Continuous detection of forest loss from Sentinel-1 : the TropiSCO project

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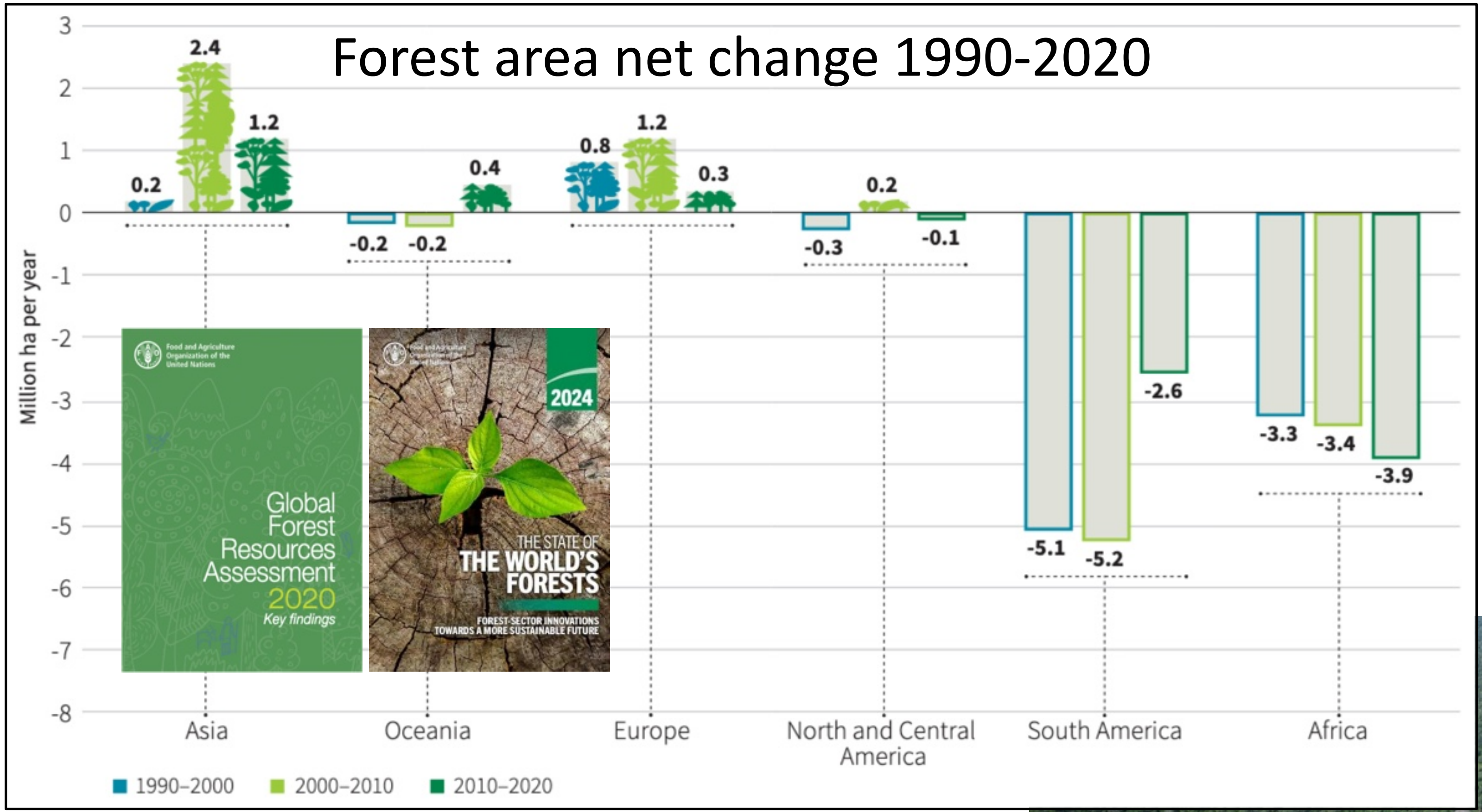
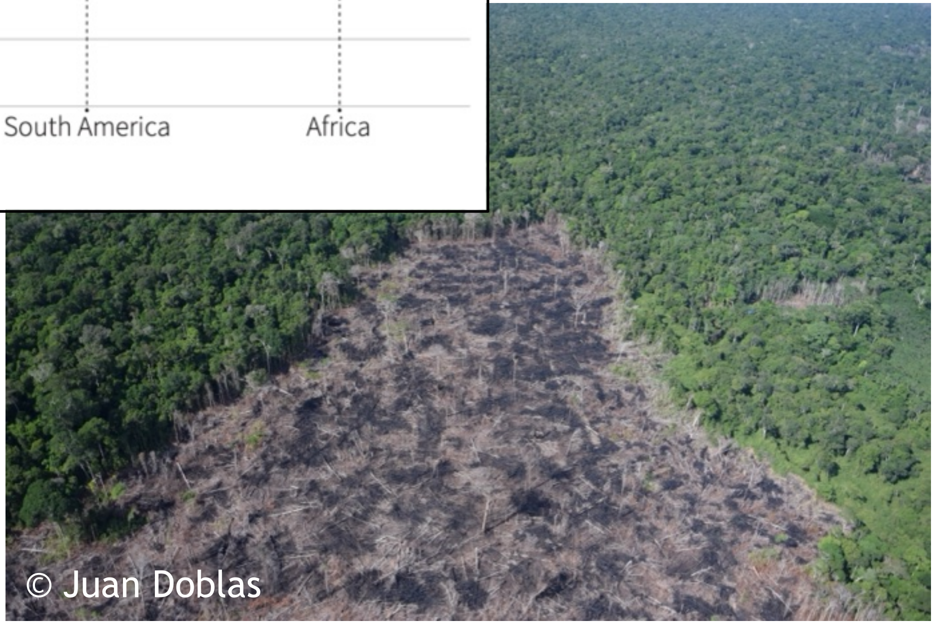
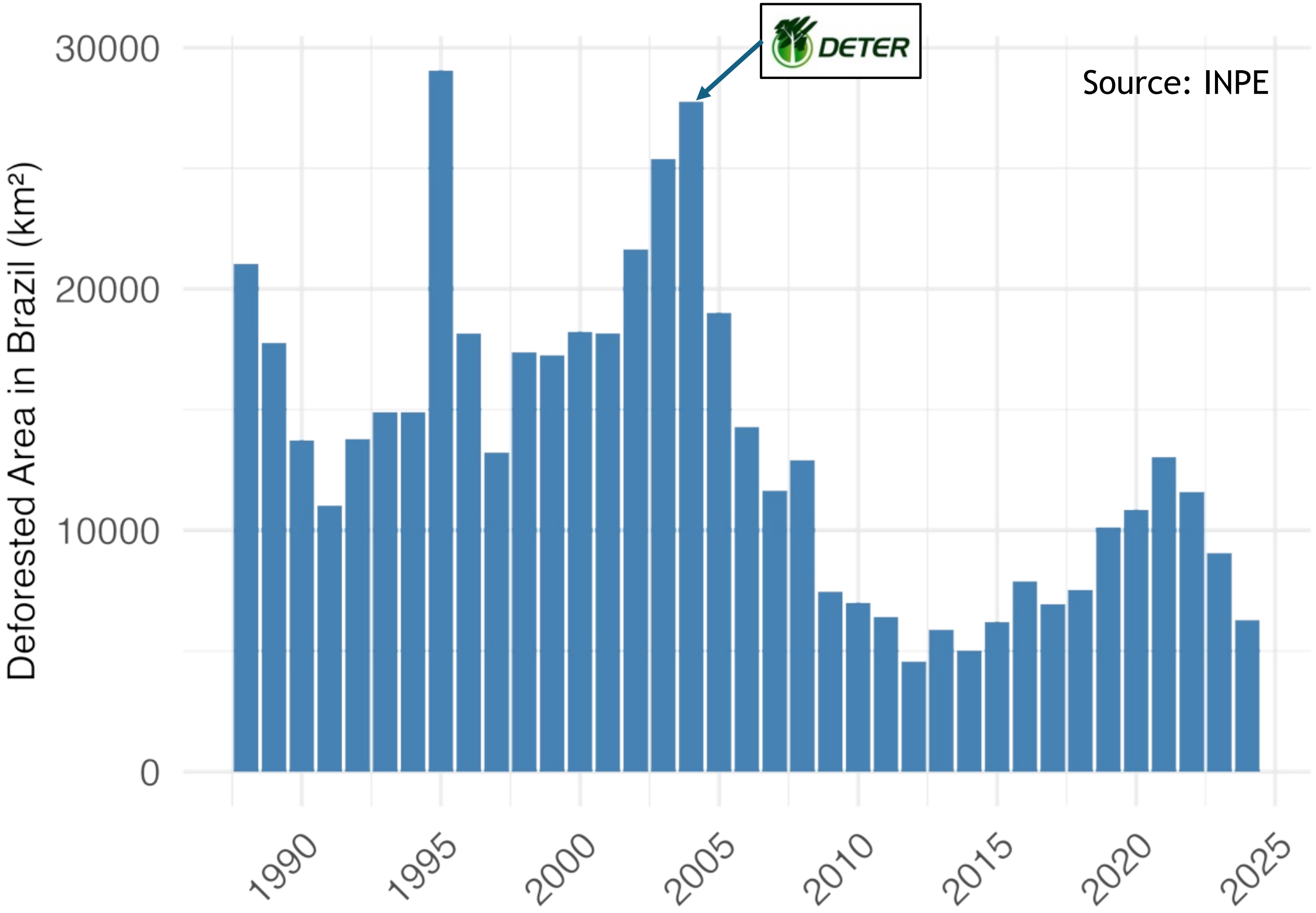
Deforestation is far from being over



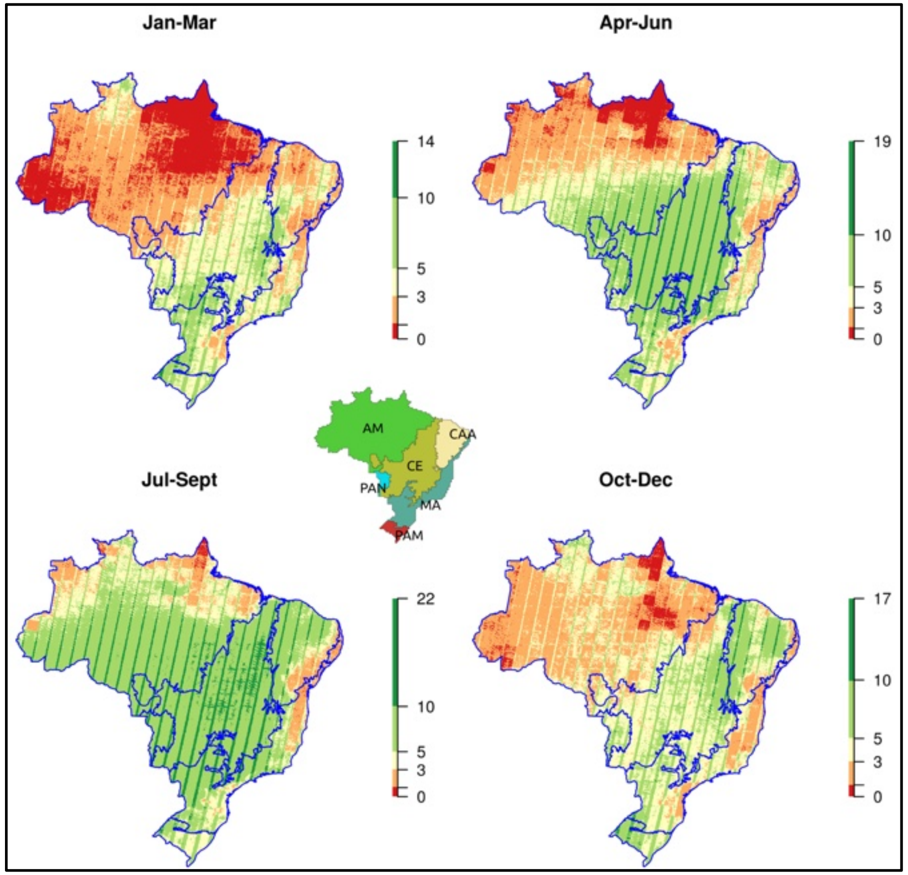


- Forests act as carbon sinks, slowing climate change
- Deforestation release carbon into the atmosphere
- Climate change is making forests more vulnerable to abiotic and biotic stresses, such as forest fires and pests

Deforestation can be curbed with satellite alerts system & political action



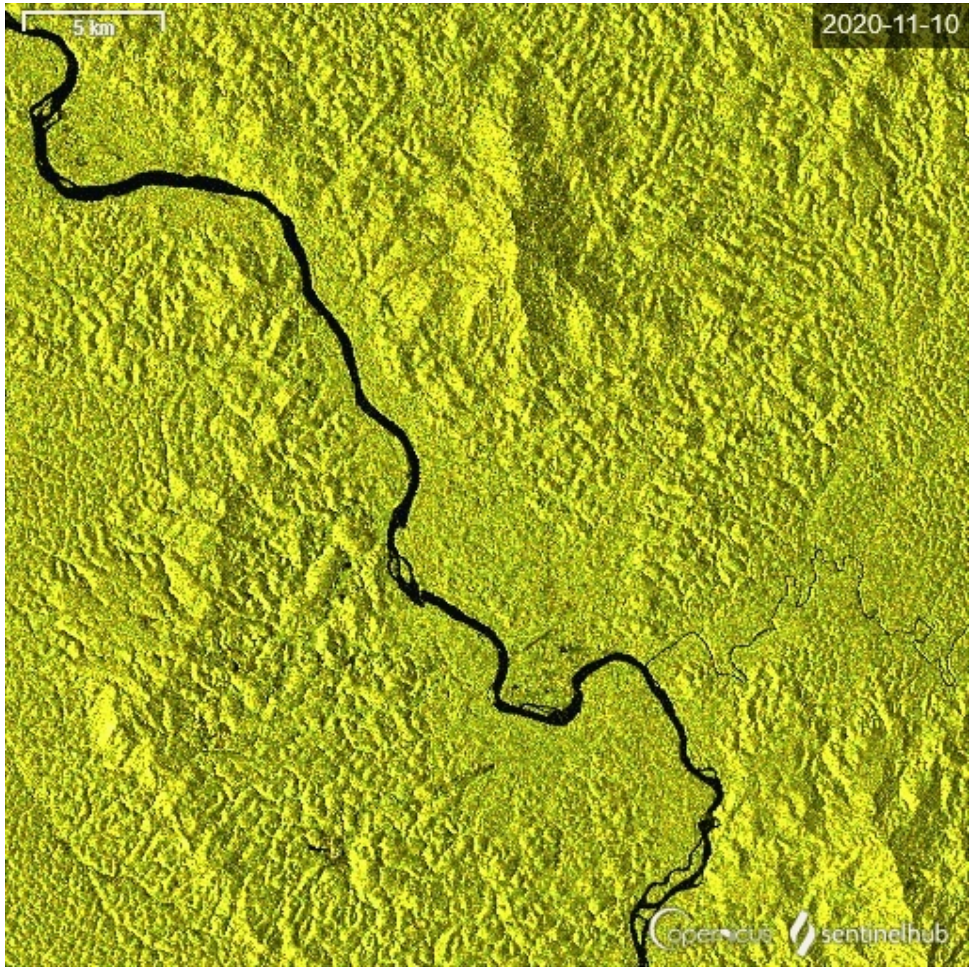
But clouds may delay timely detection in the tropics



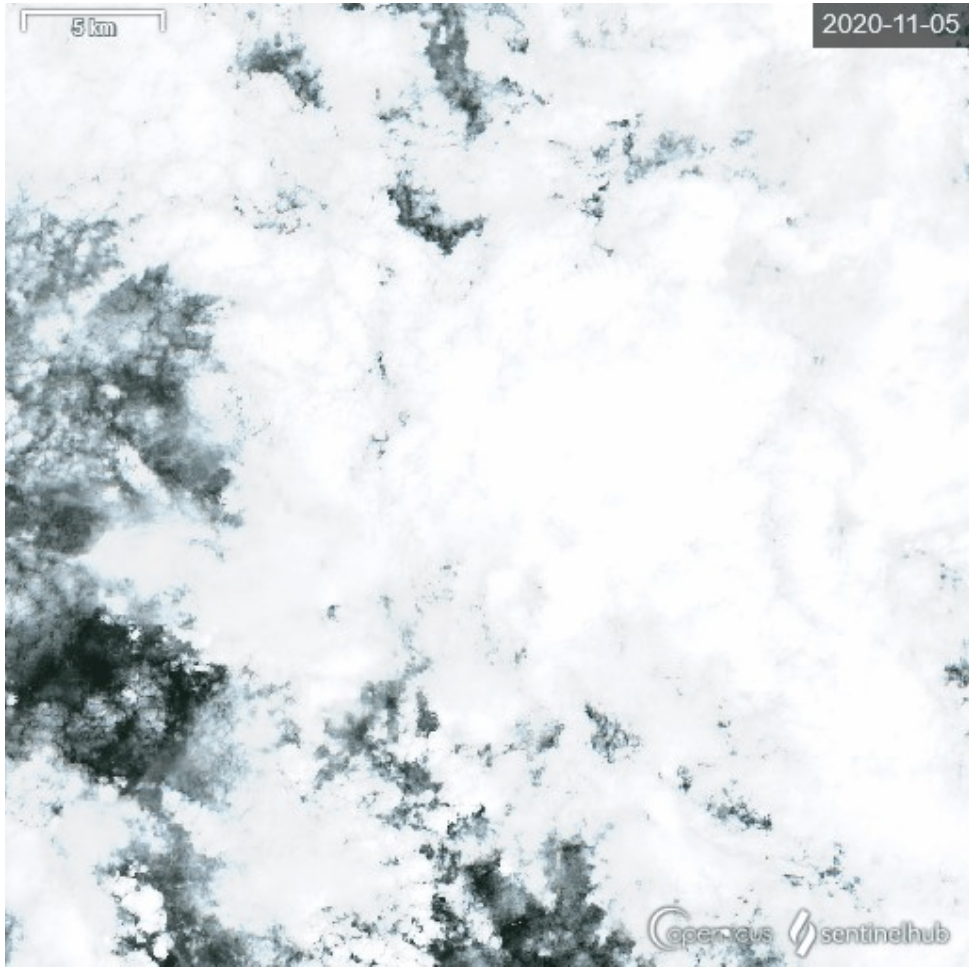
Number of valid Landsat images
In Brazil from 2014 to 2019
Source: Mas et al. 2021

Radar can see through clouds

Sentinel-1 (radar)



Sentinel-2 (optique)



Sentinel-1 Copernicus mission

A constellation of C-band Synthetic Aperture radars, developed by the European Space Agency (ESA):

- Sentinel-1A (April 2014) – Now nearing the end of its lifetime
- Sentinel-1B (April 2016) – Failed in December 2021
- Sentinel-1C (December 2024)
- Sentinel-1D (November 2025)

Mission lifetime: 2014 to >2030

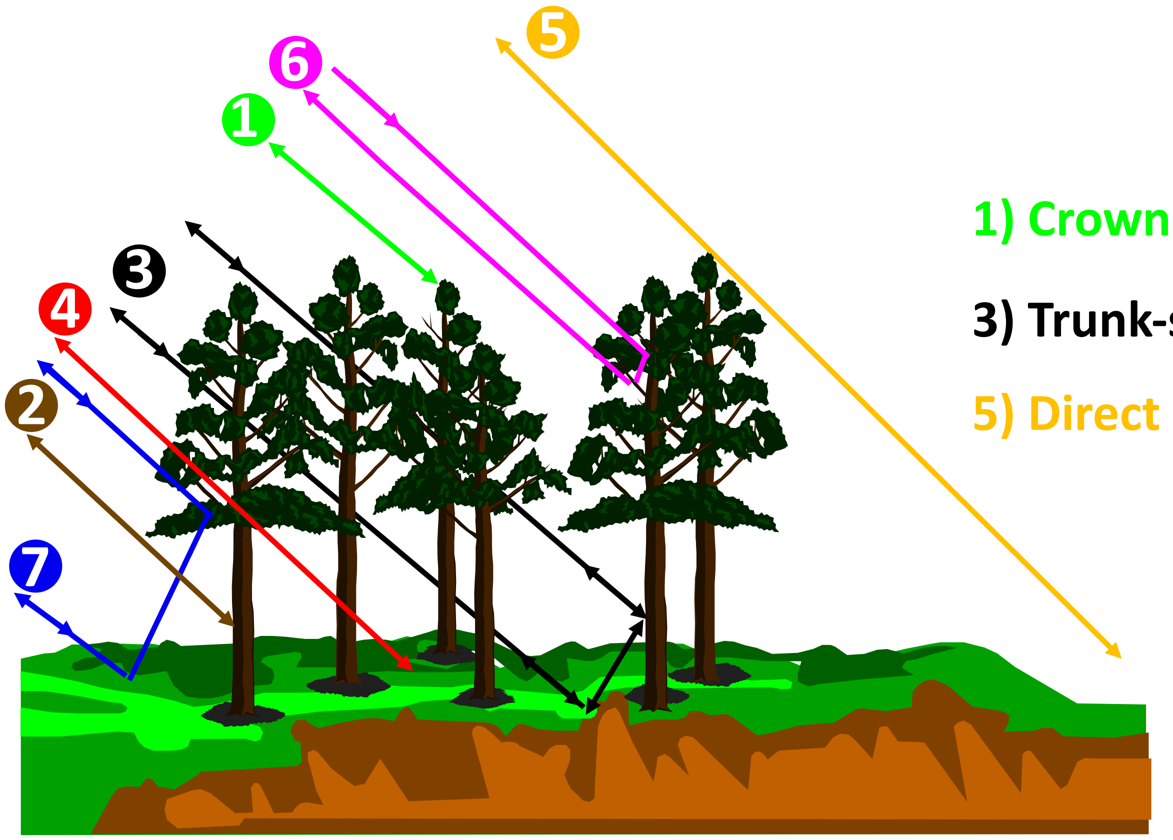
Large and unprecedented amount of free data.

C-Band SAR data continuity

- Systematic all weather observations
- Repeat Cycle: 12 days, 6 days with 2 satellites
- Multimode, resolution 5-20m, swath width up to 250-400 km
- Free access
- Preprocessing tools and Analysis Ready Data (ARD) available

⇨ Since 2015-2016, we have been constantly **developping and improving methods** for **forest loss monitoring** with Sentinel-1

Backscattering mechanisms in forests



1) Crown scattering

2) Trunk scattering

3) Trunk-soil interaction

4) Attenuated soil scattering

5) Direct soil scattering

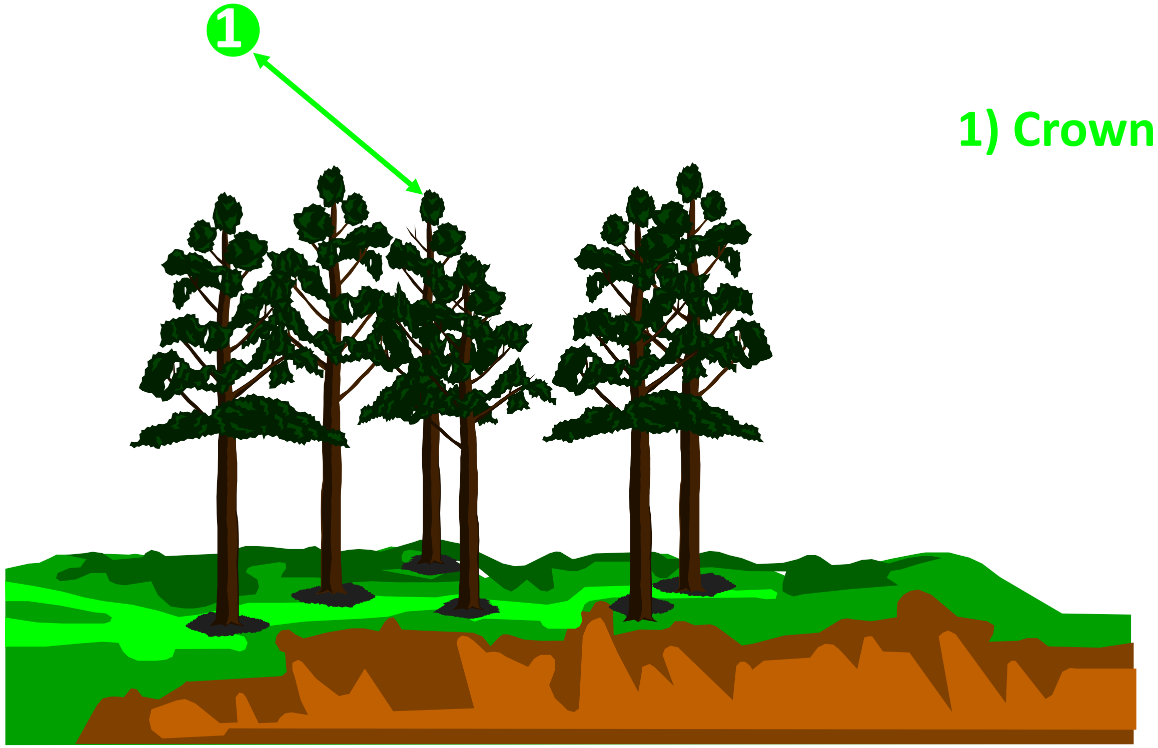
6) Trunk-branch interaction

7) Soil-branch interaction

Depends on:

1. Frequency
2. Polarization
3. Incidence angle

Backscattering mechanisms in forests at C band



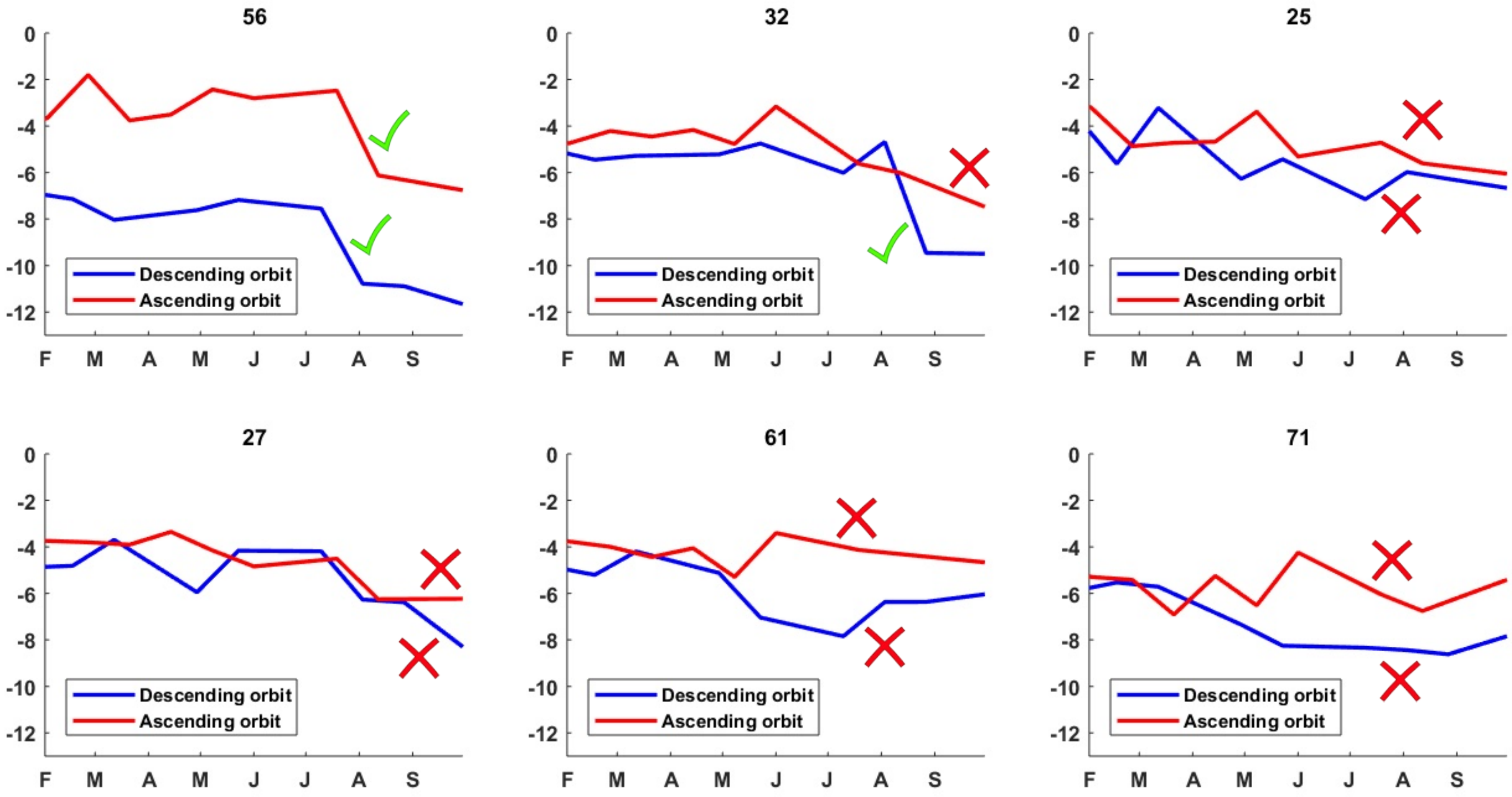
1) Crown scattering

The dominant scattering term is the scattering from the tree canopy, resulting in high backscatter values, especially at VH or HV polarization.

Assumption: Forest loss is expected to be characterized by a **backscatter decrease**.

Is the backscatter decrease a reliable indicator of forest loss?

Temporal backscatter profiles of deforestation plots in the Peruvian Amazon:



⇨ Other approaches are needed!

Why isn't the backscatter decrease always reliable?

Different kinds of clearcutting / post-logging management

Clearcutting for rubber plantation in Cambodia and Vietnam

Plantation harvest in Australia

Clearcutting in Brasil

Plantation harvest in South Africa

Cleaned/burnt fields → Easy detection in dry season with C-band SAR

Clear cutting In Peru

Slash-and-burn agriculture in Peru

Indonesia

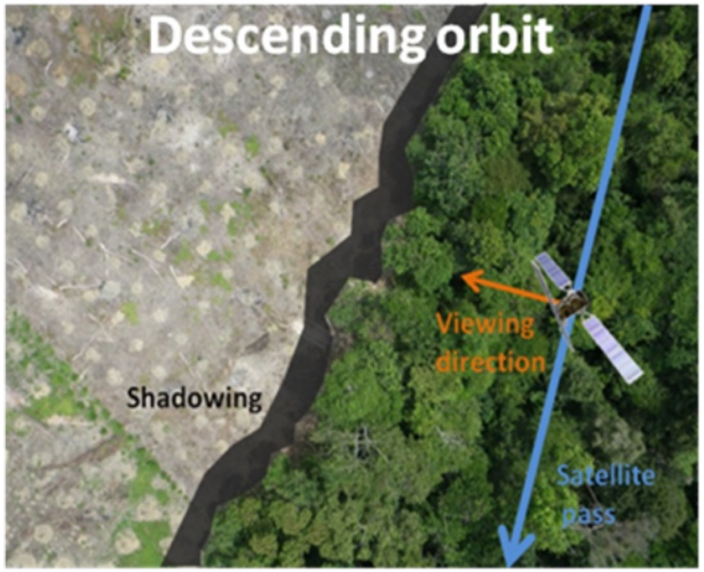
Brasil

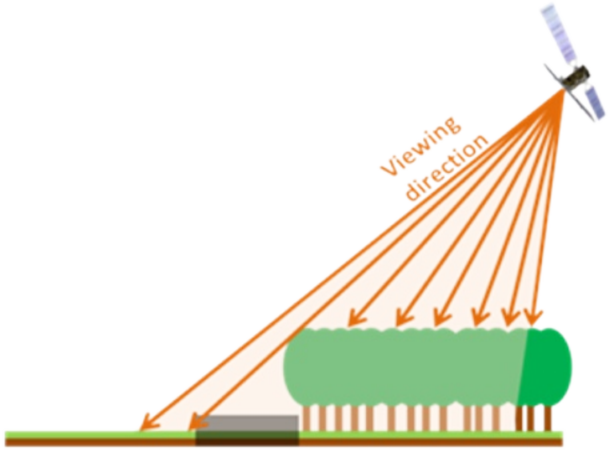
Fields with debris/remaining vegetation → Poor detection with C-band SAR

The TropiSCO method

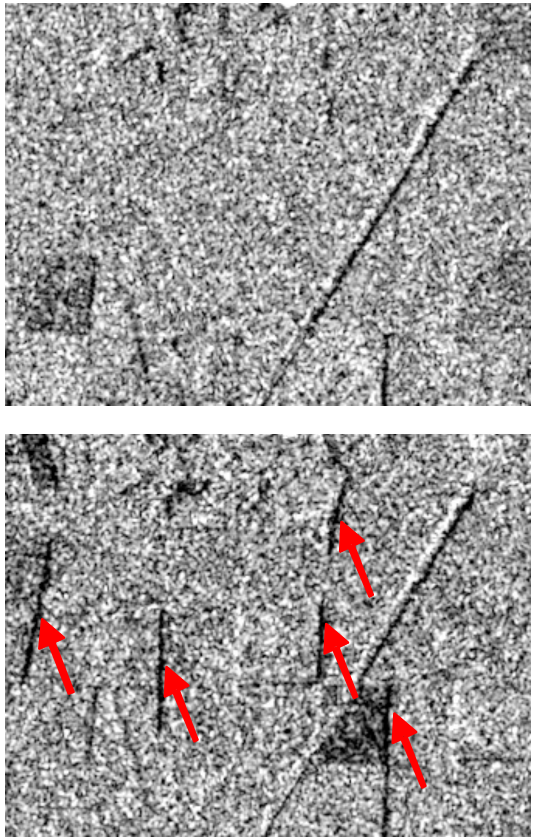
Based on **shadow detection** in SAR images.
SAR instruments have a **side-looking** geometry.
At high resolutions (e.g. 10m), the **edges of forest patches** are characterized by a **shadow**: an area on the ground which is not reached by the SAR wave, and therefore appear as a dark target.

Geometrical effect, relevant for automatic detection



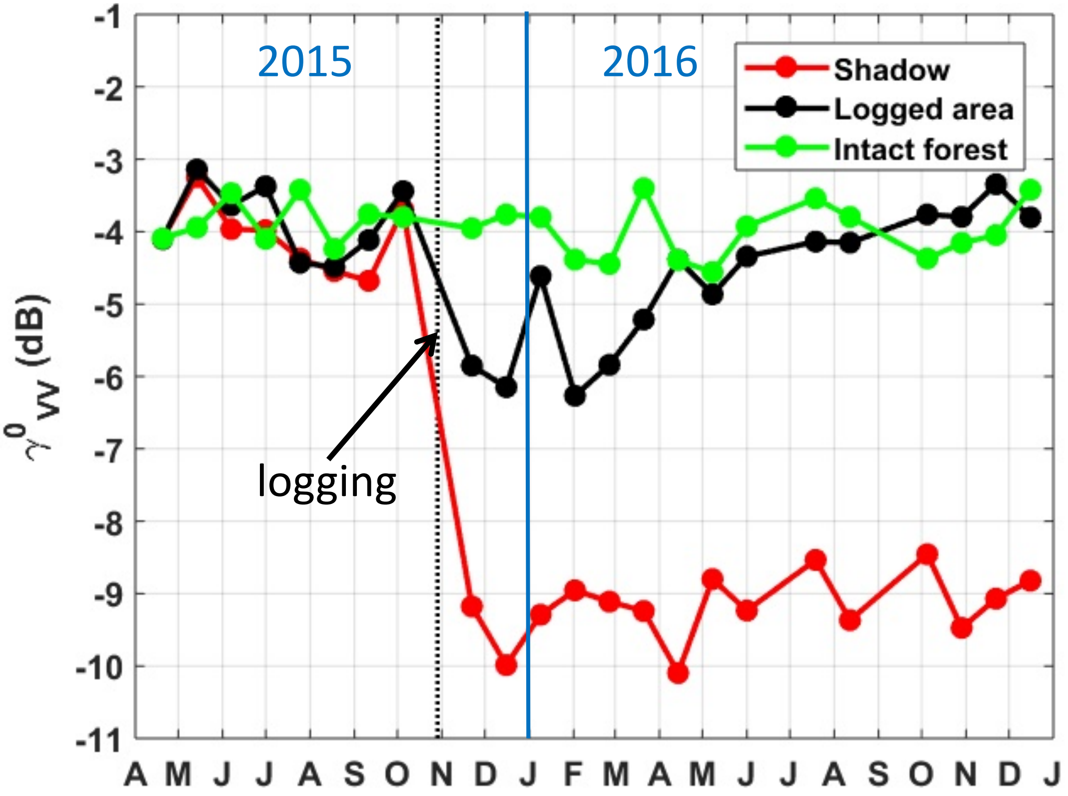


10 May 2015



1 October 2016

The TropiSCO method



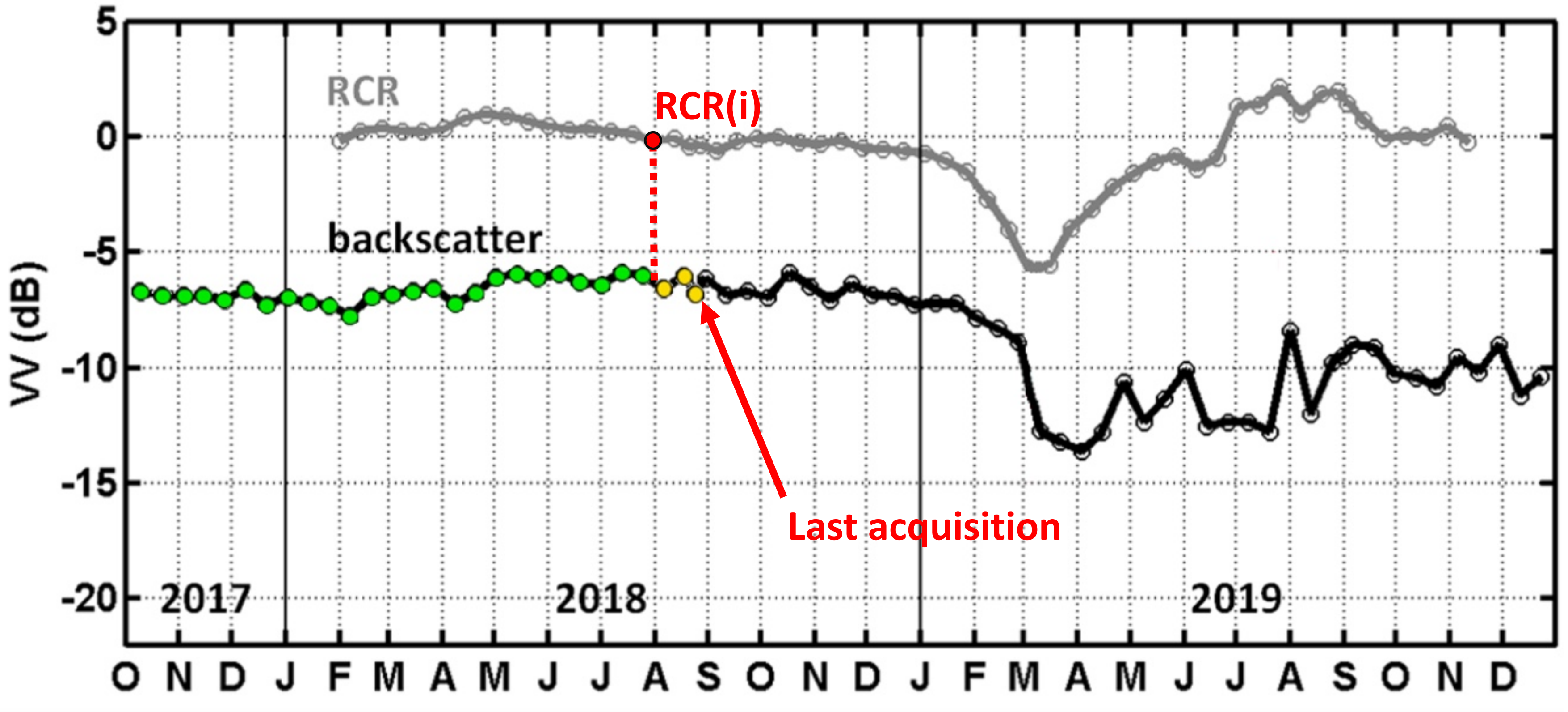
In this example, logging occurs in October-November 2015.

The temporal backscatter profile of :

- **Intact forest**: stable backscatter
- **Logged area**: moderate decrease (~2.5dB), but post-disturbance backscatter then gradually increases to its original level (impact of environmental conditions)
- One **edge of the logged patch** : a **shadow** appears ⇨drastic backscatter decrease (~5dB), with no apparent evolution after (purely **geometrical** artifact, **no impact of environmental conditions**)

The TropiSCO method

RCR: Radar Change Ratio (Tanase et al., 2018)



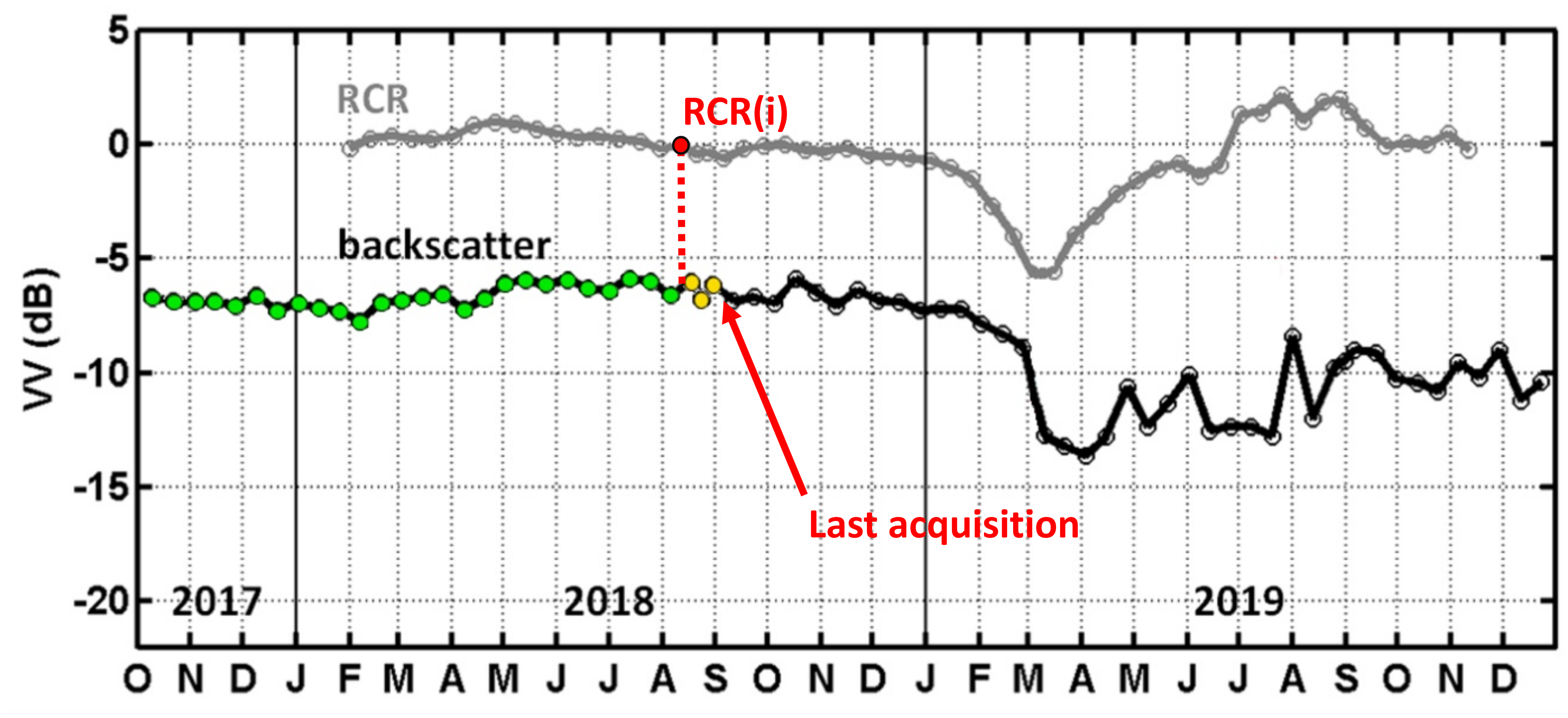
Temporal backscatter and associated RCR

$$RCR(i) = \frac{mean(\text{yellow points})}{mean(\text{green points})}$$

Lower sensitivity to environmental effects and speckle

The TropiSCO method

RCR: Radar Change Ratio (Tanase et al., 2018)

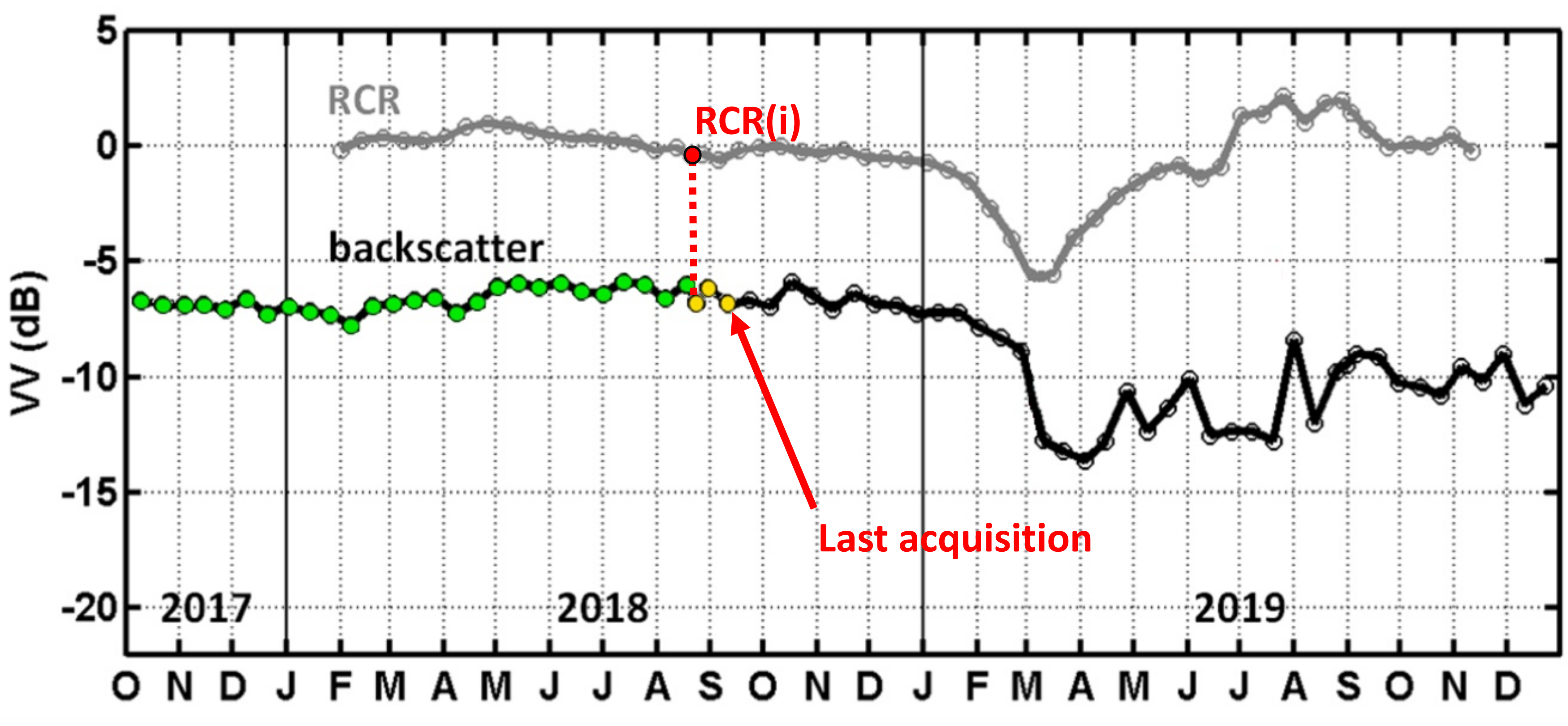


Temporal backscatter and associated RCR

RCR(i)= $\frac{mean(\text{yellow dots})}{mean(\text{green dots})}$

The TropiSCO method

RCR: Radar Change Ratio (Tanase et al., 2018)



Temporal backscatter and associated RCR

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The TropiSCO method

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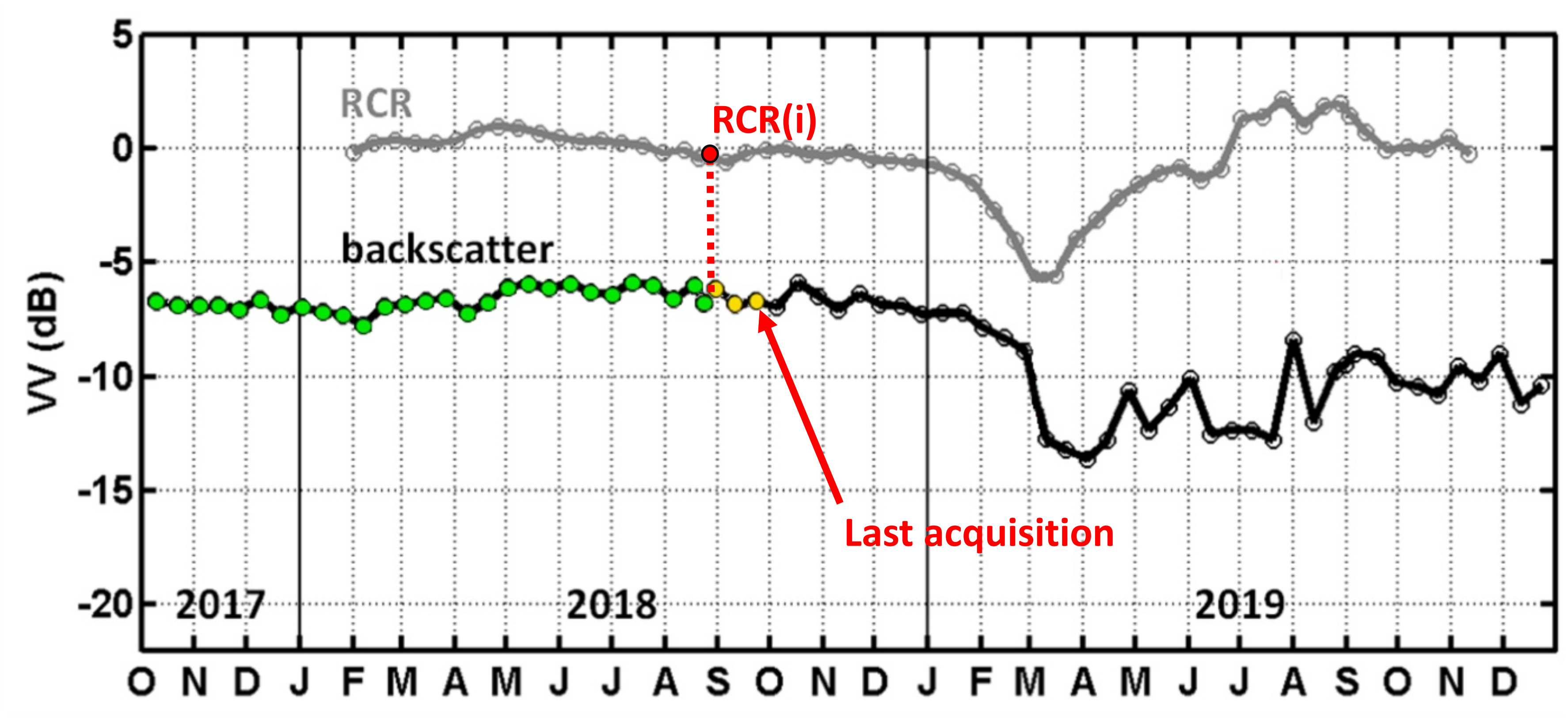

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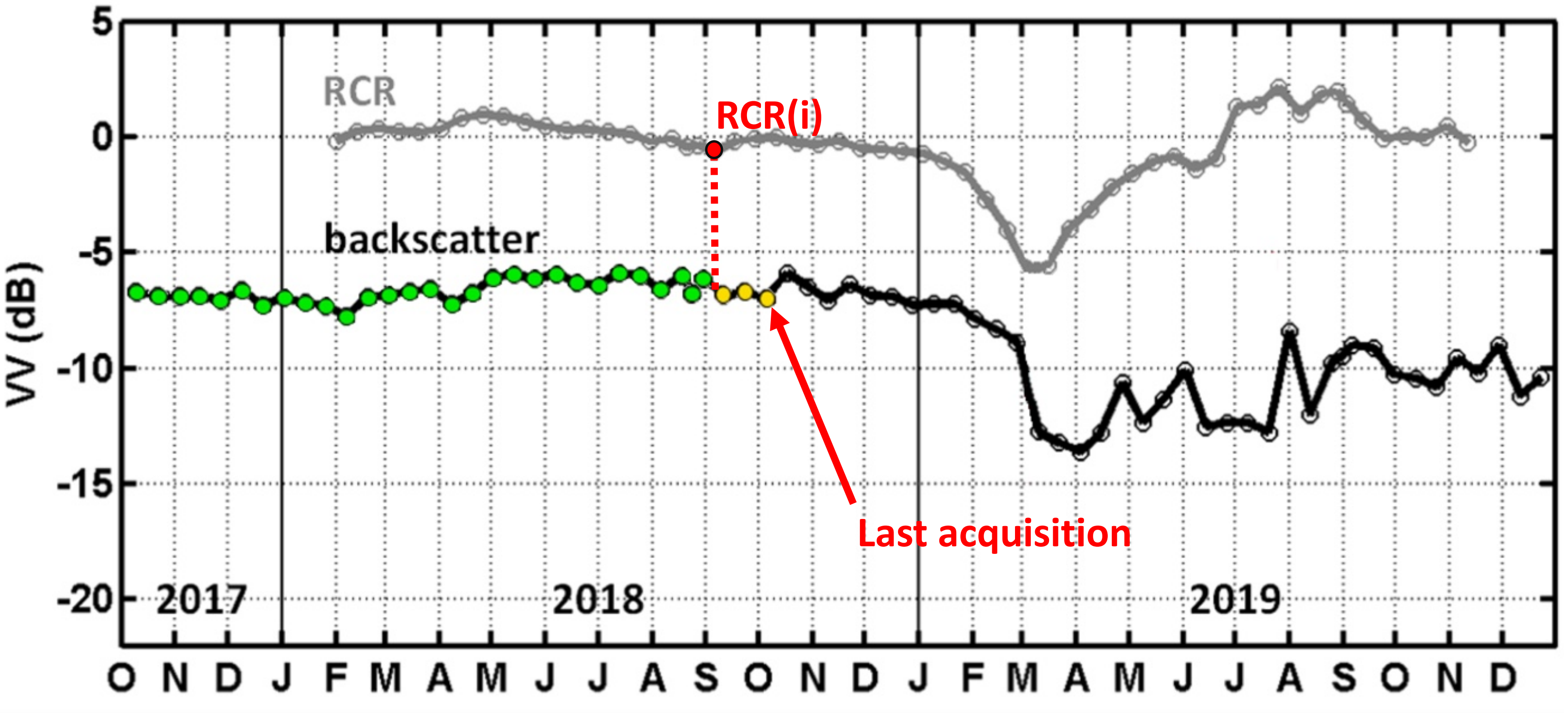

Temporal backscatter and associated RCR

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The TropiSCO method

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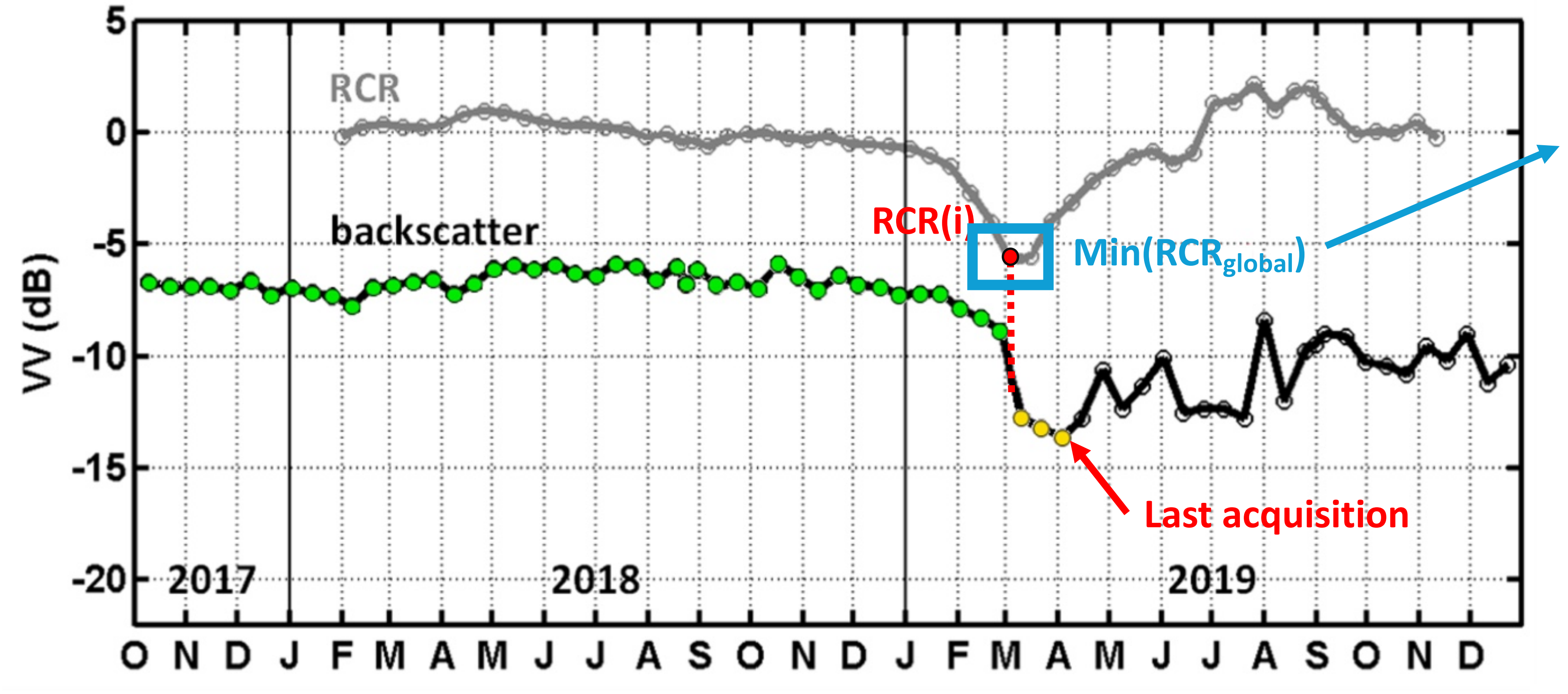
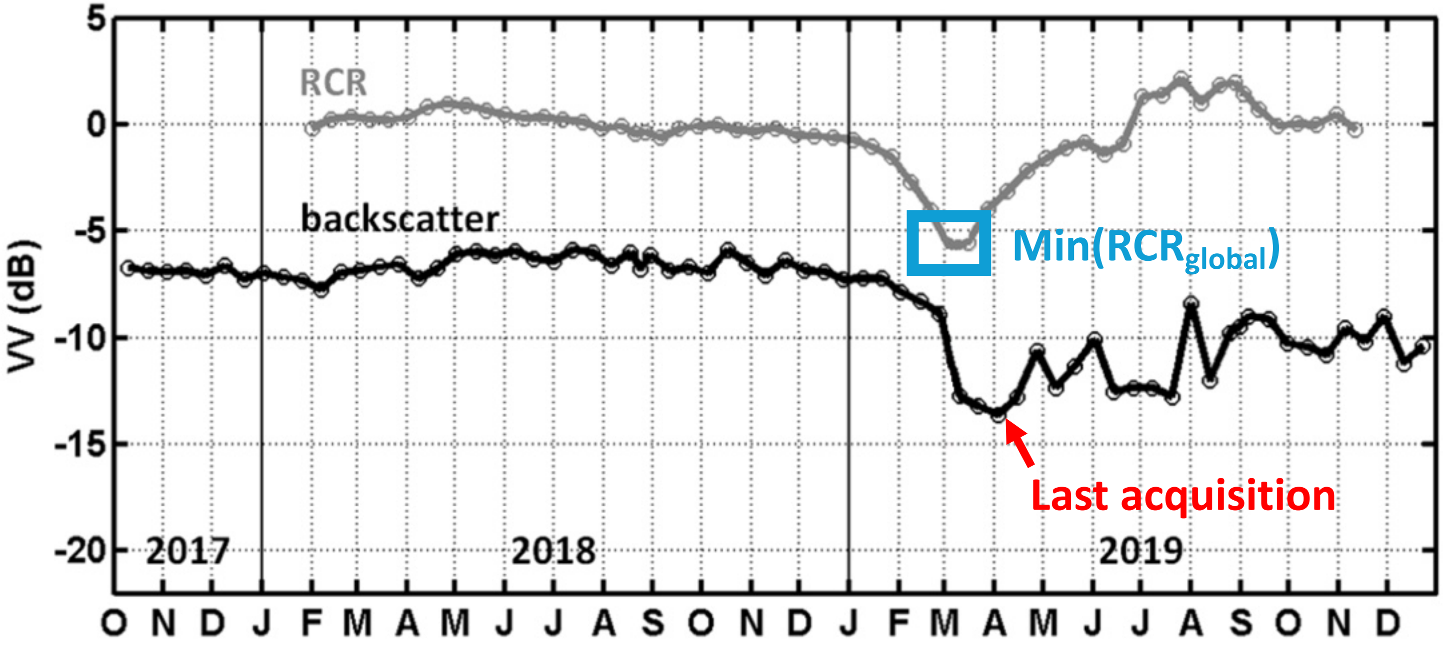


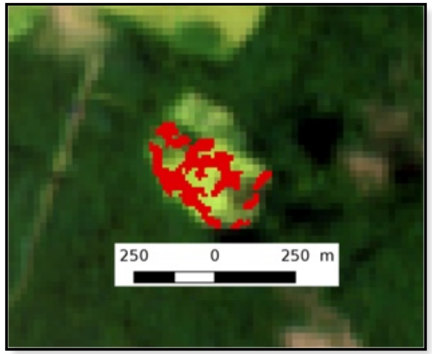
Temporal backscatter and associated RCR

20-30 images (1 year)

3 images (0.6 to 1.2 month)

The TropiSCO method

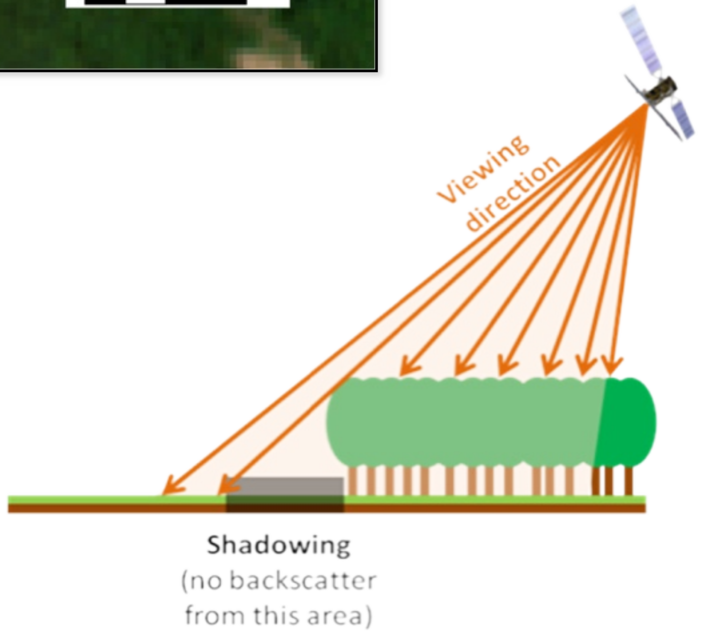




Low threshold= -4,5 dB

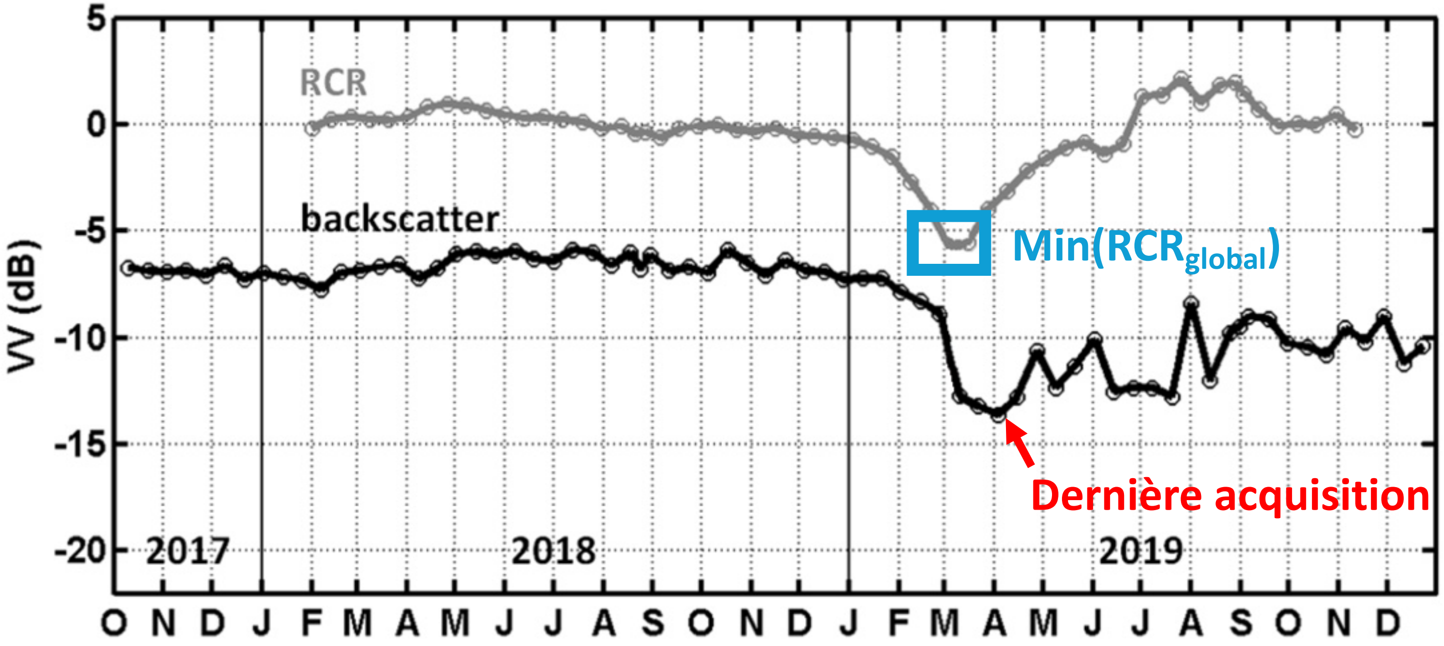
Shadow

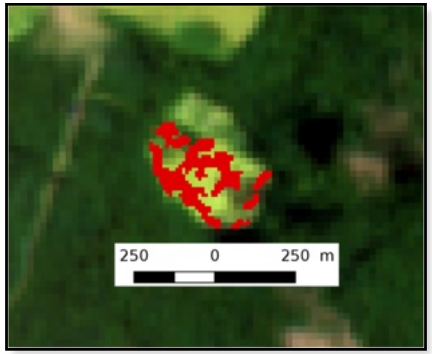
Reliable indicator



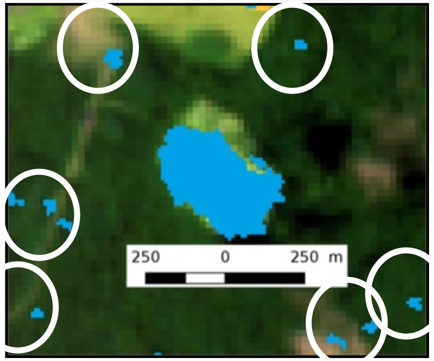
Min(RCR_{global}) < α et Minimum Mapping Unit = 4 pixels

The TropiSCO method





Low threshold= -4,5 dB
Shadow
Reliable indicator

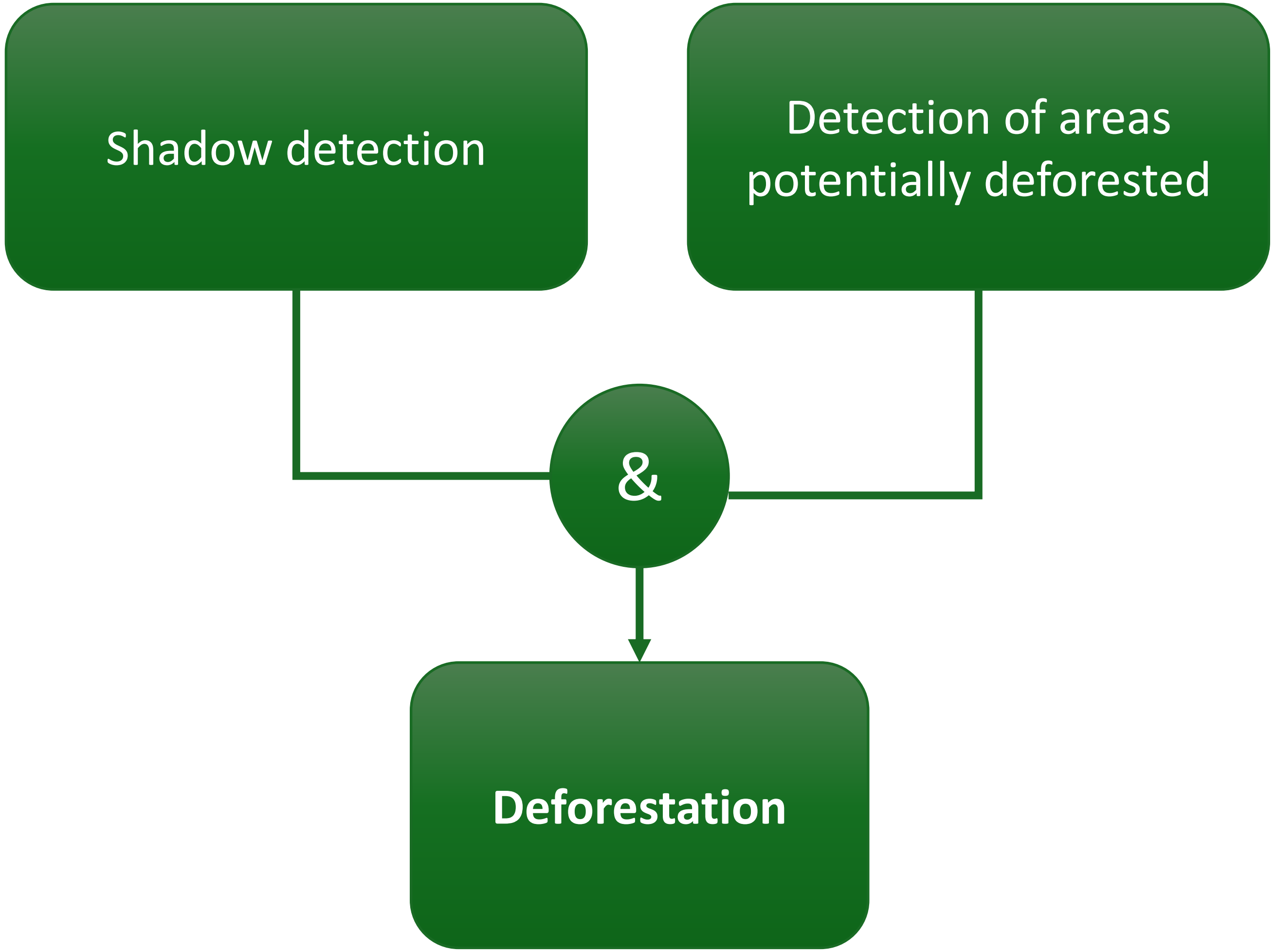


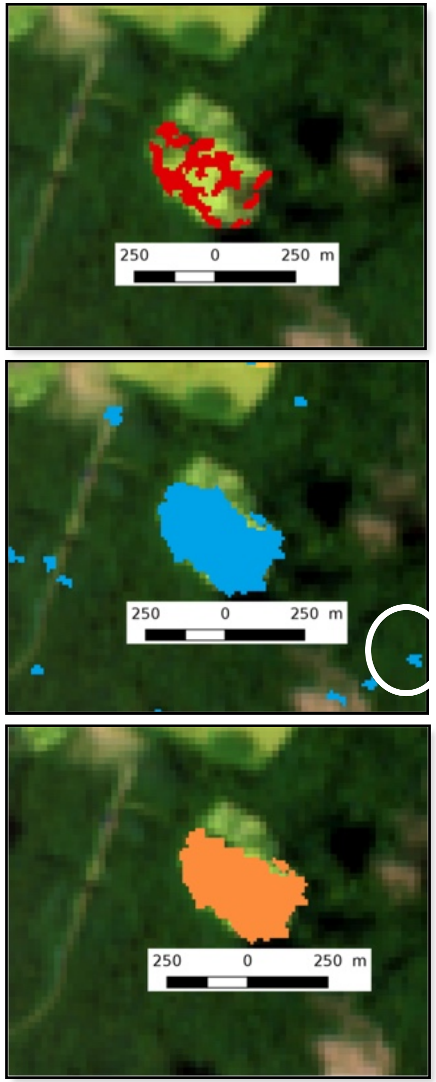
Higher threshold= -3 dB
False alarms

Min(RCR_{global}) < α et Minimum Mapping Unit = 4 pixels

Min(RCR_{global}) < β (α < β) et Minimum Mapping Unit = 20 pixels

The TropiSCO method





Low threshold= -4,5 dB
Shadow
Reliable indicator

Higher threshold= -3 dB
False alarms

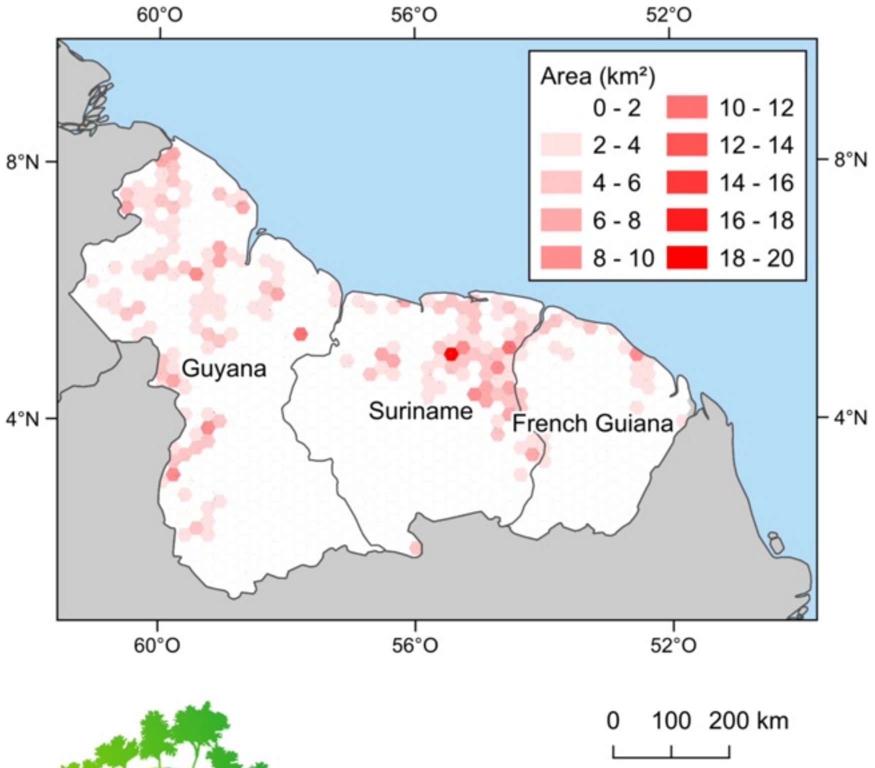
Intersection

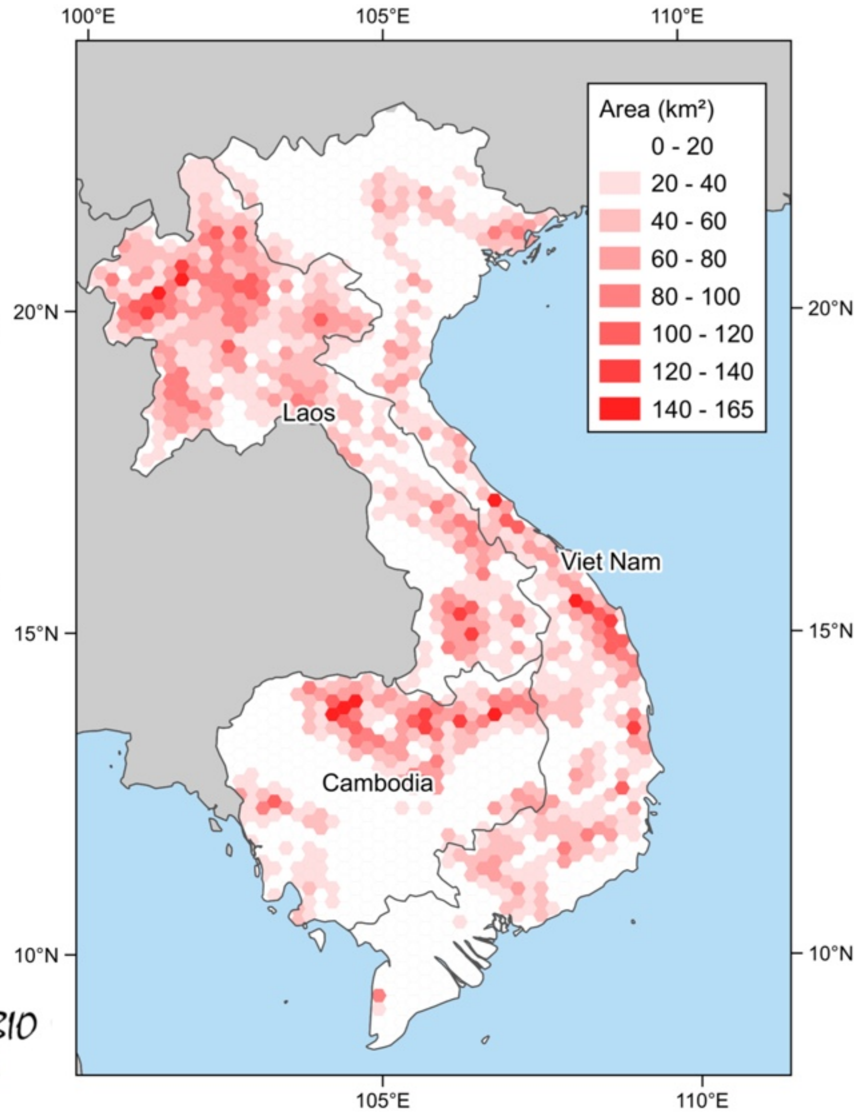
Deforested area

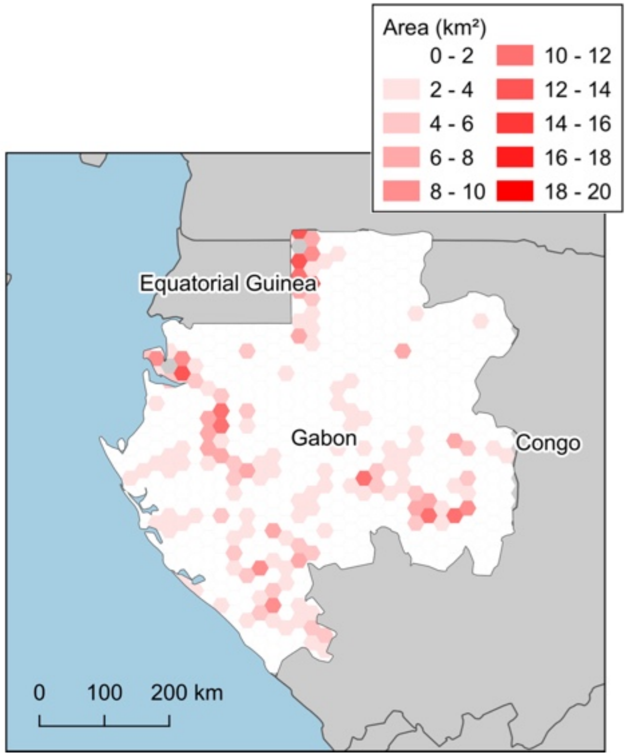
The TropiSCO maps

Forest loss (2018-2021)

One hexagon = 460 km^2







TropiSCO cnes GlobEO Global Earth Observation CESBIO

Errors of commission and omission of 10% and 0.9% (Mermoz et al., 2021)

Methods and results are validated and published

2018

remote sensing
MDPI

Article

Use of the SAR Shadowing Effect for Deforestation Detection with Sentinel-1 Time Series

Alexandre Bouvet [1,*], Stéphane Mermoz [1], Marie Ballère [1], Thierry Koleck [1,2] and Thuy Le Toan [1]

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stephane.mermoz@gmail.com (S.M.); marie.ballere@cesbio.cnes.fr (M.B.); thierry.koleck@cnes.fr (T.K.);

2021

remote sensing
MDPI

Article

Continuous Detection of Forest Loss in Vietnam, Laos, and Cambodia Using Sentinel-1 Data

Stéphane Mermoz [1,*], Alexandre Bouvet [1,2], Thierry Koleck [3], Marie Ballère [3,4,5,6] and Thuy Le Toan [2]

[1] GlobEO, 31400 Toulouse, France; alexandre.bouvet@cesbio.cnes.fr

2021

Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse
ELSEVIER

SAR data for tropical forest disturbance alerts in French Guiana: Benefit over optical imagery

Marie Ballère [a,b,c,*], Alexandre Bouvet [d], Stéphane Mermoz [d,e], Thuy Le Toan [d], Thierry Koleck
Caroline Bedeau [f], Mathilde André [f], Elodie Forestier [f], Pierre-Louis Frison [c], Cédric Lardeux [g]

[a] Centre National d'Etudes Spatiales, 31400 Toulouse, France
[b] World Wildlife Fund France, 93310 Le Pré-Saint-Gervais, France
[c] LaSTIG, University of Gustave Eiffel, IGN, 77420 Champs-sur-Marne, France
[d] CESBIO, Université de Toulouse, CNES/CNRS/INRAE/IRD/UPS, 31400 Toulouse, France
[e] GlobEO, 31400 Toulouse, France
[f] Office National des Forêts Guyane, 97300 Cayenne, France
[g] ONF International, Paris, France

2023

International Journal of Remote Sensing
ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tres20

Inter-comparison of optical and SAR-based forest disturbance warning systems in the Amazon shows the potential of combined SAR-optical monitoring

Juan Doblas Prieto, Lucas Lima, Stephane Mermoz, Alexandre Bouvet, Johannes Reiche, Manabu Watanabe, Sidnei Sant Anna & Yosio Shimabukuro

2024

IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 17, 2024 13743

Submonthly Assessment of Temperate Forest Clear-Cuts in Mainland France

Stéphane Mermoz, Juan Doblas Prieto, Milena Planells, David Morin, Thierry Koleck, Florian Mouret, Alexandre Bouvet, Thuy Le Toan, David Sheeren, Yousra Hamrouni, Thierry Bélouard, Éric Paillassa, Marion Carme, Michel Chartier, Simon Martel, and Jean-Baptiste Féret

2025

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ELSEVIER

Novel unsupervised Bayesian method for Near Real-Time forest loss detection using Sentinel-1 SAR time series: Assessment over sampled deforestation events in Amazonia and the Cerrado

Marta Bottani [a,b,c,d,*], Laurent Ferro-Famil [b,d], Juan Doblas Prieto [e], Stéphane Mermoz [e], Alexandre Bouvet [d], Thierry Koleck [c,d], Thuy Le Toan [e]

[a] TéSA, 7 boulevard de la Gare, Toulouse, 31500, France
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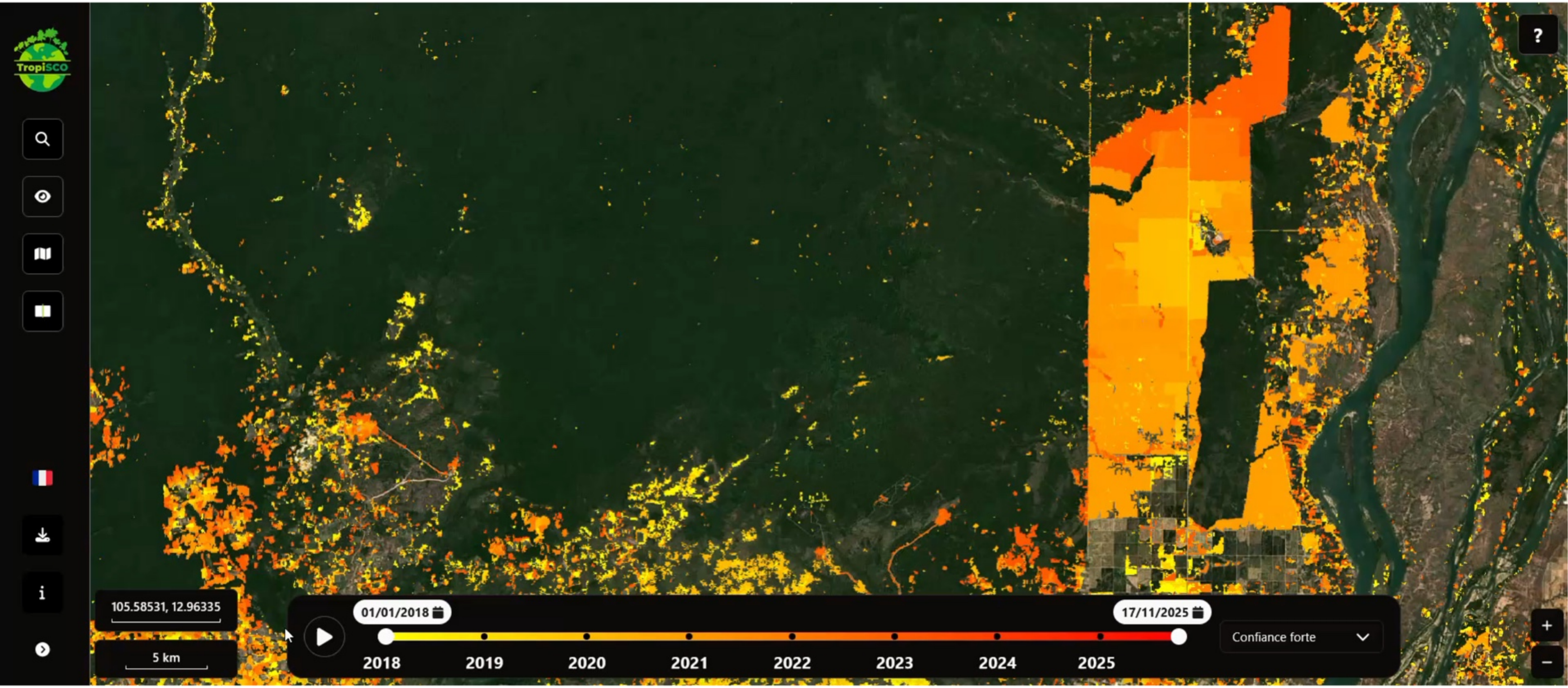
[c] Centre National d'Etudes Spatiales (CNES), 18 Avenue Edouard Belin, Toulouse, 31400, France
[d] CESBIO, University of Toulouse, CNES/CNRS/INRAE/IRD/UT3, 18 Avenue Edouard Belin, Toulouse, 31400, France
[e] GlobEO, 18 Avenue Edouard Belin, Toulouse, 31400, France

https://www.tropisco.org/



Examples of cooperation

Methods can be adapted in each country to fit the country's needs.
(Different forest definitions, etc)

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

UN environment programme

GRID Geneva

Examples of cooperation

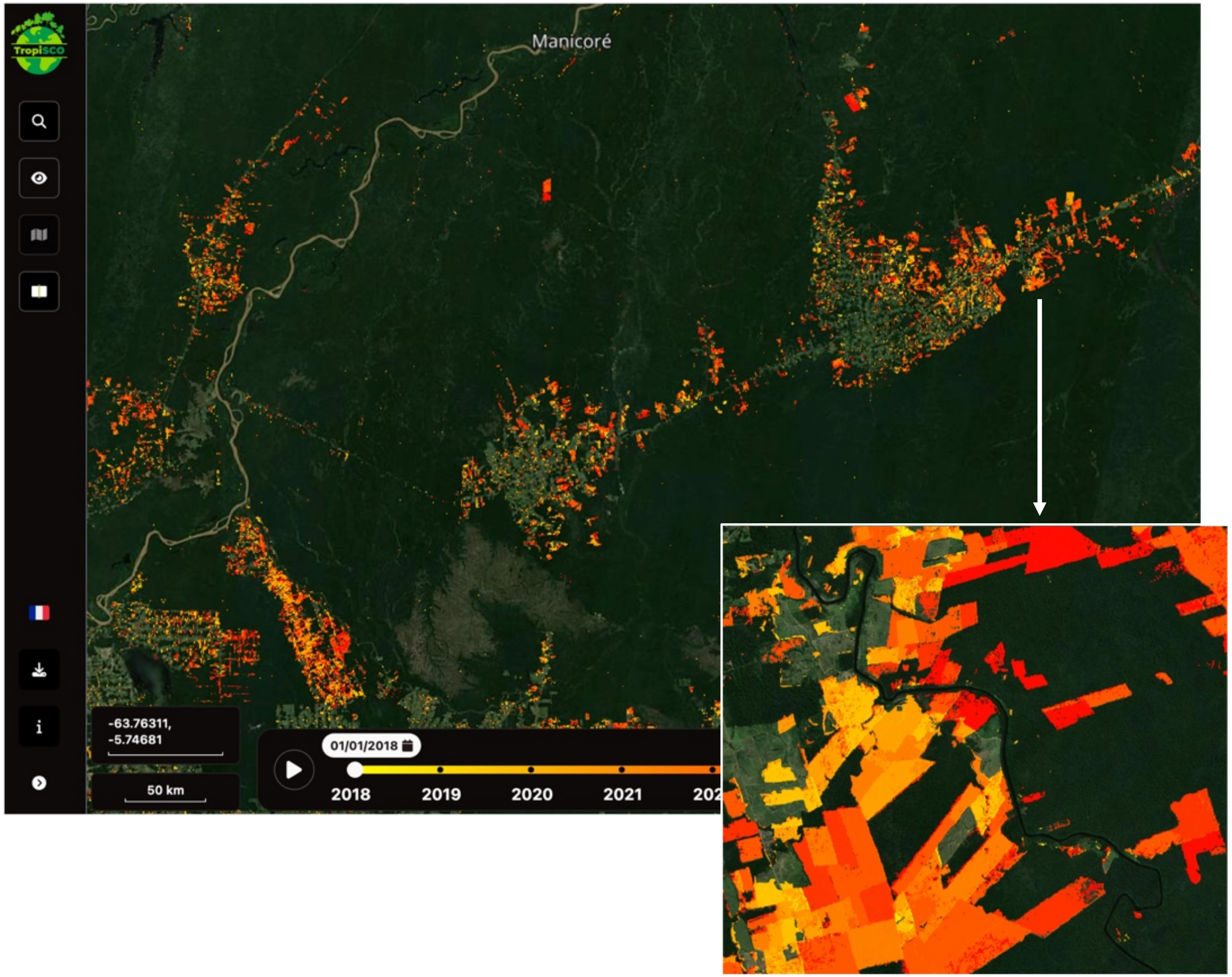
INPE — TropiSCO

Deter-R (2022) → **Deter-RT (2025)**

TropiSCO (2022) → **Deter-RT (2025)**

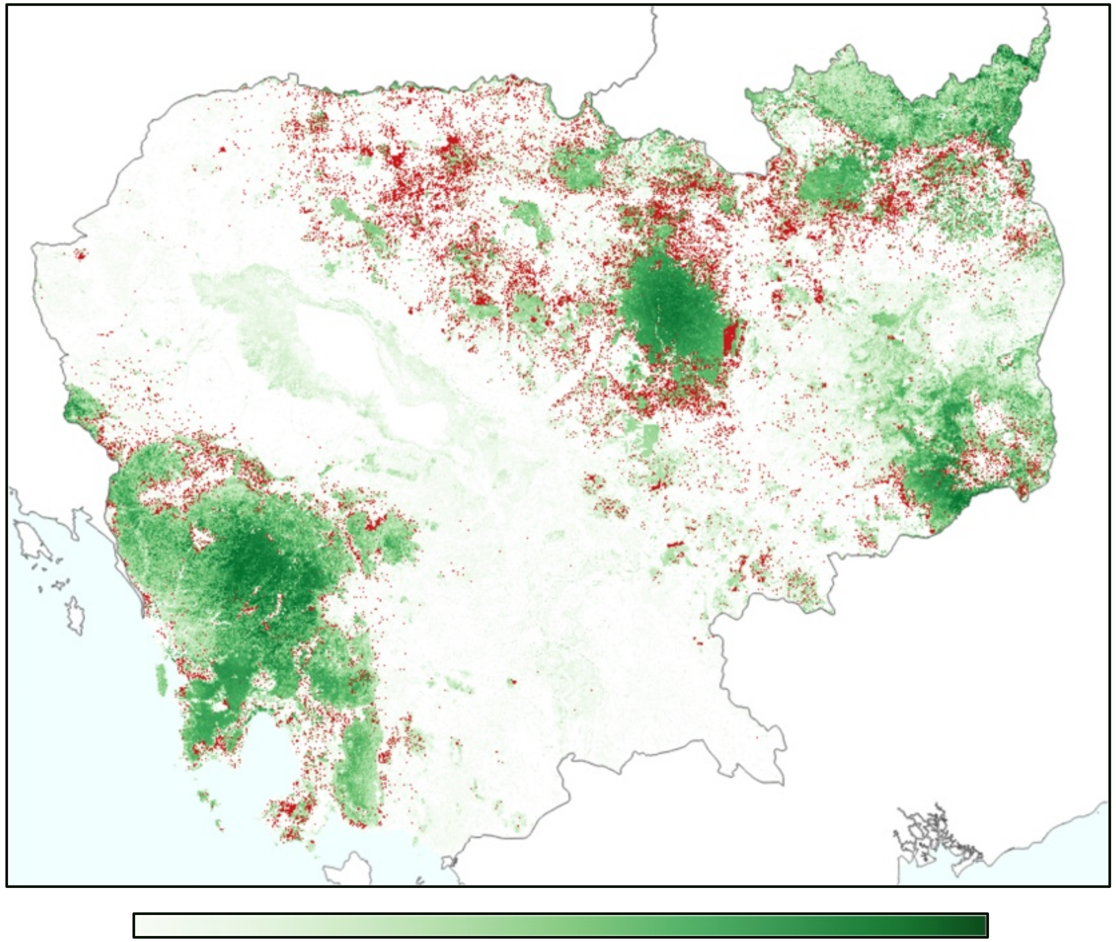
INPE · cnes · GlobEO (Global Earth Observation) · CESBIO

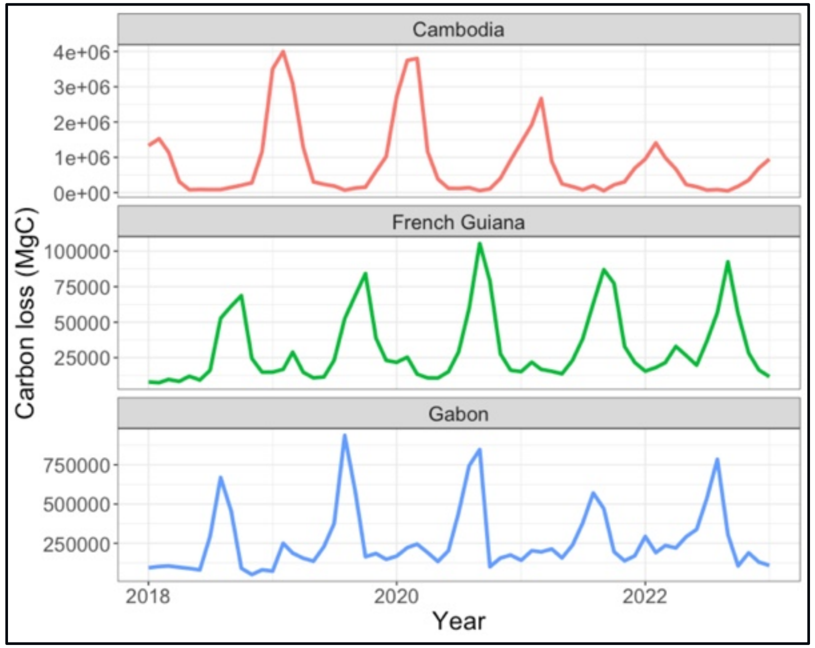
www.tropisco.org



Carbon emissions estimation

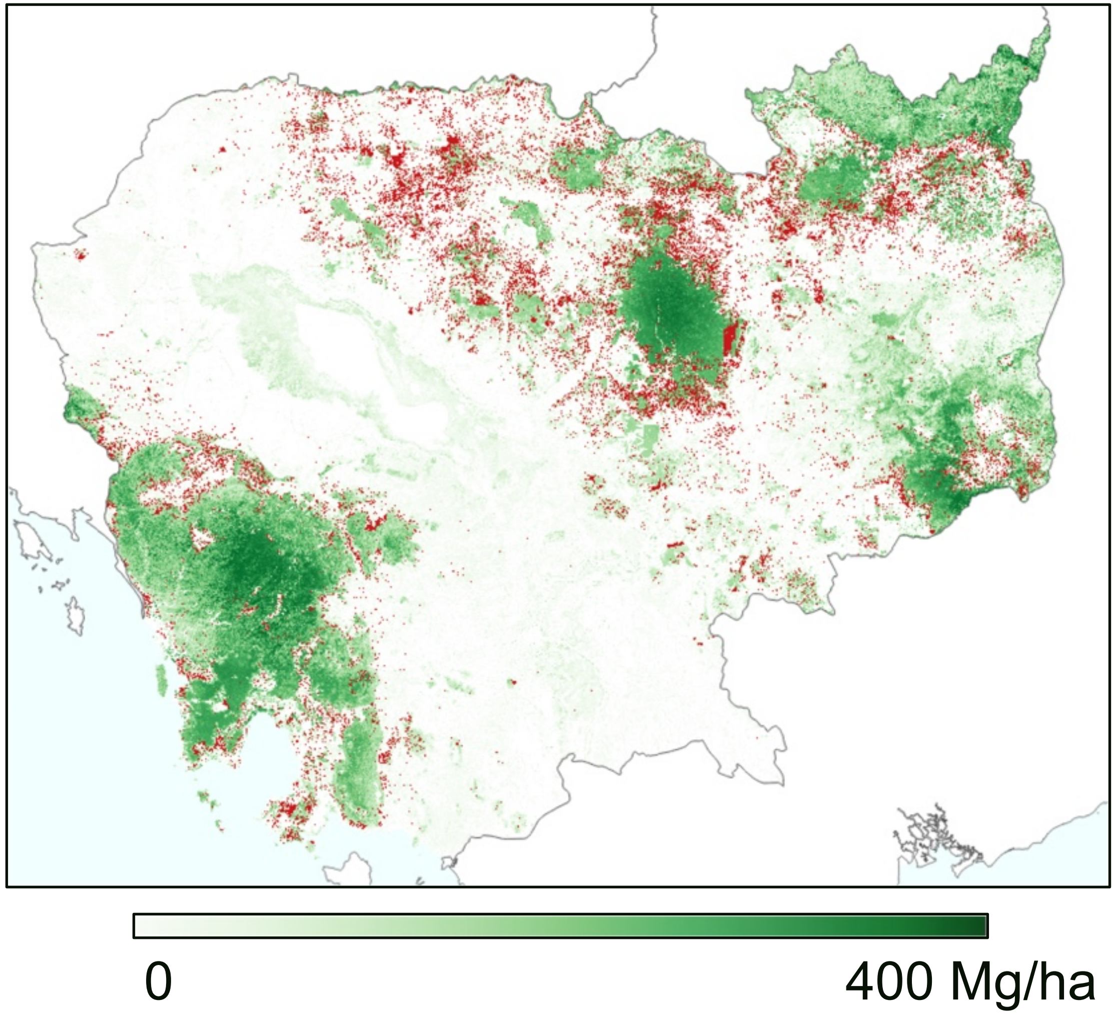
Biomass and forest loss in Cambodia

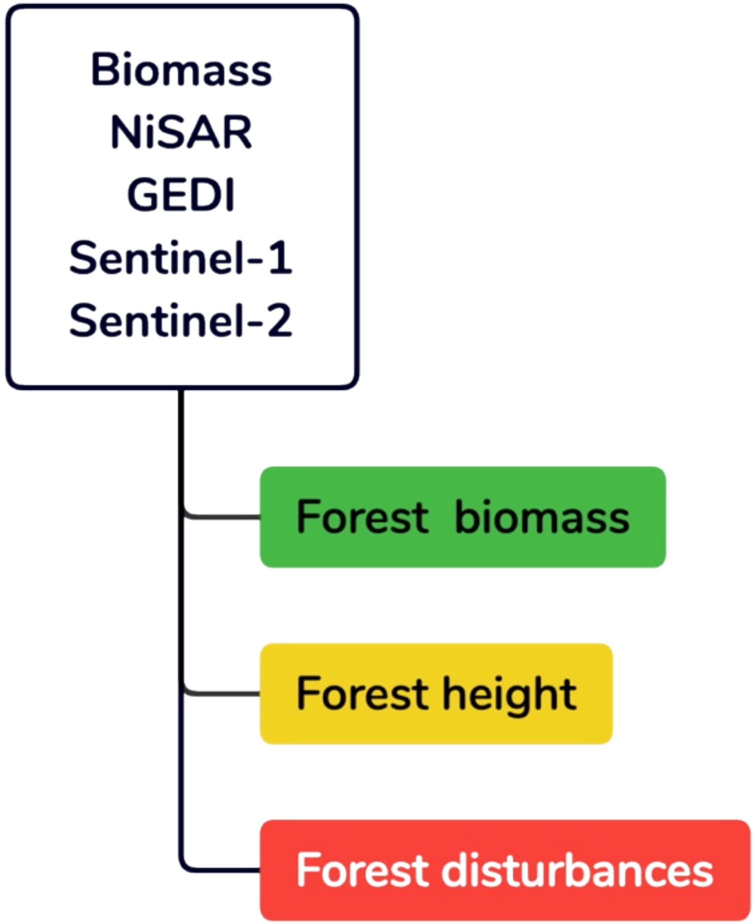




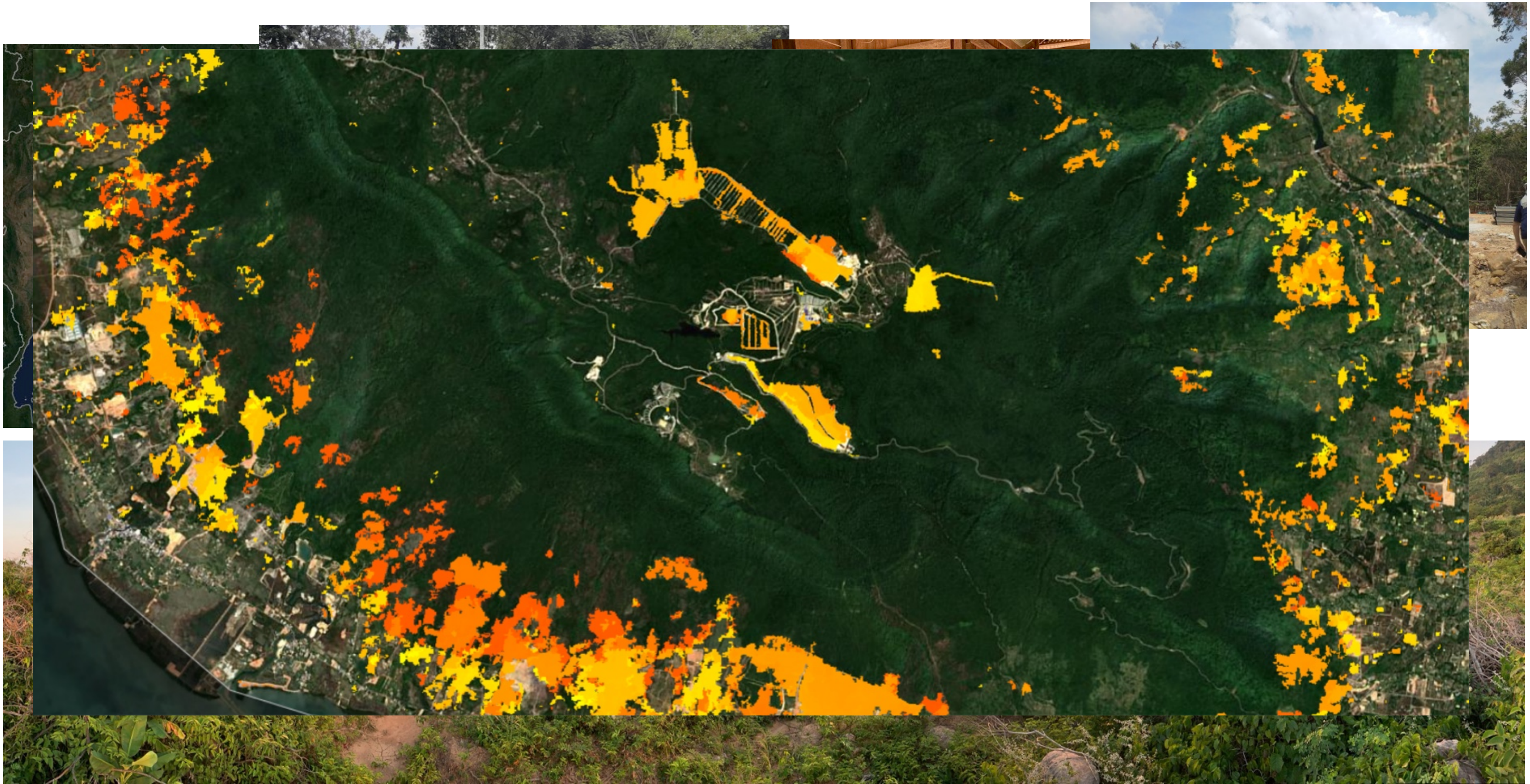
Carbon emissions estimation

Biomass and forest loss in Cambodia





Field trip in Cambodia in February 2023



Conclusion & Perspectives

■ **Contribution of SAR** to near-real time forest loss monitoring can be enhanced by adopting methods based on the detection of shadows and reconstruction of deforested plots, rather than on the backscatter decrease only.

■ The method can be improved by exploring **synergy with optical imagery** (Sentinel-2, Landsat-7/8) and other SAR sensors (NISAR, BIOMASS)

■ Use of TropiSCO data in Cambodia could be developed: co-construction of study cases, method improvement/adaptation, etc