Mapping forest natural disturbances dynamics in the Aosta Valley (Italy) through long-term trends derived from Landsat time series and innovative statistical approaches

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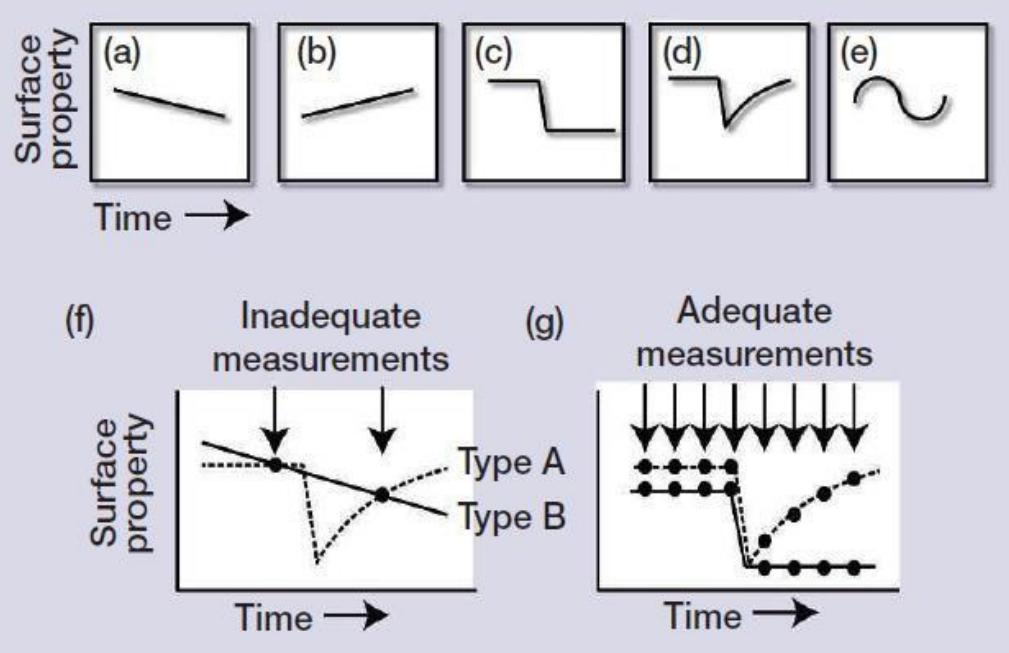
How forest ecosystems change

- Ecological processes alter several biophysical quantities of forested ecosystems (Kennedy et al. 2014).
- Natural disturbances (e.g. fires, windthrows, insect outbreaks, snow avalanches, landslides) cause either abrupt (c, d) or gradual changes (a, b).

Canopy closure

Biomass level

Vertical structure



from Kennedy et al. 2014

- Underlying processes can be characterized and understood only if observations are adequately taken.
- Trajectories of biophysical quantities can be conceptualized using mathematical response functions.

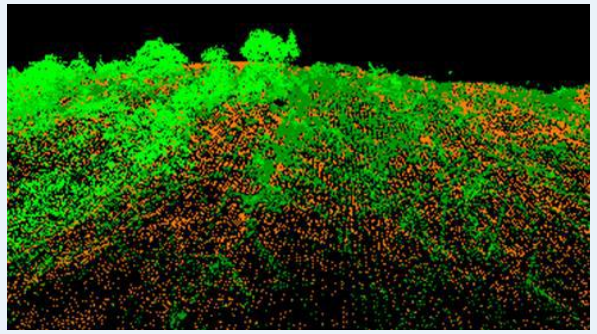
Forest recovery assessment

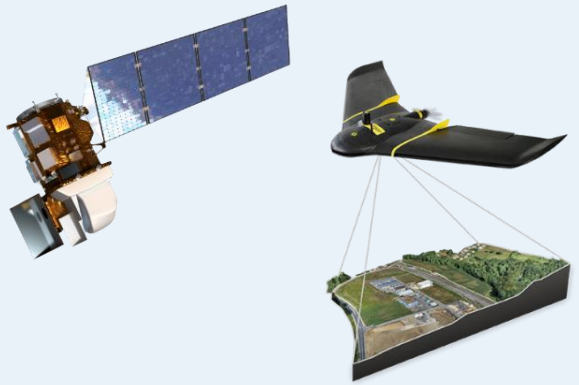
Field surveys
(from plot to stand scale)

Remote sensing
(from stand to global scale)

- Tree regeneration structure and species composition.
- **Field sensors** for microclimate conditions (soil moisture and temperature).
- **Validation** of remote sensing products (e.g. land cover maps, biophysical variables).

- **Platforms:** aircrafts, satellites and UAVs.
- **Data:** historical aerial orthoimagery, multispectral and hyperspectral imagery, LiDAR, SAR.
- **Tecniques:** pixel and object-based classification, time series analysis, Spectral Mixture Analysis, canopy heigth models.





GENERAL HYPOTHESIS

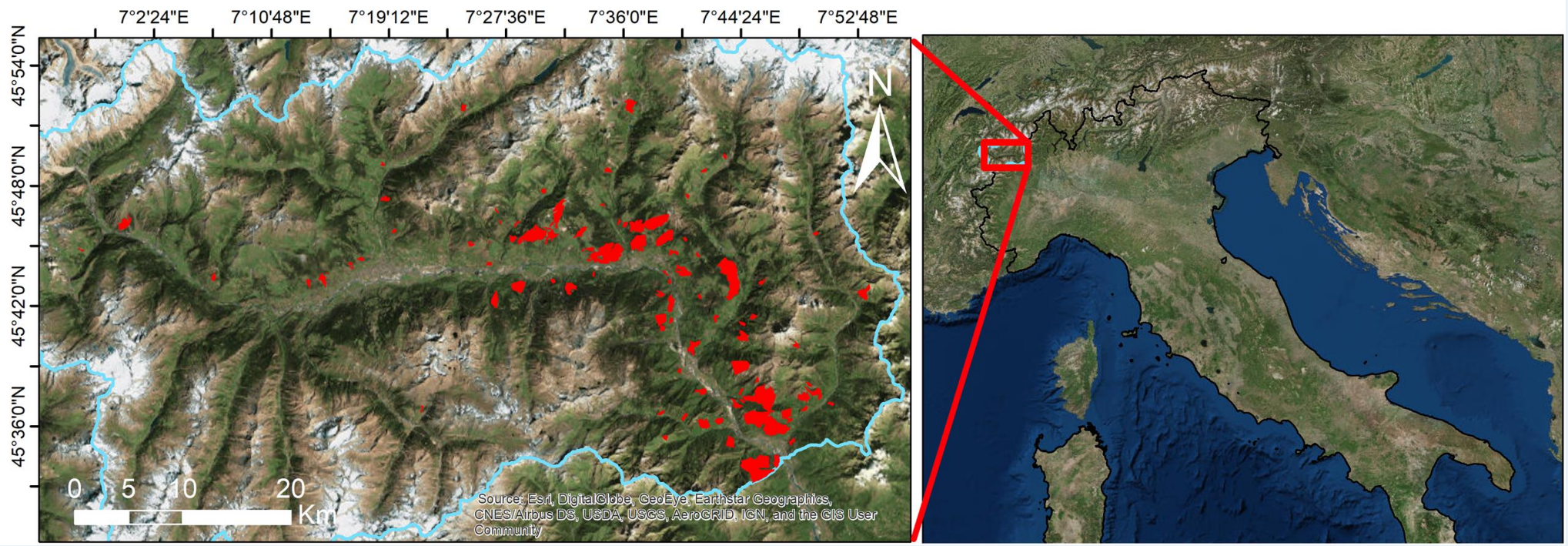
- Disturbance severity, spatial pattern and post-disturbance management are among the main drivers of forest recovery.

OBJECTIVES

- Mapping forest disturbances along with their severity at the regional scale.
- Investigating drivers of forest recovery in stands dominated by tree species with low fire adaptations.

Crown fire in Nus and Verrayes municipalities (AO) occurred in March 2005. Burned forest was dominated by *Pinus sylvestris* (160 ha). Photo credit G. Cesti.

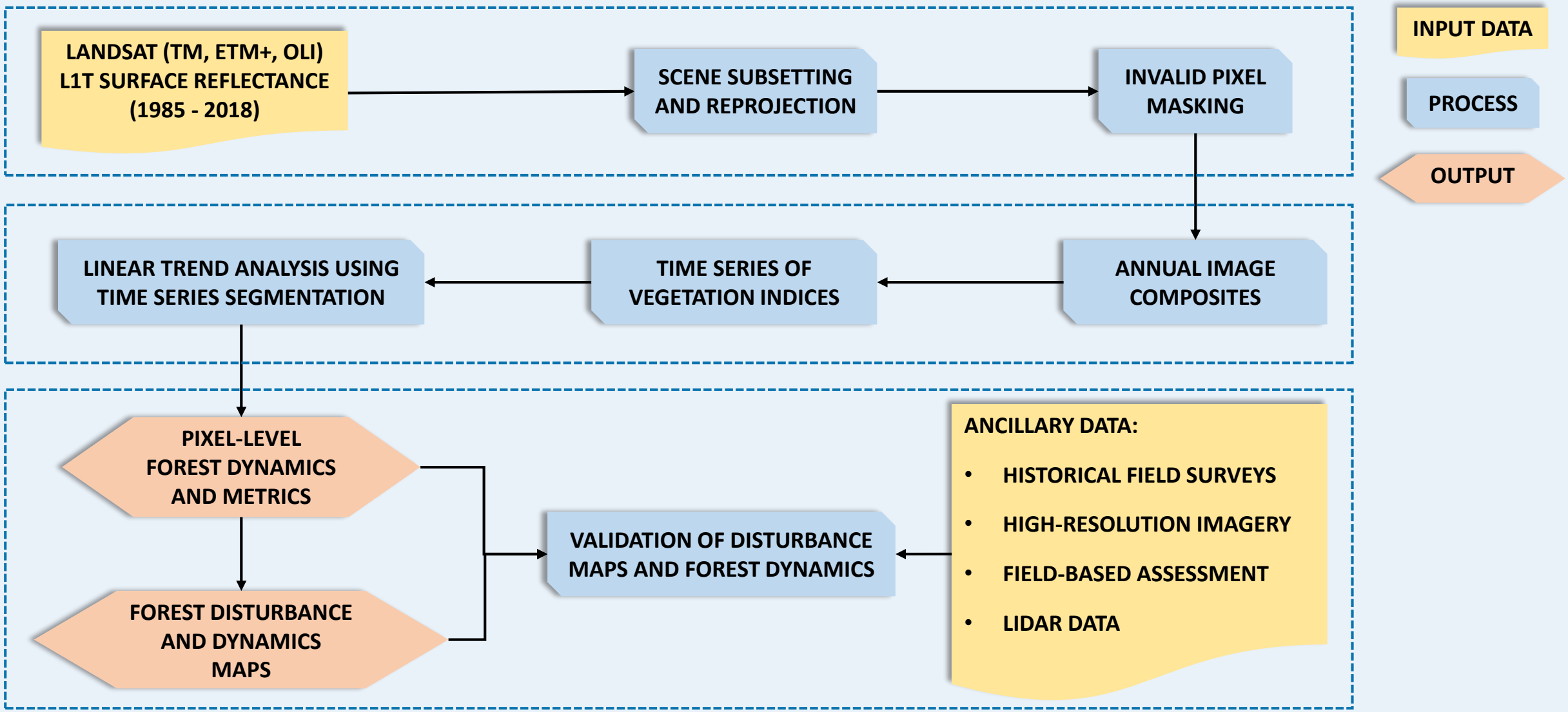
Study area: Aosta Valley



Red polygons indicate the location of historical fires occurred since 1961 in the Aosta Valley.

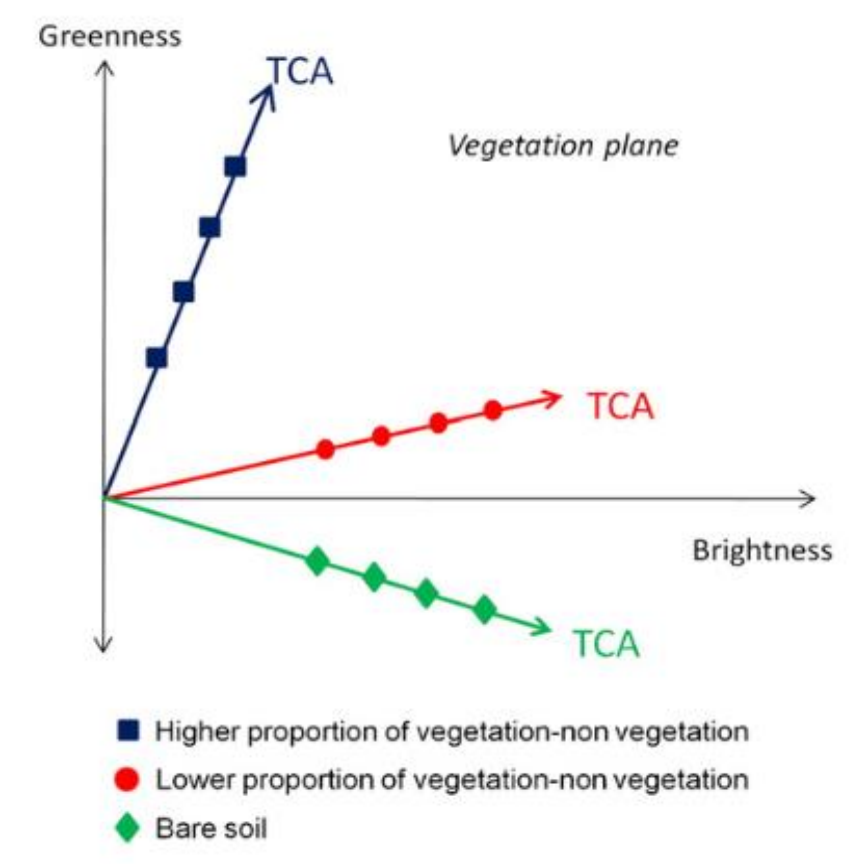
- Wildfires in the Aosta Valley mostly occur in south-facing slopes where xeric conditions favor the presence of highly flammable conifer stands dominated by Scots pine (*Pinus sylvestris*).
- Although stand-replacing wildfires affected about 20% of the total burned forest surface from 1989 to 2017, the scarce fire adaptations of Scots pine poses serious problems for its natural regeneration.

Remote sensing workflow



Vegetation indices

- Normalized Burn Ratio (NBR) sensitive toward forest disturbances (Key & Benson 2006, Kennedy et al. 2010, Hermosilla et al. 2015).
- Tasseled Cap Angle (TCA) measures the proportion of vegetation to non-vegetation.
- Tasseled Cap Wetness (TCW) is highly correlated with water content of plants biomass and soil.
- TCW useful to detect variations in forest structural characteristics due to stand replacing disturbances (Healey et al. 2005, DeVries et al. 2016).
- Robust Distance to Forest (RDF) is a novel index corresponding to the spectral distance of a given pixel to the spectral characteristics of the forest canopy cover, accounting for the covariance structure of TCA and TCW.

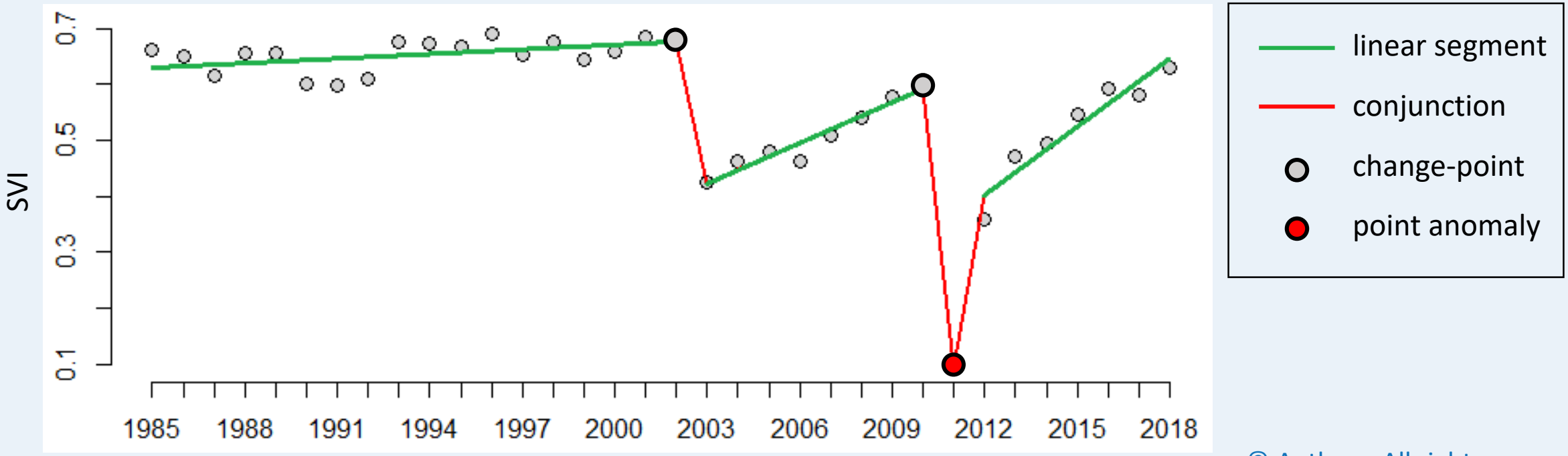


from Gomez et al. 2011

$$\mathrm{TCA} = \arctan\left(\frac{TCB}{TCG}\right)$$

Linear trends segmentation

- Bottom-up approach to merge neighboring segments of the data.
- At each change-point, the slope and/or the intercept changes.
- Point anomalies are large jumps with respect to the typical signal.
- One-year data gaps filled using values from the neighboring years with a multi-step approach.

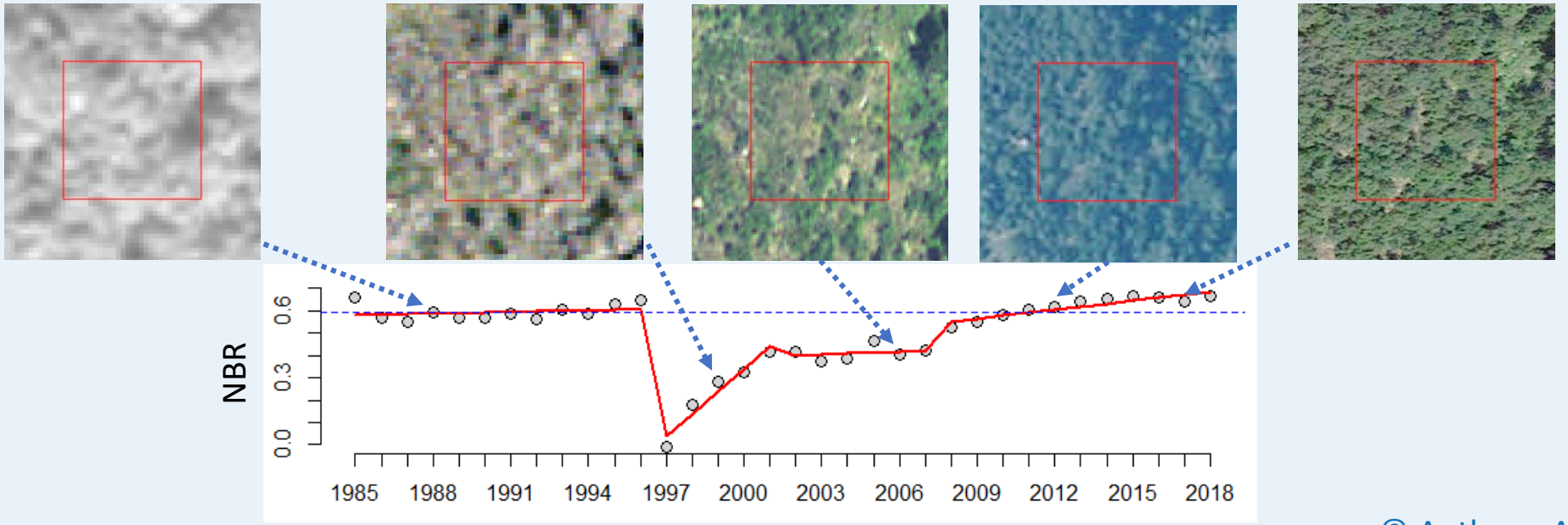


Linear trends metrics

Years of change-points Piecewise length, slope and intercept Change magnitude (positive and negative) Piecewise Mann-Kendall tau and p-value	Single value per year
Number of change points (positive and negative) Maximum magnitude (positive and negative) Year of maximum magnitude (positive and negative) Regeneration Index (Kennedy et al. 2012) (positive and negative magnitude) Root Mean Squared Error	Single value per time series

Validation: sources and methods

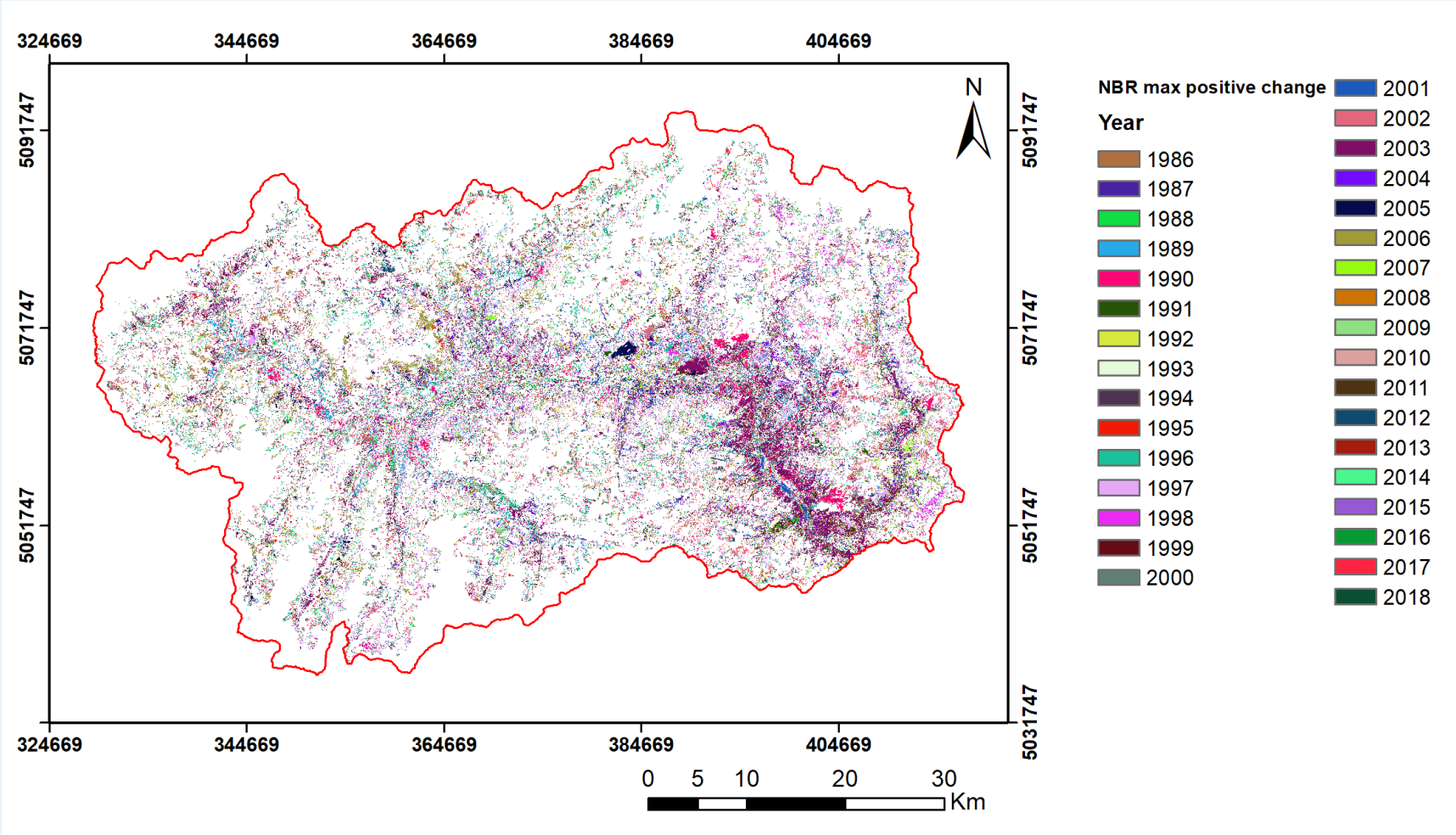
- Google Earth and historical aerial orthoimagery (1988, 1994, 2000, 2006, 2012) employed to visually assess pre and post disturbance forest cover at the Landsat pixel scale.
- Fire perimeters and high severity patches were provided by the forest fire fighting corps of the Aosta Valley.
- Information about the majority of disturbances occurred since 1985 is going to be collected.



Year of change occurrence

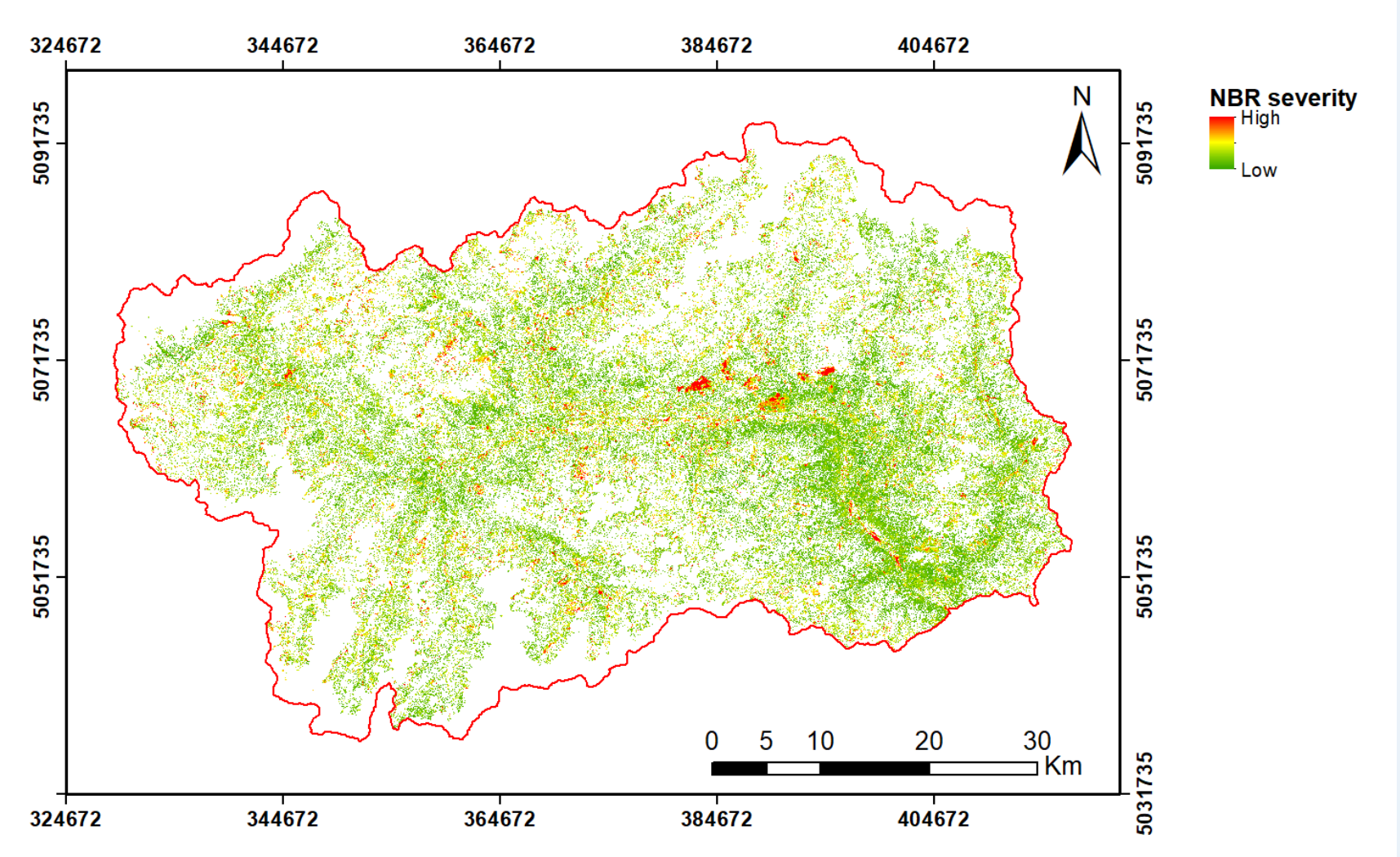
- When the greatest positive change was detected in a pixel time series.
- NBR time series selected as reference to detect change-points in linear trends.

- Wildfires generally detected in the same year they occurred given the peak of fires typically occurs in late winter.
- Minimum mapping unit (MMU) = 0.5 hectares.



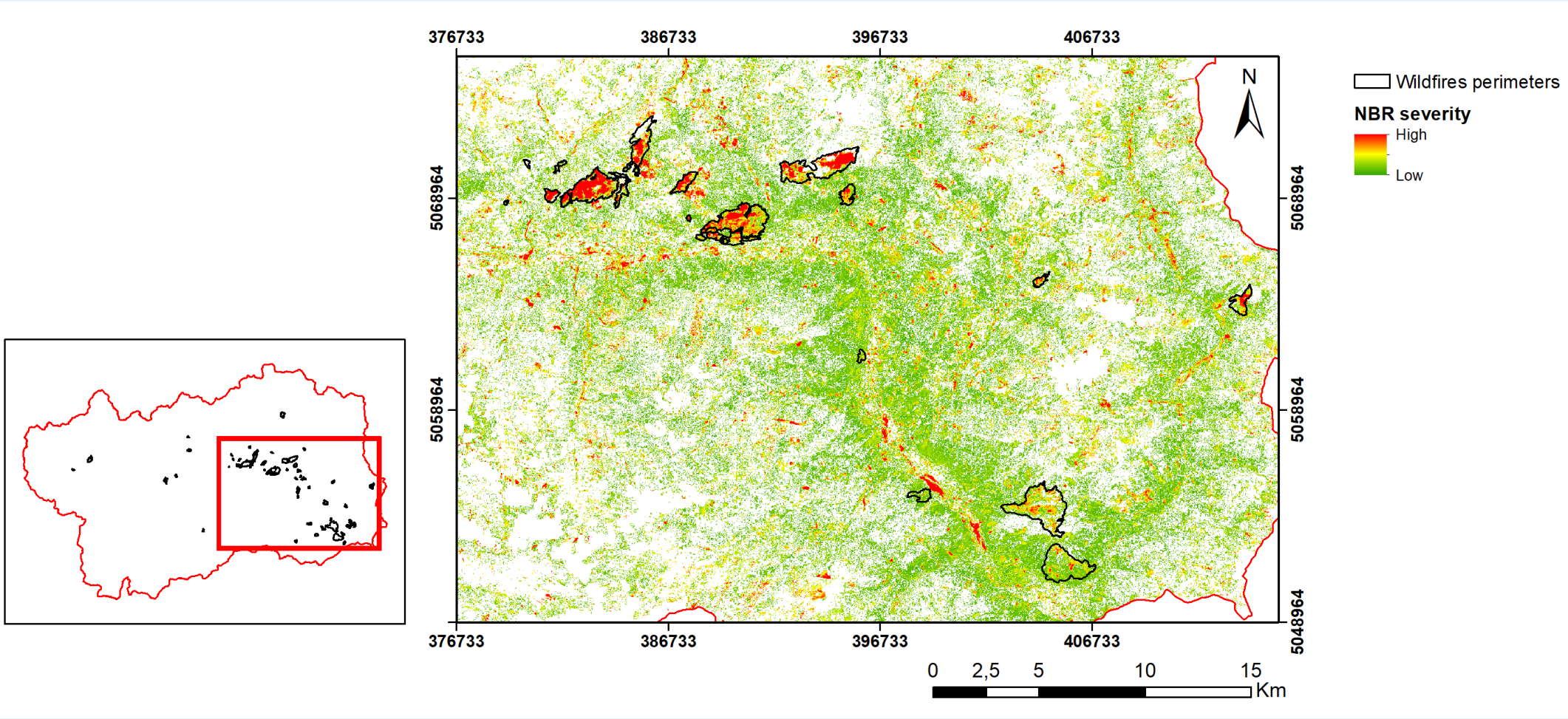
Disturbance severity

- The greatest magnitude detected within the pixel time series, useful to detect stand-replacing disturbances.



Severity map: validation

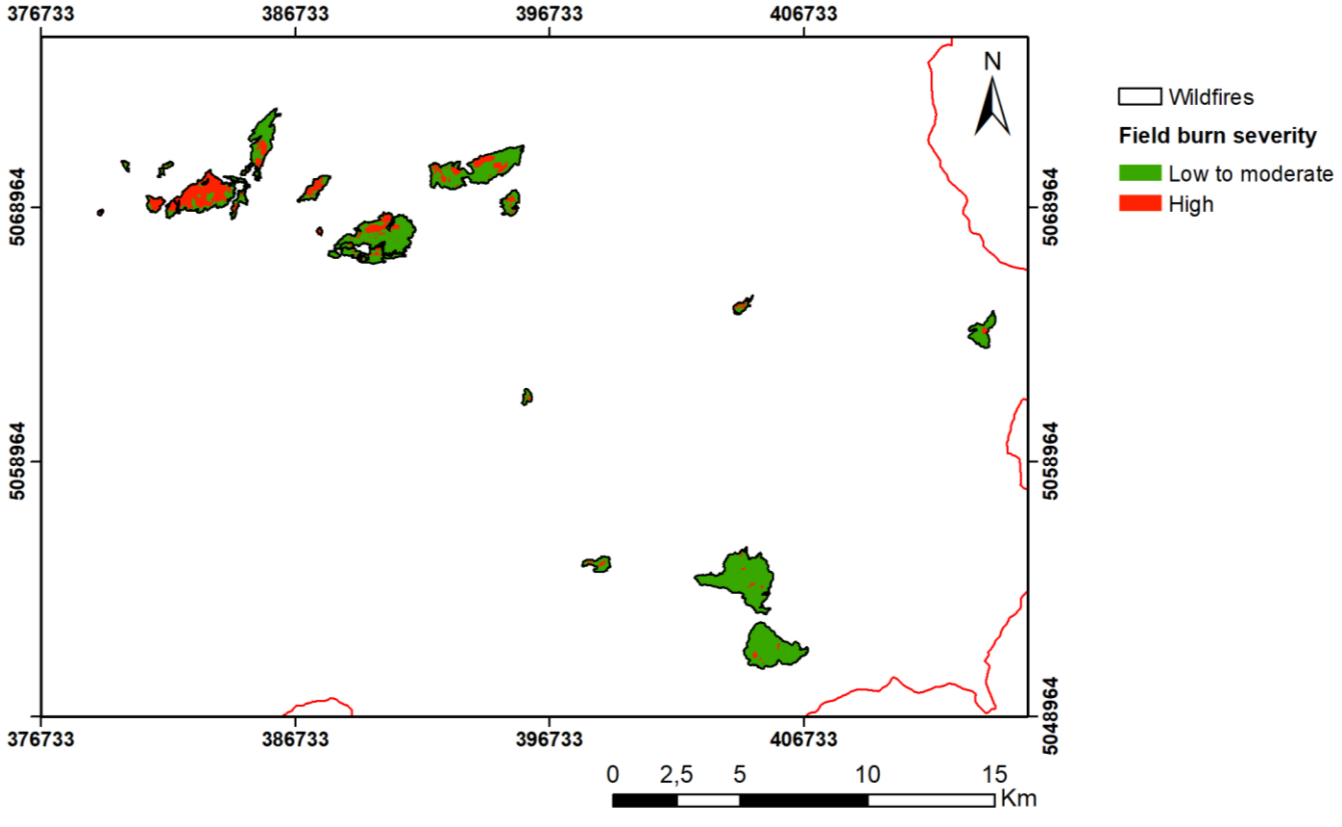
- Severity of wildfires validated using historical fire perimeters and patches with crown fires provided by the forest fire fighting corps of the Aosta Valley.



Burn severity: map validation

- NBR thresholds proposed by Key & Benson (2006) used to classify low to moderate-low and moderate-high to high burn severity.
- 405 random points used for validation.

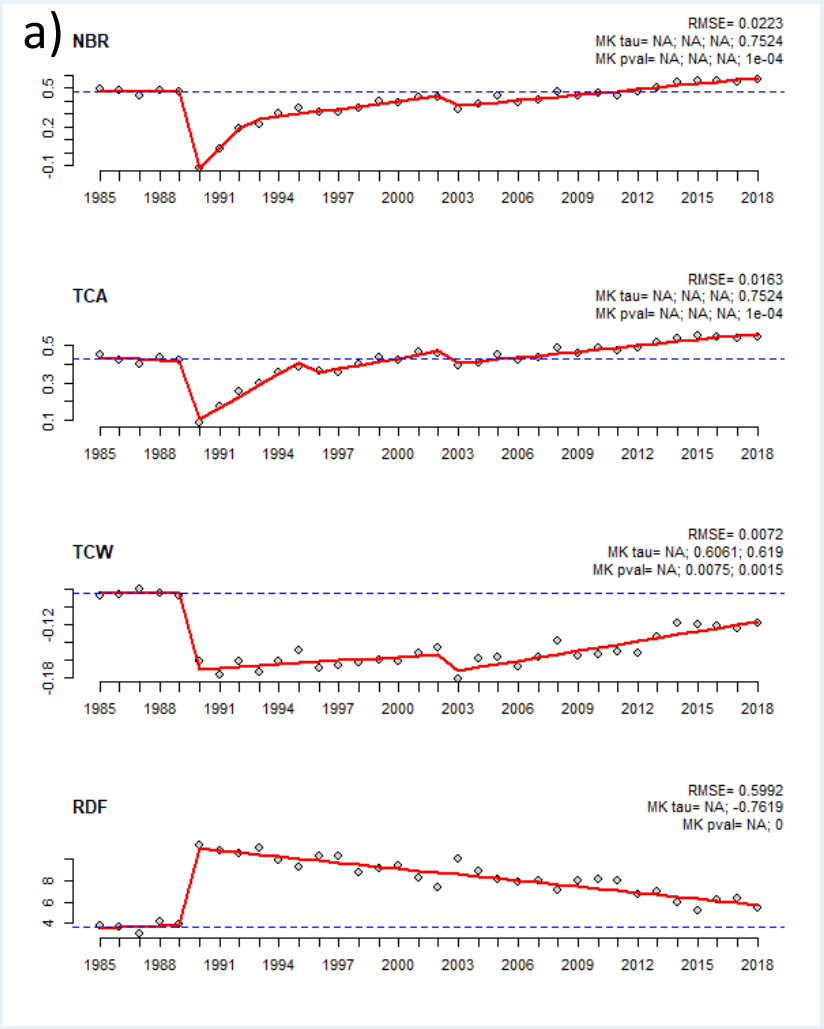
Burn severity	User's accuracy	Producer's accuracy	Overall accuracy	Cohen's Kappa
Low to moderate-low (0,1 ≤ dNBR < 0,44)	89,4	86,3	82,72	0,58
Moderate-high to high (dNBR≥ 0, 44)	67,2	73,2		

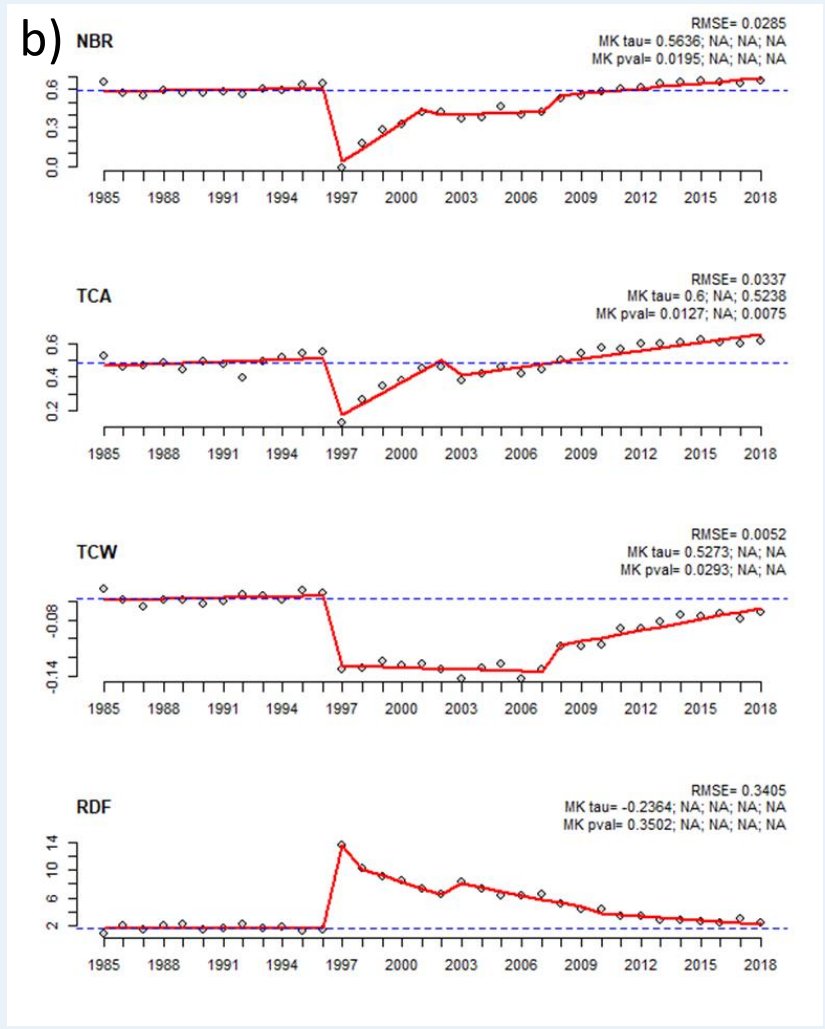


Forest recovery through natural regeneration

a)

b)





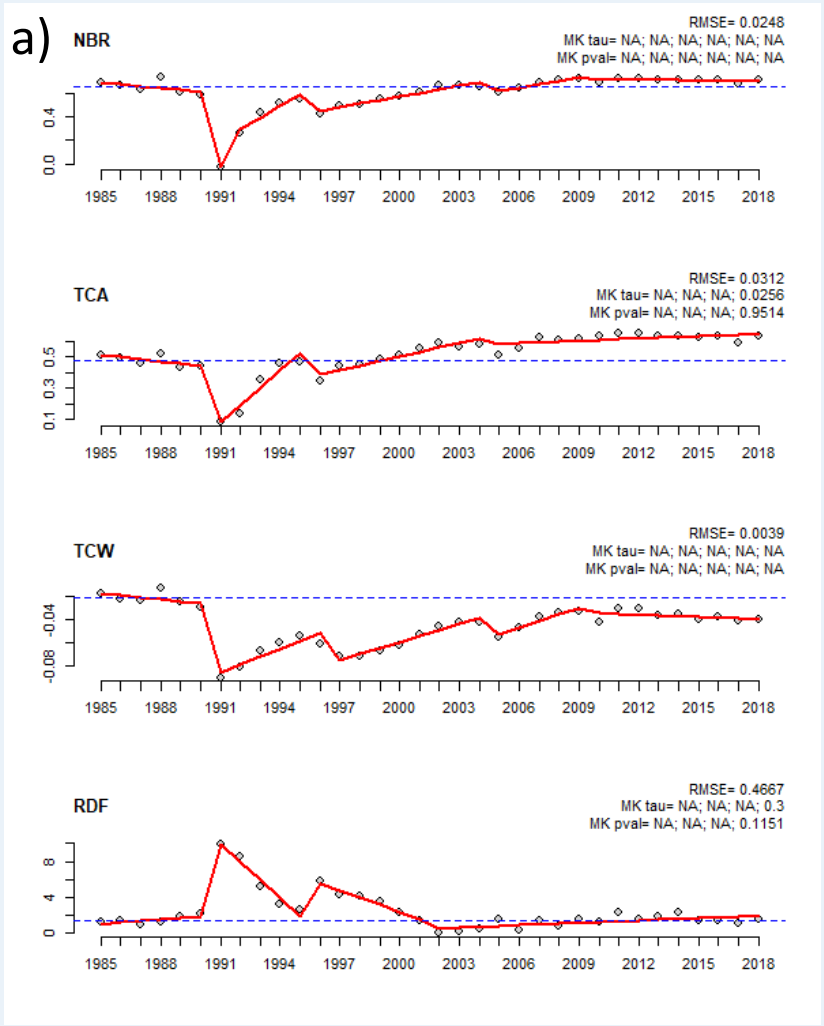
a) crown fire occurred on 26/3/1990 in the municipalities of Chatillon and Saint Vincent; **b)** crown fire occurred on 11/4/1997 in the municipalities of Sarre and Aosta. Landsat pixels (red contours) were superimposed on a Google Earth image acquired on 3/9/2017.

Reforestation and delayed forest recovery

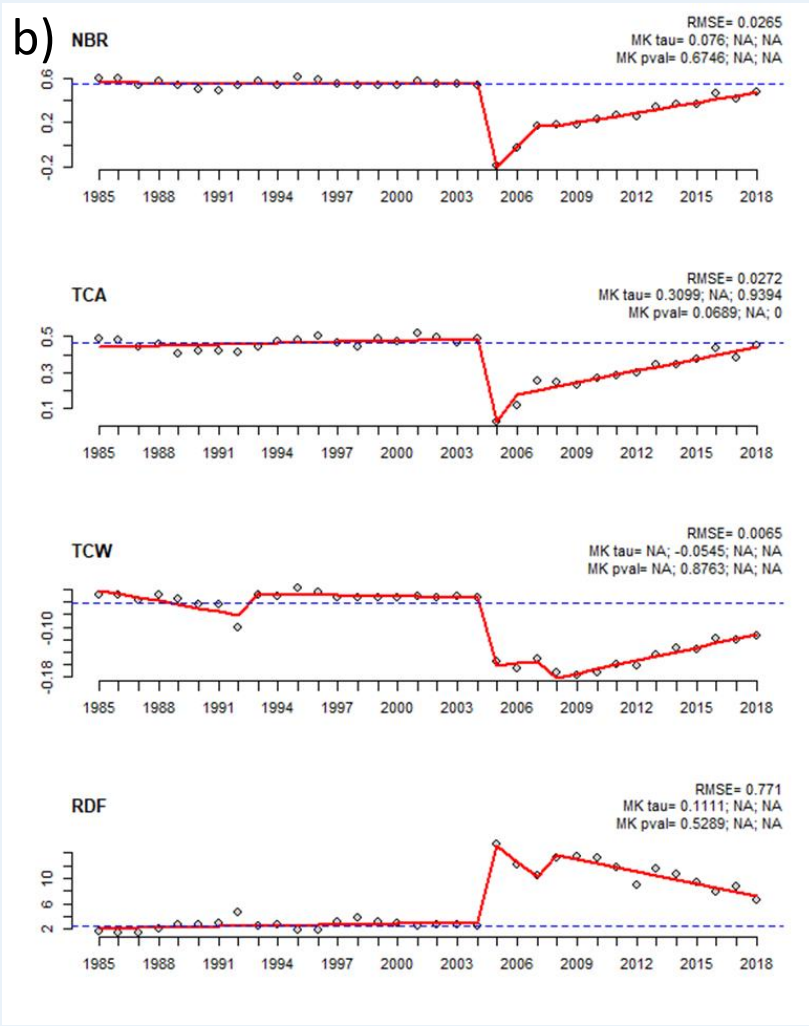
a)

b)

a)



b)



a) crown wildfire occurred on 11/8/1990 in the municipality of Nus; **b)** Crown fire occurred on 12/3/2005 in the municipalities of Nus and Verrayes. Landsat pixels (red contours) were superimposed on a Google Earth image acquired on 3/9/2017.

Discussion and future perspectives

- Promising capability in detecting fire-related forest dynamics.
- Patterns of vegetation indices time series can serve to infer phases of forest recovery and can be useful for forest managers.
- Different combinations of Landsat bands caused different rates of spectral recovery. NBR and TCA display faster recovery patterns compared to those exhibited by TCW and RDF.
- Field surveys and LiDAR data will provide information about the vertical structure of regenerating stands.
- Commission errors in disturbance maps mostly occur when yearly observations are scarce.

Thank you for your attention

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photo credit R. Marzano