Detection of bark beetle outbreak from Sentinel-2 time-series analysis: an open-source framework for operational monitoring

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The bark beetle crisis

Climate change

- Facilitates bark beetle development
- Increases probability of drought

Amplification of bark beetle outbreaks

Need for an operational outbreak monitoring system to :

- Accurately quantify surfaces affected by bark beetles
- Support forest management with early detection of outbreaks

Sentinel-2 time series, an appropriate data source for continuous and early detection of bark beetle outbreaks.

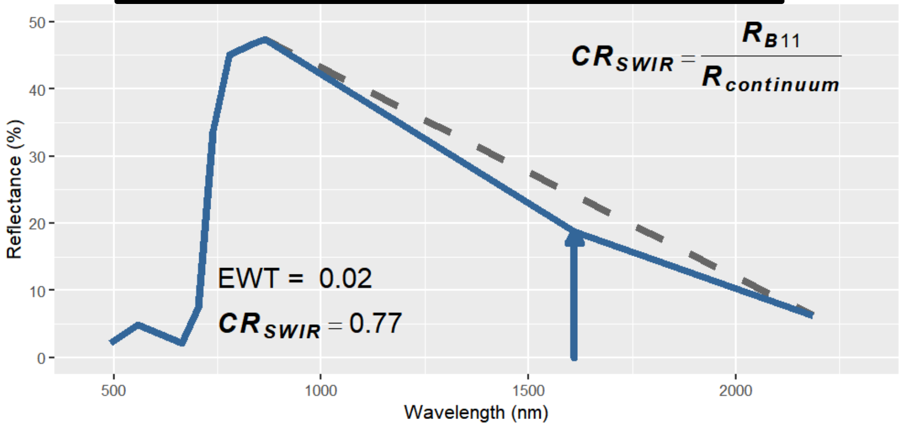
- Large scale acquisitions (290km swath width)
- Continuous monitoring (5 days revisit)
- High spatial resolution (10-20m)
- Multispectral (Bands in visible and infra-red)
- Free and open data
- SENTINEL-2A launched in June **2015**, SENTINEL-2B in March 2017
- Corrected for atmosphere and topography by THEIA data and services center

Theia

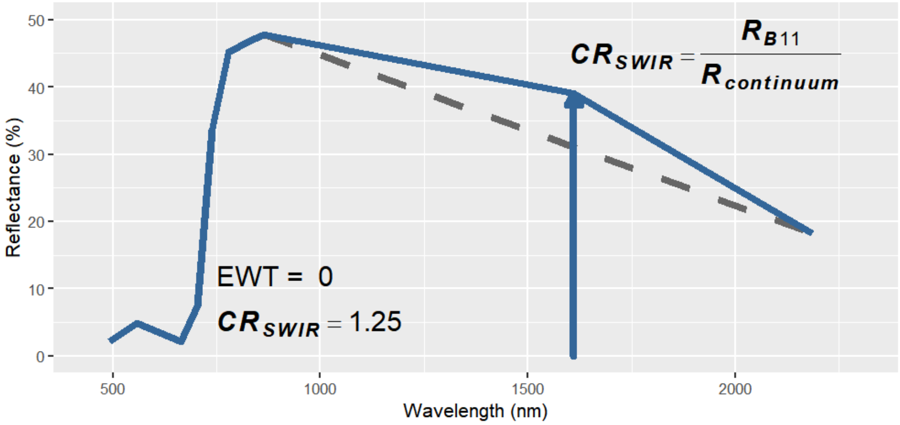
https://www.theia-land.fr

- **Using a relevant vegetation index**
  - **Canopy water content** : a relevant indicator for the **early detection** of bark beetle attacks (Abdullah et al. 2019)
  - CR_{SWIR} (Continuum removal SWIR) : **sensitive to vegetation water content**

Healthy spectrum
Normal vegetation water content



Attacked spectrum
Low vegetation water content

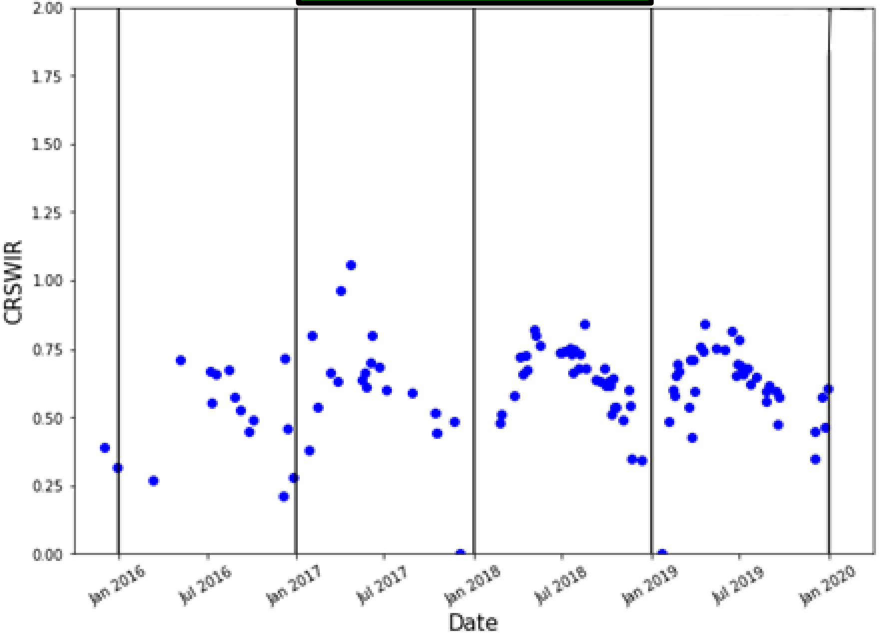


Compute vegetation index from Sentinel-2 time series

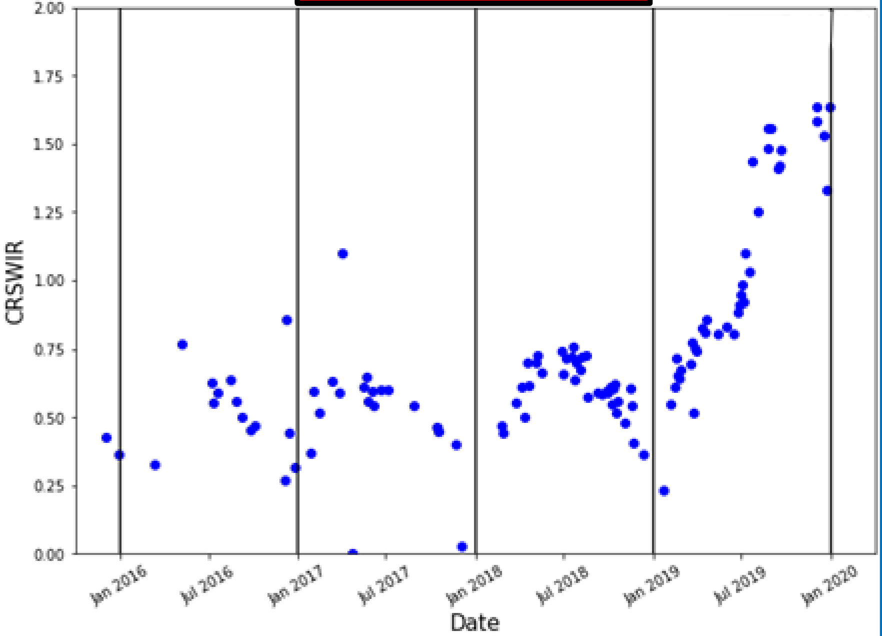
Using the complete time series requires **masking clouds and shadows**

Unmasked time series

Healthy pixel



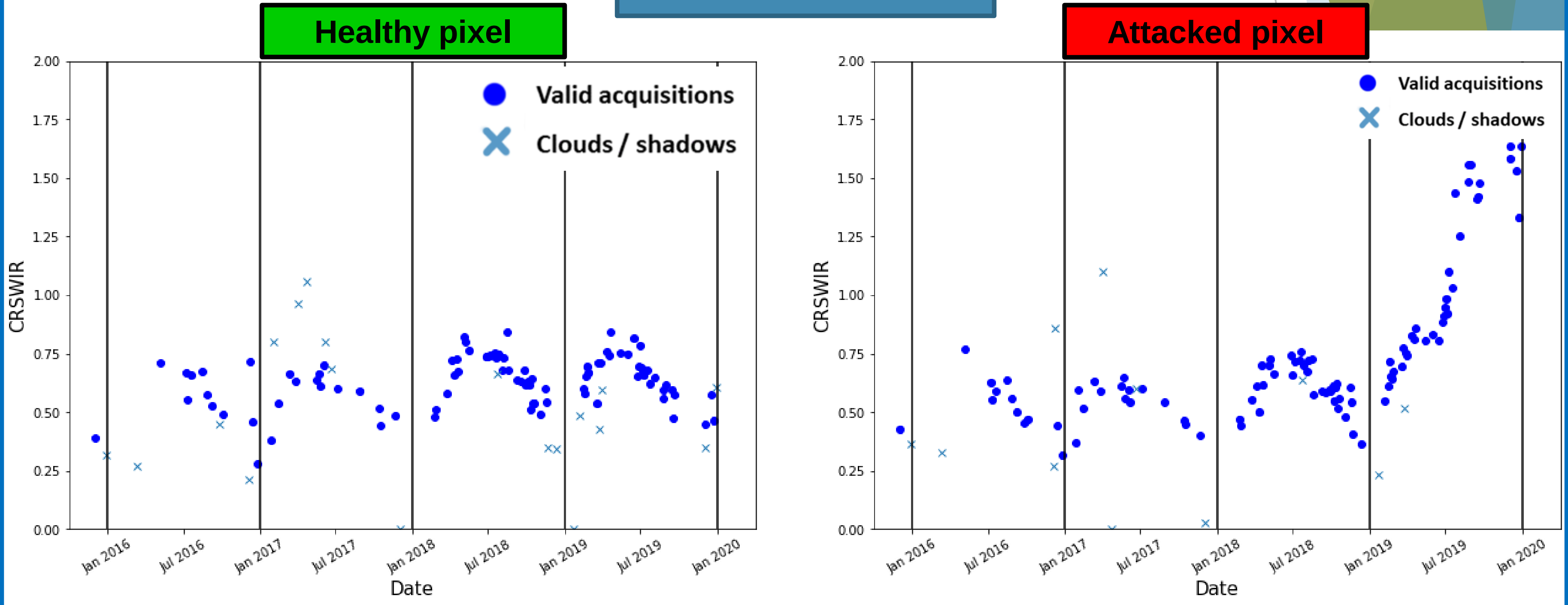
Attacked pixel



Discard clouds and shadows from the time series

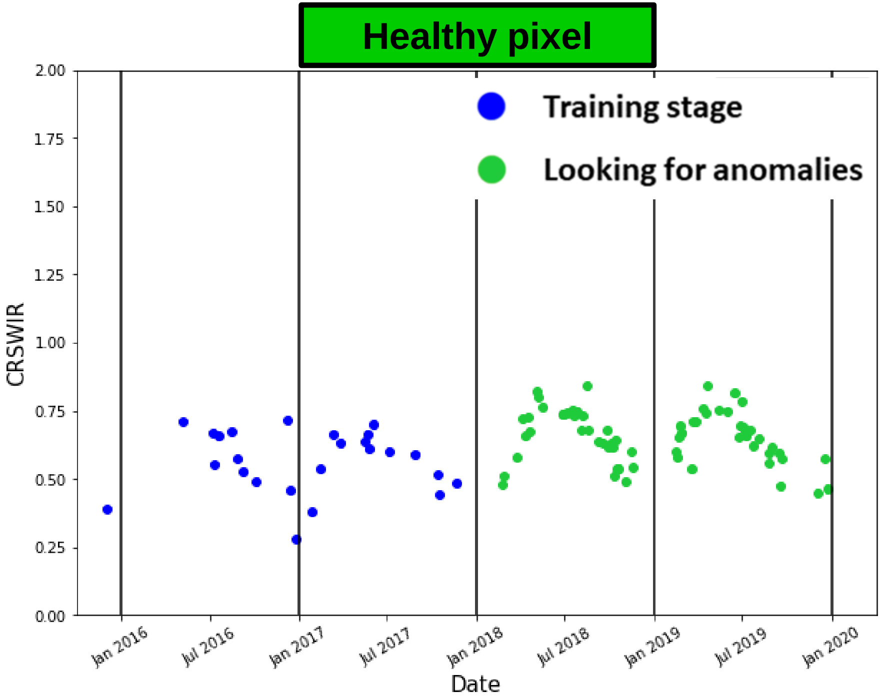
- Strong periodicity observed for healthy spruce stands
- Sudden increase of $\mathrm{CR}_{\mathrm{SWIR}}$ in case of outbreak

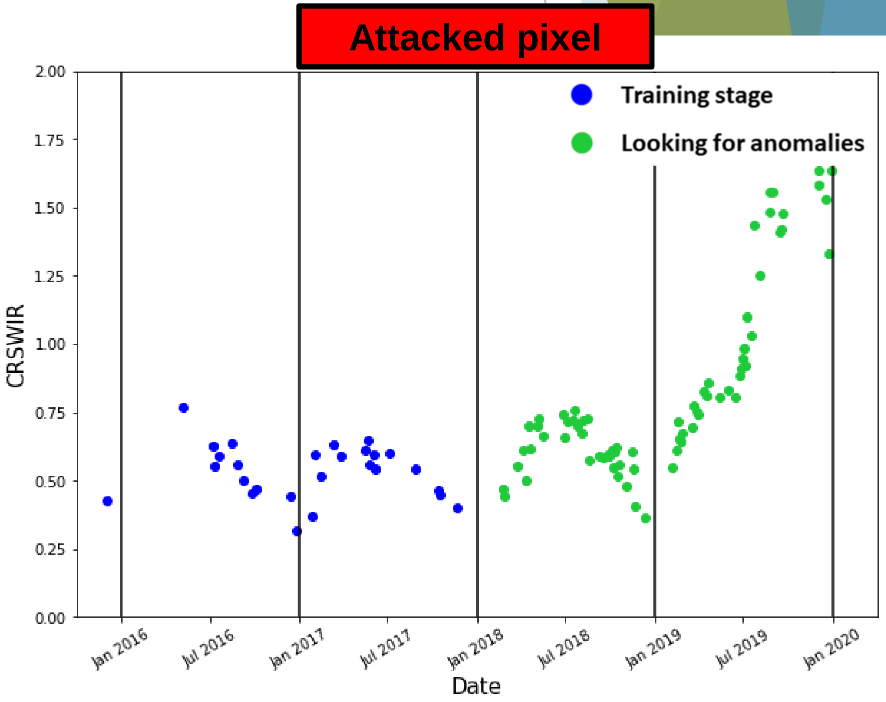
Masked time series



Adjust a harmonic model for each pixel

Using two seasons of vegetation to train the model
The model is based on all Sentinel-2 acquisitions of a time period before disturbances





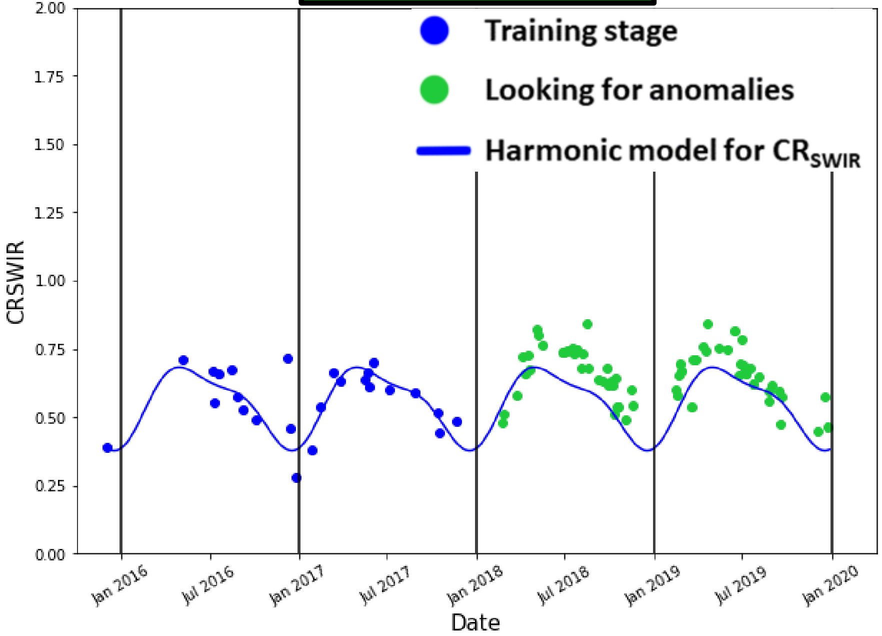
Adjust a harmonic model for each pixel

The harmonic model applied to vegetation index time series

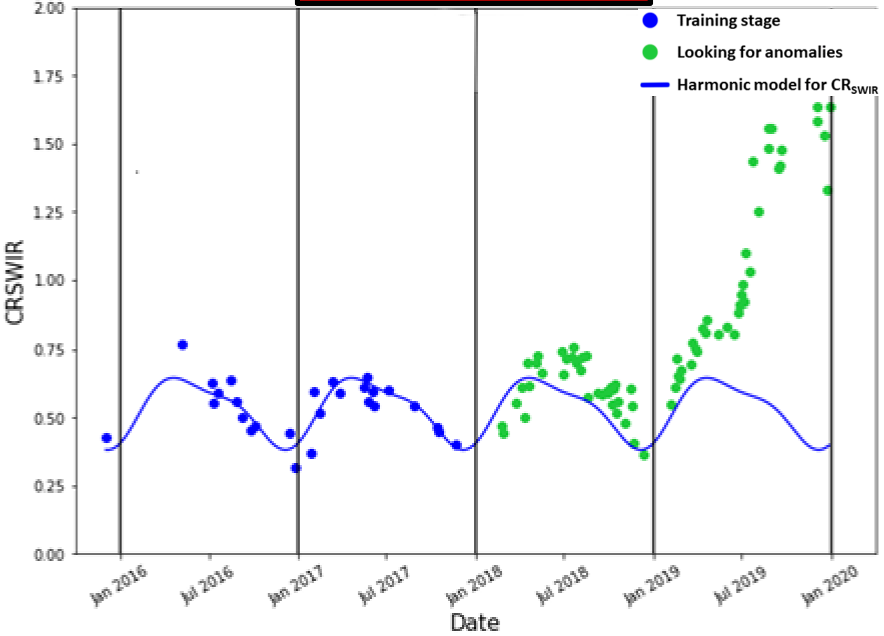
A harmonic function is used to model and predict vegetation index seasonality of each pixel of forest stands supposedly healthy.

$$f(t) = a_1 + b_1 \sin\frac{2\pi t}{T} + b_2 \cos\frac{2\pi t}{T} + b_3 \sin\frac{4\pi t}{T} + b_4 \cos\frac{4\pi t}{T} \text{ où } T = 365{,}25$$

Healthy pixel



Attacked pixel

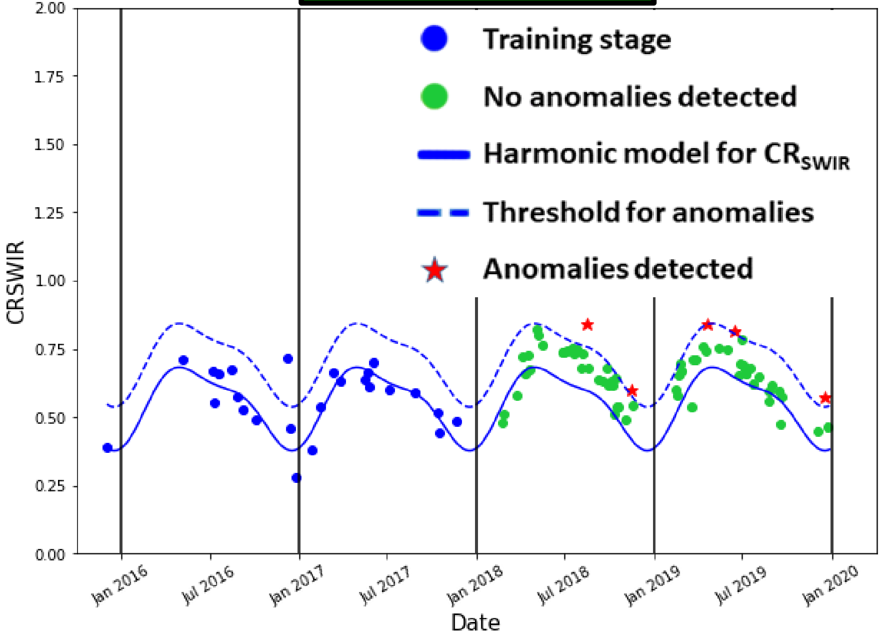


Detect dieback from successive anomalies

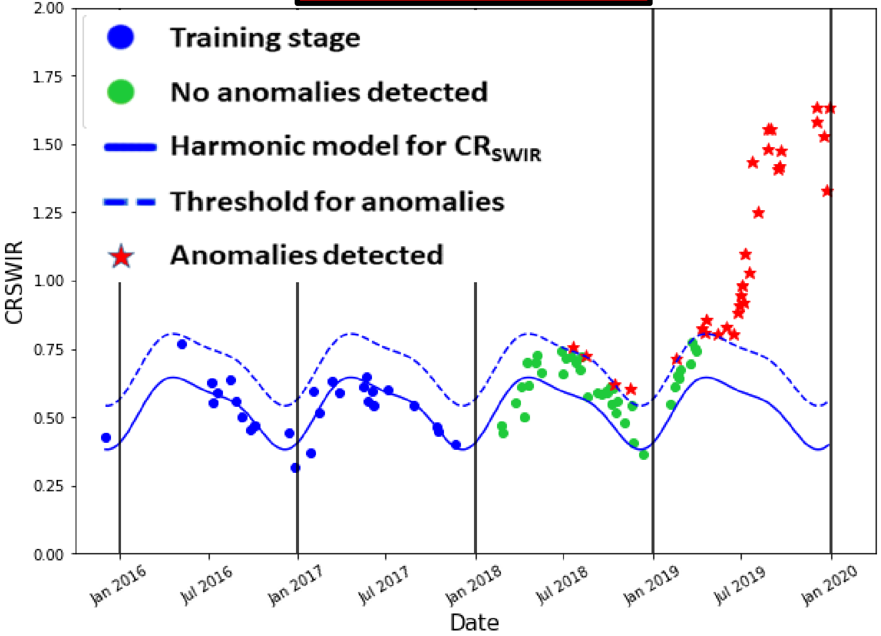
Detection of anomalies

Sentinel-2 acquisitions whose difference between the vegetation index and its prediction reaches a threshold are considered as anomalies.

Healthy pixel



Attacked pixel

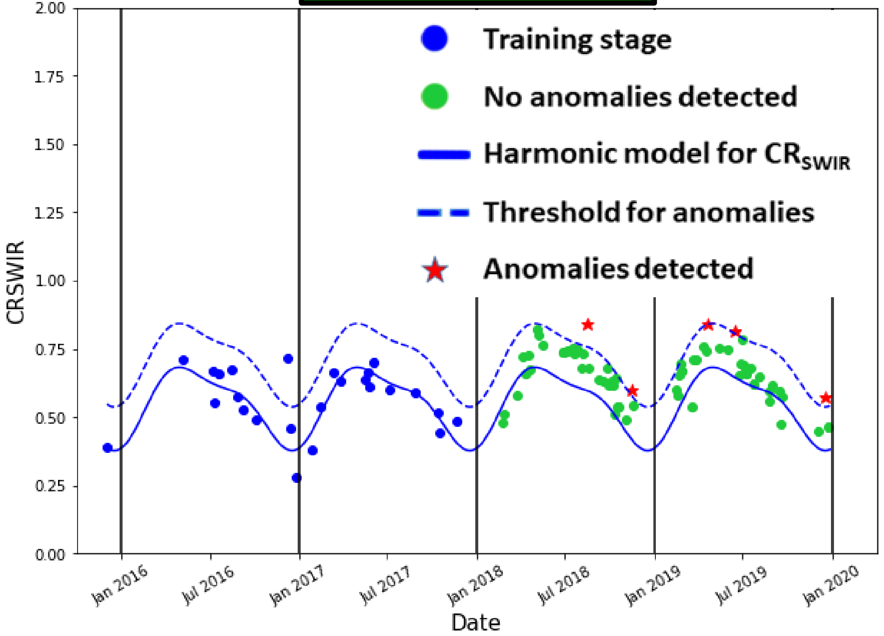


Detect dieback from successive anomalies

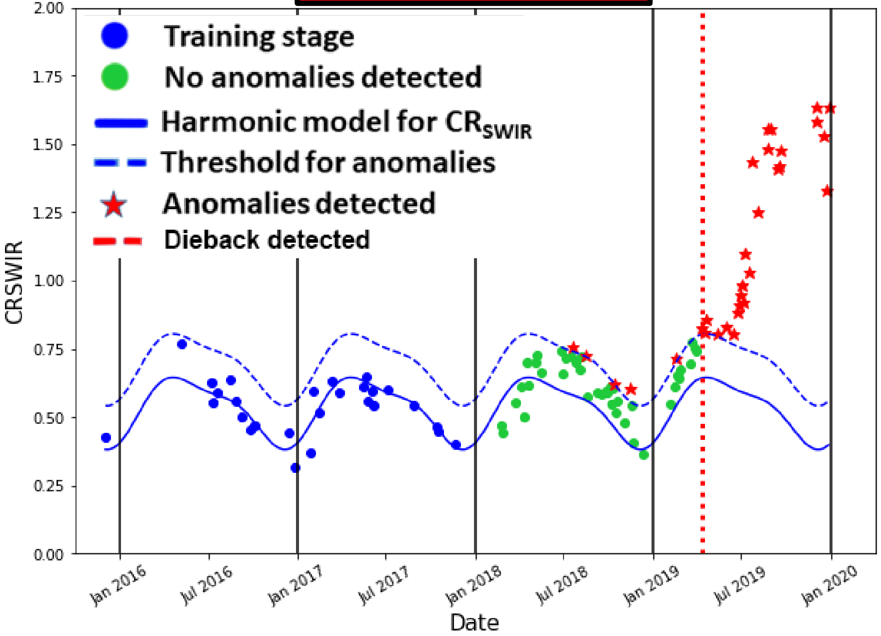
Dieback detection

Pixels are detected as dieback as soon as **three successive anomalies** are detected, to prevent false positives.

Healthy pixel



Attacked pixel

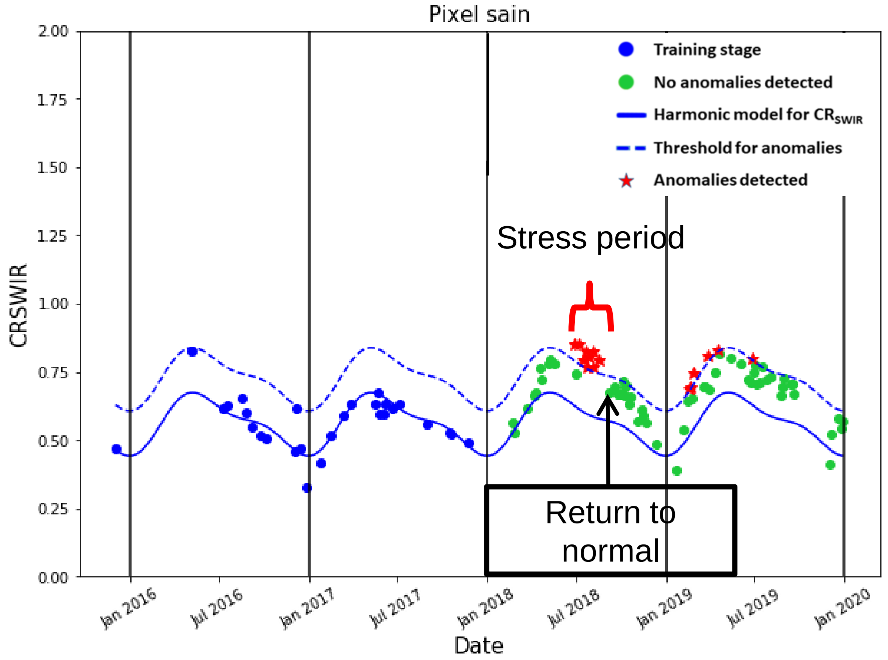


Detecting dieback from successive anomalies

Return to normal

CR_{SWIR} is sensitive to water content : droughts can also lead to successive anomalies

→ Return to normal possible if **three successive acquisitions without anomalies**



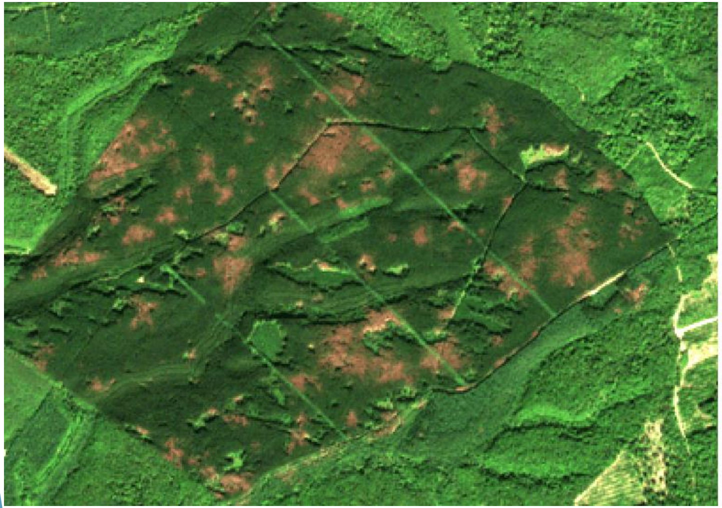
Stress periods :

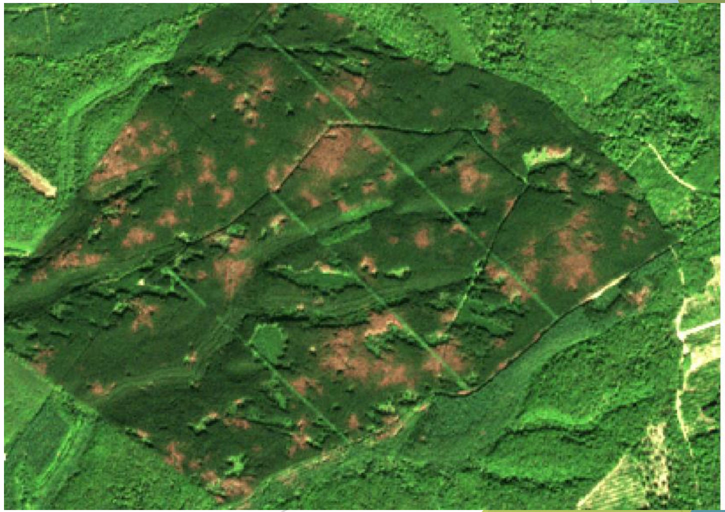
- temporary false positives ?
- Interesting in themselves ?

Export results

Results can be exported as vector files where each polygon contains :

- the period when the first anomaly was detected
- a confidence class based on the intensity of anomalies

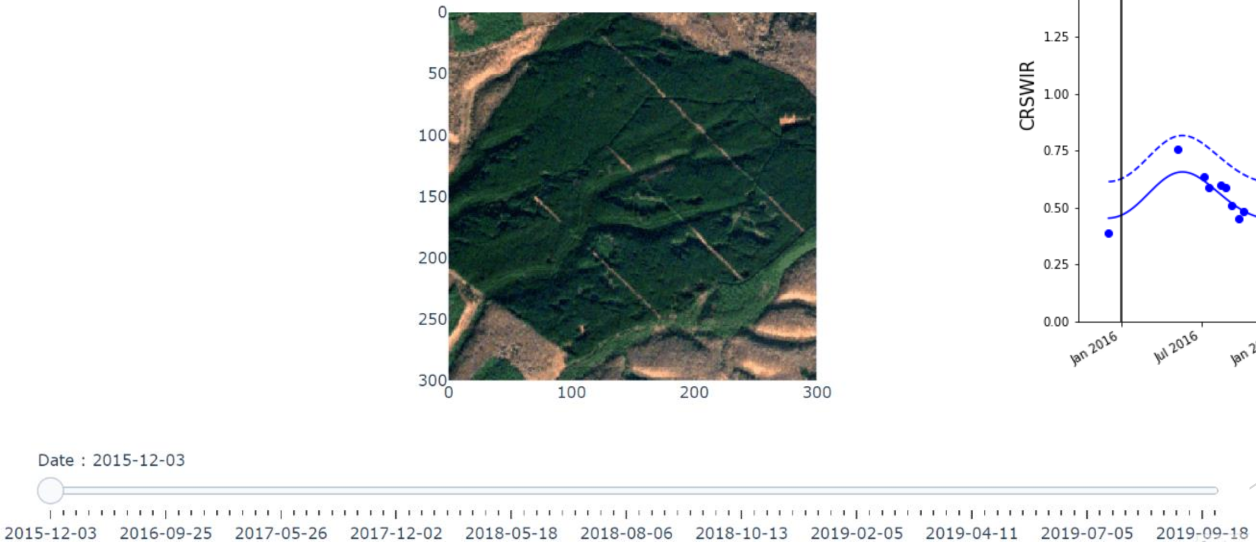


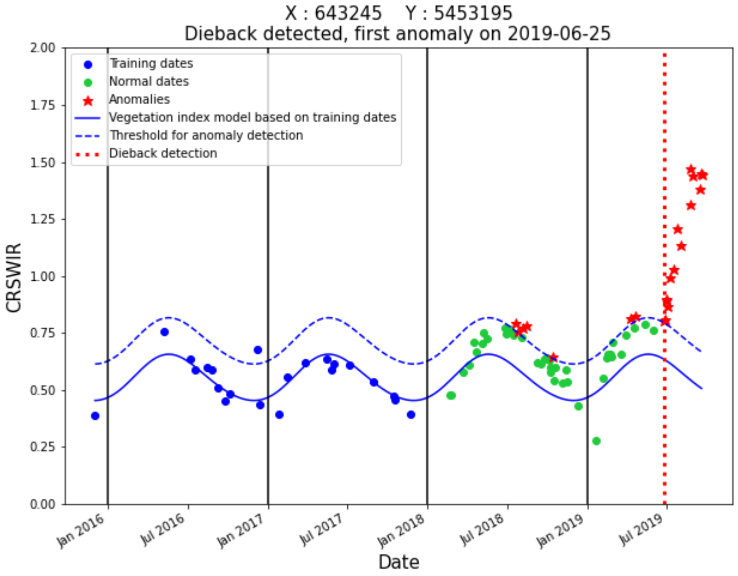


Other visualisation tools

Time series graphs

Timelapses

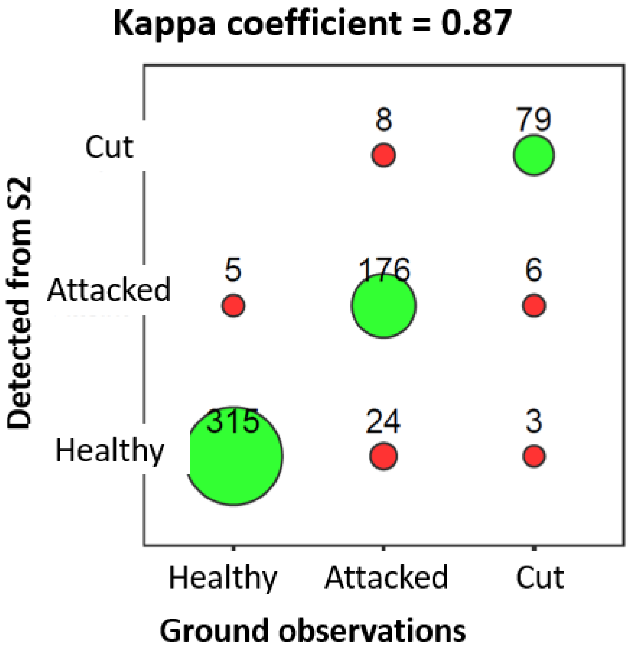




Validation using ground observations obtained by the french institutions ONF, DSF, CNPF

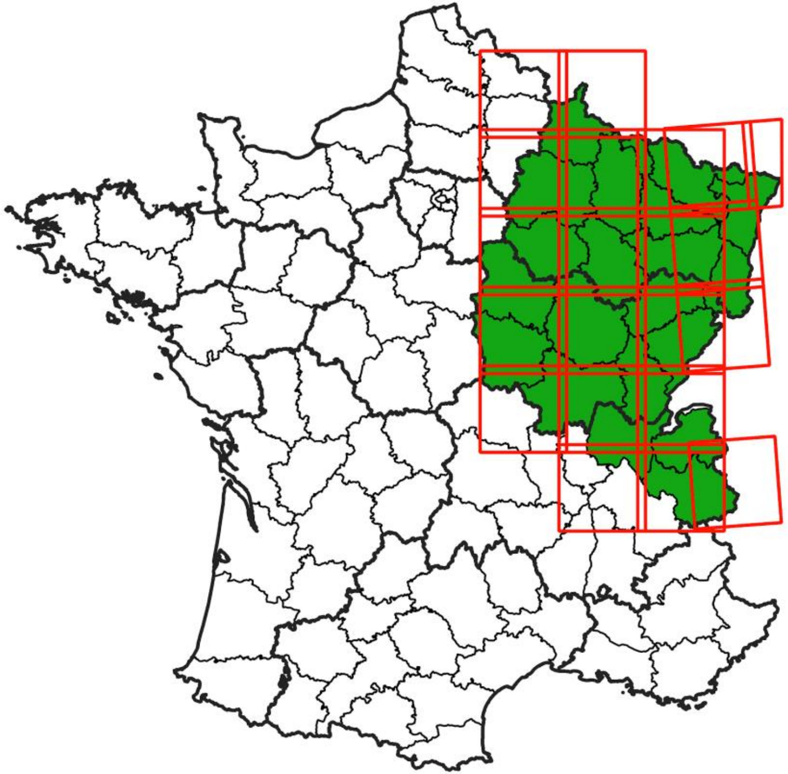
Comparing observed state and predicted state of the nearest acquisition :

- **Good overall agreement with the 619 ground observations**



Class	Precision	Recall	F-score
Healthy	0.90	0.98	0.94
Attacked	0.94	0.79	0.86
Cut	0.86	0.90	0.88
Total	**0.90**	**0.89**	**0.90**

Operational mapping of bark beetle outbreaks



- 120 000 km² analysed
- 21 Sentinel-2 tiles were used to cover the entire area
- Updated production delivered to the ministry in charge of forests every few months since summer 2021

Computing time

~ **6 hours** for each tile the first time

~ **20 minutes** when updating

(depends on the number of acquisitions)

Limitations

- Climate change and forest management can make harmonic models obsolete
- Confusions with other forest cover alterations (cuts, wind or snow damage…)

The method fulfills the need for an operational outbreak monitoring system

- **Monitoring :** The outbreak mapping can be udpated whenever a new Sentinel-2 acquisition is available
- **Good performance even in diverse contexts**

The method is fully encapsulated in a python package that is :

- **Open**
- **Documented**, along with **tutorials** and a small dataset for testing
- **Simple** enough to be used and understood by non-experts
- **Highly parametrable** : can be adapted for other issues

https://fordead.gitlab.io/fordead_package/

Thank you !

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