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A Preliminary Assessment of Tactical Fire Spread Observations during the 2020 California Fire Season

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Abstract

While the undesired effects of wildfire continue to increase in many regions, the fire science community continues to suffer from an important shortage of observational data of fire behaviour, especially at the landscape scale. Observations of landscape-scale fire spread have traditionally been incomplete, infrequent or qualitative. Airborne remote sensing technologies are changing this paradigm with the increasing adoption of infrared and multispectral optical sensors by fire management agencies. However, fire observations acquired during firefighting operations are designed with the goal of supporting tactical fire management decisions and they may not completely meet the needs of a rigorous scientific analysis. In this paper, we discuss tactical fire observations collected by CAL FIRE in 2020 in California (USA), specifically regarding their utility for fire behaviour studies. Generic data properties are summarized and example data is presented for two fire events. Our inspection of the data suggests that the collected imagery will be useful to study fire progression with varying temporal resolution between a few minutes and 24 hours. Imagery was successfully georeferenced and the geographic location of active fire lines could be estimated with a spatial resolution of O(10m). However, the temporal resolution of observations is inconsistent across flights and frequently not enough to study fire behaviour in detail. Furthermore, radiated energy could not be successfully characterized because the sensors utilized were not radiometrically calibrated and saturated at high irradiances. We expect that these observations will be useful to (i) approximate the response of fire behaviour to topographic features as well as changing weather and vegetation conditions, and (ii) validate fire spread simulators at the landscape scale. However, a detailed analysis of local fire rate of spread requires observations made at a higher frequency, while a complete fire behaviour characterization is impossible without accurate measurements of fire radiated energy. Similarly, ecological fire effects and fire emissions can hardly be estimated using such sparse observations.

1. The 2020 California Fire Season

2020 was one of the worst years on record in the Western United States in terms of burned area, social impact and economic losses caused by fire. During the 2020 fire season, 8,648 fires burned over 4.3 million acres in California, more than 4% of the state's total land, making that year the largest wildfire season recorded in California's modern history. 11,116 structures were damaged or destroyed, 33 people died as a consequence of fires, and Emergency Fund expenditures exceeded USD $1B (CAL FIRE, 2020a; CAL FIRE, 2020b). Five fires occurred in 2020 are among the seven largest fires in California's history, and five are listed in the list of 20 most destructive California fires. Among them, the August Complex fire stands out as the first fire that has ever burnt an area larger than 1 million acres. Figure 1 shows the area burned in California during 2020.

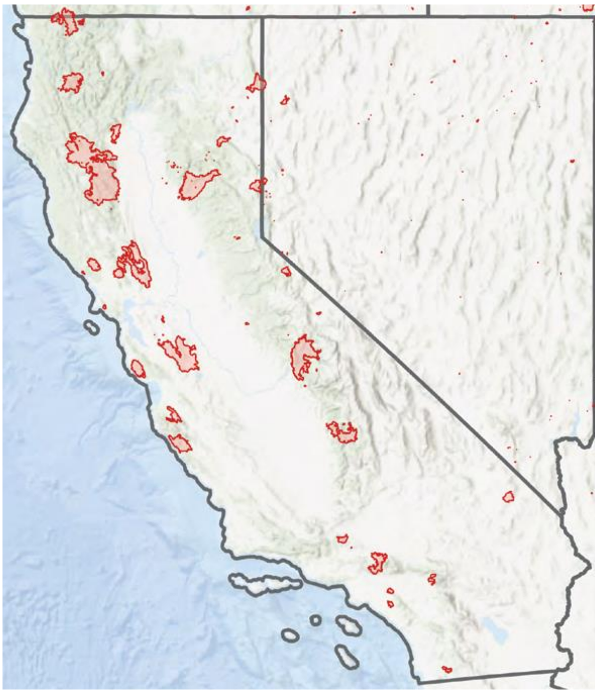


Figure 1- Area burned in California in 2020. Source: CAL FIRE.

2. Tactical Observations of Fire Spread

Fire management agencies deployed airborne imaging sensors during the largest and most impactful fires in 2020. In addition to using the imagery in real time, the data was stored for posterior analysis. This dataset is still being worked on by CAL FIRE. During our preliminary analysis of the dataset, we have identified a subset of the most impactful fires for which there is remote sensing information. The list of selected fires is summarized in Table 1. Two example fires were further selected from this list and are presented in Section 3.

Table 1- High-impact wildfires occurred in 2020 in California which have been selected for analysis based on the existence of fire spread remote sensing information.

Fire name	**Location**	**Start Date**	**Containment Date**	**Area burned**	**Structures damaged**	**Casualties/Injuries**
Creek	San Joaquin River near Mammoth Pool, Shaver Lake, Big Creek, Sierra National Forest	September 4, 2020	December 24, 2020	379,895 acres	71 structures damaged, 856 structures destroyed	26 injuries
North Complex (Clairmont, Bear)	Plumas National Forest	August 17, 2020	November 30, 2020	318,935 acres	2,455 structures destroyed	16 deaths
Glass	Napa county	September 27, 2020	October 20, 2020	67,484 acres	282 damaged, 1555 destroyed	None reported
Slater	Klamath, Six Rivers, and Rogue-Siskiyou National Forests in Siskiyou and Del Norte Counties in California and Josephine County in Oregon	September 8, 2020	November 16, 2020	157,229 acres	440 destroyed, 11 damaged	12 injured 2 dead
LNU	Napa, Sonoma, Lake, Yolo and Solano Counties	August 17, 2020	October 2, 2020	363,220 acres	1491 structures destroyed, 232 damaged	6 killed, 5 injured
Loyalton	Mount Ina Coolbrith, Sierra County, Tahoe National Forest	August 14, 2020	August 26, 2020	47,029 acres	None reported	None reported
Lake	Southwest Lake Hughs, Angeles National Forest	August 12, 2020	September 28, 2020	31,089 acres	33 structures destroyed, 6 damaged	4 injuries

Ranch 2	North San Gabriel Canyon Rd and Ranch Rd, San Gabriel Canyon	August 13, 20	October 2020	4,237 acres	None reported	None reported
CZU	San Mateo and Santa Cruz Counties	August 16, 2020	September 22, 2020	86,509 acres	1,490 Structures Destroyed, 140 Structures Damaged	1 injury, 1 fatality
Bond	Silverado Canyon, near Santa Ana (LA)	December 2, 2020	December 10, 2020	6,686 acres	21 structures damaged, 31 destroyed	None reported
Airport	Near Corona city (Riverside/LA)	December 1, 2020	December 12, 2020	1,087 acres	None reported	None reported
Crews	Crews Rd north of Gilroy	July 5, 2020	July 13, 2020	5,513 acres	1 structure destroyed	None reported
August Complex (Doe Fire - August south, Elkhorn Fire - August north)	Mendocino, Shasta-Trinity and Six Rivers National Forests	August 17, 2020	November 15, 2020	1,032,648 acres	995 structures destroyed	1 fatality
Red Salmon	14 miles northeast of Willow Creek	July 27, 2020	November 17, 2020	144,698 acres	None reported	None reported

3. Description of Remote Sensing Data

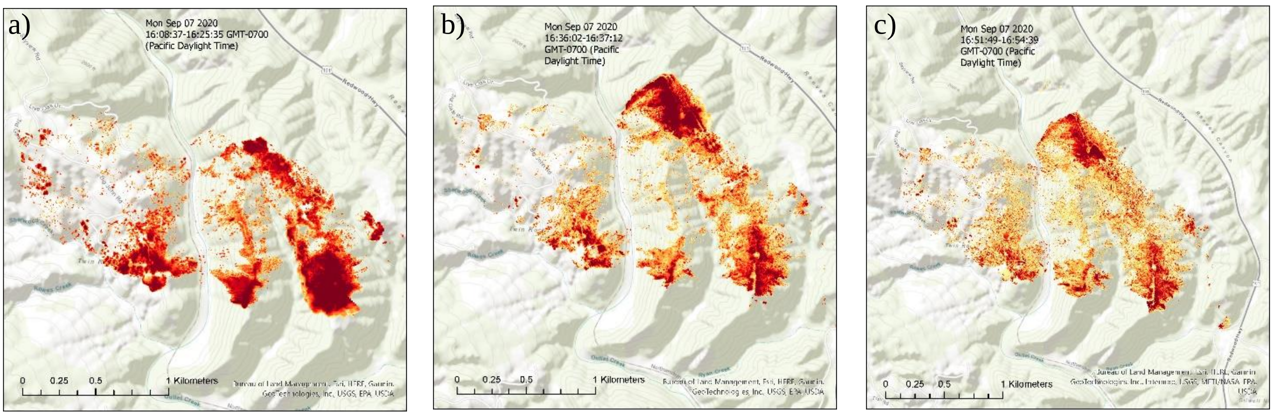
The primary source of data is aerial long-wave infrared (LWIR) imagery. Imagery was acquired on multiple flights for each fire. Time intervals between flights vary among fires and go from a few minutes to one day. Each video frame was timestamped and accompanied by camera position and attitude measurements, which allows for image georeferencing and accurate time referencing. The estimated spatial resolution of geocorrected images is in the order of 10m. However, LWIR images are non-radiometric and most of the them are saturated. This prevents retrieving fire radiative properties from this dataset.

4. Examples

This section showcases the available data in two example fire events with high temporal resolution data. In order to create the figures shown in this section, we applied georeferencing transformations to every video frame and stitched together all frames acquired during each flight. The resulting LWIR mosaics were then thresholded to identify active fire pixels. Because images are not radiometric, the optimum thresholding values were determined manually through inspection of image histograms.

4.1. Oak Fire

Fig. 2 shows a subset of the mosaics constructed from aerial LWIR frames captured during the 2020 Oak Fire. The time interval between observations is approximately 20 min. This frequency allows monitoring the fire progression and identifying significant events. For example, Fig. 2.c shows spotting on the south-east section of the fire perimeter. Such spotting significantly contributed to the advance of the fire as depicted in Fig. 2.d-e. Similarly, Fig. 2.f shows how the fire crossed a major highway through spotting.



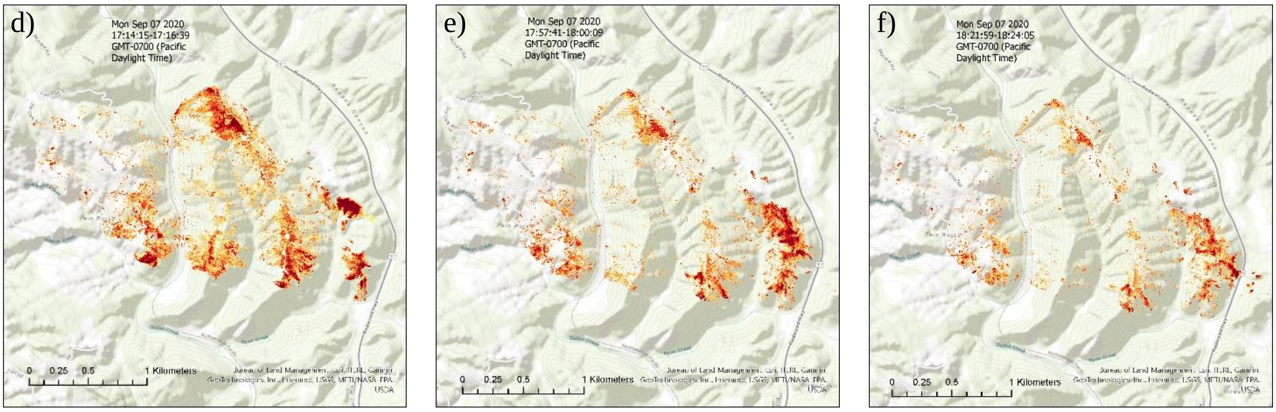


Figure 2. Observations of the 2020 Oak Fire progression. Darker colours represent a higher fire emittance, although images are not radiometric.

4.2. Glass Fire

Fig. 3 depicts the Glass Fire progression. In this case, only one LWIR mosaic is available per day. While the lower temporal resolution hinders the detailed analysis of fire behaviour, fire progression can still be observed in Fig. 3. Fire radiative properties could not be characterized due to the radiometric limitations of the deployed sensor.

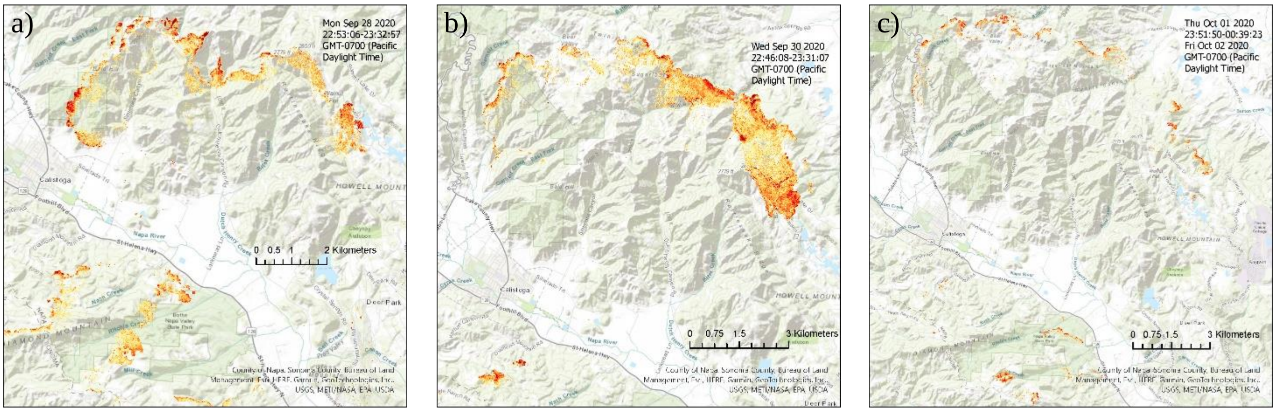


Figure 3. Observations of the 2020 Glass Fire progression. Darker colours represent a higher fire emittance, although images are not radiometric.

5. Discussion, Conclusions and Future Work

Systematic observation of fire behaviour is essential to support ongoing efforts in other areas like fire modelling, fire risk assessment and fire ecological studies. Acquiring fire behaviour observations is challenging, especially at the landscape scale. Remote sensing capabilities provide unprecedented opportunities to overcome the logistical challenges of fire behaviour observation. This paper discusses state-of-the-art data collected during firefighting operations in 2020 in California.

Our preliminary assessment of the data encourages further analysis. The ability to precisely locate active fire lines, track the fire perimeter and detect spot fires allows documenting fire progression and contextualizing it with terrain characteristics, vegetation properties and weather conditions. The primary limitations detected in this dataset relate to the unavailability of accurate radiative measurements and the inconsistent temporal resolution. Suggestions for the improvement of future fire observation systems include the addition of radiometric capabilities and the increase of frequency in observations.

Future work regarding this dataset includes (i) the development of an automated methodology to process the complete dataset, (ii) the development of a database with fire behaviour information collocated with topography, vegetation and weather data, and (iii) the detailed analysis of fire behaviour in individual fire events.

6. References

CAL FIRE, 2020a. "Wildfire Activity Statistics". Available at https://www.fire.ca.gov/media/0fdfj2h1/2020_redbook_final.pdf [last accessed: March 27, 2022].

CAL FIRE, 2020b. "Fire Siege". Available at https://www.fire.ca.gov/media/hsviuuv3/cal-fire-2020-fire-siege.pdf [last accessed: March 27, 2022].