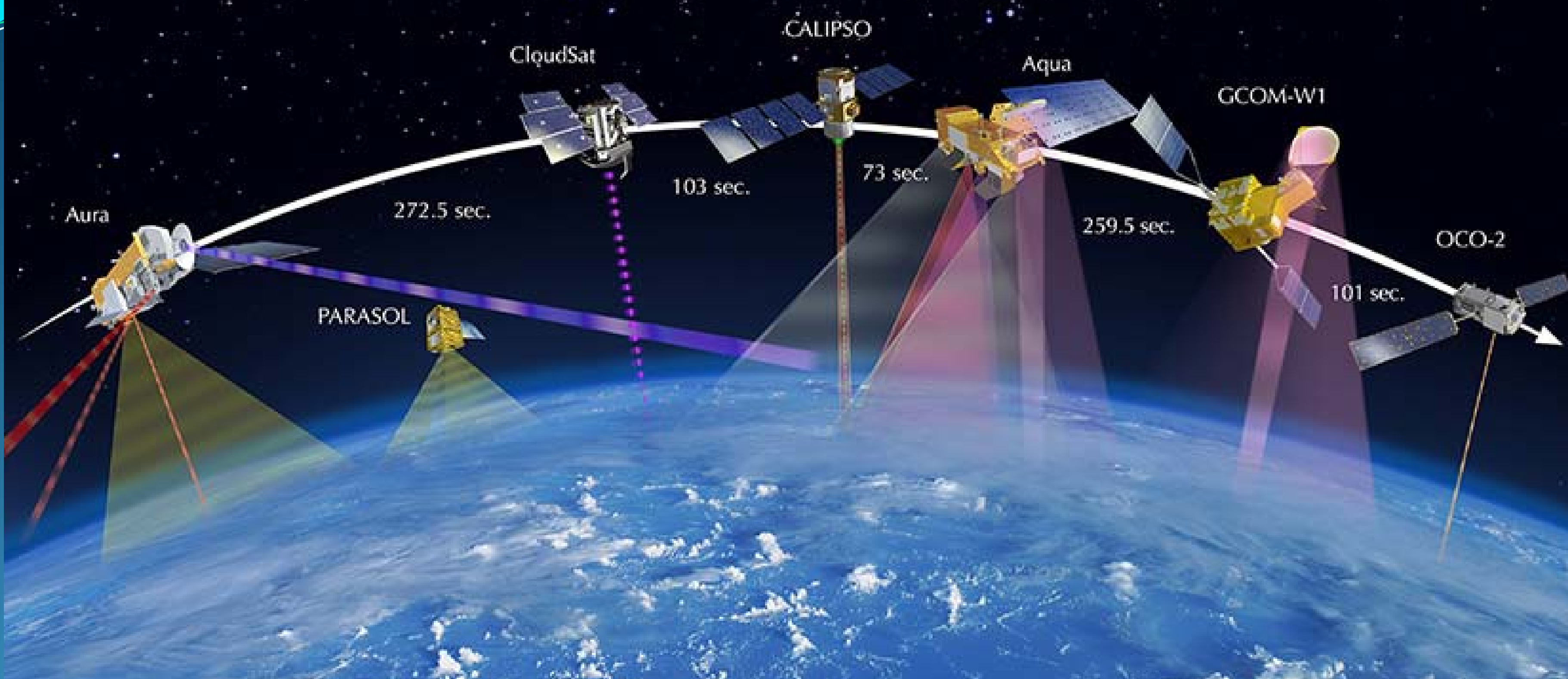
MET 611 – Satellite Data Applications



MODIS Fire and Burned Area

Jennifer D. S. Griswold

Level 2 Fire Products: MOD14 (Terra) and MYD14 (Aqua)

- This is the most basic fire product in which active fires and other thermal anomalies, such as volcanoes, are identified.
- The Level 2 product is defined in the MODIS orbit geometry covering an area of approximately 2340 × 2030 km in the along-scan and along-track directions, respectively.
- It is used to generate all of the higher-level fire products, and contains the following components:

Level 2 Product

- An active fire mask that flags fires and other relevant pixels (e.g. cloud)

- A pixel-level quality assurance (QA) image that includes 19 bits of QA information about each pixel

- A fire-pixel table which provides 19 separate pieces of radiometric and internal-algorithm information about each fire pixel detected within a granule

- Extensive mandatory and product-specific metadata

- A grid-related data layer to simplify production of the Climate Modeling Grid (CMG) fire product (later)

Level 2 MOD14 Input

- MOD021KM
  - Bands 1,2,7,21,22,31,32
- MOD03
- Based upon the Temperature Sensitivity difference between 4 and 11 microns
- Contextual Fire Detection Algorithm
  - Infrared static Brightness Temperature thresholds
  - Dynamic thresholds compare pixel to surrounding background
- Variety of output product temporal and spatial resolutions

Level 2 Product

- Product-specific metadata within the Level 2 fire product includes the following, occurring within a granule to simplify identification of granules containing fire activity:

- fire_mask (8 bit unsigned integer)
  - 0 missing input data
  - 3 water
  - 4 cloud
  - 5 non-fire
  - 6 unknown
  - 7 fire (low confidence)
  - 8 fire (nominal confidence)
  - 9 fire (high confidence)

- Line and element of fire pixel
- Latitude and longitude of fire pixel
- Fire pixel confidence (one value for each fire detected per scene)

Detection Confidence

- A detection confidence intended to help users gauge the quality of individual fire pixels is included in the Level 2 fire product.

- This confidence estimate, which ranges between 0% and 100%, is used to assign one of the three fire classes to all fire pixels within the fire mask:
  - low-confidence fire
  - nominal-confidence fire
  - high-confidence fire

Output Products

Product	Level	Temporal Resolution	Spatial Resolution
MOD14	2	5 minute granules	1 km
MOD14GD MOD14GN	2G	5 minute tiles	1 km
MOD14A1	3	Daily	1 km Sinusoidal Grid
MOD14A2	3	8 Day	1 km Sinusoidal Grid

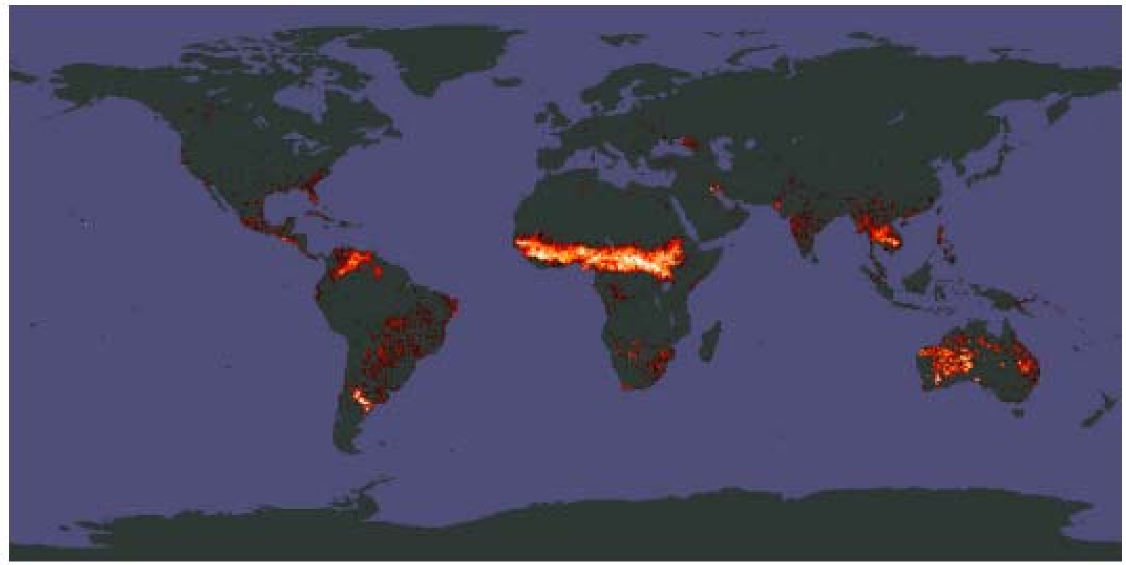
Global Daily Browse Product

Rapid Response Product ~ 4 hours behind real time

Goal: To provide rapid access to MODIS data globally

Climate Modeling Grid Fire Products (MOD14CMH, MYD14CMH, etc.)

- The CMG fire products are gridded statistical summaries of fire pixel information intended for use in regional and global modeling.

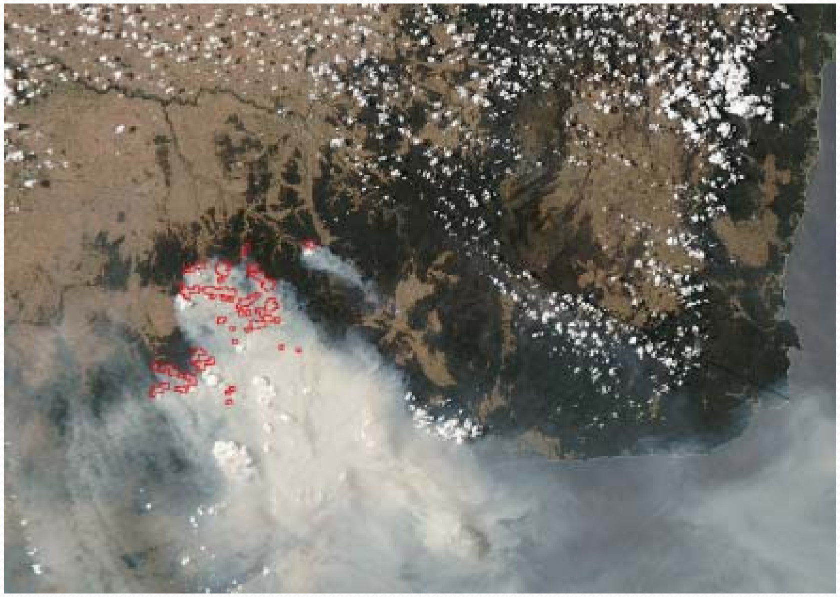


- The products are currently generated at 0.5° spatial resolution for time periods of one calendar month (MOD14CMH and MYD14CMH) and eight days (MOD14C8H and MYD14C8H).
- Higher resolution 0.25° CMG fire products will eventually be produced as well. An example of the corrected fire pixel count layer of the product is shown above.

Global Monthly Fire Location Product (MCD14ML)

- For some applications it is necessary to have the geographic coordinates of individual fire pixels.

- Collection 5 includes the global monthly fire location product (MCD14ML), which contains this information for all Terra and Aqua MODIS fire pixels in a single monthly ASCII file.



Algorithm Description

- **MODIS bands 21 and 22 (3.99 micron)**
  - Band 22 saturates at 331 K
  - Band 21 "fire channel" saturates at ~ 500 K
    - 12 bit range broader – less sensitive
    - The calibration of B21 uses fixed calibration coefficients and not using the scan-by-scan onboard black body

- **MODIS band 31 (11 micron)**
  - Saturates at ~ 400 K for Terra
  - Saturates at ~ 340 K for Aqua

- **Potential Fire Pixel identified**
  - BT4 > 310 K
  - BT4-11 > 10 K
  - .86 µm reflectance < .3

Screening Potential Fire Pixels

(1) $BT4 > 360$ K

Contextual Tests: Performed on as many as 21 x 21 box surrounding potential fire pixel to separate out from background

(2) $BT4-11 > \overline{BT4-11} + 3.5\partial_{BT4-11}$

(3) $BT4-11 > \overline{BT4-11} + 6K$

(4) $BT4 > \overline{BT4} + 3\partial_{BT4}$

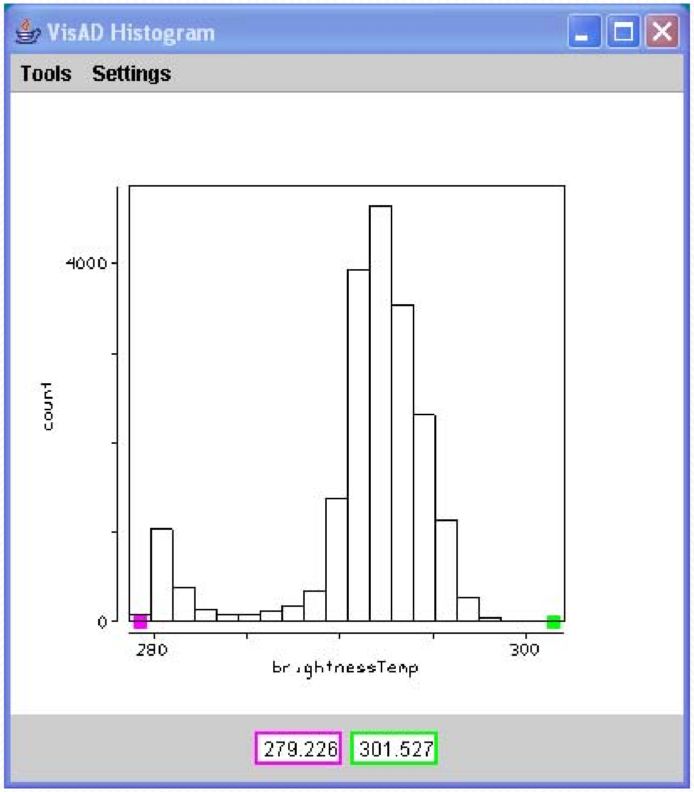
(5) $BT11 > \overline{BT11} + \partial_{BT11} - 4K$

(6) $\partial'_4 > 5K$

Algorithm Description (cont.)

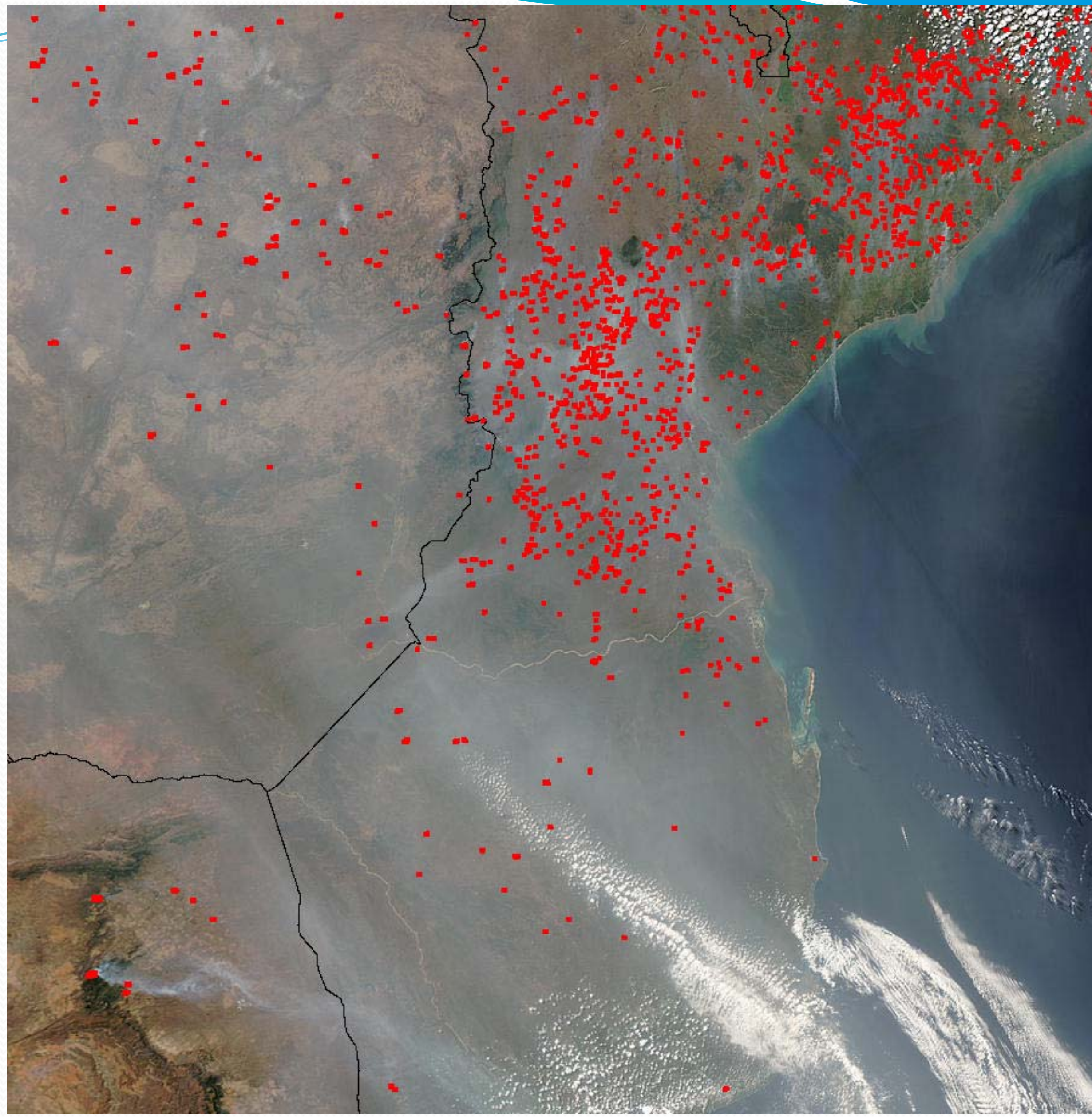
Aqua MODIS true color image 18 April 2003 12:45 UTC

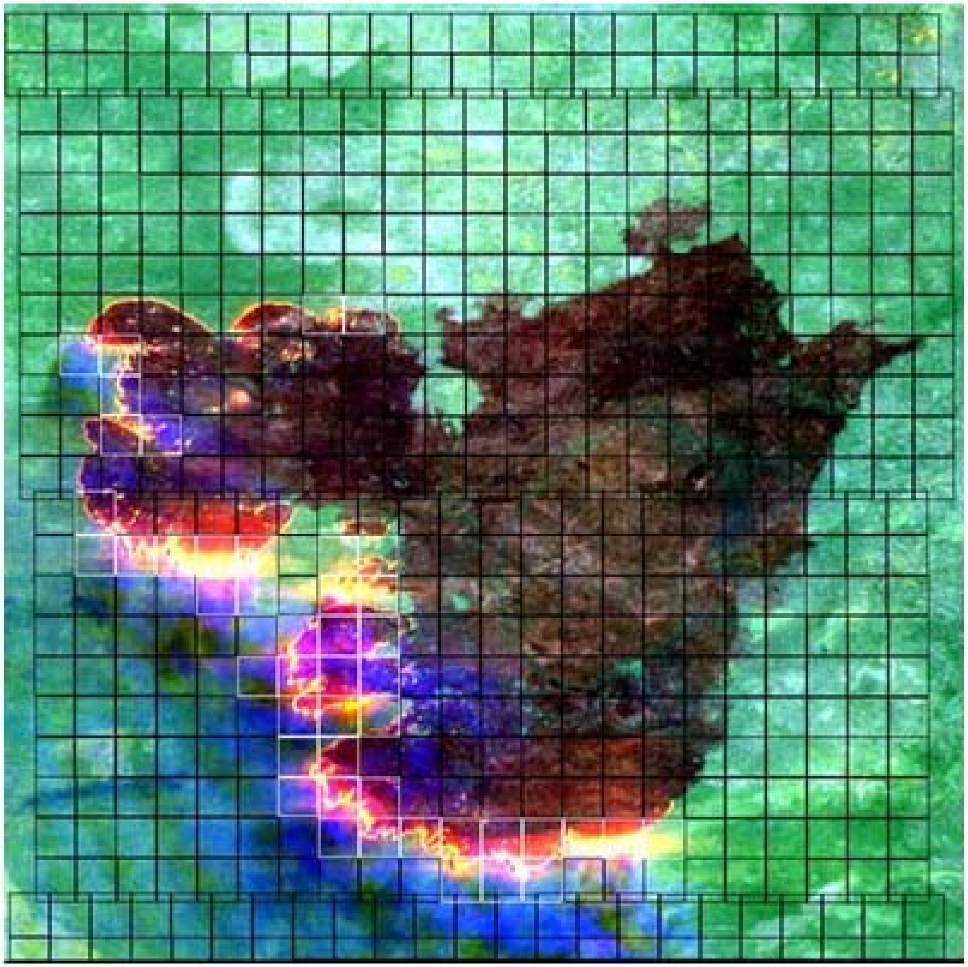
Algorithm Description (cont.)



Problem Areas

- **Lots of fires** – hard to get representative background temperature
- **Sunglint** – Affects 4 micron band radiance
- **Transition areas** – contextual tests pick up boundary
- **Coastal areas** – need really good geolocation so no mixed pixels are included
- **Clouds** – BT4-11 large over water and thick ice cloud





Red (2.4 µm; channel 9) - green (1.6 µm;, channel 4) - blue (0.5 µm; channel 1) false color ASTER image of a large fire complex from Aug 17 2001 9:08 UTC, centered at 18.8S 19.9 E. The gridded overlay denotes the nominal footprints of the MODIS pixels. The white cells are pixels flagged as fire by the MODIS version 3 algorithm.

Caveats and Known Problems

- **Fire Pixel Locations vs. Gridded Fire Product**
  - Use caution in using fire pixel locations in lieu of the 1-km gridded MODIS fire products.
    - The former includes no information about cloud cover or missing data and, depending on the sort of analysis that is being performed, it is sometimes possible to derive misleading (or even incorrect) results by not accounting for these other types of pixels.
    - It is also possible to grossly misuse fire pixel locations, even for regions and time periods in which cloud cover and missing observations are negligible.

Caveats and Known Problems

- **Some caveats to keep in mind when using MODIS fire pixel locations**:
  - The fire pixel location files allow users to temporally and spatially bin fire counts arbitrarily.
    - Severe temporal and spatial biases may arise in any MODIS fire time series analysis employing time intervals shorter than about eight days.
    - Known fires for which no entries occur in the fire-pixel location files are not necessarily missed by the detection algorithm.
    - Cloud obscuration, a lack of coverage, or a misclassification in the land/sea mask may instead be responsible, but with only the information provided in the fire location files this will be impossible to determine.

Known Problems

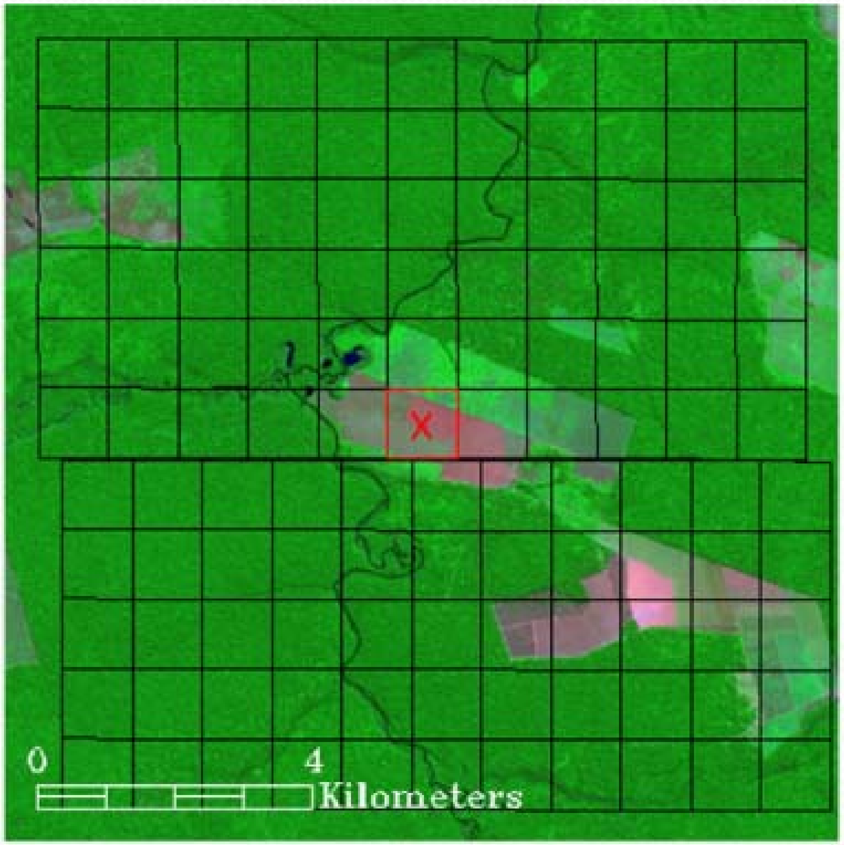
- **Pre-November 2000 Data Quality**
  - Prior to November 2000, the **Terra MODIS** instrument suffered from several hardware problems that adversely affected all of the MODIS fire products.
  - Some detectors were **rendered dead or otherwise unusable** in an effort to reduce unexpected crosstalk between many of the 500 m and 1 km bands.
  - The **dead detectors are known to introduce at least three specific artifacts** in the pre-November 2000 fire products:
    - striping
    - undetected small fires
    - undetected large fires.
  - In some very rare instances severe miscalibration of band-21 in the first weeks of the MODIS data archive (February and March 2000) will cause entire scan lines to be identified as fire.

Known Problems

- **Detection Confidence**
  - intended to help users gauge the quality of individual fire pixels is included in the Level 2 fire product.
    - This confidence estimate, which ranges between 0% and 100%, is used to assign one of the three fire classes to all fire pixels within the fire mask:
      - low-confidence fire
      - nominal-confidence fire
      - high-confidence fire
  - C4 fire product this confidence estimate did not adequately identify highly questionable, low confidence fire pixels.
    - Such pixels, which by design should have a confidence close to 0%, were too often assigned much higher confidence estimates of 50% or higher.
  - C5 code partially mitigated this problem, some highly questionable fire pixels are still classified as nominal-confidence fires.
  - A more substantial adjustment that fully corrects this problem has been implemented in the C6 algorithm.

Known Problems

- **False Alarms in Small Forest Clearing**
- Small clearings within rainforest were a source of persistent false alarms in the Amazon.
- Efforts were made to reduce the frequency of this type of false alarm for Collection 6.



Fire FAQ

- **What is the smallest fire size that can be detected with MODIS? What about the largest?**
  - MODIS can routinely detect **both flaming and smoldering fires ~1000 m² in size**.
  - Under **very good observing conditions** (e.g. near nadir, little or no smoke, relatively homogeneous land surface, etc.) **flaming fires one tenth this size** can be detected.
  - Under **pristine (and extremely rare) observing conditions** even smaller flaming fires **~50 m² can be detected**.
  - Unlike most contextual fire detection algorithms designed for satellite sensors that were never intended for fire monitoring (e.g. AVHRR, VIRS, ATSR), **there is no upper limit to the largest and/or hottest fire** that can be detected with MODIS.

Fire FAQ

- **Why didn't MODIS detect a particular fire?**
  - This can happen for any number of reasons.
  - The fire may have started and ended **in between satellite overpasses**.
  - The **fire may be too small or too cool** to be detected in the 1 km^2 MODIS footprint.
  - Cloud cover, heavy smoke, or tree canopy may completely obscure a fire.
  - Occasionally the MODIS instruments are inoperable for extended periods of time (e.g. the Terra MODIS in September 2000) and can of course observe nothing during these times.

Fire FAQ

- **I don't want to bother with strange file formats and/or an unfamiliar ordering interface and/or very large data files. Can't you just give me the locations of fire pixels in plain ASCII files and I'll bin them myself?**

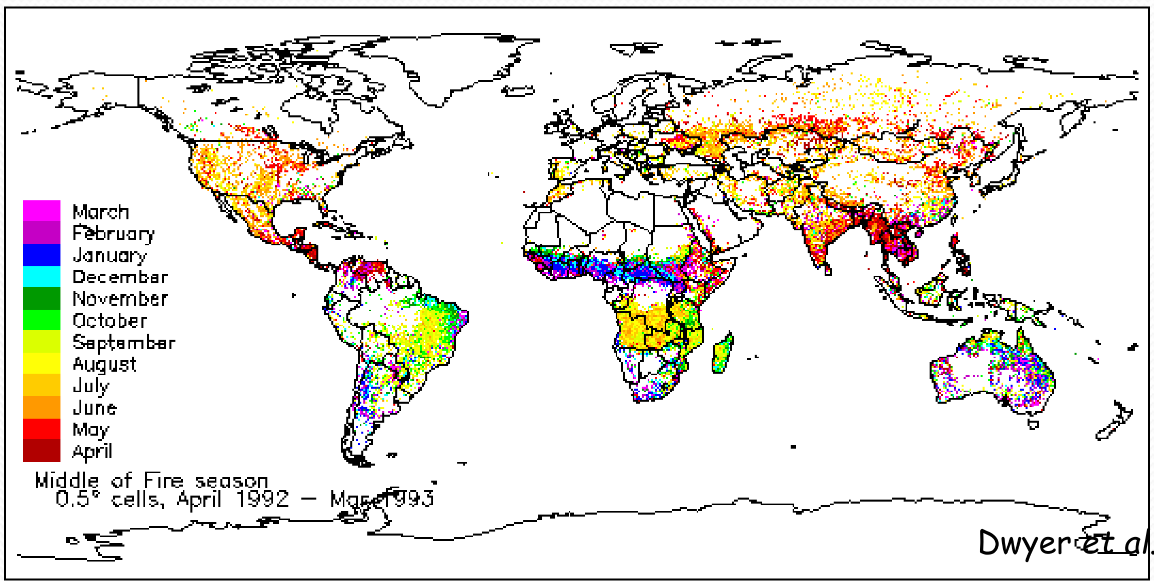
  - You can use the **MCD14ML monthly fire location product**, or obtain MODIS fire pixel locations via the Web Fire Mapper, but this doesn't necessarily mean that fire pixel locations are the most appropriate source of fire-related information.

  - The fire pixel location files include **no information about cloud cover or missing data**, and depending on the sort of analysis you are performing, it is sometimes possible to derive misleading (or even incorrect) results by effectively ignoring these other types of pixels.

  - In many cases it is more appropriate to use one of the **1-km Level 3 or CMG fire products**.

Why Map Burned Area?

- Vegetation burning is a global scale phenomena
- Global change research
  - estimates of trace gas and particulate emissions for climate modeling:
    - **Biomass burned (g) = burned are (m^2) * fuel load (g/m^2) * completeness of combustion.**



Dwyer *et al.*, 1999, J. of Biogeography

Burned Areas

- **Characterized by**
  - The removal of vegetation and change of its structure
  - deposits of charcoal and ash on surface
  - exposure of the soil layer

Burned Areas

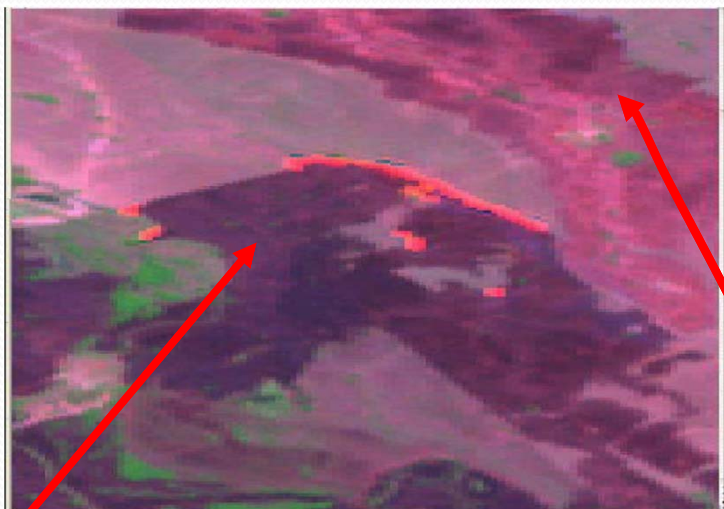
- **Vary temporally and spatially due to**
  - The **type** of vegetation that burns(land=cover)
  - The **completeness** of the combustion process
  - The **rate** of charcoal and ash dissipation by wind/rain
  - The **post fire evolution** and re-vegetation of the burned area

Burned Areas

- **Remote sensing (MODIS): Key monitoring tool due to:**
  - The usually large extent of the area affected by fire
  - The very dynamic nature of the processes
  - The low accessibility of many fire regions

When to Detect Burned Areas

- **Remote sensing of burned areas in tropical regions should be performed during the fire season**

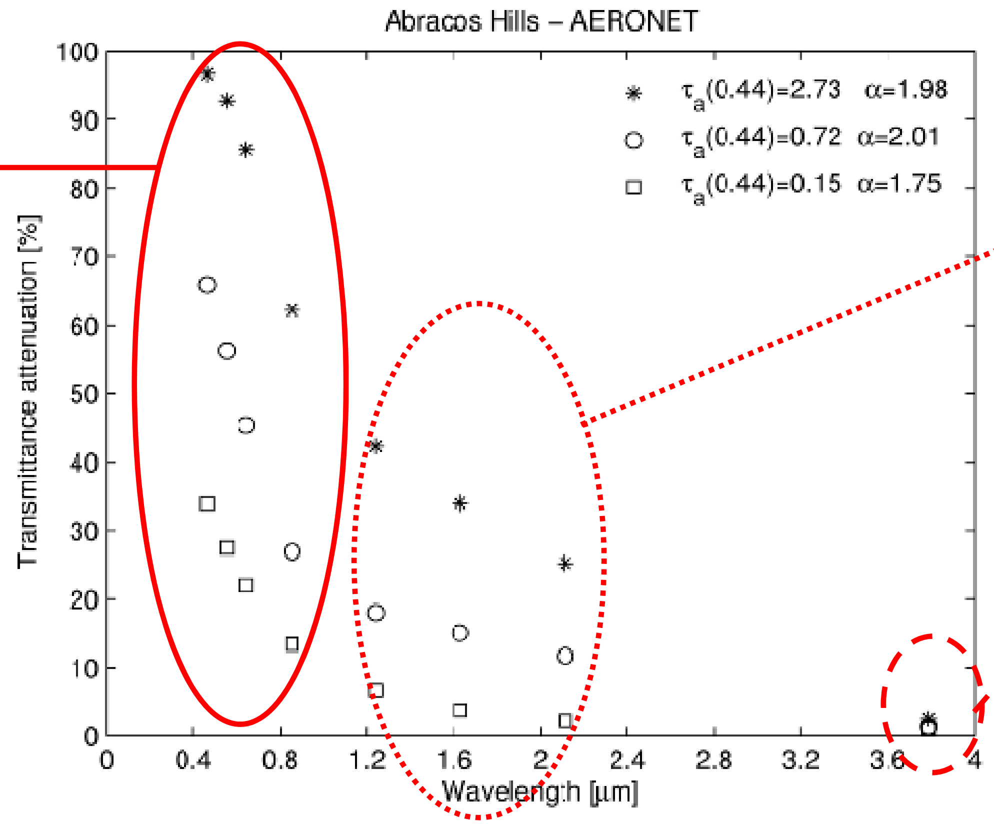


Recently burned area and **attenuated signal**, just a few days old, in the Colombian savanna.

Scars of variable ages in the Siberian boreal forest.

During the dry season, in an atmosphere contaminated by smoke (*)....

the VIS channels will be useless for Earth surface observation



the SWIR region will also be very attenuated.

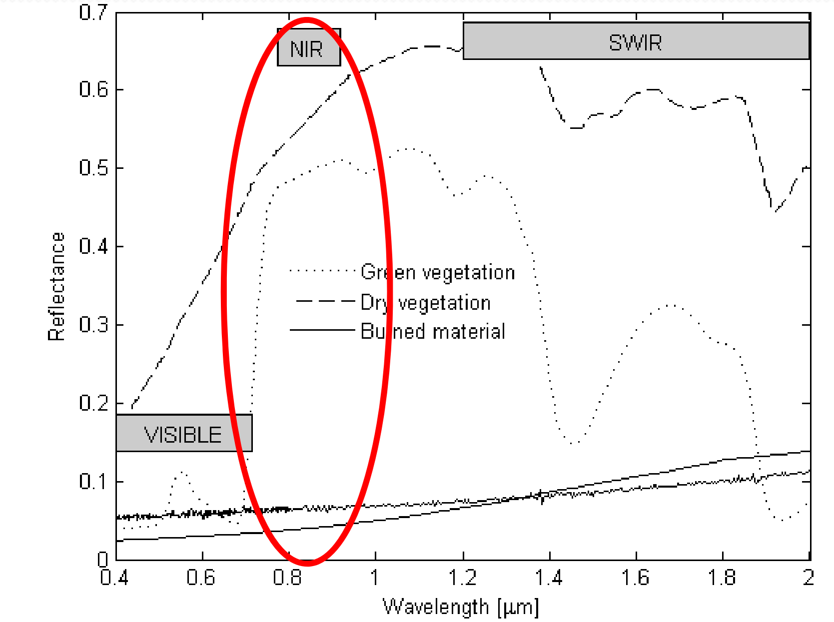
the MIR domain is practically not affected by smoke, allowing for an unperturbed surface observation

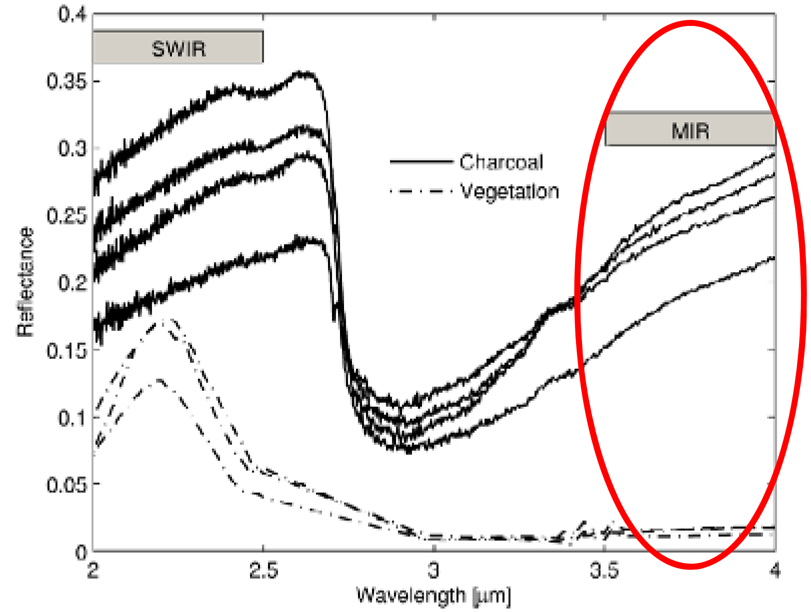
α **Angstrom parameter, characterizes aerosol particle size distribution.**

τ_a **Aerosol optical depth at 0.44 µm, measures the attenuation of radiation propagating through the atmosphere.**

Retrieving middle-infrared reflectance for burned area mapping in tropical environments using MODIS. Libonati, R.; DaCamara, C.C.; Pereira, J.M.C.; Peres, L.F. *Remote Sensing of Environment* vol. 114 issue 4 April 15, 2010. p. 831-843

Why MIR/NIR domain?

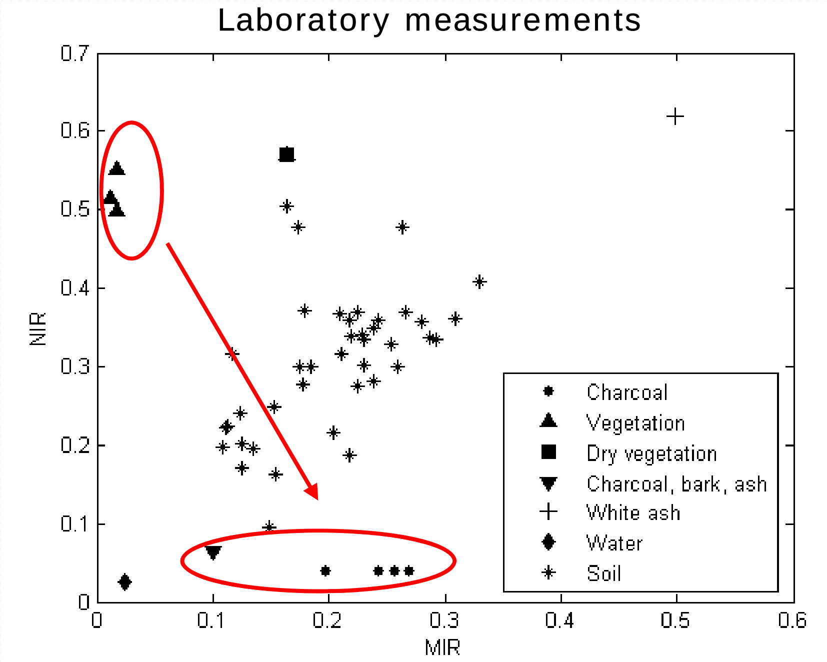


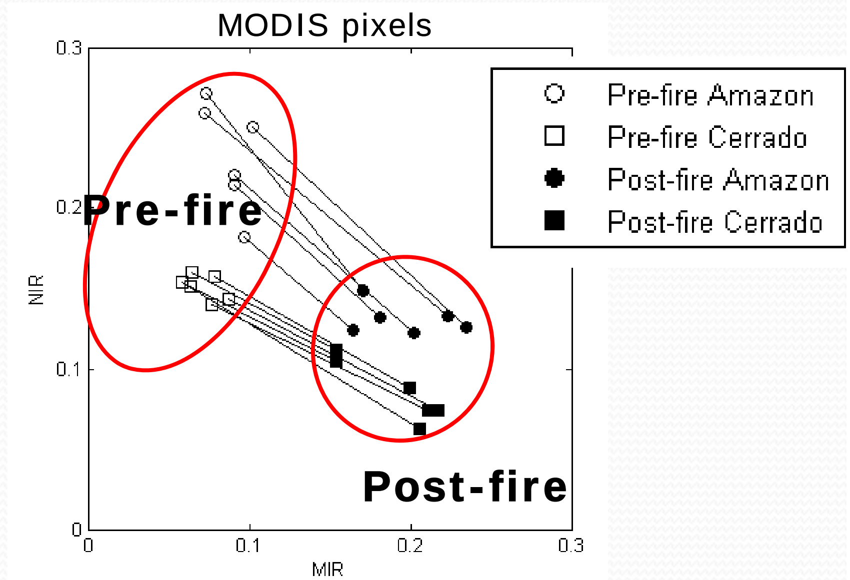


- In VIS, charcoal is mixed up with dense dark vegetation, water, dark soils, wetlands, cloud and terrain shadows.
- Similar problems occur in the SWIR region, especially at 2.0-2.5 um.
- The MIR/NIR is, unquestionably, the best bi-spectral region to discriminate between burned areas and other types of surfaces

Retrieving middle-infrared reflectance for burned area mapping in tropical environments using MODIS. Libonati, R.; DaCamara, C.C.; Pereira, J.M.C.; Peres, L.F. *Remote Sensing of Environment* vol. 114 issue 4 April 15, 2010. p. 831-843

Development of a new index





- Different materials/surfaces tend to form clusters on the MIR/NIR space
- There is an overall displacement along the diagonal of the graph, from vegetation, down to burned materials across the soil surfaces.

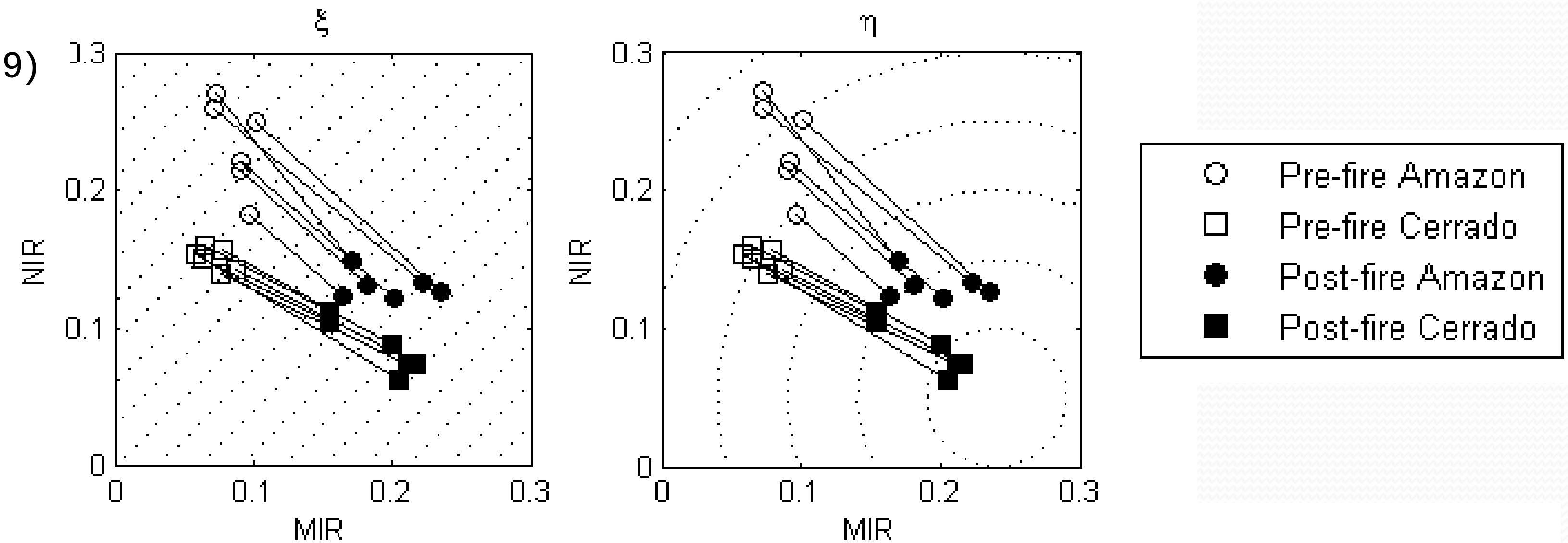
On a new coordinate system for improved discrimination of vegetation and burned areas using MIR/NIR information. Libonati, R.; DaCamara, C.C.; Pereira, J.M.C.; Peres, L.F. *Remote Sensing of Environment* vol. 115 issue 6 June 15, 2011. p. 1464-1477

Towards an optimal index

(Martín, 1998)

$$VI3 = (\rho_{NIR} - \rho_{MIR})/(\rho_{NIR} + \rho_{MIR}) \qquad BAI = 1/(\rho_{NIR} - \rho_{CNIR})^2 + (\rho_{RED} - \rho_{CRED})^2$$

(Pereira, 1999)



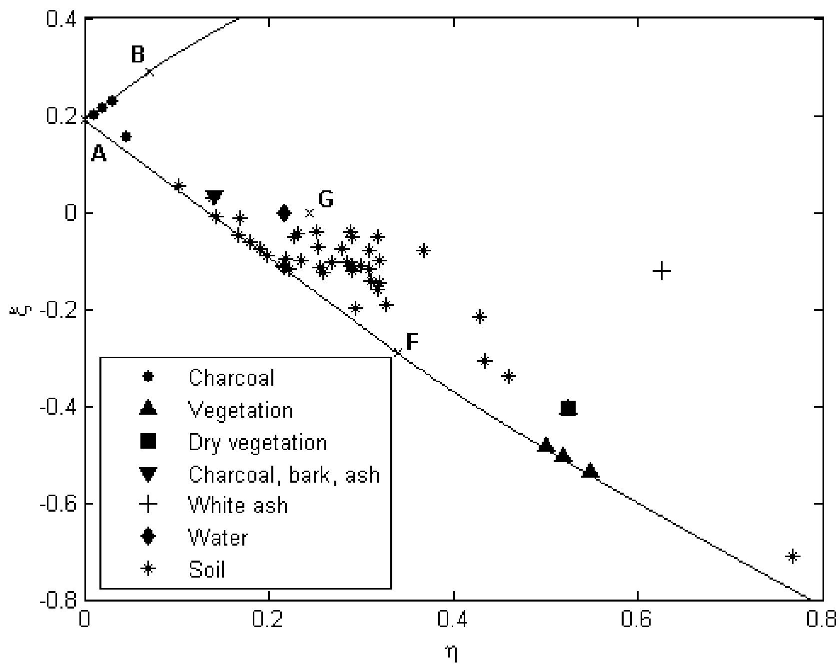
$$\xi = x - y$$

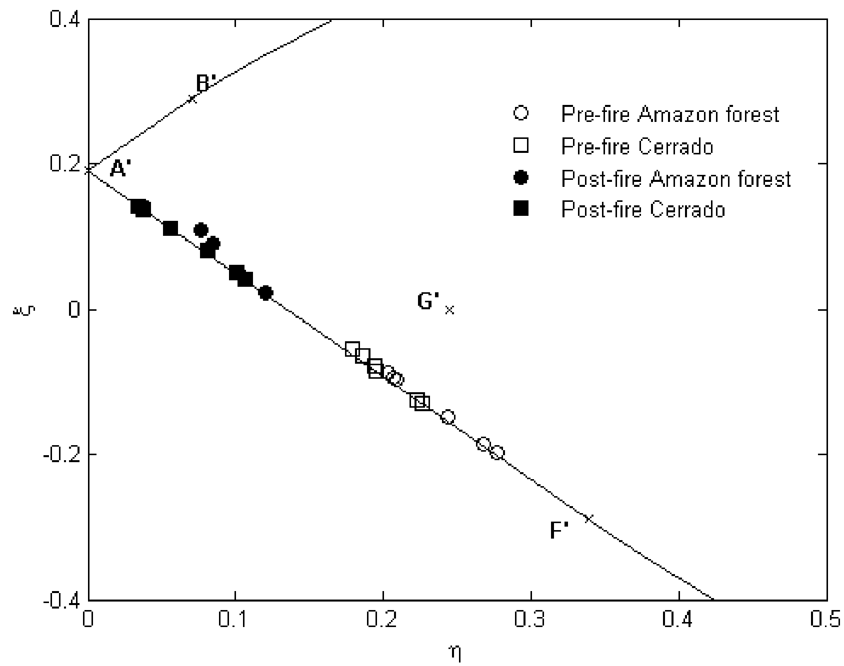
$$\eta = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

- Verstraete and Pinty (1996): the more perpendicular a displacement vector is to the contour lines of a given index, the better the sensitivity of the index to the observed change at the surface.
- It seems that η is especially sensitive to burning events in the Amazon forest, whereas ξ is more appropriated in Cerrado.

On a new coordinate system for improved discrimination of vegetation and burned areas using MIR/NIR information. Libonati, R.; DaCamara, C.C.; Pereira, J.M.C.; Peres, L.F. *Remote Sensing of Environment* vol. 115 issue 6 June 15, 2011. p. 1464-1477

Development of a new space

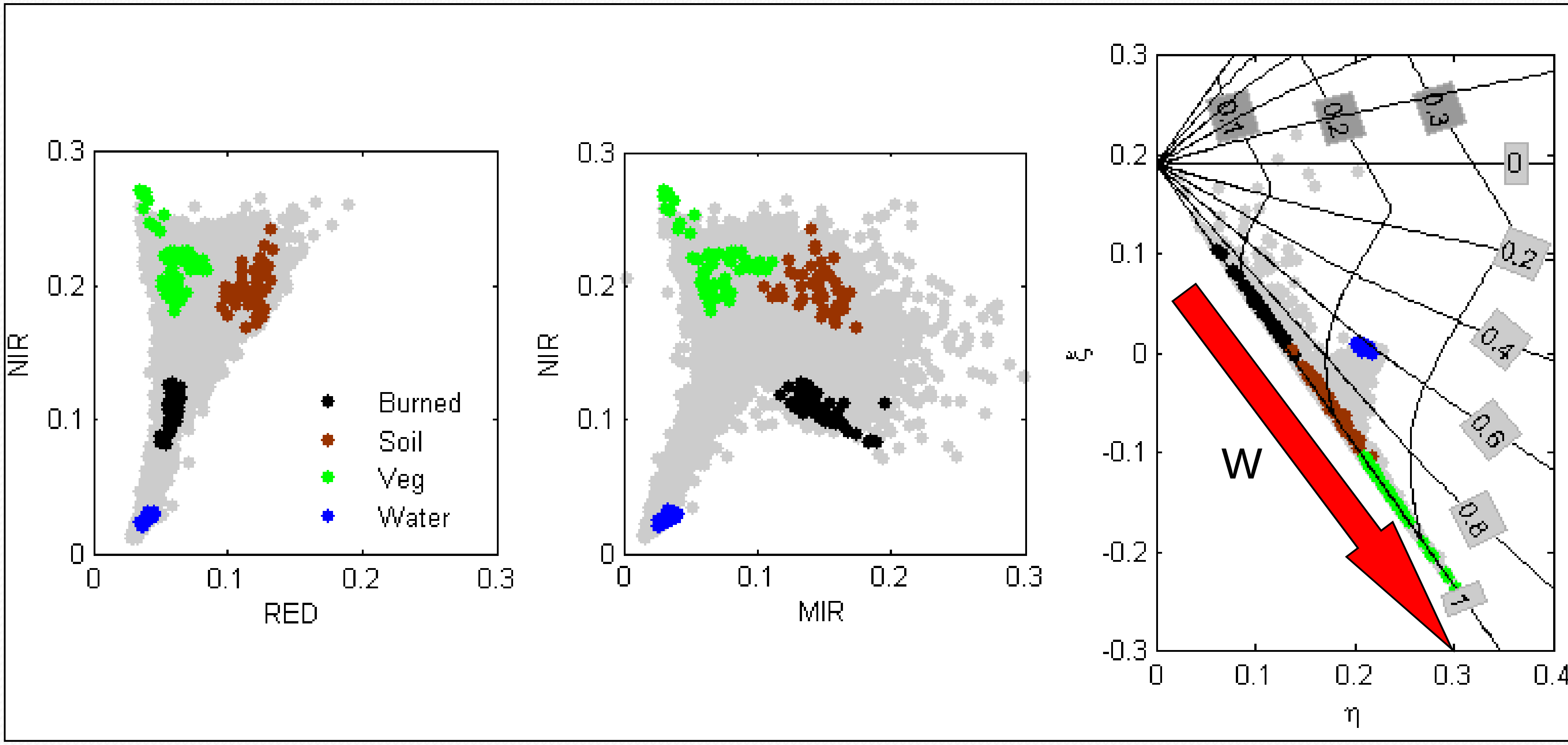




- Natural constrain in η/ξ space
- Surfaces related to vegetation (green, dry, mixture, burned) tend to align
- Other kind surfaces are dispersed inside this limits
- On the order hand, the surfaces related to vegetation seems to be aligned accordingly to water content.

On a new coordinate system for improved discrimination of vegetation and burned areas using MIR/NIR information. Libonati, R.; DaCamara, C.C.; Pereira, J.M.C.; Peres, L.F. *Remote Sensing of Environment* vol. 115 issue 6 June 15, 2011. p. 1464-1477

Development of a new index



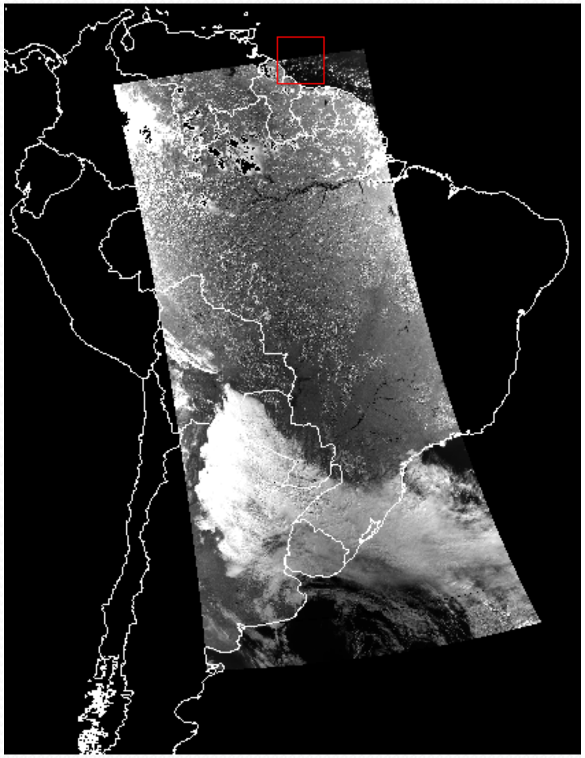
V – WATER AND CLOUD MASK

W – BURNED/UNBURNED

Algorithm – Burned Area

https://lpdaac.usgs.gov/products/modis_products_table/mcd45a1

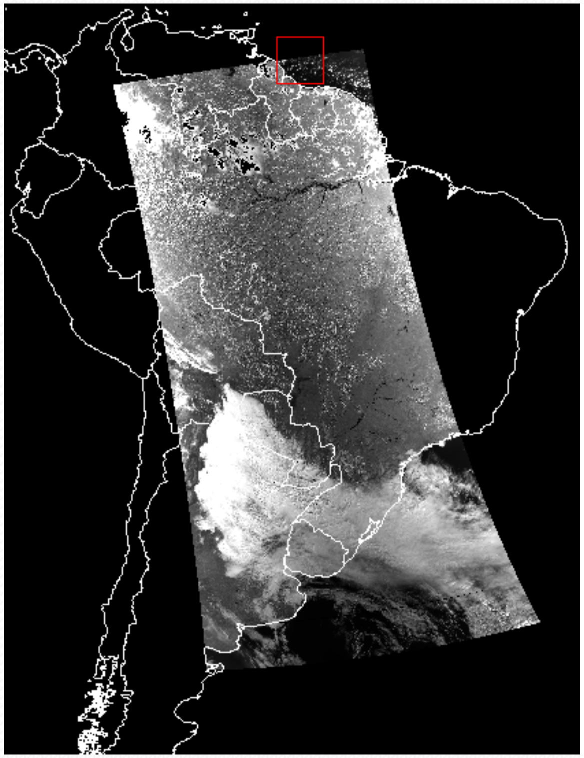
- **MCD45A1**
  - monthly Level-3 gridded 500m
  - burning and quality information on a per-pixel basis.
  - Available for Terra and Aqua MODIS
    - Based on derived daily surface reflectance inputs



- **Algorithm analyzes:**
  - daily surface reflectance dynamics to locate rapid changes
  - uses that information to detect the approximate date of burning
  - maps only the spatial extent of recent fires

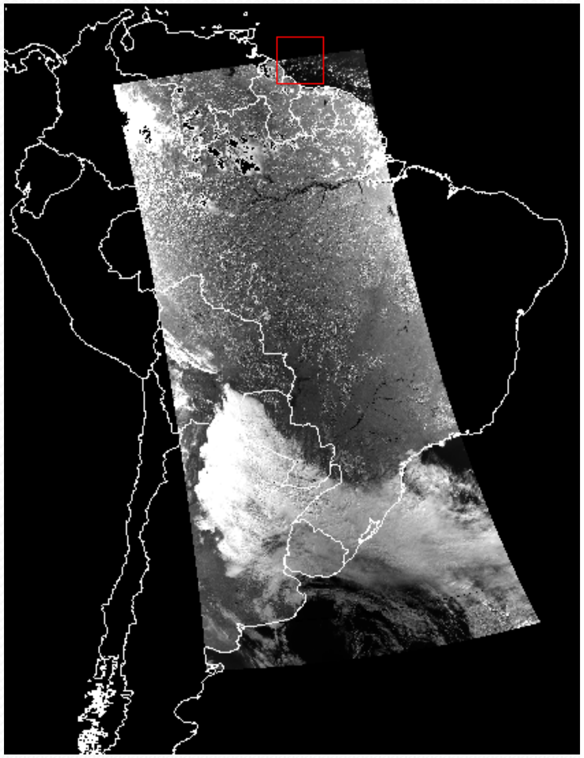
Algorithm – Burned Area

- **MCD45A1 - Algorithm**
  - Varied quality assessment information and a single summary quality assessment score for each pixel.
  - Improves on previous methods by using a bidirectional reflectance distribution function (BRDF) model-based change detection approach to handle angular variations in the data.
  - Uses a statistical measure to identify change probability from a previously observed state.



Algorithm – Burned Area

- **MCD45A1 - Algorithm**
  - The monthly MCD45A1 product is based on **three months** of atmospherically- and geometrically-corrected, cloud-screened daily reflectance data.
  - Based on Multi-temporal thresholds applied to a spectral index specifically designed to burnt area identification, namely, V, W index (Libonati et al. 2011)
  - Based on MIR (3.9 um) and NIR (0.8 um) reflectances – (V,W burned index)



Product Format

- The product is produced in the standard MODIS Land tile format in the sinusoidal projection (Wolfe et al. 1998).
- Each tile has fixed earth-location, covering approximately 1200 x 1200 km (10° x 10° at the equator).
- The product is distributed in the standard Hierarchical Data Format, and includes the following data layers, defining for each 500m pixel:

Product Format

- **Burndate:** Approximate Julian day of burning from eight days before the beginning of the month to eight days after the end of the month, or a code indicating unburned, snow, water, or insufficient data to make a decision.

- **Burn quality assessment:** Confidence of the detection; 1 (most confident) to 4 (least confident).

- **Number of Passes:** Number of MODIS observations where the temporal consistency test is passed.

- **Number Used:** Number of MODIS observations used in the temporal consistency test.

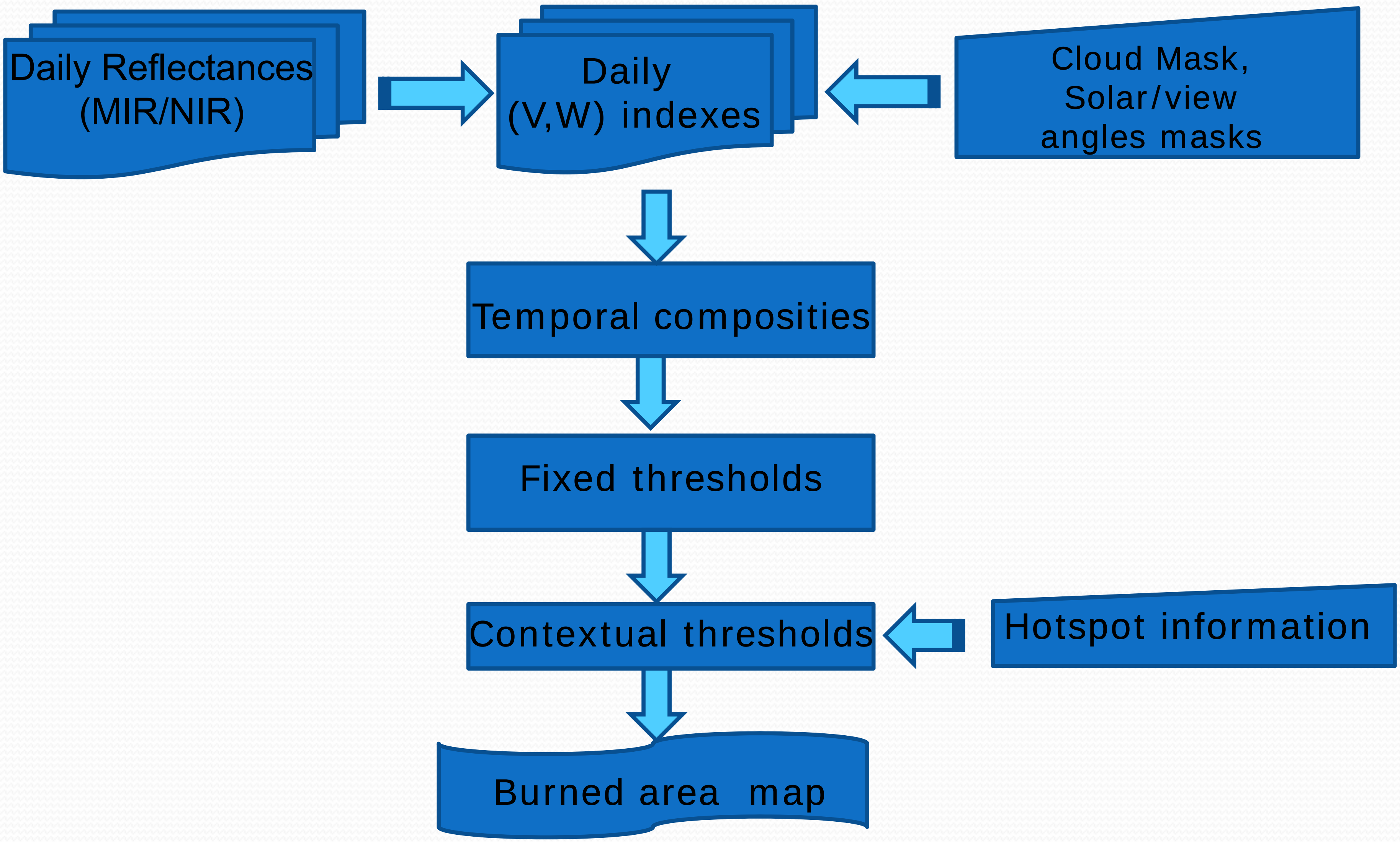
Product Format

- **Direction:** Direction in time in which burning was detected (forward, backward or both).

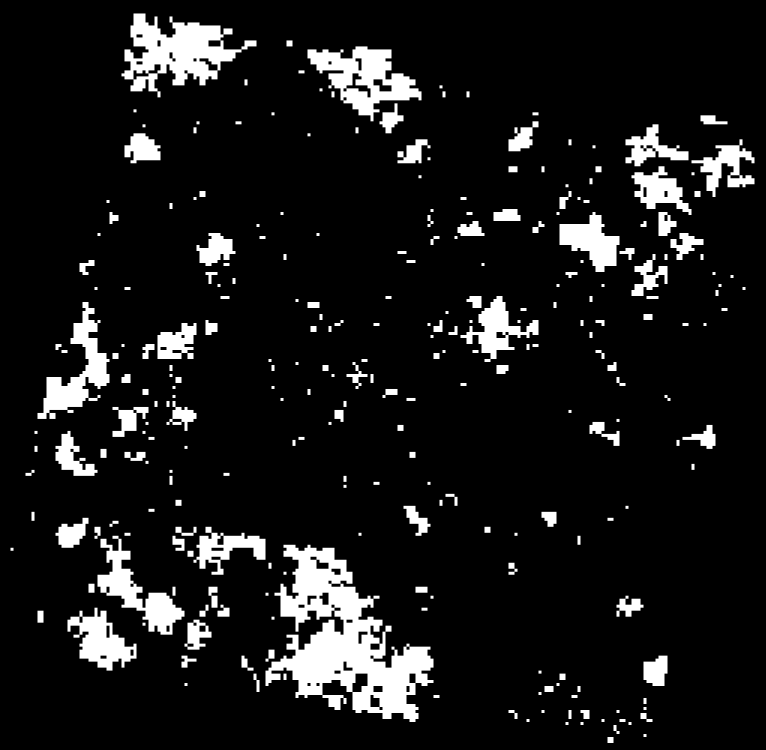
- **Surface Type:** Information describing the land and atmospheric properties (e.g. water, snow, high aerosol, high view and solar zenith angles).

- **Gap Range 1 and 2:** Information describing the two largest numbers of consecutive missing/cloudy days (if any) in the time series and their start day.

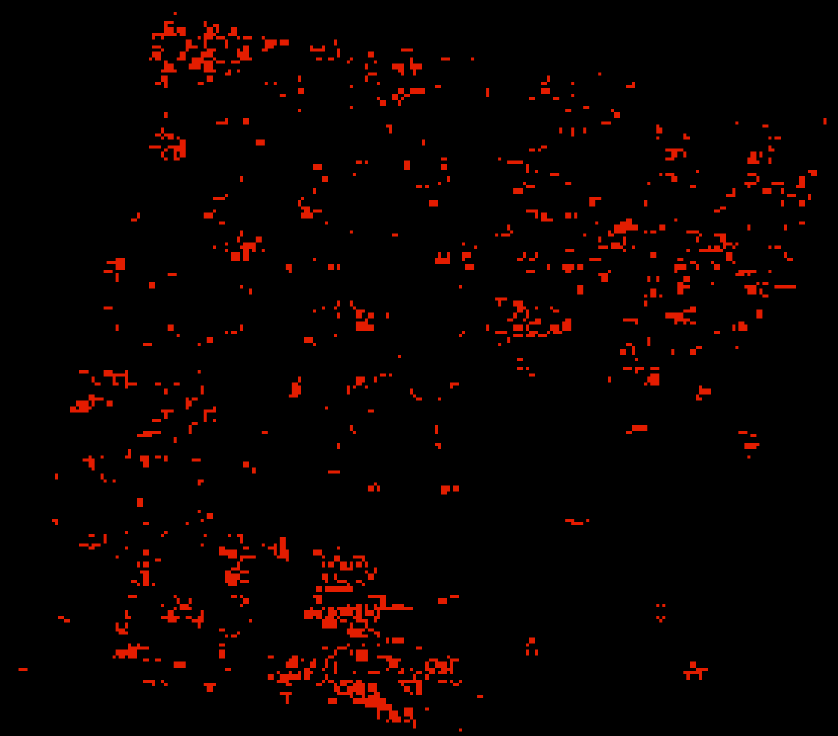
Detection Algorithm



Comparison – hotspots locations

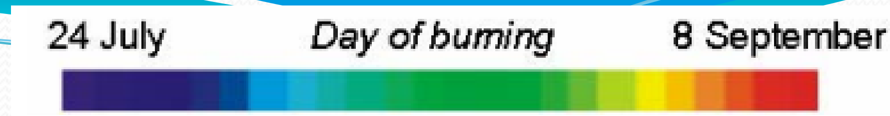


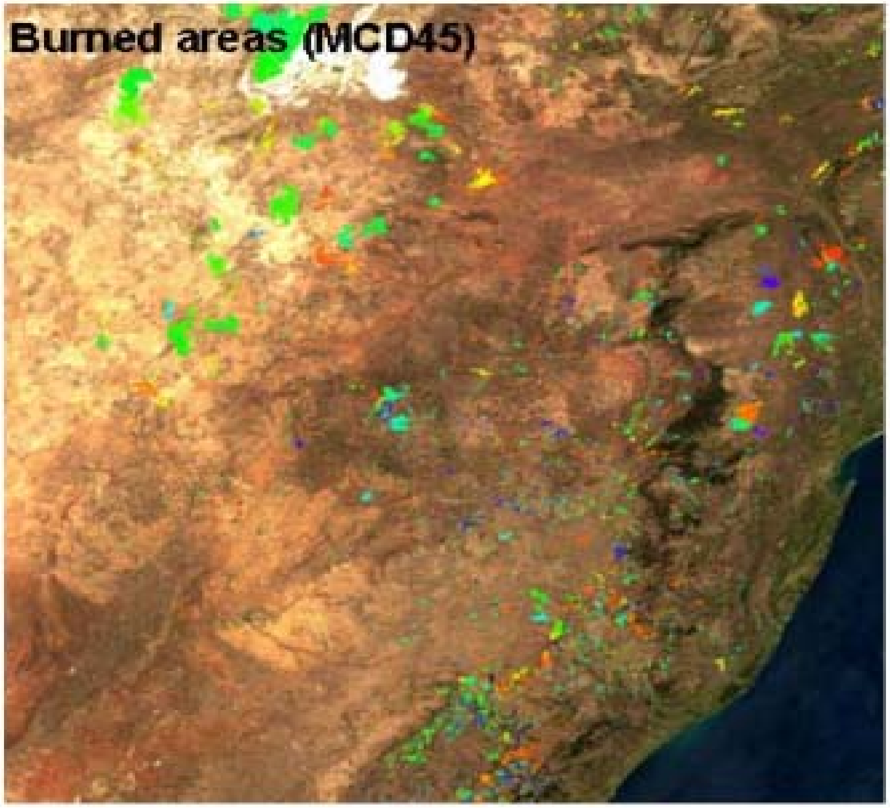
Burned area map

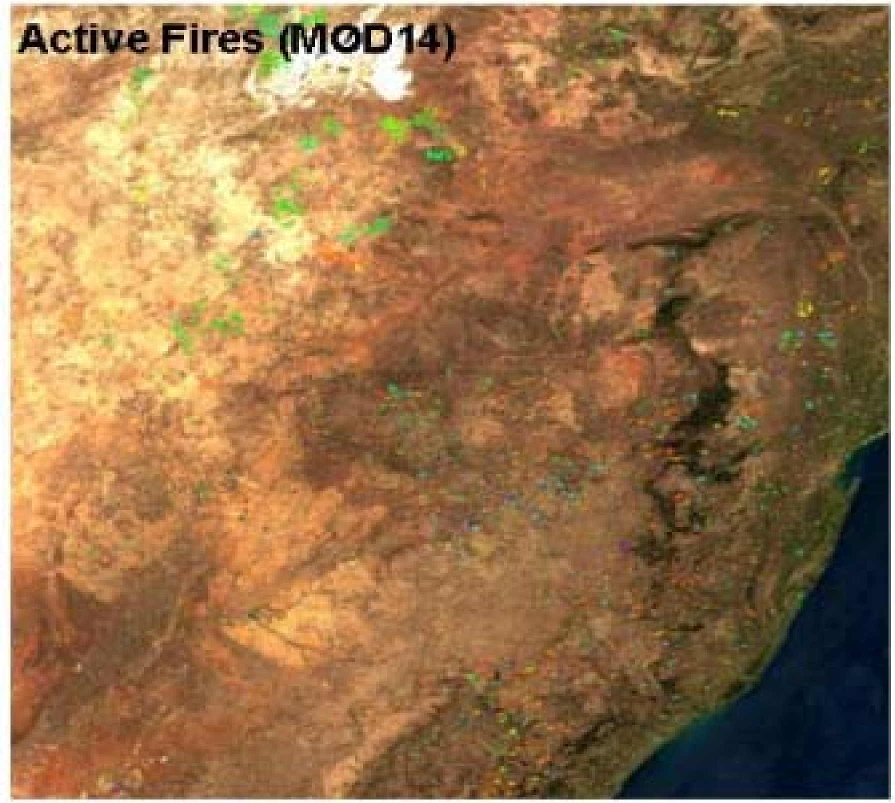


MODIS hotspots

Example Product







- Comparison between MODIS 500m Burned Areas (left) and cumulative 1km day and night MODIS active fires (right) for August 2001 over the 1200x1220km MODIS land tile h20v11 (Southern Africa).
- The approximate **day of burning** is overlain on MODIS surface reflectance to provide geographic context.