Universidad
Central de Venezuela
La casa que vence la sombra

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

BURNED AREA ESTIMATION USING MODIS FIRE PRODUCTS AS A SUBSIDY FOR BIOMASS BURNING EMISSIONS ESTIMATION IN THE BRAZILIAN AMAZON AND CERRADO BIOMES.

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CENTRAL UNIVERSITY OF VENEZUELA

Institute of Geography and Regional Development

Introduction

Biomass Burning

Emission

M = A x B x FAB x E

M **=** biomass burned

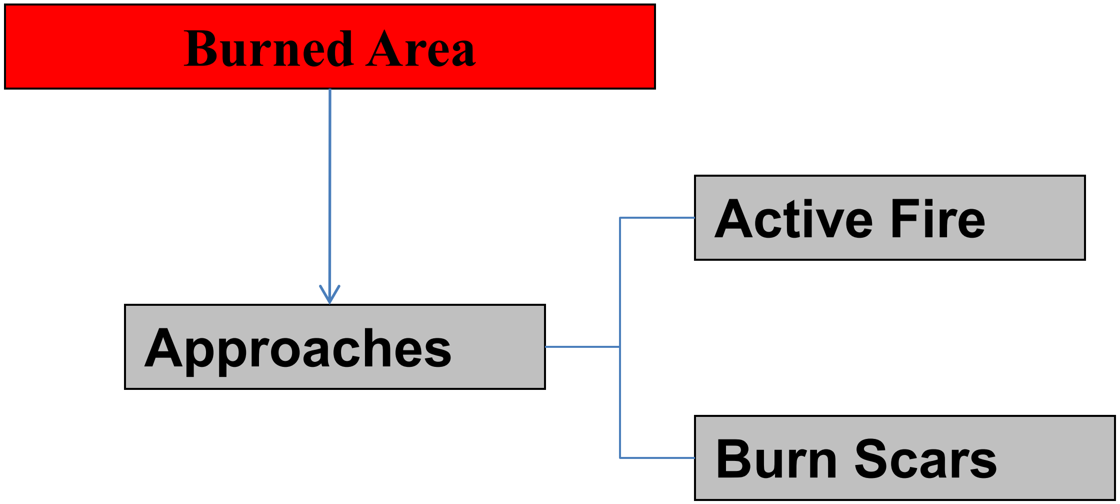
A = burned area

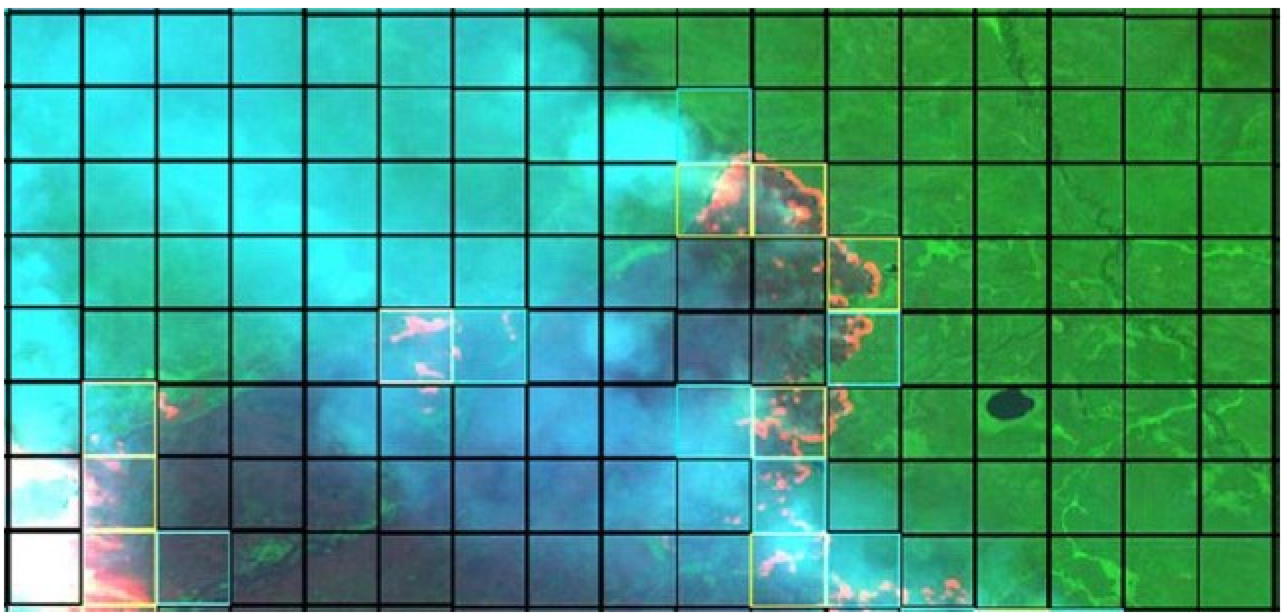
B = biomass density

FAB = fraction of live biomass above-ground

E = burning efficiency

Introduction





ASTER (8,3,1) image of a large fire complex on July 23, 2002. (*63° N, 126° E*). Csiszar et al. (2006)

Introduction: Research Questions

a) What is the influence of spatial and temporal resolutions for detecting burned areas?

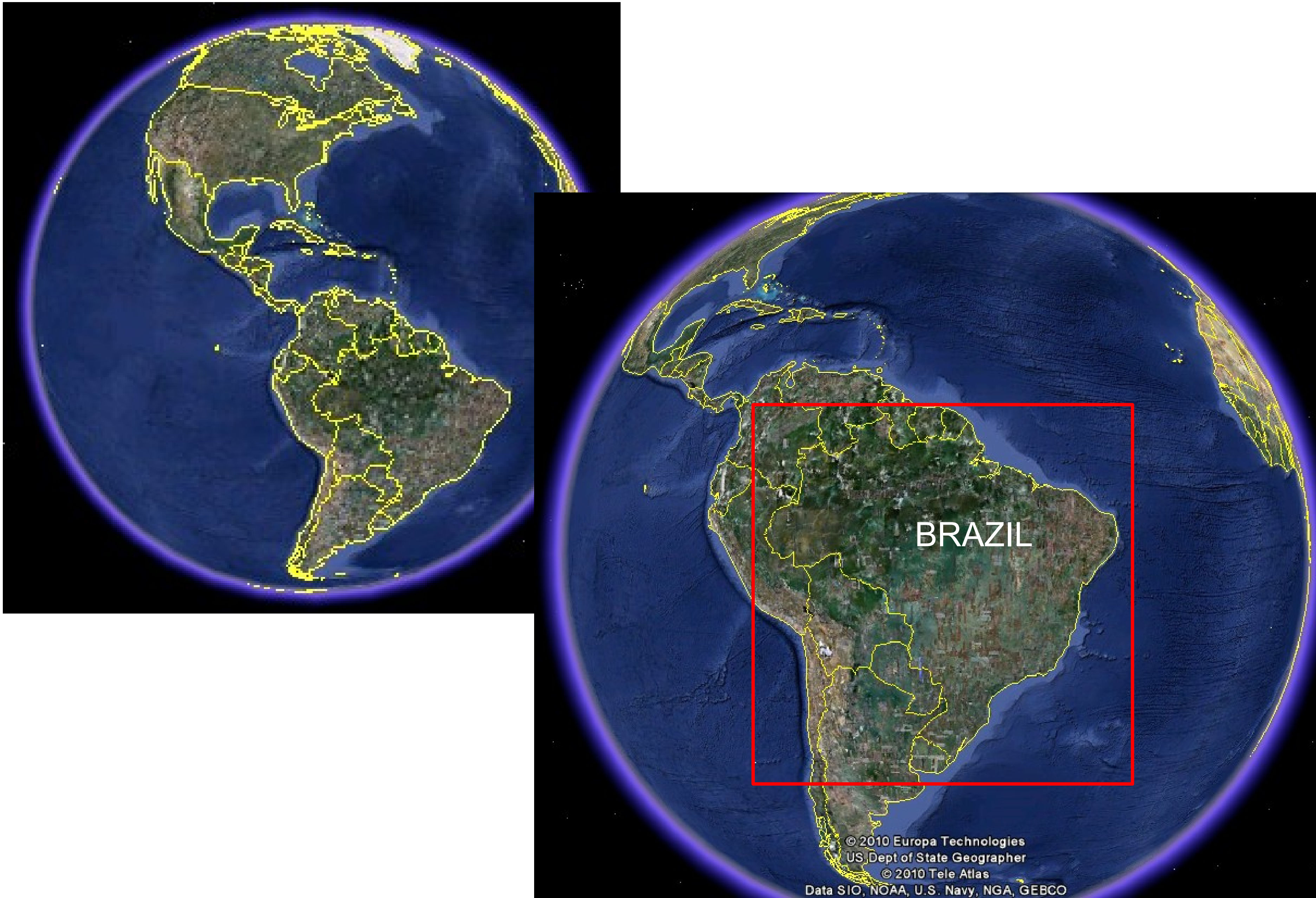
b) Do different biomass burning approaches (active fire – burned scars) and/or algorithms have influence in the estimation of the extent of burned areas, using the same MODIS dataset ?

c) Could MODIS dataset provide support to the needs of the scientific community for detecting burned areas?

Introduction: Objetive

To assess different procedures to estimate biomass burning from MODIS burned area products, in order to estimate gross atmospheric emissions (2005) in the Amazonia and Cerrado (Savannas) biomes.

Study Area


BRAZIL
© 2010 Europa Technologies
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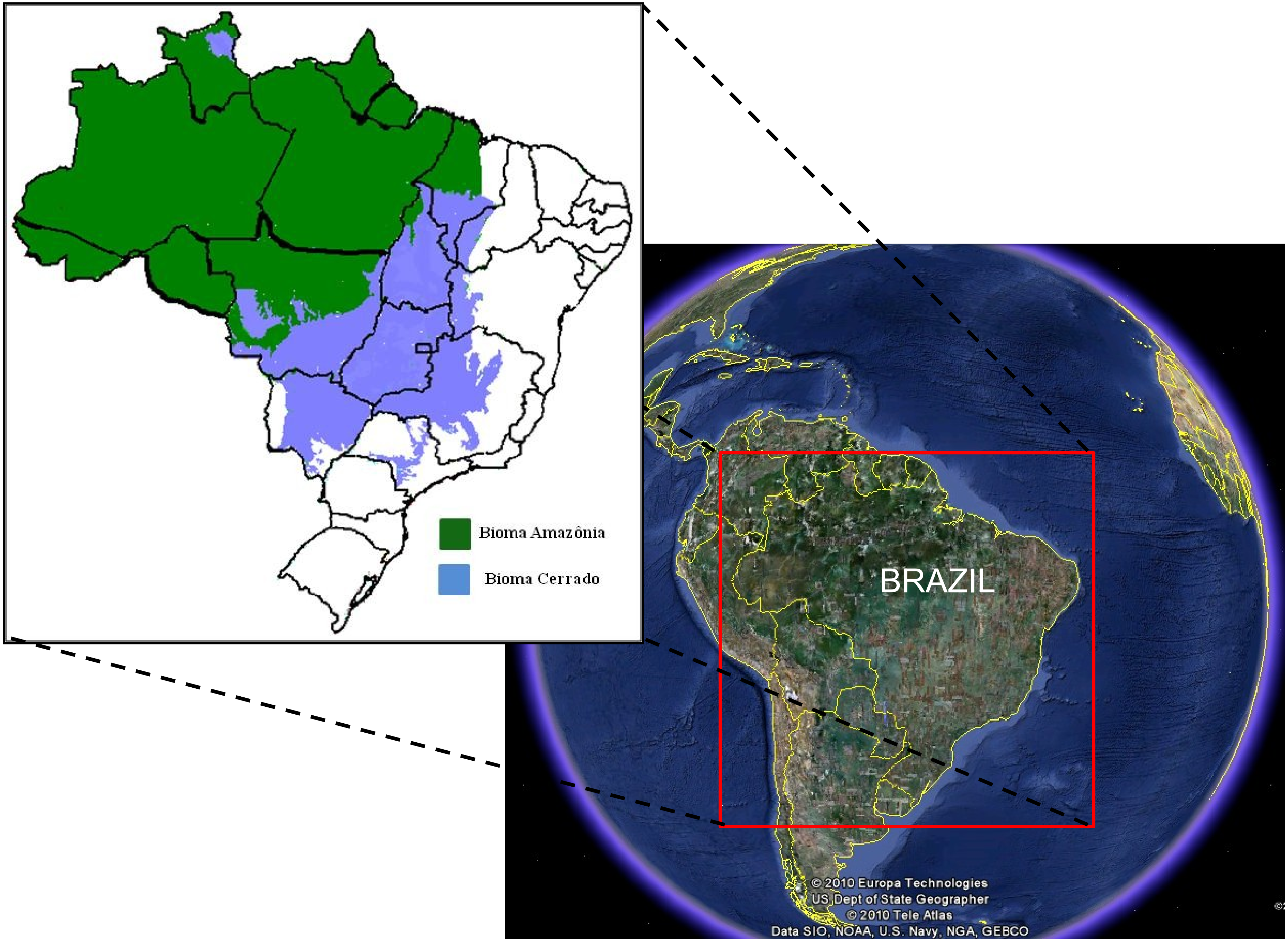
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Study Area



Bioma Amazônia
Bioma Cerrado
BRAZIL
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US Dept of State Geographer
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Algorithms and Satellite Data Used

BURNED AREA ALGORITHMS			VALIDATION
Burn Scar Mapping	**MCD45** (Global Burned Area Product)	**Burned Area Detection**	**VISUAL INTERPRETATION**

Algorithms and Satellite Data Used

BURNED AREA ALGORITHMS			VALIDATION
Burn Scar Mapping	**MCD45** (Global Burned Area Product)	**Burned Area Detection**	**VISUAL INTERPRETATION**
SATALLITE/RESOLUTIONS			
MODIS/TERRA (250 m) **1-2 days** **CH 1,2,6**	**MODIS/AQUA-TERRA** (500 m) **1-2 days** **CH 2,5,7**	**MODIS/AQUA** (1000 m) **1-2 days** **CH 1,2,20,21**	**LANDSAT/TM** (30 m) **16 days** **CH 3,4,5**
Product 1 **INPE** **(Setzer, et al, 2007)**	**Product 2** **NASA/GSFC**	**Product 3** **INPE** **(Lima et al, 2009)**	

Algorithms and Satellite Data Used

MODIS land team

Status for: Burn Area (MCD45)

General Accuracy Statement

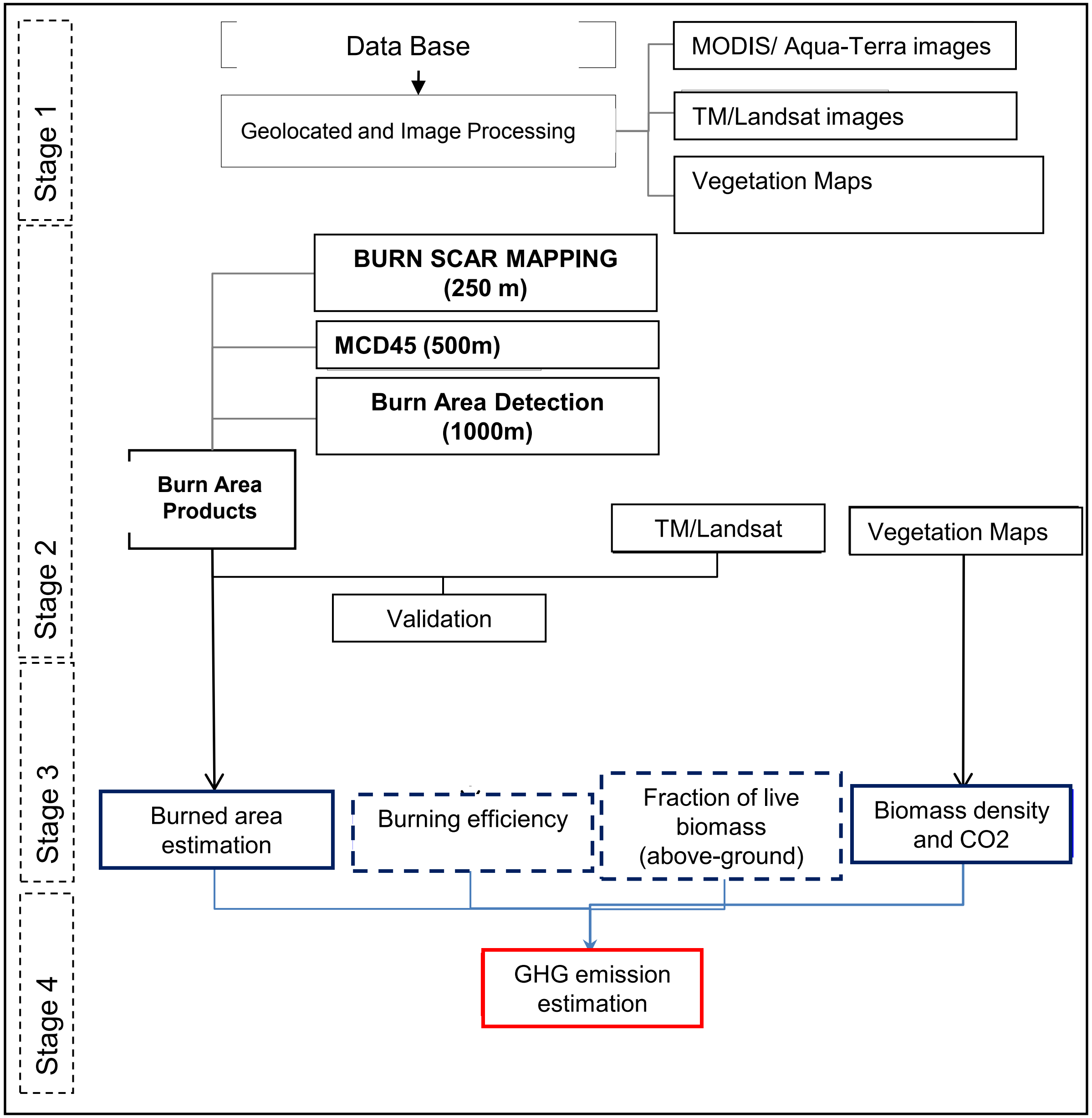
The validation of the MODIS burned area product relies mainly on the use of high-resolution Landsat scenes. Stage 1 validation was conducted parallel to the development of the product with a number of validation sites in Africa, Australia, Brazil, Siberia and the United States. Stage 2 validation of the Level 3 combined Aqua-Terra burned area product is currently ongoing. A comprehensive validation over Africa has been completed and validation in Europe, India, Australia and Siberia is currently ongoing.

The analysis of the proportion of area detected as burned in 5km by 5km cells by the MCD45 product and by 11 Landsat validation scenes for Southern Africa in 2001 resulted in a correlation (r^2) of 0.746, a slope of 0.75, and an intercept of -0.005.

Product status updated: September 2008 (reviewed November 2009)
Product version: Collection 5

http://landval.gsfc.nasa.gov/ProductStatus.php?ProductID=MOD45

METHODS


Stage 1
Data Base
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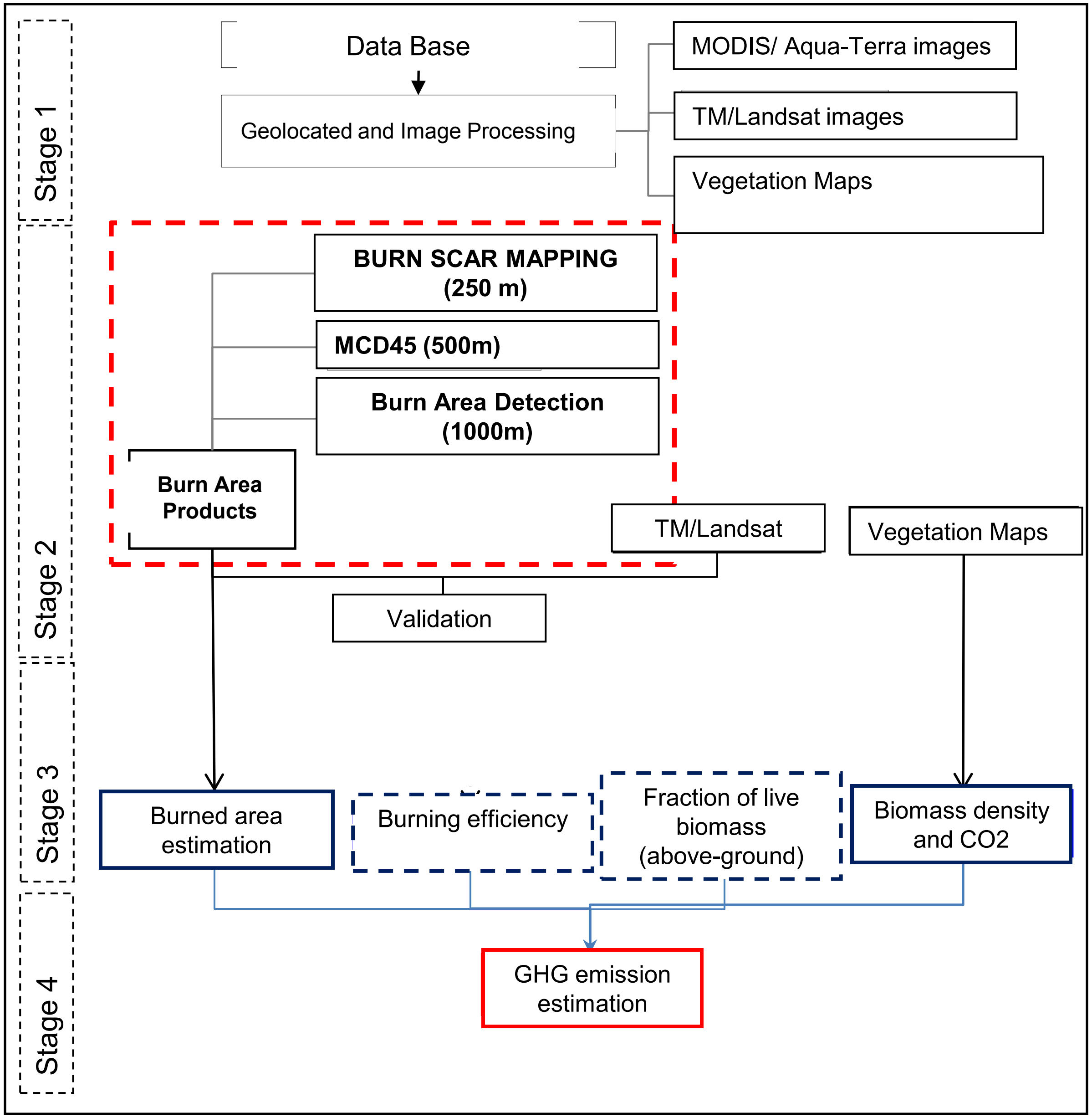
MODIS/ Aqua-Terra images
TM/Landsat images
Vegetation Maps
Stage 2
BURN SCAR MAPPING (250 m)
MCD45 (500m)
Burn Area Detection (1000m)
Burn Area Products
TM/Landsat
Vegetation Maps
Validation
Stage 3
Burned area estimation
Burning efficiency
Fraction of live biomass (above-ground)
Biomass density and CO2
Stage 4
GHG emission estimation

METHODS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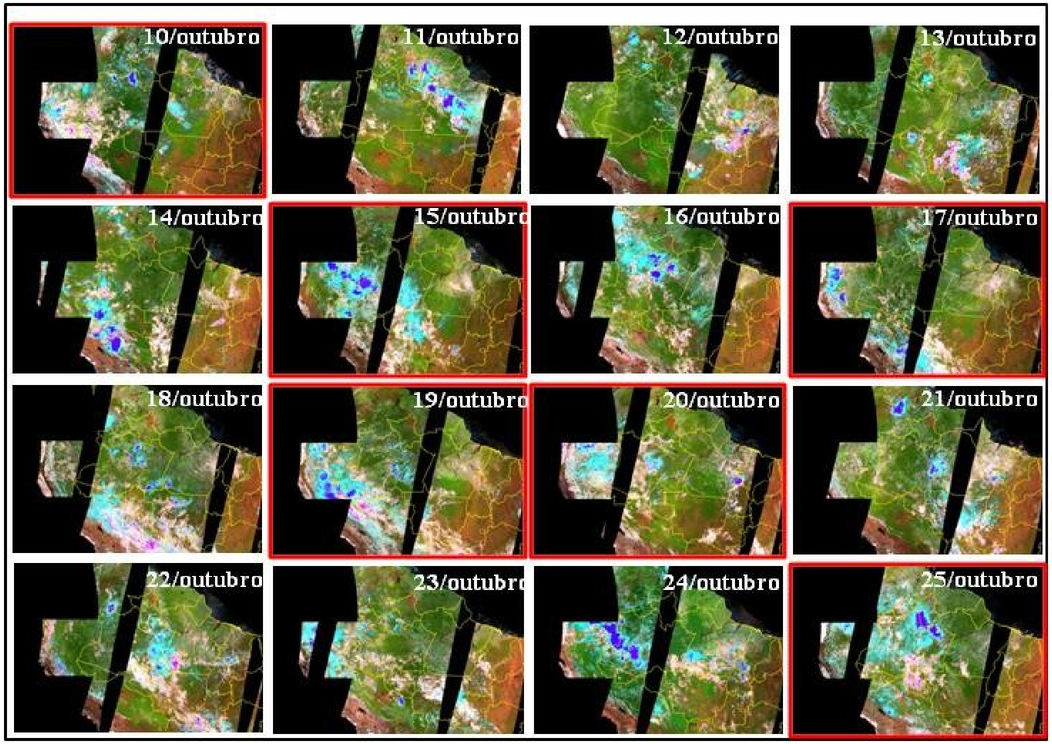
METHODS

**PRODUCT 1:
BURN SCAR MAPPING
(250m)**

1- Burn scar detection based on linear mixture model.

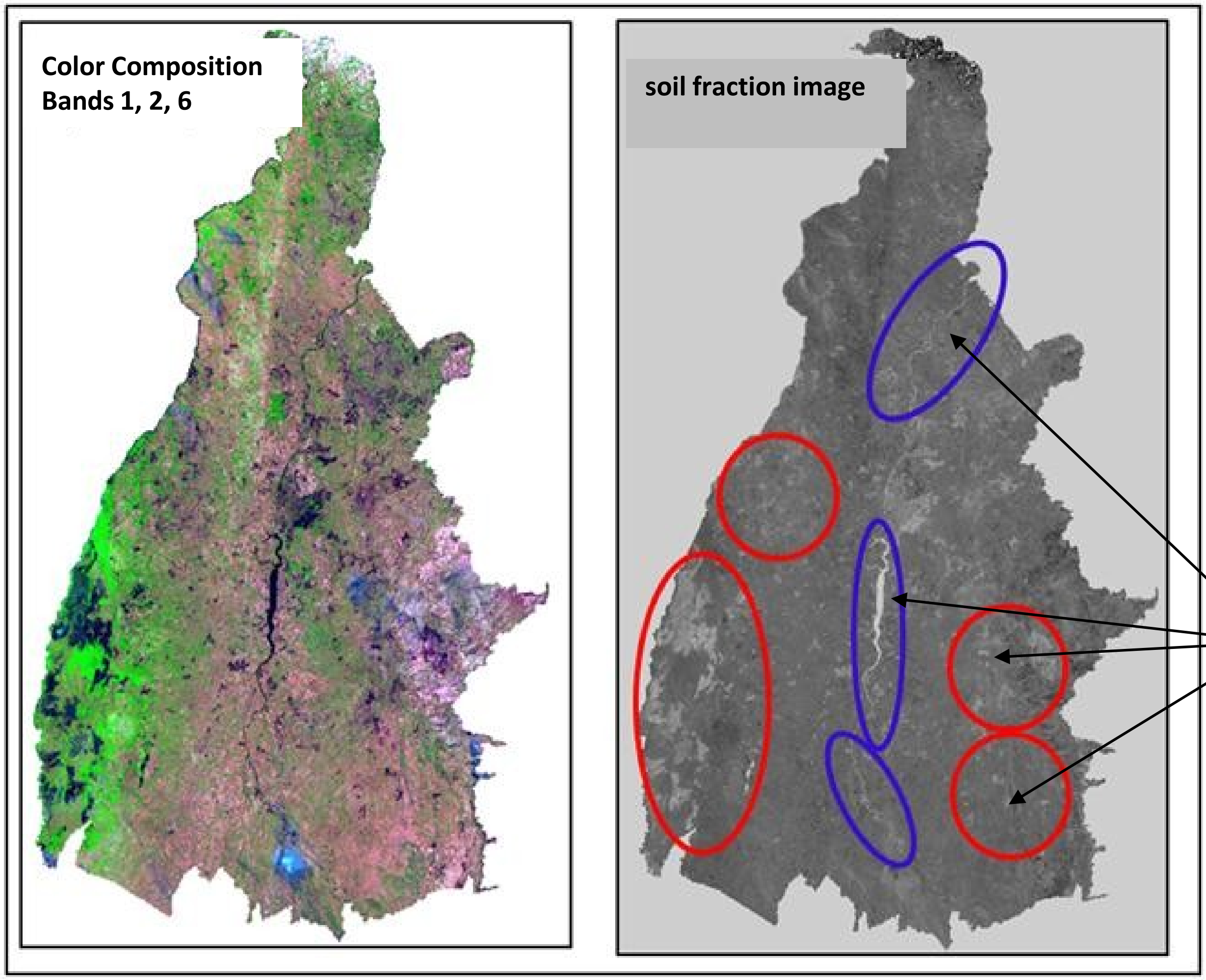
2- Product MOD09/TERRA. Bands 1, 2 (250 m) and 6 (500 m)



METHODS

PRODUCT 1:
BURN SCAR MAPPING
(250m)

3- Use linear mixture model to generate fraction images (vegetation, soil and shade)

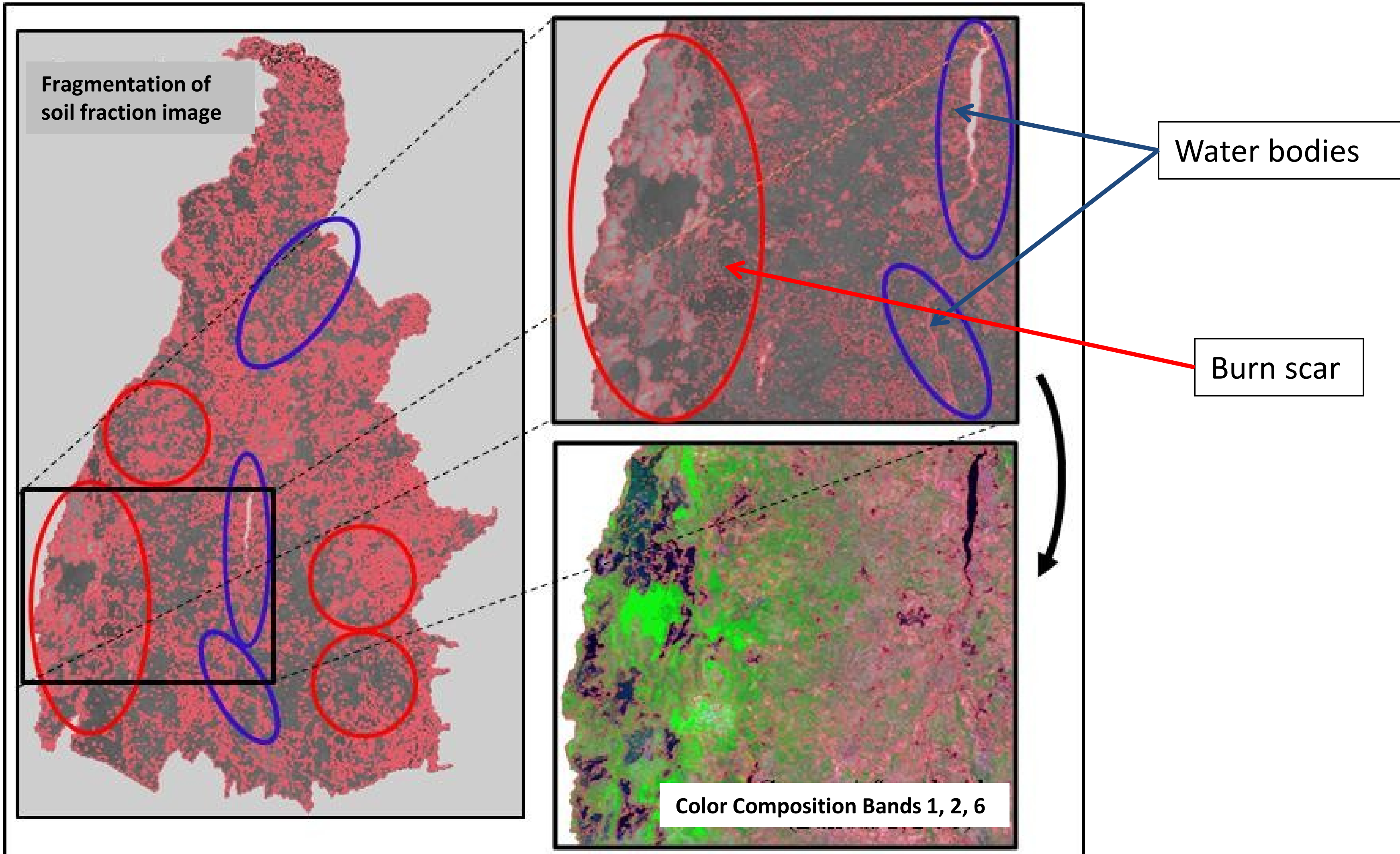


Soil fraction image showing low reflectance targets (burn scars, water bodies, clouds shadow and surface relief shadow)

METHODS

PRODUCT 1:
BURN SCAR MAPPING
(250m)

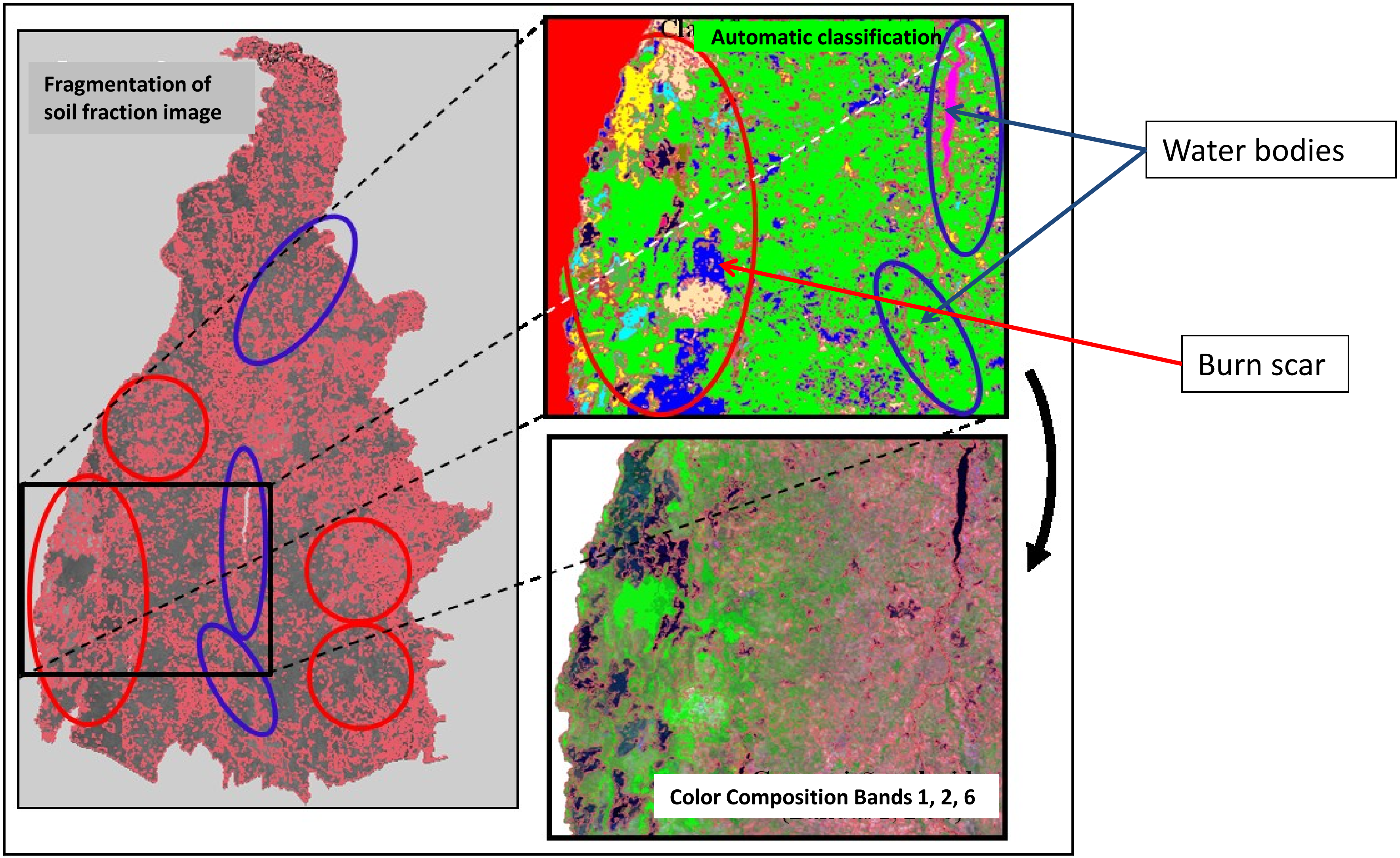
4- Segmentation of soil fraction image highlighting low reflectance targets



METHODS

PRODUCT 1:
BURN SCAR MAPPING
(250m)

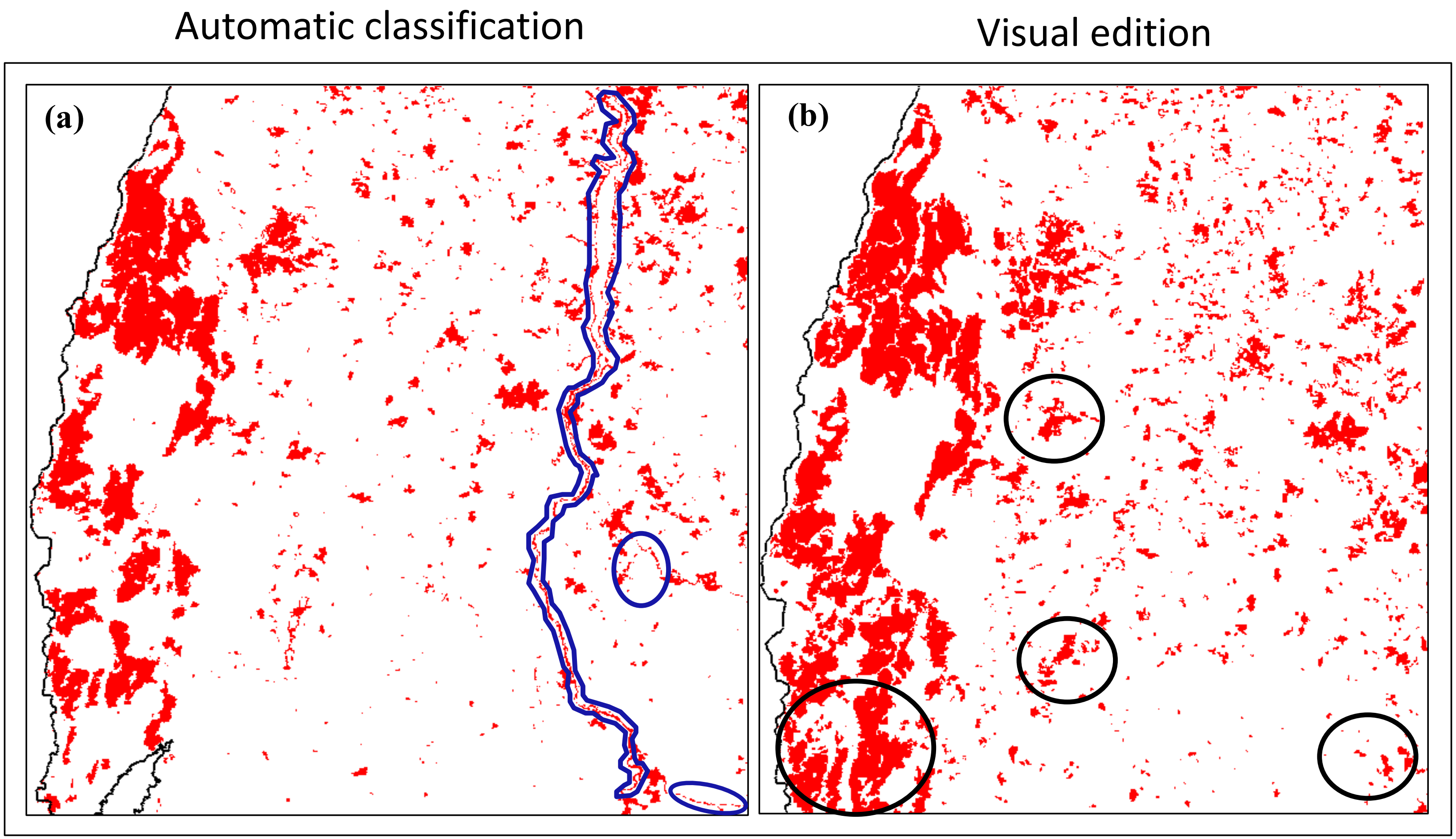
5- Burn scars automatic classification



METHODS

PRODUCT 1:
BURN SCAR MAPPING
(250m)

6- Visual interpretation edition of Burn scars (false detection and/or omissions)



METHODS

PRODUCT 2:
MCD45
(500m)

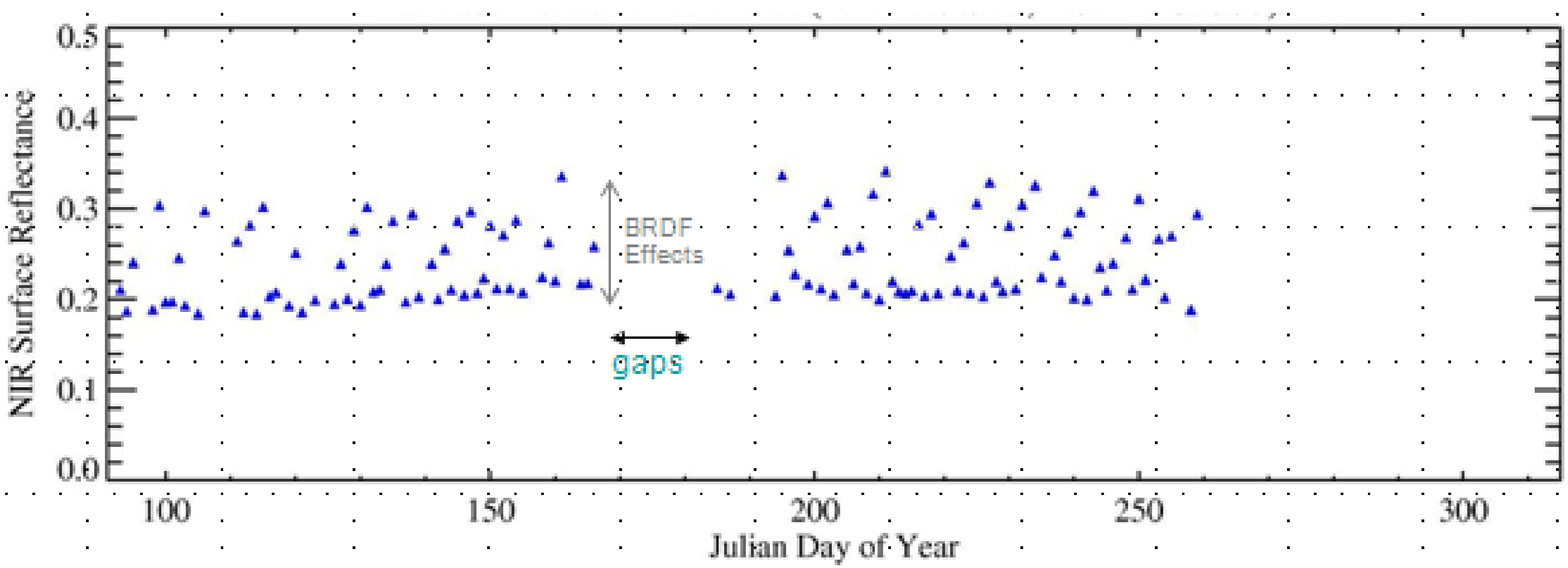
→

- Rolling BRDF based expectation change detection.
- Product MOD09/AQUA-TERRA. Bands 2 (250 m) and 5, 7 (500 m).
- Automated, without training data or human intervention.
- Applied independently per pixel to daily gridded MODIS 500m land surface reflectance time series.
- Map 500m location and approximate day of burning.

METHODS

PRODUCT 2:
MCD45
(500m)

- Bi-directional Reflectance Distribution Function (BRDF) based in expectation change detection.

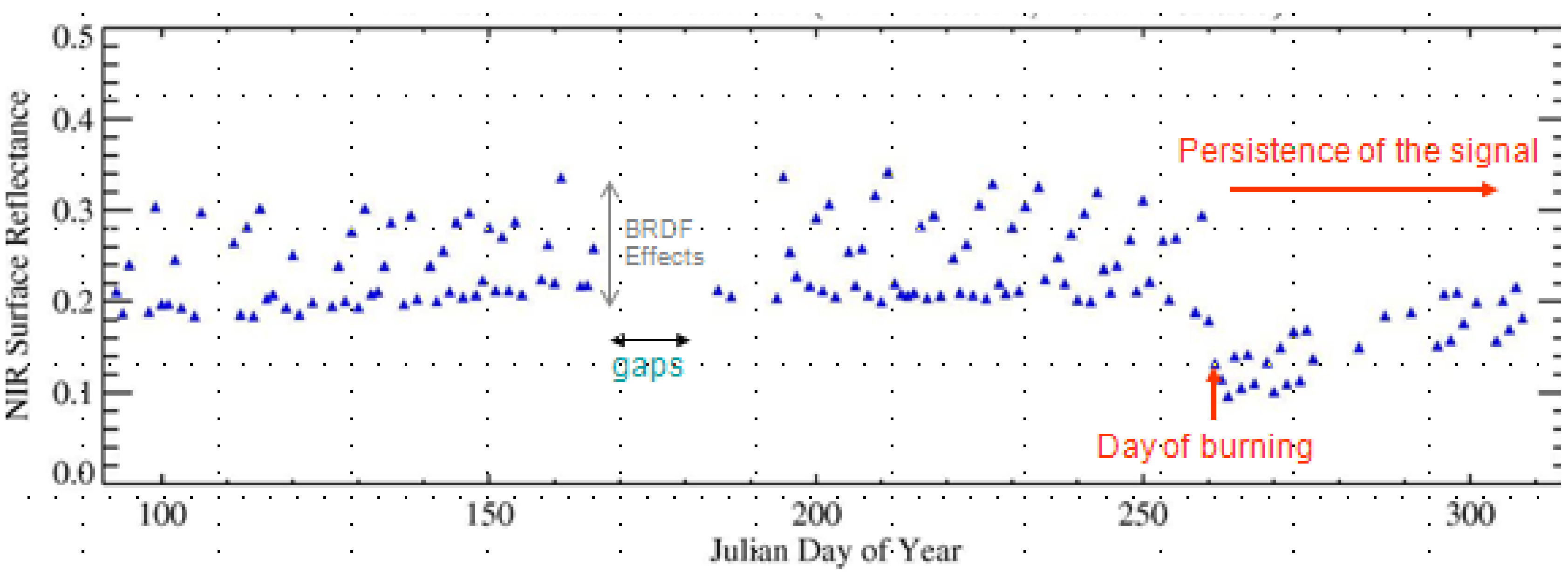


(Roy et al, 2007)

METHODS

PRODUCT 2:
MCD45
(500m)

- BRDF based in expectation change detection.
- Method is applied over a time series of NIR reflectance observation of a single MODIS pixel

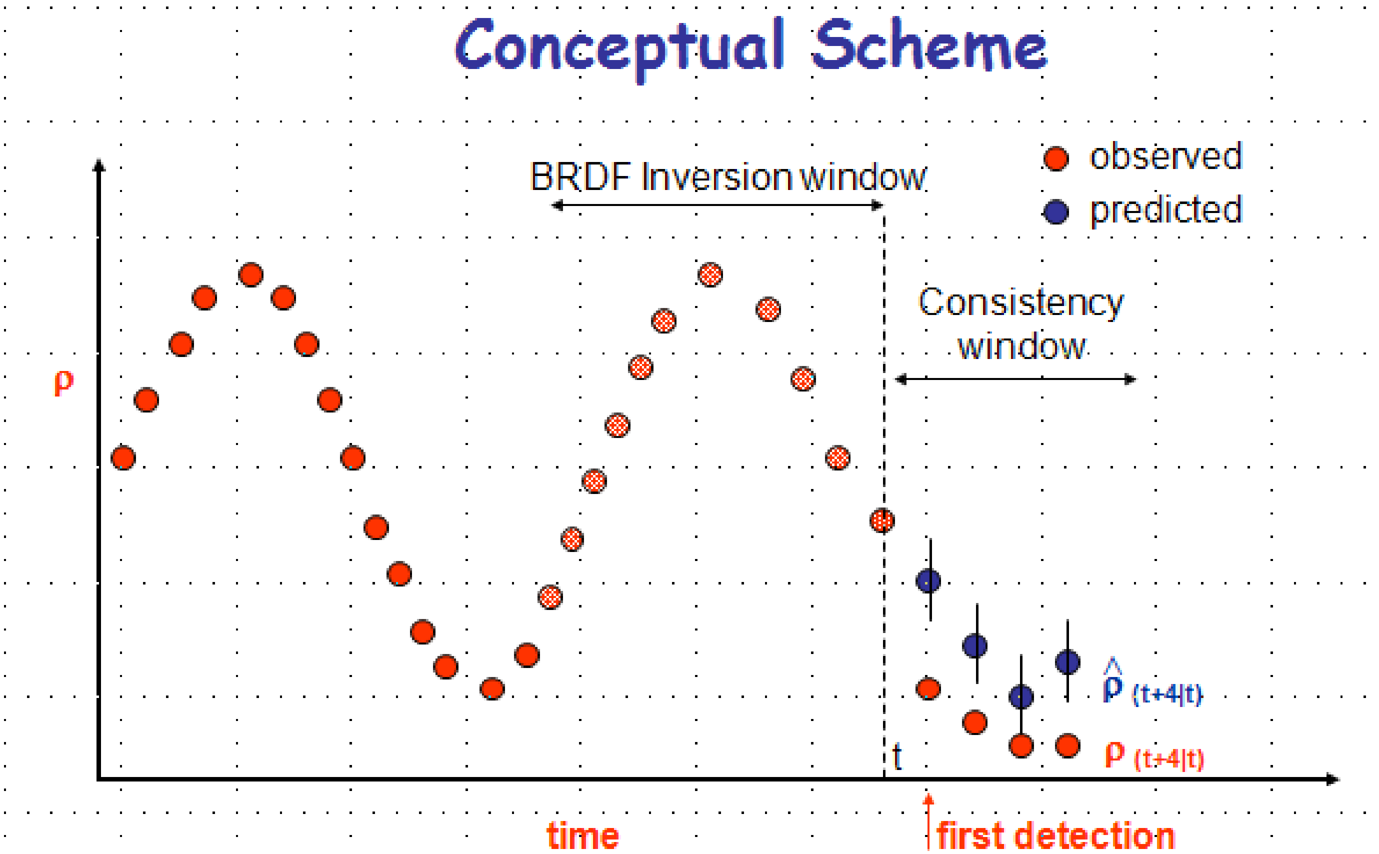


(Roy et al, 2007)

METHODS

PRODUCT 2: MCD45 (500m)

2- BRDF used to predict change in surface reflectance from the previous state (observed reflectance)

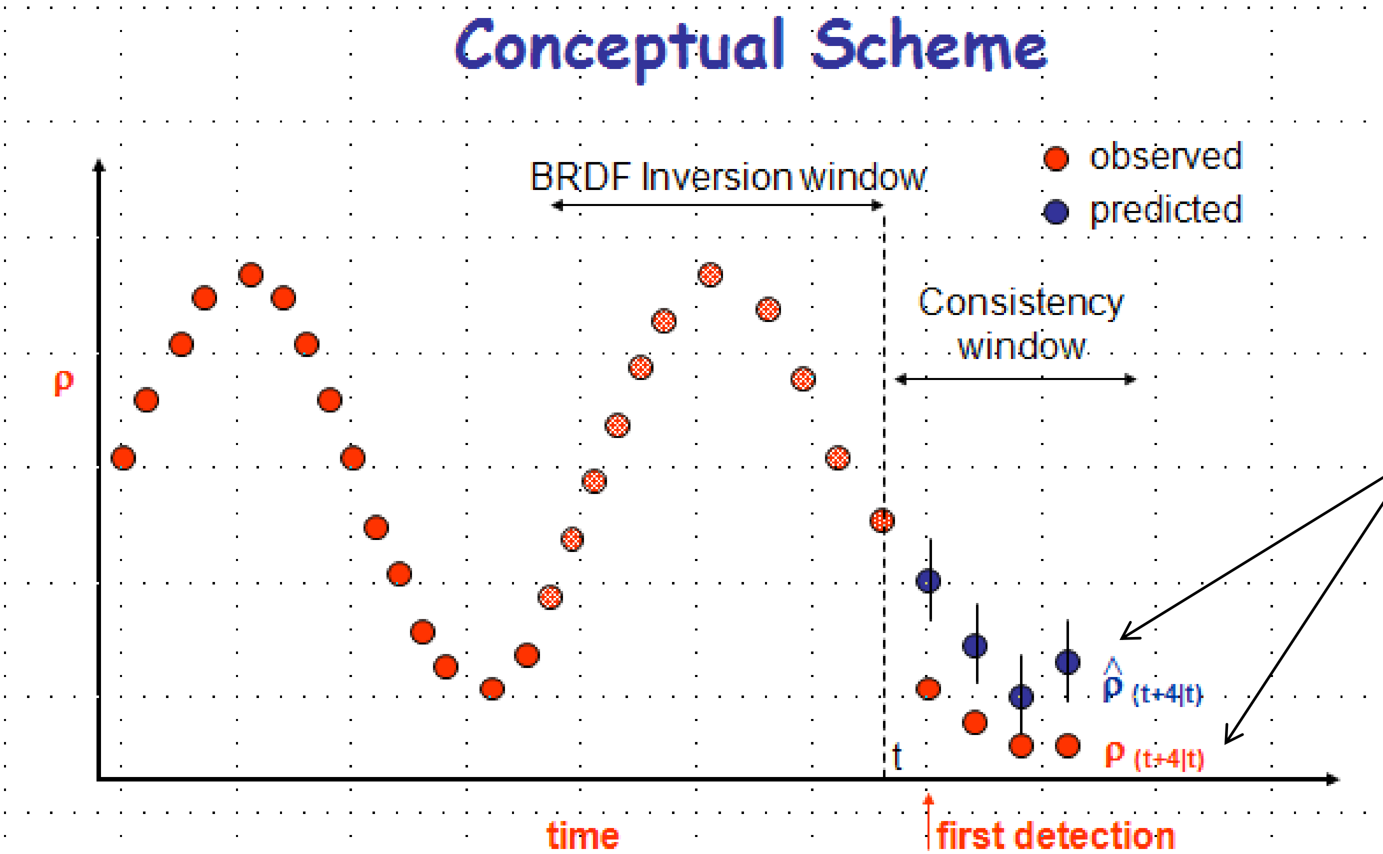


(Roy et al, 2007)

METHODS

**PRODUCT 2:
MCD45
(500m)**

2- BRDF used to predict change in surface reflectance from the previous state (observed reflectance)



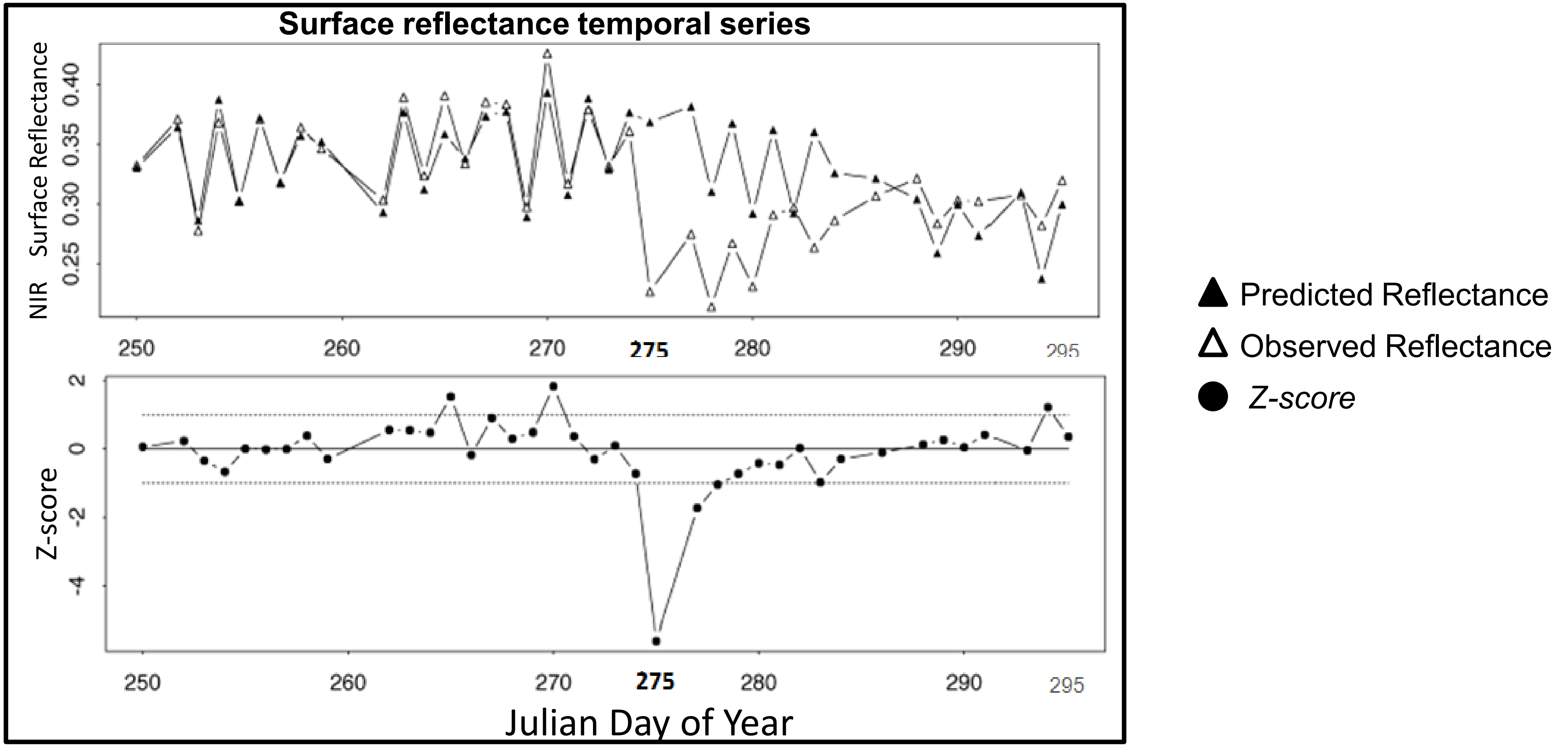
Differences between observed and predicted reflectance it is a sign of surface change

(Roy et al, 2007)

METHODS

PRODUCT 2: MCD45 (500m)

3- A statistical measure (Z-score) is used to determine if the difference between the predicted and observed reflectance is a significant change of interest



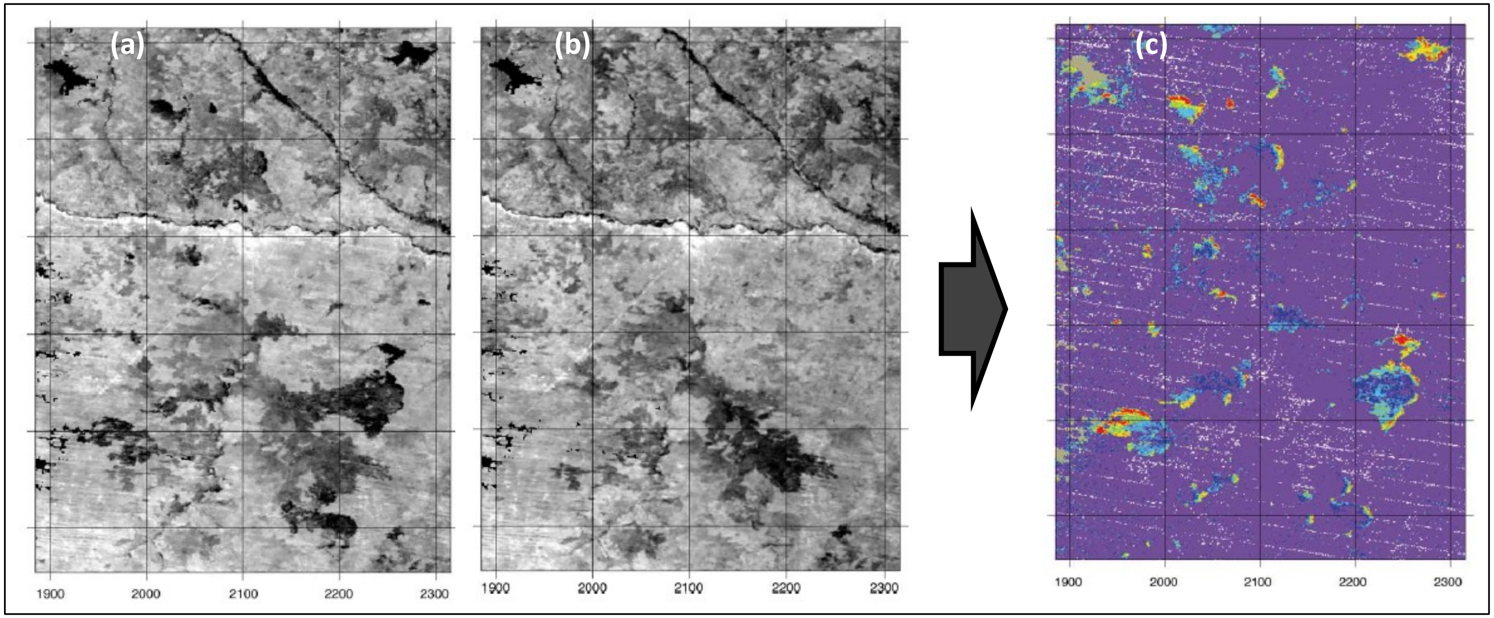
(Roy et al, 2002)

METHODS

PRODUCT 2:
MCD45
(500m)

3- A Z-score is used as a normalized measure related to the probability of the new observation belonging to the same set as that used in the BRDF model inversion

probability of change Z-score = (predicted-observed)/error



(Roy et al, 2007)

(a) Predicted Reflectance; (b) Observed Reflectance
(b) and (c) *Z-escore (probability of change)* (colored scale).

METHODS

PRODUCT 2:
MCD45
(500m)

4- The Z-score is computed for MODIS band 2 and 5 as these bands are both sensitive to burning and decrease post-fire.

A new observation is considered as a bunt candidate if:

$$(Z_{band\ 2} < (-)\ Z_{tresh}) \text{ or } (Z_{band\ 5} < (-)\ Z_{tresh})$$

Z-score band 2   *Z-score* band 5

METHODS

PRODUCT 2:
MCD45
(500m)

→ 5- Burn candidates are selected if provide persistent evidence of fire occurrence in order to reduce errors of commission

Condition 1 = $(N_{detected} \geq 3$ and $(N_{detected}/N_{used}) \geq 0.5$

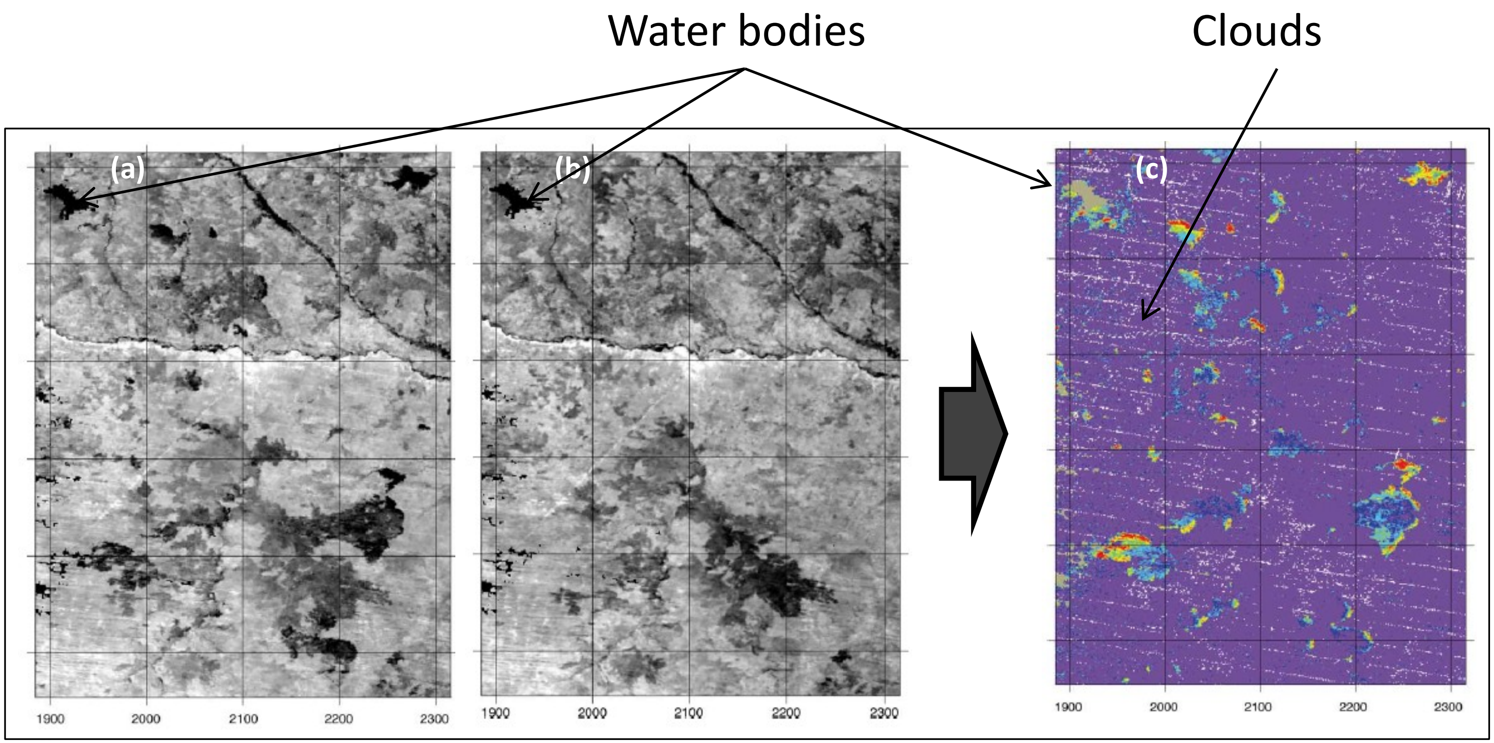
At least 3 observations are detected as burn areas

Condition 2 = the residual burn candidates, not selected in the condition 1, are considered if at least three neighbors have been selected

METHODS

PRODUCT 2:
MCD45
(500m)

5- Burn candidates are selected if there is persistent evidence of fire occurrence



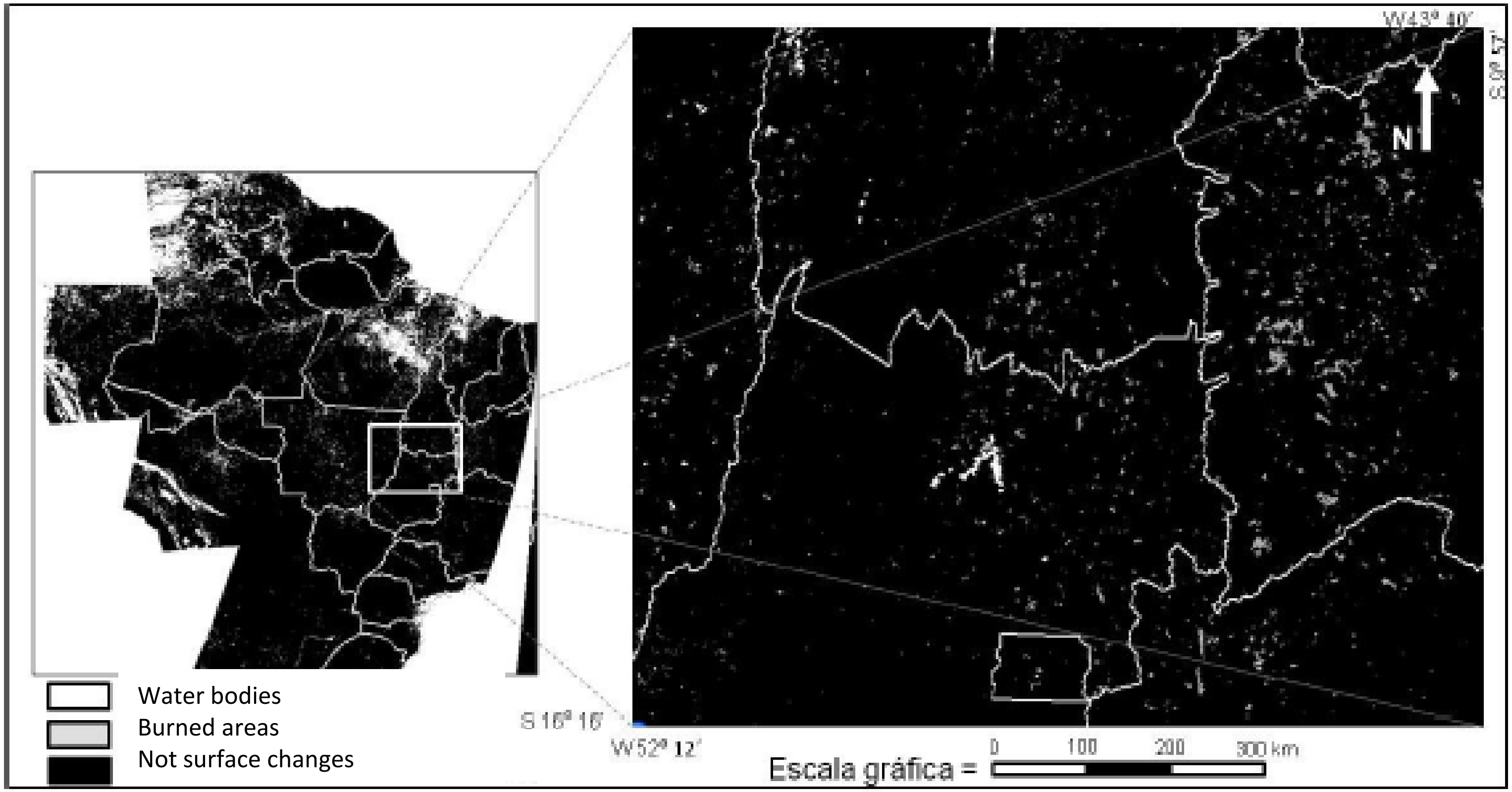
(Roy et al, 2007)

Temporary changes

METHODS

PRODUCT 2:
MCD45
(500m)

5- Burn candidates are selected if there is persistent evidence of fire occurrence



Example of burn candidates selected by the MCD45 algorithm (October, 2005)

METHODS

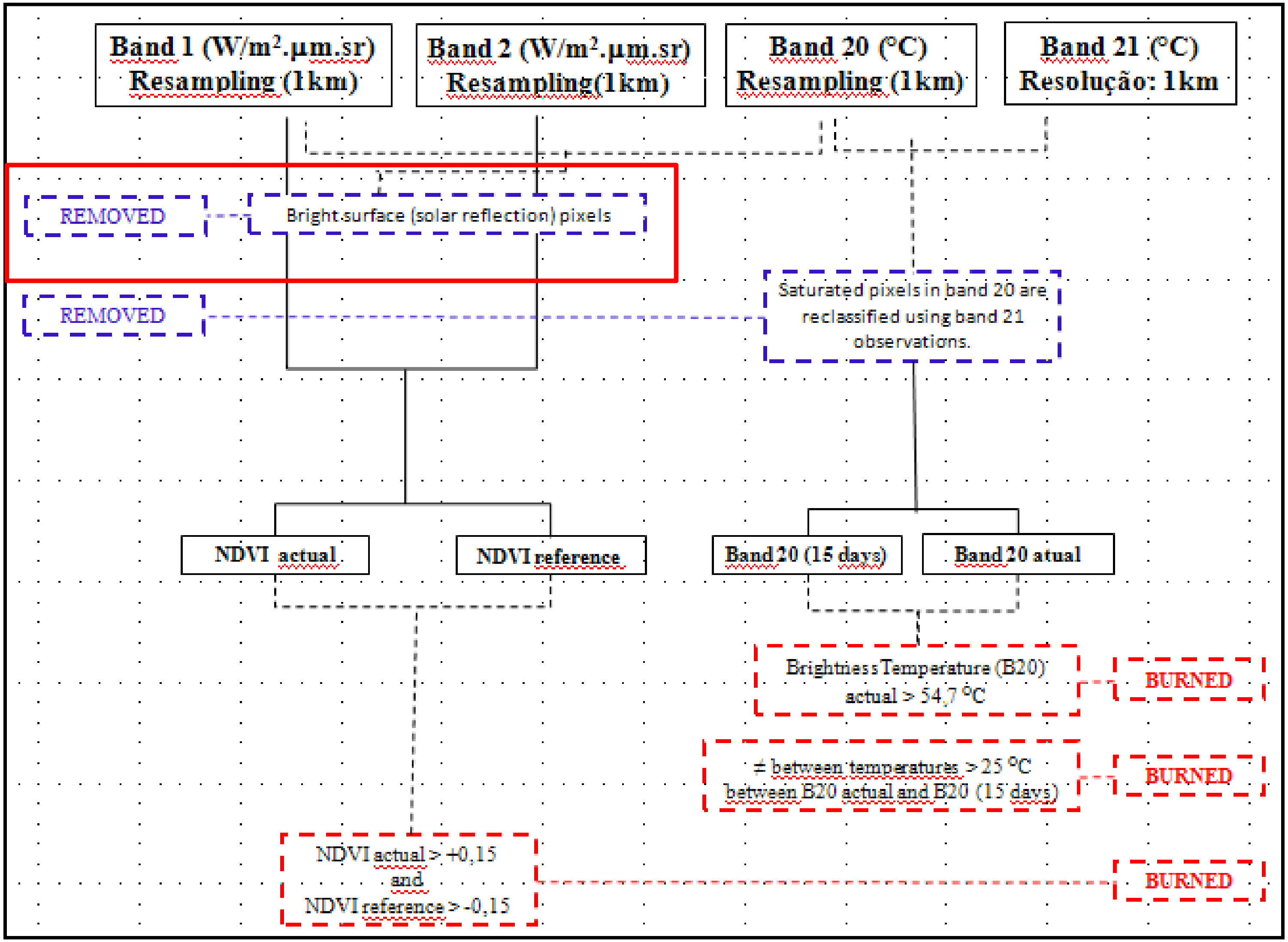
PRODUCT 3:
Burn Area Detection
(1000m)

-Algorithm based in NDVI and MID-IR empirical criteria threshold to detect burned areas.
-MODIS/AQUA. Bands 1,2 (250 m) and 20, 21 (1000 m).

METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

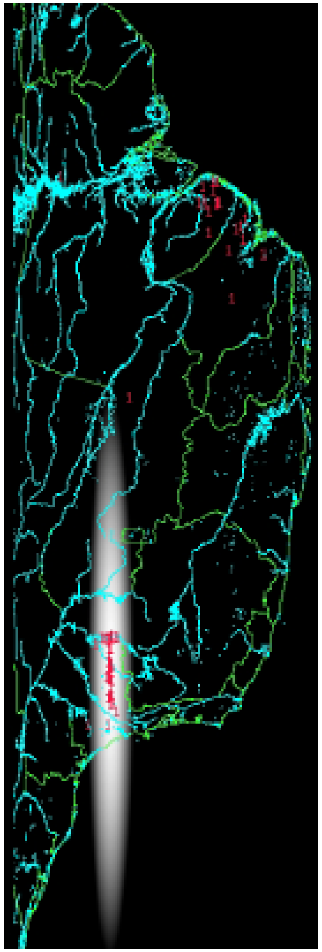
1- Bright surface (solar reflection) pixels are removed (band 20)



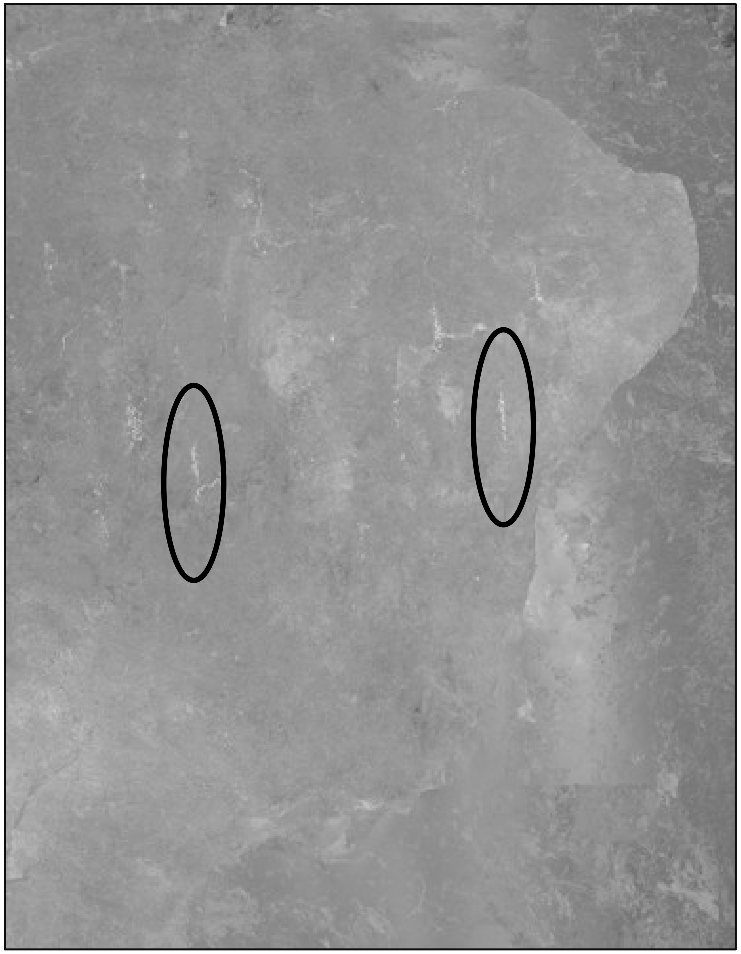
METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

1- Bright surface (solar reflection) pixels are removed (band 20)



Solar Zenith Reflection angle

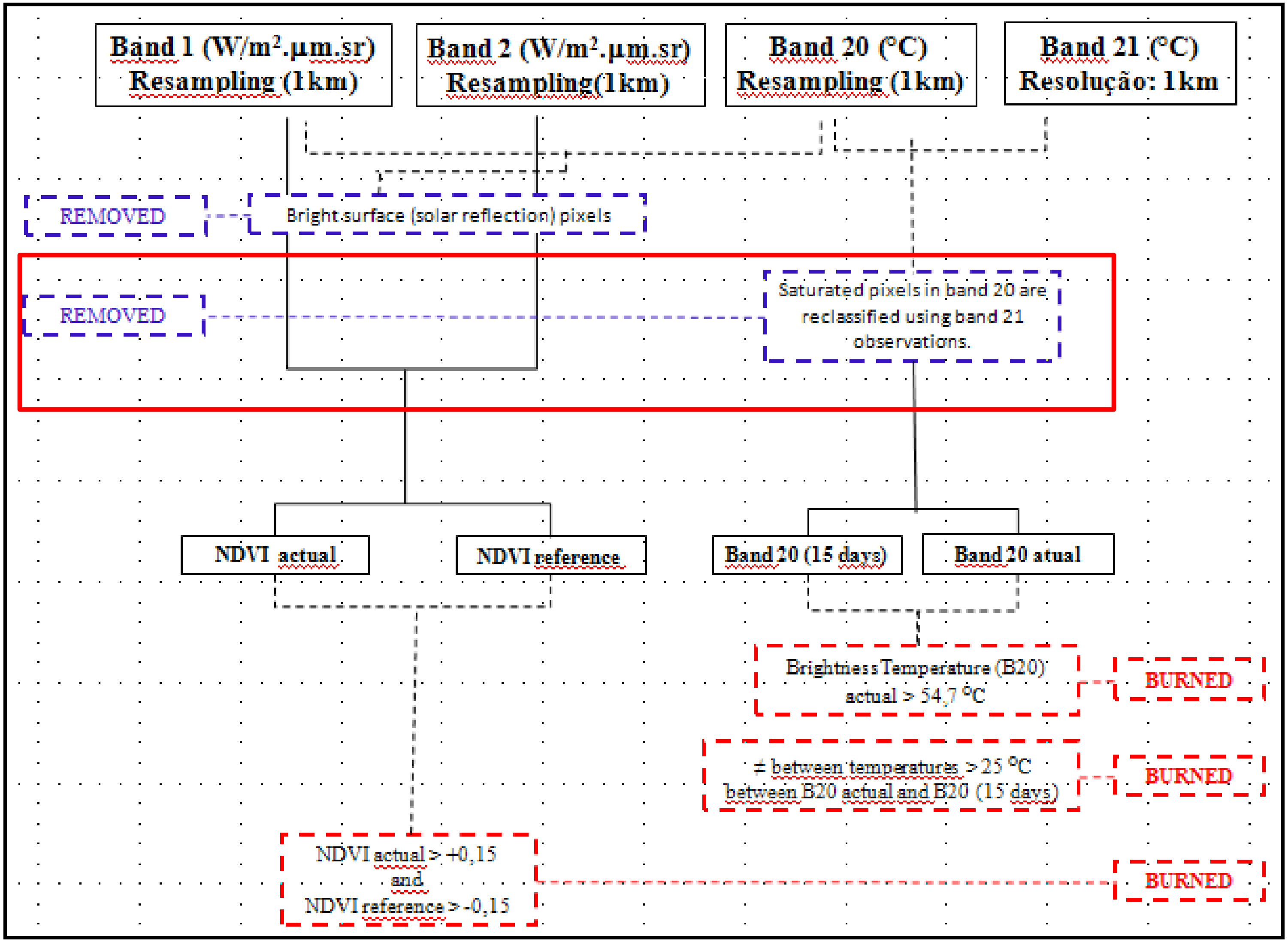


Band 20

METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

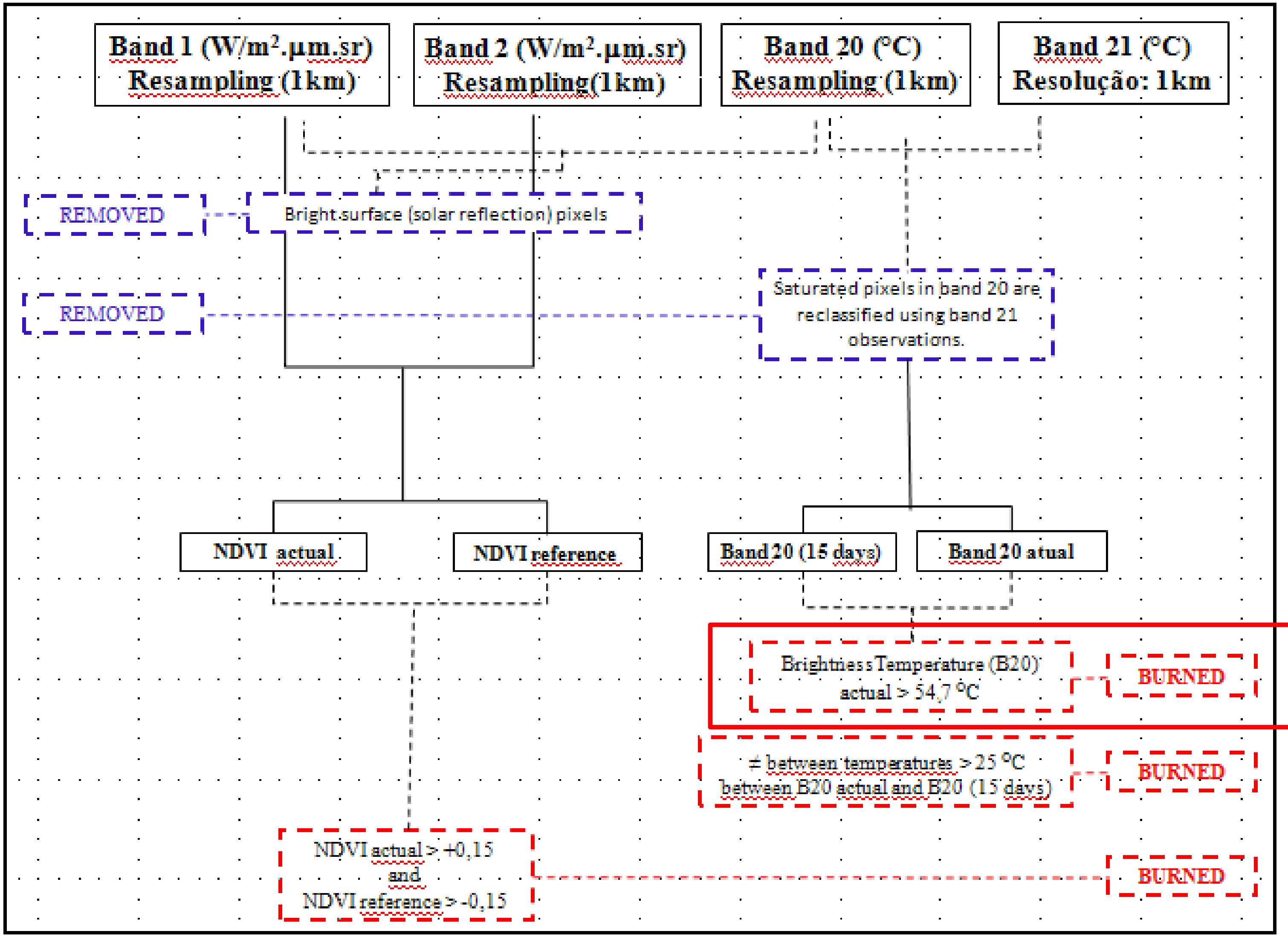
2- Saturated pixels in band 20 (~300ºK) are reclassified using band 21 observations. Low-saturation threshold (~500 ºK)



METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

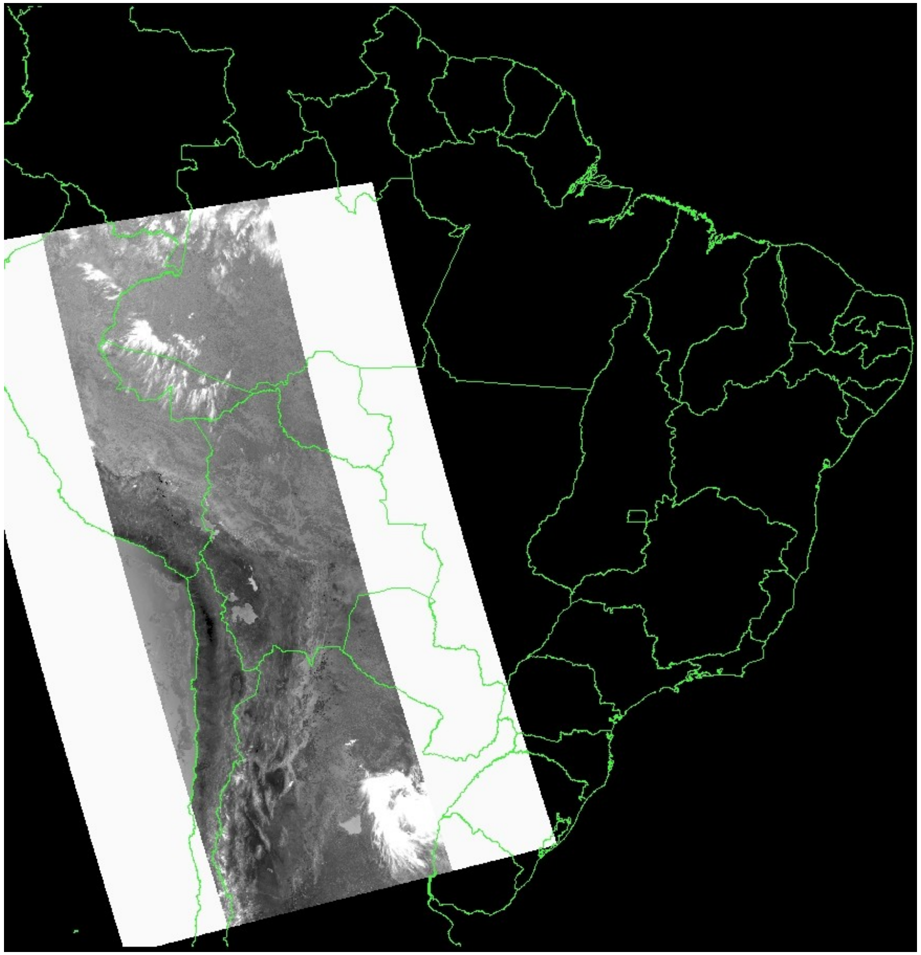
3- If T_{actual} > 54.7 ºC (band 20) pixels are classified as burn candidate



METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

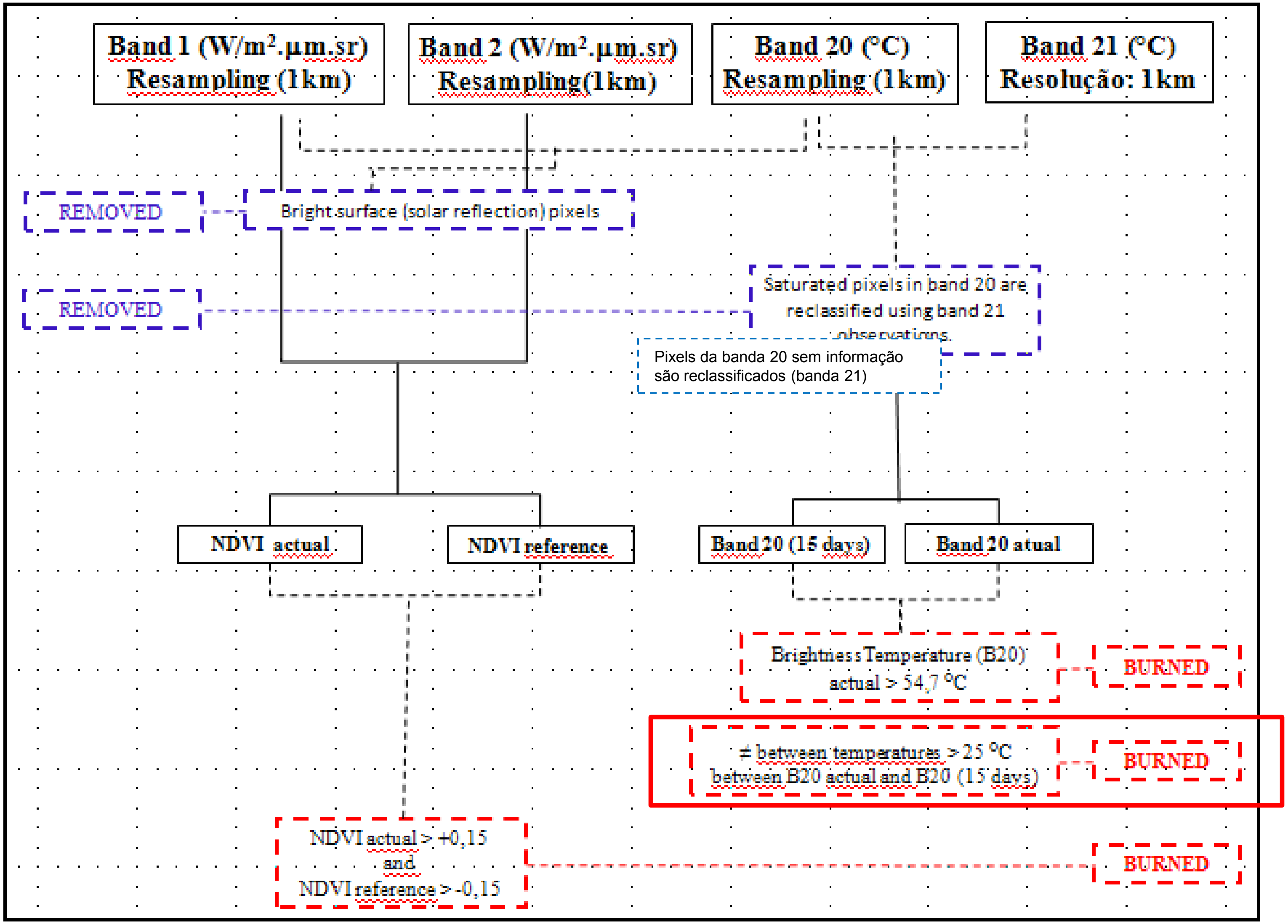
3- If $T_{actual} > 54.7\ ^{o}C$ (band 20) pixels are classified as burn candidate



METHODS

PRODUCT 3: Burn Area Detection (1000m)

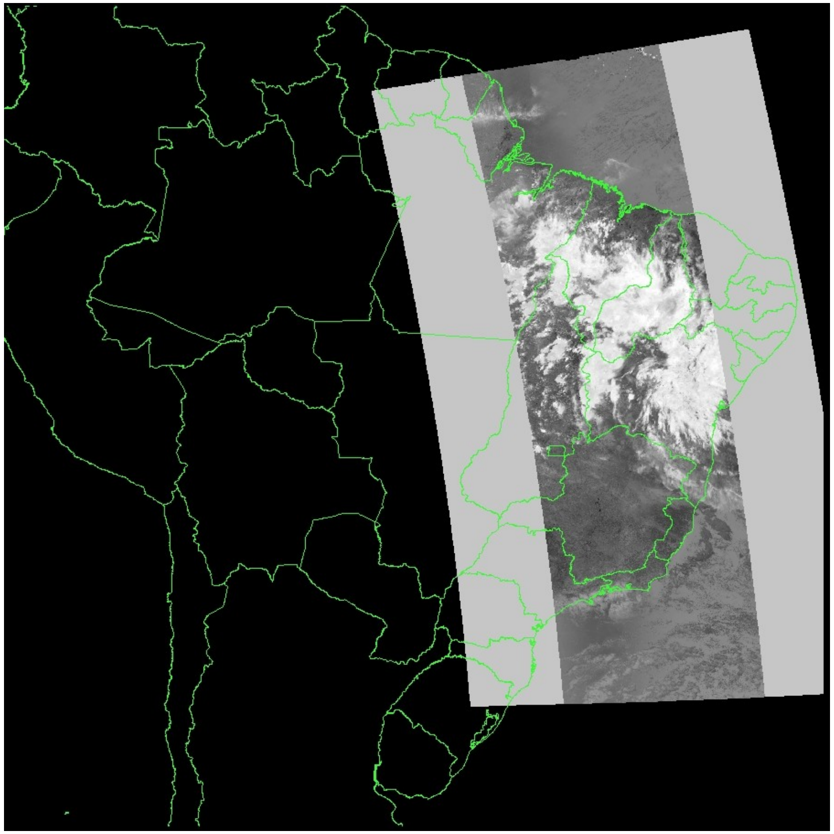
4- If differences between T_{actual} and $T_{15\ days}$ > 25 °C (band 20) pixels are classified as burn candidate



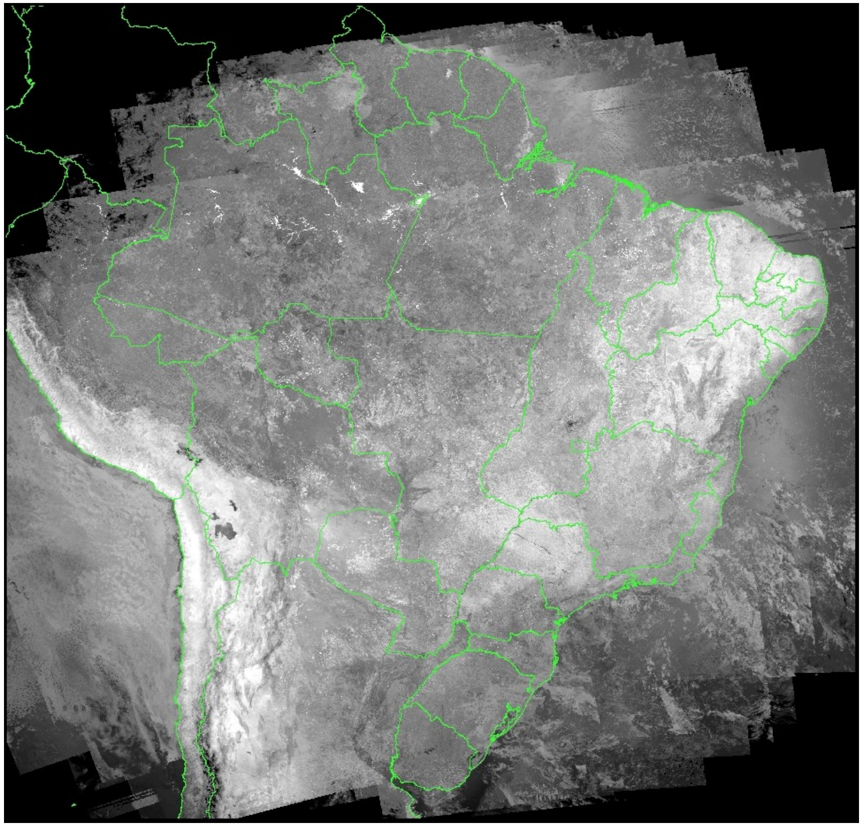
METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

4- If differences between T_{actual} and $T_{15\ days}$ > 25 ^{o}C (band 20) pixels are classified as burn candidate



band 20 (MID-Infrared) Actual Temperature

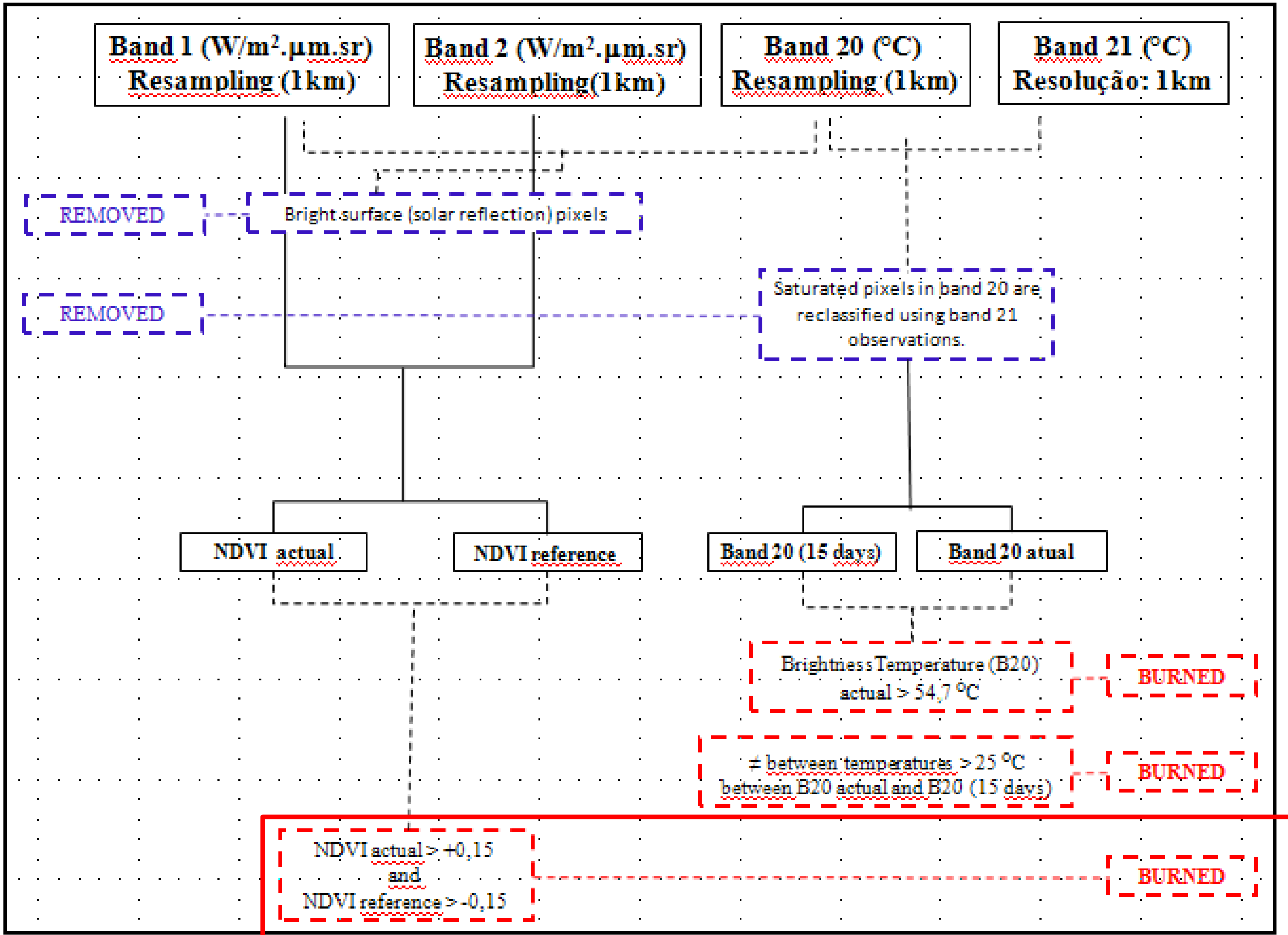


band 20 (MID-Infrared) Maximum temperature (15 days)

METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

5- Pixels classified as burned candidate are compare with surface change detection pixels (NDVI estimation)



METHODS

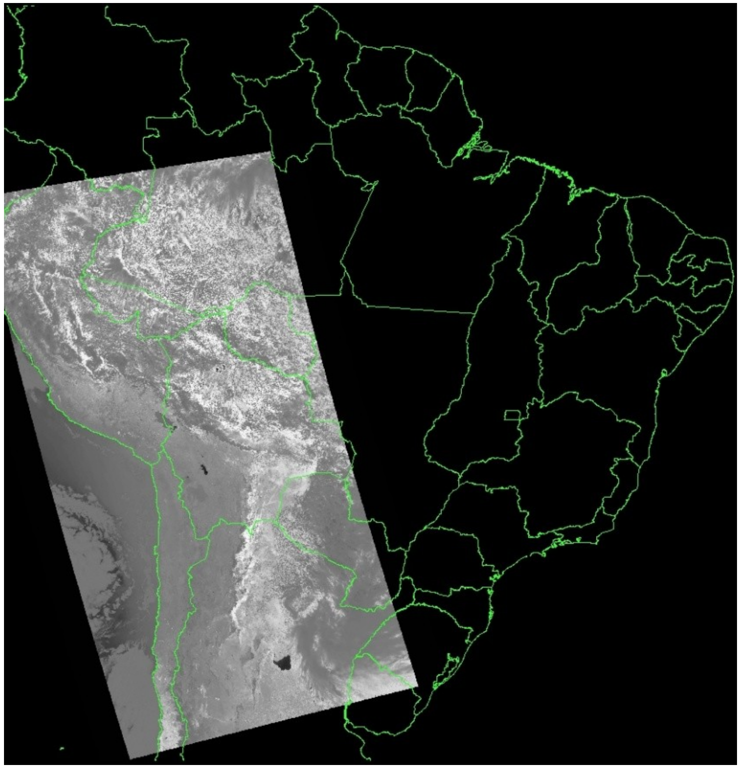
PRODUCT 3:
Burn Area Detection
(1000m)

5- Pixels classified as burned candidate are compare with surface change detection pixels (NDVI estimation)

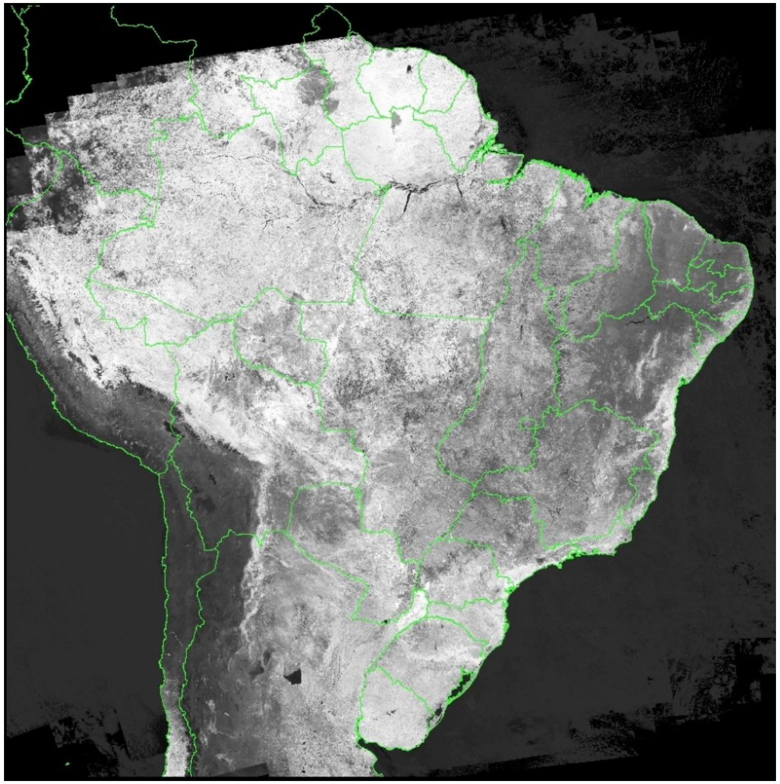
If:

$\mathbf{NDVI_{actual} > +0.15}$ **and** $\mathbf{NDVI_{reference} > -0.15}$

pixels are reclassified as effective burned area



Actual NDVI

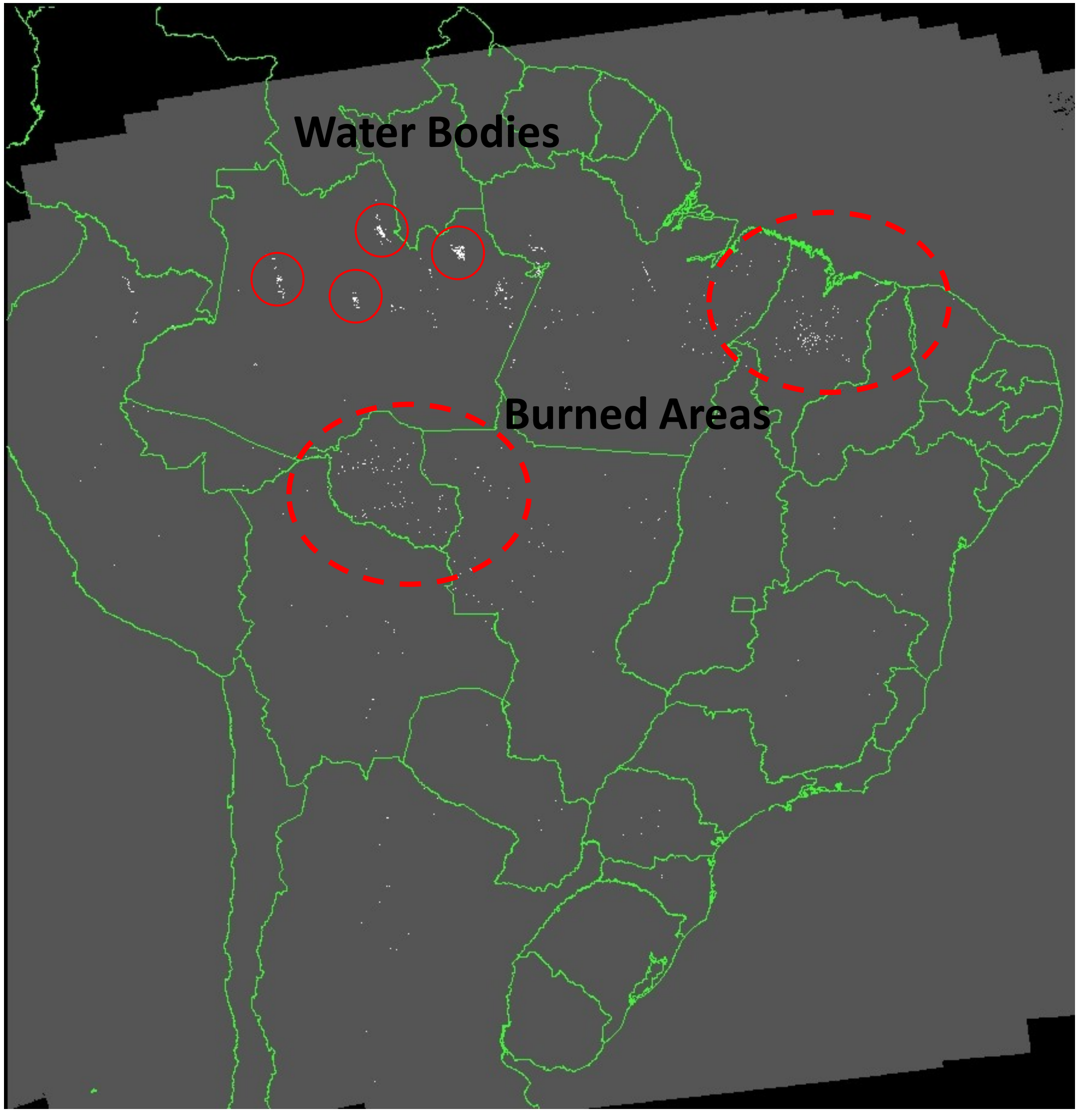


Reference NDVI (annual)

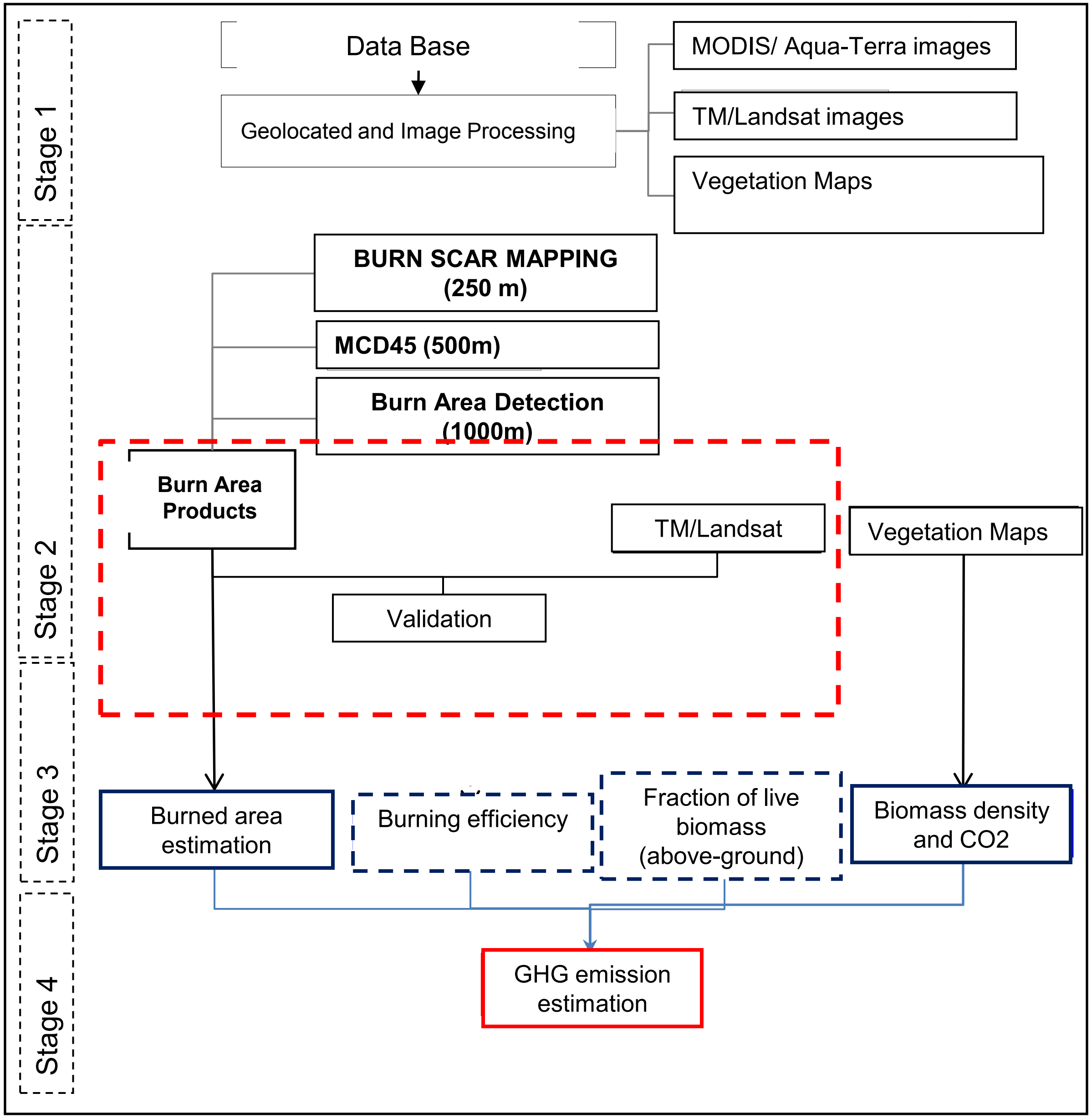
METHODS

PRODUCT 3:
Burn Area Detection
(1000m)

Example of burned area detected by the algorithm



METHODS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Stage 4
GHG emission
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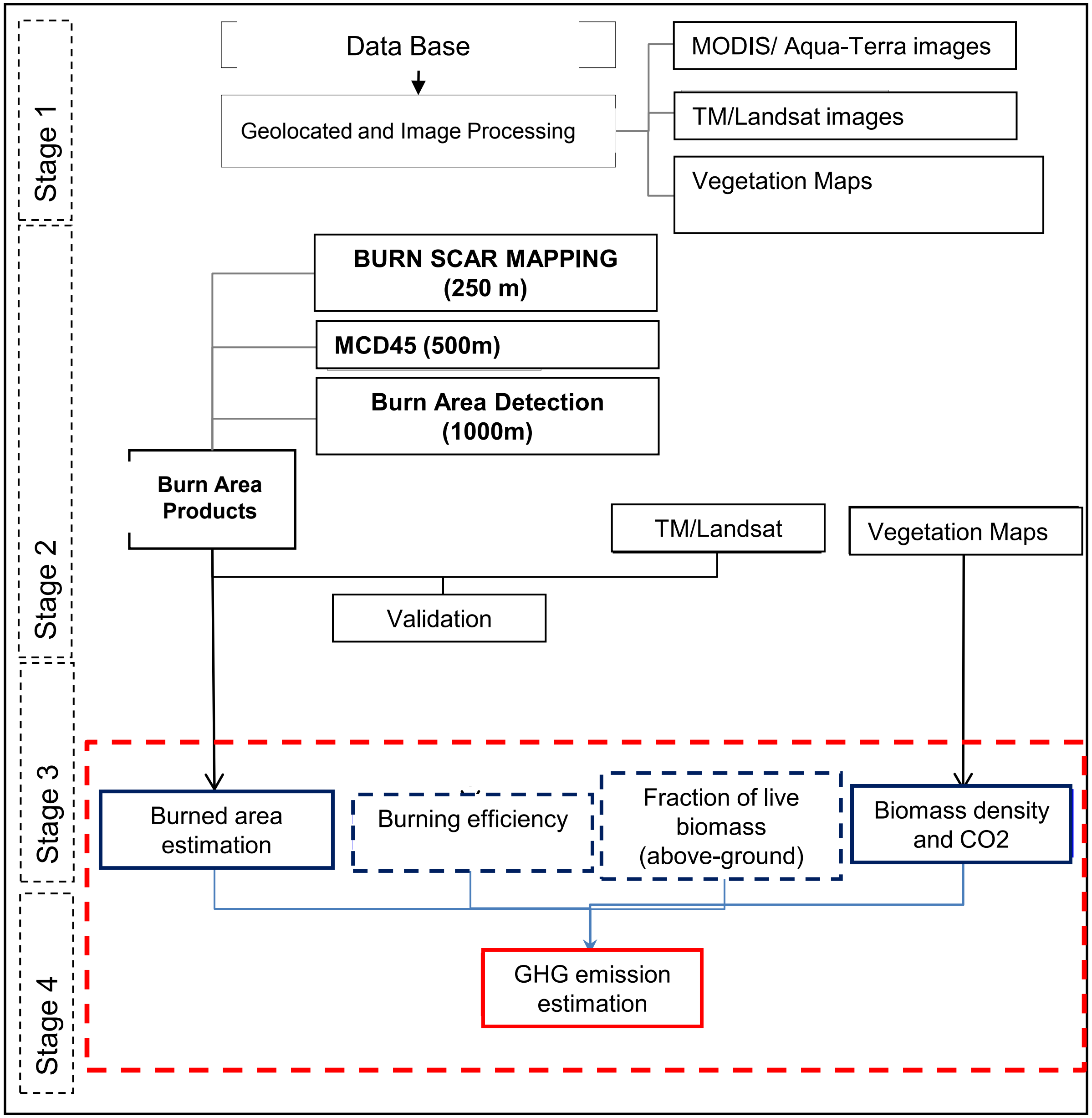
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Methods

Biomass Burning Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

***M* = biomass burned**

A = burned area

B = biomass density

FAB = fraction of live biomass above-ground

E = burning efficiency

$$M(CO_2) = \mathbf{M} \times C \times EC$$

M ***(CO_2)*** = Total CO_2 released

***M* = biomass burned**

C = proportion of CO_2 in the biomass consumed by fire

EC = combustion efficiency

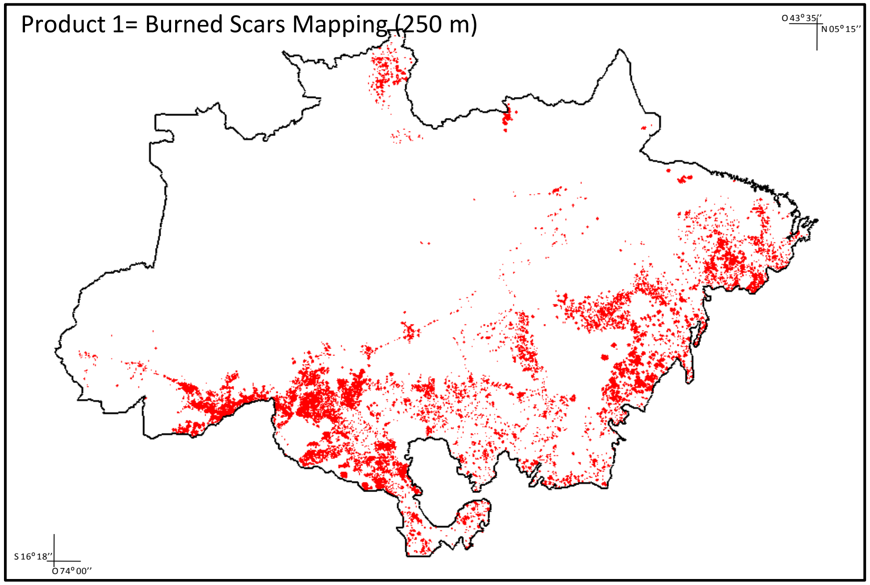
Methods

Biomass Burning Emission

M = A x B x FAB x E

M **= biomass burned**

A = burned area (ha)



Methods

Biomass Burning

Emission

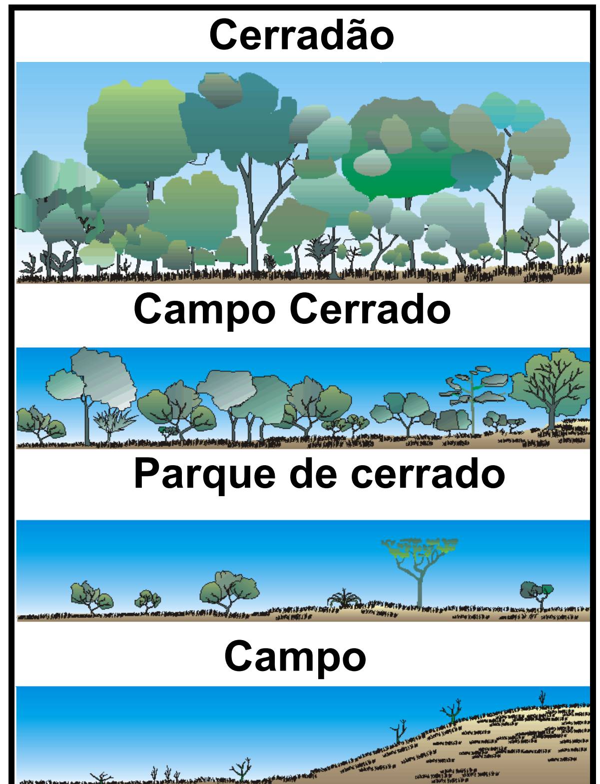
$M = A \times B \times FAB \times E$

M **= biomass burned**

A = burned area

B = biomass density

(Total amount of vegetation – live or dead-above ground availabel to be consumed by fire, in kg. m^{-2})



Cerrado (Savanna) biome

Methods

Biomass Burning

Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

***M* = biomass burned**

A = burned area

B = biomass density

FAB = fraction of live biomass above-ground (0 to 1, coefficient)

Methods

Biomass Burning

Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

***M* = biomass burned**

A = burned area

B = biomass density

FAB = fraction of live biomass above-ground

E = burning efficiency

water contents in combustion matter (0 to 1, coefficient)

Methods

Biomass Burning

Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

***M* = biomass burned**

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$$M (CO_2) = \mathbf{M} \times C \times EC$$

M (CO_2) = Total CO_2 released

***M* = biomass burned**

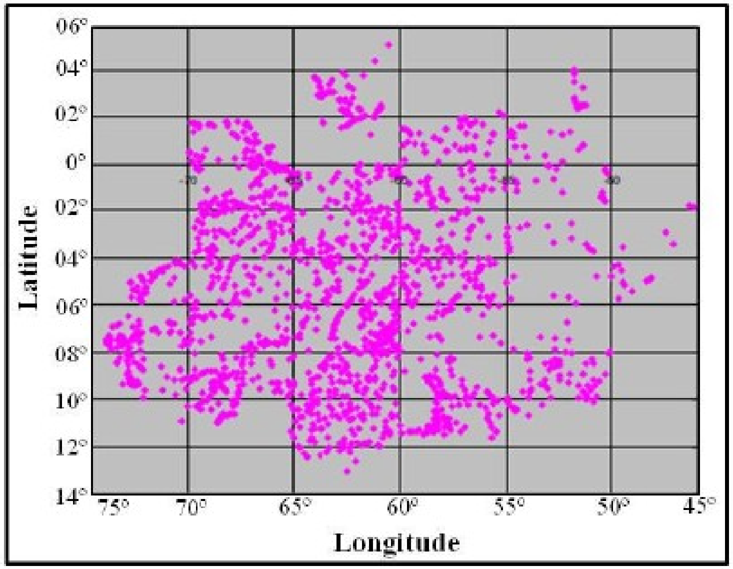
C = proportion of CO_2 in the biomass consumed by fire

EC = combustion efficiency

Methods

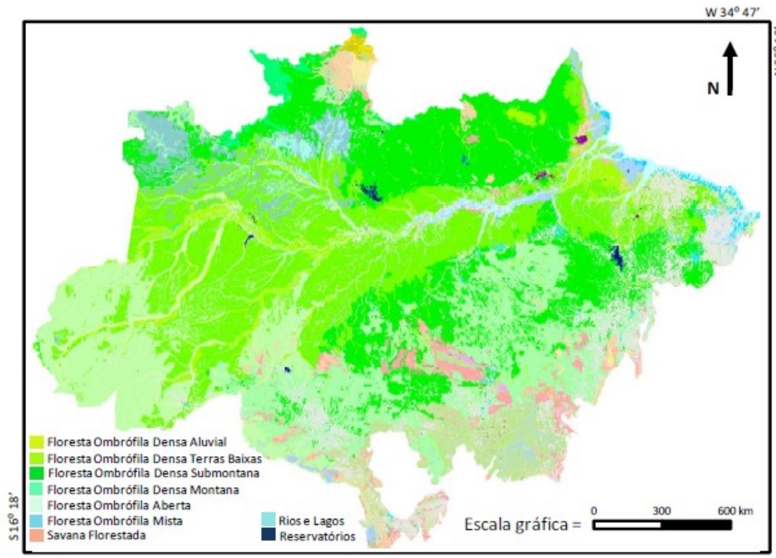
Biomass density (B)

Proportion of CO_2 in the biomass



B and C sample units
(MCT, 2006)

Vegetation Map (MCT, *in press*)

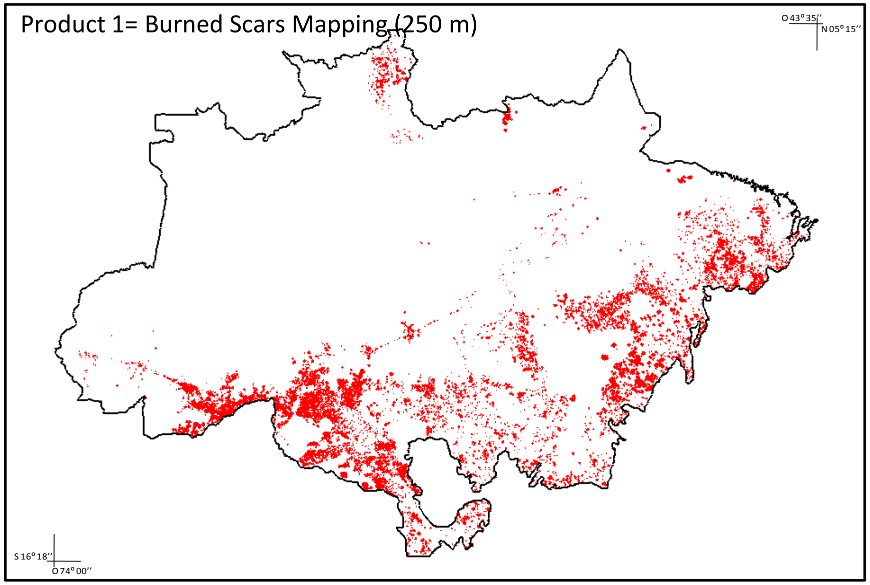


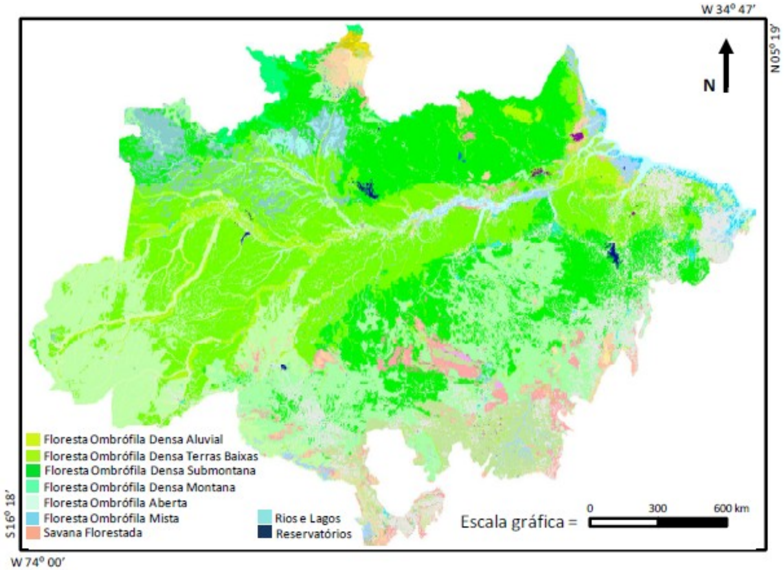
Methods

Proportion of CO_2 in the biomass consumed by fire (C)

Burned Areas

Vegetation Map (MCT, *in press*)





Methods

Biomass Burning

Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

***M* = biomass burned**

A = burned area

B = biomass density

FAB = fraction of live biomass above-ground

E = burning efficiency

$$M(CO_2) = \mathbf{M} \times C \times EC$$

M (CO_2) = Total CO_2 released

***M* = biomass burned**

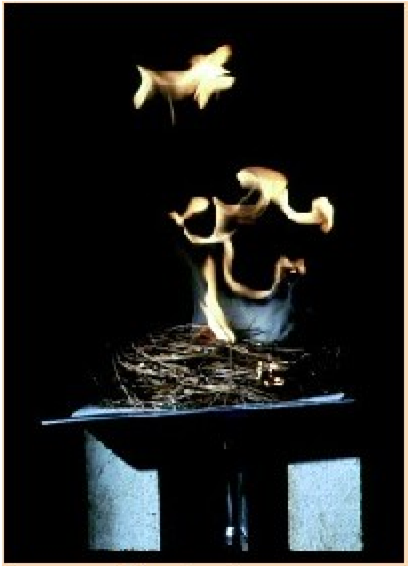
C = proportion of CO_2 in the biomass consumed by fire

EC = combustion efficiency

Combustion stages (flaming or smoldering)

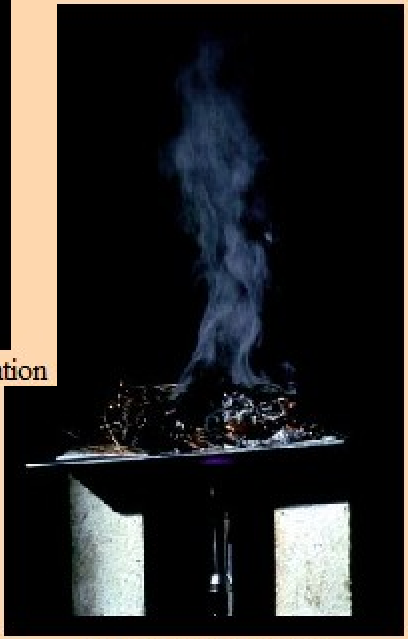
(0 to 1, coefficient)

EC = combustion efficiency

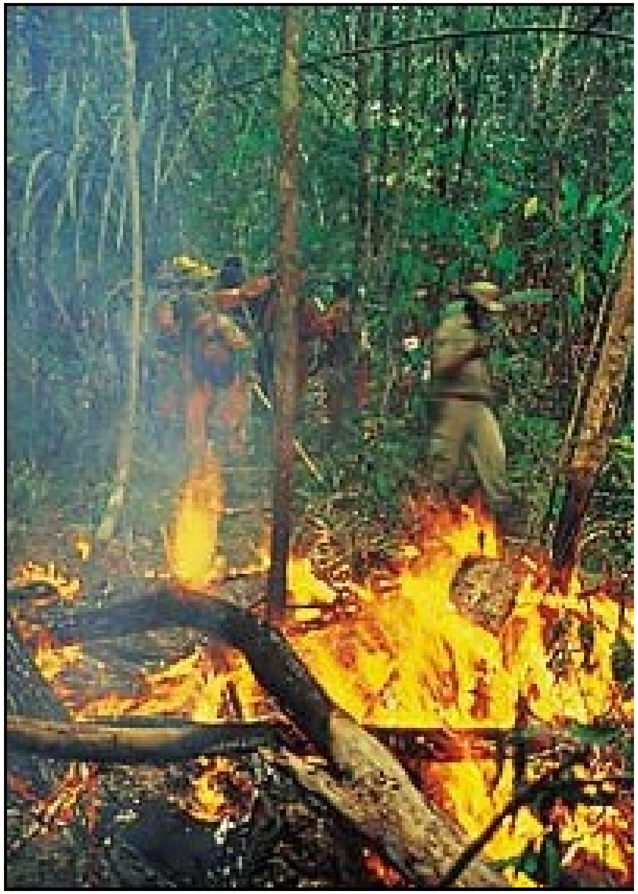


Flaming stage

Flaming & Residual Smoke Generation



Residual /Smoldering



Methods

Biomass Burning

Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

M **= biomass burned**

A = burned area

B = biomass density

FAB = fraction of live biomass above-ground

E = burning efficiency

$$M(CO_2) = \mathbf{M} \times C \times EC$$

M ***(CO_2)*** = Total CO_2 released

M **= biomass burned**

C = proportion of CO_2 in the biomass consumed by fire

EC = combustion efficiency

Methods

Biomass Burning Emission

$$\mathbf{M} = A \times B \times FAB \times E$$

M **= biomass burned**

A = burned area

B = biomass density

FAB = fraction of live biomass above-ground

E = burning efficiency

$$M(CO_2) = \mathbf{M} \times C \times EC$$

M (CO_2) = Total CO_2 released

M **= biomass burned**

C = proportion of CO_2 in the biomass consumed by fire

EC = combustion efficiency

$$M(CO) = M(CO_2) \times ER$$

$$M(NO_x) = M(CO_2) \times ER$$

$$M(CH_4) = M(CO_2) \times ER$$

ER = emission ratio

Results

Burned area estimative for Amazonia (AM) and Cerrado (CE) biomes

	PRODUTOS DE AREAS QUEIMADAS (km²)		
	Produto 1	**Produto 2**	**Produto 3**
Bioma AM	70.500	20.900	64.100
Bioma CE	115.700	77.400	26.000
TOTAL	186.200	98.300	90.100

70 %

Product 1= Burned Scars Mapping (250 m)
Product 2= Land Cover Change-MCD45 (500 m)
Product 3= Burned Area Detection (1000 m)
Product 3= Thermal Anomalies (1000 m)

Results

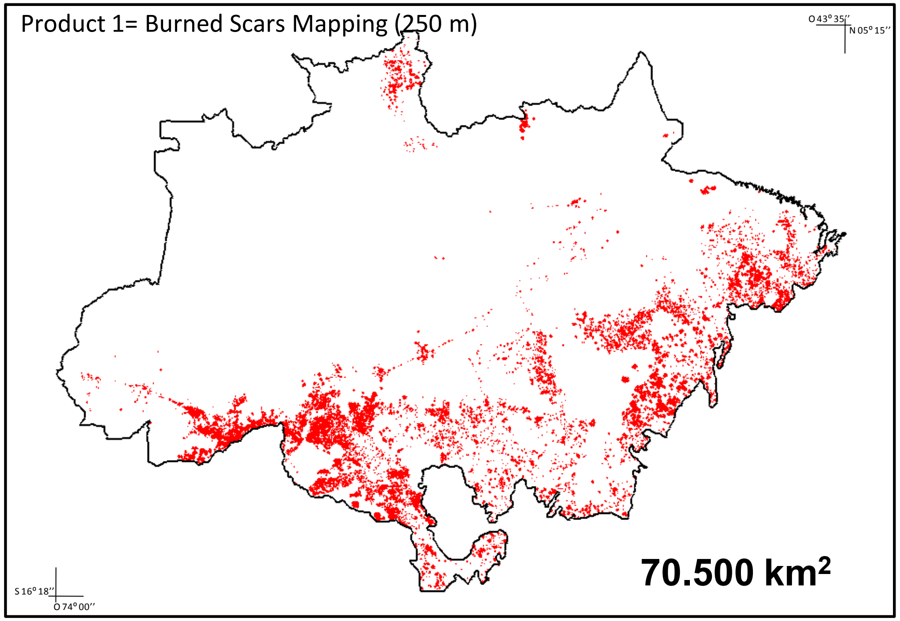
Burned area estimative for Amazonia (AM) and Cerrado (CE) biomes

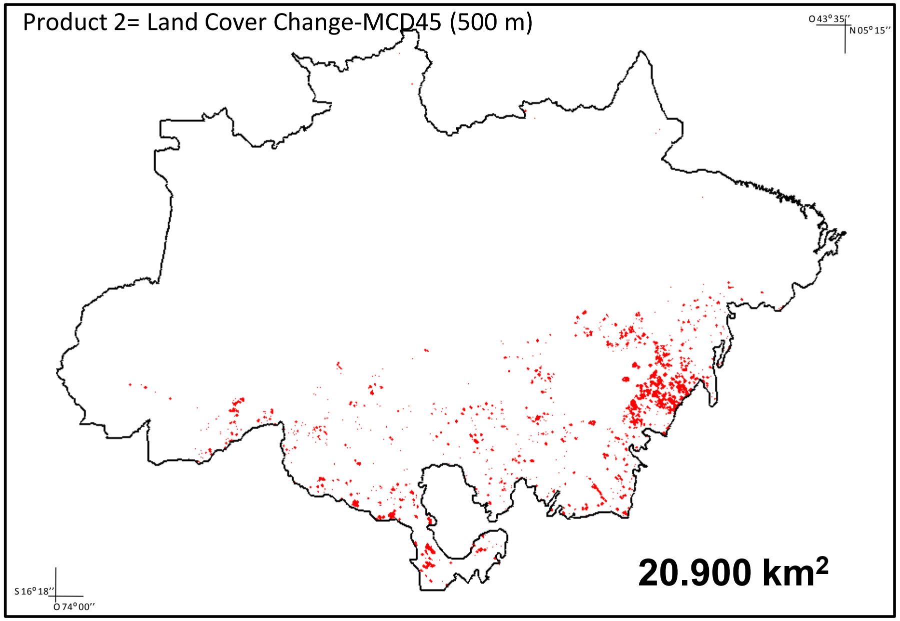
	PRODUTOS DE AREAS QUEIMADAS (km²)			
	Produto 1	**Produto 2**	**Produto 3**	**Thermal Anomalies**
Bioma AM	70.500	20.900	64.100	149.200
Bioma CE	115.700	77.400	26.000	80.400
TOTAL	186.200	98.300	90.100	229.600

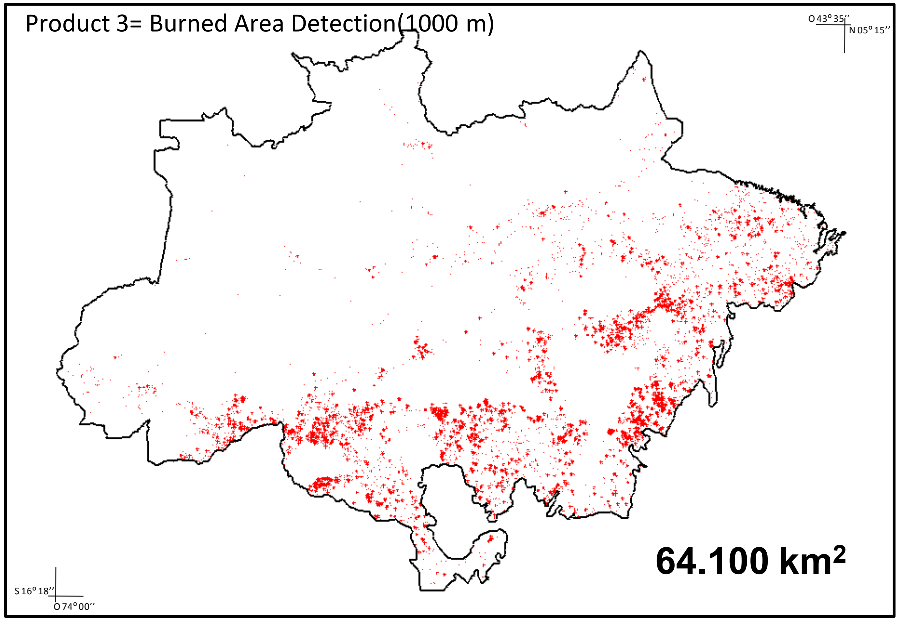
85%

Product 1= Burned Scars Mapping (250 m)
Product 2= Land Cover Change-MCD45 (500 m)
Product 3= Burned Area Detection (1000 m)
Product 3= Thermal Anomalies (1000 m)

Results


Product 1= Burned Scars Mapping (250 m)
O 43° 35''
N 05° 15''
S 16° 18''
O 74° 00''
70.500 km²


Product 2= Land Cover Change-MCD45 (500 m)
O 43° 35''
N 05° 15''
S 16° 18''
O 74° 00''
20.900 km²


Product 3= Burned Area Detection(1000 m)
O 43° 35''
N 05° 15''
S 16° 18''
O 74° 00''
64.100 km²

Results

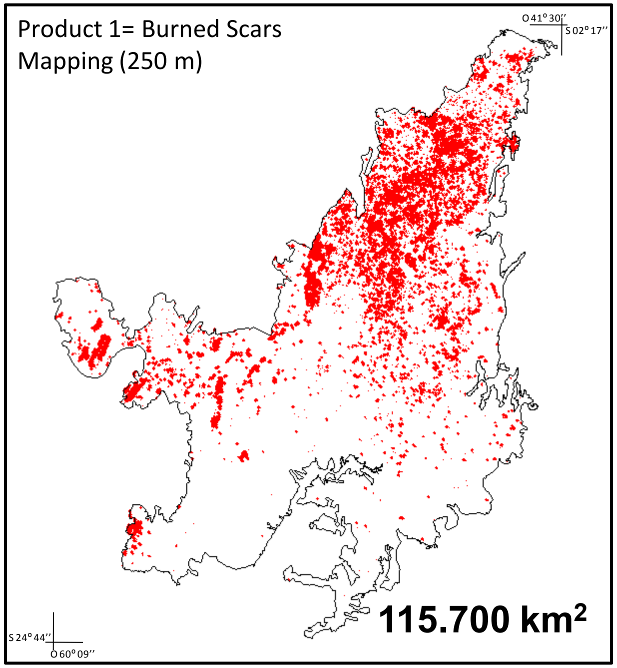
Burned area estimative for Amazonia (AM) and Cerrado (CE) biomes

	PRODUTOS DE AREAS QUEIMADAS (km²)			
	Produto 1	**Produto 2**	**Produto 3**	**Thermal Anomalies**
Bioma AM	70.500	20.900	64.100	149.200
Bioma CE	115.700	77.400	26.000	80.400
TOTAL	186.200	98.300	90.100	229.600

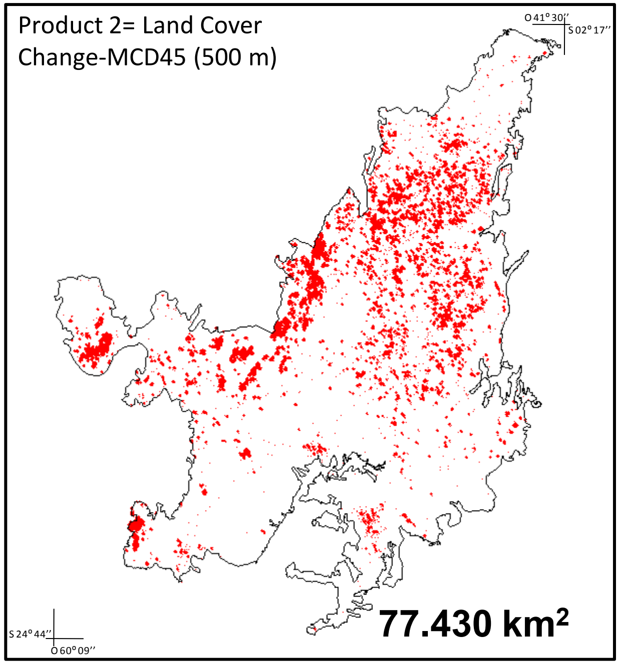
77%

Product 1= Burned Scars Mapping (250 m)
Product 2= Land Cover Change-MCD45 (500 m)
Product 3= Burned Area Detection (1000 m)
Product 3= Thermal Anomalies (1000 m)

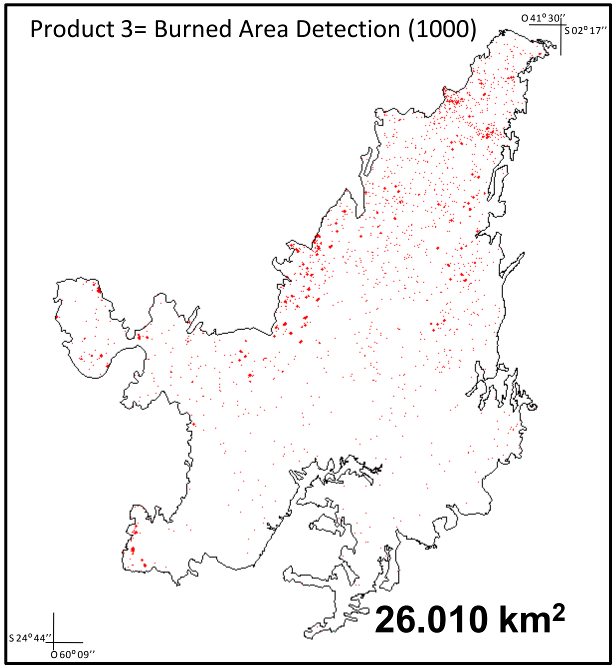
Results



Product 1= Burned Scars
Mapping (250 m)
O 41° 30′
S 02° 17″
S 24° 44″
O 60° 09″
115.700 km²



Product 2= Land Cover
Change-MCD45 (500 m)
O 41° 30′
S 02° 17″
S 24° 44″
O 60° 09″
77.430 km²



Product 3= Burned Area Detection (1000)
O 41° 30′
S 02° 17″
S 24° 44″
O 60° 09″
26.010 km²

Results

BURNED AREA ESTIMATION:

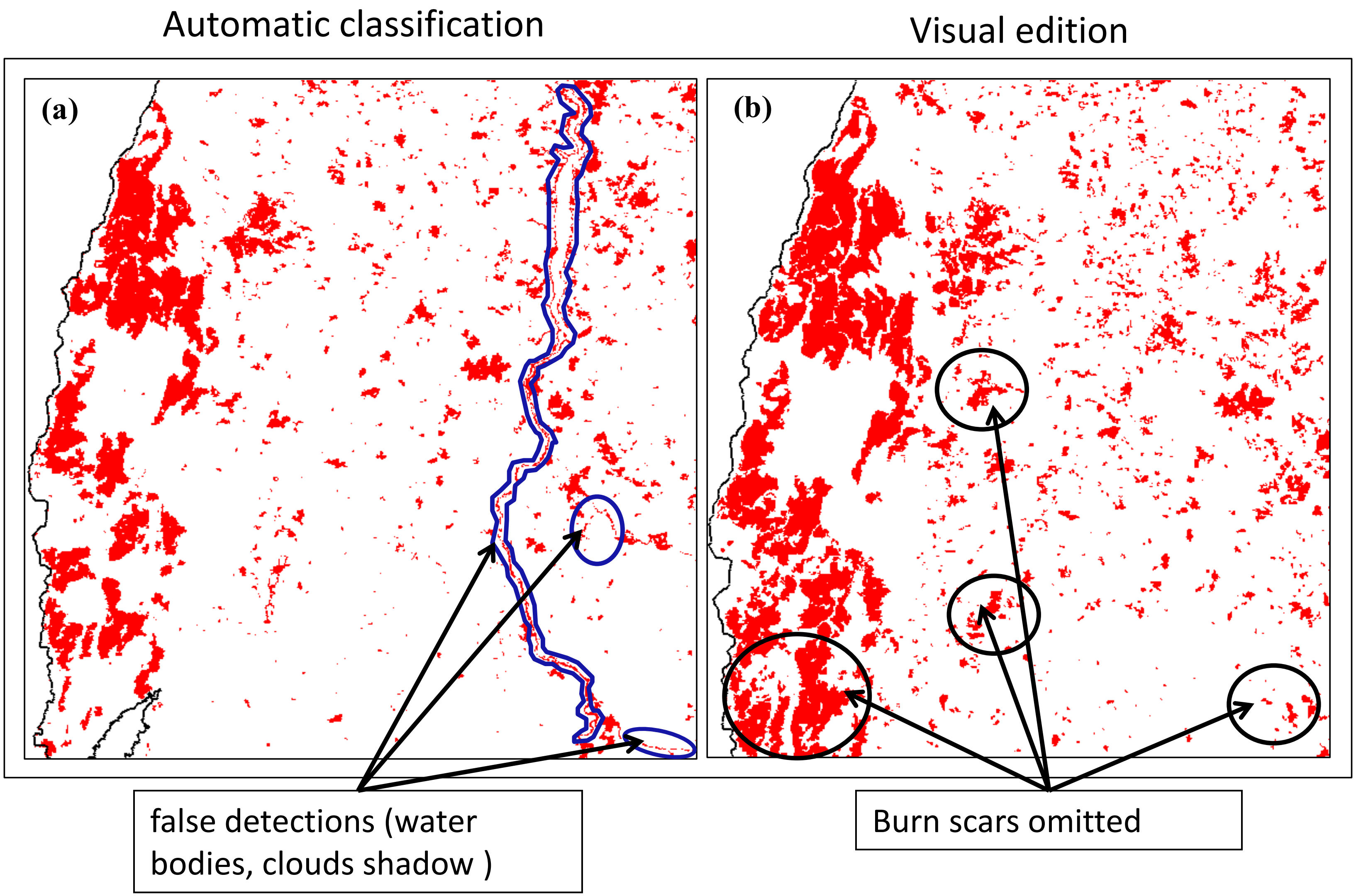
Discrepancy between fire products?

- **Different algorithm criteria for detecting burned areas?**

- **Different spatial and temporal resolutions for detecting burned areas?**

Results

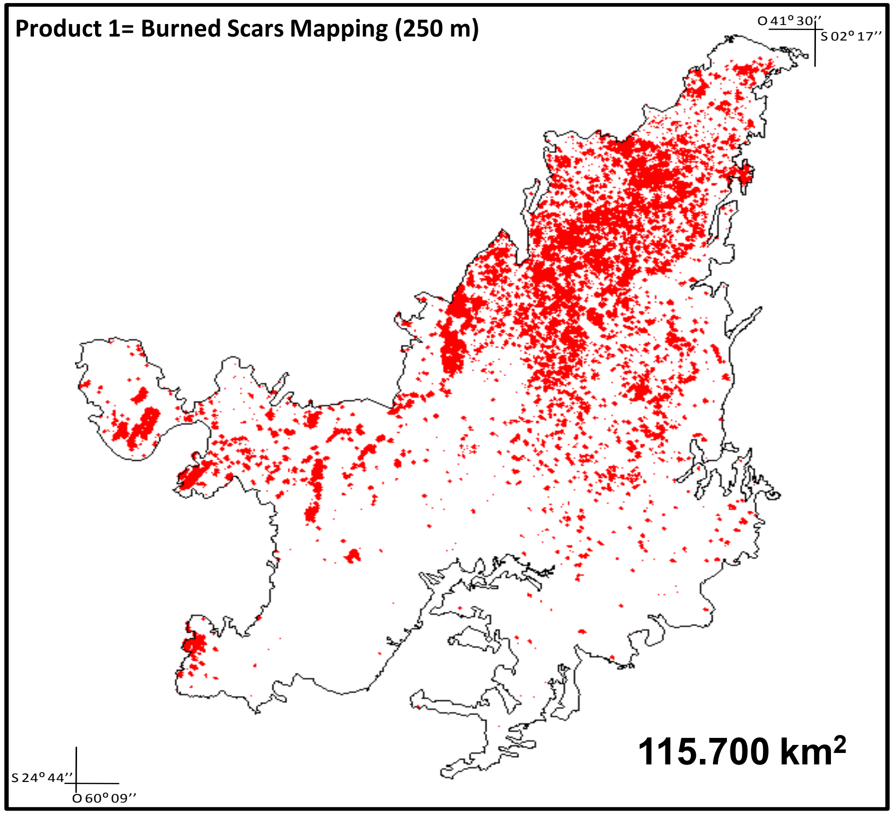
PRODUCT 1:
BURN SCAR MAPPING
(250m)

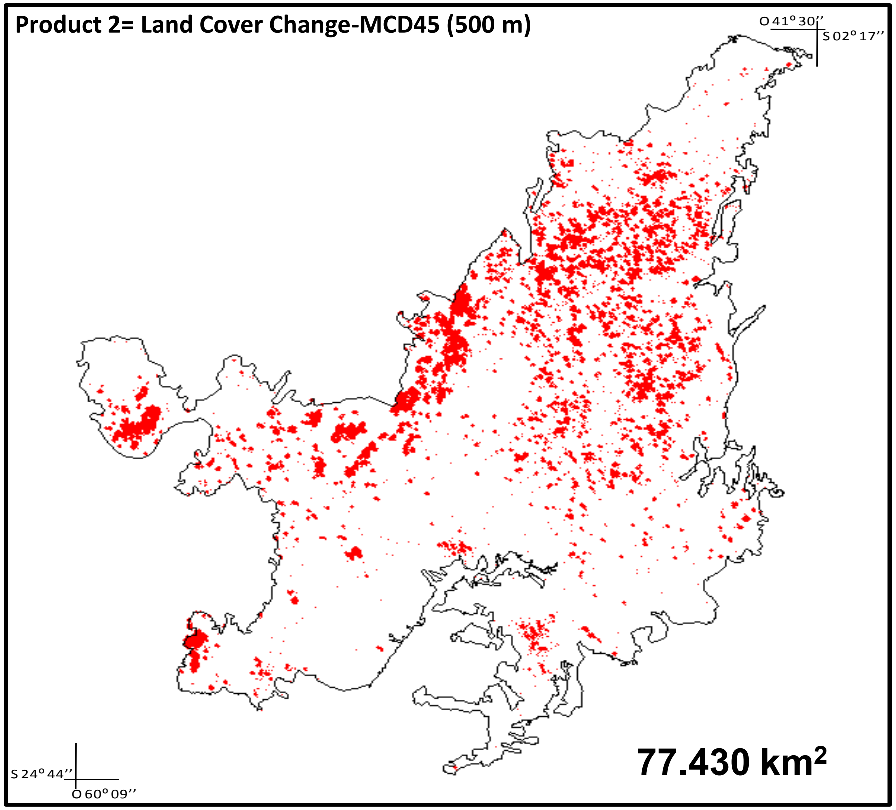


Results

PRODUCT 2:
MCD45
(500m)

Burn scars omitted

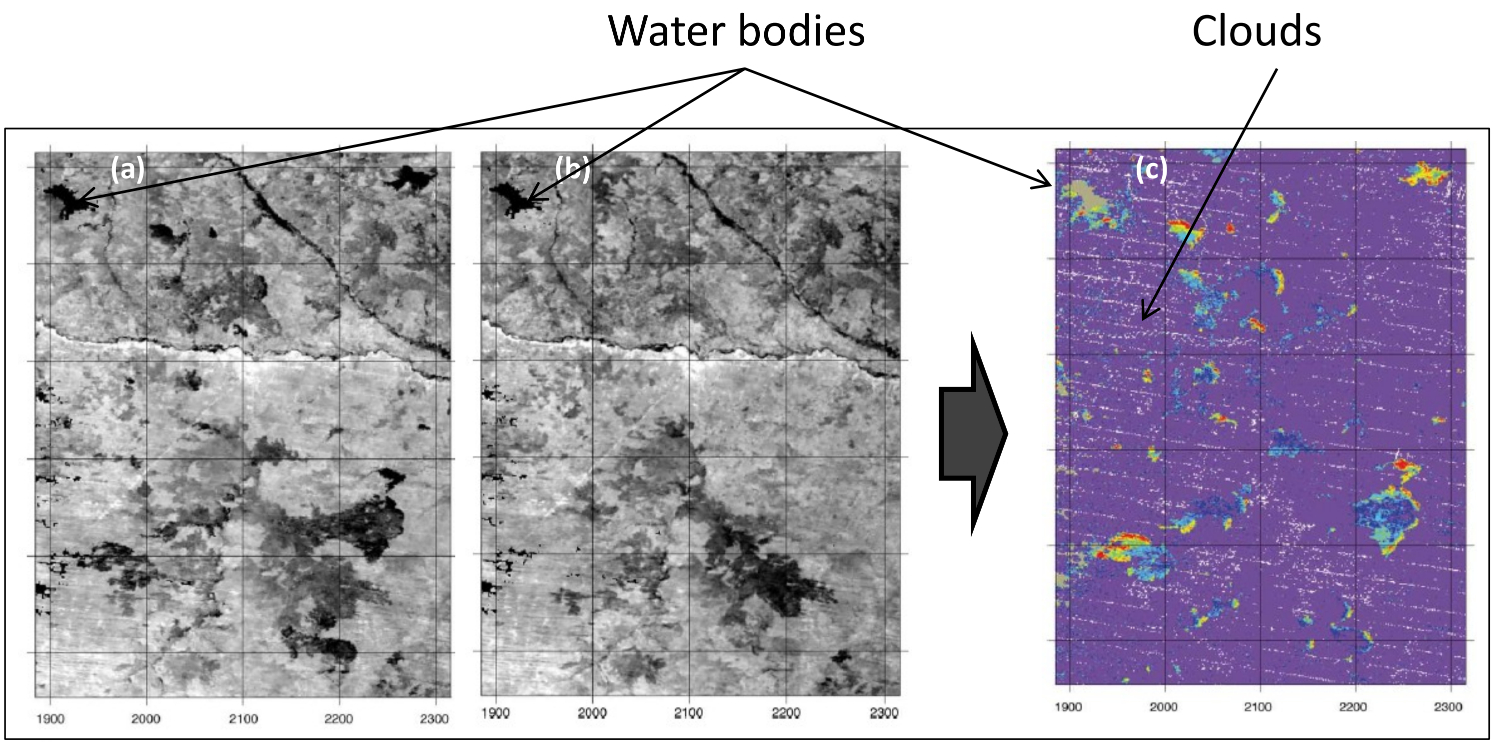




Results

PRODUCT 2:
MCD45
(500m)

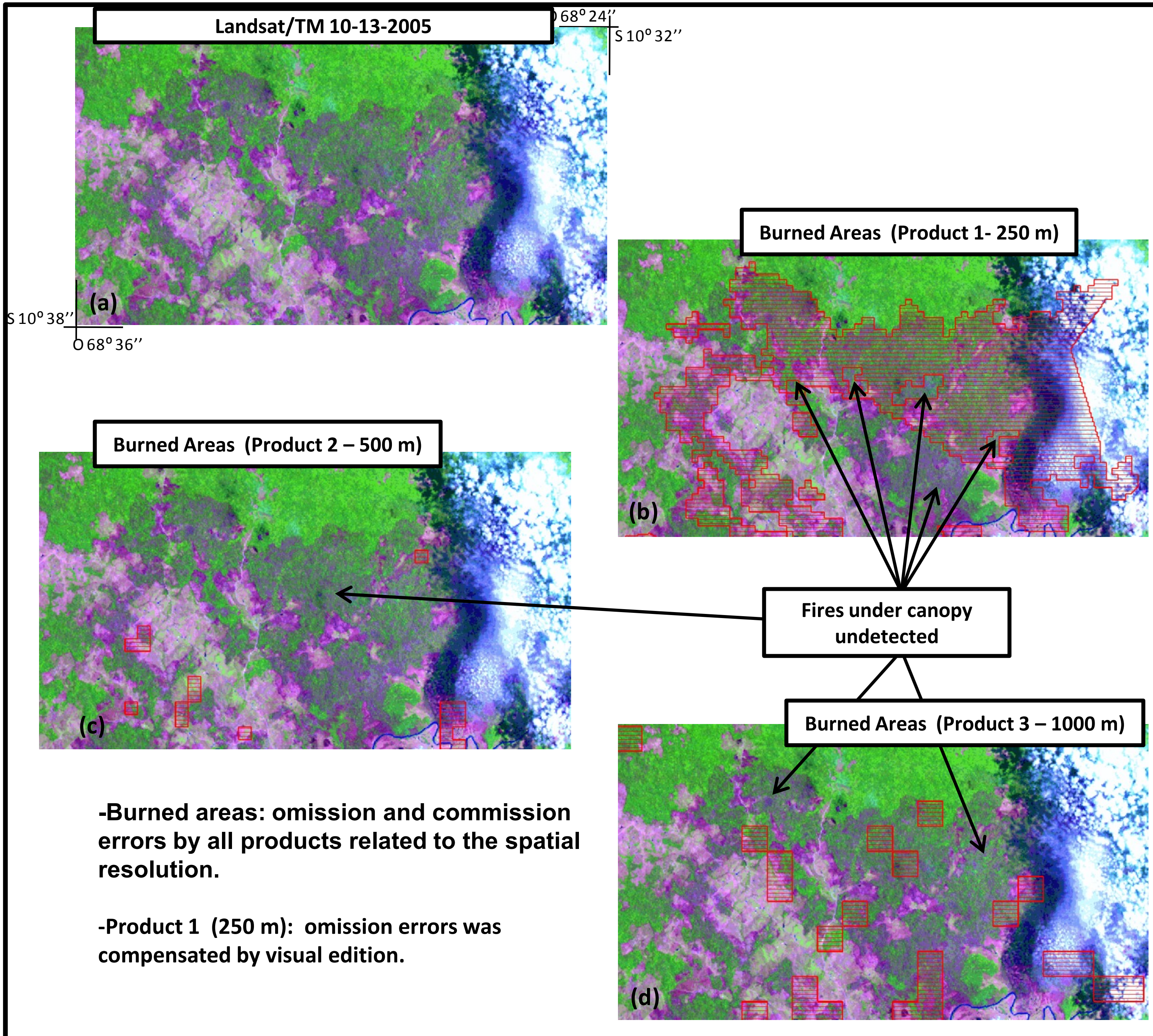
SOURCE: Threshold and equations selecting burned pixels between observed and predicted reflectance



(a) Predicted Reflectance; (b) Observed Reflectance

Temporary changes

(Roy et al, 2007)



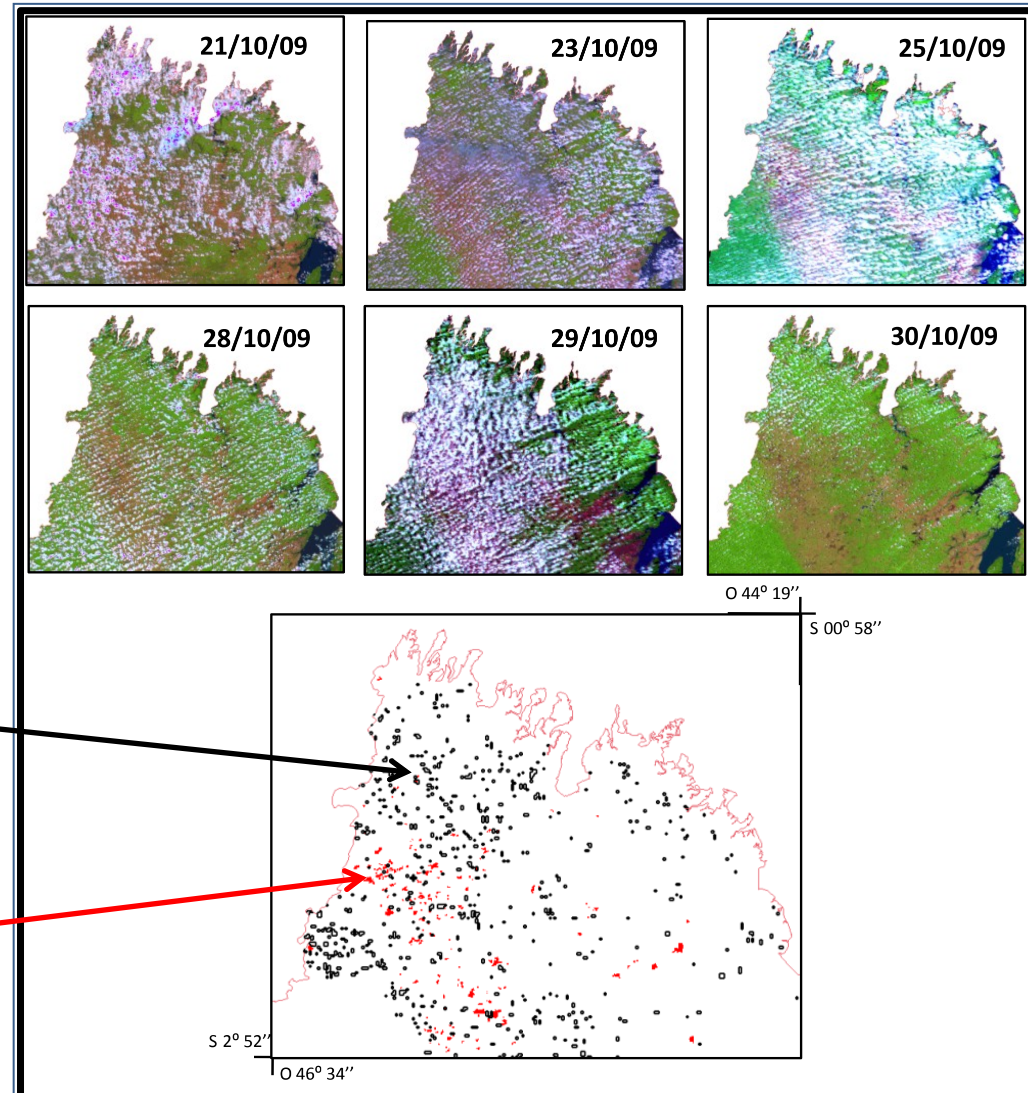
Landsat/TM 10-13-2005
O 68º 24''
S 10º 32''
(a)
S 10º 38''
O 68º 36''
Burned Areas (Product 1- 250 m)
(b)
Burned Areas (Product 2 – 500 m)
(c)
Fires under canopy undetected
Burned Areas (Product 3 – 1000 m)
(d)
-Burned areas: omission and commission errors by all products related to the spatial resolution.
-Product 1 (250 m): omission errors was compensated by visual edition.

Results

-Burned areas detected by Product 3. Burned areas was omitted by Product 1 related to temporal resolution (time series images with high cloud cover)

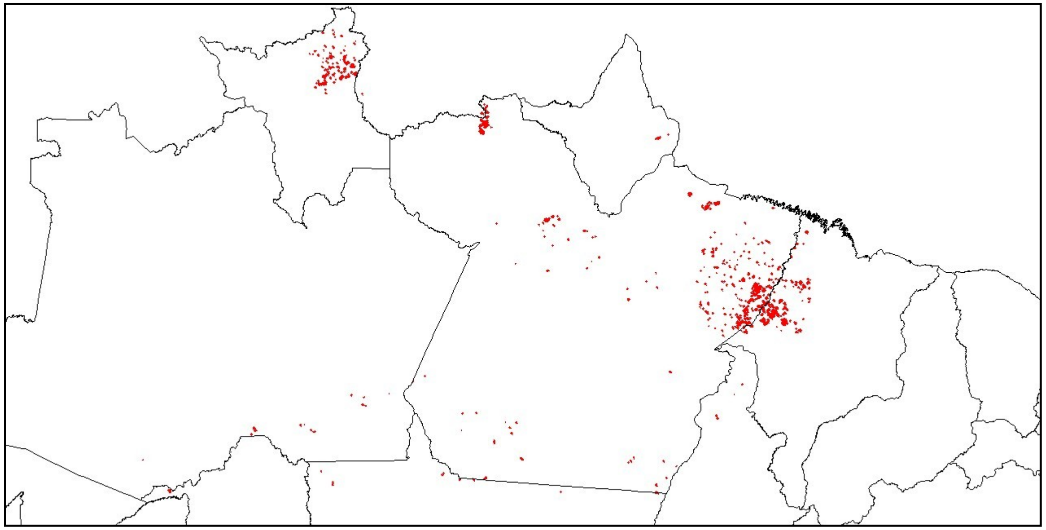
PRODUCT 3:
Burn Area Detection
(1000m)

PRODUCT 1:
BURN SCAR MAPPING
(250m)



Results

-Burned areas detected by Product 3. Burned areas was omitted by Product 1 related to temporal resolution (time series images with high cloud cover)



~ 8.900 km^2

Results

Validation Dataset

- -No a representative validation sites
- -Validation comparing different spatial resolution data (Landsat/TM – 30 m vs. MODIS – 250, 500 and 1000 m)

Results: Validation

Validation of fire detection products

Concordance between different burned area products (Acre Region)

	Global	Kappa	Tau	Commission error (%)	Omission error (%)
Produto 1	0,91	0,58	0,81	37	35
Produto 2	0,88	0,16	0,75	12	89
Produto 3	0,87	0,13	0,61	59	89

Concordance between different burned area products (Rondonia Region)

	Global	Kappa	Tau	Commission error (%)	Omission error (%)
Produto 1	0,93	0,42	0,85	50	57
Produto 2	0,94	0,10	0,88	31	94
Produto 3	0,92	0,15	0,83	75	84

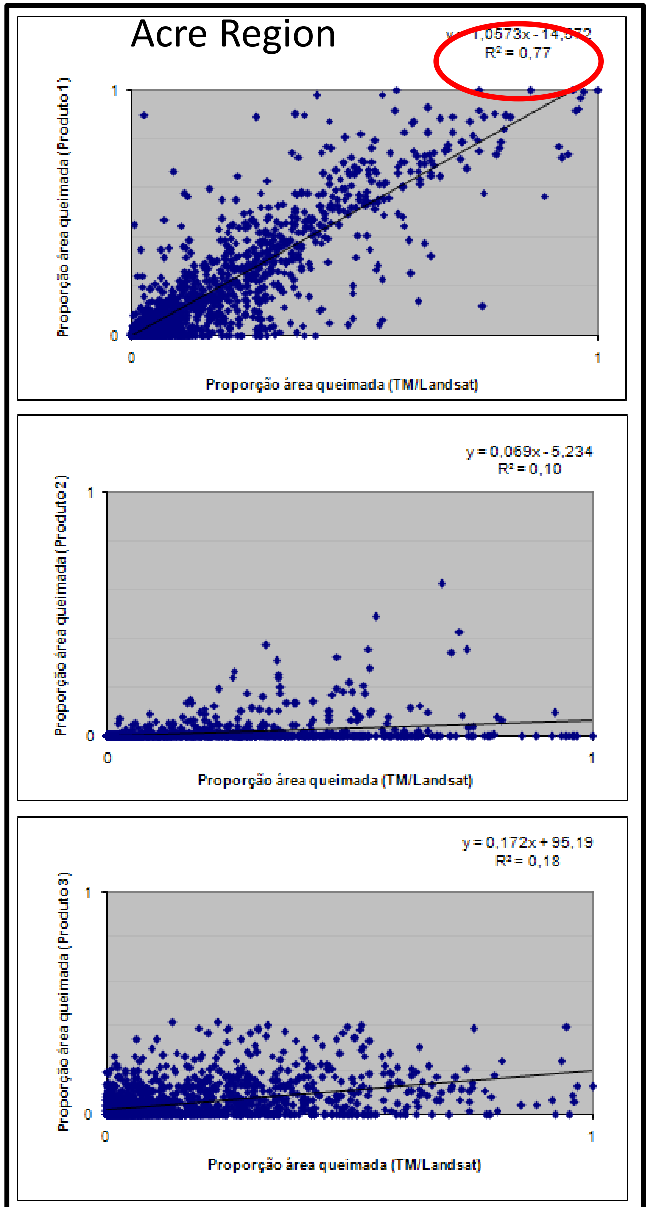
Results: Validation

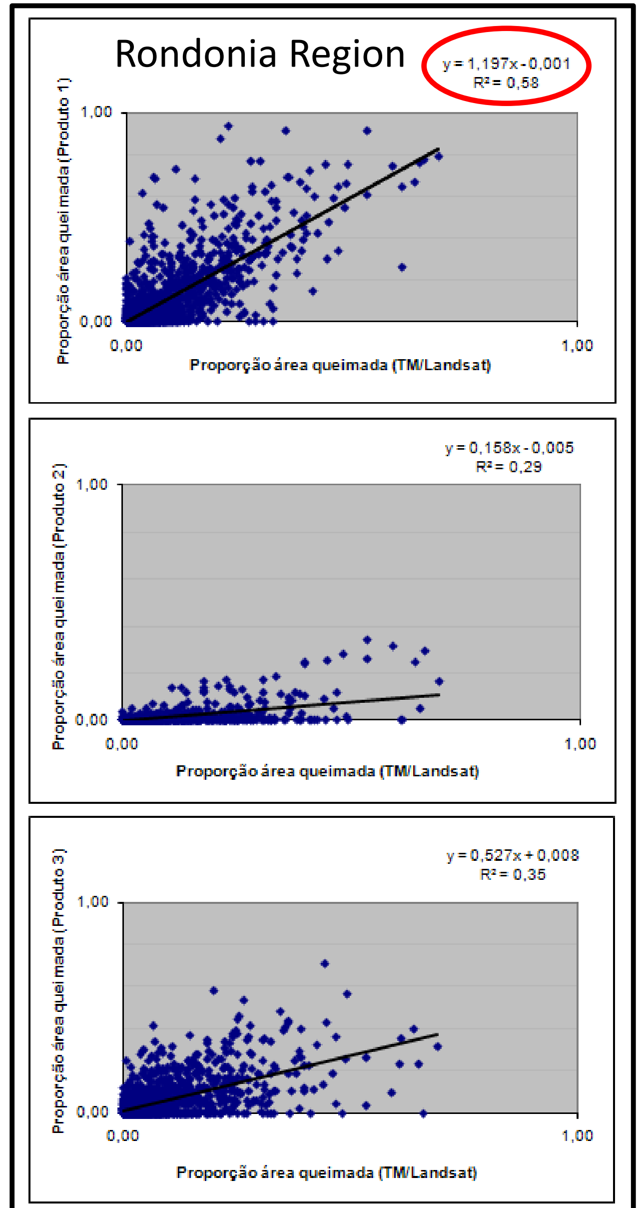
Product 1= Burned Scars Mapping

Highest accuracy between the observed values and the reference classification

Validation Dataset

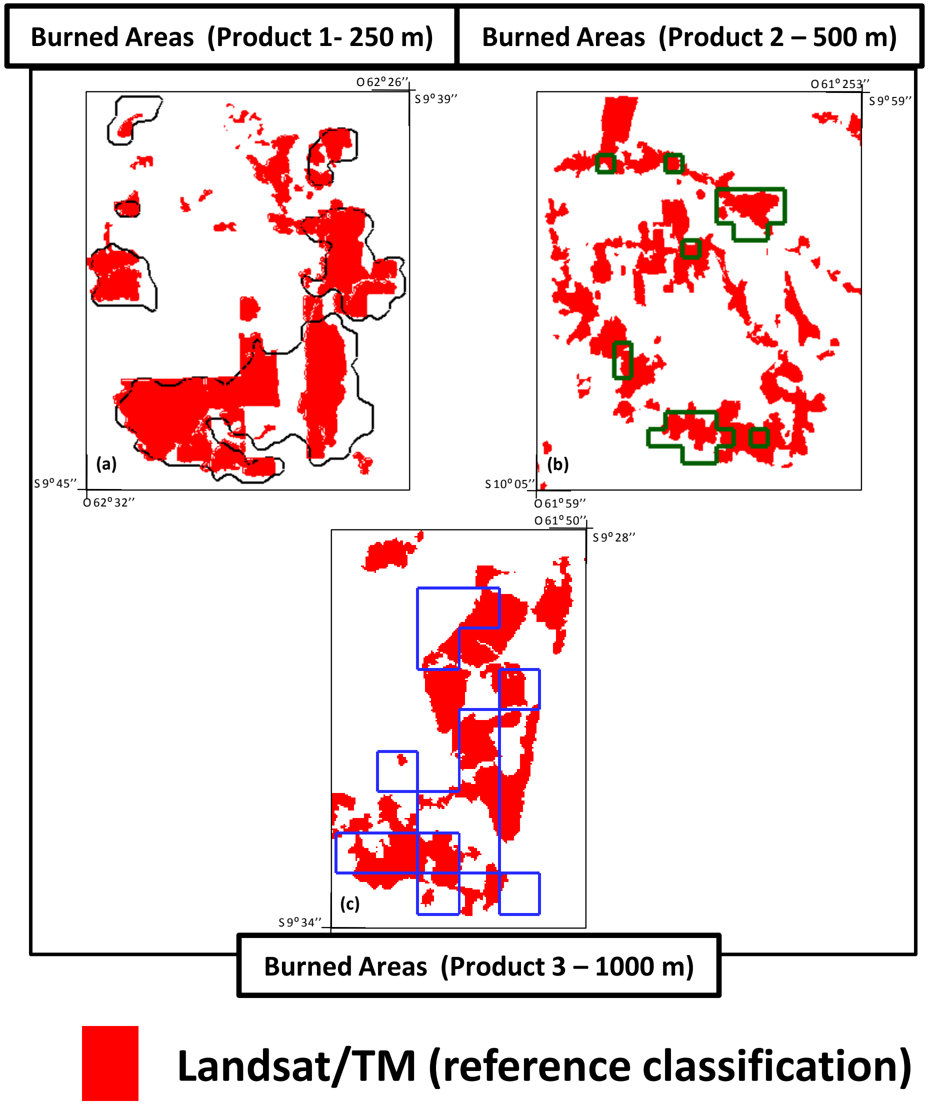
Linear Correlation Coefficient



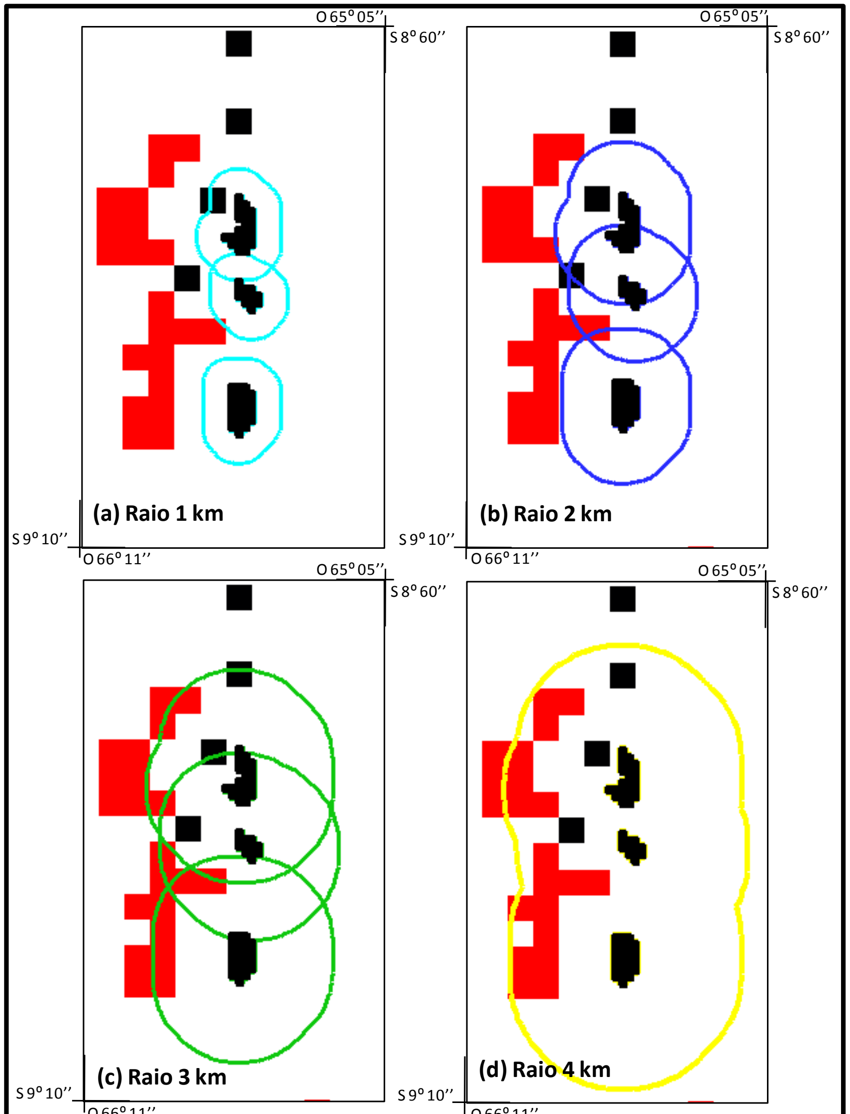


Results: Validation

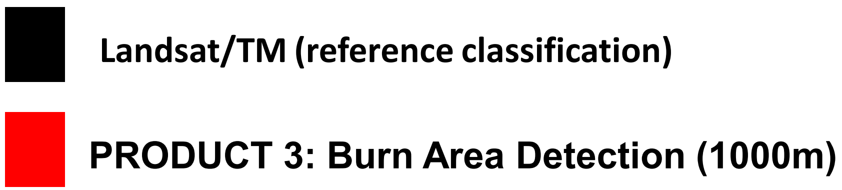
-Burned areas Validation: omission and commission errors related to the spatial resolution



Results: Validation



Low concordance between fire products related to Geolocation pixels (1 to 4 km)



Results

GHG emissions estimative for Amazonia (AM) and Cerrado (CE) biomes, in Tg (1 Tg = 10^{12} g)

	Produto 1	Produto 2	Produto 3	Thermal Anomalies
Bioma AM				
M(CO_2)	163,300	46,220	136,070	334,99
M(CO)	12,130	3,310	10,850	26,62
M(CH_4)	0,562	0,140	0,541	1,322
M(NO_x)	0,252	0,074	0,201	0,595
M(N_2O)	0,021	0,006	0,017	0,042
Bioma CE				
M(CO_2)	132,030	74,640	32,350	94,600
M(CO)	8,920	4,800	2,340	6,720
M(CH_4)	0,308	0,148	0,095	0,263
M(NO_x)	0,241	0,134	0,060	0,174
M(N_2O)	0,017	0,010	0,004	0,012

86 %

Product 1= Burned Scars Mapping (250 m)
Product 2= Land Cover Change-MCD45 (500 m)
Product 3= Burned Area Detection(1000)
Product 3= Thermal Anomalies (1000)

Results

GHG emissions estimative for Amazonia (AM) and Cerrado (CE) biomes, in Tg (1 Tg = 10^{12} g)

	Produto 1	Produto 2	Produto 3	Thermal Anomalies
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$M(NO_x)$	0,252	0,074	0,201	0,595
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$M(CO_2)$	132,030	74,640	32,350	94,600
$M(CO)$	8,920	4,800	2,340	6,720
$M(CH_4)$	0,308	0,148	0,095	0,263
$M(NO_x)$	0,241	0,134	0,060	0,174
$M(N_2O)$	0,017	0,010	0,004	0,012

75 %

Product 1= Burned Scars Mapping (250 m)
Product 2= Land Cover Change-MCD45 (500 m)
Product 3= Burned Area Detection(1000)
Product 3= Thermal Anomalies (1000)

Final Considerations

-1. Uncertainties in burned area estimates are linked to the automatic detection algorithms criteria for identification of the burned area and the limitations related to the orbital platform (MODIS).

-2. MODIS Products for estimating the extent of burned areas require validation standards. Validation is required to incorporate adjustments to the current performance of the algorithms of burned areas.

-3. An alternative approach to decrease the uncertainties could be the development of a hybrid algorithms, combining the spectral information of reflective and emissive bands of spectrum (detection of active fires and fire scars of discrimination).

Final Considerations

-4. Although a lot of progress has been observed in RS field, accuracy of estimates of burned area has to be improved as input of the emission models. This improvement depends on the ability of the scientific community to develop more accurate techniques and procedures to estimate burned area.

-5. The procedures and methodologies used to estimate biomass burning with Remotely sensed data are more appropriate for savannah than for forest ecosystems.

-6. Finally, estimates of burned area using remote sensing data have some limitations; however, currently such measurements represent the only alternative to estimate global biomass burning used by the GHG models.