A rule-based semi-automatic method to map burned areas using Landsat and Sentinel-2 images – revisited and improved

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Maps of burned areas are important for various reasons

Reconstruction of recent fire history - Attica, Greece (1984-2015)

Fire return interval
- 13,51 - 27,00
- 9,01 - 13,50
- 6,76 - 9,00
- 5,41 - 6,75
- 4,51 - 5,40
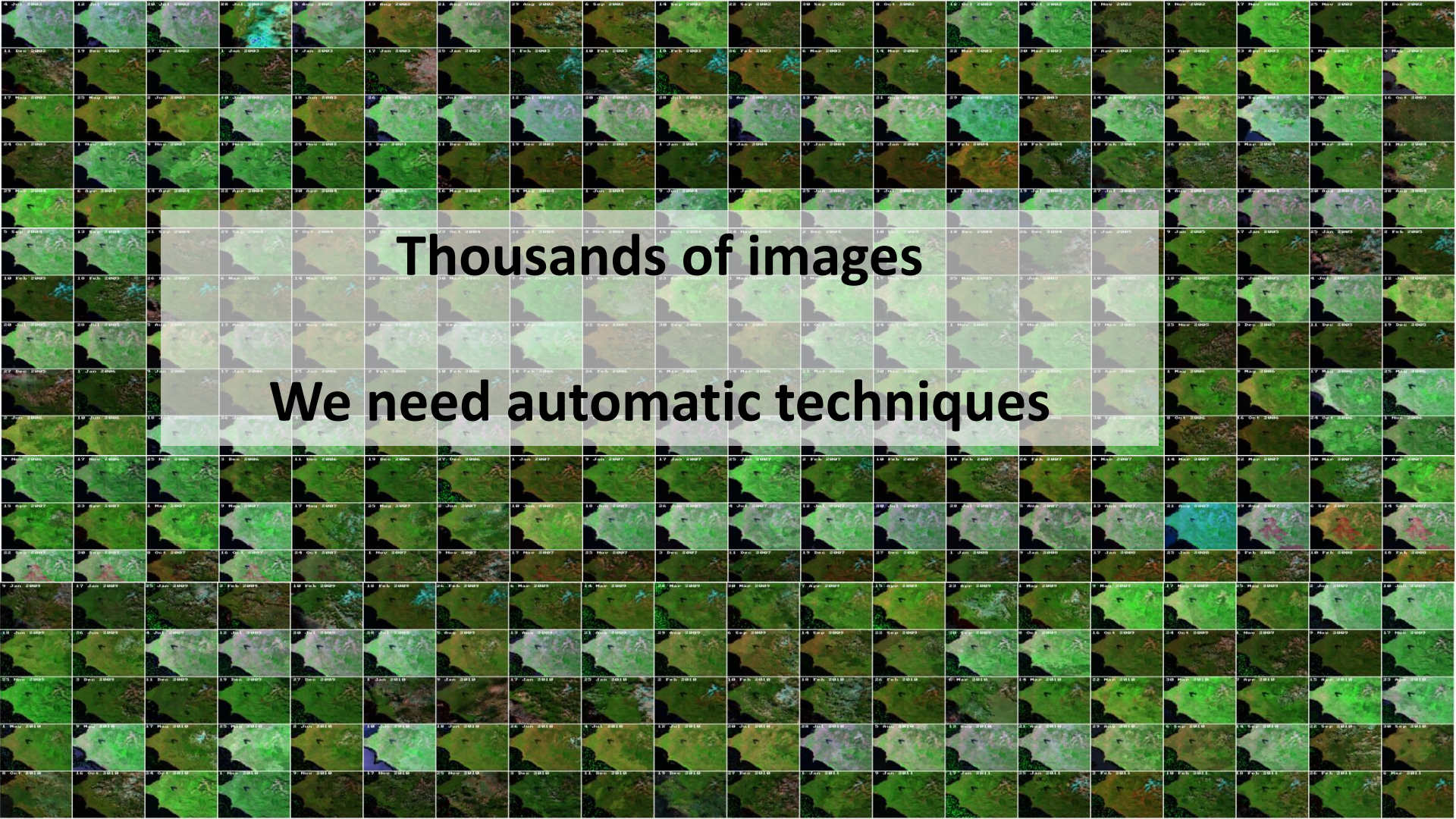- 4,50

Frequency
- 1
- 2
- 3 - 4
- 5 - 7
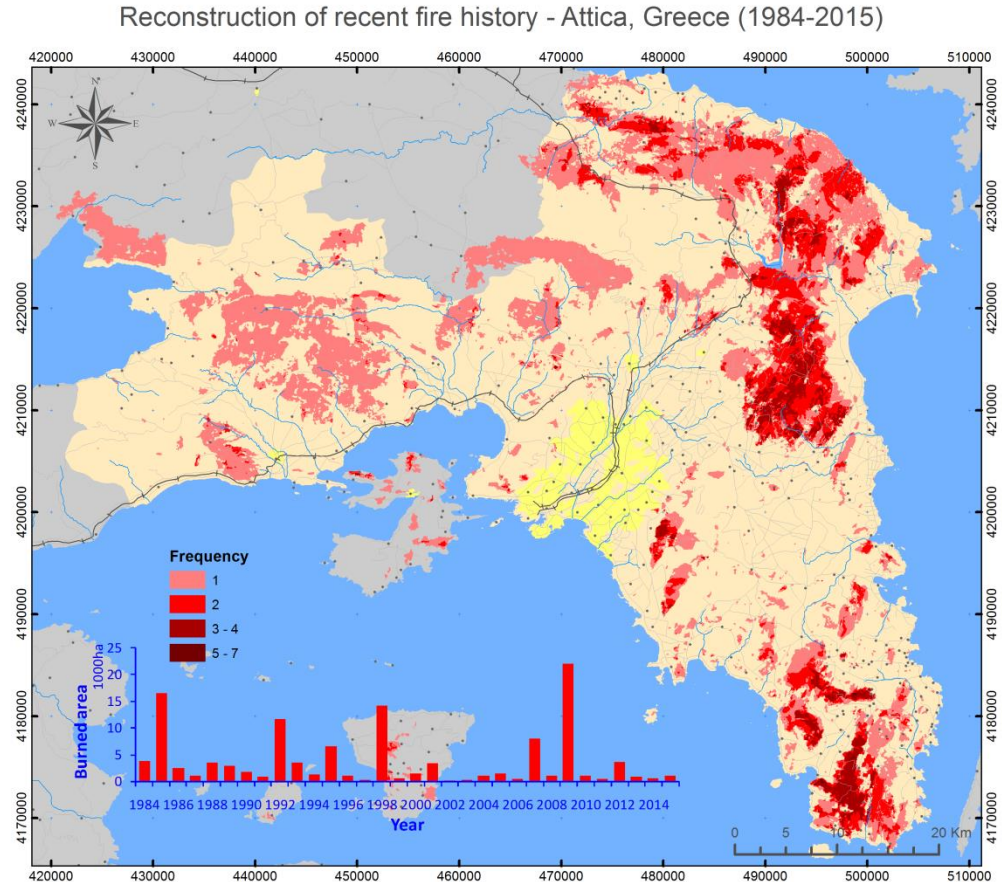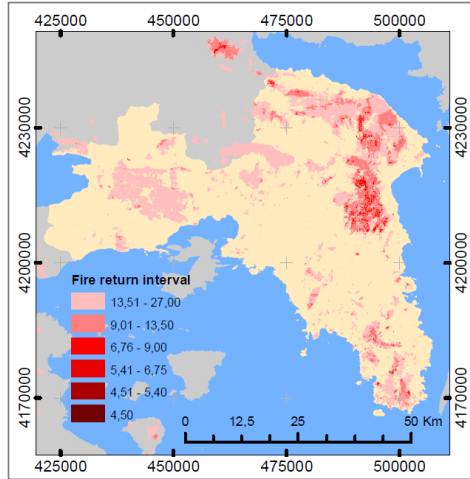
There are various products of burned areas but most are at global scale

However, recently USGS started providing the Landsat Level-3 Burned Area (BA) Science Product but only for US
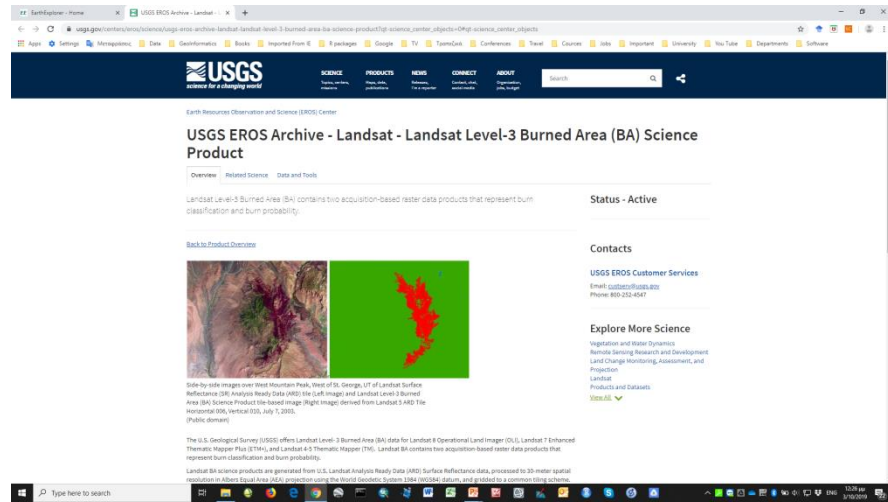
Thousands of images

We need automatic techniques

Taylor & Francis
Taylor & Francis Group

A rule-based semi-automatic method to map burned areas: exploring the USGS historical Landsat archives to reconstruct recent fire history

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Space Applications and Remote Sensing, National Observatory of Athens,
GR-15236 Pendeli, Greece;* [d]*European Research Council Research Agency, Brussels, Belgium*

	Rule	Arithmetic expression	Description
uni-temporal rules	*1st rule*	*If Landsat TM4 post < Landsat TM5 post then 1 (burned) otherwise 0 (unburned)*	The reflectance of burned areas in the near-infrared band (e.g. TM4 in Landsat-5 or -7) is less than that in short-wave infrared band (e.g. TM5 in Landsat-5 or -7). However, for many other land-cover types (mainly the vegetated ones), their reflectance in near infrared band is higher than that in short-wave infrared band. Therefore, this rule differentiates burned areas with special emphasis on vegetated areas.
	2nd rule	*If Landsat TM5 post < Landsat TM7 post + a Landsat TM7 post then 1 (burned) otherwise 0 (unburned)*	The reflectance of burned areas in the short-wave infrared band (e.g. TM7 in Landsat-5 or -7) plus an additional threshold value (a in 0.10-0.25) is slightly higher than that in short-wave infrared band (e.g. TM5 in Landsat-5 or -7), while for other land cover types their reflectance in short-wave infrared band (e.g. TM7 in Landsat-5 or -7) is lower than in short-wave infrared band (e.g. TM5 in Landsat-5 or -7). Therefore, this rule differentiates burned areas with special emphasis on various land cover types and more specifically to vegetated areas.
	3rd rule	*If Landsat TM3 post > Landsat TM1 post then 1 (burned) otherwise 0 (unburned)*	The reflectance of sea water in the red band (e.g. TM3 in Landsat-5 or -7) is less than that in blue band (e.g. TM1 in Landsat-5 or -7), while for many other land cover types including the burned areas, their reflectance in red is higher than in blue. Therefore, this rule differentiates burned areas with special emphasis on water bodies.
multi-temporal rules	*4th rule*	*If TM4 post + a TM4 post < TM4 pre then 1 (burned) otherwise 0 (unburned)*	The reflectance of burned areas in the near infrared band (e.g. TM4 in Landsat-5 or -7) in the post-fire image is lower than that of the pre-fire image. An additional threshold value should be defined (a in 0.10-0.25), otherwise features having even a 1 DN value difference between the pre- and post-fire image are captured as changed.
	5th rule	*If TM7 post > TM7 pre + a TM7 pre then 1 (burned) otherwise 0 (unburned)*	The reflectance of burned areas in the mid infrared band (e.g. TM7 in Landsat-5 or -7) in the post-fire image is higher compared to the pre-fire image. An additional threshold value should be defined (a in 0.10-0.25), otherwise features having even a 1 DN value difference between the pre- and post-fire image are captured as changed.

Only post-fire image

1st rule

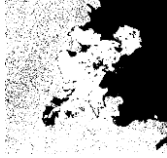TM4 post<TM5 post

2nd rule

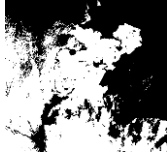TM5 post<TM7 post+threshold

3rd rule

TM3 post>TM1 post

Pre- and post-fire image
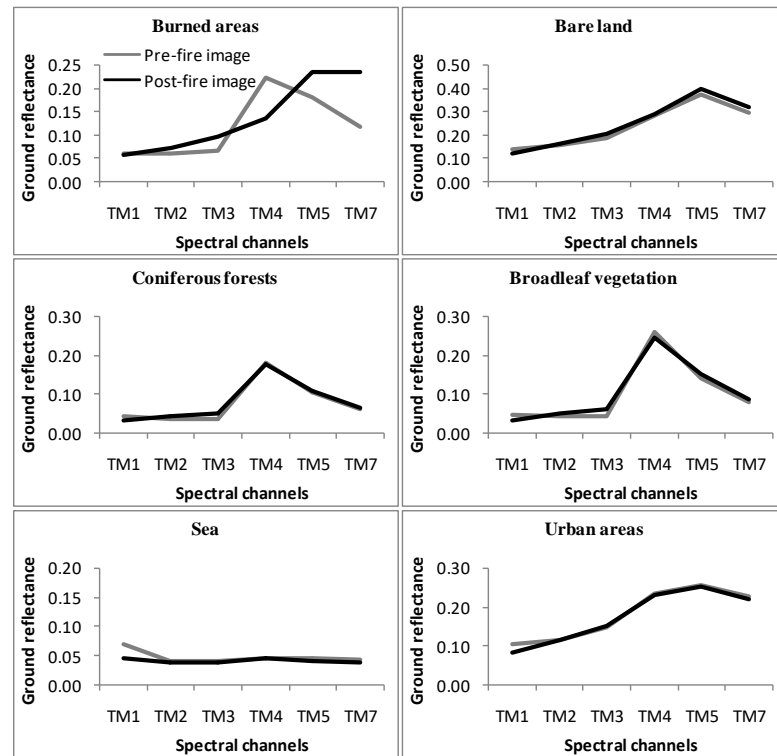
4th rule

TM4 post+threshold<TM4 pre

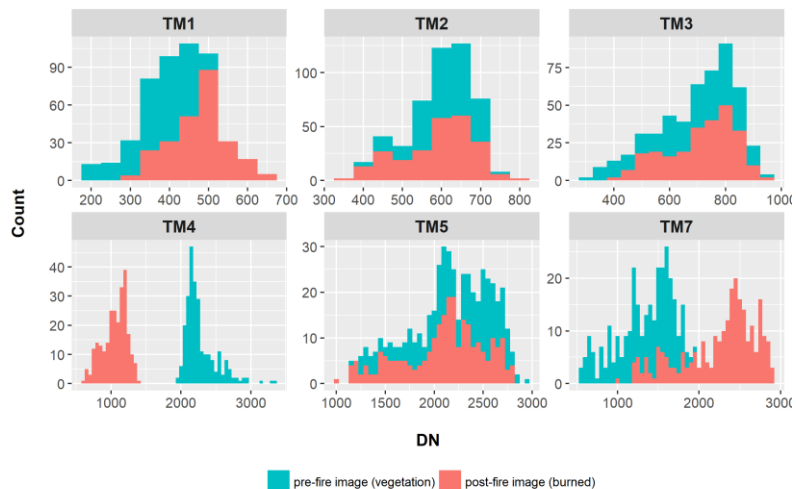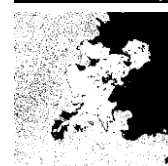**5th rule**

TM7 post>TM7 pre+threshold

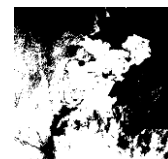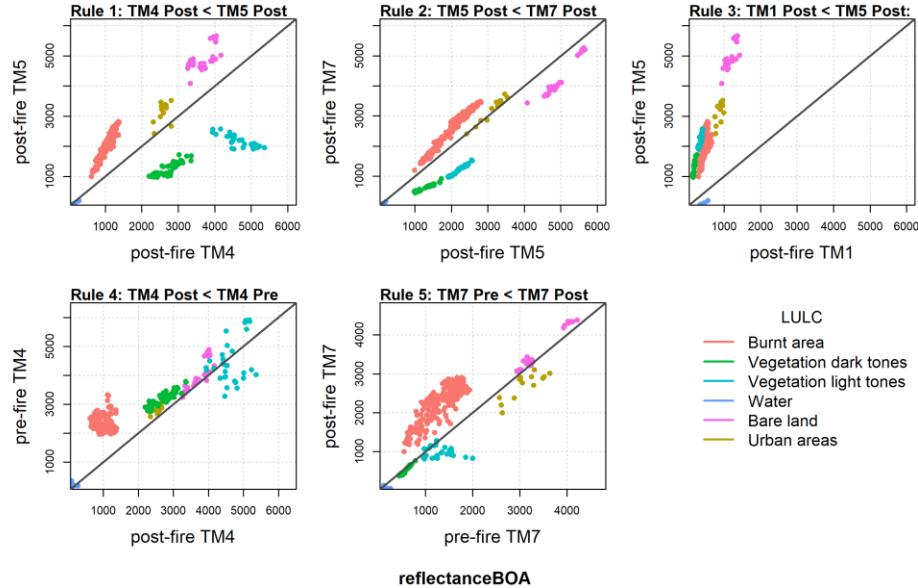|	Rule	*Old set of rules*	
		Expression	*Application*
uni-temporal rules	*1st rule*	*If Landsat TM4 post < Landsat TM5 post then 1 (burned) otherwise 0 (unburned)*	
	2nd rule	*If Landsat TM5 post < Landsat TM7 post + a Landsat TM7 post then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*	
	3rd rule	*If Landsat TM3 post > Landsat TM1 post then 1 (burned) otherwise 0 (unburned)*	
multi-temporal rules	*4th rule*	*If TM4 post + a TM4 post < TM4 pre then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*	
	5th rule	*If TM7 post > TM7 pre + a TM7 pre then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*	

Italy - Landsat

pre-fire image / post-fire image

reflectanceBOA

Channels: TM1, TM2, TM3, TM4, TM5, TM7

LULC
Burnt area — Vegetation dark tones — Vegetation light tones
Water — Bare land — Urban areas

Italy - Landsat

Count / DN

TM1, TM2, TM3, TM4, TM5, TM7

pre-fire image (vegetation) / post-fire image (burned)

Burned areas

Pre-fire image
Post-fire image

Ground reflectance / Spectral channels

Bare land

Coniferous forests

Broadleaf vegetation

Sea

Urban areas

Italy - Landsat

pre-fire image / post-fire image

reflectanceBOA vs Channels (TM1, TM2, TM3, TM4, TM5, TM7)

LULC: Burnt area, Vegetation dark tones, Vegetation light tones, Water, Bare land, Urban areas

Italy - Landsat

TM1, TM2, TM3, TM4, TM5, TM7

Count vs DN

pre-fire image (vegetation), post-fire image (burned)

Only post-fire image

1st rule

TM4 post<TM5 post

2nd rule

TM5 post<TM7 post+threshold

3rd rule

TM3 post>TM1 post

Pre- and post-fire image

4th rule

TM4 post+threshold<TM4 pre

5th rule

TM7 post>TM7 pre+threshold

Rule	Old set of rules	
	Expression	*Application*
uni-temporal rules 1st rule	*If Landsat TM4 post < Landsat TM5 post then 1 (burned) otherwise 0 (unburned)*	
2nd rule	*If Landsat TM5 post < Landsat TM7 post + a Landsat TM7 post then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*	
3nd rule	*If Landsat TM3 post > Landsat TM1 post then 1 (burned) otherwise 0 (unburned)*	
multi-temporal rules 4th rule	*If TM4 post + a TM4 post < TM4 pre then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*	
5th rule	*If TM7 post > TM7 pre + a TM7 pre then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*	

A successful example

Italy - Landsat

Rule 1: TM4 Post < TM5 Post
Rule 2: TM5 Post < TM7 Post
Rule 3: TM1 Post < TM5 Post:
Rule 4: TM4 Post < TM4 Pre
Rule 5: TM7 Pre < TM7 Post

reflectanceBOA

LULC
- Burnt area
- Vegetation dark tones
- Vegetation light tones
- Water
- Bare land
- Urban areas

Italy - Landsat

Landsat OLI Pre-fire (2017-06-27)
Landsat OLI Post-fire (2017-08-30)

rule1
rule2
rule3
rule4
rule5

Uni-temporal rules 1-3
Multi-temporal rules 4-5
All rules
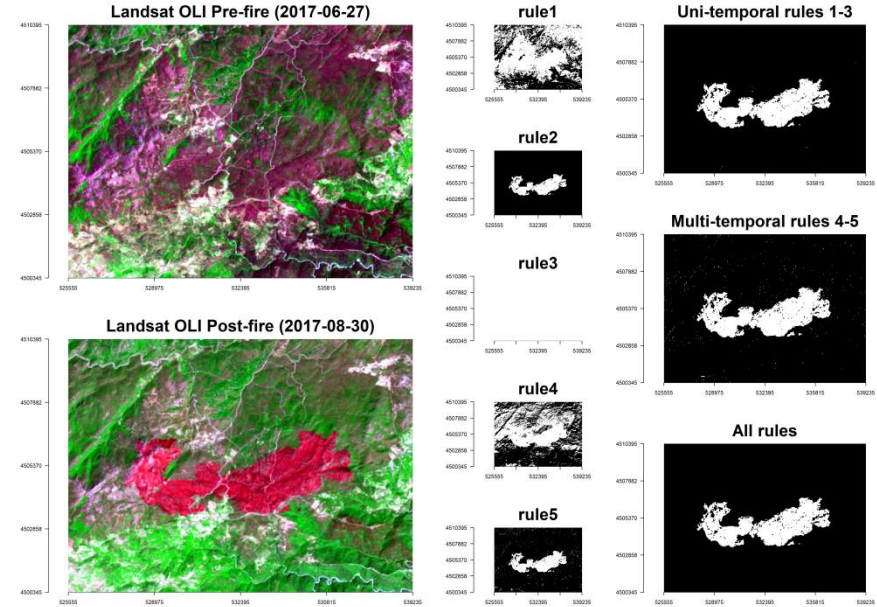
A non-successful example

Serifos - Landsat

Landsat OLI Pre-fire (2013-07-12)

Landsat OLI Post-fire (2013-07-28)

rule1

rule2

rule3

rule4

rule5

Uni-temporal rules 1-3

Multi-temporal rules 4-5

All rules

Serifos - Landsat

TM1 TM2 TM3 TM4 TM5 TM7

Count

DN

pre-fire image (vegetation)   post-fire image (burned)
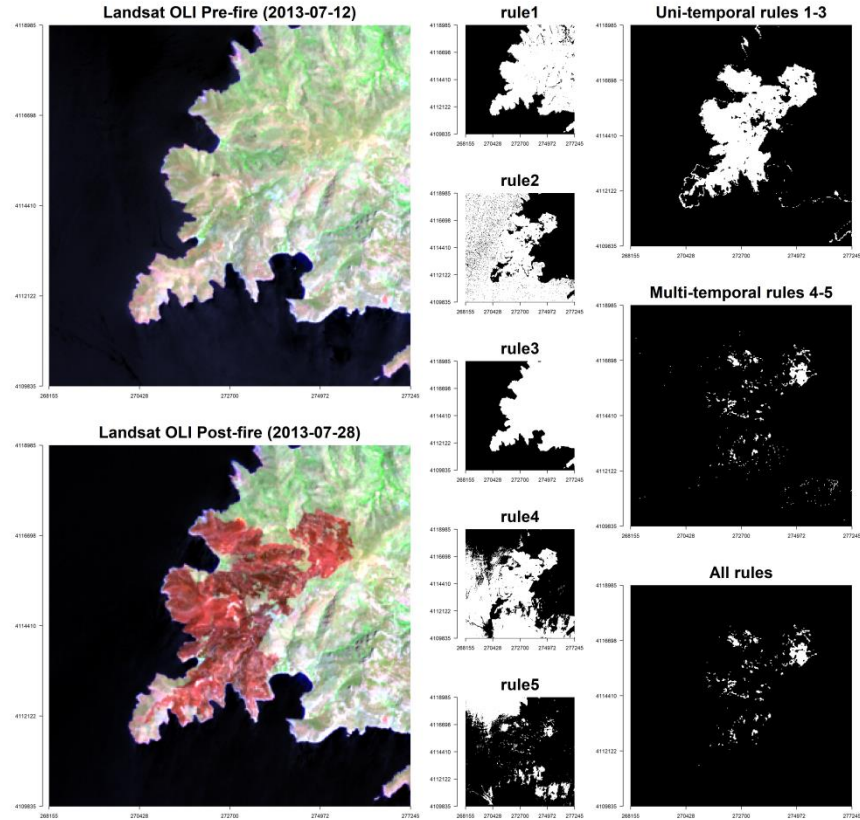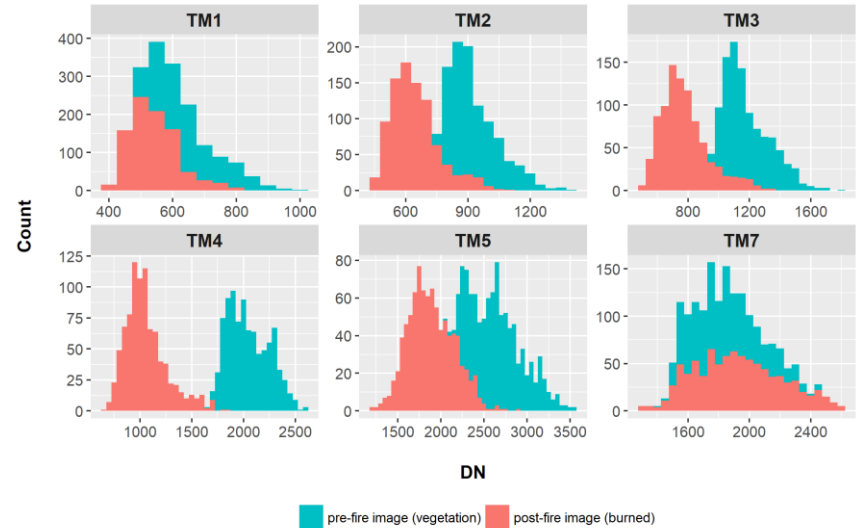
A non-successful example

Portugal - Landsat

Landsat OLI Pre-fire (2017-06-15)

Landsat OLI Post-fire (2017-07-17)

rule1

rule2

rule3

rule4

rule5

Uni-temporal rules 1-3

Multi-temporal rules 4-5

All rules

Portugal - Landsat

Rule 1: TM4 Post < TM5 Post

Rule 2: TM5 Post < TM7 Post

Rule 3: TM1 Post < TM5 Post:

Rule 4: TM4 Post < TM4 Pre

Rule 5: TM7 Pre < TM7 Post

reflectanceBOA

LULC
- Burnt area
- Vegetation dark tones
- Vegetation light tones
- Water
- Bare land
- Urban areas

Old set of rules

Only post-fire image

1st rule

TM4 post<TM5 post

2nd rule   thres=0.25

TM5 post<TM7 post+threshold

3rd rule

TM3 post>TM1 post

Pre- and post-fire image

4th rule   thres=0.10-0.25

TM4 post+threshold<TM4 pre

5th rule   thres=0.10-0.25

TM7 post>TM7 pre+threshold

New set of rules

Only post-fire image

1st rule

TM4 post<TM5 post

2nd rule   thres=0.35

TM5 post<TM7 post+threshold

3rd rule

TM5 post>TM1 post

Pre- and post-fire image

4th rule   thres=0.05

TM4 post+threshold<TM4 pre

5th rule   thres=0.05
TM7 post>TM7 pre+threshold
TM5 post+threshold<TM5 pre

Rule	Old set of rules		New set of rules	
	Expression	*Application*	*Expression*	*Application*
uni-temporal rules 1st rule	*If Landsat TM4 post < Landsat TM5 post then 1 (burned) otherwise 0 (unburned)*		*If Landsat TM4 post < Landsat TM5 post then 1 (burned) otherwise 0 (unburned)*	
2nd rule	*If Landsat TM5 post < Landsat TM7 post + a Landsat TM7 post then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*		*If Landsat TM5 post < Landsat TM7 post + a Landsat TM7 post then 1 (burned) otherwise 0 (unburned) a=0.35*	
3rd rule	*If Landsat TM3 post > Landsat TM1 post then 1 (burned) otherwise 0 (unburned)*		*If Landsat TM5 post > Landsat TM1 post then 1 (burned) otherwise 0 (unburned)*	
multi-temporal rules 4th rule	*If TM4 post + a TM4 post < TM4 pre then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*		*If TM4 post + a TM4 post < TM4 pre then 1 (burned) otherwise 0 (unburned) a=0.2*	
5th rule	*If TM7 post > TM7 pre + a TM7 pre then 1 (burned) otherwise 0 (unburned) a=0.10-0.25*		*If TM7 post > TM7 pre + a TM7 pre or If TM5 post+ a TM5 post < TM5 pre then 1 (burned) otherwise 0 (unburned) a=0.05*	
An example	*Pre-fire image*	*Post-fire image*	*Old set of rules*	*New set of rules*

Applying the new set of rules to the previous examples

Old set of rules

New set of rules

Applying the new set of rules to the previous examples

Old set of rules

New set of rules

Applying the new set of rules to the previous examples

Old set of rules

New set of rules

Applying the new set of rules to the whole image

New set of rules

Applying the new set of rules to the whole image

New set of rules

Portugal - Landsat

Landsat OLI Pre (2017-06-15)

Landsat OLI Post (2017-07-17)

rule1

rule2

rule3

rule4

rule5

Uni-temporal rules 1-3

Multi-temporal rules 4-5
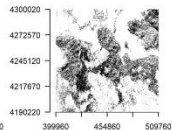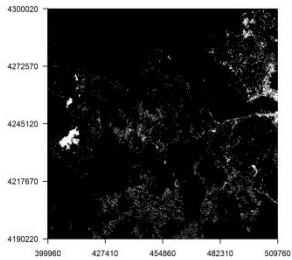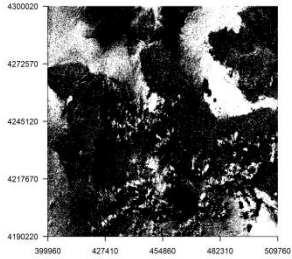
All rules

All rules
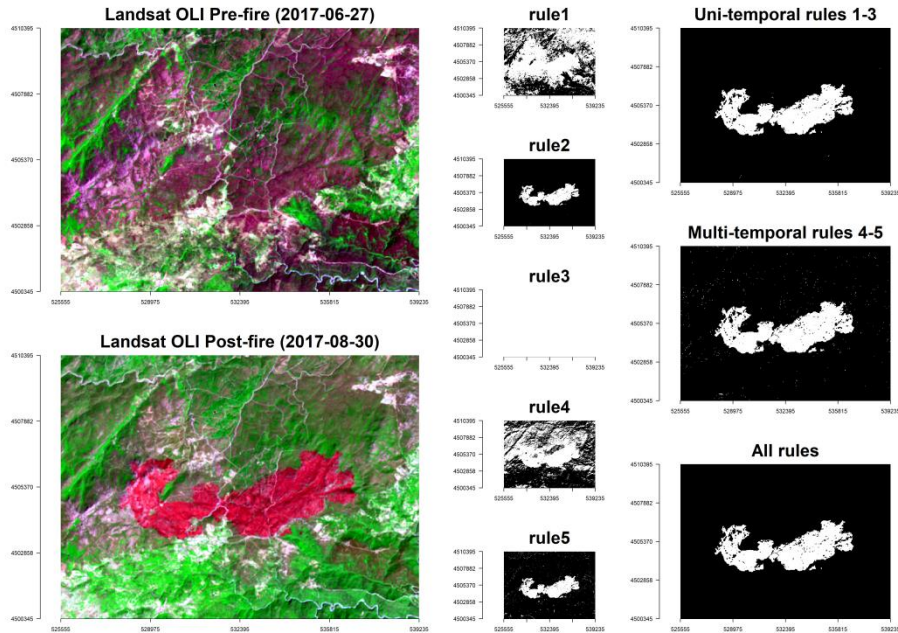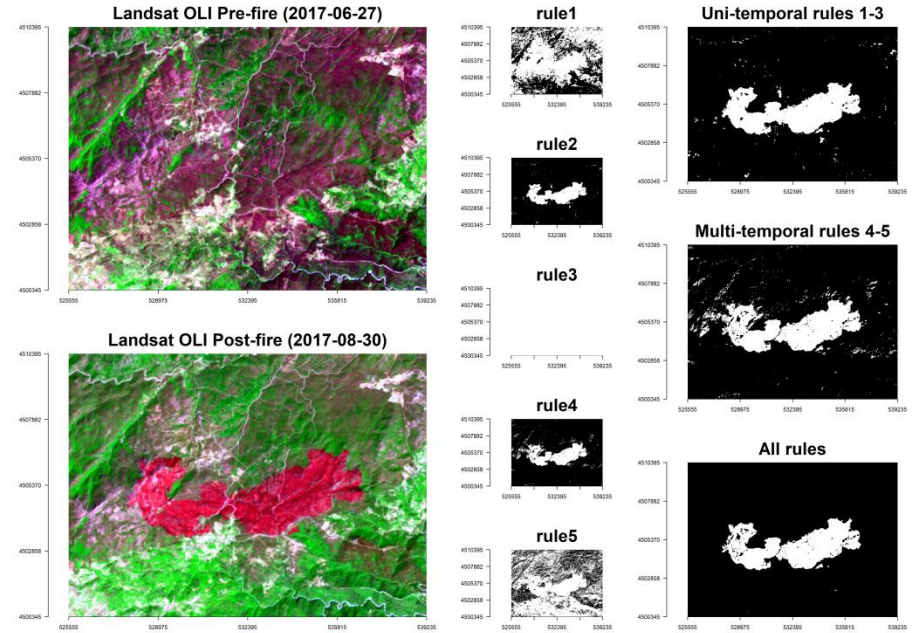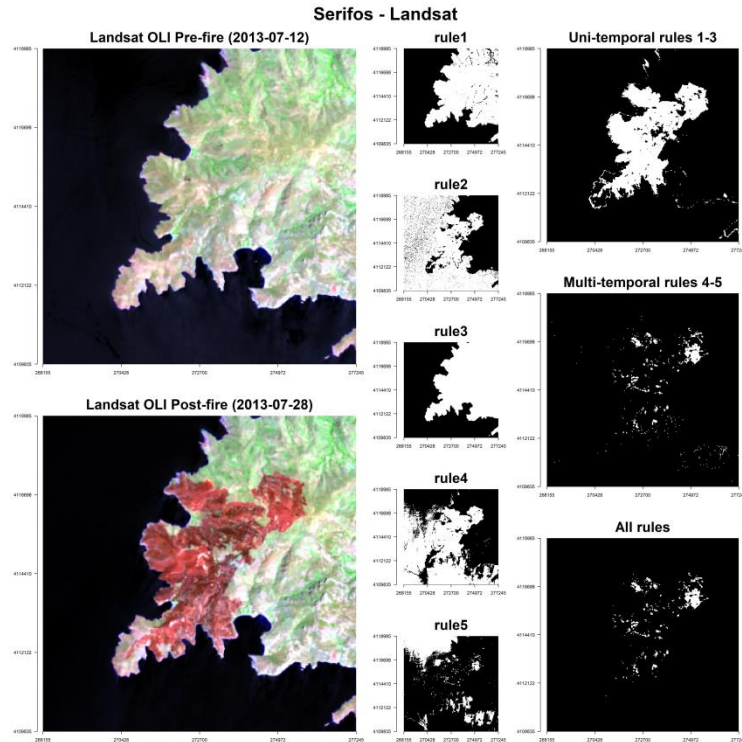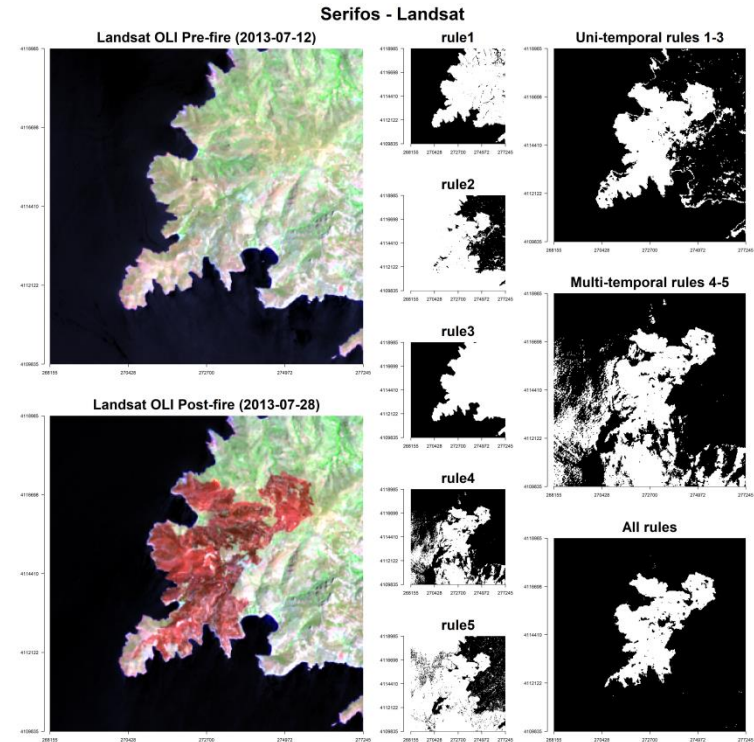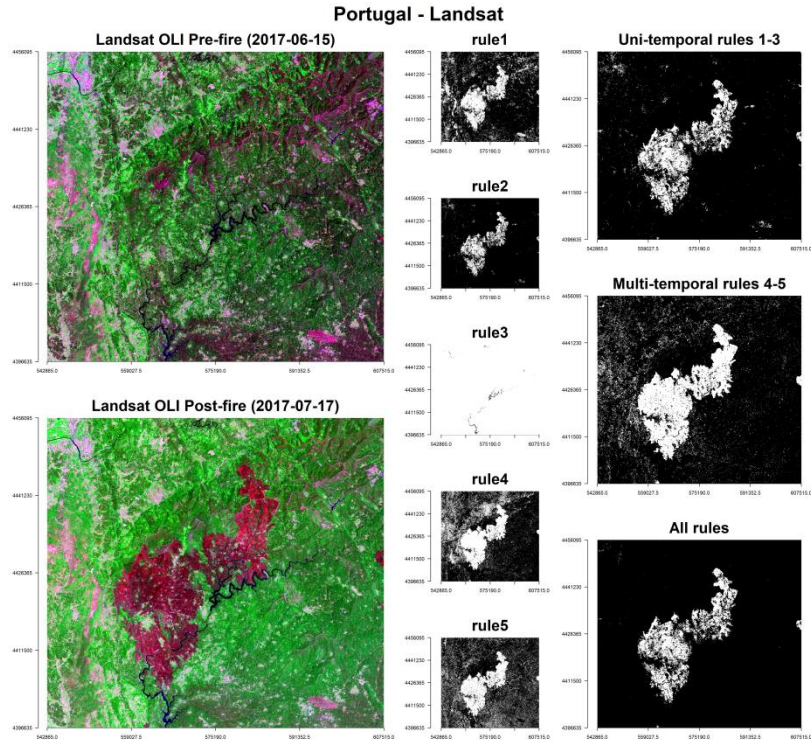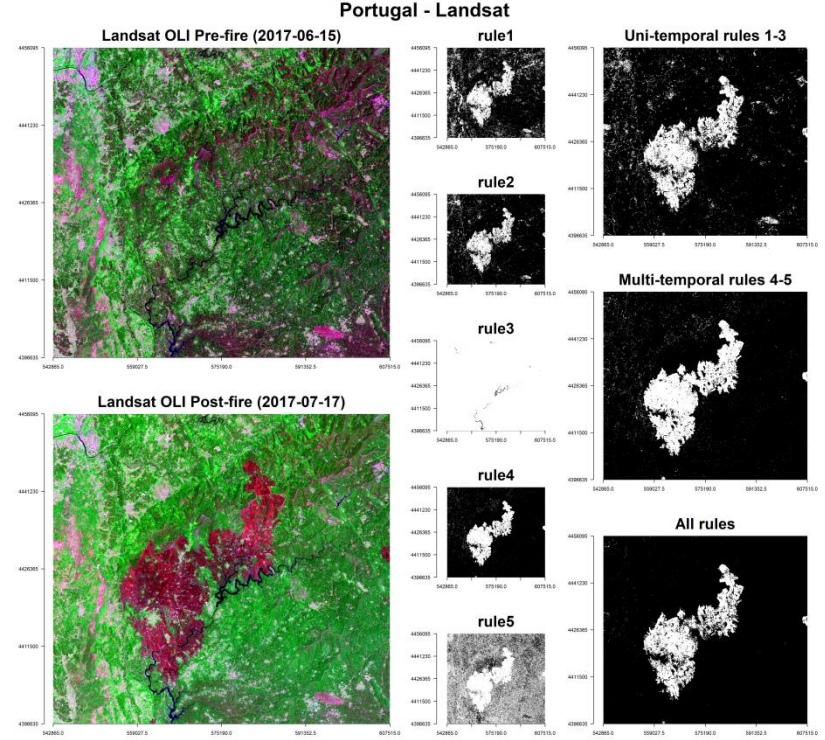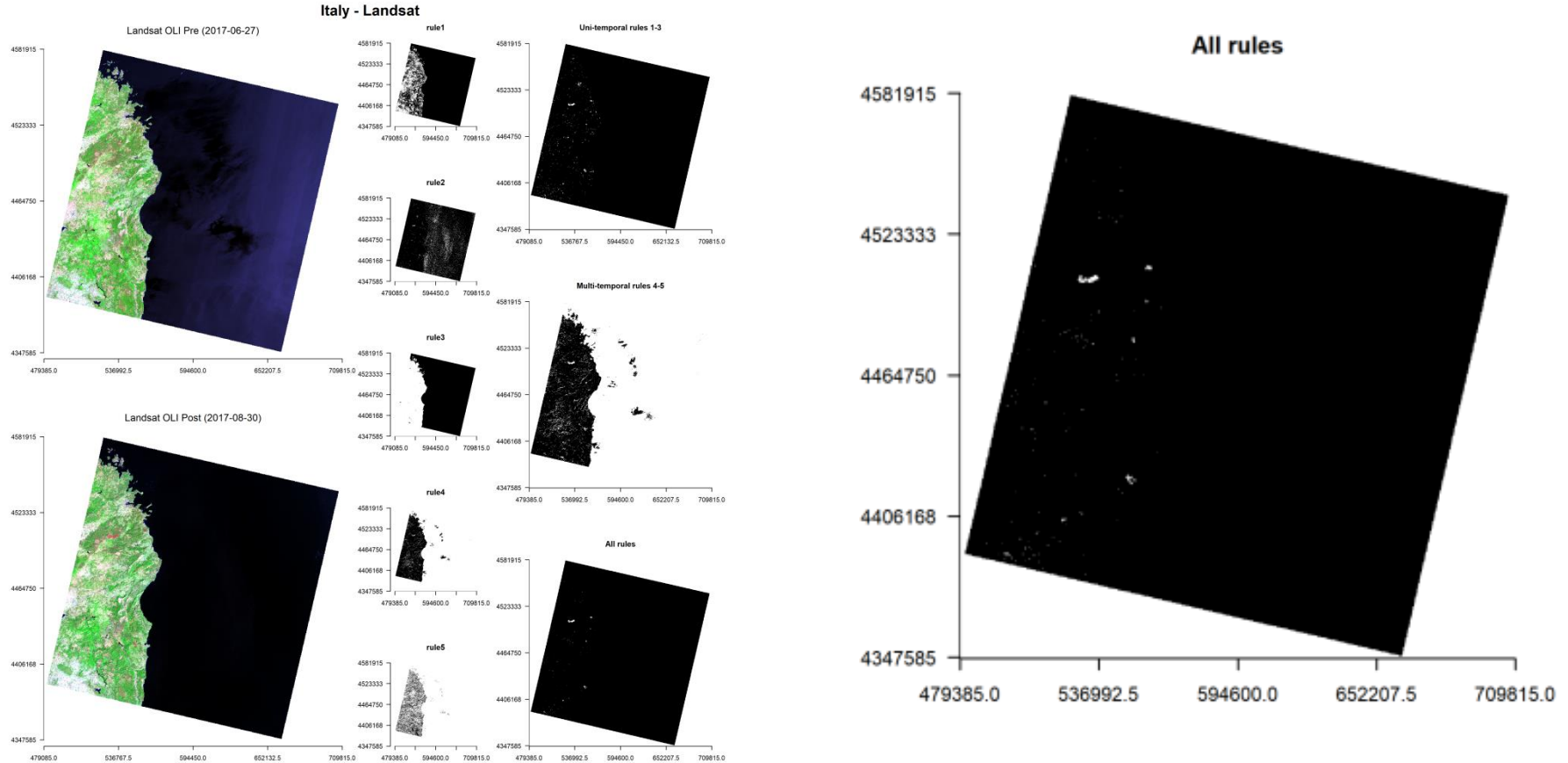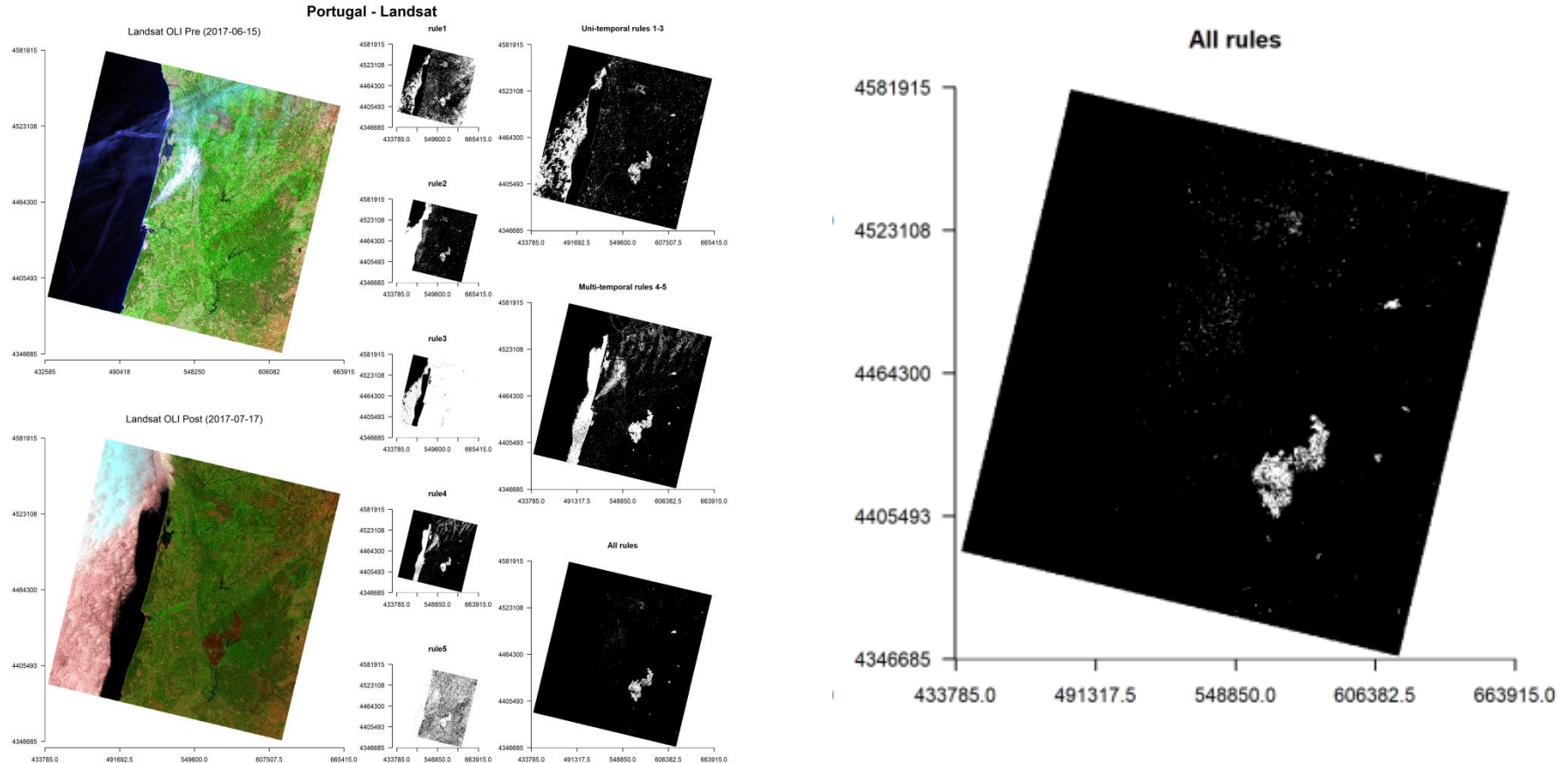
Spectral resolution of Sentinel-2 & Landsat satellites
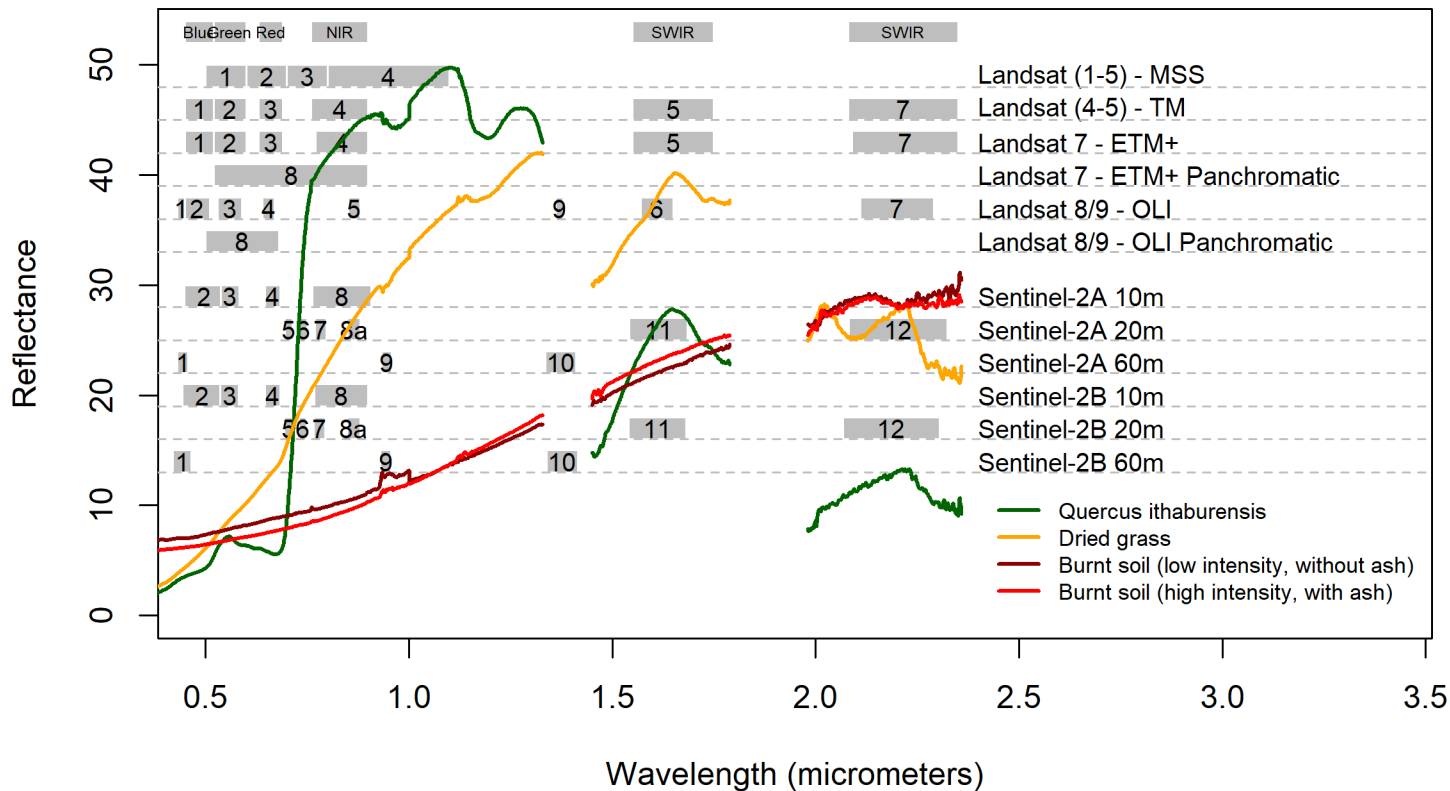
Applying the new set of rules to Sentinel-2 images

Pre-fire sentinel image

Sentinel-2 Pre-fire images

Post-fire sentinel image

Sentinel-2 Post-fire images
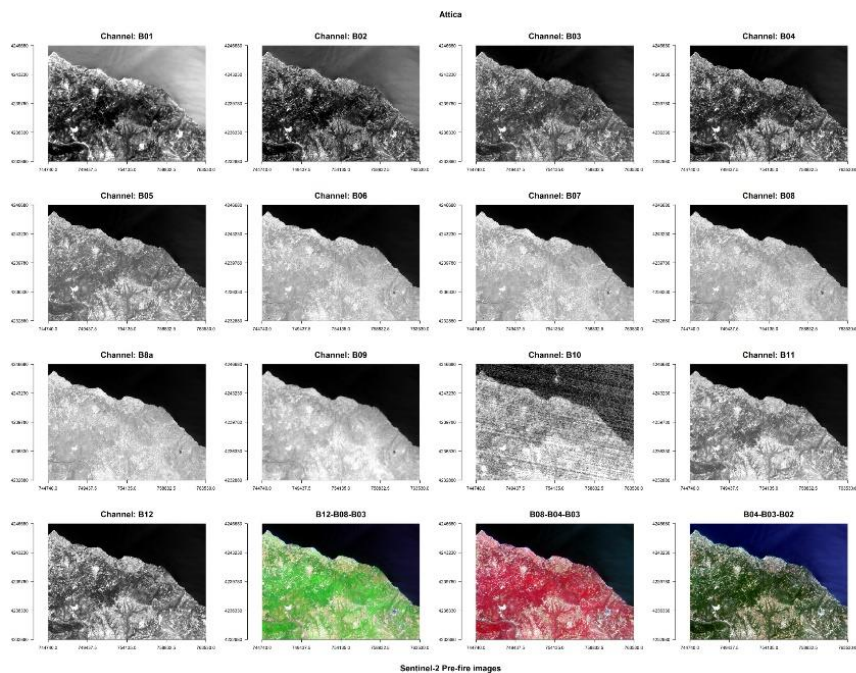
Applying the new set of rules to Sentinel-2 images
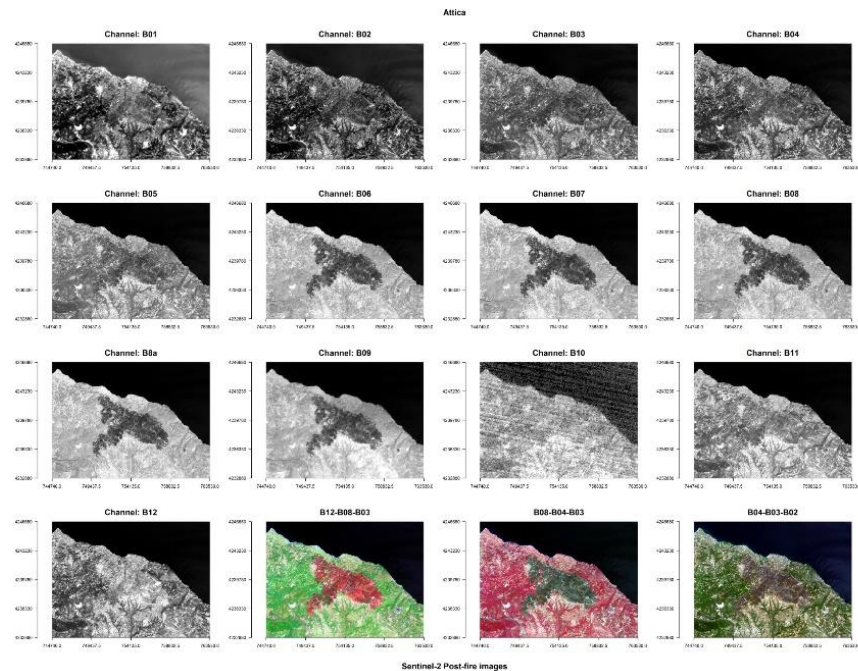
Sentinel-2 Pre-fire images
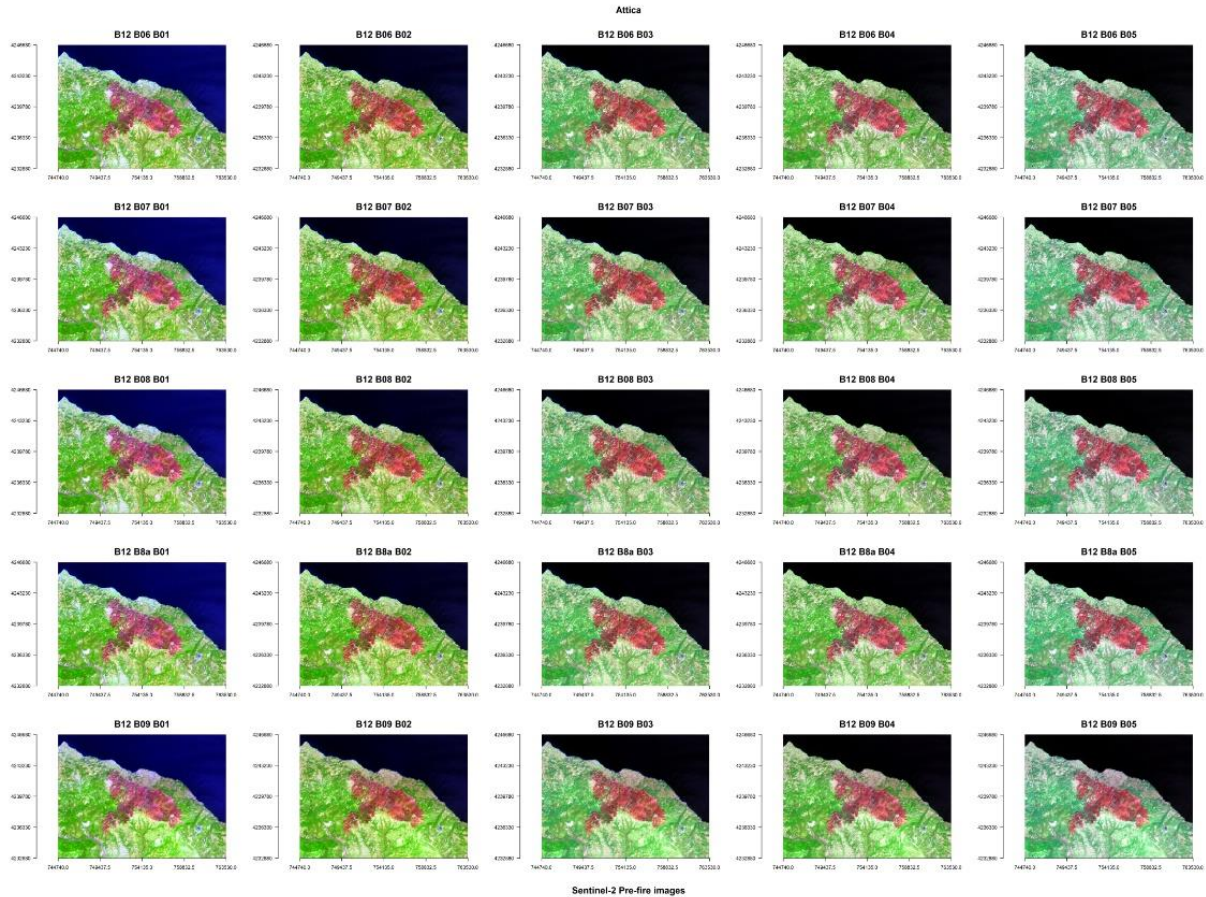
Landsat

Italy - Landsat

pre-fire image / post-fire image

Channels

LULC: Burnt area, Vegetation dark tones, Vegetation light tones, Water, Bare land, Urban areas

Italy - Landsat

TM1, TM2, TM3, TM4, TM5, TM7

Count / DN

pre-fire image (vegetation) / post-fire image (burned)

Burned areas — Pre-fire image / Post-fire image

Bare land

Coniferous forests

Broadleaf vegetation

Sea

Urban areas

Ground reflectance / Spectral channels
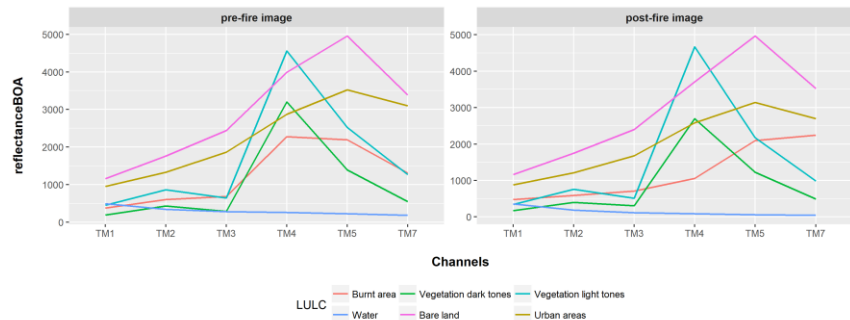
Sentinel-2

Attica - Landsat

Attica - Sentinel

Sentinel OLI Pre (2017-07-25) B02-B03-B04-B08-B11-B12

Sentinel OLI Post (2017-09-03) B02-B03-B04-B08-B11-B12

rule1

rule2

rule3

rule4

rule5

Uni-temporal rules 1-3

Multi-temporal rules 4-5

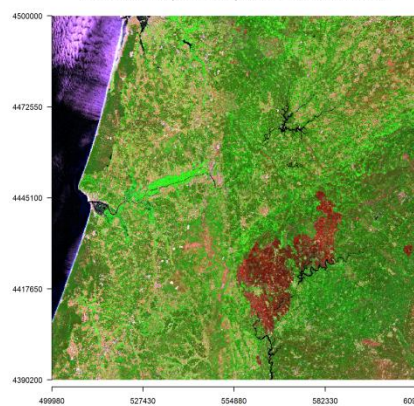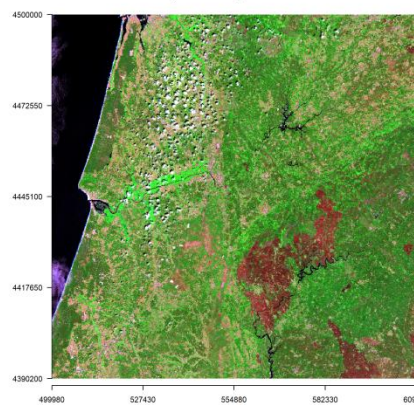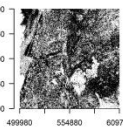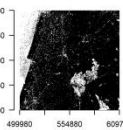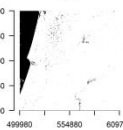All rules

Applying the new set of rules to Sentinel-2 images
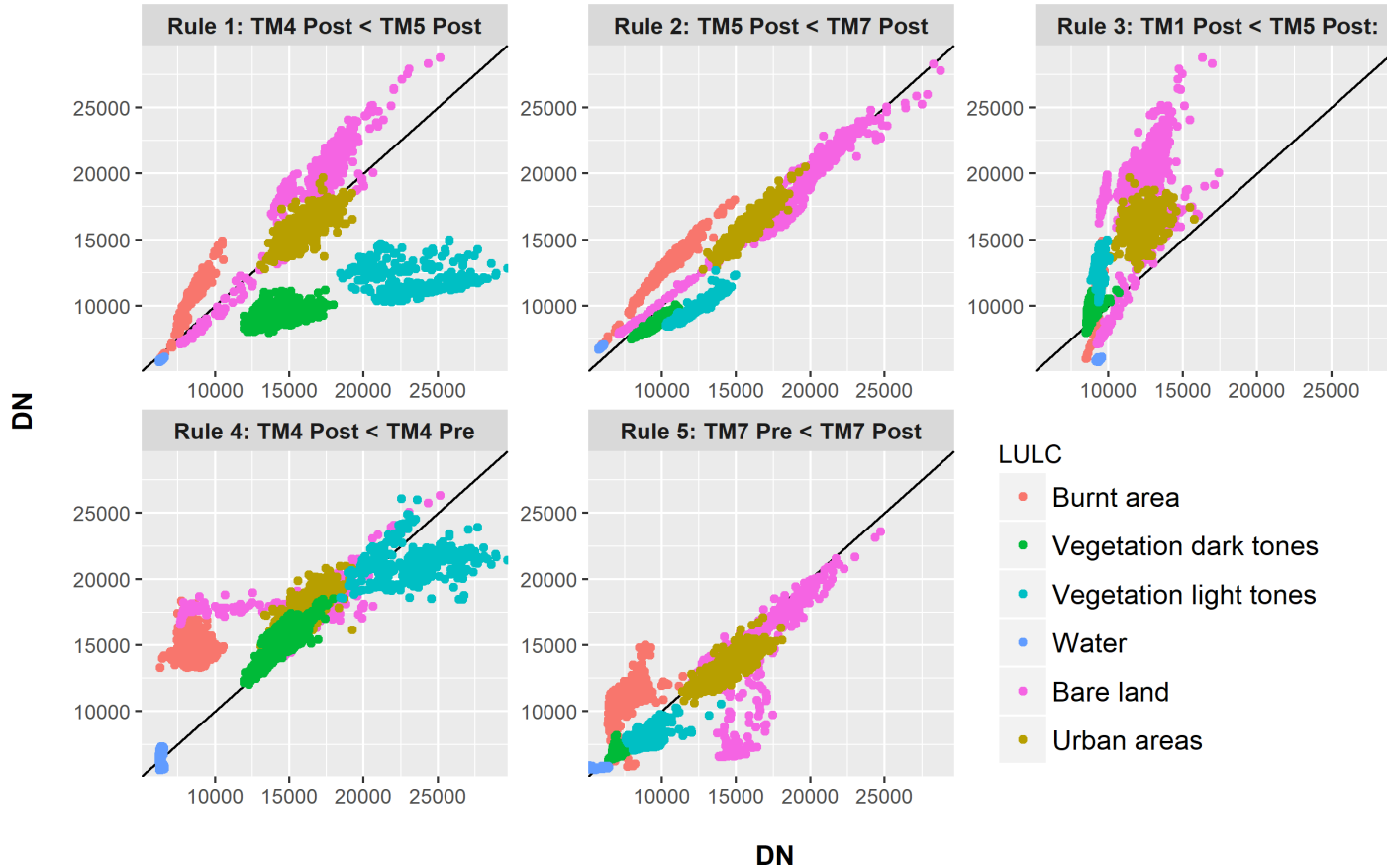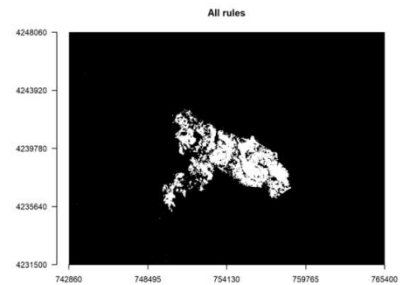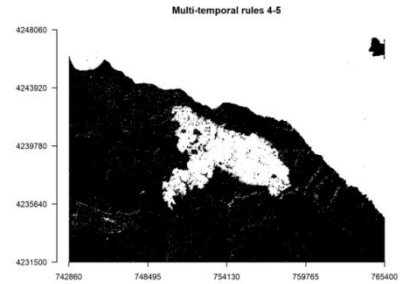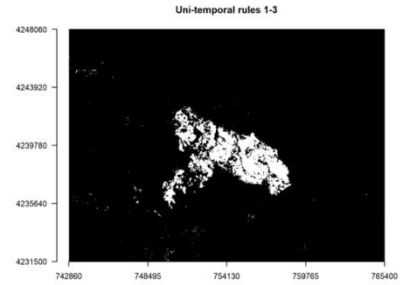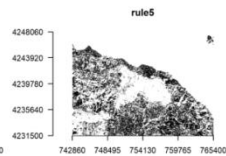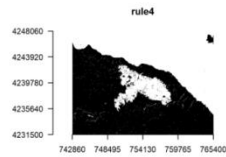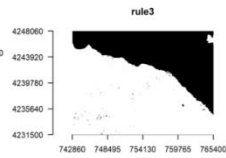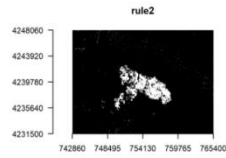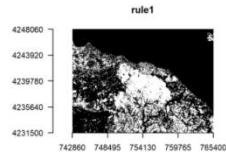
Applying the new set of rules to Sentinel-2 images

Old set of rules
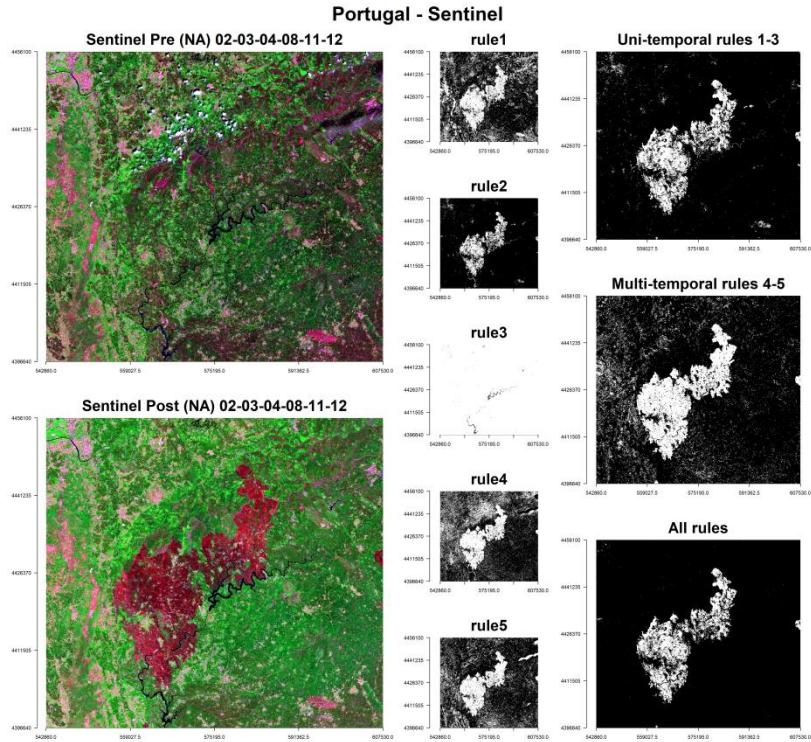
New set of rules
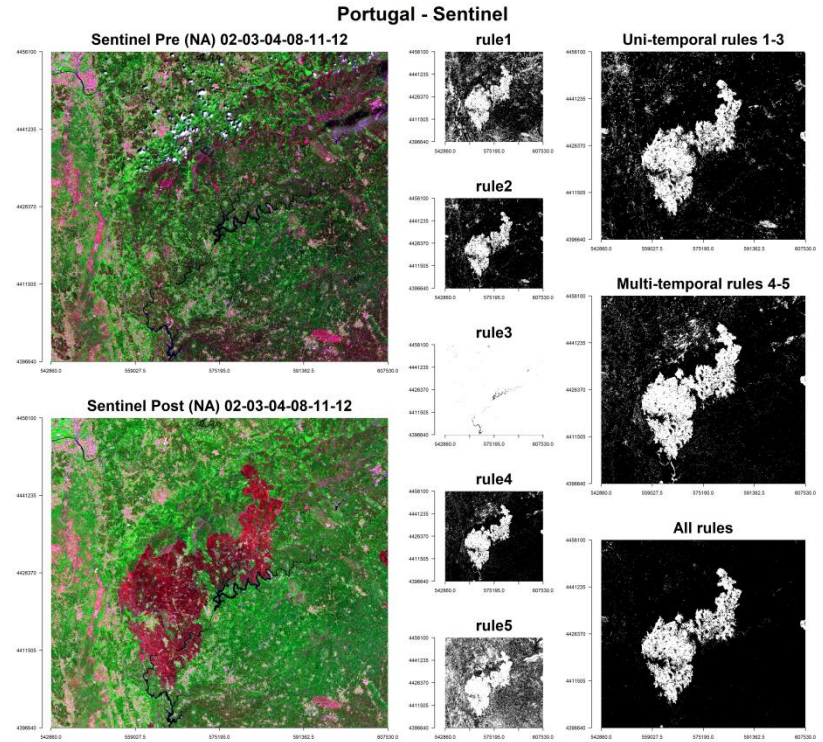
Chios - Sentinel

Sentinel OLI Pre (NA) B02-B03-B04-B08-B11-B12
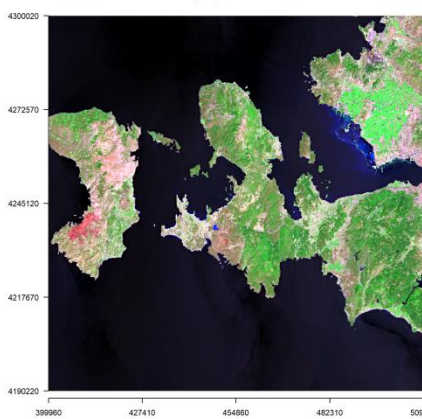
Sentinel OLI Post (NA) B02-B03-B04-B08-B11-B12
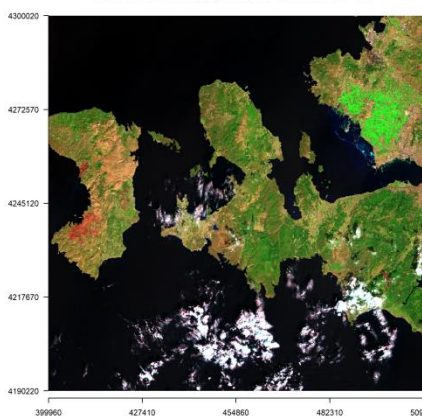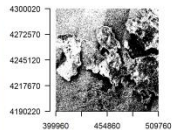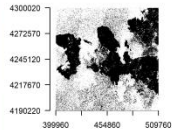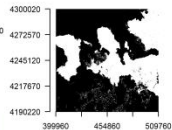
rule1
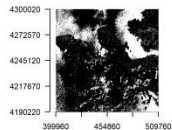
rule2

rule3

rule4

rule5

Uni-temporal rules 1-3

Multi-temporal rules 4-5
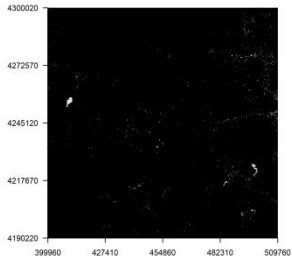
All rules

Portugal - Sentinel

Sentinel OLI Pre (2017-07-14) B02-B03-B04-B08-B11-B12

Sentinel OLI Post (2017-08-03) B02-B03-B04-B08-B11-B12
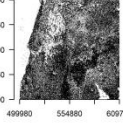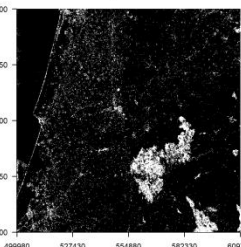
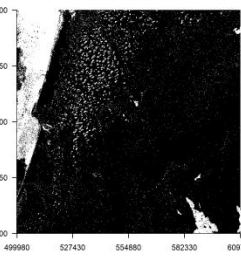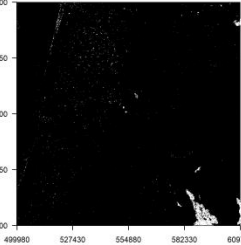rule1

rule2

rule3

rule4
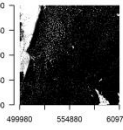
rule5

Uni-temporal rules 1-3

Multi-temporal rules 4-5

All rules

Thank you for your attention