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Sentinel 2 data and a fuzzy algorithm for mapping burned areas and fire severity in the Vesuvio National Park, Italy

Erika Piaser, Giovanna Sona, Matteo Sali, Mirco Boschetti, Pietro Alessandro Brivio, Gloria Bordogna and Daniela Stroppiana

Image credit: NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

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1 Introduction

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3 Methods

4 Results

5 Conclusions

Image credit: *The San Diego Union Tribune* (Meg Oliphant)

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INTRODUCTION: fire season 2017

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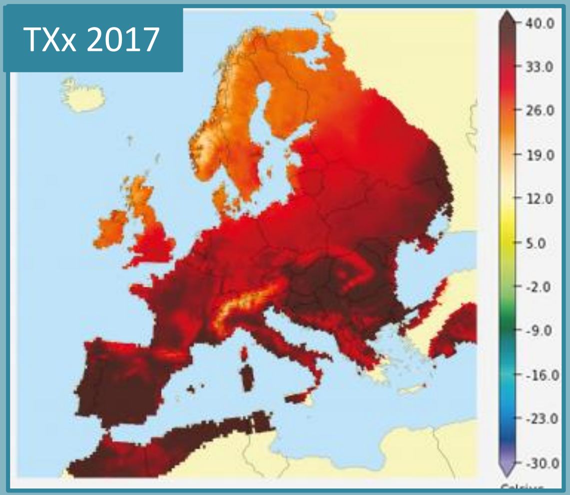
Fire season with significant severe fires in southern Europe



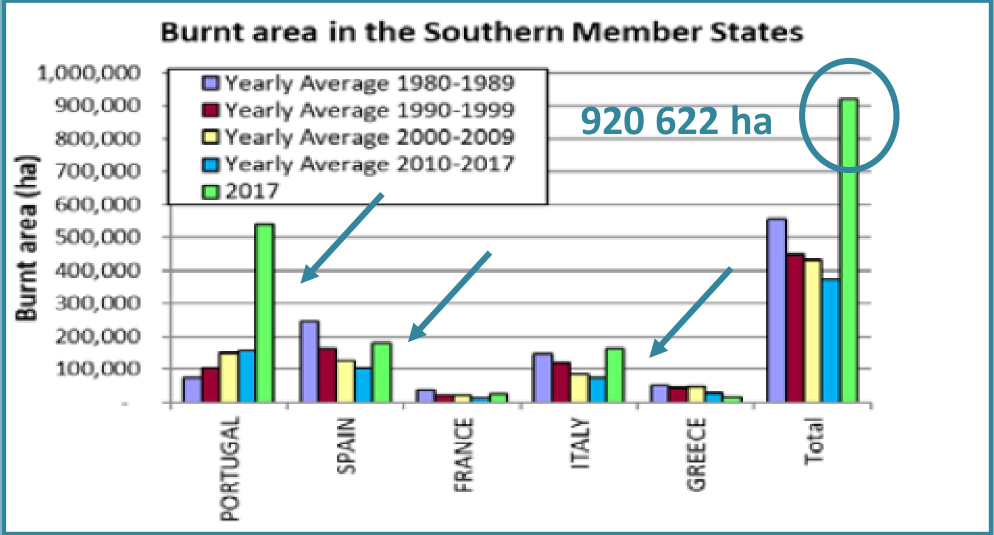
European State of the Climate 2017 (ECMWF, C3S, CAMS)

Climatic conditions

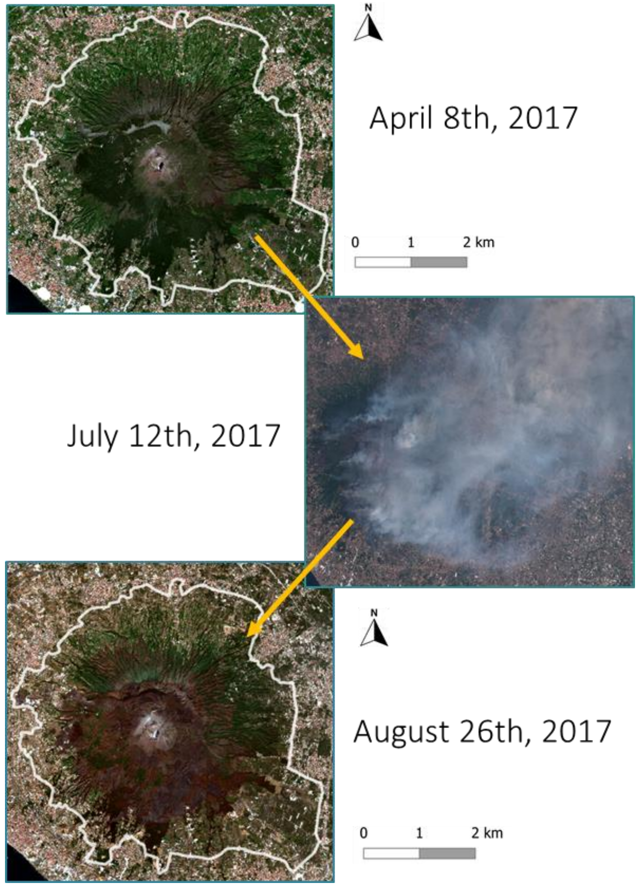
- Temperature above seasonal average
- Dry and hot conditions

Large forest fire

- Increased burned areas
- Increased average fire size
- Increase number of severe fires



EFFIS *“ Forest Fires in Europe, Middle East and North Africa 2017»*



Fires in the Vesuvio National Park observed by Sentinel -2

Image credit: *The San Diego Union Tribune* (Meg Oliphant)

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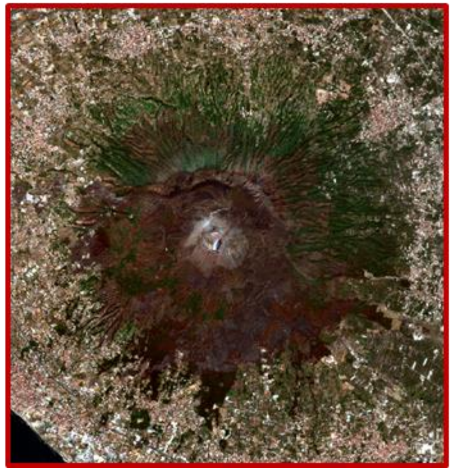
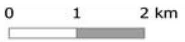
Data: Sentinel-2 imagery

Pre-evento: April 8

Post-evento: July 17

Post-evento: August 26





Sentinel-2

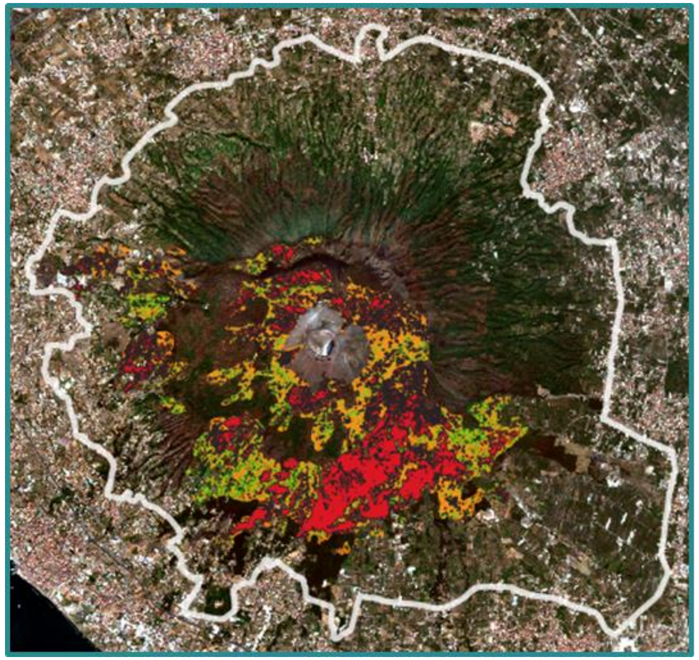
- Sentinel-2A (from June 2015) and Sentinel-2B (from March 2017)
- MSI 13 spectral bands with variable spatial resolution (10,20 e 60 m)
- Temporal frequency (combined A&B) 5 days

S-2 data downloaded and processed with **Sen2r** (Ranghetti & Busetto, 2019)

BANDE SPETTRALI	RISOLUZIONE GEOMETRICA [m]
Banda 1-Coastal aerosol	60
Banda 2-Blue	10
Banda 3-Green	10
Banda 4-Red	10
Banda 5-Red Edge 1	20
Banda 6-Red Edge 2	20
Banda 7-Red Edge 3	20
Banda 8- NIR	10
Banda 8A- NIR	20
Banda 9-Water vapor	60
Banda 10-SWIR-Cirrus	60
Banda 11-SWIR1	20
Banda 12-SWIR2	20

Ancillary datasets: fire grading maps and forest type

Copernicus EMSR213



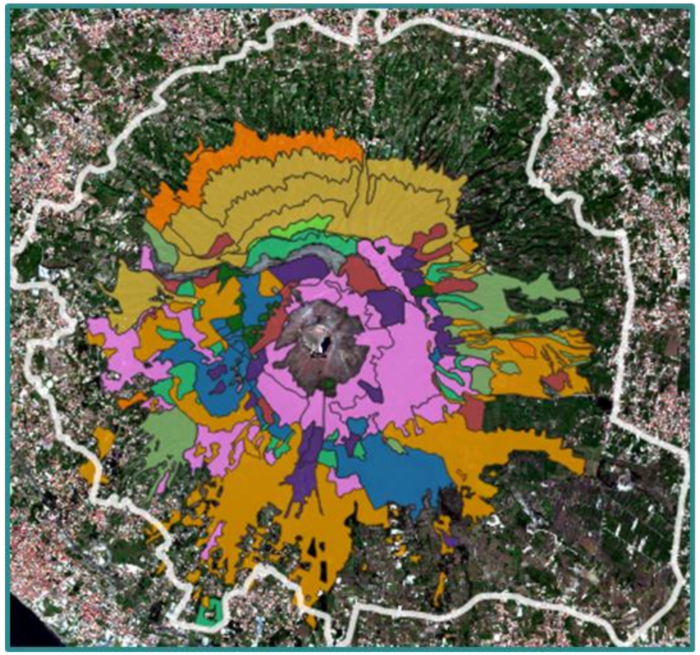
- Derived from high resolution GeoEye-2 images (0.5 m) acquired on **July 14 (2017)**
- Three «fire severity» levels (fire damage levels)

SlightlyDamaged (SD)
CompletelyDestroyed (CD)
HighlyDamaged (HD)

0 1 2 km

1. ***Training sample***
2. ***Algorithm validation***

Forest type map (Cona et al. 2005)



Pinete di pino domestico (A)
Pinete di pino marittimo (B)
Pinete di pino nero (C)
Pinete miste (D)
Leccete (E)
Querceti (F)
Castagneti (G)
Boschi misti (H)
Boscaglie miste cespugliose (I)
Robinieti (L)
Arbusteti (M)

0 1 2 km

1. Identify **forested areas** within the Park
2. ***Training sample***

Image credit: *The San Diego Union Tribune* (Meg Oliphant)

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METHODS: multi-source fuzzy algorithm training

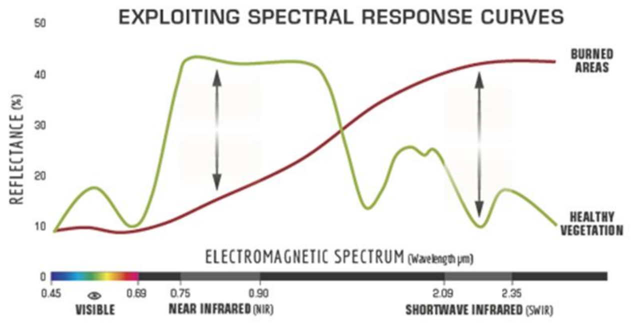
1
- **Training**
- Selection of *training sample (burned/unburned)*
- *Feature selection* based on separability analysis
- Definition *fuzzy Membership functions* (MF)

2
- **Assignement**
- Aggregation with *soft* operators (OWA)

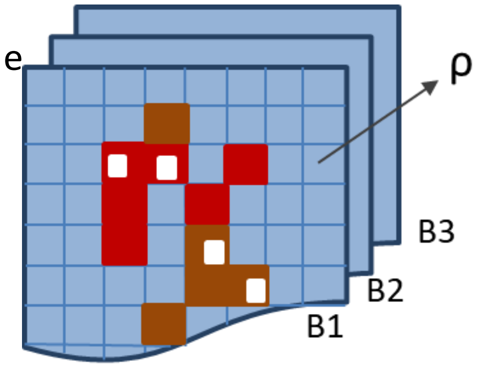
3
- **Segmentation & validation**

4
- **Independent test over Portugal 2017 (Pedrógão Grande)**

1. *Training sample for classes* «**Burned**» e «**Unburned**»



Fonte: US Forest Service



Features «**POST**» event

Features «**DELTA**» (temporal difference)

2. Extraction of density distribution (Kernel) for each class and *feature*

3. *Feature selection*: separability analysis with **metric M** (Boschetti, 2014)

$$M = \left|\frac{\mu_1 - \mu_2}{\sigma_1 + \sigma_2}\right|$$

M > 1 classes can be discriminated

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METHODS: membership functions

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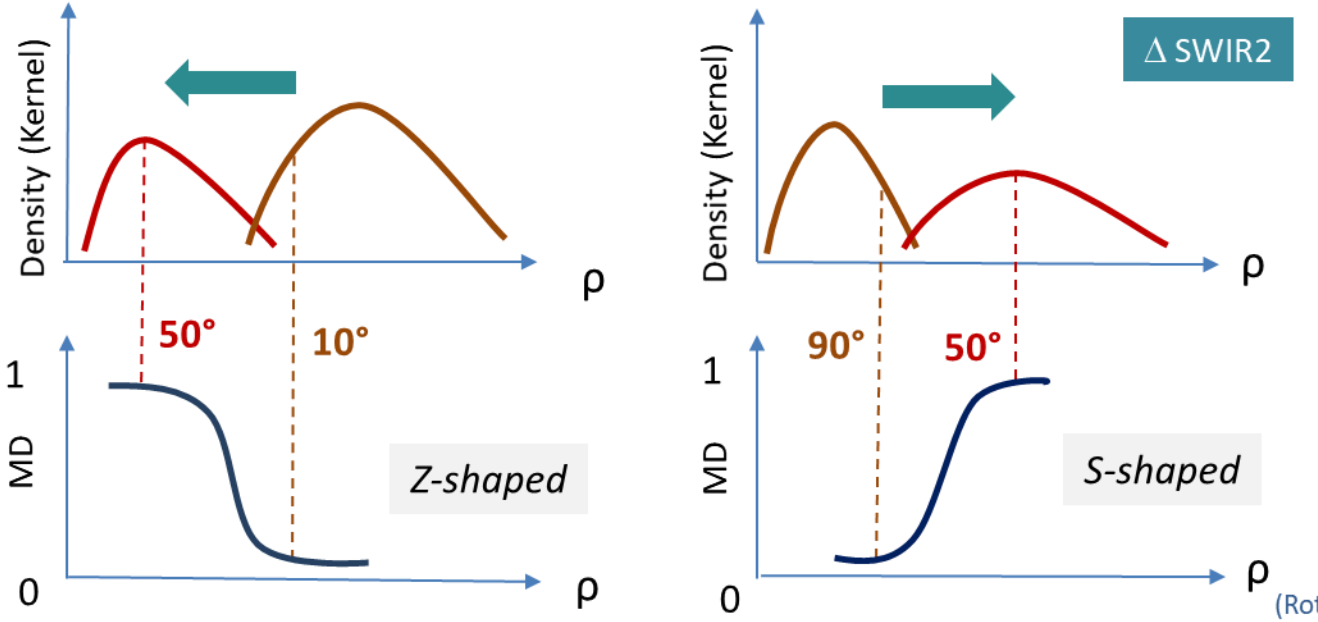
Reflectance (**ρ**)
or reflectance difference (**Δρ**) → *Membership Degree* (**MD**)

0 < **MD** < 1

$$f(x) = \frac{L}{1 + e^{-k(x-x0)}}$$

Funzione logistica

Slope Inflection point



(Roteta et al., 2019)

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METHODS: from partial to global evidence

1
- **Training**
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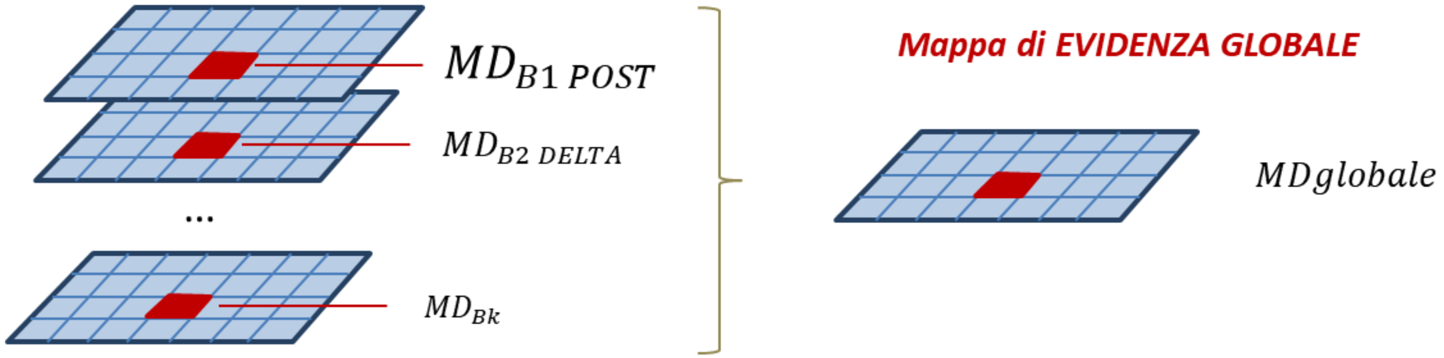
Mappa delle EVIDENZE PARZIALI

Mappa di EVIDENZA GLOBALE



k = *features* selezionate mediante separabilità

1. $W_{OR} = [1,0,0,\ldots,k]$ (Pessimistic approach)
2. $W_{quasi\ OR} = [0.5, 0.5, 0, \ldots, k]$ (Partial pessimistic approach)
3. $W_{Average} = \left[\frac{1}{k}, \frac{1}{k}, \ldots\right]$ (Average approach)
4. $W_{quasi\ And} = [0, 0, \ldots, 0.5\ , 0.5\ ]$ (Partial optimistic approach)
5. $W_{And} = [0, 0, \ldots, 0\ , 1\ ]$ (Optimistic approach)

METHODS: binary maps and validation

1
- **Training**
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- **Independent test over Portugal 2017 (Pedrógão Grande)**

Segmentation

Global evidence $\xrightarrow{\text{Threshold } TH}$ Binary map *burned/unburned*

MD > *TH* → «**Burned**»

MD < *TH* → «**Unburned**»

Validation

$$OE = \frac{FN}{TP + FN}$$ Omission Error

$$CE = \frac{FP}{TP + FP}$$ Commission Error

$$DC = \frac{2TP}{2TP + FP + FN}$$ Dice coefficient

		Actual	
		Positive	Negative
Predicted	Positive	True Positive	False Positive
	Negative	False Negative	True Negative

Confusion matrix computed for variable TH (0 < *TH* < 1)

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METHODS: multi-source fuzzy algorithm training

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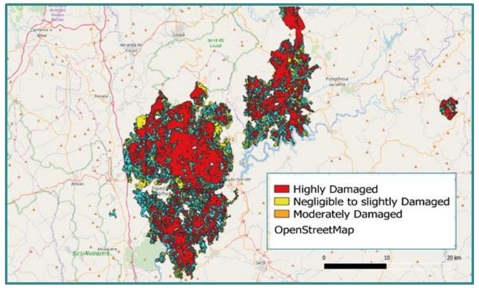
- **Independent test over Portugal 2017 (Pedrógão Grande)**

Sentinel-2 data over Portugal

RGB (11,8,4)

- This step aims at assessing **EXPORTABILITY** of the algorithm in different conditions (vegetation, fire severity) compared to those used for training ther algorithm (Vesuvio National Park).
- The algorithm has been applied with no changes (input features, membership functions, OWA) to **Pedrógão Grande fire event (**June 17th, 2017**)**
- Two S-2 images (pre-fire and post-fire images)
- **Validation** by coparison with Copnernicus maps of the event
- Accuracy metrics for TH in [0, 1]

Copernicus EMSR207



(Source: SPOT-7 June 20th, 2017)

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Image credit: *The San Diego Union Tribune* (Meg Oliphant)

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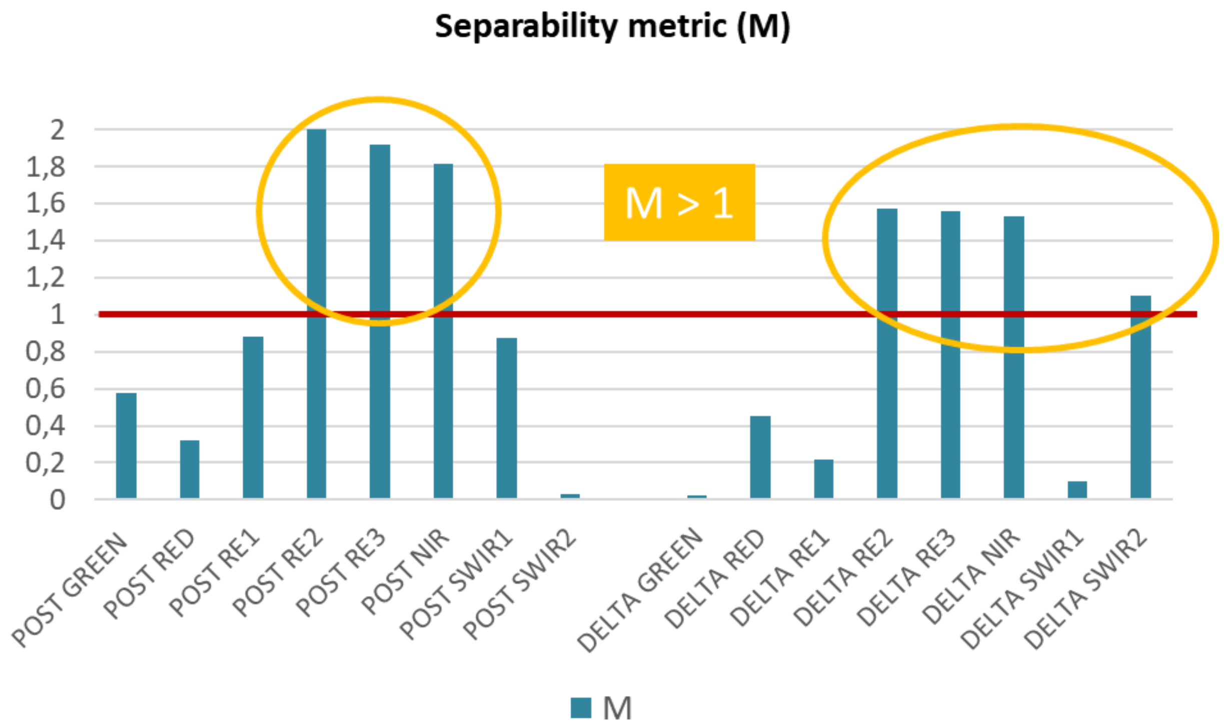
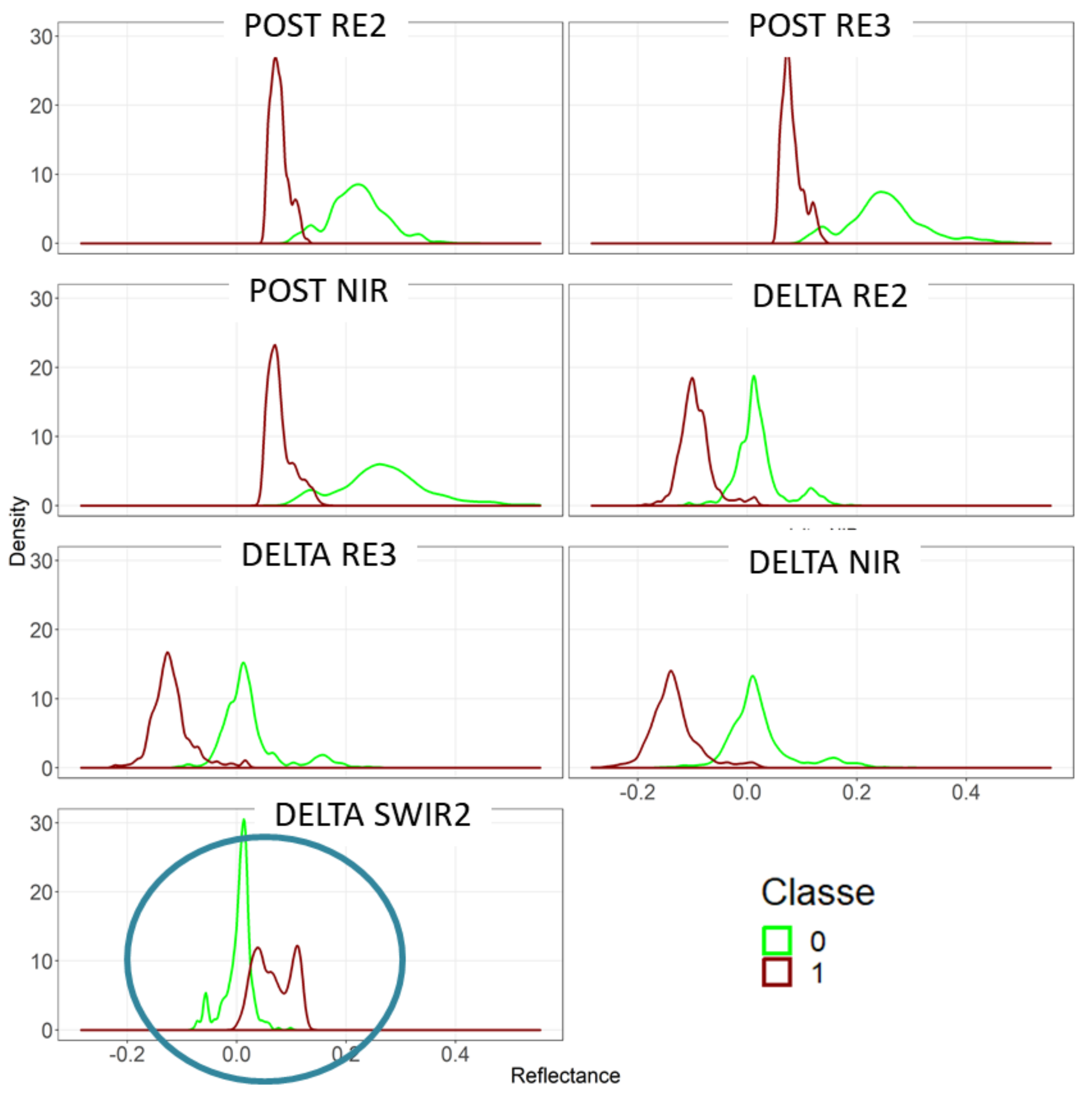
RESULTS: separability & density distribution

Training sample: 67 ROI, 3744 pixels



***7 features** were selected (those that showed M>1): POST RE2, POST RE3, POST NIR, DELTA RE2, DELTA RE3, DELTA NIR e DELTA SWIR2*



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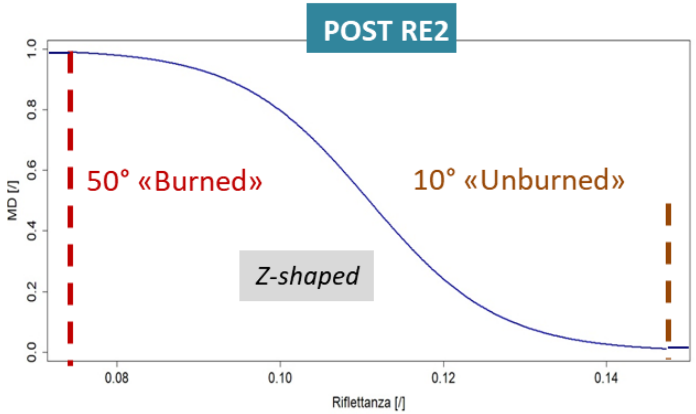
RESULTS: fuzzy membership functions (MF)

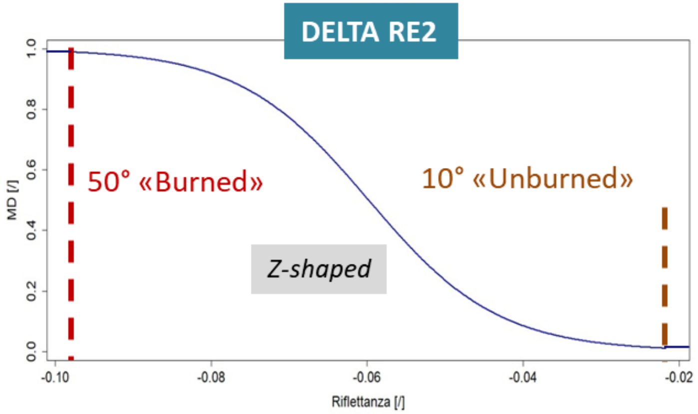
Logistic function

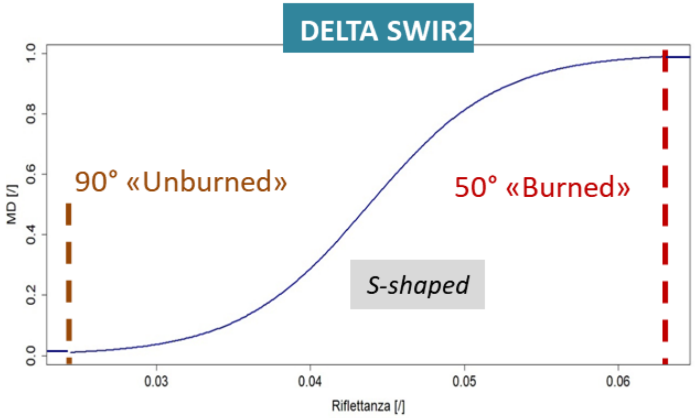
$$f(x) = \frac{L}{1 + e^{-k(x-x0)}}$$

BANDE SPETTRALI	K	X0
POST RE2	-125.894	0.1109
POST RE3	-115.775	0.11659
POST NIR	-123.658	0.10986
DELTA RE2	-120.291	-0.0598
DELTA RE3	-93.7206	-0.07527
DELTA NIR	-87.1443	-0.08657
DELTA SWIR2	236.984	0.04381

- Exploiting training and density disitrbution (percentiles) the two parameters of the logistic functions (K, X0) have been estimated
- Logistic function relies on two assumptions:
  f(x)->1 for x-> -∞ (opposite for ΔSWIR2)
  f(x)->0 for x-> +∞ (opposite for ΔSWIR2)







Opposite behaviour

RESULTS: global evidence maps

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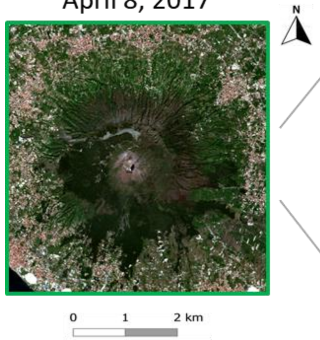
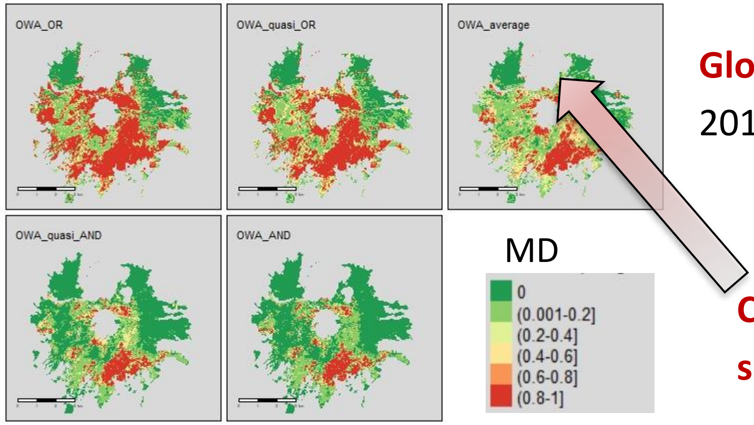
- **Global evidence maps** have been derived by combing pre-event S-2 image (April 8, 2017) with two post-event S-2 images: July 17 and August 26;
- **July 17 is the S-2 image closest in time to Copernicus reference** date (most suited for validation but with clouds and shadows). Clouds have been masked out during pre-processing and shadows have been masked oput manually;
- **August 26 is cloud-free post-event image** (best signal, no atmospheric disturbance but later with respet to reference)

Pre-event:
April 8, 2017



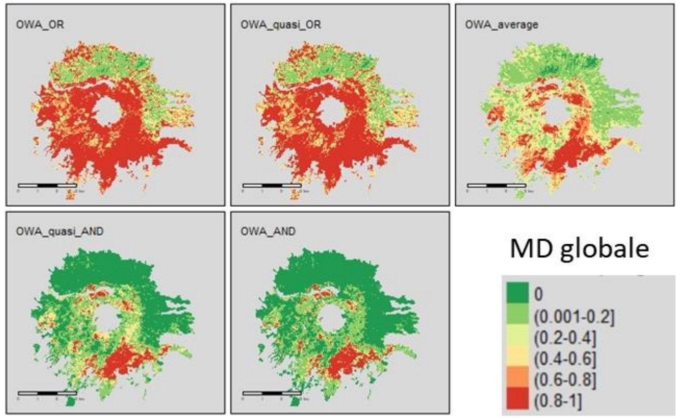
Post-event:
July 17, 2017
senza ombre



Global evidence maps July 17, 2017, as post-event S-2 image

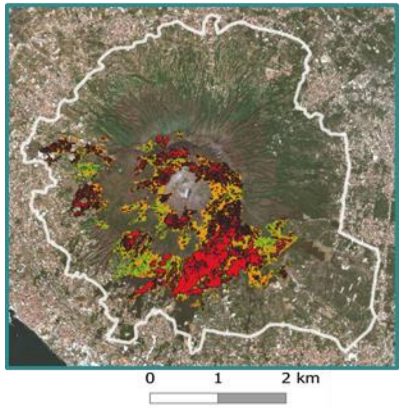
Clouds&cloud shadows removed

Post-event:
August 26, 2017



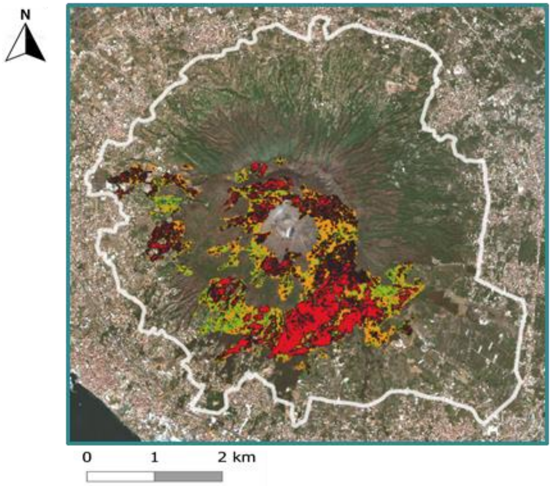
Global evidence maps August 26, 2017, as post-event S-2 image

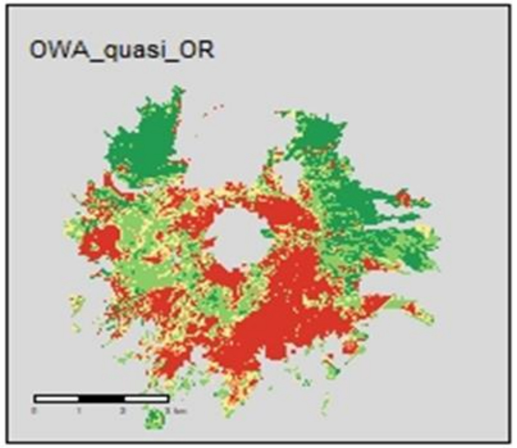
Copernicus EMSR213



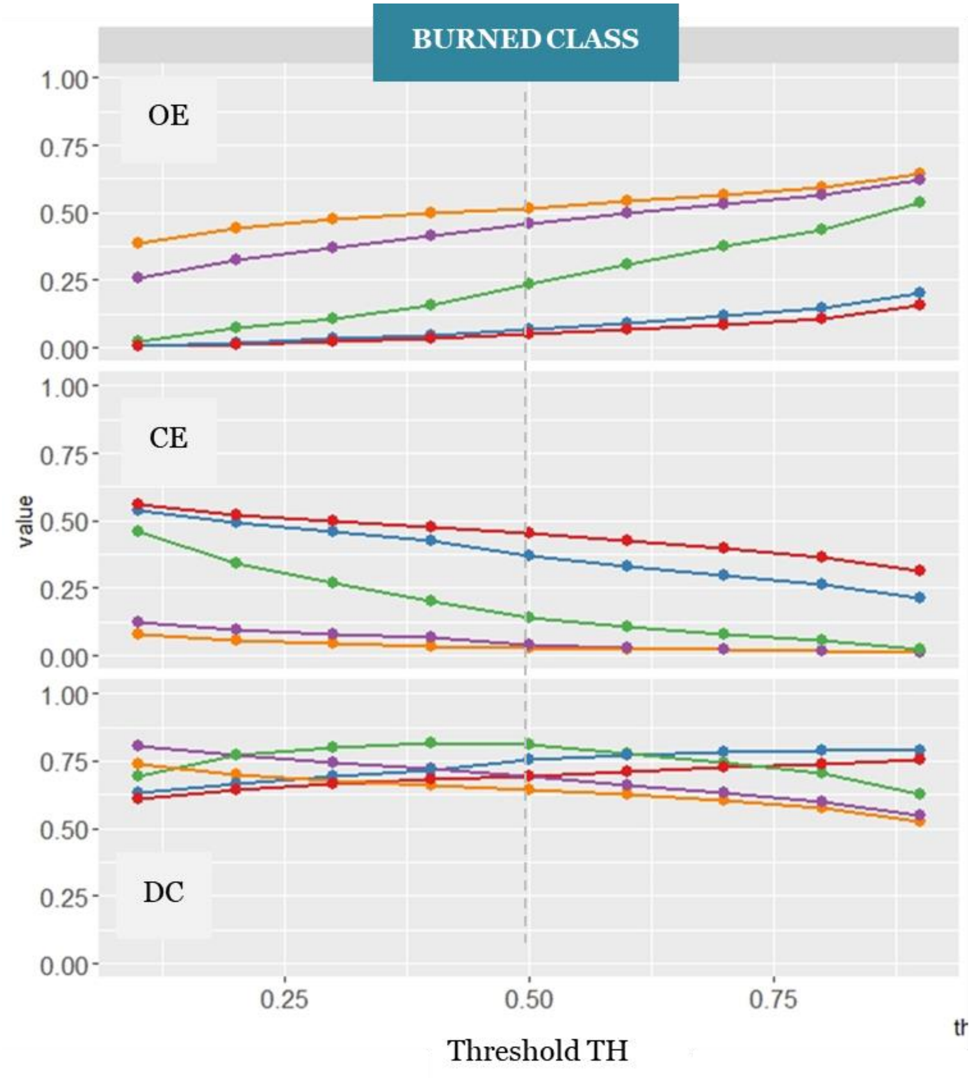
RESULTS: validation & accuracy metrics

Copernicus EMSR213





- **Comparison of Copernicus** (left) **& Global evidence map** for OWA Almost OR (right)
- Global evidence map ranges in [0, 1] showing the degree os **membership to burned class**
- Once threshold TH is fixed a binary burned/unburned map can be derioved and compared to reference
- Accuracy metrics are computed from the confusion matrix for all OWAs (see graphs)



Post-event:
July 17 2017

owa
- OR
- quasi_OR
- average
- quasi_AND
- AND

TH > 0.5

OE → 10 – 23 %
CE → 40 – 23 %
DC → 75 – 85 %

RESULTS: exportability test (Portugal)

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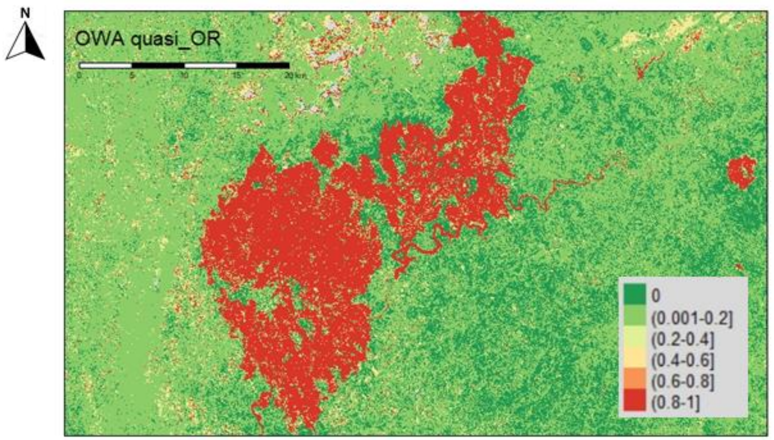
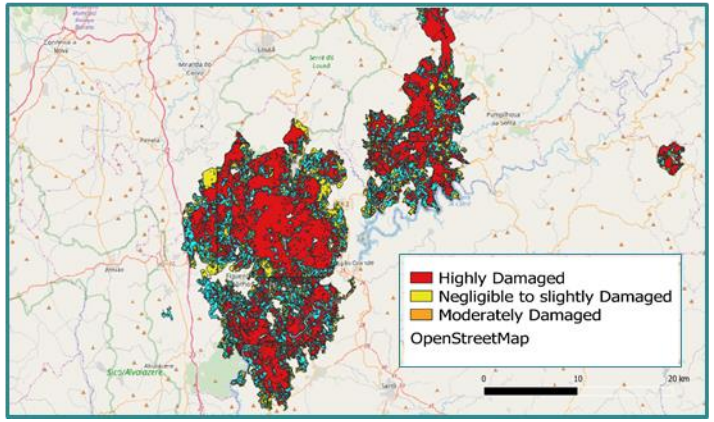
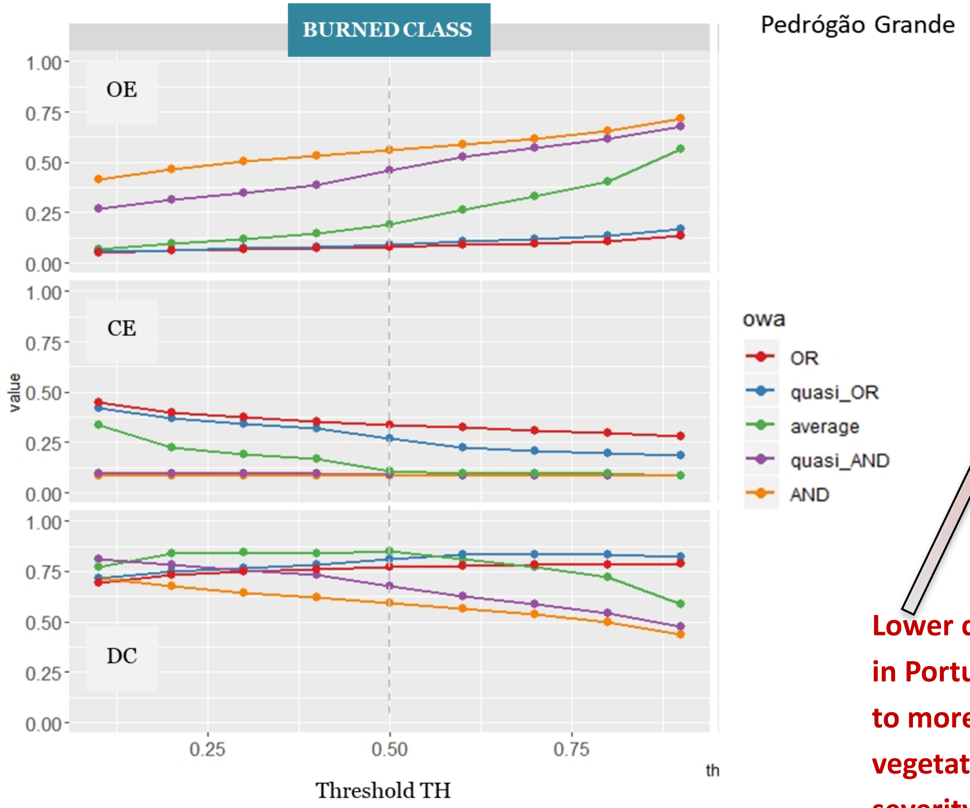


Copernicus EMSR207



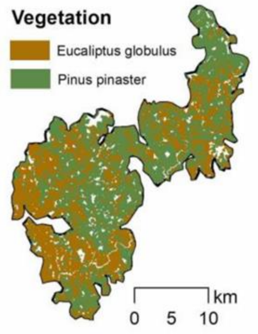
- Also for test area in Portugal (Pedrógão Grande) **global evidence maps** have been compared with **Copernicus** (in the figure only OWA Almost OR is shown as global evidence map)
- Graphs below show accuracy metrics for variable threshold TH values (x-axis) used for deriving the binary burned/unburned map



Comparison between accuracy metrics for testing and training area: range of values for TH > 0.5

Pedrógão Grande	Vesuvio National Park
Per *TH* > 0.5	Per *TH* > 0.5
OE → 10 – 23 %	OE → 10 – 23 %
CE → 25 – 19 %	CE → 40 – 23 %
DC → 81 – 85 %	DC → 75 – 85 %

Lower commission error in Portugal probably due to more homogeneous vegetation and higher fire severity



Alfornso Fernàndez Manso et al., 2020

Image credit: *The San Diego Union Tribune* (Meg Oliphant)

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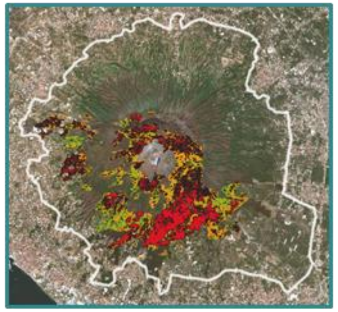
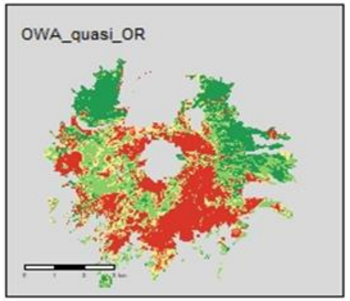
CONCLUSIONS

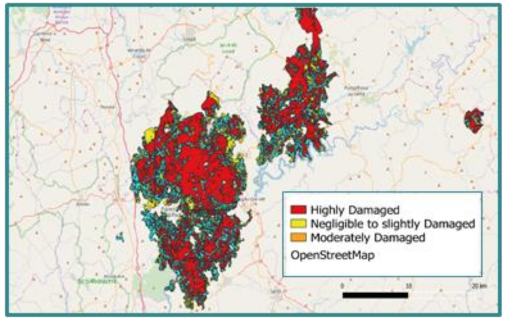
- Our results highlighted that the best ***features*** for discriminating **burned vs. unburned areas** are the same spectral bands generally used for monitoring **vegetation conditions and status** (Red Edge, NIR e SWIR2) expressed as both post-fire and temporal difference reflectance;
- Frequency of observation offered by Sentinel-2 is suitable for monitoring a dynamic (in space and time) phenomenon as **wildfires;**
- **The proposed algorithm** produces satisfactory results when compared to reference data Copernicus damage maps (OE < 25 % e 23 < CE < 40 % , per TH > 0.5);
- **Among inspected and tested OWA,** Almost_OR showed best results in both test and training areas.

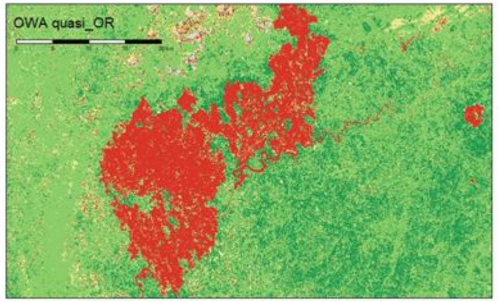
Vesuvio National Park





Portugal (Pedrógão Grande)





PERSPECTIVES

- Algorithm improvement for **better discrimination** of surfaces with similar spectral signal, such as **cloud shadows and water**;
- The above objective can be achieved by integrating spectral information from thermal infrared bands (integration of Sentinel-3 data in a multi-source approach)**;**
- **The fuzzy approach could integrated a Region Growing (RG) algorithm:** exploiting global evidence derived with different OWA (pessimistic and/or optimistic) could be used as seed and growing layers. Commission errors can be reduced;
- Contextual approach
- Active fires could be exploited for automatic defintion of fuzzy memebership functions so that site specific characteristics are derscribed;
- Test with spectral indices (NDVI, NBR, EVI, SAVI)
- Multi-source approach by including information from SAR (Sentinel-1) for areas with persistent cloud cover

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