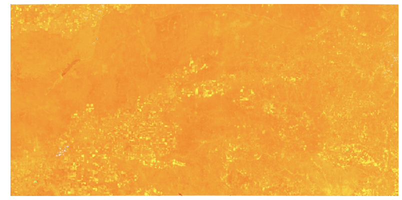

Fig. 6. Recovery potential map from Sentinel-2

From Fig. 1., the dNBR map indicates that the highest severity areas spanned eastward of the map and towards the center. This was the main Smokehouse Creek fire, with a smaller wildfire to the near the bottom center of the map to indicate the smaller Windy Deuce fire. Light green dominates the Fig. 4 map indicating that most of the study area did not burn but the small different colored patches reveal that some areas were more severely damaged.

Comparing the burn indices on how they detect burn patterns, BAI index in Fig. 2.1 presents a mostly white map which would otherwise indicate low severity, BAIS2 has a mean of 0.69 and Fig. 2.2 reveals that the surface is likely dominated by ash and char hence it is dark purple to black in many areas, the black-dominant MIRBI map in Fig. 2.3 indicates high thermal alteration which could be from fire effects as well. BAI map was the least helpful and did not identify similar burn areas as BAIS2 or MIRBI maps. Out of all indices, dNBR index provides the strongest burn signal for Smokehouse Creek fire and other fires in the Texas panhandle area during 2024, with its map aligning closely with the reports on fire spread at the time. For burned areas, BAIS2 could be 0.71, for unburned areas it would be -2.1 to indicate irrigated farmland or water bodies. For burned areas, BAI could be 120192.3 and for unburned areas it could be 0.3.

There was not that much vegetation lost as seen by Fig. 3.1 where the map is blue-dominant indicating that dNDVI values hovered around -0.2 to 0.0. There is more moisture lost as can be seen by dNDMI values of around 0.2 and the white and light blue dominant map in Fig. 3.2 which could indicate that certain burn areas experienced higher moisture losses than others. Fig. 3.3 was the dEVI map but most values were blue-dominant with mean values around 0.32, indicating little vegetation loss so it did not improve fire detection.

In this study, single-index dNBR was better than composite severity index at fire detection. In bottom Fig. 4., the more severe classes can be seen clumping around the middle and bottom of the map which corresponds to knowledge about locations of fires in the Texas panhandle area, however there were also clumps of yellow at the corners where there were no recorded fires in the selected 2024 study time period. According to area severity classification statistics: Around 218627 hectares were classified in class 1 severity, around 1464 hectares were classified in class 2 severity, and around 4 hectares were classified in class 3 severity level. In the area where the Smokehouse Creek Fire occurred, the mean composite severity value was around 0.31.

For this study, there were little areas with high confidence. As seen by the white top image in Fig. 5. The postBAI > 0.05 and dNDVI > 50maps disagreed with the dNBR > 0.1 condition for most pixels, not passing the threshold for those two conditions made it difficult for high confidence. The bottom Fig. 5 is a mask that is conditioned by only dNBR > 0.1 which reveals more areas where there could have been severe fire. This may be due to the fact that BAI is not as optimal as BAIS2 to represent Burn Area Index on Sentinel-2 data. Additionally, NDVI is minimal to start with in Texas for the study time period because vegetation is sparse during the winter, therefore the difference values do not vary much from sparse versus burned vegetation.

Recovery potential map in Fig. 6 indicates that most of the vegetation may struggle or take longer to regrow but can do so via natural recovery. The yellow spots follow the shape of the wildfire which may indicate that vegetation may have better regeneration capabilities there than compared to non-burned areas.

# Discussion and Conclusion

The reason why the composite-index related mappings did a poor job at fire detection was because most other indices that didn’t rely on burn indices were relying on vegetation. The natural environment is prairie and grasslands, therefore it would not have a high EVI, NDVI, or even NDMI to start with compared to say somewhere such as Sierra Nevada in California where there is denser canopy cover and vegetation that has the potential to be lost during wildfire. Additionally, in the panhandle area of Texas in 2024 during winter, these regions are already very sparse in vegetation, with EVI around 0.05 to 0.15. In the spring, which is the post-fire period, new grass growth begins, hence some areas even showed more vegetation than less after the fire. In conclusion, for cases where vegetation is not dense, single-index analysis may describe wildfire more accurately than composite-index that attempts to include more vegetation-related indices.