**Title: Utilizing L-band Synthetic Aperture Radar HV Polarization for Potential Near-Real-Time Fire Damage Detection**

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The abstract should be a total of about 200 words maximum.1) Background: Place the question addressed in a broad context and highlight the purpose of the study; 2) Methods: Describe briefly the main methods or treatments applied; 3) Results: Summarize the article's main findings; and 4) Conclusion: Indicate the main conclusions or interpretations. The abstract should be an objective representation of the article: it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.

**Abstract**:

We present results from a study in which we evaluate the use of synthetic aperture radar imagery from NASA’s Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) sensor to detect fire damage to vegetation due to fires in California. The motivation behind this study is to validate the use of the UAVSAR for active fire monitoring. The need for efficient wildfire monitoring and assessment of wildfires has become paramount in California due to the ongoing, severe drought conditions facing the state. The UAVSAR instrument mounted on NASA’s Gulfstream III plane has a high spatial resolution of 5m, can be flown day or night, and can penetrate clouds and smoke. The cross-polarized component of the UAVSAR’s radar backscatter return is sensitive to the amount of vegetative volume present in a target area. Thus, burned areas show up as areas of low backscatter return compared to areas of non-burned vegetation. We analyzed before and after radar scenes from fires throughout California from 2009 to the present for changes in this signal. Our results show that... [state numerical summary of results...blah blah the UAVSAR sensor is capable of detecting changes in vegetation due to wildfires with accuracy]. This preliminary study suggests that polarimetric SAR has the potential to become a powerful tool for active fire response.

**Keywords: wildfire monitoring; radar backscatter; UAVSAR; cross-polarization (3-10)**

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**1. Intro**

While wildfires are a natural and necessary part of Californian ecosystems, warmer-than-average temperatures and severe drought conditions in the past few years have exacerbated the risks associated with these destructive forces of nature, resulting in longer fire seasons and increased danger from explosively dry conditions [1]. According to the USDA Forest Service: “In the West, climate change and other factors have contributed to hotter, drier, and longer fire seasons, on average 60 to 70 days longer than in the prior decade” [2], and, “in FY 2014...The continued severe drought in California magnified the challenges presented by high fuel loads and dry conditions, so any wildfire that occurred there had the potential to become a catastrophic event” [3]. In addition, erratic fire behavior from regional weather patterns such as Santa Ana winds, and the hilly or mountainous terrain characteristic of much of California often contribute to fire responders’ difficulty in monitoring and assessing active burns [4]. Increasingly, fire responders are turning to remote sensing technologies which enhance their ability to respond to fires quickly and effectively. This is taking place on a federal level, with the US Forest Service Remote Sensing Activities Center (RSAC) leading the way nationally with programs that “provide technology evaluation and development and training support in the use of remote sensing, GIS, image processing, and GPS” [5]. This is also taking place on regional levels, for example, the recent five-year partnership between the California Department of Forestry and Fire Protection (CAL FIRE) and NASA which explored the use of uninhabited aerial vehicles (UAVs) with thermal sensors for hotspot detection [6].

In this paper we present results from a study of a new application for NASA’s airborne L-band radar sensor, the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR). We conducted this study in partnership with CAL FIRE and RSAC, two agencies that are committed to exploring and increasing the use of remote sensing technology in the field of fire response. While the use of remote sensing for post-fire response is well-established, fire-response agencies are generally limited when it comes to use of remote sensing technology in the field during an active fire response. These limitations are due to the relatively coarse spatial and temporal resolutions of non-commercial fire-detecting technologies. For example, thermal imagery from infrared-detecting sensors can be used to identify fire perimeters and hot spots. Non-commercial satellite-based thermal imaging has a minimum spatial resolution of thirty meters (the Landsat series) and minimal temporal resolution of one day (NASA’s Moderate Resolution Imaging Spectroradiometer - MODIS). Much finer spatial resolution imagery is available through the US Forest Service’s National Infrared Operations (NIROPs) Center in Boise, ID, which is frequently used by agencies responding to large or rapidly increasing fires. The NIROPs unit uses airborne infrared sensors that are mounted on three different airplanes that fly out of Idaho. [DO WE NEED A CITATION HERE?] NIROPs collects data at night when the effects of solar irradiation are minimal and delivers fine-resolution fire perimeter and hotspot maps after a few hours to the fire responder agencies. Unfortunately, NIROPs is useful in gathering data only during the night and serves other Western states, limiting the amount of data that can be collected in California.

 The use of radar to detect fires was first proposed by \_\_\_\_. Volumetric vegetation change detection is possible with polarized radar signals. [explain, in brief, cross-polarization (HV) signals] Synthetic aperture radar produces higher resolution imagery by [explain briefly]. Some important studies involved these instruments and were authored by these scientists/agencies, who concluded \_\_\_\_\_\_\_.

NASA UAVSAR instrument went into operation in 2009. [Give brief explanation of science objectives for most missions, and some nerd details of the antenna and processing system.]

For our study, we identify and gather data from [80+, give number] case studies from the UAVSAR data archives. We process this data to show changes in the cross-polarized backscatter brightness (CBB) between before and after images. We use a simple algorithm involving minimal processing time and power as soon as the UAVSAR data becomes available [this statement is vague because we are at the moment still unclear on the way that the actual radar signal is processed and how long that takes. As far as we know, it currently takes a week or so for the data from a flight to be processed. If someone could provide us with more details or a resource, that would be great]. We use official fire perimeters from the US Forest Service and CAL FIRE to analyze the effectiveness with which the UAVSAR product is capable of detecting regions damaged by fire. We also compare our data to field data and post-fire burn scar products created from Landsat imagery. Lastly, we present the results of a near-real-time fire detection exercise we conducted during the latter stages of the Lake Fire in San Bernadino, California, in June 2015.

**Methods**

*2.1 Datasets/Image Acquisition/Data Acquisition*

The study area was wildfires that occurred throughout California from January 2009 to the present. We identified case studies by examining a comprehensive list of California wildfires that burned in excess of 300 acres and checking for the availability of UAVSAR data at the wildfire location. Once we identified case studies, pre and post UAVSAR scenes were obtained per case study from NASA’s UAVSAR website. We downloaded orthorectified .grd files from the website, which consisted of gridded pixel values of the power backscattered to the UAVSAR antenna in linear power units, projected onto a Shuttle Radar Topography Missiondigital elevation model (SRTM DEM) that is associated with the .grd file. The SAR dataset consisted of L-band horizontal-to-vertical (HV) cross-polarized products. The HV cross-polarized products, in which the sensor transmits radar wave signals by a horizontal antenna but are detected by a vertical antenna, were collected for this study since vegetation transforms the horizontally-polarized waves into vertically-polarized waves. Wildfires affect vegetative cover on the ground thus limiting the vertically-polarized radar backscatter since there is less volumetric scattering from burned vegetation. We also acquired Landsat 8 Operational Land Imager (OLI) and Landsat 5 Thematic Mapper (TM) scenes recorded before and after each fire occurrence date.

*2.2 Data Processing*

The UAVSAR raw radar products were converted into decibels (dB) for better visualization of the data, as well as for easy comparison between pre-fire and post-fire images. The following equation was used to convert the raw product into decibels:

 dB = 10\*log10(“UAVSAR.grd”) [remember to use word equation format]

where dB represents decibels and (“UAVSAR.grd”) is the raw UAVSAR grid file.

To see the effects of the fire on the vegetation, the difference between the before and after scenes was applied to create a differenced Cross-polarized Backscatter Brightness (dCBB) map:

dCBB= (dBprefire - dBpostfire) [remember to use word equation format]

where dCBB is the differenced Cross-polarized Backscatter Brightness and dBprefire is the dB processed image of the UAVSAR scene before a fire whereas dBpostfire is the processed dB scene after a fire.

A python script in ArcGIS was used to create the dCBB with minimal processing time. The dCBB image showed where the HV response had changed between the pre-image and the post-image which are likely due to the effects of fire on the vegetative cover. The brighter pixels indicate areas where there was the most change, whereas darker pixels indicate areas where there was little to no change.

Landsat derived differenced Normalized Burn Ratio (dNBR) products downloaded from the Monitoring Trends in Burn Severity (MTBS) website was used as a visual comparison on how well the dCBB can detect burn scar. The dNBR products were not available for most of the case studies in this research, so we produced our own dNBR’s. The pre-fire and post-fire Landsat scenes were atmospherically corrected to Top of Atmosphere (TOA) reflectance using the Radiometric Calibration tool in ENVI 5.2. The Landsat imagery were processed into a dNBR using the near infrared and shortwave infrared bands. These correspond to bands 4 and 7 in Landsat 5 TM sensors and bands 5 and 7 in Landsat 8 OLI sensors. The dNBR was then created using the following equations that was encoded into a simple Arc model toolbox for faster processing in ArcMap: \*\**note*\*\**cite carl albury here for providing the arcmodel toolbox*

NBR= (NIR - SWIR)/(NIR+SWIR) [remember to use word equation format]

 dNBR= NBRprefire - NBRpostfire

where NBR is the Normalized Burn Ratio and NIR and SWIR represents the near infrared and shortwave infrared bands respectively. The dNBR is the differenced Normalized Burn Ratio and NBRprefire represents the NBR processed image for the scene before the fire event while NBRpostfire represents the NBR processed image for the scene after the fire event.

*2.3 Analysis/Statistical Analysis/Comparison Method?*

We compared the dNBR and dCBB maps side by side to differentiate spatiotemporal patterns and to determine if UAVSAR products provide an alternative to the currently used Landsat derived burn maps. We also quantitatively compared the dNBR and dCBB maps using correlation graphs. The look direction of the UAVSAR sensor had to be considered before comparing the images since the UAVSAR sensor is a side-looking instrument that images the terrain on the left side of the Gulfstream III plane. We removed pixels that were located in the steep slopes facing away from the sensor for quantitative analysis since these pixels had poor quality data. For the correlation graphing, we resampled the dCBB image to the dNBR image using the Nearest Neighbor resampling method. We extracted and plotted pixels that were only within the fire perimeter for our correlation graphs using LibreOffice. We then estimated the relationship between the dCBB and dNBR using a linear regression model.

2.4 *Ancillary Datasets*

We used fire perimeter shapefiles for creating the correlation graphs between the dNBR and dCBB. We acquired fire perimeter data from the CAL FIRE Resource and Assessment Program (FRAP) website. In addition we used vegetation cover data from the USGS National Land Cover Database (NLCD) and USFS California Vegetation Mapping Zones (CALVEG) to aid in the interpretation of the dCBB backscatter. It was important to know the existing vegetation where the fires occurred since the radar backscatter varied depending on the vegetation type.

**3. Results**: *Will be expanded upon our case study processing completion*

3.1 Case studies? (Canyon Fire?)

 The Canyon Fire occurred on September 4, 2010 in Kern County burning 14,585 acres. Comprised of mostly pines and conifers this region did in fact show change in the backscatter signature. With data provided to us by Sander Veraverbeke and Natasha Stavros (Post-Doctoral Research Scientist at NASA Jet Propulsion Laboratory), we were able to create our own correlation graph with the GeoCBI and dCBB resulting in an R2 of approximately 0.63.

3.1.1 mostly shrubs/chaparral

3.1.2 mostly forest

3.1.3 Mixed vegetation

* achievement in clearly outlining fire perimeters that were derived from Landsat imagery.
* correlation graph comparisons with R2 values for each significant case study
* *will include correlation graphs as well as table showing the …*

Note: table of results in supplementary material?

**4. Discussion**:

 (The advantage of using this method is the use of a single cross polarized product. This allows for faster processing since there is no need for using all the polarization products to detect vegetation change from a fire. )

Although UAVSAR can detect burn scars in most vegetation, it did not detect well in grassland environments due to the lack of backscatter interaction with the vegetation present. The UAVSAR sensor performs better in forested and shrubland environments where there is adequate volumetric scattering. It is also important to consider slopes due to the SAR instrument look direction because the effects of shadows and layover are displayed. In light of this it is desired to take two or more look directions to fully picture the burn scar. With multiple look directions, a mosaic can be done to create a final output with the slopes that have been masked out for a better visual comparison, but the final mosaic image would not be too useful for quantitative analysis. The final mosaicked image would have pixels that overlay the previous images’ pixels and the offset in the pixel values could misrepresent the study area, thus hindering any statistical analysis.

Our results are also hindered due to some of our case studies having large temporal differences between the time of data acquisition and the time of the fire. With these huge temporal differences there are a number of other factors that must be considered. Some major factors include soil moisture content, vegetative regrowth, and human activities. Soil moisture would influence the UAVSAR results because under wet conditions, the backscatter signal of all the land cover classes can be higher than usual and thus show little variation between classes. In dry soil conditions, the backscatter would look dark while wet soil looks brighter (add reference--). So areas with wet soils may appear to have more change caused by a wildfire due to its brighter backscatter pixel values, but in reality there may not be any change caused by a wildfire. Hence, it is best to collect UAVSAR data in drier conditions for a more accurate fire damage identification. For many of our case studies, the after scene was acquired many months after the fire occurrence date. This allows a large timeframe for vegetative regrowth and human disturbance in the study area and this can greatly affect the backscatter response.

Due to limited number of UAVSAR data sets available during a wildfire, more observations and analyses need to be done to see if UAVSAR is an effective tool for fire assessment.

**Should we say this? ->** *Correlation graphs were created between the dNBR and the UAVSAR derived dCBB. These correlations are not feasible for validation for the dCBB due to the fact that the dNBR is presented in linear space whilst the dCBB is in logarithmic space.*

**5. Conclusion**:

 For most of our case studies, the UAVSAR instrument was able to detect burn scars and burn severity. The dCBB and the dNBR showed similar patterns in burn severity, although it can vary based off of vegetative type. The processing of the dCBB products were quite fast since only the cross-polarized dataset was used which has potential for near-real-time fire response. Although we did not obtain data during a wildfire, the results for post-burn assessment look promising and should have the same results for near-real-time burn assessment. In the future, more research needs to be done to validate the dCBB involving field data as well as lower temporal resolution between UAVSAR datasets. Many of our case studies had temporal resolutions of about a year which brings in additional factors in what we are actually seeing/depicting in the finalized dCBB. Vegetative regrowth, moisture content, seasonal variations, and human disturbance may play a role in what we see. This is why data sets closest to the fire are necessary/needed. With the right resources we believe that the UAVSAR instrument has great potential in providing yet a new method for fire responders to use on the field.

**Acknowledgements:**

**\***in progress

Naiara Pinto

Natasha Stavros

Sander Veraverbeke/Simon Hook

Joshua Verkerke

**Appendix A**

**References**

[1] (cite the news article describing CAL FIRE’s assessment of fire conditions)

[2] (USFS FY2015--budget justification)

[3] (USFS FY2016 budget explanation)

[4] CAL FIRE Cheir (ret.) Rich Strazzo, personal communication

[5] (RSAC website cite)

[6] (need citation. look for Vince Ambrosia publications)