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Detection of Sugar Cane Harvest Burning Using Satellite Imaging

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the California Environmental Protection Agency

Disclaimer

The statements and conclusions in this Report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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Cloud-based processing was provided via the Google Earth Trusted Testers program.

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Abstract

This project developed a system enabling Air Resources Board (ARB) Staff to determine what proportion of a specific cluster of sugar cane fields had been burned prior to harvest. ARB Staff provided the project with a series of sugar cane fields and were provided a set of geographic information system (GIS) maps in which MODIS satellite burn scar data were overlain onto sugar cane fields identified by producers seeking to register for the Brazilian sugar cane ethanol pathway that included a mechanized harvest credit. The resulting GIS maps allowed ARB to calculate the percentage of the cane harvest area in which burns occurred. This was based on the assumption that manually harvested areas are burned prior to harvest.

Executive Summary

Background

ARB Staff developed three Brazilian sugar cane ethanol pathways which reflect the three primary production methods in common use in Brazil; two production methods where fields are burned, and a production method when cane is harvested mechanically, the field is not burned, avoiding significant greenhouse gas emissions. Brazilian producers are asked to document the proportions of hand- and mechanically harvested cane they process. However, it is required for burn areas can be detected independently with reasonable accuracy in some forms of satellite imagery. Using an existing MODIS satellite based processing step selected as an available method for burn detection.

Methods

We developed method to determine how much sugarcane harvesting was burned as compared to mechanical harvesting. From this methodology we created a semi-automated report generation facility given a set of input sugarcane fields from ARB. The method also provides for the generation of yearly burn summary maps. Because MODIS does not have a direct satellite replacement, we also looked at the possibility of developing a similar methodology using other satellites. Because of the difficulty in satellite image processing, we investigated the use of cloud-based computing, in particular Google's Earth Engine platform, as the basis for that investigation.

The methodology for detecting burns is quite simple, and based almost exclusively on an existing MODIS product, the MODIS Burned area product (MCD45A1), along with the locations of the sugarcane fields as provided to the application. MCD45A1 is a 500-meter data product, developed from both Terra and Aqua surface reflectance inputs. It provides a simple summary of burned vegetation and various quality assessment and supporting information.

Using this raster product, we developed a workflow which combined the identified burns with sugar cane field locations provided by ARB for each application. The processing is fairly straight-forward, where the pixels that overlay a field are investigated for any burning. If a burn is detected, than those pixels are reported, and that field is also identified as having been at least partially burned. These data are then combined in an automatically generated KML file, and delivered to ARB along with a summary report. The format of the reporting process allows that GIS data to be examined with open source tools, and does not require any specialized GIS applications. They can be shared directly within ARB or to the producers themselves.

An alternative method that was added in the project extension was to provide yearly summary burn maps for large regions of Brazil and Costa Rica. With the summary maps, ARB can perform additional field evaluations without the requirement to go back to the MODIS raster imagery. The methodology for the summary maps also uses the MCD45A1 product, but the results are collected for each each, and turned into a vector layer for ARB. Pixel values are also located with States and countries using administrative boundary data layers.

For the cloud-based processing we looked at some simple methods to use LandSAT 8 to perform a similar burn detection task. Landsat data is more complicated to process on a local computing system, and so instead scripts were developed on Google's Earth Engine. The detection method used for Landsat based processing uses the Normalized Burn Index. which takes advantage of the large spectral differences between green vegetation and burned vegetation.

Results

We provided ARB with sugar cane burning reports for 34 separate applications, or field collections. These reports included the fields processed, the underlying MODIS pixels, whether they were burned, and if they were, on approximately what day. These data were provided to ARB on an application by application based reporting scheme, with each application receiving an individual report. These reports spanned from 2011 through 2014, and were provided as KML files, making them available to both ARB and the producers. The individual reports can be quite large as they include GIS data relating to every pixel involved in the processing, but taken on an application basis, they provide a highly descriptive overview of the harvest burns. In addition, we provided ARB with yearly summary burn maps, for 2011, 2012, 2013 and 2014. These cover all states in Brazil and Costa Rica that received any applications to ARB in the duration of this project. The summary maps show all burning throughout that year, as described by the MCD45A1 Burned Area product. This allows for ARB staff to respond to any new applications from ethanol producers. We created a set of Landsat based processing algorithms, implemented in Google's Earth Engine framework. Preliminary results are encouraging, but the burned areas detected bythe Landsat BARC and MCD45A1 methods can vary substantially.

Conclusions

The processing methodology based on the MODIS MCD45A1 product provided, timely, relatively straight-forward support for the burn detection requirements for ARB Staff. Using an existing, and tested data product made creating a simple product possible, and the extra step in creating an intermediate KML format provided a convenient method of communications between ARB and the ethanol producers.
Difficulties in ethanol producers being able to provide a standard input format, required that the initial data formulation step could not be automated, and questions on particular results from the producers also required expert knowledge in remote sensing applications. While initial results of a Landsat-8 based detection algorithm were encouraging, building a complete product generation will require additional research. Alternative possibilities, most notably using VIIRS satellite data should also be investigated.

Introduction

This proposal developed an automated method to determine how much sugarcane harvesting was burned as compared to mechanical harvesting. The basic idea is that sugarcane farm boundaries are input into the system, and the amount of burning over those regions are calculated. This proposal primarily uses the MODIS burned area product (MCD45A1) as a simple method of determining the amount of burning occurring during the harvesting.

Tasks for the project included:

- Application and Development
- Automated Report Generation
- 2013 and 2014 MODIS Burn Summary Maps
- Evaluation Support
- Cloud-based Processing Evaluation

Application and Development

We developed core processing for the sugarcane fields, and provided data to CARB. From those input data, we developed a workflow, which processed these data, and provided detailed reports for the sugarcane processes, and summaries of the burning. We provided CARB with all the MODIS pixels used in the image processing. CARB has reviewed and approved the methodology and the reports generated in this application development.

We have provided the source code for the project, in an open repository (https://github.com/qjhart/sugarcane). The code is executed primarily in PostGIS, and open source spatial database; and Grass, an open source GIS tool which is used to process the raster imagery. The repository includes all the code needed to create and maintain the GRASS database, and to process the requests and create the output KML summarizations.

Methods

The methodology for developing the sugarcane field burn maps is quite simple, and based almost exclusively on an existing MODIS product, the MODIS Burned area product (MCD45A1), along with the locations of the sugarcane fields as provided to the application. These data are compared, to determine the overlapping regions, and therefore give an indication of when and where field burning has occurred.

The primary work for this project has been to build an automated system to do this processing on a case by case basis for new sets for fields as supplied to the application. Most of the processing is performed in a PostGIS database.

MODIS MCD45A1 Product

The MODIS Burned area product (MCD45A1) is a monthly Level-3 gridded 500-meter product, that describes the day that a particular pixel was burned throughout the year. Fires are determined by detecting rapid changes in bands most affected by burning vegetation. Pixels are compared over the course of about 2 weeks, so areas under clouds can eventually be detected. Changes are compared to a certain threshold level, but this value is not reported and there is not an estimate on the extent of the burning in the pixel.

In addition to the burn date, the product includes supporting information regarding the detection and the underlying land cover for the pixel.

Produced from both the Terra and Aqua MODIS-derived daily surface reflectance inputs, It provides varied quality assessment information and a single summary quality assessment score for each pixel.

The algorithm incorporates a bidirectional reflectance distribution function (BRDF) model-based change detection for seasonal variations in the sun angle, and a statistical method for determining the probability of a changed or burned pixel. Each monthly MCD45A1 product uses three months of daily reflectance data.

Figure 1 shows an overview of the processing used to automate the sugarcane field burning.

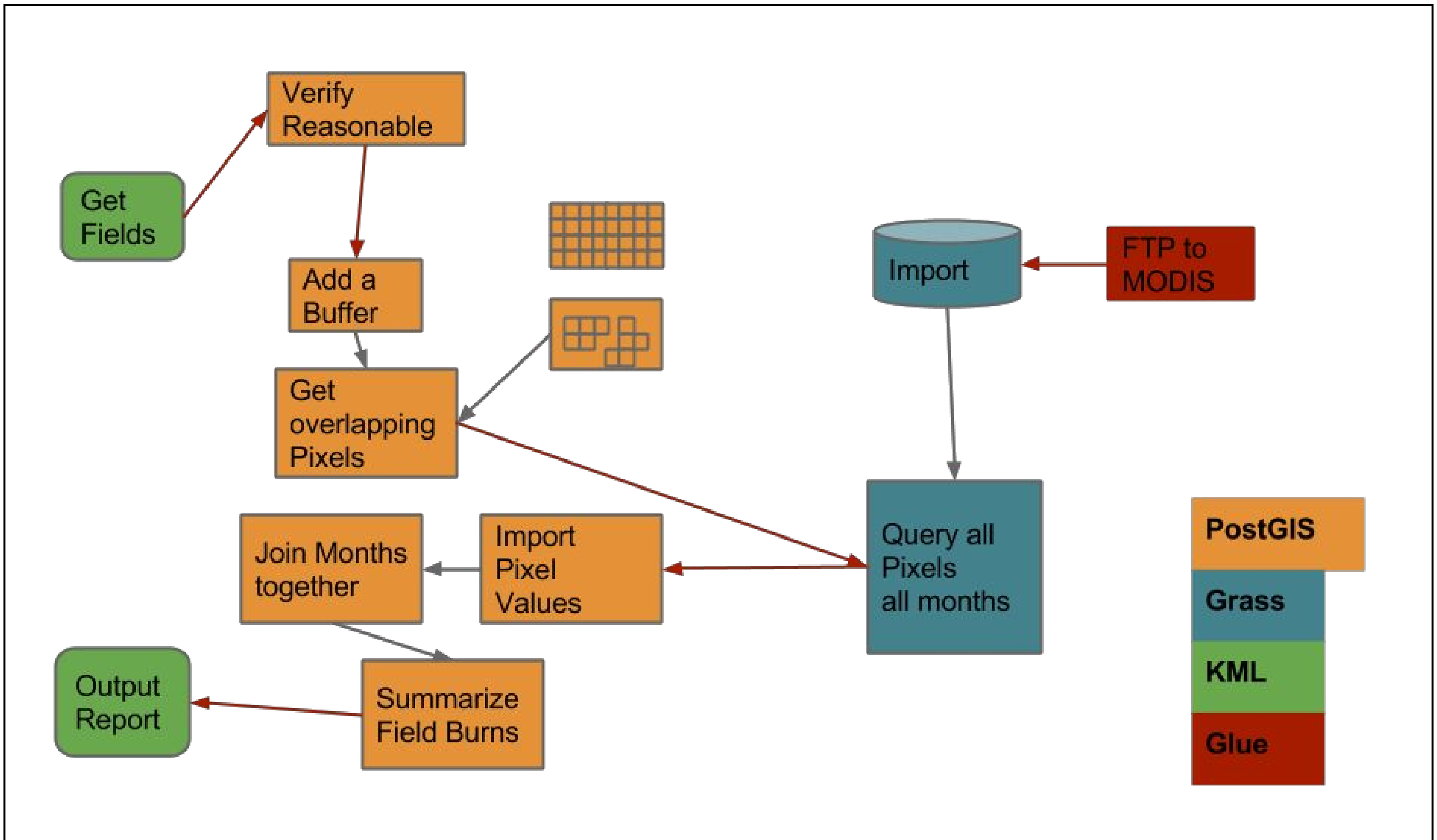


Figure 1. Sugarcane field processing overview.

The two inputs are the MCD45A1 products (on the right), and the field locations (upper left). The output are the maps of burned area locations, (bottom left).

MCD454A1 collection is a periodic event, where data for a number of MODIS tiles are checked, and if they are available, are downloaded from an FTP site. The current requests spanned 5 different tiles. These tiles are imported into a Grass Database The grass database provides a good interactive platform for the data for testing and evaluation purposes.

A new request comes to the system as a list of fields and their locations. Although the original plan was for CARB to standardize a format for that input, the data as provided by the growers was often technically challenging enough that UC Davis assumed the role of standardizing the incoming field data. This included accommodations to the format, the type of geometry used, the identifier, and the coordinate system of the incoming data. UC Davis would verify the incoming data, and modify as appropriate. The automated system supports incoming data as either ESRI shapefiles or KML files.

From those inputs, a buffer is added to each field of about half the width of a MODIS pixel, and then overlapping pixels are found by finding all pixels with a centroid in that buffered field location.

The MCD45A1 rasters are then interrogated for their values at each of these locations. This is done for every month in the timeframe of interest. Inside the database, these monthly data are aggregated together. The fields corresponding to any of the burned pixels are identified. These data are then summarized and reported in both a tabular and map format.

The tabular format shows for each field, how many pixels overlap that field, and how many of them were burned, and then the particular days of burning for any pixel within the field. The map format is a KML file that includes the following layers:

- The input fields
- The buffered fields
- All overlapping MODIS pixels
- The burned pixels
- The burned fields

The burned fields data is basically equivalent to the summary table provided.

Yearly Field Burn Maps

The automated process works well, but does need to be run with every new set of fields. An alternative method that was added in the project extension was to provide yearly summary burn maps for large regions of Brazil. This would allow CARB to directly respond to new field evaluations without the requirement to go through the automated process. The processing is very similar to the above, however, burned pixels for the entire region are reported.

In addition, a few modifications were made to the reported burned pixels. First, the pixel data was combined with administrative boundaries for Both Brazil and Costa Rica. Each burned pixel includes an indication of the country and state of origin. Also, for each region, overall statistics of the burns were calculated to determine the normal time of sugarcane burning. In addition to the actual doy for the burns, the offset from this average time is also reported. This can help determine burns not consistent with sugarcane harvesting.

Landsat based Burn detection (Cloud-based Processing Evaluation)

As discussed, the project uses a monthly MODIS based burn product to determine whether or not fields have been burned. For an alternative cloud-based processing we looked at some simple methods to use LandSAT 8 to perform a similar task. The goal for the processing is that AHB provides a set of fields from which the sugarcane was harvested. Using scripts developed on Google's Earth Engine, UCD would process those fields in a manner similar to the MODIS based processing, but using instead a methodology based on Landsat imagery, and tools available in the earth engine platform.

Burned Area Reflectance Classification (BARC)

Detecting burns within vegetation areas using BARC takes advantage of the large spectral differences between green vegetation and burned vegetation, especially in the near and short infrared regions.

BARC uses relationship between these two bands. The idea is to measure the relationship between these bands prior to the fire and then again post fire. An individual measurement is the Normalized Burn Index (NBI) and is defined as (SWIR-NIR)/(SWIR+NIR).

Where these values have changed the most indicate burned areas. If the NBI is relatively unchanged, then burning is more unlikely. The size of the BARC can indicate the severity of the burn. The idea using Landsat imagery for the calculation of BARC is fairly straight-forward, and summarized in Figure 21.

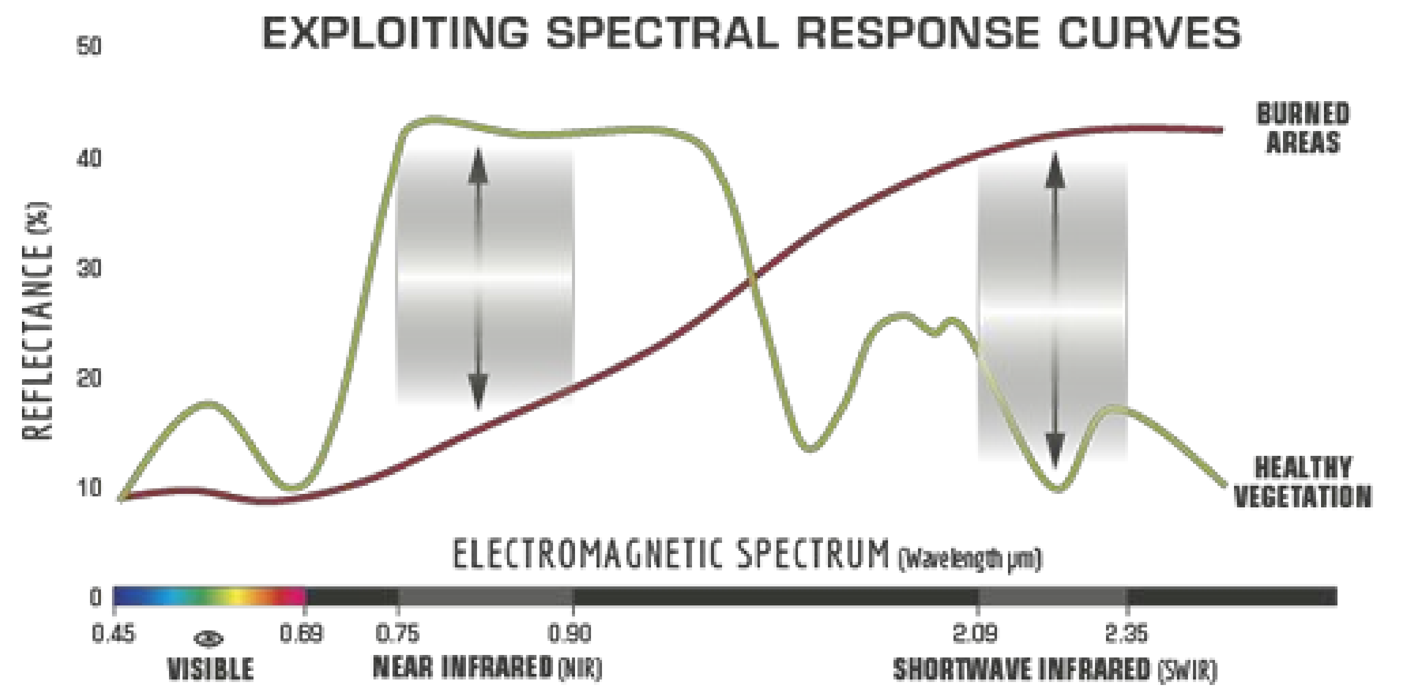


Figure 20. Spectral response to field burning. Image from retrieved from the USFS Remote Sensing Applications.

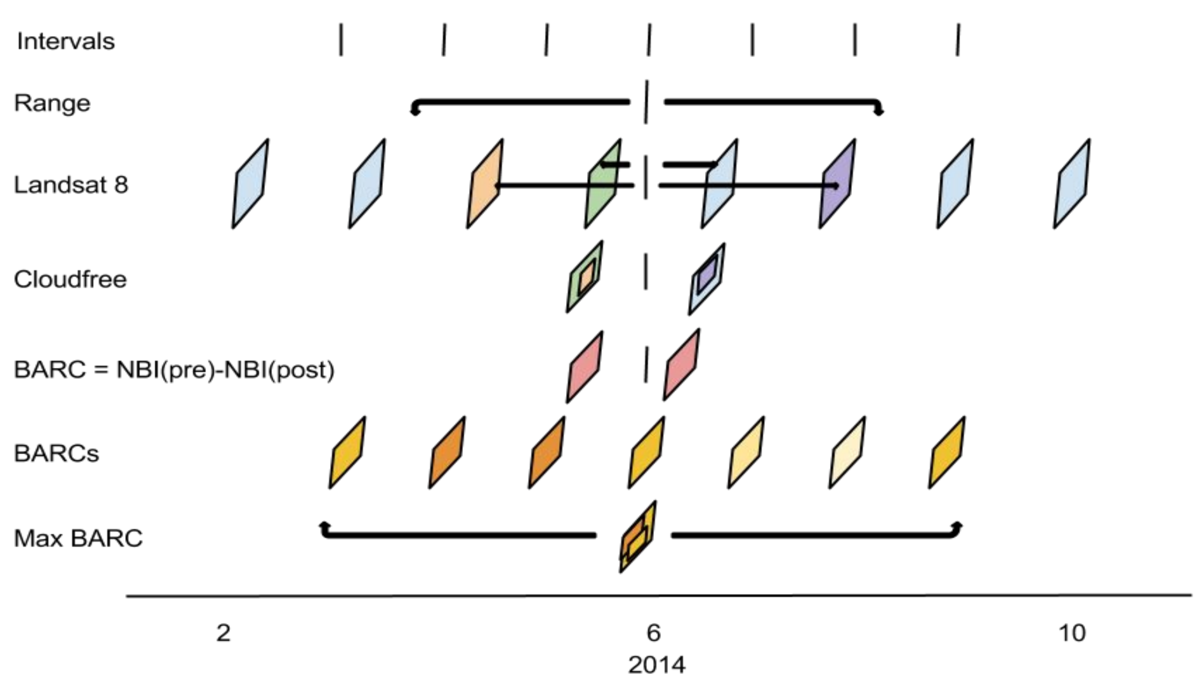


Figure 21. Landsat Image collection for burned area estimates.

For every month, determine the normalized burn index (NBI) for each pixel in the sugarcane fields. If the NBI has increased dramatically, then identify that as a potential burned pixel. This is somewhat confused by the fact that the NBI is affected by cloud cover, and our overpasses are substantially less frequent than the overpasses from MODIS. In addition, fields that are mechanically harvested also show an increase in NBI, though presumably, not as high as a burned pixel.

These values are calculated at each month, and the greatest change is saved, along with the date of that large change. These data would then be overlaid with the fields, and summarized at the field scale to determine the burning extent for the fields in general.

The code repository includes the example scripts to be used in the Earth Engine environment, as well as summary workspace definitions to interactively examine some cases of this processing methodology.

The nbi.js script in particular is a complete example of the processing described above. With this script, the user can specify a set of farms, and a year. The result is an export of the farms with the mean and 80th percentile Max Barc values for each field processed. As an example, this script also shows the same data for burned MODIS pixels within the fields as well. These can be used to calibrate the Landsat based processing steps.

Results

A brief summary of the products delivered by this project are described below. After this summary is a more detailed description of some of the major results for this study.

Automated Report Generation We have delivered burn summary maps, allowing CARB will be able to process incoming request in-house. However, we continued to support automated summary generation to allow CARB the ability to compare their results with UC Davis results.

- CARB submitted a number of new sugarcane fields in a mutually agreeable format. UCD processed the fields and returned automatically generated reports in the form of KML files.
- The service was maintained for the duration of the project.
- The summaries included a table of estimates of acreage burned on a per-field basis.

2013 and 2014 MODIS Burn Summary Maps We provided Burned Area Summary map for years 2011,2012, 2013, and 2014, for the regions originally proposed, as well as an extension to those regions based on additional field processing requests. These maps provide the basis for CARB to develop in-house processing of sugarcane burn requests.

- We delivered a number of maps showing all the MODIS derived burned area pixels, in a vector-based format. Each polygon corresponds to a MODIS pixel, and includes a summary of the day(s) of year the burn occurred.

Evaluation Support UC Davis supported a number of expanded evaluation of the generated results. In particular, to support CARB's burned area claims, UC Davis compared MODIS derived product to similar products derived from higher resolution imagery, most notably Landsat 7 and Landsat 8. UC Davis provided evaluation as requested.
UC Davis provided three extended evaluation support reports.

- Destilaria Alcidia
- Jalles Machado

- Monta Alegre

These were supplied to CARB for the purposes of validating CARB's original Burn summary evaluations. They included higher resolution imagery and value added products to support or moderate CARB's original MODIS based assessment, and a description of the processes used

Cloud-based Processing Evaluation UC Davis investigated a cloud-based (Google Earth Engine) evaluation methods of burned area detection. This solution would eliminate the current requirement of locally processing satellite data, which is a potential burden for continued efforts by CARB. Additionally, the procedure began the process of updating the methodology for new satellite source data, Landsat 8. Additional information is available in the Landsat Processing section.

- UC Davis investigated Earth Engine as a potential platform for sugar-cane burning detection.
- UC Davis developed an initial processing methodology using Landsat 8 imagery in burned area detections.
- UC Davis developed a number of scripts to automate the processing of new field investigations.

Automated Report Generation

UC Davis was asked to process 34 separate farm applications. The majority of these in the São Paulo State of Brazil, but also other states, and one request for Costa Rica. In total there were about 135,000 individual fields included in the processing. Table 1 includes an overview of the processing included.

Table 1: Processing Overview

Identifier	**Country**	**State**	**Number Fields**
adecoagro_monte_alegre	BRA	Minas Gerais	265
alta_mogiana	BRA	São Paulo	1389
alto_alegre_junqueira	BRA	Paraná	6116
biosev_lem	BRA	São Paulo	2926
biosev_sel	BRA	São Paulo	5061
biosev_umb	BRA	São Paulo	2663
biosev_vro	BRA	Minas Gerais	5
biosev_vro	BRA	São Paulo	7558
bunge_frutal	BRA	Mato Grosso do Sul	207
bunge_frutal	BRA	Minas Gerais	1970
bunge_ouroeste	BRA	São Paulo	5821
cargill_mosaico	BRA	Minas Gerais	119
cargill_mosaico	BRA	São Paulo	2968
catsa_costa_rica	CRI	Guanacaste	1467
conquista_do_pontal	BRA	São Paulo	241

copersucar	BRA	Minas Gerais	4804
copersucar_cerradao	BRA	Minas Gerais	4146
destilaria_alcidia	BRA	São Paulo	88
itb	BRA	Goiás	2958
itt	BRA	Minas Gerais	5348
jalles_machado	BRA	Goiás	518
meridiano	BRA	São Paulo	3145
noble_meridiano	BRA	São Paulo	3145
noble_potireendaba	BRA	São Paulo	3524
odebrecht_alto_taquari	BRA	Mato Grosso	70
parceria	BRA	São Paulo	2141
propia	BRA	São Paulo	782
raizen_costapinto	BRA	São Paulo	224
renuka	BRA	São Paulo	23848
santa_candida	BRA	São Paulo	3907
sao_joao	BRA	São Paulo	3201
sao_luiz	BRA	São Paulo	9342
sao_martinho	BRA	São Paulo	4597
solazyme	BRA	Minas Gerais	522
solazyme	BRA	São Paulo	8217
usm	BRA	São Paulo	4652
usmshp	BRA	São Paulo	4597
vista_alegre	BRA	Mato Grosso do Sul	2321

Table 2 shows the two countries, and the States involved in processing. São Paulo showed most requests, but five other states had some processing requests.

Table 2: Countries and States included in sugarcane field processing.

Country	**State**	**Fields**
BRA	Goiás	3476
BRA	Mato Grosso	70

BRA	Mato Grosso do Sul	2528
BRA	Minas Gerais	17179
BRA	Paraná	6116
BRA	São Paulo	104037
CRI	Guanacaste	1467

These included 4 separate MODIS tiles that were included in the processing. The MODIS tile extents, country and State boundaries, and boundaries of the individual processing requests are shown in Figures 3 and 4.

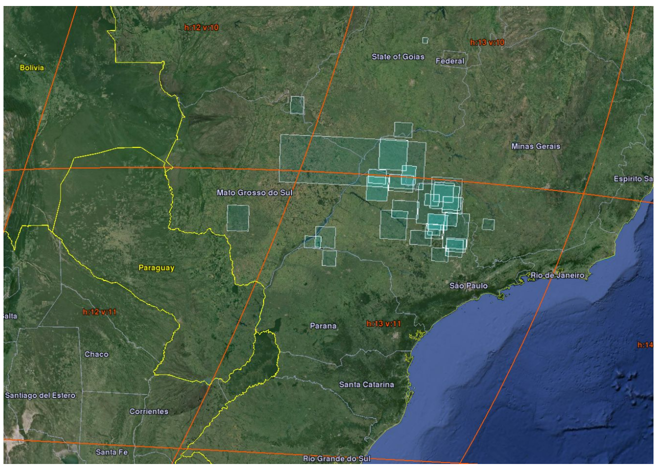


Figure 2: Brazil Processing Overview

Figure 3: Costa Rica Processing Overview

2013 and 2014 MODIS Burn Summary Maps

The burned area summary map for years 2011,2012, 2013, and 2014, provide the basis for CARB to develop in-house processing of sugarcane burn requests. These maps have been delivered on a state by state basis, and are divided by year. The data is available as KML files. A single shapefile containing all burned pixels for all regions is also included.

Since the project has compiled sugarcane burning maps over the years 2011-2014, it is possible to investigate some of the changes in burning practices over that time. We investigated the changes in burn practices for a number of states in Brazil, as well as Costa Rica.

Regional Changes

Table 2 Shows the changes in the total number of burned pixels for regions where sugarcane fields were processed. Note, that these do not necessarily cover the entire regions, but only those that overlapped the 5 MODIS tiles used for the overall processing steps. Still, they offer good insight into the changes over the last 4 years. The values are in terms of individual MODIS pixels, which are about 25 hectares in size.

Table 2. Changes in the number of burned pixels for 2011 through 2014.

Region	**2011**	**2012**	**2013**	**2014**

Goiás	56497	98822	20091	102923
CRI	471	1701	1914	1944
Mato Grosso	94046	196296	71184	121060
Mato Grosso do Sul	23449	67111	26282	10469
Minas Gerais	49844	45858	10771	42152
Paraná	3522	9464	5522	3831
São Paulo	20144	10155	5961	21716

These changes can be seen in Figure 5. There are a few items to note in these data. First, that while there had been a general decrease in burning, 2014 showed an increase in burning throughout most regions, particularly as compared to 2014.

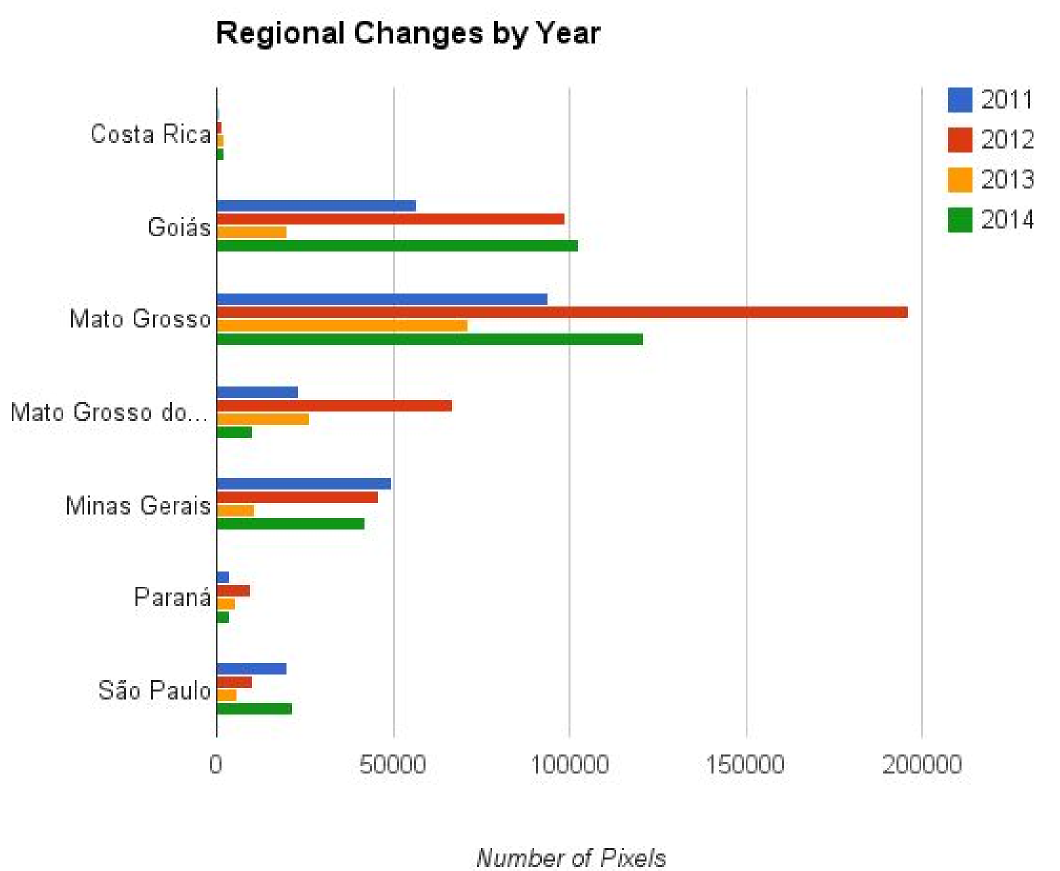


Figure 5. Changes in burning by year

Timing of Burning

We also looked at the average timing of the burning practices. These did not change dramatically from year to year. From region to region, Costa Rica shows a different schedule than Brazil, Table 3.

Table 3 Average Day of Burning by region

region	2011	2012	2013	2014
Costa Rica	91	80	71	74
Goiás	241	250	240	239
Mato Grosso	235	238	231	226
Mato Grosso do Sul	244	229	240	209
Minas Gerais	248	261	244	254
Paraná	232	237	209	135
São Paulo	231	234	230	233

Figures 6 and 7 show as an example the trends in the day of year (doy), burning for São Paulo and Costa Rica. These bell shaped curves are typical for most regions, and could be used to determine possible out of season burns that might be reconsidered in terms of the estimation of mechanization.

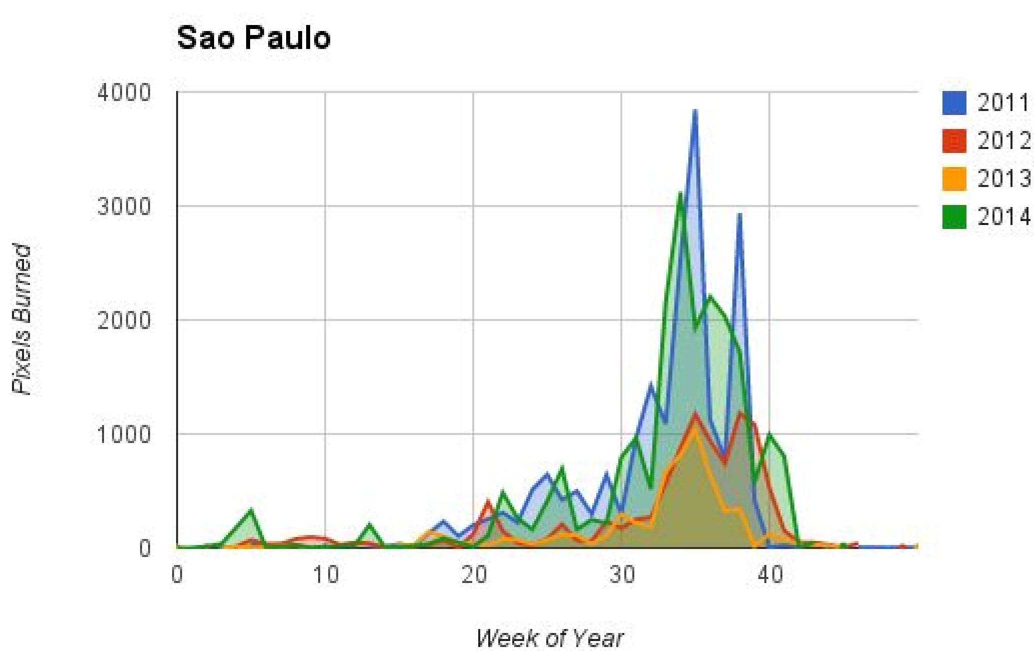


Figure 6. São Paulo Seasonal Burning

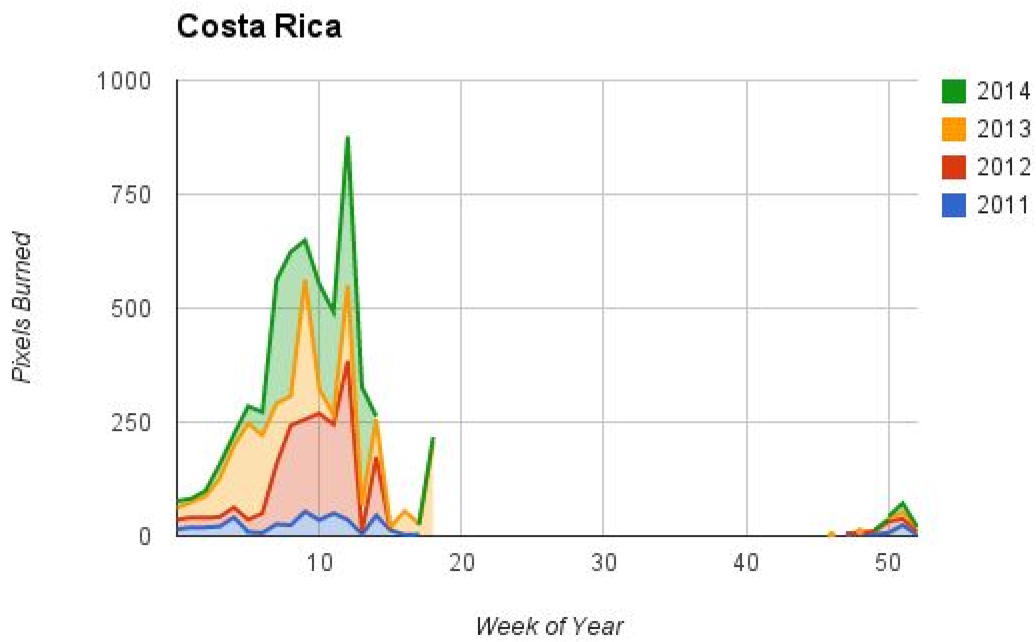


Figure 7. Costa Rica Seasonal Burning

A table of all weekly burns for all years is included in the provided summary spreadsheet.

Evaluation Support

UC Davis supported a number of expanded evaluation of the generated results. In particular, to support CARB's burned area claims, UC Davis compared MODIS derived product to similar products derived from higher resolution imagery, most notably Landsat 7 and Landsat 8. UC Davis provided evaluation as requested.

Destilaria Alcidia - January 23rd, 2014

The MODIS based Burned area detection algorithm is based on discovering changes in the spectral characteristics of the underlying pixels tuned to discover changes related to the addition of charcoal and ash, and the removal of vegetation. The MODIS based dataset is used primarily for it's ease of use in determining burned areas, as the time of the burn is included in the results.
The MODIS based algorithm identified burning in late September and early October, as shown in Table 4.

Table 4: Reported Burning

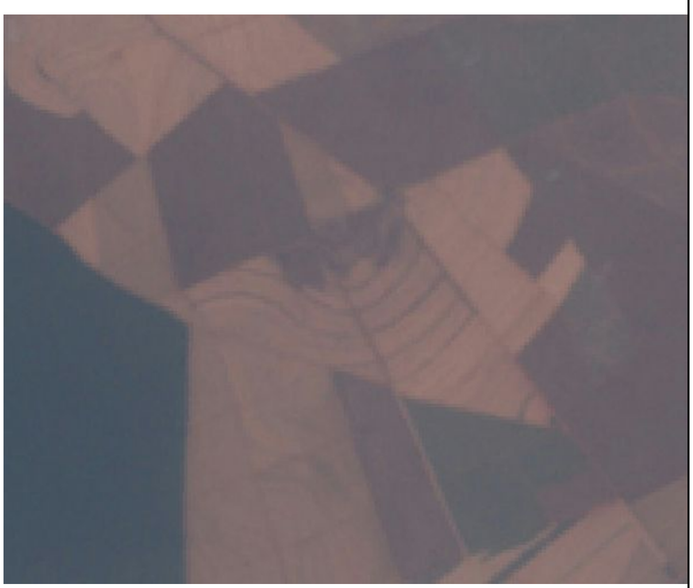
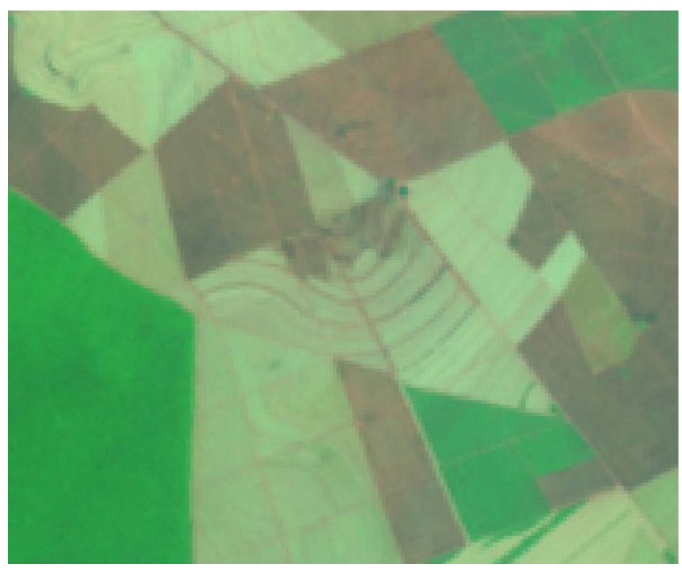
Farm	Burn Julian Days	Burn Dates	Reported Rebuilding
110001	270	Sep 26, 2013	
110007	267,275	Sep 23,2013	September
110013	281	Oct 8,2013	

110025	267,268,272,275	Sep 23,24,29, Oct 2	July
110039	275,280,282,289	Oct 2, 6, 8, 15	Oct / November

The investigation below looks primarily at fields 110007,110025 and 110039 The fields identified as being mis-characterized with respect to plantation rebuilding. Field 110136 was shown to burn at an earlier date, Mar 11 2012.

Landsat imagery, when looked at temporally, can provide similar insights at a finer scale, but a coarser temporal resolution. The following set of images describe the changes in the fields, and their classification. The red pixels indicate the locations of the MODIS pixels that were used as the determining locations of burning. The images are at coarser time scales because of the most infrequent visitation of the Landsat Satellite, as well a few cloudy days in the time period of interest. For Landsat imagery, a false color image, using band 7 (SWIR) as red, can indicate (with reddish or purplish colors) and increase in the reflectance in the SWIR as related to the NIR (band 4) and red (Band 3). This increase is a typical signal for added charcoal and ash. In a similar way, the Burned Area Index (BAI) is a red and NIR index which compares a surface to the spectral signature of charcoal. In BAI imagery, high values indicate a strong correlation to charcoal.

The imagery shows a typical pattern for the the fields of interest. High greenness in August, defoliation in late August, possibly due to harvesting, and then a later increase in BAI, in September and October. This could be related to bare soil alone, or burning, or burning followed by clearing of the land.
The farms 1110025 and 110007 show an interesting pattern for the Landsat overflight of Sept 19th, 2012. This particular date captures the transition from the non-burned to burned identification. The pattern seems to start from the North of the fields in an irregular pattern.

	
RGB Image	False Color 743 Image

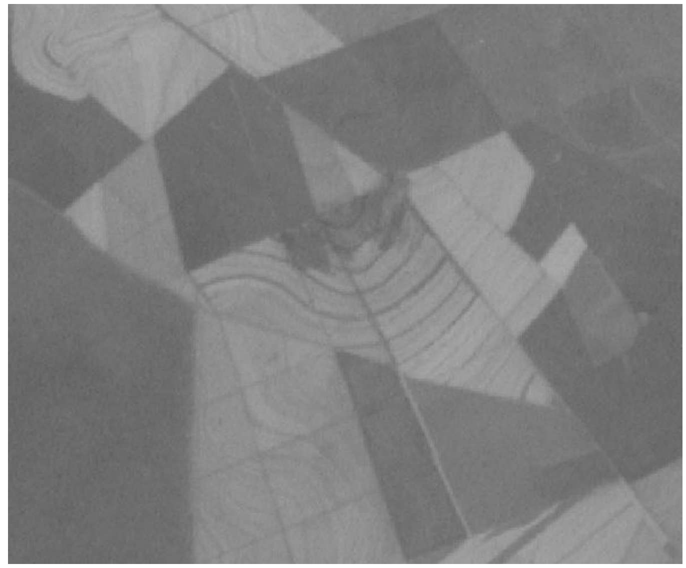
<table>
<tr><td></td><td></td></tr>
<tr><td>BAI</td><td>Panchromatic</td></tr>
</table>

Figure 8. showing a more detailed image for farms 110025 and 110007, for Sept 19, 2012. The images indicate irregularly high BAI in the Northern part of the fields. This anomaly is visible in the BAI, RGB, False color (743), and Panchromatic images.

Adedcoagro Monte Alegre - 2014-09-02

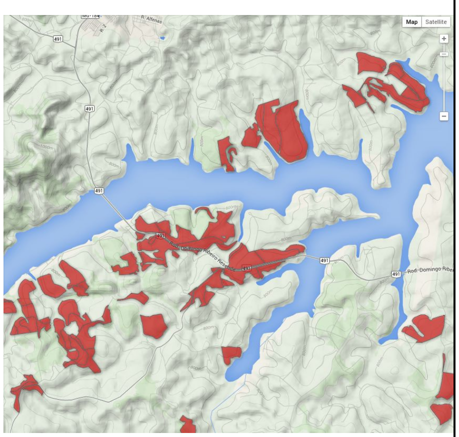
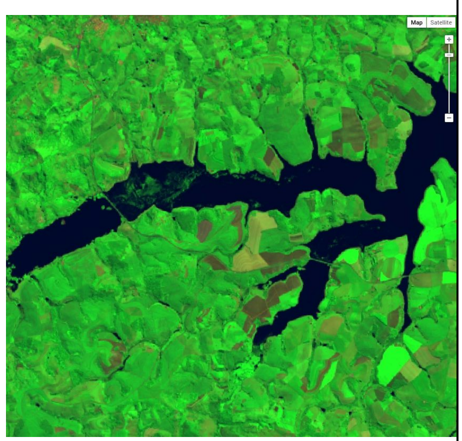
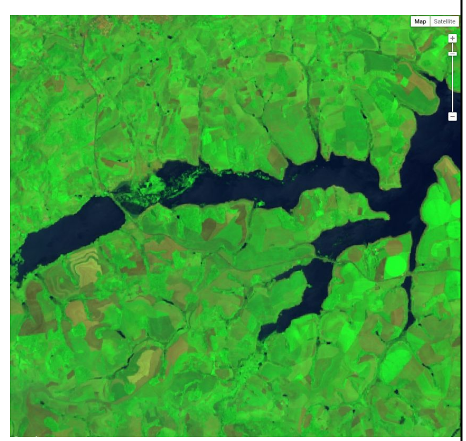
For some farm regions, the MODIS (MCD45A1) Based Burned area detection, underpredicts the reported burning for the Aldecoagro Monte Alegre farms, for 2013. We investigate a Landsat approach, and look to the process of automating a Landsat based approach for this. For this example, we look at all the Landsat 8 imagery for the region (Landsat 8 commenced in April, but probably captures most of the burning for this region). As a quick test, we will compare the Normalized Burn Ratio for two dates, before and after the harvesting season. We calculate the Delta NBR between the dates, and Threshold these into the classes as defined above.

Table 5. Landsat 8-day image availability

Landsat 8-day TOA Composite	**Cloudy**	**Use**
Apr 23, 2013 - May 1, 2013	No	Start
May 9, 2013 - May 17, 2013	No	
May 25, 2013 - Jun 2, 2013	Very	
Jun 10, 2013 - Jun 18, 2013	No	
Jun 26, 2013 - Jul 4, 2013	Very	
Jul 12, 2013 - Jul 20, 2013	No	

Jul 28, 2013 - Aug 5, 2013	No	
Aug 13, 2013 - Aug 21, 2013	Very	
Aug 29, 2013 - Sep 6, 2013	No	
Sep 14, 2013 - Sep 22, 2013	Yes	
Sep 30, 2013 - Oct 8, 2013	Yes	
Oct 16, 2013 - Oct 24, 2013	Partly	
Nov 1, 2013 - Nov 9, 2013	Yes	
Nov 17, 2013 - Nov 25, 2013	No	End
Dec 3, 2013 - Dec 11, 2013	Partly (Scattered)	
Dec 19, 2013 - Dec 27, 2013	Yes	
Jan 1, 2014 - Jan 9, 2014	Partly (Scattered)	

Figure 9 shows the comparison of the before and after burned regions for part of the Monte Alegre farms. This area was chosen as it has the highest variation in the DeltaNBR, and shows fields that are both being harvested and fields that are growing back in 2013.

Overview and Delta NBR	2013-04-23	2013-11-17
		

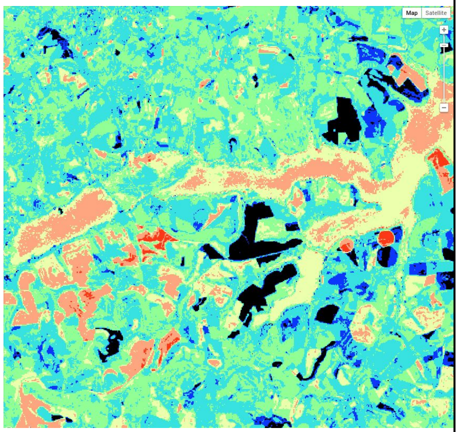
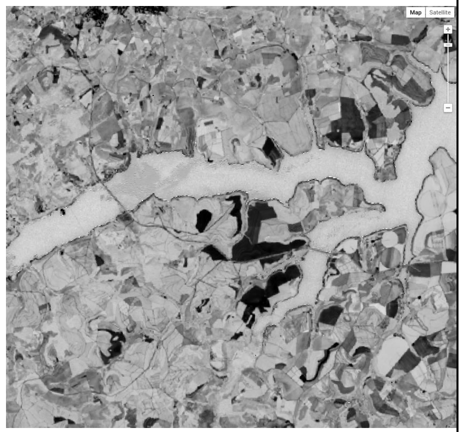
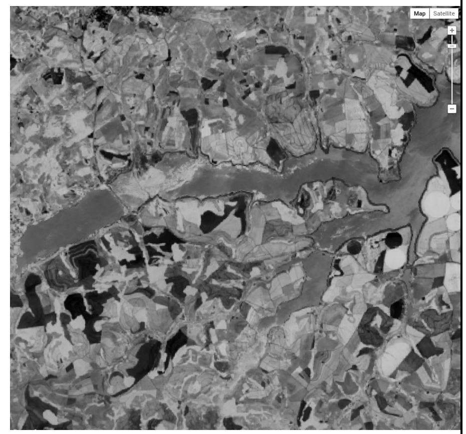
		

Figure 9. Burned regions around Monte Alegre farms

A comparison with the MODIS MCD45A Burned area product does not show a strong correlation with areas with High Delta NBR. This is unexpected, as the MCD45A product also uses a comparison of NIR and SWIR bands as it's method of discerning burned areas. The region above doesn't contain and MODIS burned pixels, the example below compares the MCD45A MODIS burned pixels with the Delta NBR for close region. Only a small subset of the High Delta NBR areas are included, and the MCD45A product also identifies areas for which the delta NBR is low, (Eg. in the lower left of the image.)

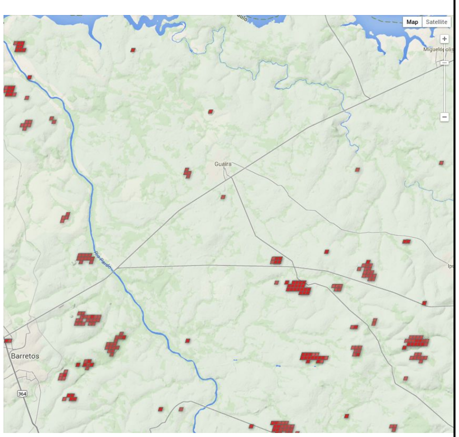
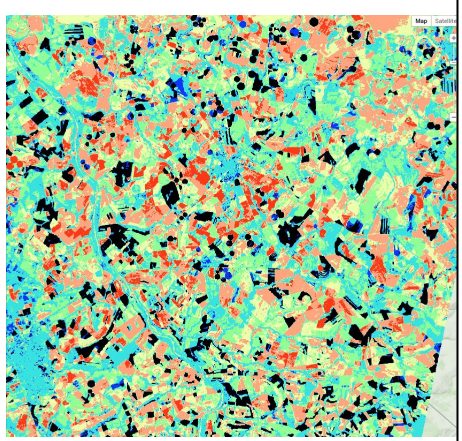
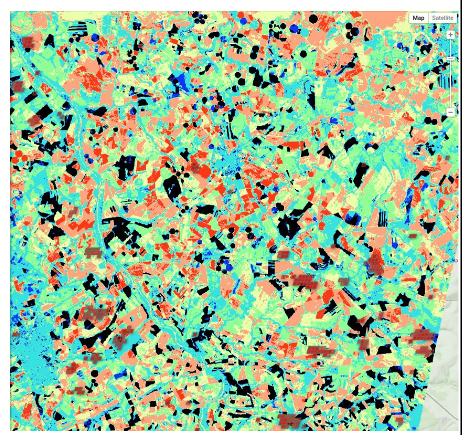
Fields	**Burns**	**Composite**
		

Figure 10. MCD45A1 Comparison to Landsat derived Delta NBR.

The before burning data is Jun18th, and the Post date is July 4th. Although we see a difference in the brightness of the fields post harvest, the normalized versions do not show much difference. This seems to indicate that we are not seeing the difference between a harvested and burned field. If we jump to September 6th, we see the color of the fields become similar. I think what are seeing in this case is maybe a defoliant (or lack of water) in June prior to Harvest.

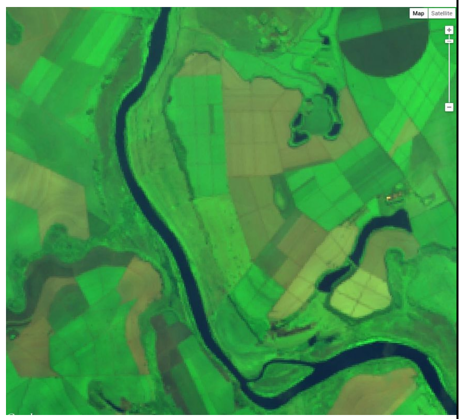
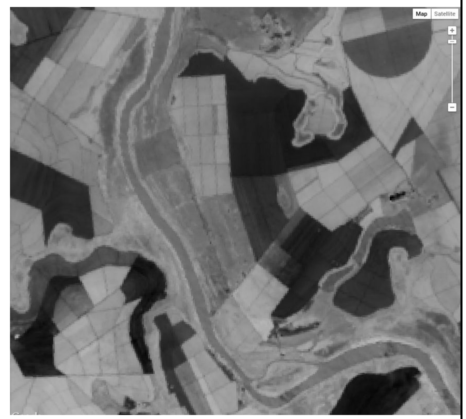
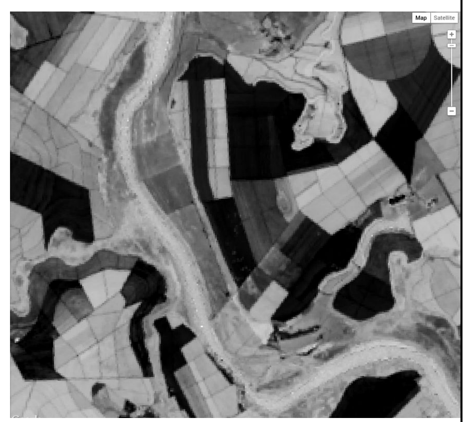
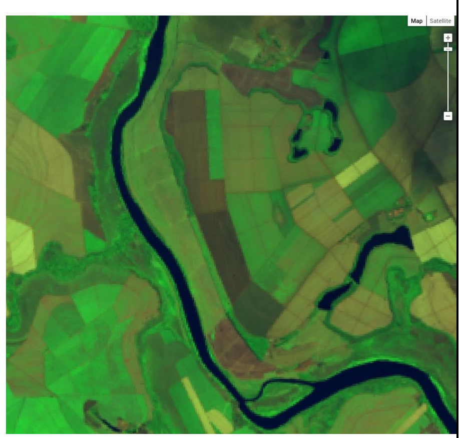
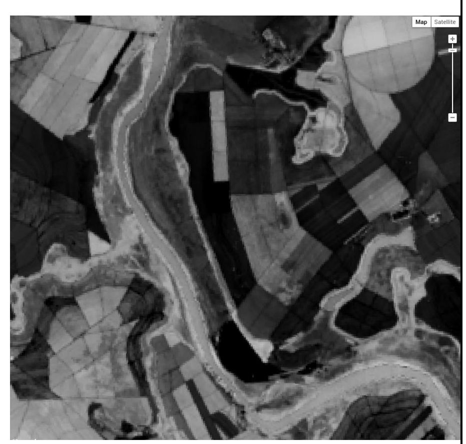
True Color (432)	False Color (752)	NBR
		
		
		

Figure 11. Example field temporal study

Jalles Machado 2015-03-05

UCD was asked to investigate the extent of particular sugarcane fields for Jalles Machado, as the MODIS evaluation potentially suggested burning outside of the designated fields.

Evaluation of the area apparently shows an uncontrolled fire to the north of the fields of interest. The fire is estimated at 10-15 sq km, through an area that is more hilly, with some native vegetation. That fire occurred at approximately the same time as some of the fields identified as burned also burned.

The following request was submitted to UCD.

With regards to the Jalles Machado evaluation, and the burn pixels detected during August 2014 (see screenshot below), is it possible to obtain historic imagery for the same pixels (pre-2013)? John Courtis is interested in the history, because it appears that the Company may be engaged in land clearing for cultivation / expansion. Else, it could be sugarcane straw / litter burn at the edge of the fields. In any case, the Company claims that it was an accidental event with the fire spreading to their Cristalina farms for which a police complaint was filed by a motorist travelling near the farms. We want to make sure there is no history to their claim.

Figure 12 shows an overview of some of the burned fields, and the MODIS pixels shown as being burned.

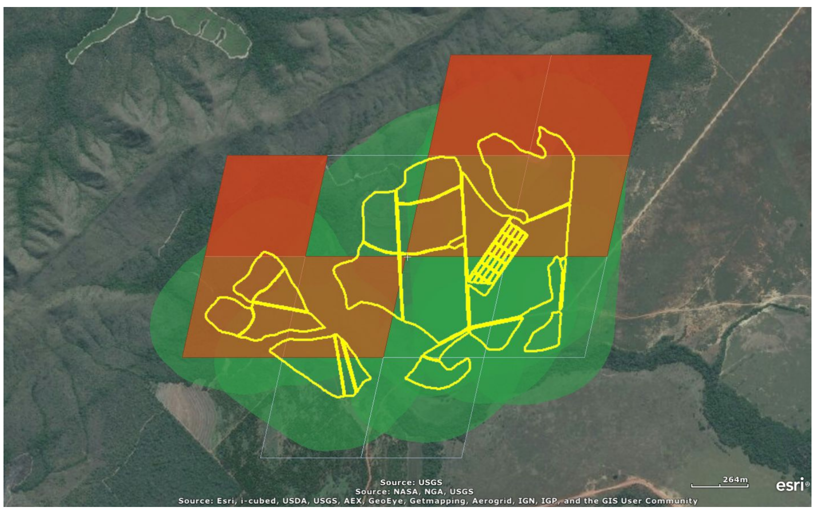
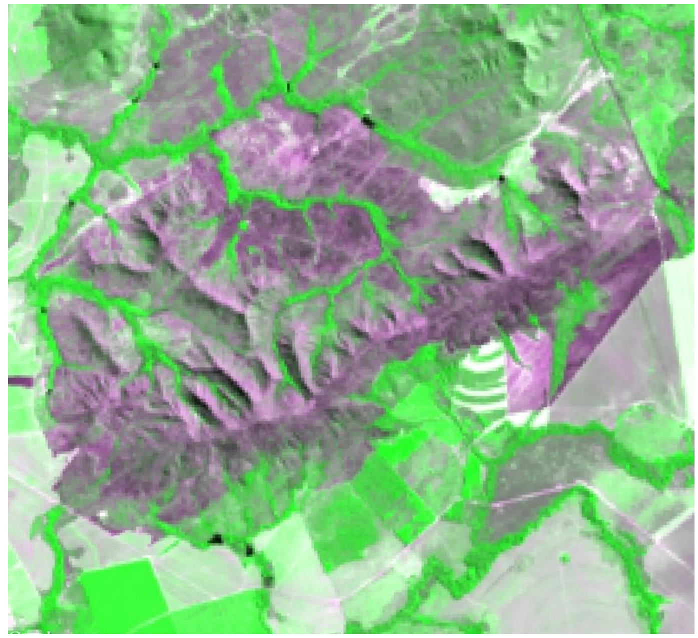


Figure 12: Overview of Jalles Machado Burns of interest.

Figure 13. Location of Fields

Landsat 8 imagery was used to investigate the area before and after the detected burn. Figure 13. Shows the fields of interest with a false color Landsat image right before the burn.

Figures 14 and 15 show the same image, without the superimposed fields, for the time before and after the fire. This false color image uses (SWIR) for red, (NIR) for green, and (RED) for blue. In this configuration, vegetation appears green, soil brown, and burned area dark and purplish. Examination of these images already give a good indication of the fire that occurred and it's extent.

	
Figure 14. Prefire false Color image	Figure 15. Postfire false Color image

Figures 16 and 17 show the normalized burn index (NBI) for the same region and the same times. NBI is a normalized relationship between the SWIR and the NIR Landsat bands. This relationship shows areas that are likely to have been burned. Typically, the index is composed to show fire scars as dark.

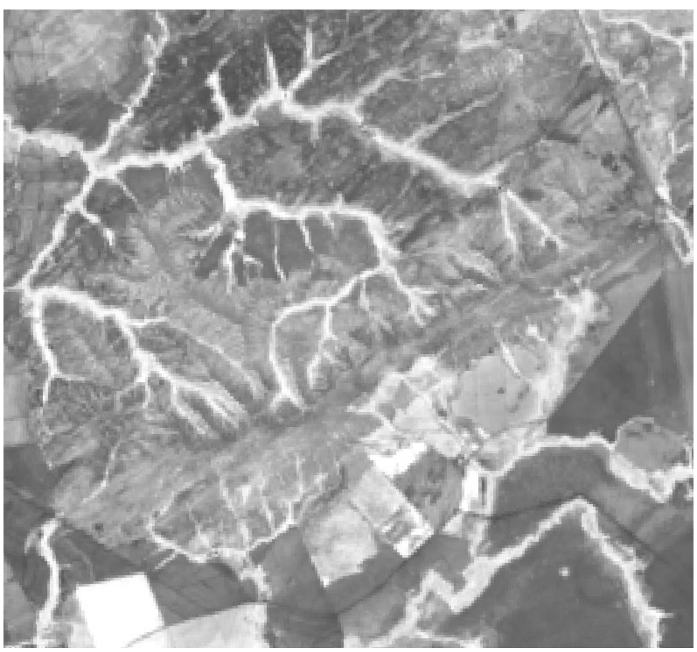
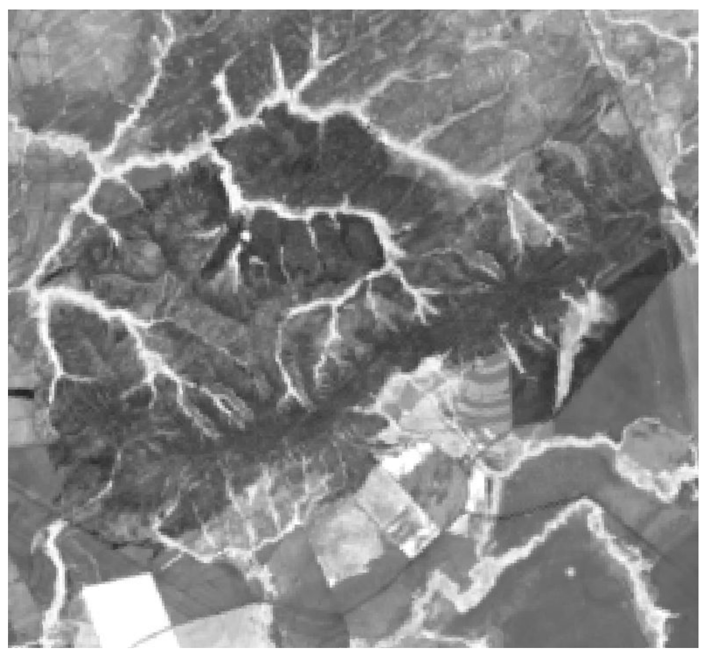
	

Figure 16. Prefire NBI	Figure 17. Postfire NBI

Finally, Figures 19 and 19 show the difference between these NBI values. The darker area for the fire is not an indication of a more severe burn necessarily, as the area started out greener, with a higher NBI.

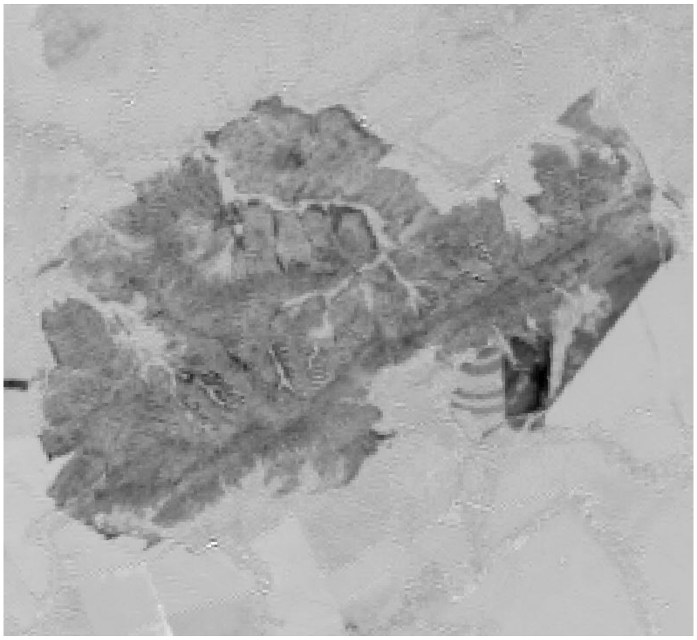
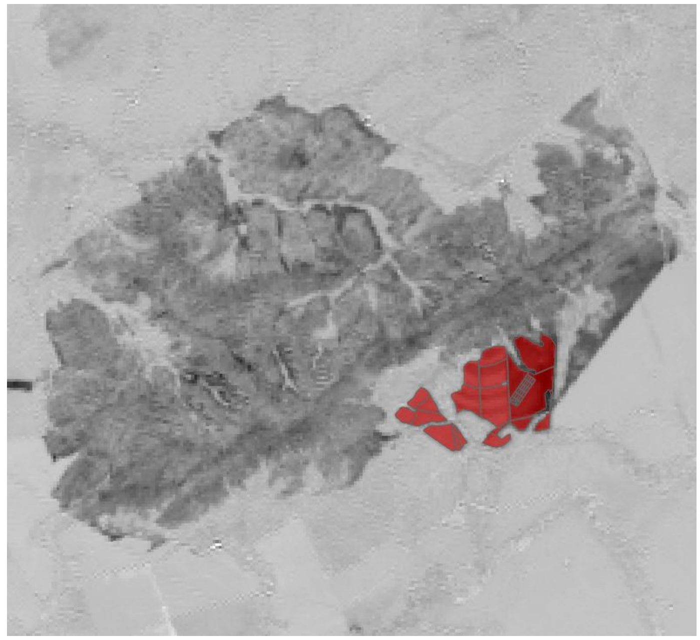
	

Figure 18. NBI Difference	Figure 19. NBI Difference with fields

Landsat based Burn detection (Cloud-based Processing Evaluation)

Using the cloud based processing scripts, we are able to run some example Landsat processing for some of the previously examined field sets, for the purposes of comparing the MCD45A1 based methodology to the Landsat based version. Two of the latest processed field sets were investigated, one in Costa Rica, and one in Brazil.

Costa Rica Processing Example

The first example shows a Landsat based vs MODIS processing example for sugar cane fields in Costa Rica for 2014. These fields -- *catsa_costa_rica* -- were investigated in 2014-08-29 for MODIS based burn detection. The figures below compare the MODIS burn product for 2014 to a landsat product. Figure 22 shows an overview of a swath of Costa Rica, with a large number of sugar cane fields in the center of the image. MODIS derived burned pixels for 2014 are shown in red.

Figure 22. Costa Rica, 2014. Fields are green. MODIS burned pixels are red.

Figure 23 shows the Maximum BARC for the same region. One thing to note, is that the BARC is affected by any harvesting, as shown in the bright regions of the sugar cane fields. The absolute scale of the BARC does not detect fires in the natural regions as detected by the MCD45A1 algorithm.

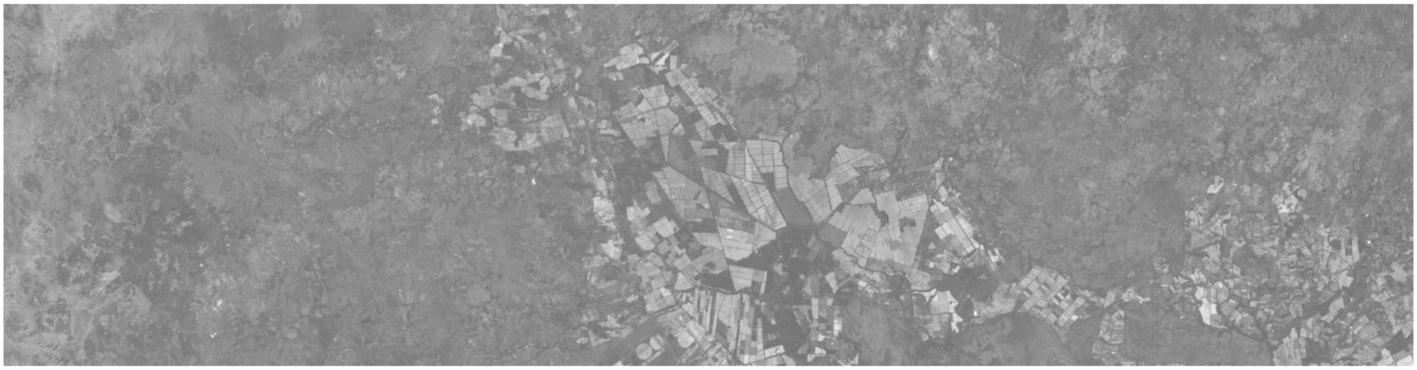


Figure 23. Costa Rica, 2014. Burned Area Reflectance Classification. Bright areas are burned.

Figure 24 shows a closeup of the center of the region of Figure 22. The two methods for determining burned sugarcane fields. The middle image shows the MCD45A1 pixels, while the right hand side shows fields determined as burned from the Landsat BARC.

First, while the images are similar, even in the sugar cane fields, there are differences in what fields are identified as being burnt. While the MCD45A1 pixels cannot be modified, it would be possible to mark many more BARC fields as burned, by modifying the threshold value (0.6) downwards.

It is possible to tell in both the MCD45A1 product, and the BARC product when burn occurred, and where both products overlap, the dates agree quite well generally.

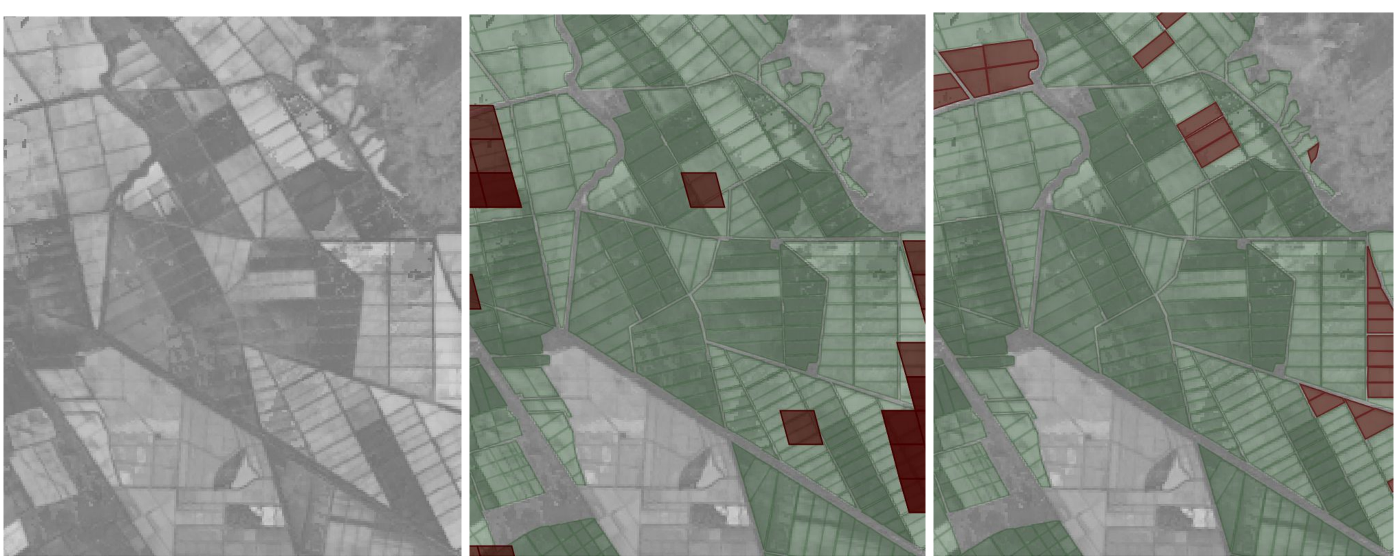


Figure 24. Costa Rica Farms, 2014. The left image shows the BARC for the region. The middle image shows the MCD45A1 detected burns, and the right image shows the fields identified as burned from the

Landsat BARC (80% percentile > 0.6).

Although the timescale for the BARC product is much coarser, with an overpass about every 28 days, with such smaller pixels, the product does give a better sense of the spatial distribution of the burns, over smaller fields.

Brazilian Processing Example

The Brazilian example shows a Landsat based vs MODIS processing example for fields -- *jalles_machado* -- that were investigated in 2014-01-29 for MODIS based burn detection. This particular field set was requested for additional evaluation support. Figure 25 shows a swath of the region of interest. The field set is mainly in the left hand side. Note that large amount of MCD45A1 detected burning outside the fields, but no detection within.

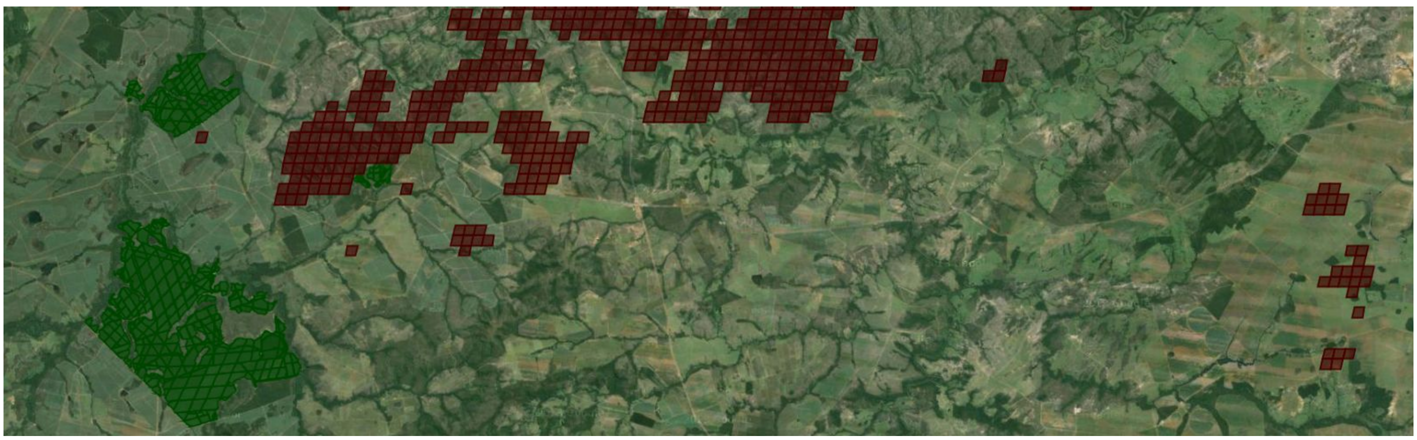


Figure 25. Jalles Machado, 2014. Fields are in green, MCD45A1 burned areas are in red

Figure 26 shows the maximum BARC over 2014. In this image it can be seen that while some variation of BARC is seen in the natural areas, the values are much higher for fields, even those mechanically harvested.

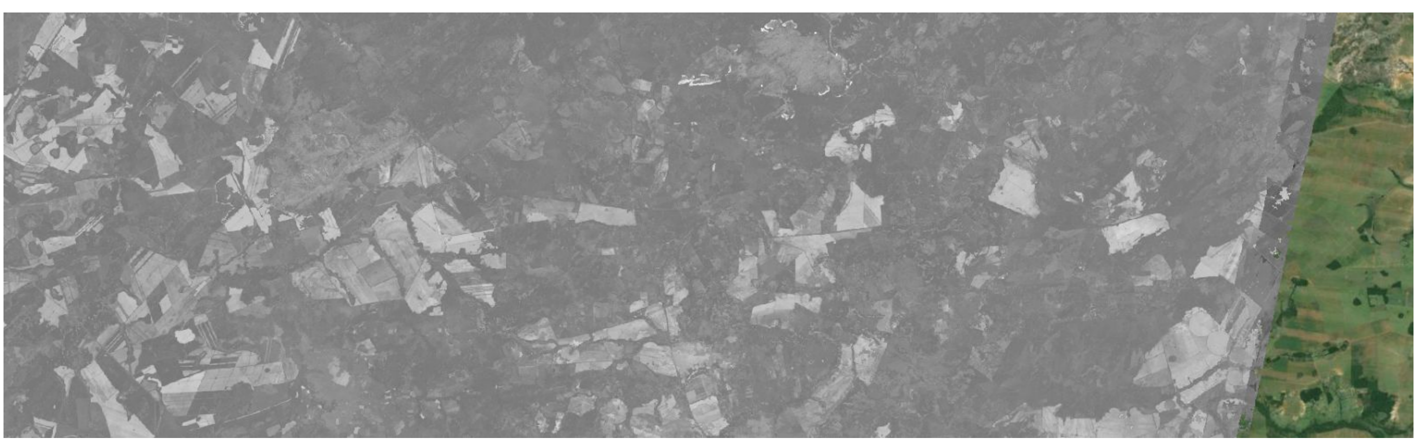


Figure 26. Jalles Machado, 2014. Burned Area Reflectance Classification. Bright areas are burned.

Figure 27 shows the BARC based processing for a region around an uncontrolled burn. This was the area investigated in the Evaluation Support section, for Jalles Machado. While the previous evaluation very clearly showed a fire scar using the BARC approach, (See Figure 18.) the left image in Figure 27, the maximum BARC is not as clear. This is because the maximum values can overshadow an individual change. In addition, the higher BARC values in the agricultural regions can mask the smaller changes in the natural vegetation. Note on the Right hand side, since only the fields are completely processed, the large uncontrolled burn is virtually undetectable.

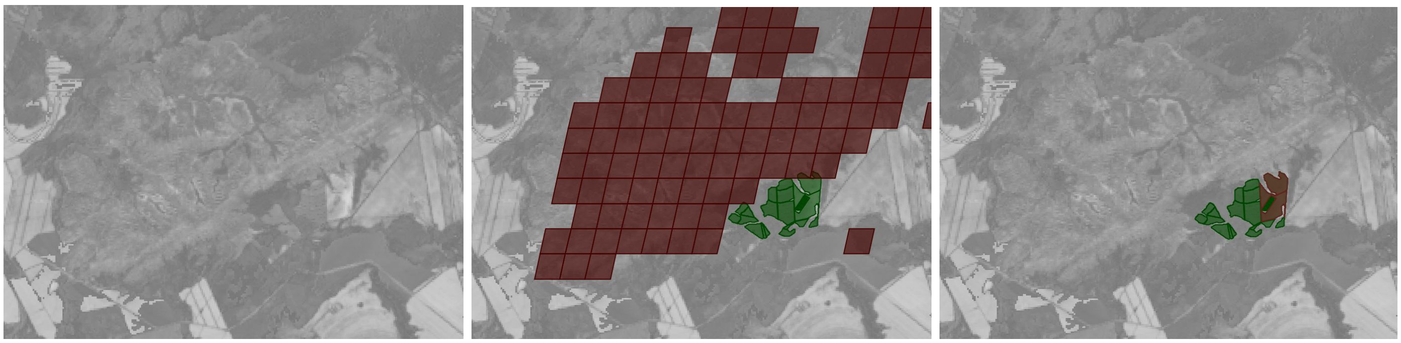


Figure 27. Jalles Machado, 2014. Close up of uncontrolled burn. (See **Evaluation Support)**

In contrast to this, Figure 28 shows a different close-up of the region, highlighting the sugar cane fields. The left hand side shows the BARC values for the region, while the right hand side shows, in this case both the MCD45A1 and the BARC burn detections. Both can be shown in this case because there is very little overlap between the products. While the MCD45A1 highlights the natural burning, the BARC picks up some fields that show unusually high BARC values. As discussed previously, a change in the threshold could add more or less fields into the burned category. This case is interesting in the fact that the MCD45A1 product underpredicted the reported burned field amounts for this particular producer.

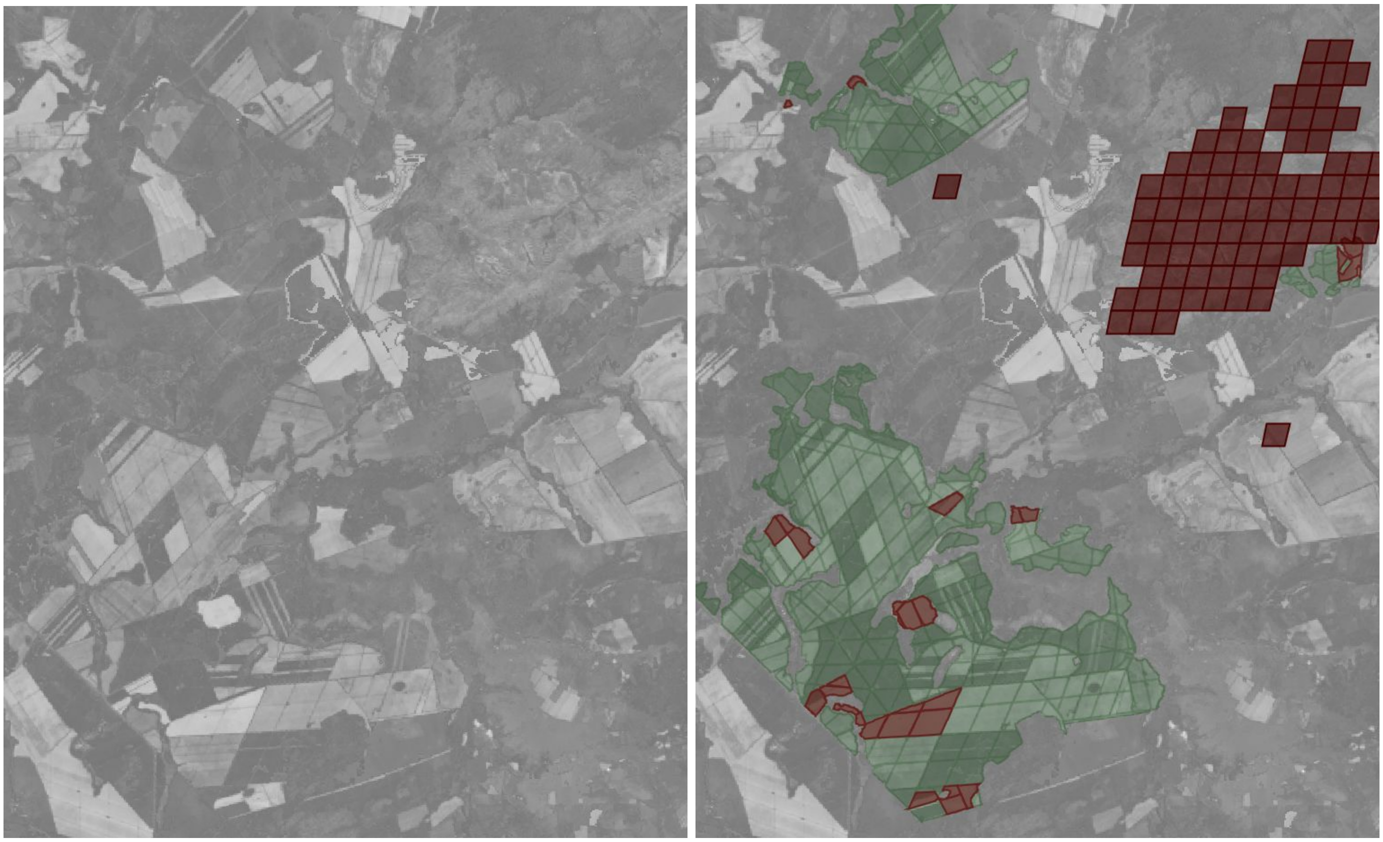


Figure 28. Jalles Machado, 2014. Close up of fields.

Conclusions

The MODIS MCD45A1 product provided, timely, relatively straight-forward support for the burn detection requirements for ARB Staff. This relatively simple product performed quite well for most of the 34 evaluation studies. In addition, the fact that the product was derived from a long standing, well tested data product, MCD45A1 allowed for a very defensible case on the burn detections. For the more detailed evaluations where the producers did request further study, the initial evaluations held up quite well.

The fact that the automated report generation tool used a KML format for the data delivery provided an important component in that no additional GIS expertise was required for evaluating the results. These KML files could also be shared among CARB staff and the producers easily.

All of the code has been made available for the continuation of this processing. However there are few issues that made the development of a completely automated system unreasonable. First was the maintenance of the locally GIS database of the MCD45A1 product. While the scripts for periodically updating this database worked most of the time, bad directory structures, or delivered files, prevented this from being a full-proof solution. Unsurprisingly, GIS expertise was required for quality control of this dataset.

In addition, difficulties in ethanol producers being able to provide a standard input format, required that the initial data formulation step could not be automated as the data received from the producers varied substantially. Again, expertise in the processing was required. Finally, any additional questions on particular results from the producers also required a deep understanding of the data products and the remote sensing applications.

The MCD45A1 burned areas is also a MODIS product, and MODIS has a limited, although unknown lifespan. Moving forward, the satellite VIIRS will be the operational replacement for the MODIS instrument, but to date, there is no replacement for the burned area product. This makes VIIRS unsuitable until such a product is made available. There are proposals for that product.

Moving from a locally maintained image processing environment to a cloud based solution, in particular, based on Google's Earth Engine, in the evaluation of a Landsat-8 based processing algorithm, proved to be an encouraging exercise. A relatively sophisticated processing algorithm for burn detection was created, with far less programming, and no required infrastructure. Only about 300 total lines of code were required. This is a promising methodology to pursue.

However, there are issues here as well. Any production system needs to develop a more robust detection algorithm, and one that needs to be compared to products like the MCD45A1. Since this would not be a standard science product, this is an important step.

In addition, there still is a requirement of specialized image processing knowledge in that algorithm development, and possibly in the actual running of the process, certainly in support of any additional reporting as requested by the producer. Finally, ARB would need to develop a relationship with Google and become a trusted tester on their Earth Engine system to use the methods developed here.