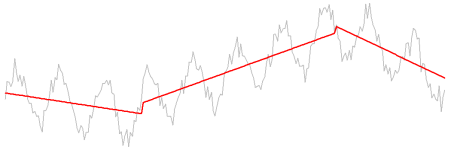
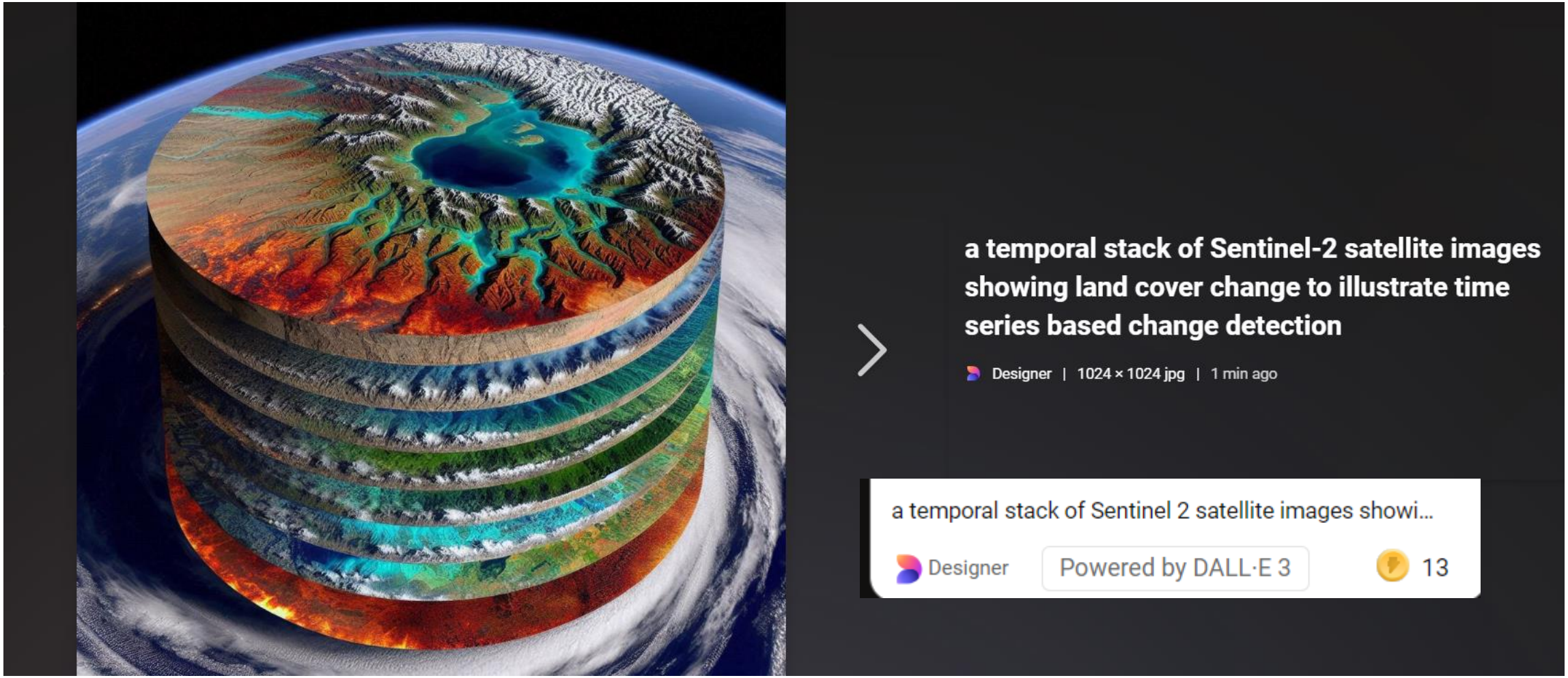
# Evolution of BFAST functions for characterizing land change using satellite image time series (Sentinel, and Landsat)




Jan Verbesselt[1,2] , Dainius Masiliūnas[2], et al.

[1]Belgian Science Policy Office, Earth Observation, Belgium

[2]Wageningen University, The Netherlands



a temporal stack of Sentinel-2 satellite images showing land cover change to illustrate time series based change detection
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a temporal stack of Sentinel 2 satellite images showi...
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13

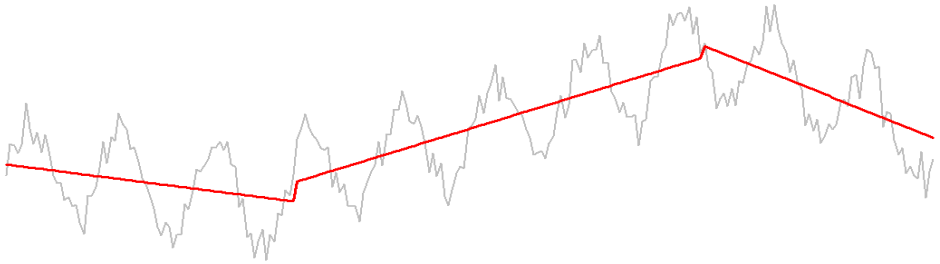
https://earth.google.com/web/@-9.92060668,-53.69293828,-304.56988932a,2010188.02739114d,35y,359.99872992h,0t,0r/data=Cg86DQgBEQAAAAAAAABAIAE6AwoBMA

# Why detect change?

- Time series help us study dynamics
- Detecting change helps to **understand** trends, time of change, etc.

Verbesselt, J., et al. (2010). Detecting trend and seasonal changes in satellite image time series. RSE.

# BFAST



**Breaks For Additive Season and Trends**

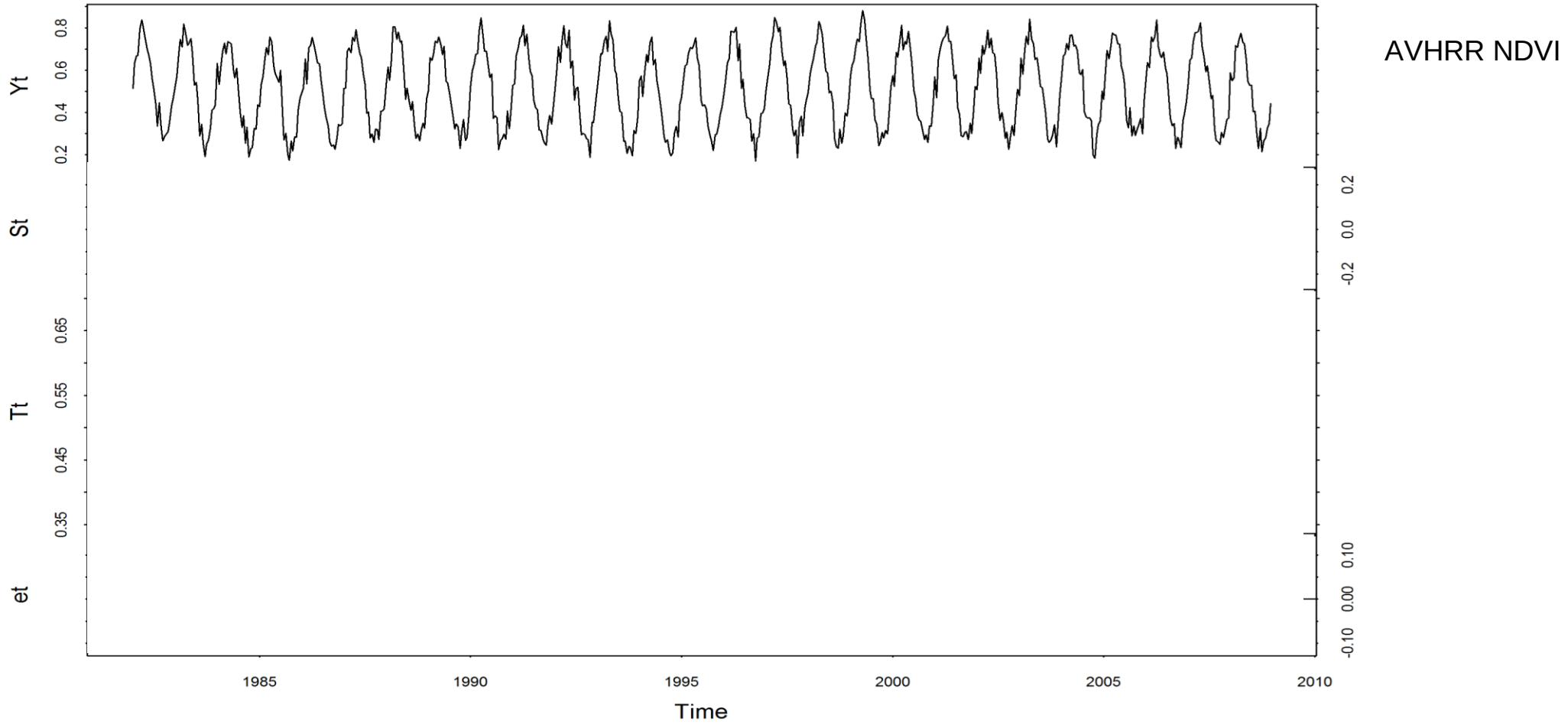
- Unsupervised Change detection method
  - No need for training/labelling
  - Understandable, transparent, and reproducible
- Open-source toolkit for detecting change
  - Github https://github.com/bfast2/
    - R
    - Python
    - Available via different platforms:
      - Google Earth Engine,
      - Amazon SEPAL,
      - OpenEO

Verbesselt, J., et al. (2010). Detecting trend and seasonal changes in satellite image time series. RSE.

Verbesselt, J., et al. (2010). Detecting trend and seasonal changes in satellite image time series. RSE.

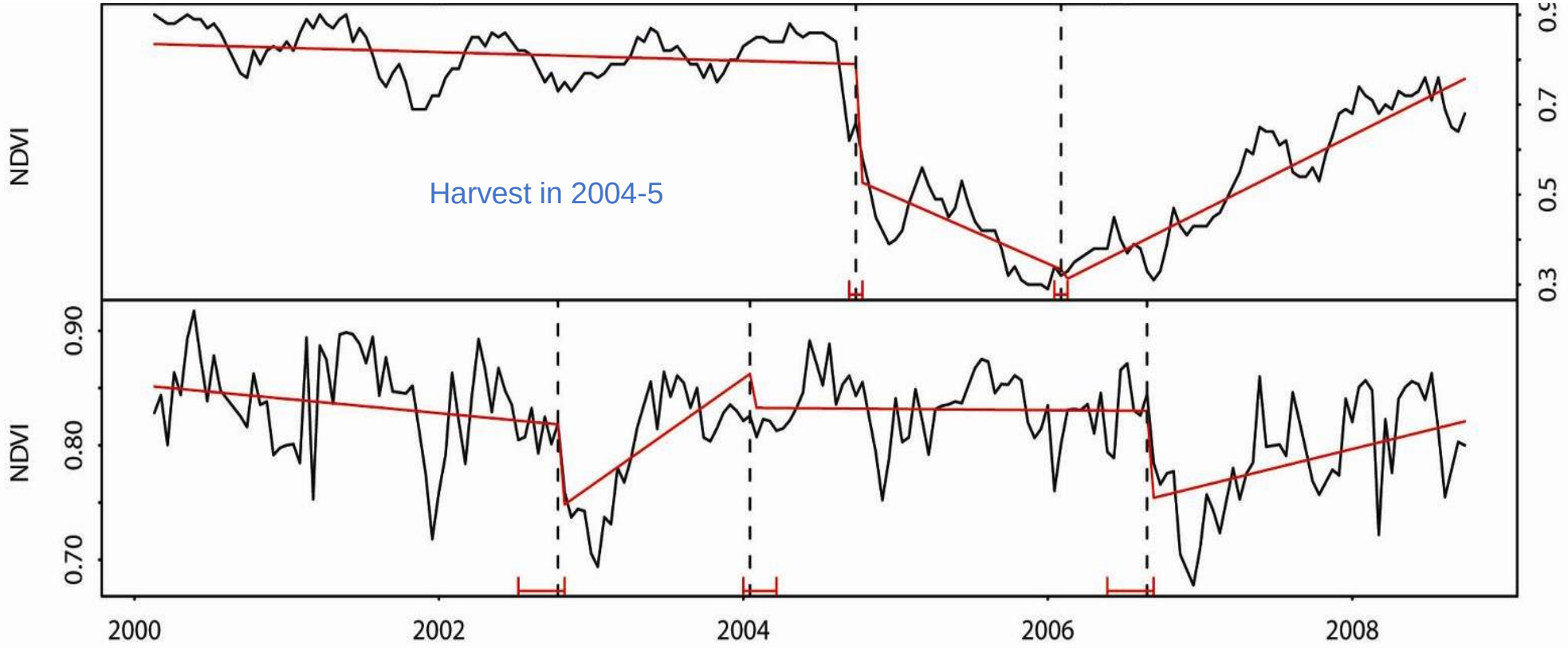
# BFAST

- Decomposition into Seasonal (St), Trend (Tt) and remainder (et)




AVHRR NDVI

# BFAST Detecting breaks and trends

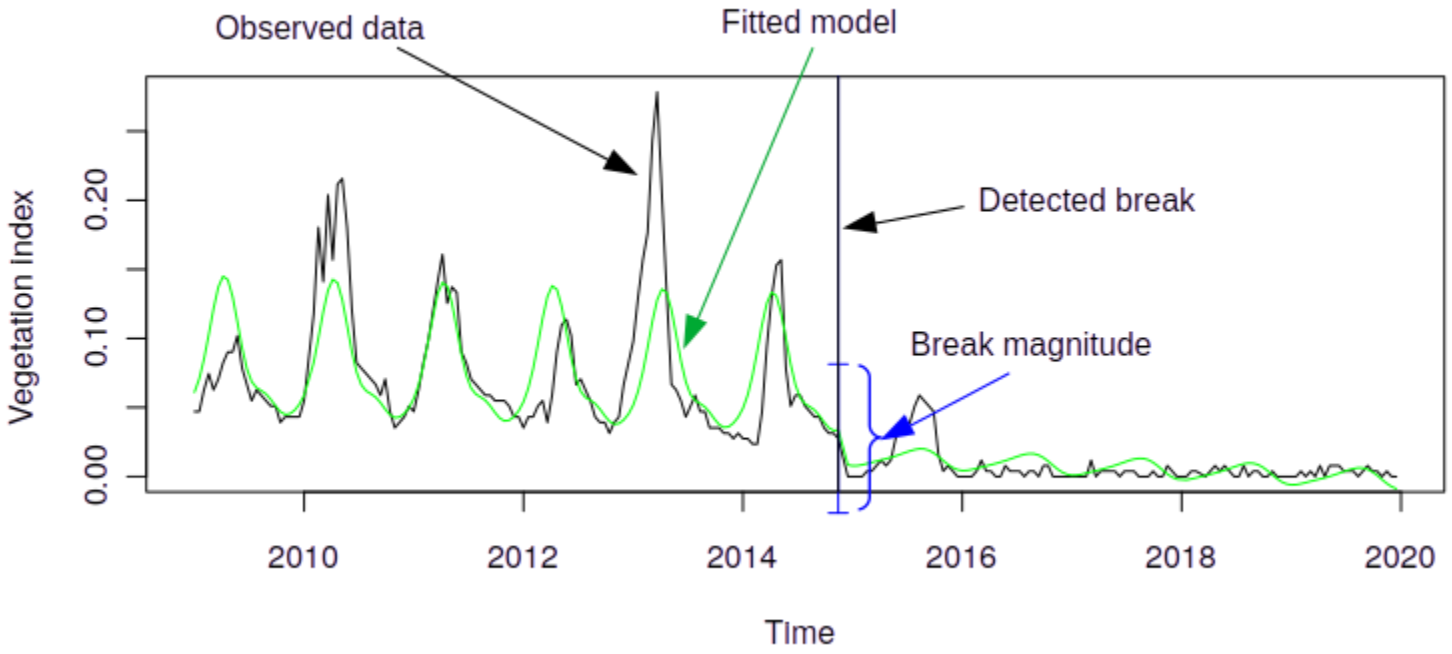



Drought stress in 2003 and tree Mortality in 2007

BFAST, Verbesselt, J., et al. (2010). Detecting trend and seasonal changes in satellite image time series. RSE.

# BFAST Lite

- Detecting breaks in all components at once in a single pass
- Can handle missing values
- Provides more parameters and statistics
- Is an order of magnitude faster than BFAST



# BFAST Lite

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- Can handle missing values
- Provides more parameters and statistics
- Is an order of magnitude faster than BFAST

**New release of the BFAST package on R CRAN (1.7):**

- BFAST Lite, speed and NA handling improvements (C++ and stlplus, thanks to Marius Appel)


- Masiliūnas, D., et al. BFAST Lite: A Lightweight Break Detection Method for Time Series Analysis. *Remote Sensing* (2021)
- Masiliūnas, D. et al. Global land characterization using land cover fractions at 100 m resolution. Remote Sens. Environ. 259, 112409 (2021)

# Global land cover mapping

- Reusing the same land cover classification model for the next year leads to too many spurious changes
- Use BFAST Lite to constrain changed pixels (CGLS-LC100)
- Or BFAST Lite model as smooth output time series of land cover fractions (ongoing)

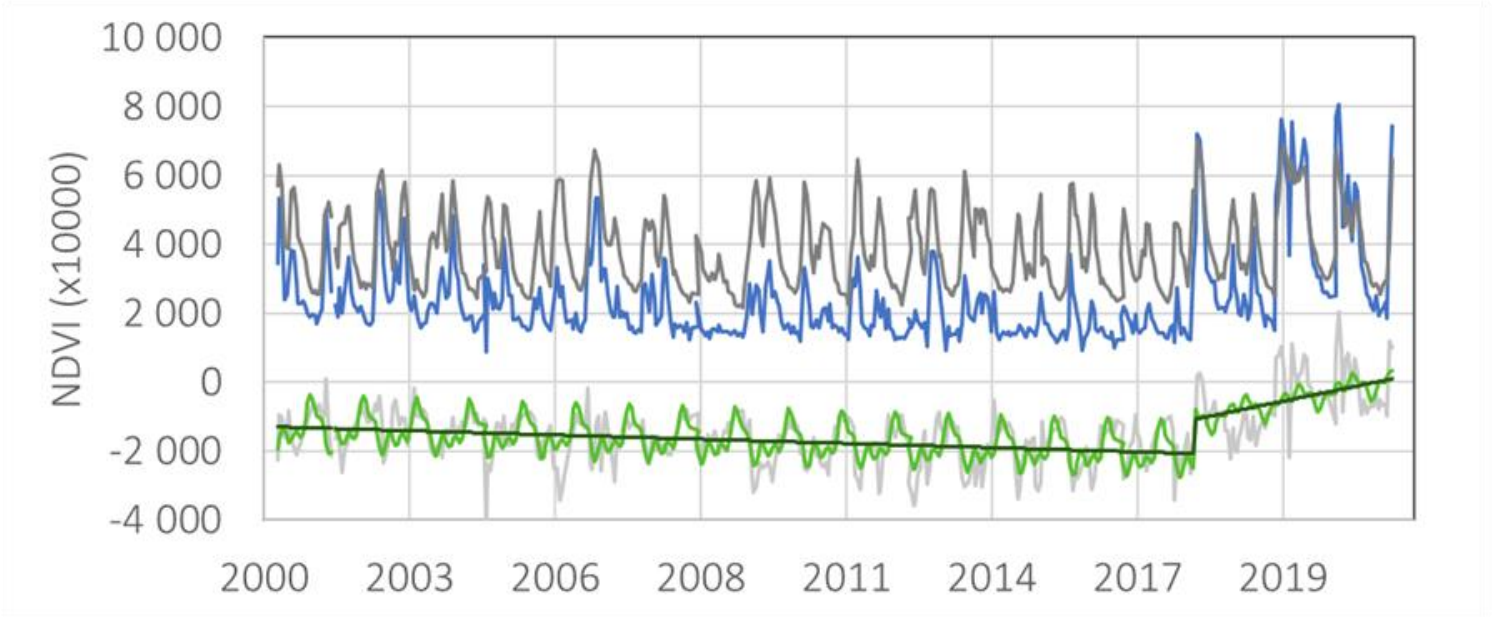
Unlikely land cover change: from urban to water

- https://land.copernicus.eu/global/products/lc

Copernicus Global Land Service

*Providing bio-geophysical products of global land surface*

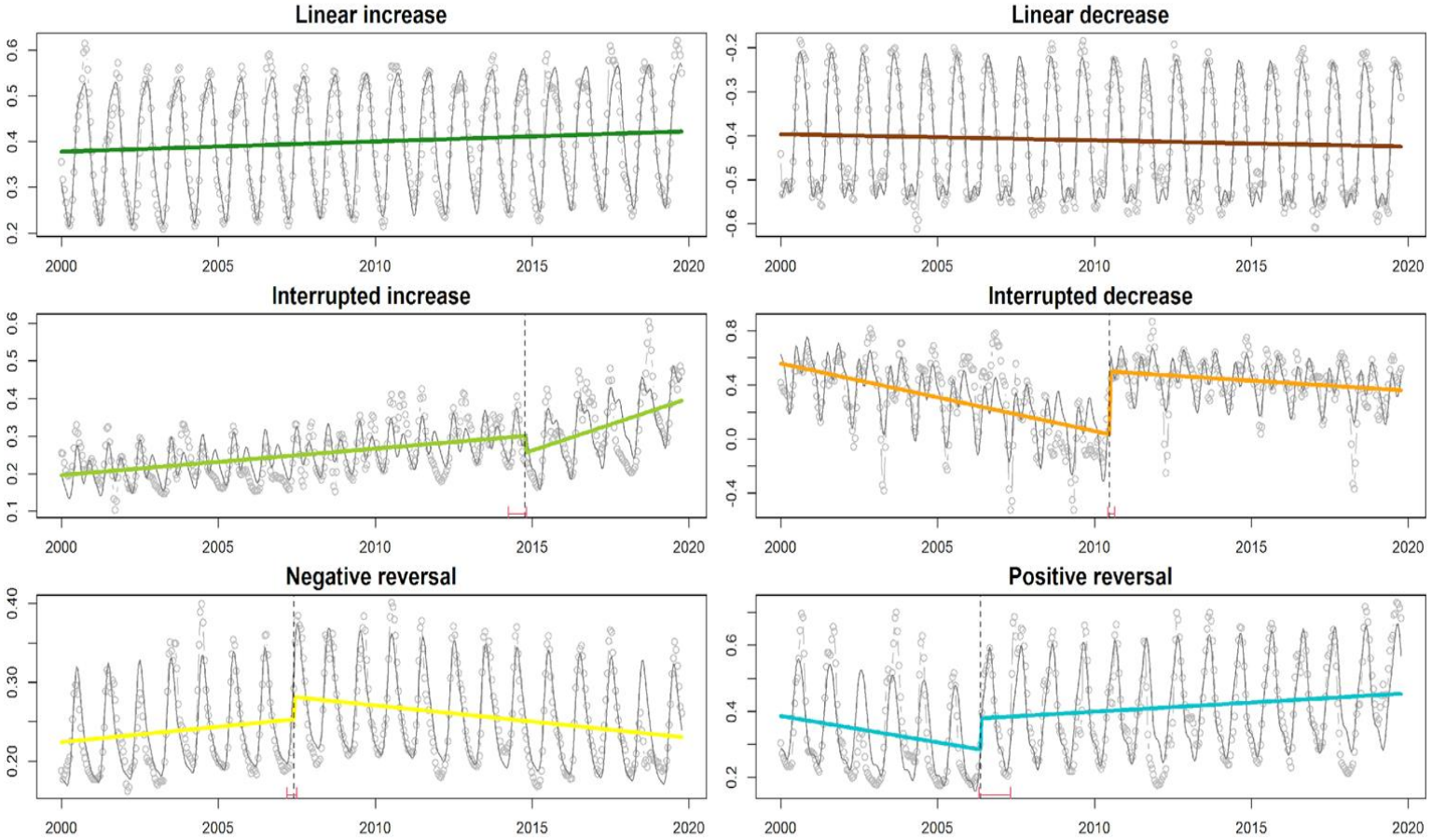
# GEE to detect small scale regreening in Africa

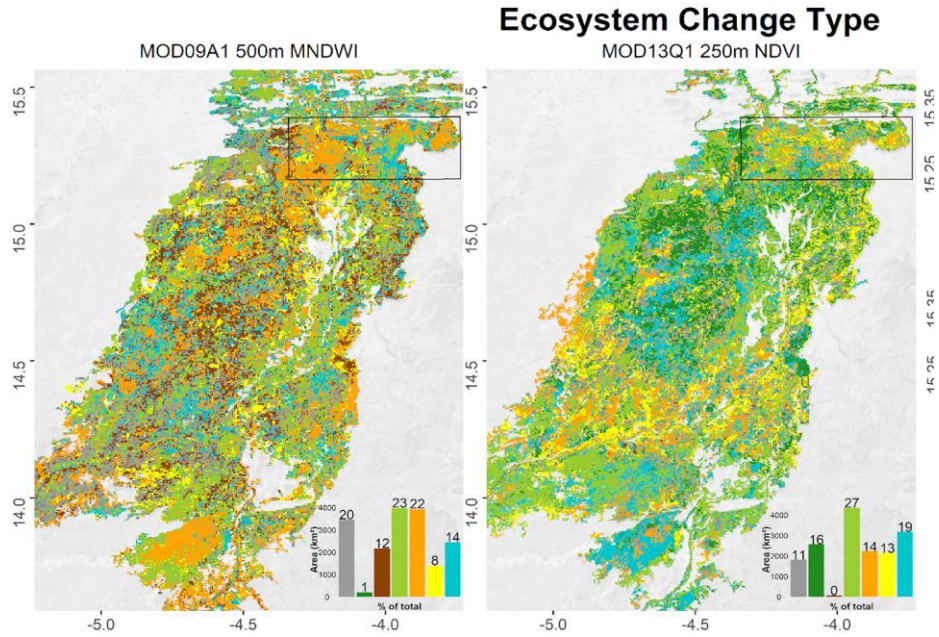




Ruijsch, J., Teuling, A., Verbesselt, J. & Hutjes, R. Landscape restoration and greening in Africa. Environ. Res. Lett. 18, (2023)

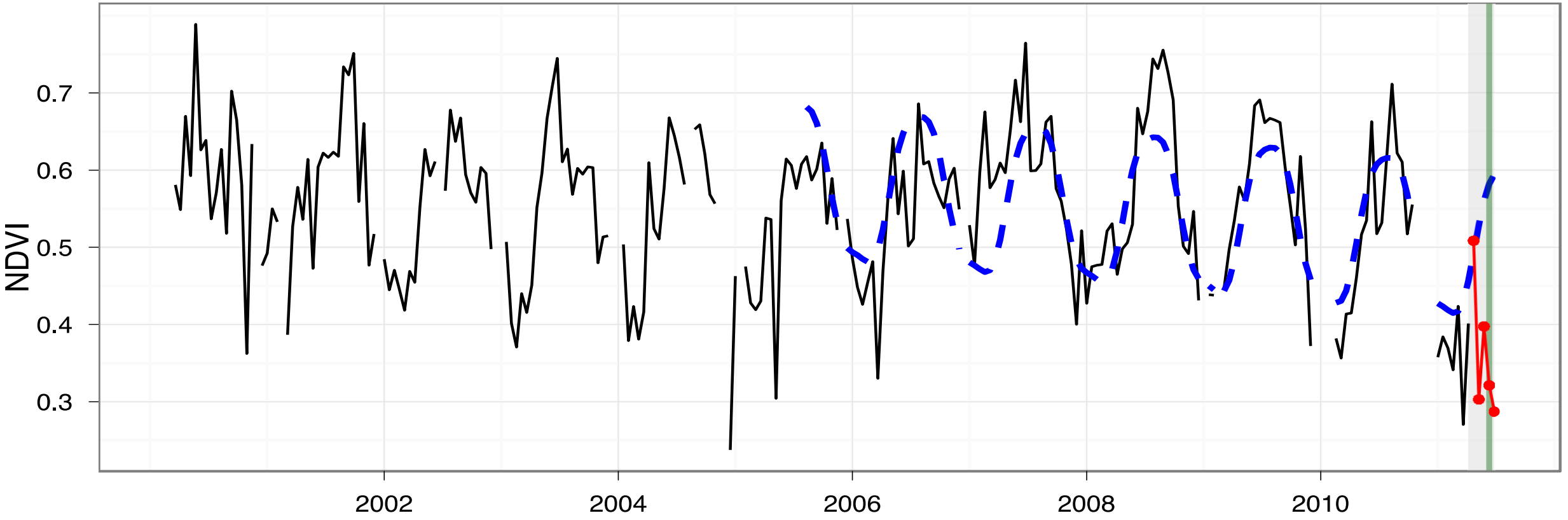
# BFAST Classify applied on Landsat and MODIS time series over a floodplain wetland in Mali in R

Kovacs, G.M., Horion, S., Fensholt, R., 2022. Characterizing ecosystem change in wetlands using dense Earth Observation time series. *RSE*. In communication.



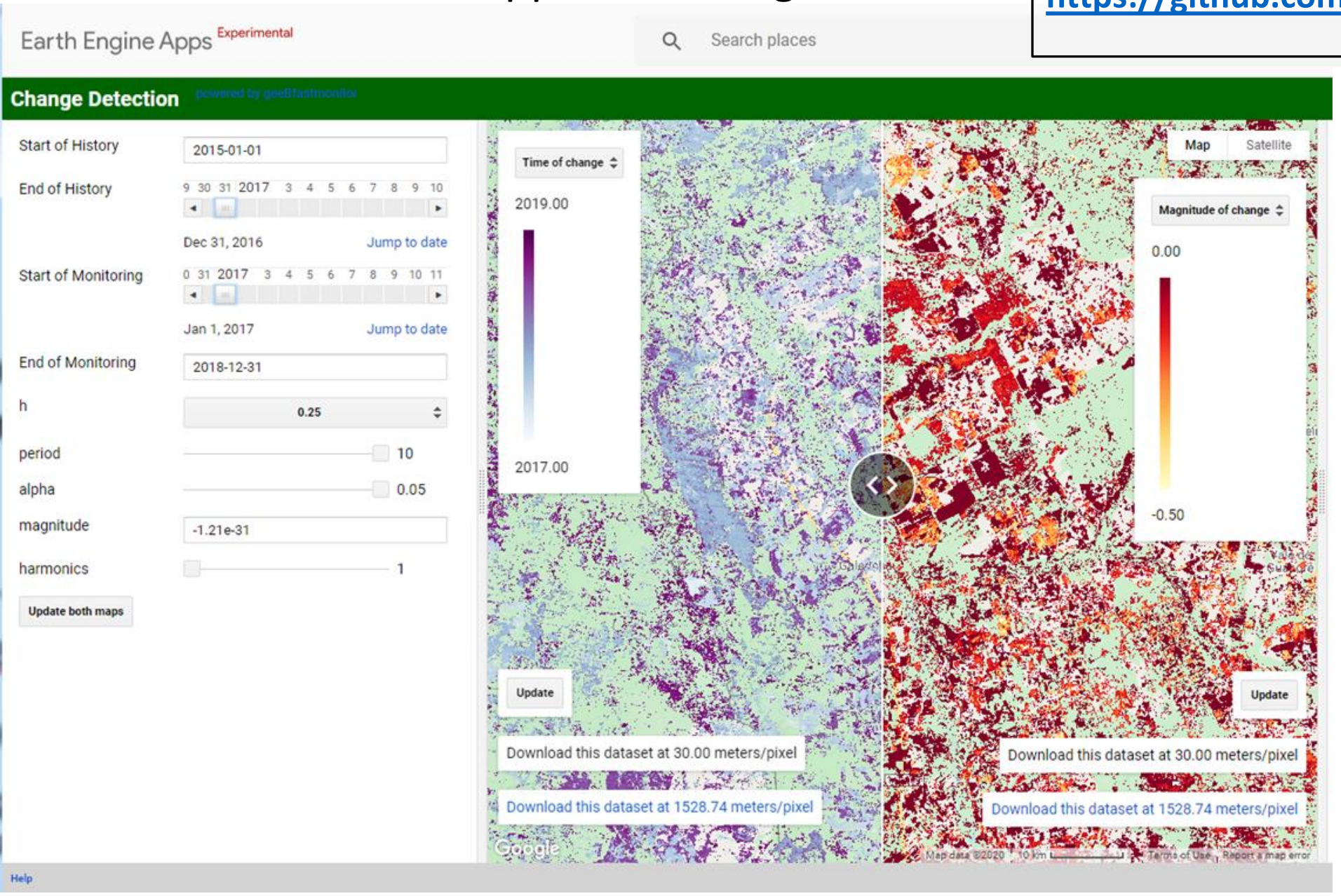
# BFASTmonitor



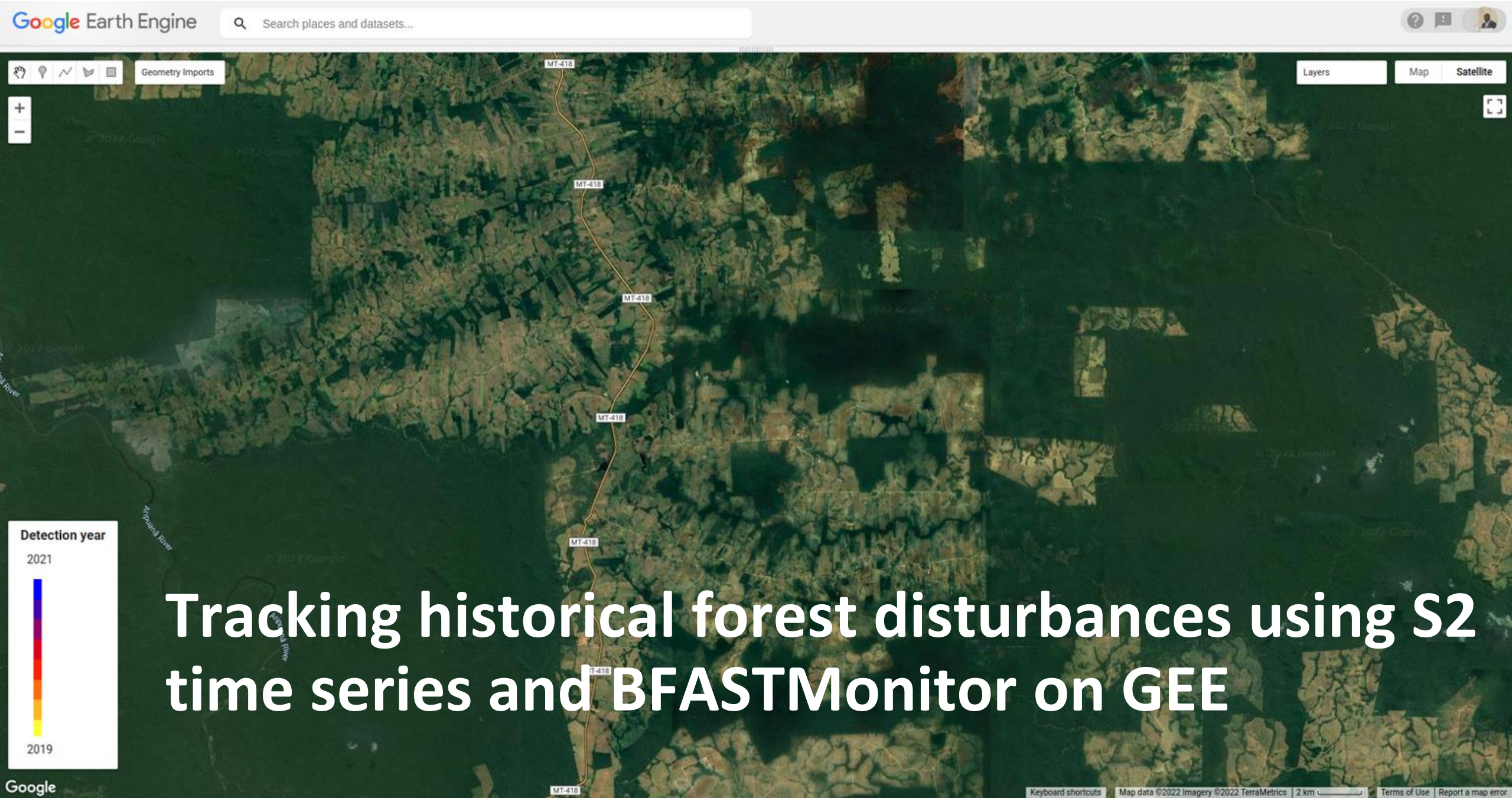

BFAST, Verbesselt, J., et al. (2012). Near real-time disturbance detection using satellite image time series. Remote Sens. Environ. 2012.

# GEE BFASTMonitor App and Package

GEE BFASTmonitor package:
https://github.com/bfast2/geeMonitor




Hamunyela, E et al. (2020) Implementation of BFASTmonitor algorithm on google earth engine to support large-area and sub-annual change monitoring using earth observation data. *Remote Sensing*


Google Earth Engine
Search places and datasets...
Geometry Imports
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Map
Satellite
MT-418
Detection year
2021
2019
Tracking historical forest disturbances using S2 time series and BFASTMonitor on GEE
Google
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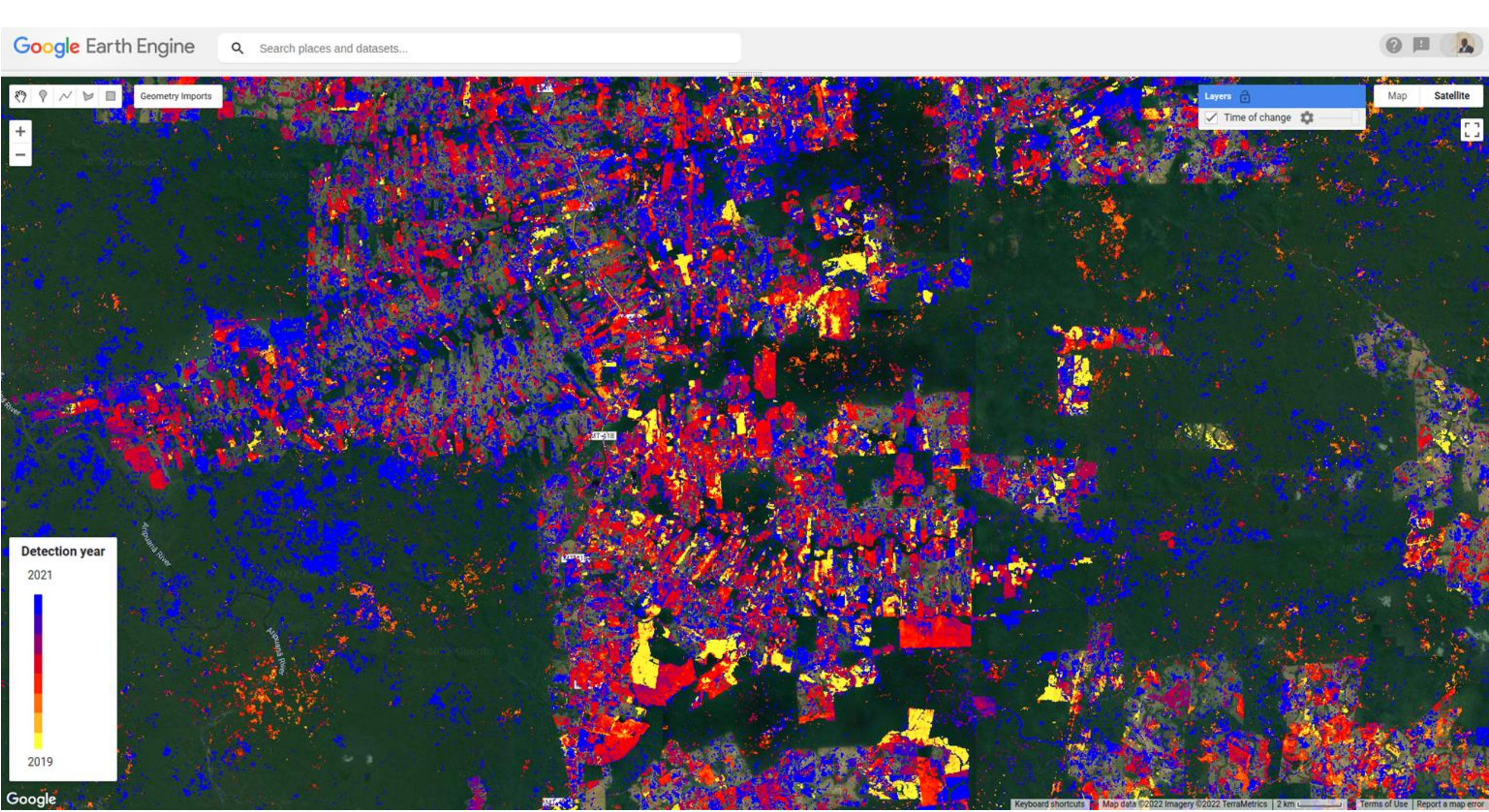
Map data ©2022 Imagery ©2022 TerraMetrics
2 km
Terms of Use
Report a map error


Google Earth Engine
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2021
2019
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Keyboard shortcuts
Map data ©2022 Imagery ©2022 TerraMetrics
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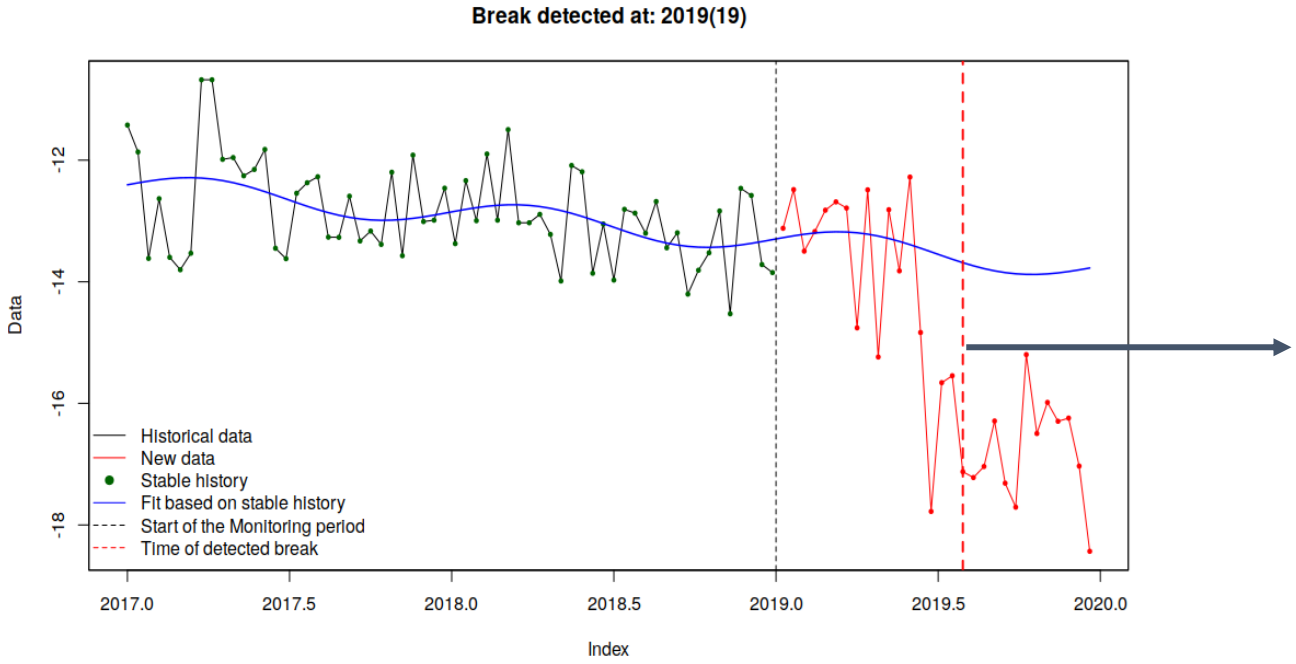
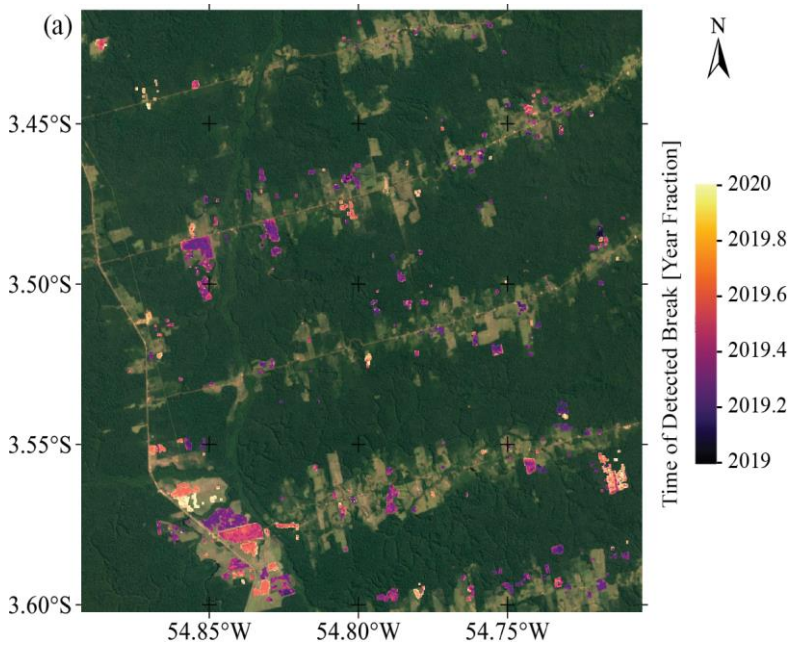
Terms of Use
Report a map error

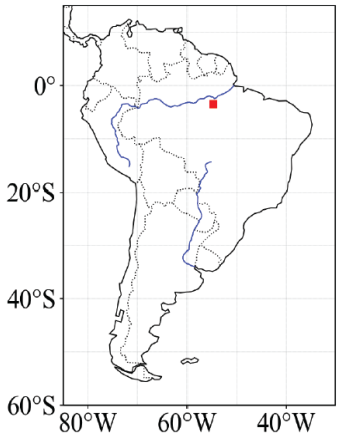
# BFASTmonitor applied on Sentinel-1 time series using openEO UDF in R (Backscatter Intensity VV-band [dB])




BFASTmonitor results: Tapajos/Santarem site, Para state, Brazil



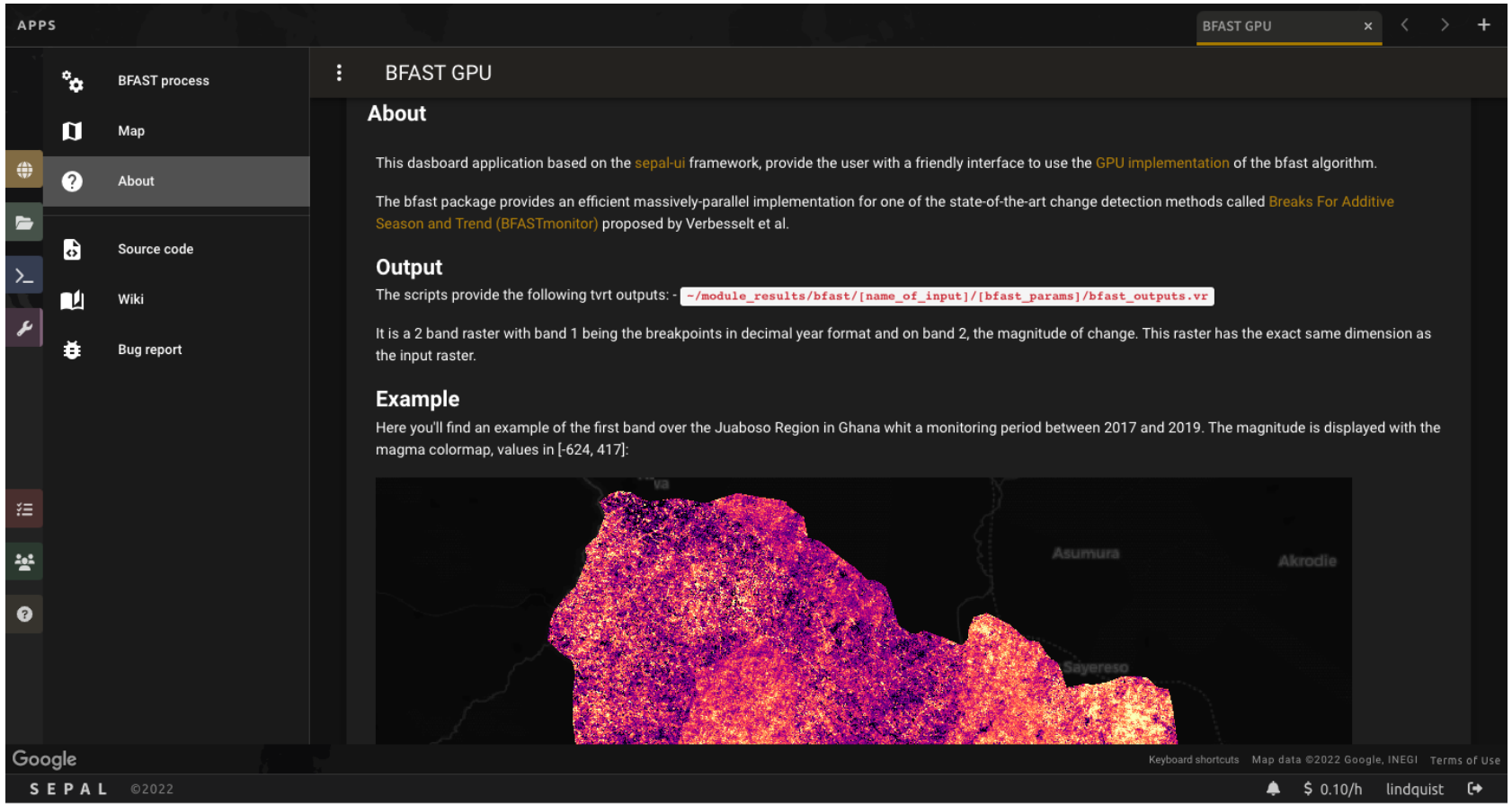

overview figure




Schramm et al. (**2021**), *13*, 1125. https://doi.org/10.3390/rs13061125

# SEPAL by FAO – Access to BFAST GPU

- **S**ystem for **E**arth observation data access, **P**rocessing, and **A**nalysis for **L**and monitoring
- A computing platform: [https://sepal.io](https://sepal.io)
- Create a timeseries from any sensor, start GPU machine, run BFASTMonitor GPU version.

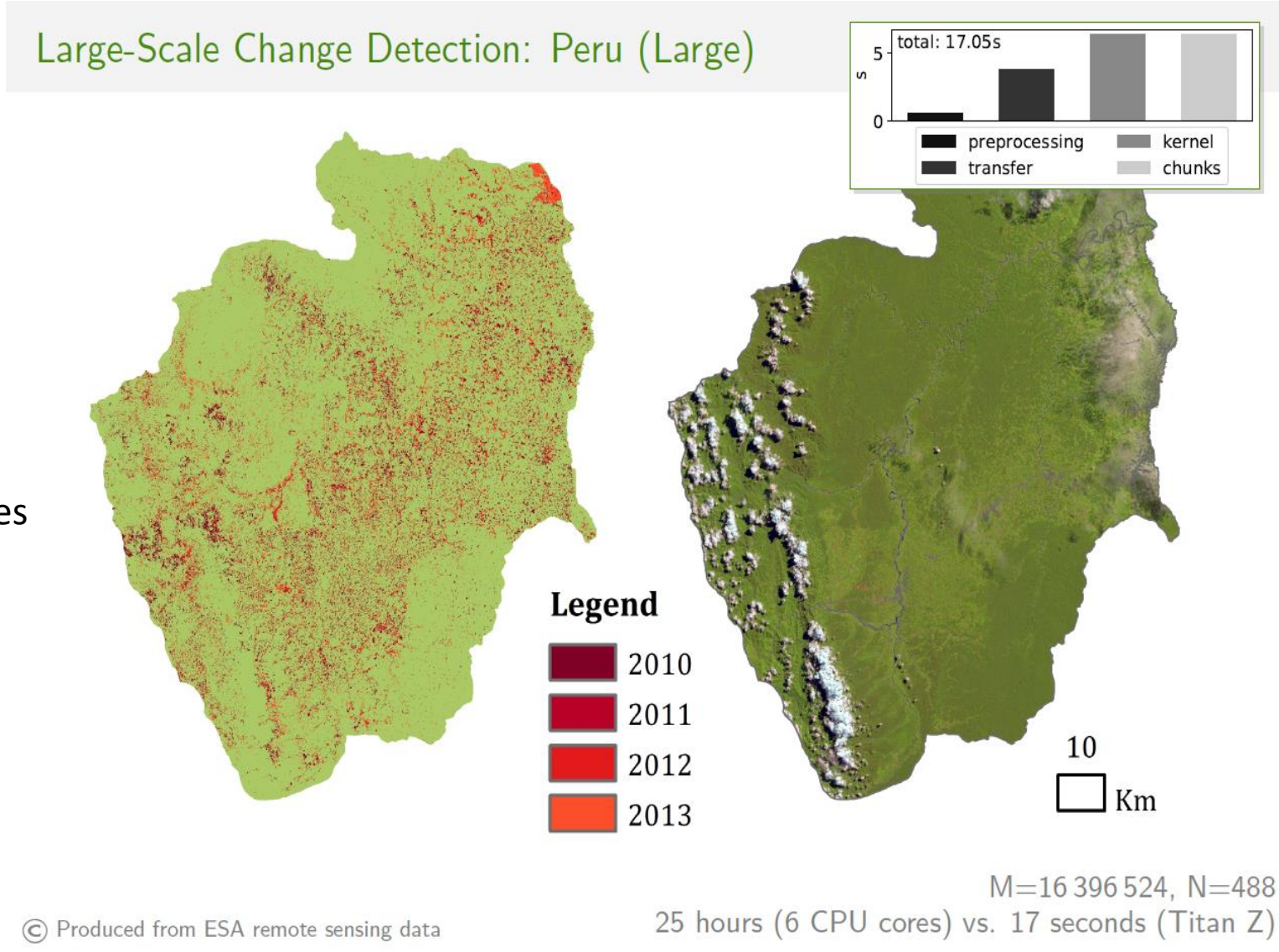


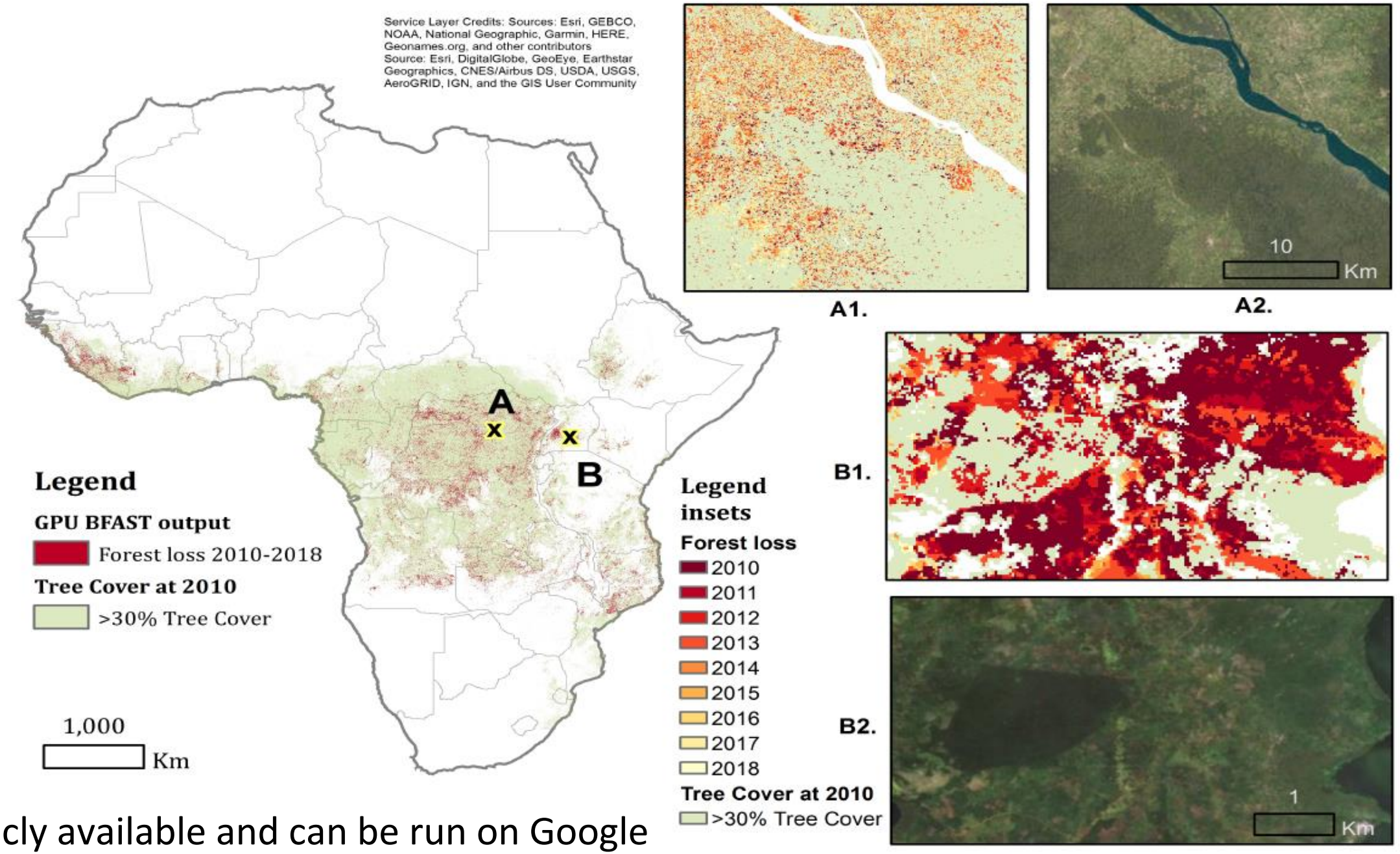
# Innovations

- BFASTmonitor speeding up:
- Python & GPU:
  - PyOpenCL
  - Futhark


- Gieseke, F., Rosca, S. & Henriksen, T. Massively-Parallel Change Detection for Satellite Time Series Data with Missing Values. *2020 IEEE 36th* (2020)

- Serykh, D. et al. Seasonal-Trend Time Series Decomposition on Graphics Processing Units. in 2023 IEEE International Conference on Big Data (BigData) 5914–5923 (IEEE, 2023).

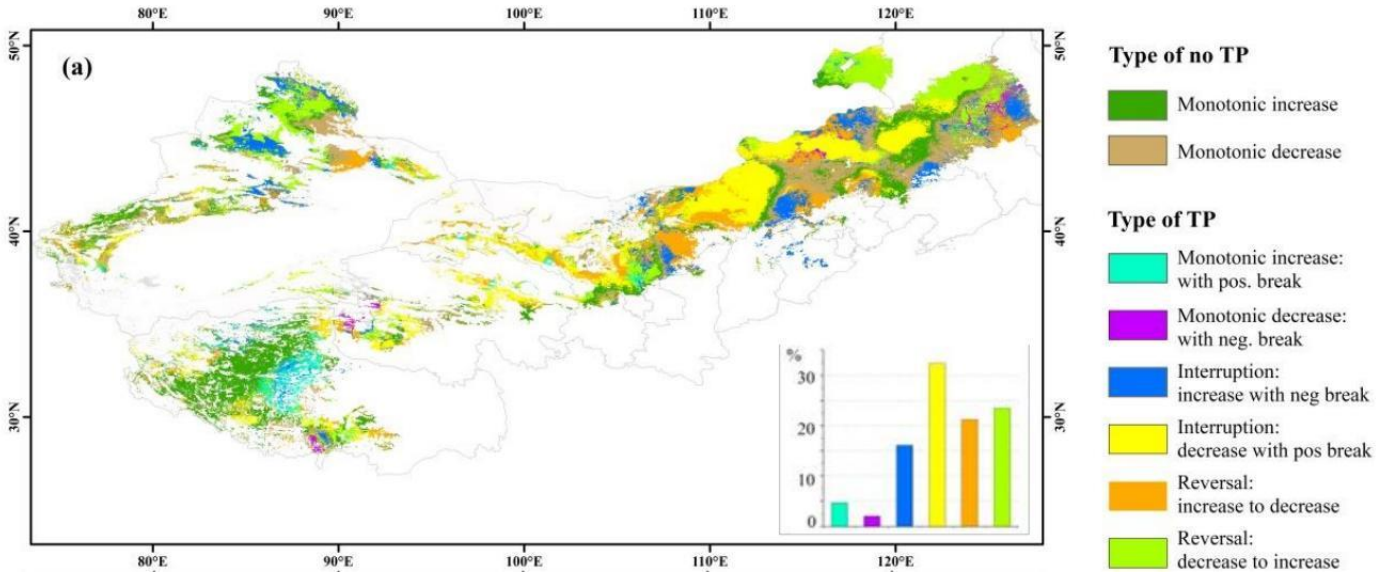






Code is publicly available and can be run on Google Colab: https://bfast.readthedocs.io/

M=6 489 380 352, N=68

# BFAST community



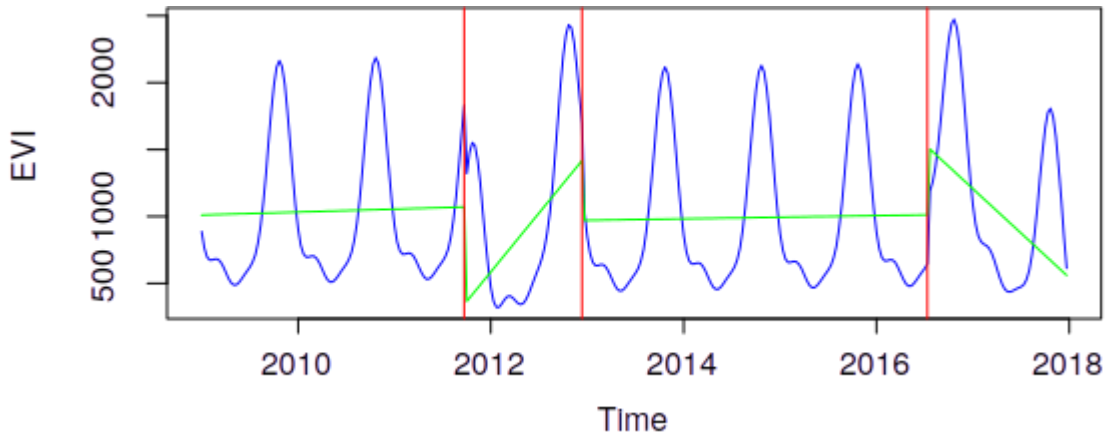

- Recent papers that have used BFAST algorithms

- Brakhasi, F., Hajeb, M., Mielonen, T., Matkan, A. & Verbesselt, J. Investigating aerosol vertical distribution using CALIPSO time series over the Middle East and North Africa (MENA), Europe, and India: A BFAST-based gradual and abrupt change detection. *Remote Sens. Environ.* **264**, 112619 (2021)
- Bernardino, P. N., Keersmaecker, W. D., Fensholt, R., Verbesselt, J., Somers, B., & Horion, S. (2020). Global-scale characterization of turning points in arid and semi-arid ecosystem functioning. *Global Ecology and Biogeography*, 29(7), 1230–1245. https://doi.org/10.1111/geb.13099
- Hong, X., Huang, F., Zhang, H., & Wang, P. (2022). Characterizing the Turning Points in Ecosystem Functioning and Their Linkages to Drought and Human Activities over the Arid and Semi-Arid Regions of Northern China. *Remote Sensing*, 14(21), 21. https://doi.org/10.3390/rs14215396
- Ngadi Scarpetta, Y., Lebourgeois, V., Laques, A.-E., Dieye, M., Bourgoin, J., & Bégué, A. (2023). BFASTm-L2, an unsupervised LULCC detection based on seasonal change detection – An application to large-scale land acquisitions in Senegal. *International Journal of Applied Earth Observation and Geoinformation*, *121*, 103379. https://doi.org/10.1016/j.jag.2023.103379

# Innovation - Upcoming features and outlook

- Automatic selection of an appropriate harmonic order
- User-defined statistics for determining optimal number of breaks
- BFAST Classify support for BFAST Lite
- An optional structural test to quickly screen large areas
- BFAST integrated into SITS?
- ...and your own favourite feature, just let us know on GitHub!

https://github.com/bfast2/bfast/issues



# More information - teaching

- Tutorials
  - BFAST Monitor and BFAST Lite using MODIS: https://janverbesselt.github.io/BFASTforAEO/

More info:

- https://bfast2.github.io/
- https://github.com/bfast2/bfast

- De Keersmaecker, W. et al. **Evaluating recovery metrics derived from optical time series over tropical forest ecosystems**. RSE (2022)
- Milenković, M. et al. **Assessing Amazon rainforest regrowth with GEDI and ICESat-2 data**. Science of RS (2022)

# Take home messages

- Script to implement and visualize your idea's
  - Data Visualization
- Open-source
  - Excellent for collaboration
  - Linux
- Take time relax, have fun,

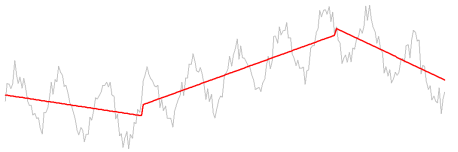
  and go for a walk in nature.

BFAST

Breaks For Additive Season and Trend

# Thanks

# Evolution of BFAST functions for characterizing land change using satellite image time series (Sentinel, and Landsat)




Jan Verbesselt[1,2] et al.

[1]Belgian Science Policy Office, Earth Observation, Belgium

[2]Wageningen University, The Netherlands

**https://www.linkedin.com/in/jan-verbesselt/**

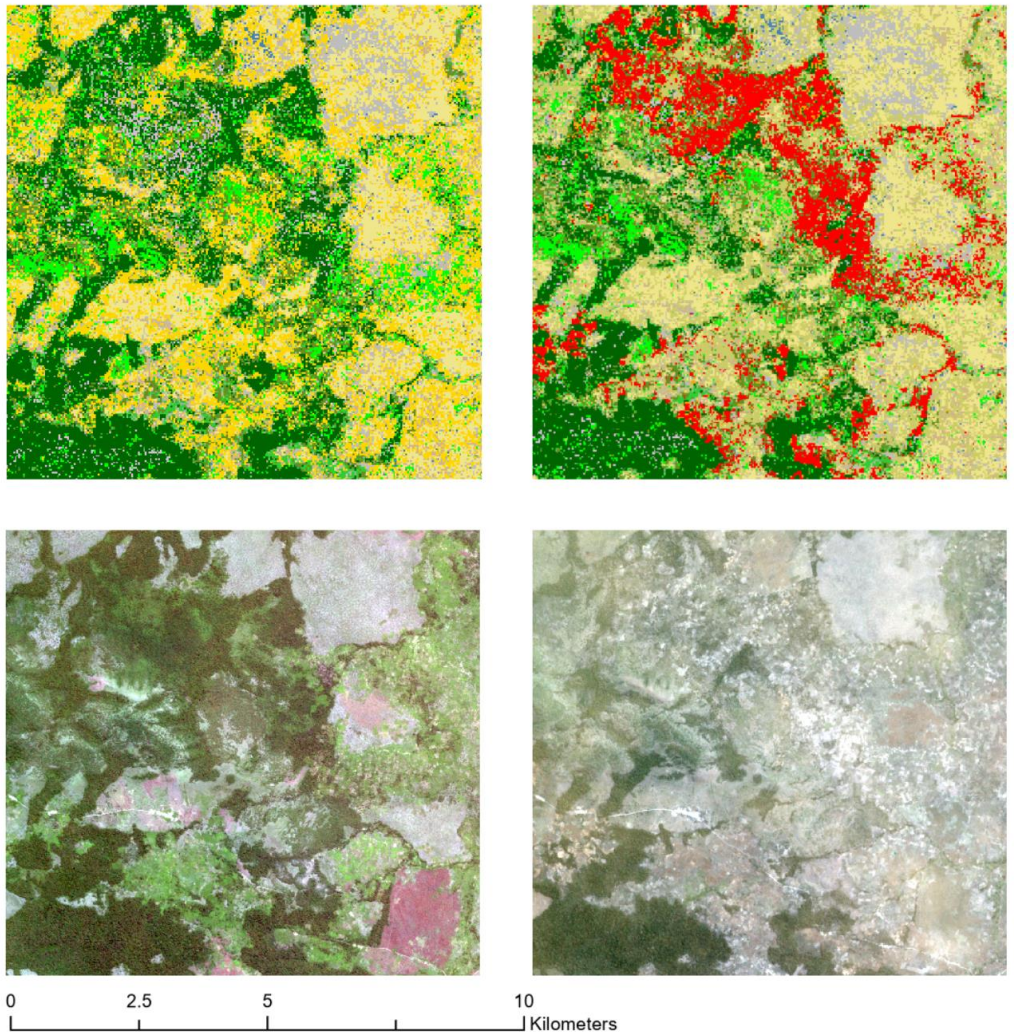
# BFAST Classify

- Classify segments from BFAST01 output (i.e. single breakpoint)
- 7 types + 4 subtypes (Bernardino et al. 2020)
- T

- Effective to characterize ecosystem/land change at large scale

# SEPAL by FAO – Access to BFAST GPU

- Create a timeseries from any sensor, start GPU machine, run BFASTMonitor GPU version.



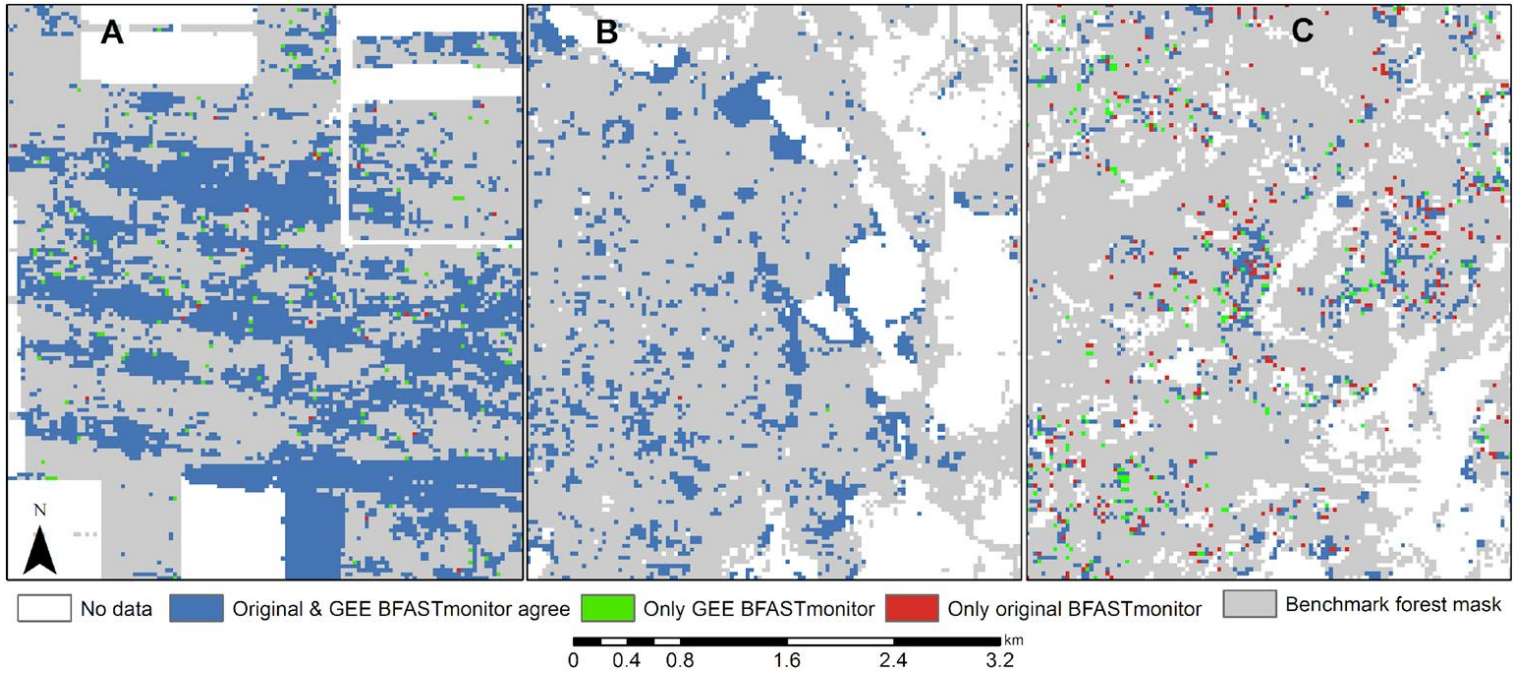


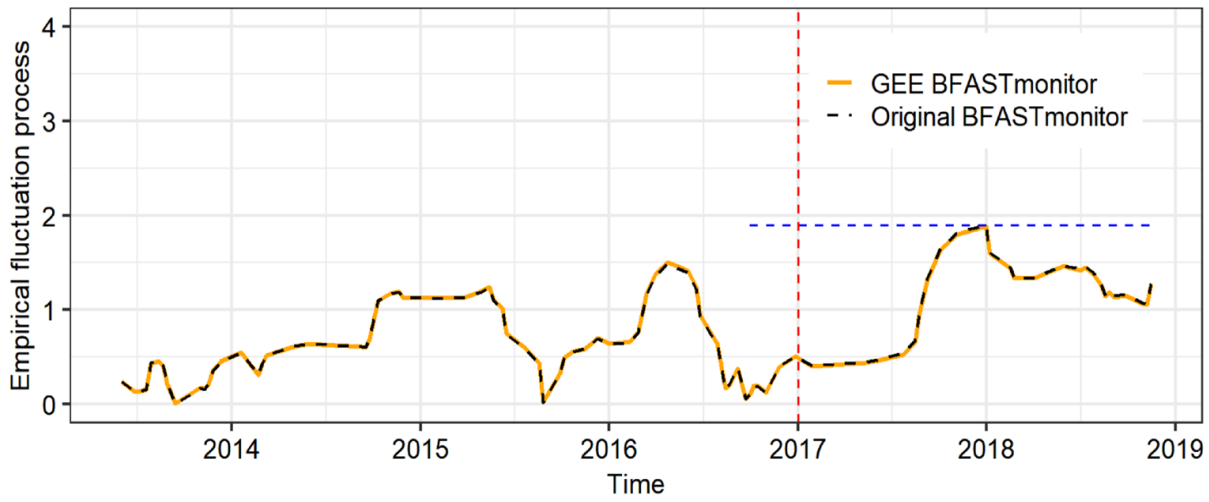
Central Africa processed for forest change using BFAST GPU

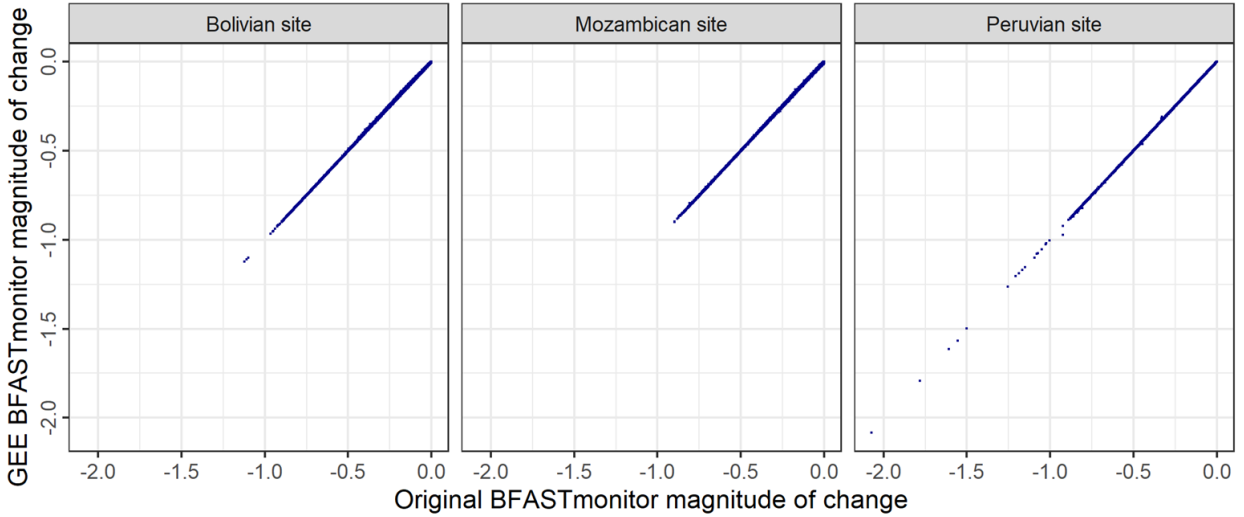
# BFASTmonitor implementation on GEE

Minor differences are observed

GEE BFASTmonitor VS Original BFASTmonitor



# Application: BFAST01 for land degradation assessment

Received: 13 July 2018 | Revised: 18 January 2019 | Accepted: 1 February 2019
DOI: 10.1002/ldr.3282

RESEARCH ARTICLE

WILEY

**Mapping European ecosystem change types in response to land-use change, extreme climate events, and land degradation**

Stéphanie Horion[1] | Eva Ivits[2] | Wanda De Keersmaecker[3] | Torbern Tagesson[1,4] | Jürgen Vogt[5] | Rasmus Fensholt[1]

[1] Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark
[2] Geospatial Information Services group, European Environment Agency, Copenhagen, Denmark
[3] Department of Earth and Environmental Sciences, KU Leuven, Heverlee, Belgium

**Abstract**
Extreme climate events and nonsustainable land use are important drivers altering the functioning of European ecosystems, resulting in loss of the services provided. Yet a consensus method for regular continental scale assessment of ecosystem condition in relation to land degradation (LD) is still lacking. Here, we propose a new remote

Land degradation LD is often defined as a long-term decreased in vegetation productivity.

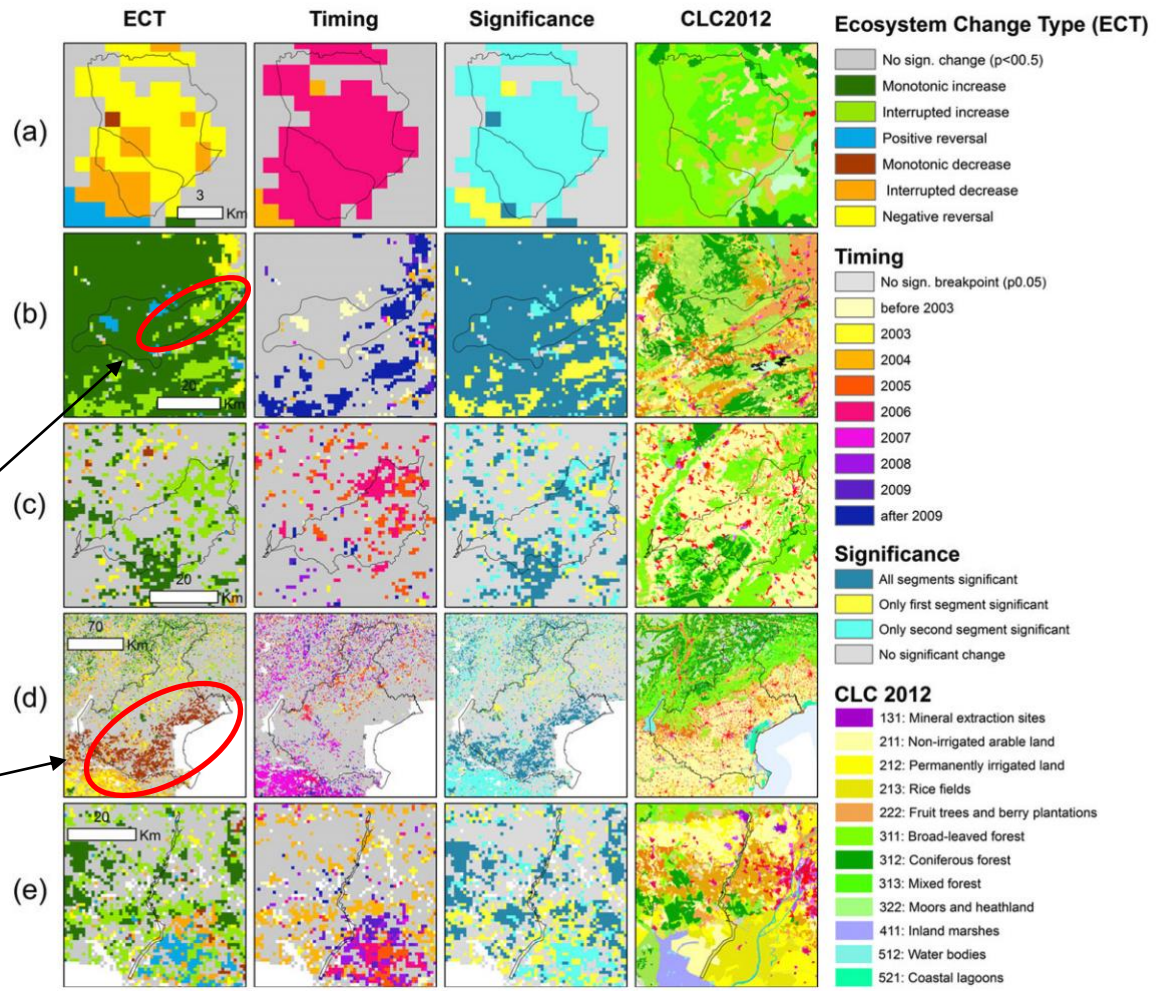
However, the processes leading to LD may be non-linear, and productivity loss may be characterized by a significant change of rate (accelerated degradation).

**Use of BFAST01 to identify the major BP can support LD assessment (Horion et al. LDD 2019):**

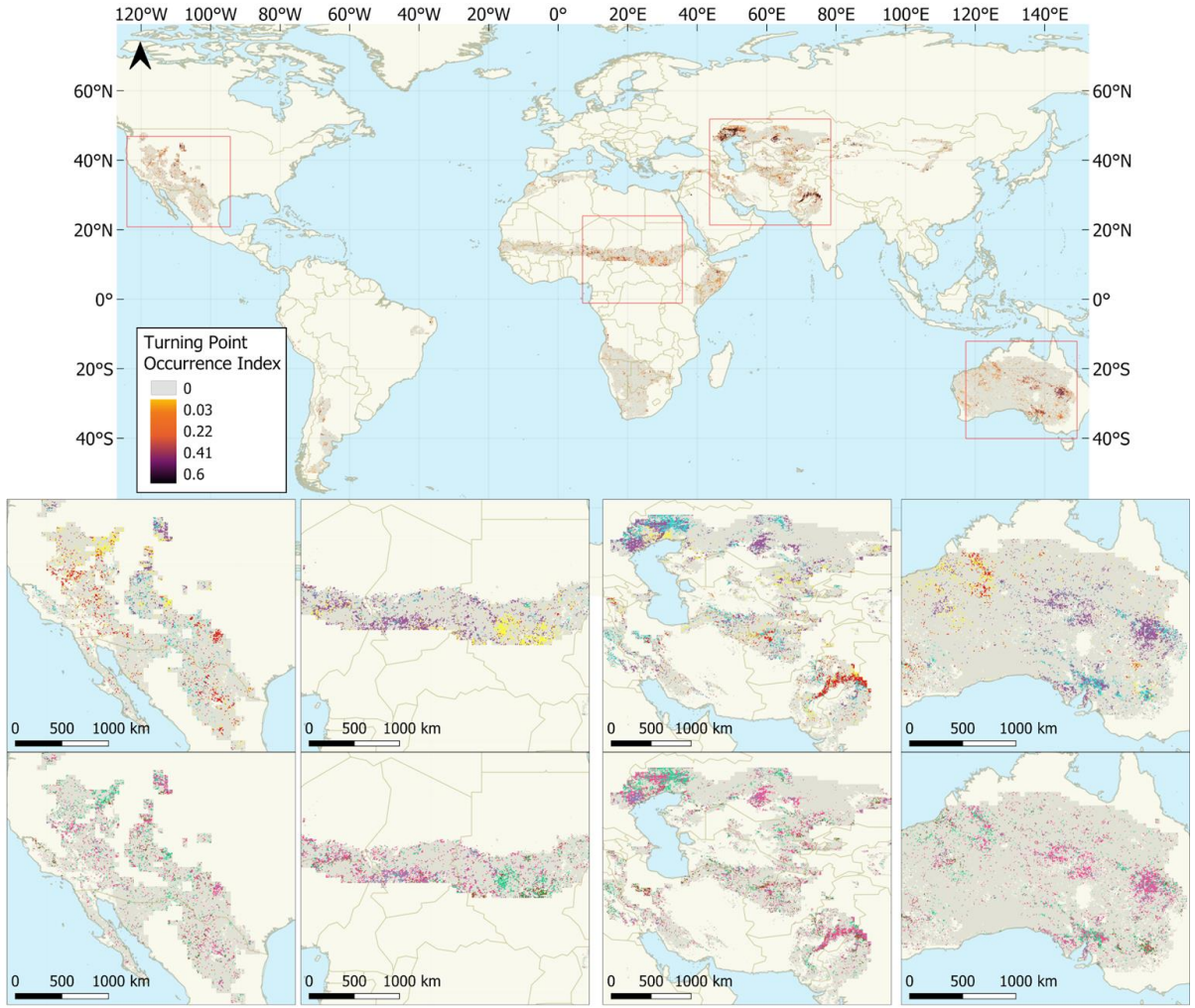
A few examples:

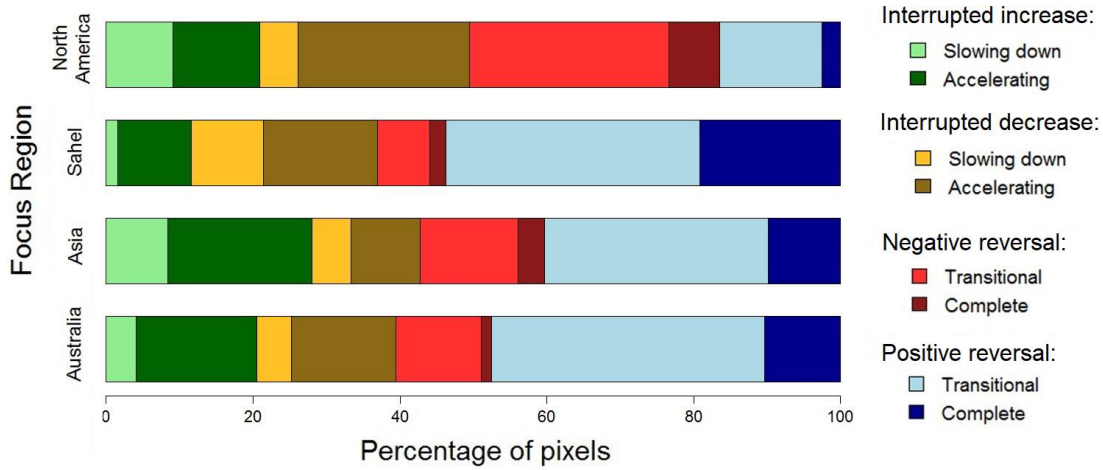
SPAIN (b) - Loss in productivity due to soil erosion in fruit tree plantations

ITALY (d) - Long-term loss in organic carbon over agricultural soil as LT gradual decrease



# BFAST01 (+ BFAST classify) for the characterization of changes in ecosystem functioning




Type
- No break/no change
- Interrupted increase
- Interrupted decrease
- Negative reversal
- Positive reversal

Subtype
- No subtype
- Slowing down
- Accelerating
- Transitional
- Complete

Global Ecology and Biogeography
A Journal of Macroecology

RESEARCH PAPER | Open Access

Global-scale characterization of turning points in arid and semi-arid ecosystem functioning

Paulo N. Bernardino, Wanda De Keersmaecker, Rasmus Fensholt, Jan Verbesselt, Ben Somers, Stéphanie Horion

# Platform as a service

- Framework for handling large amounts of EO data
- Using a client (R/Python/JavaScript), can write a script that generates a language-agnostic process graph that is sent to a backend (GEE/GRASS/WCPS/JEODPP/GeoPySpark etc.)
- The backend accesses data locally (VITO also allows remote), runs the process graph and returns results: download only what you need
- Can run UDFs!
- e.g. BFAST