

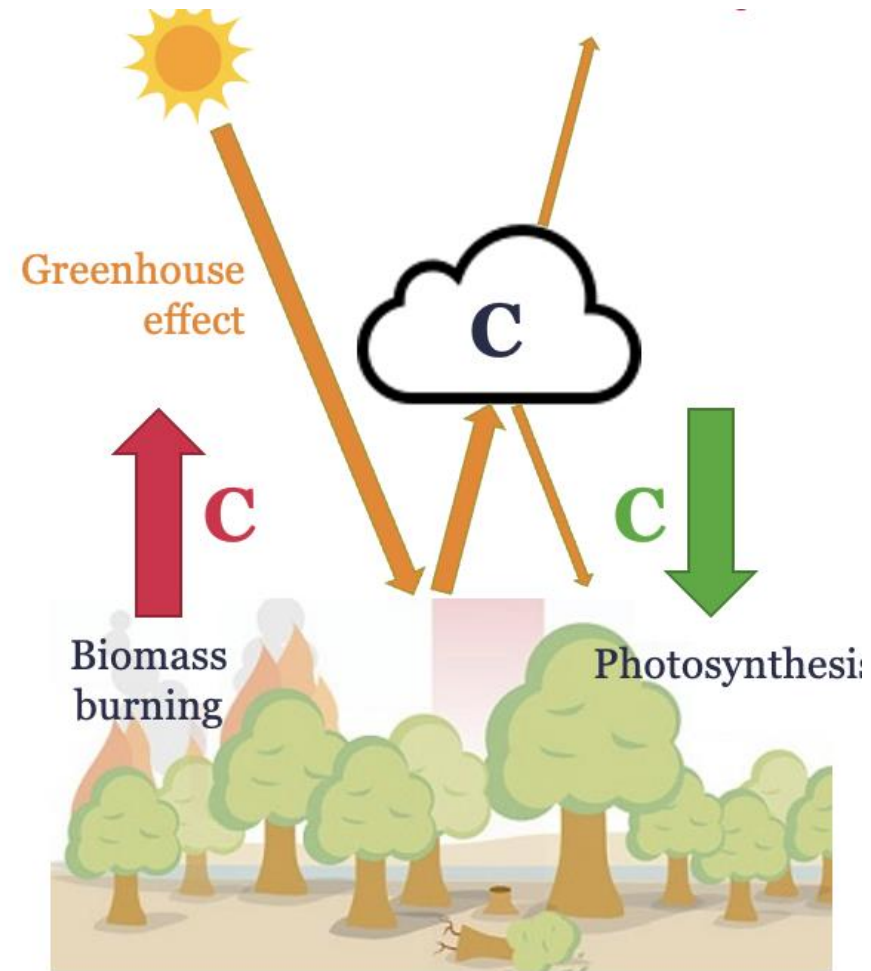
# Bilan carbone des incendies de forêt: combustion ... mais résilience?

**Florent MOUILLOT**

*IRD*

*Centre d'Ecologie Fonctionnelle et Evolutive (CEFE), Montpellier*

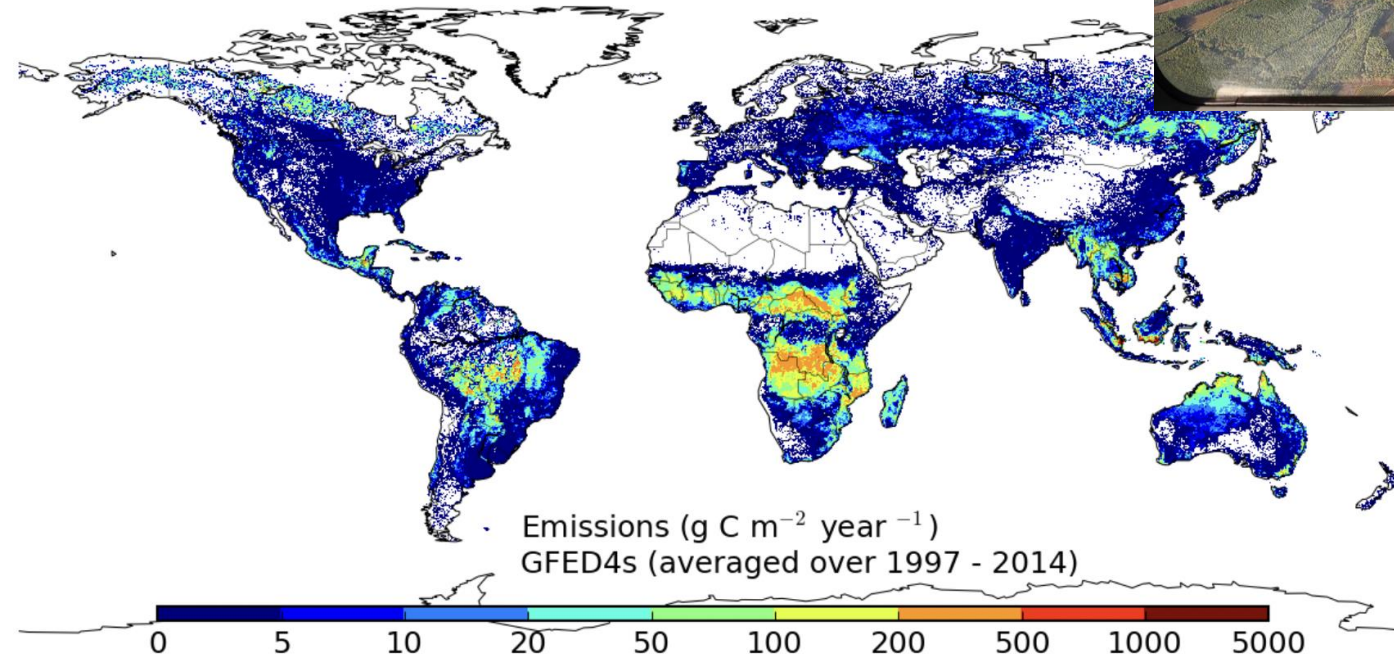
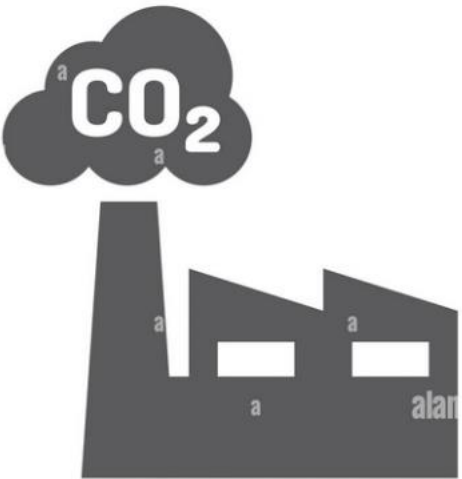
# 1. Contexte: Les incendies et le bilan de Carbone global



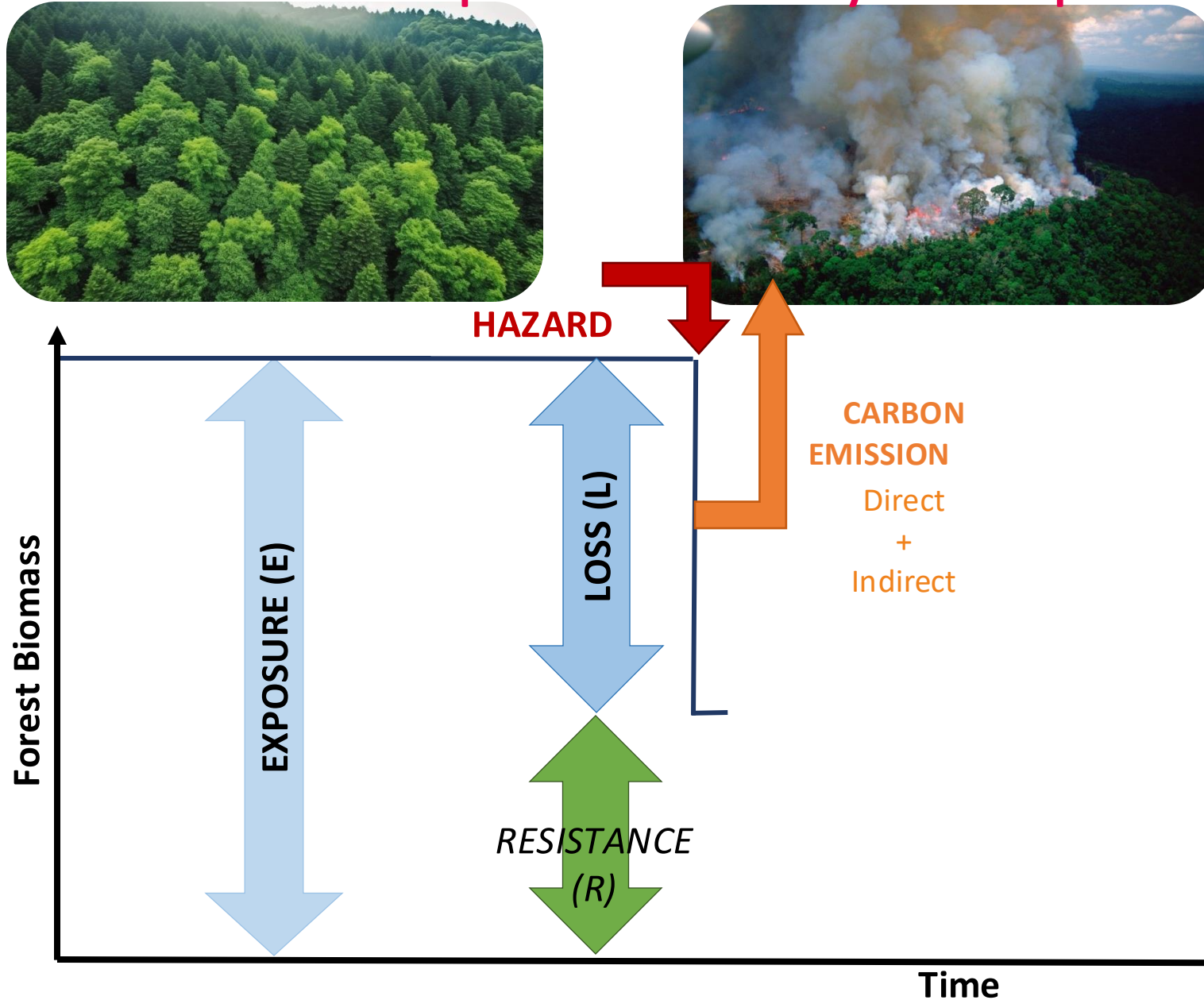
# Emissions de Carbone par les incendies: 22% des émissions anthropiques

9.5 PgC.year<sup>-1</sup>  
*Liu et al. 2022*

2.1 PgC.year<sup>-1</sup>  
van Wees et al. 2022

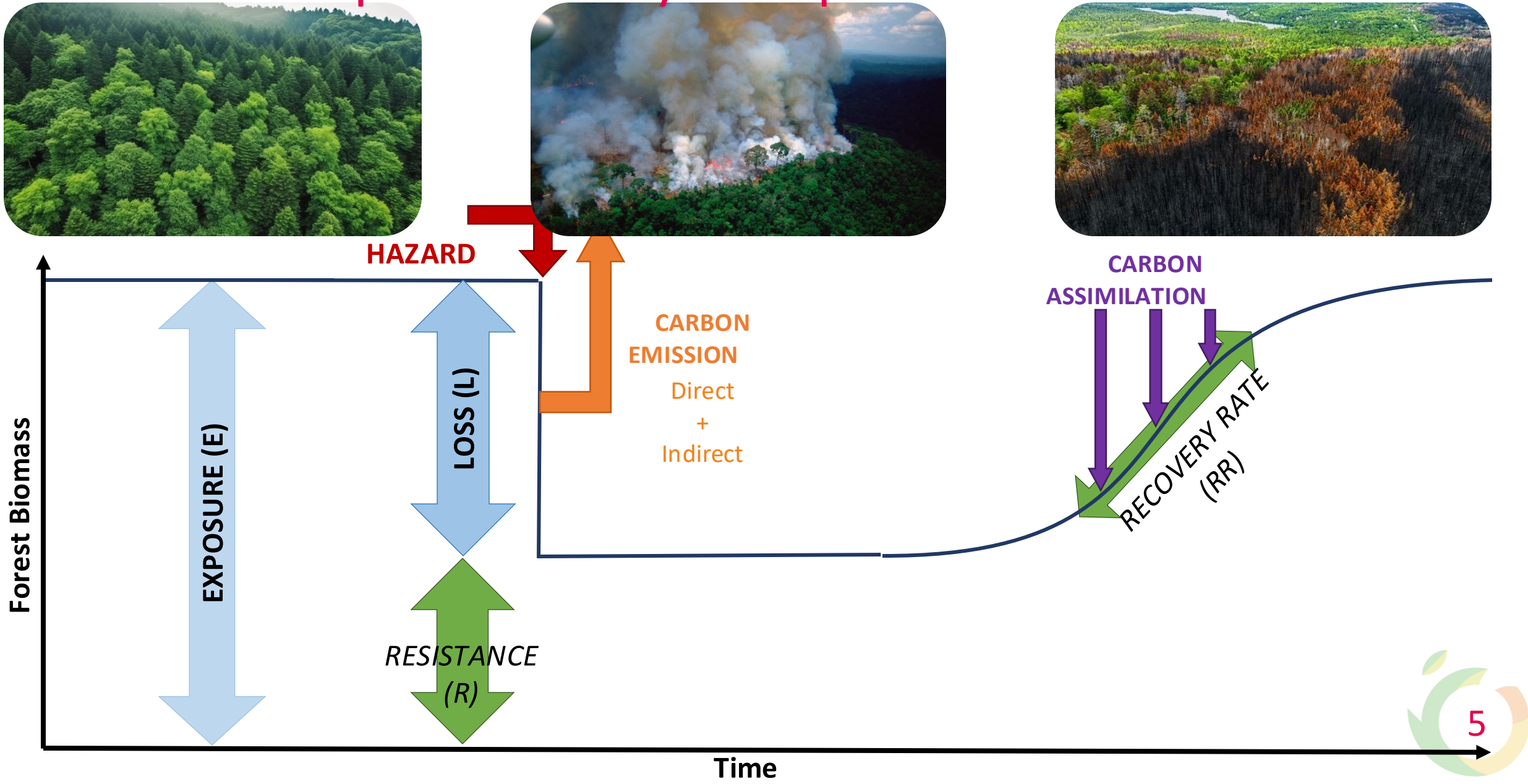


# Schema conceptuel de la dynamique du carbone

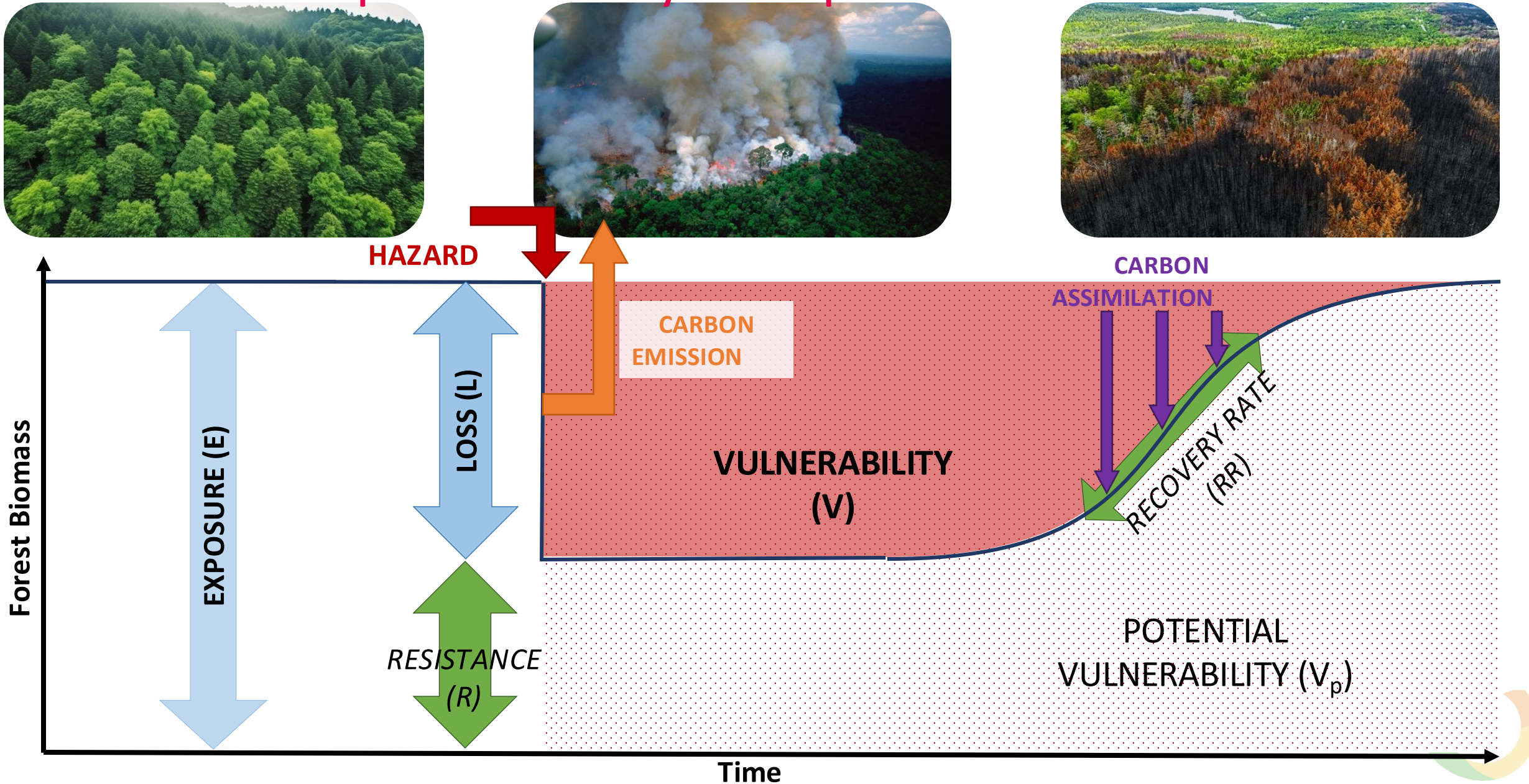




# Schema conceptuel de la dynamique du carbone

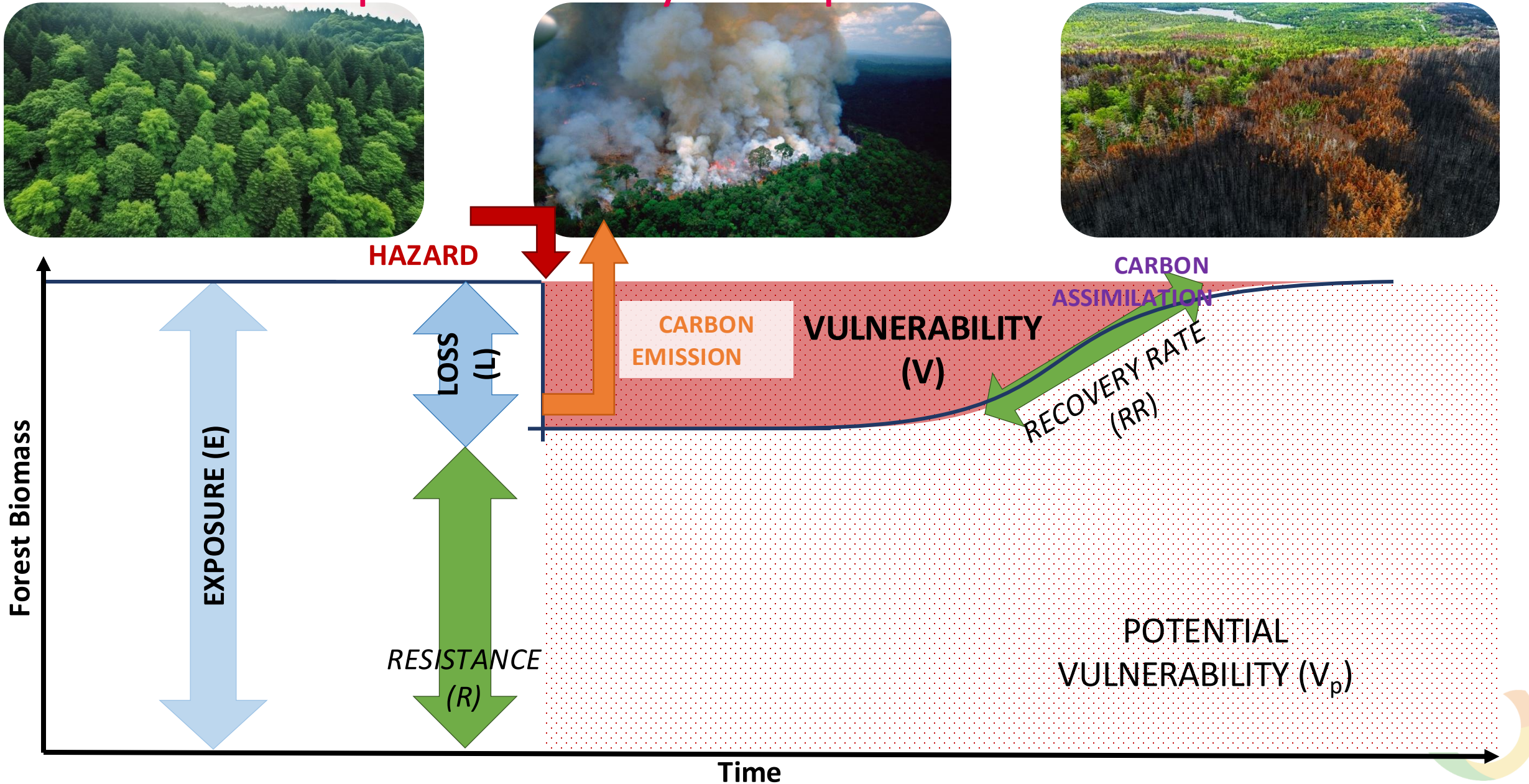


# Schema conceptuel de la dynamique du carbone

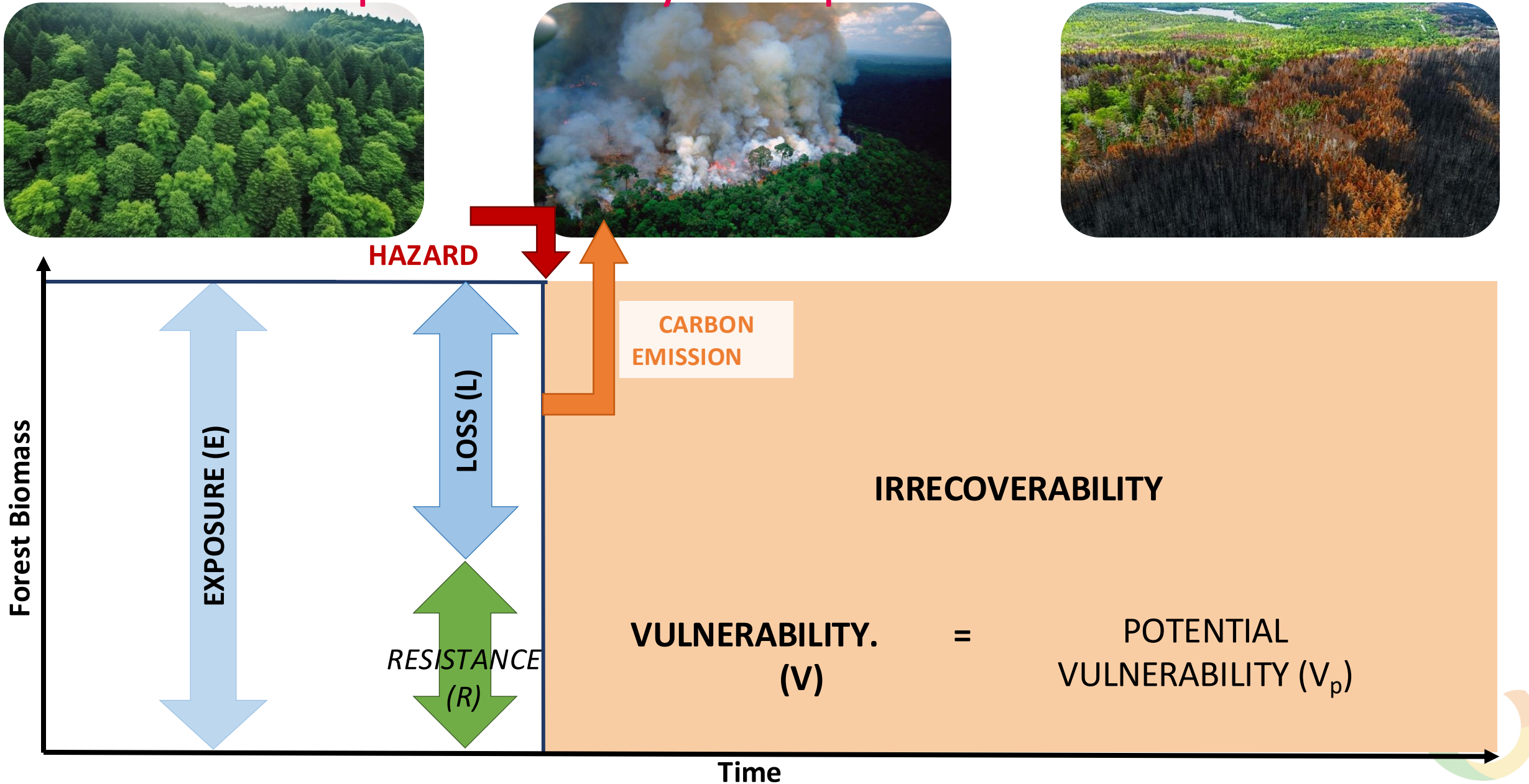




# Schema conceptuel de la dynamique du carbone



# Schema conceptuel de la dynamique du carbone





# Les émissions de carbone par les incendies sont-elles récupérables?

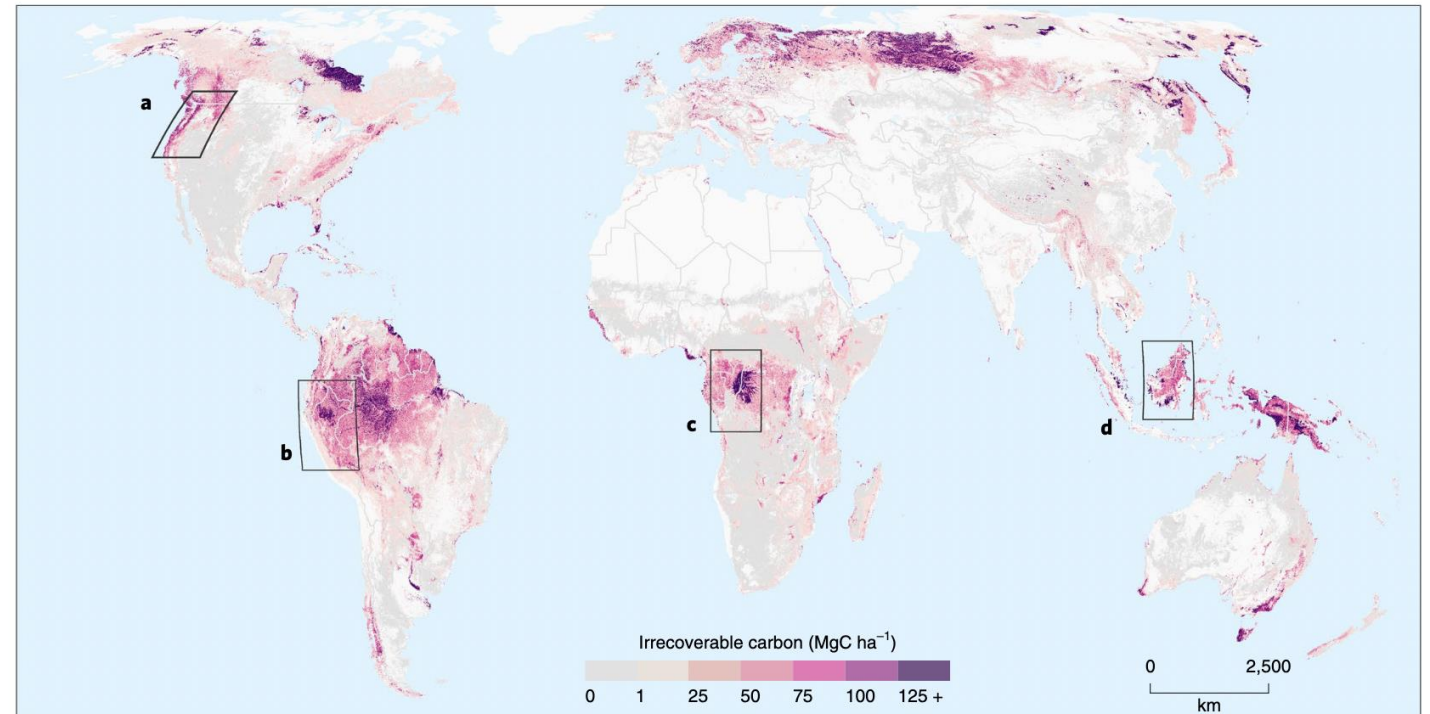
OPEN

## Mapping the irrecoverable carbon in Earth's ecosystems

Monica L. Noon<sup>1</sup>✉, Allie Goldstein<sup>1</sup>, Juan Carlos Ledezma<sup>2</sup>, Patrick R. Roehrdanz<sup>1</sup>, Susan C. Cook-Patton<sup>3</sup>, Seth A. Spawn-Lee<sup>4,5</sup>, Timothy Maxwell Wright<sup>1</sup>, Mariano Gonzalez-Roglich<sup>6</sup>, David G. Hole<sup>1</sup>, Johan Rockström<sup>7</sup> and Will R. Turner<sup>1</sup>

Notion de récupérabilité:

Sur une période de 30 ans selon le IPCC assessment que le bilan de C global doit atteindre le net-zero en 2050 pour limiter le réchauffement global <1.5 °C depuis l'ère pre-industrielle



# Les émissions de carbone par les incendies sont-elles récupérables?



ARTICLE

<https://doi.org/10.1038/s41467-021-21399-7>

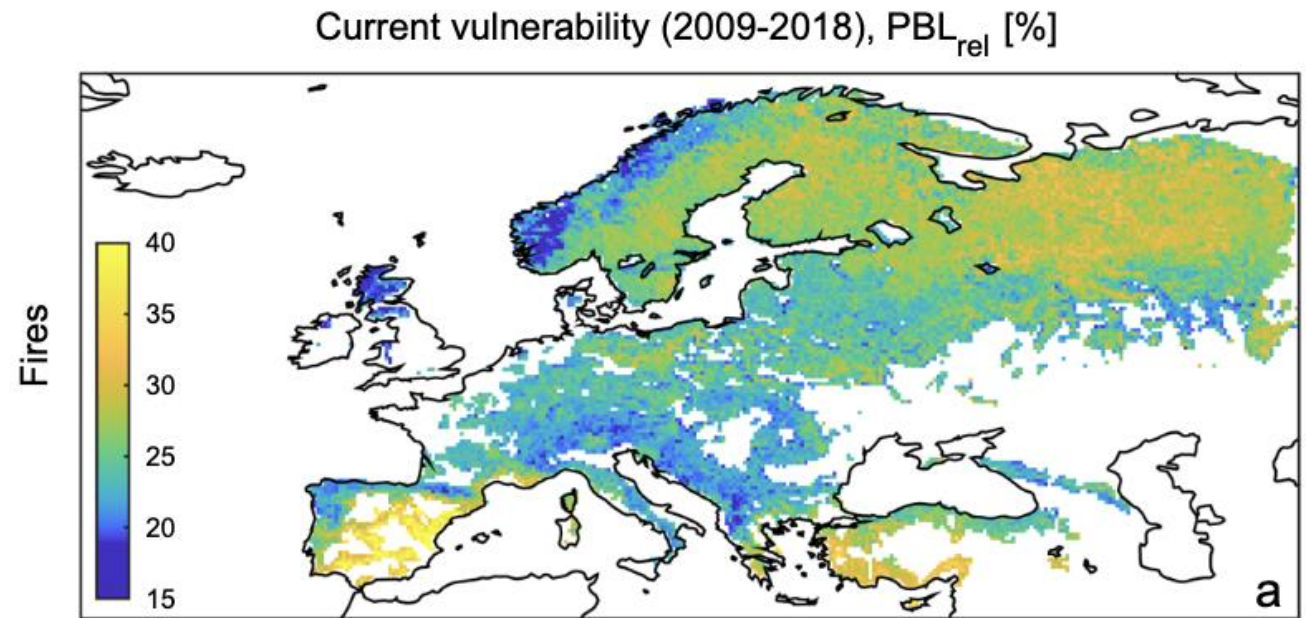
OPEN



## Emergent vulnerability to climate-driven disturbances in European forests

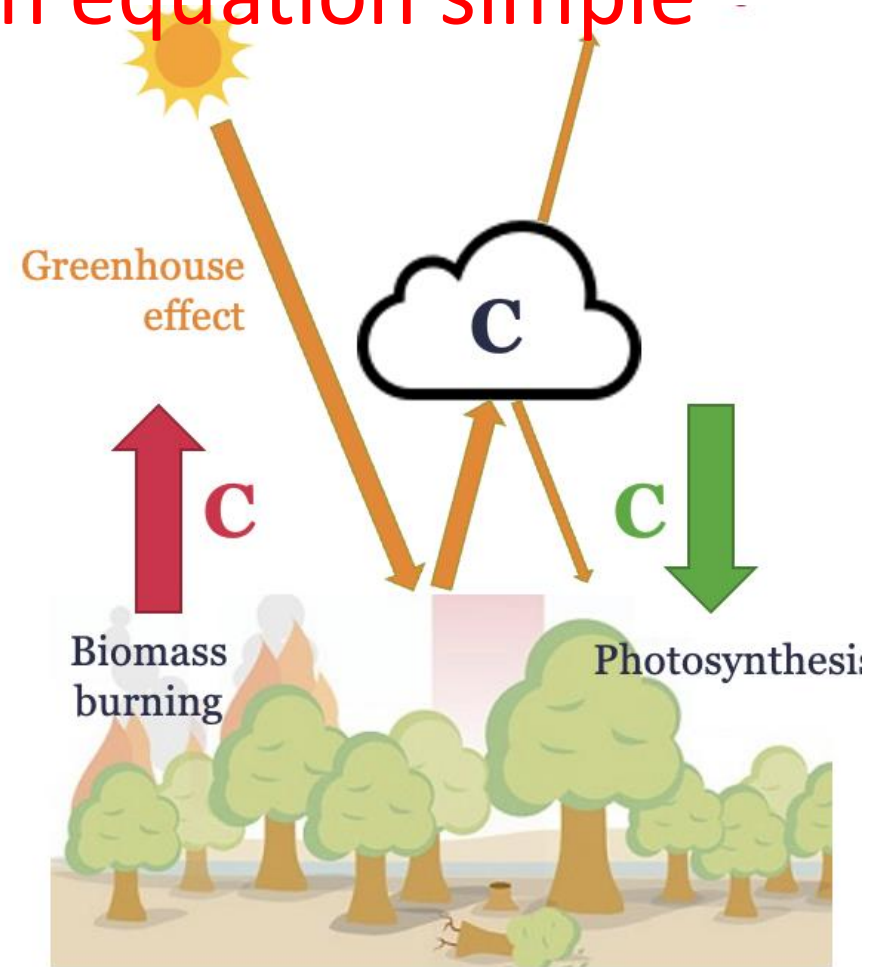
Giovanni Forzieri<sup>1✉</sup>, Marco Girardello<sup>1</sup>, Guido Ceccherini<sup>1</sup>, Jonathan Spinoni<sup>1</sup>, Luc Feyen<sup>1</sup>, Henrik Hartmann<sup>2</sup>, Pieter S. A. Beck<sup>1</sup>, Gustau Camps-Valls<sup>3</sup>, Gherardo Chirici<sup>4</sup>, Achille Mauri<sup>5</sup> & Alessandro Cescatti<sup>1</sup>

⇒ Besoin de quantifier la vulnérabilité au feu des stocks de carbone forestier.



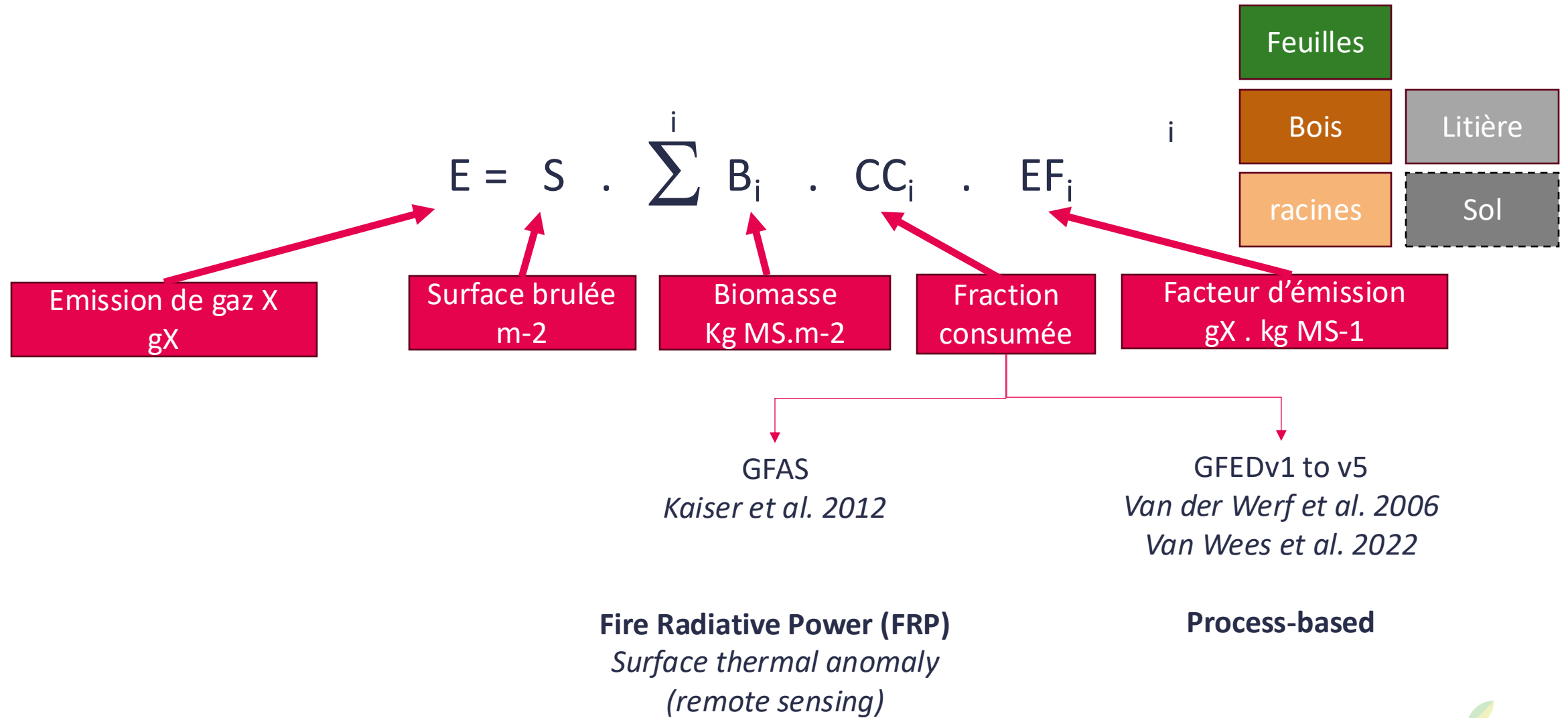
## 2. Concepts:

Les émissions de Carbone par les incendies...  
...un équation simple





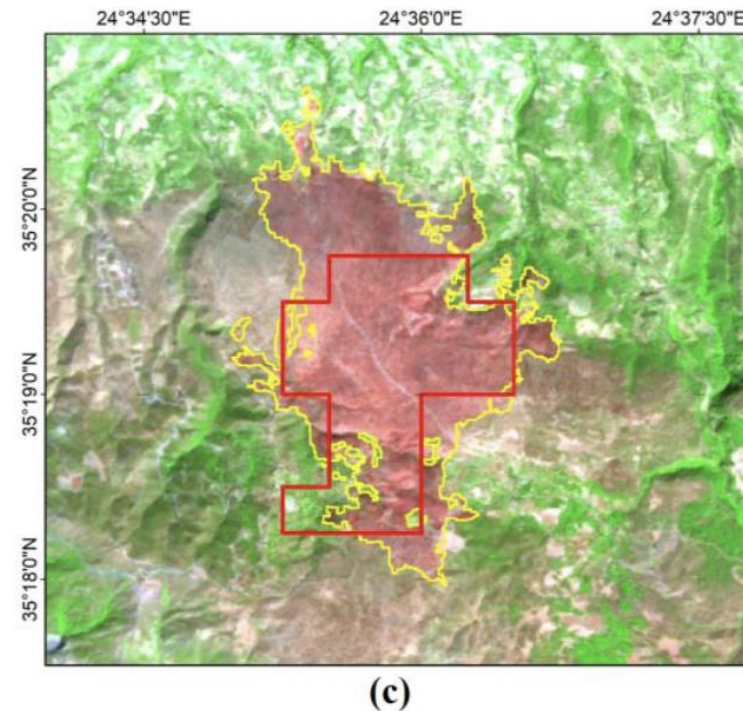
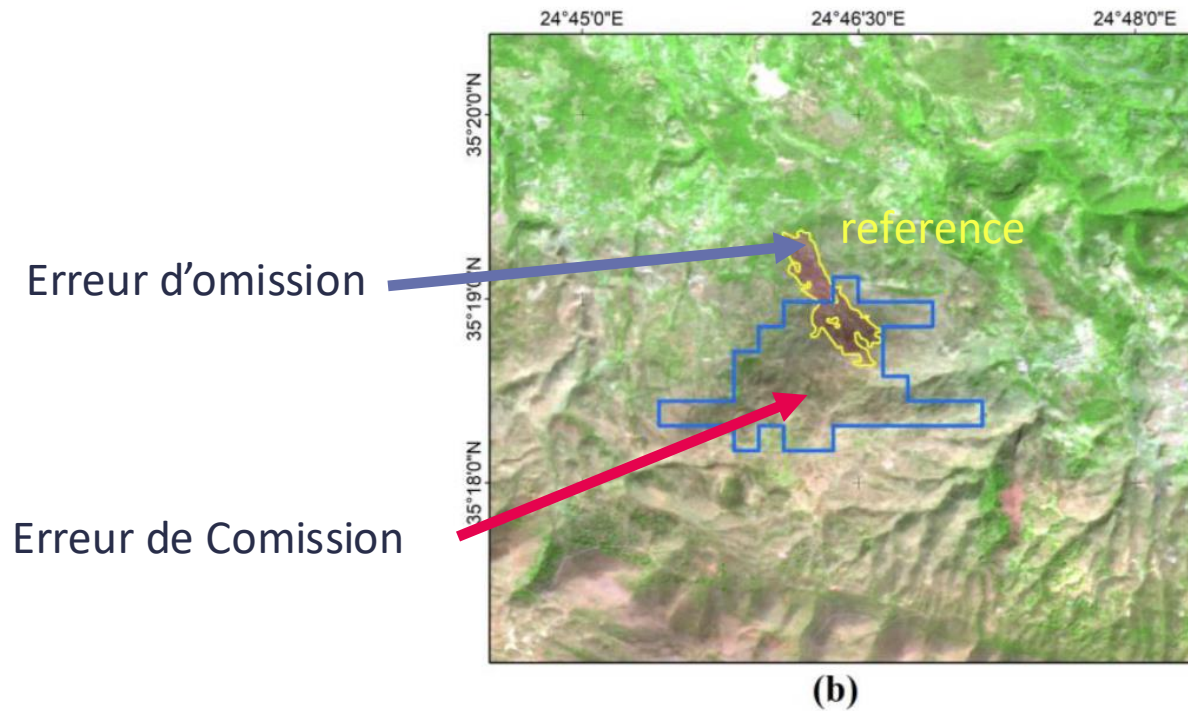
# Emissions de Carbone par combustion: une équation simple...



# ...une équation simple...aux multiples incertitudes

## 1. les surfaces brûlées (S)

Données Globales 2000-présent: **MC64A1** (Giglio et al. ) & **FireCCI51** (Chuvieco et al. 2019)



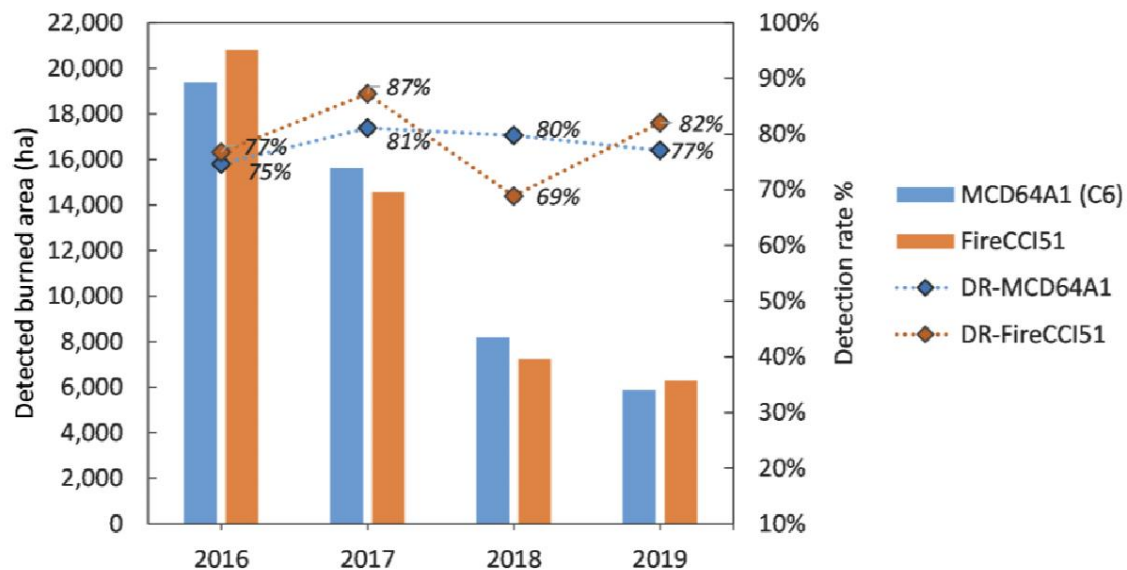
Reference GCOS:  
polygone de feu  
Haute résolution  
Confirmé expert

# ...une équation simple...aux multiples incertitudes

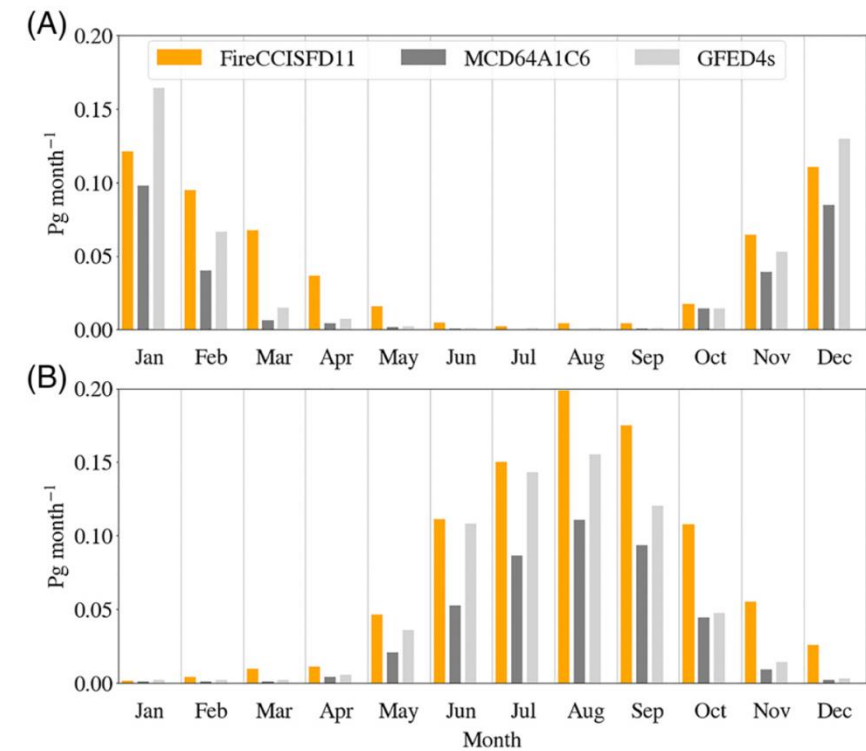
## 1. les surfaces brûlées (S)

Données Globales 2000-présent: **MC64A1** (Giglio et al. ) & **FireCCI51** (Chuvieco et al. 2019)

Evaluation MCD64A1/FireCCI51 Grèce: 69%-87%  
*Katagis & Gitas 2022, Remote Sensing*



Impact Carbone Afrique 2019: +30%/+101% avec S  
à résolution fine (*Ramo et al. 2022, PNAS*)





# ...une équation simple...aux multiples incertitudes

## 2 La biomasse (B)

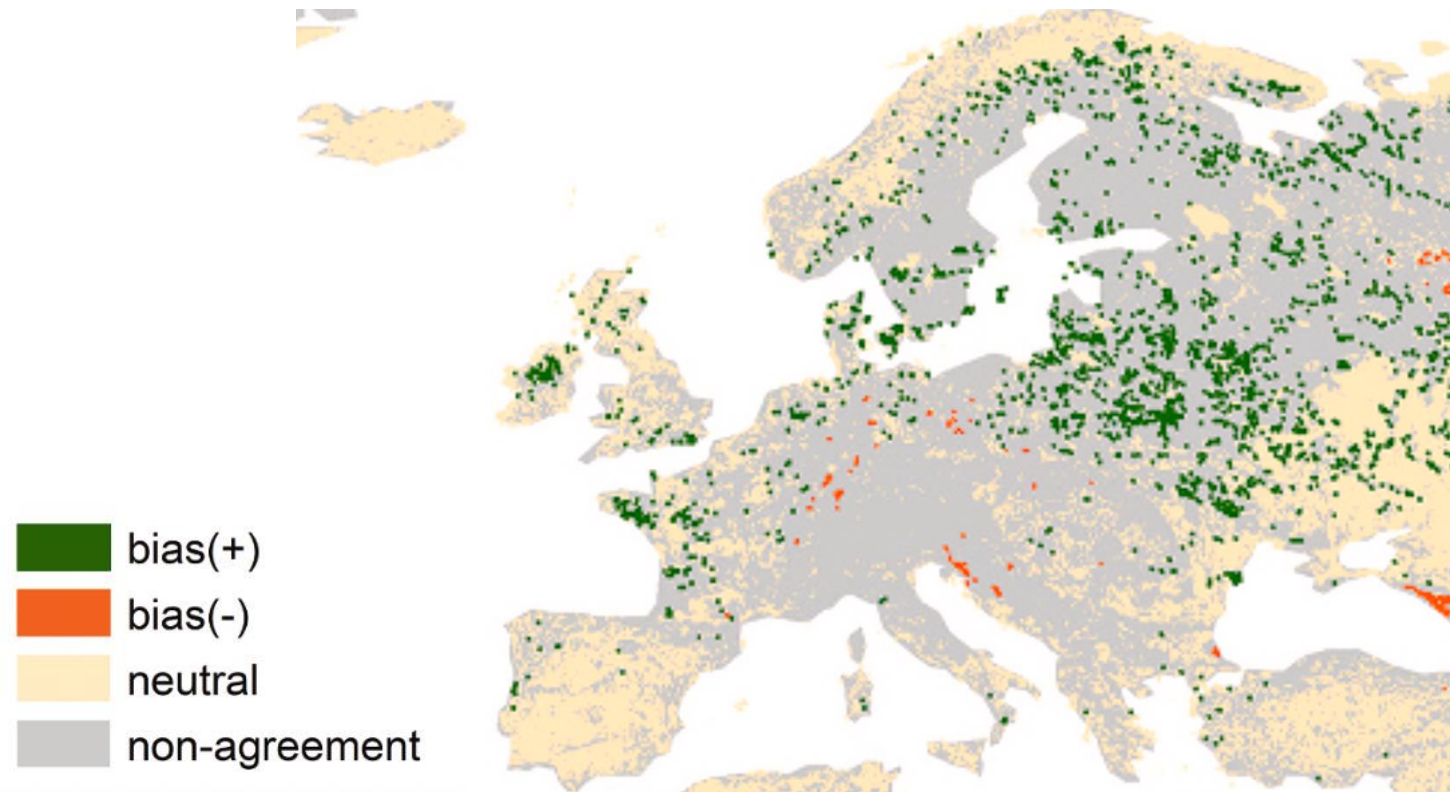
Comparaison de 4 informations globales (Araza et al. 2022, RSE):

Baccini (2000)

GEOCARBON (2008)

GlobBiomass (2010)

CCI Biomass (2017)

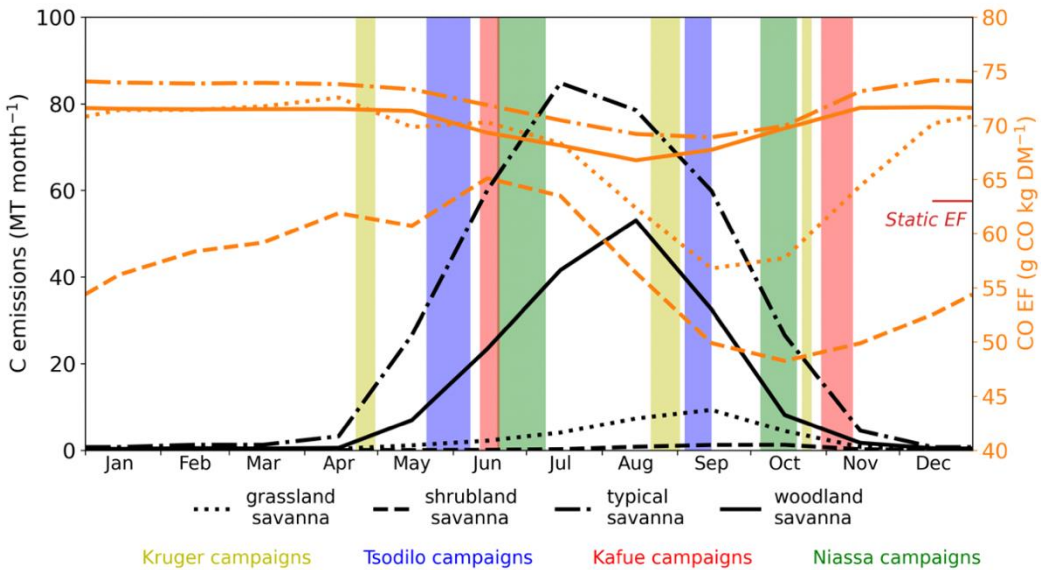
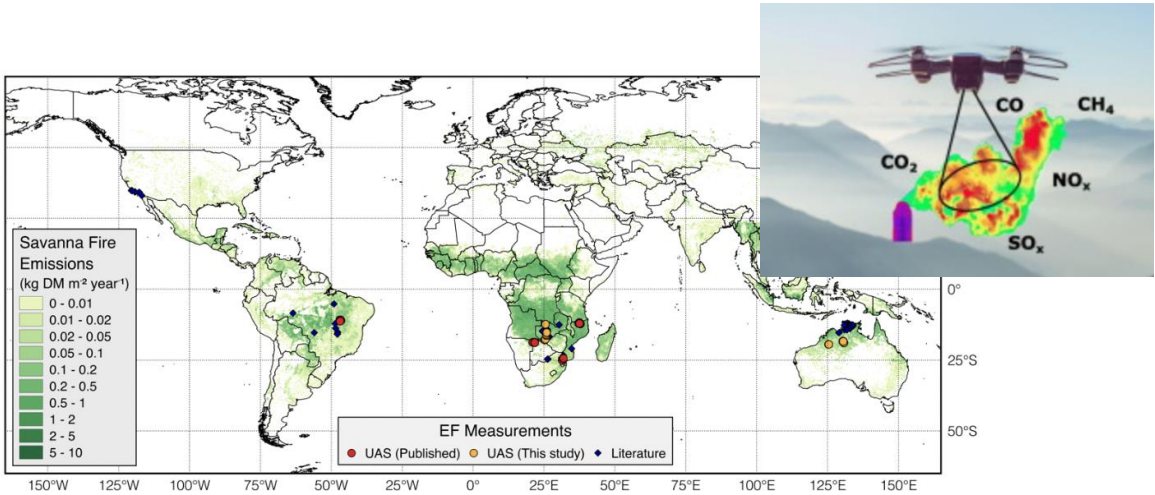


# 1. ...une équation simple...aux multiples incertitudes

## 3 Les facteurs d'émission (EF):

**Table 1.** Emission factors ( $\text{g kg}^{-1}$ ) for species emitted from different types of biomass burning<sup>a</sup>.

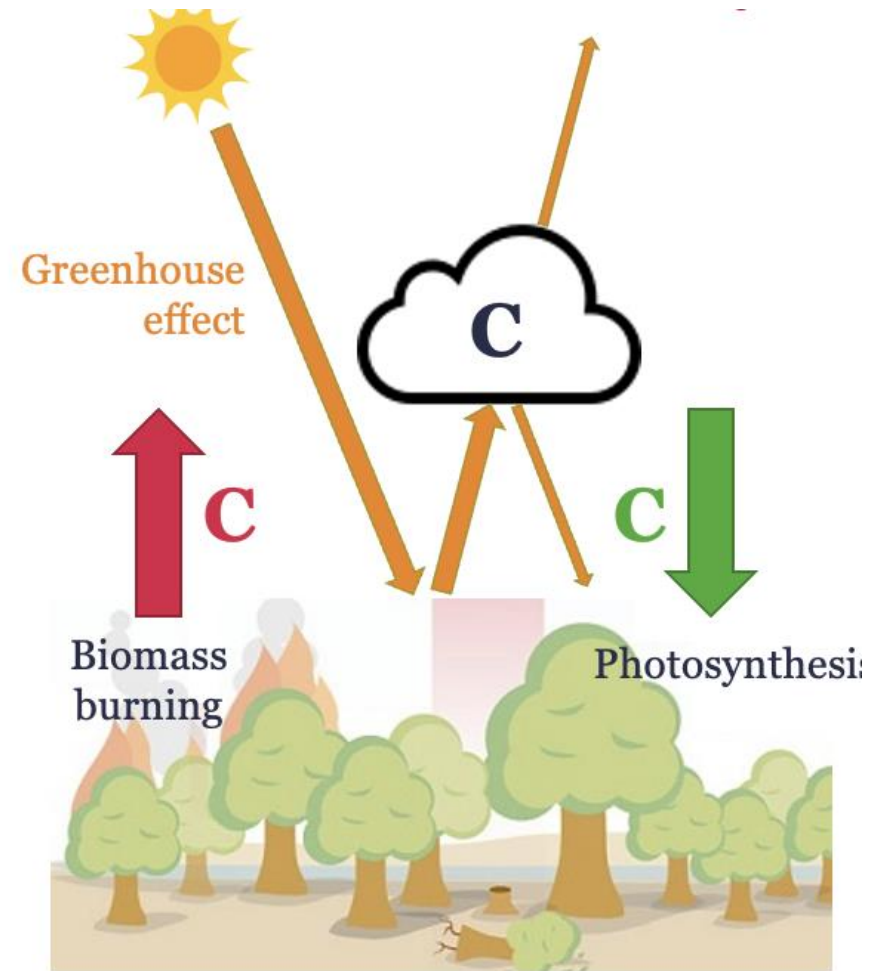
|                                   | Tropical Forest | Savanna     | Crop Residue | Pasture Maintenance | Boreal Forest | Temperate Forest | Extratropical Forest <sup>b</sup> |
|-----------------------------------|-----------------|-------------|--------------|---------------------|---------------|------------------|-----------------------------------|
| Carbon Dioxide (CO <sub>2</sub> ) | 1643 (58)       | 1686 (38)   | 1585 (100)   | 1548 (142)          | 1489 (121)    | 1637 (71)        | 1509 (98)                         |
| Carbon Monoxide (CO)              | 93 (27)         | 63 (17)     | 102 (33)     | 135 (38)            | 127 (45)      | 89 (32)          | 122 (44)                          |
| Methane (CH <sub>4</sub> )        | 5.07 (1.98)     | 1.94 (0.85) | 5.82 (3.56)  | 8.71 (4.97)         | 5.96 (3.14)   | 3.92 (2.39)      | 5.68 (3.24)                       |



STATIC  
(Akagi et al. 2011)

SEASONAL  
(Vernooij et al. 2023)

### 3. Les incendies et le bilan de Carbone en France





# Emissions de C incendie en France...les références



Rapport National d'Inventaire pour la France  
au titre de la Convention cadre des Nations Unies  
sur les Changements Climatiques

CCNUCC

Mars 2023



Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique

[https://www.citepa.org/wp-content/uploads/publications/ccnucc/CCNUCC\\_france\\_2023.pdf](https://www.citepa.org/wp-content/uploads/publications/ccnucc/CCNUCC_france_2023.pdf)

11/10/2024

Sauvons le Climat, Florent MOUILLOT, Incendies et impact Carbone



Data

About us

What we do



X close

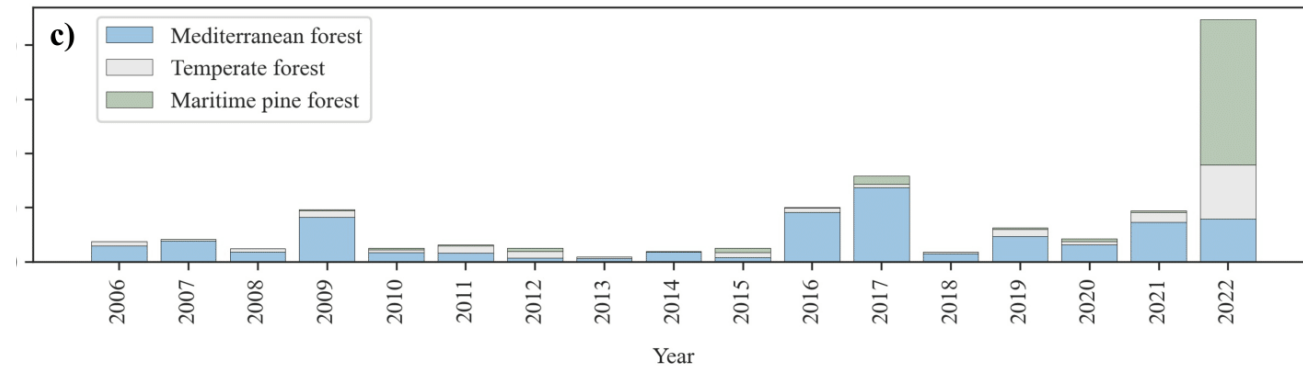
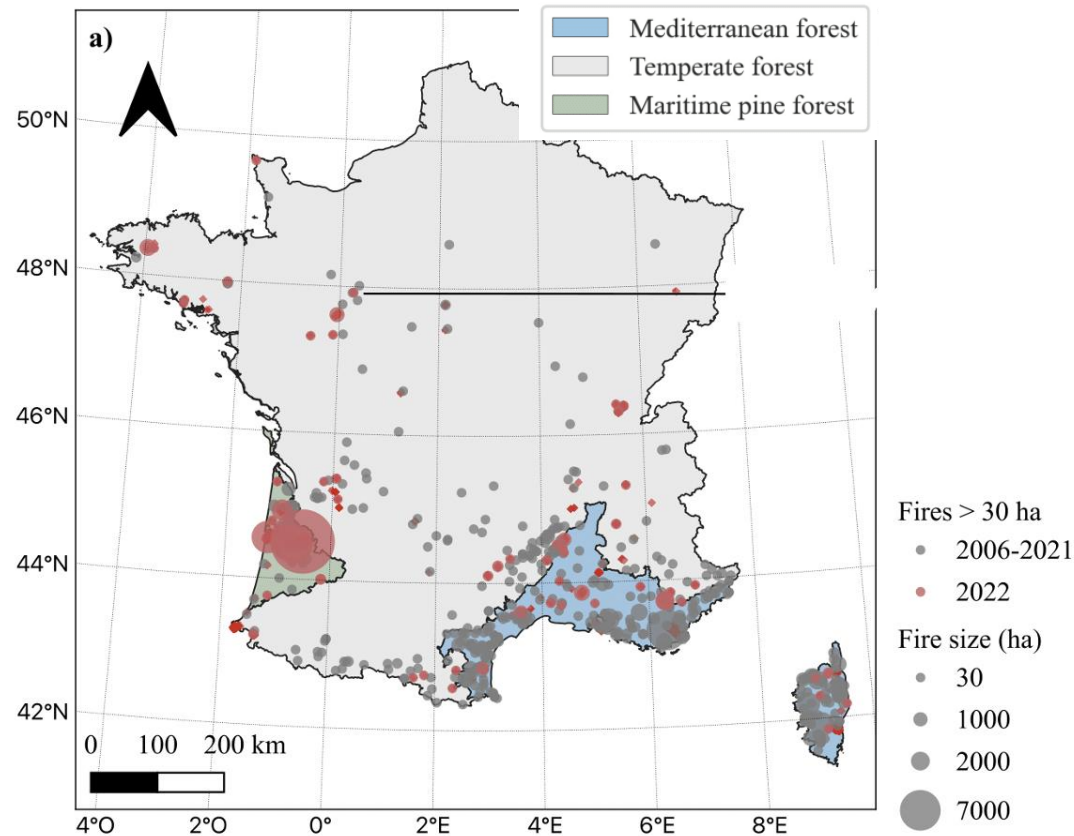
CAMS global biomass burning emissions based on fire radiative power  
(GFAS): data documentation

<https://atmosphere.copernicus.eu/global-fire-emissions>



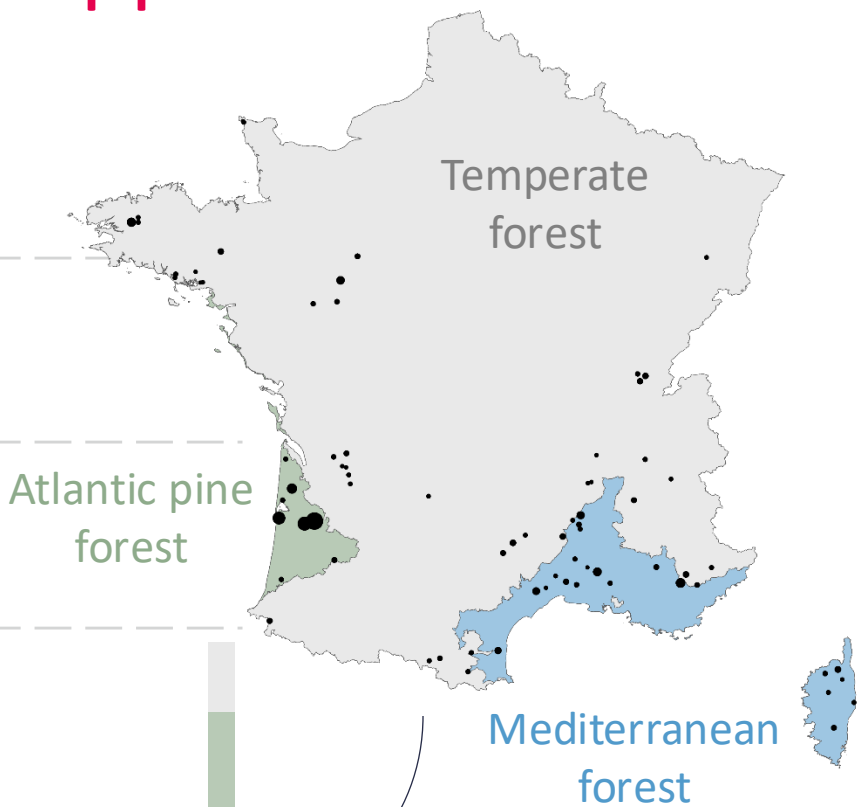
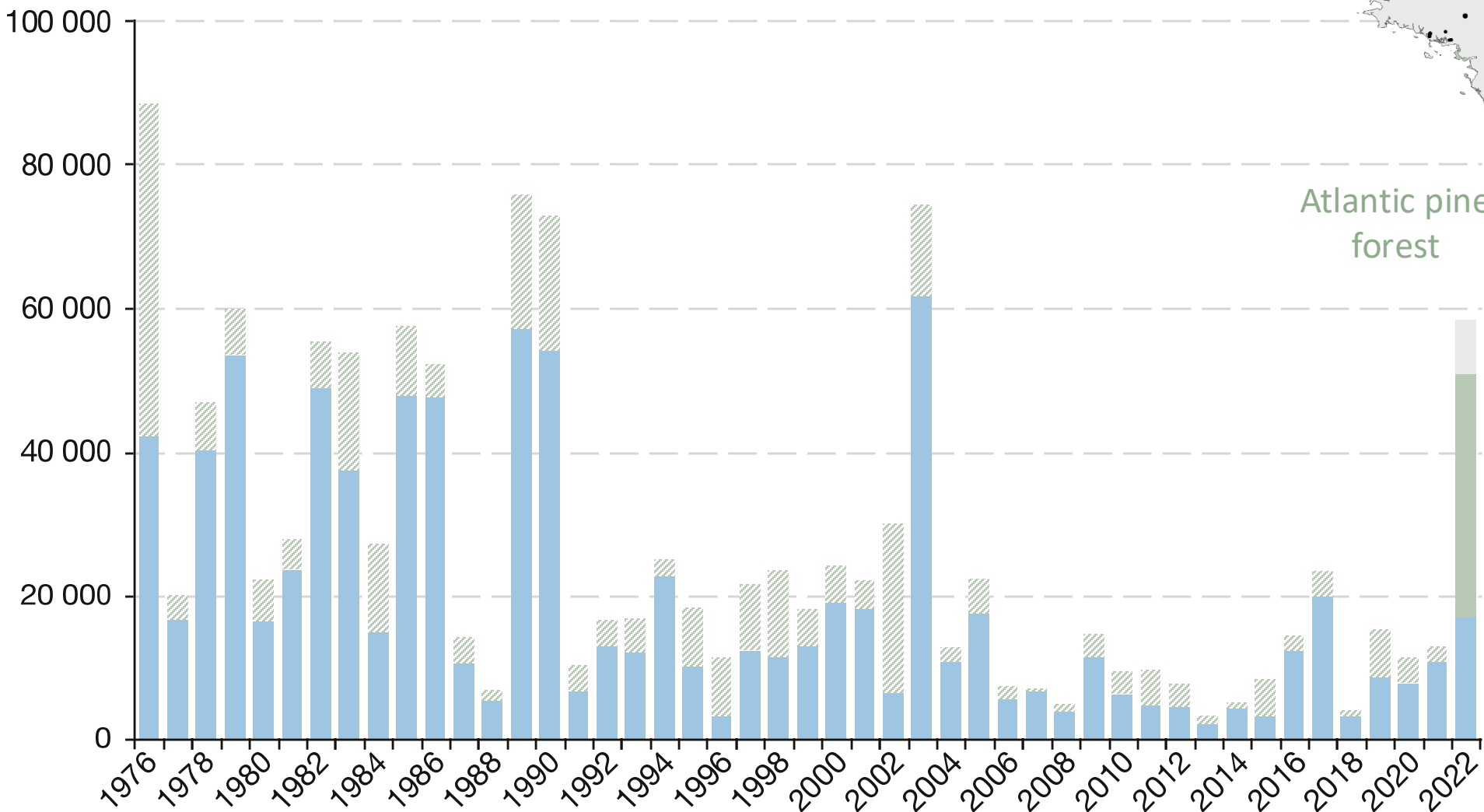
# Emissions de C en France...nouveaux développements

## 3.1. Les surfaces brûlées (S): source BDIFF (<https://bdiff.agriculture.gouv.fr/>)



# Emissions de C en France...nouveaux développements

Burned area (ha)



# Emissions de C en France...nouveaux développements

## 3.1. Les surfaces brûlées (S): vers une donnée spatialement explicite haute résolution

Sentinel and Landsat images

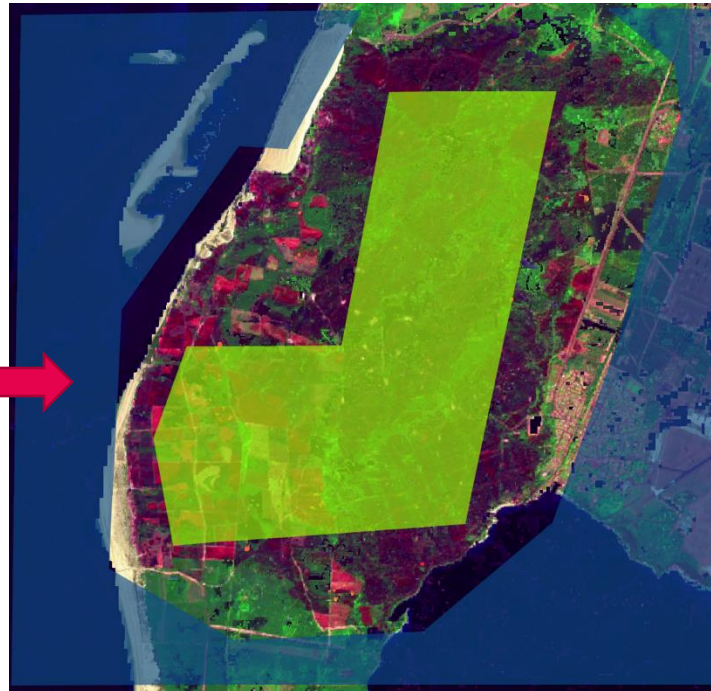


Pre- and Post- fire comparison

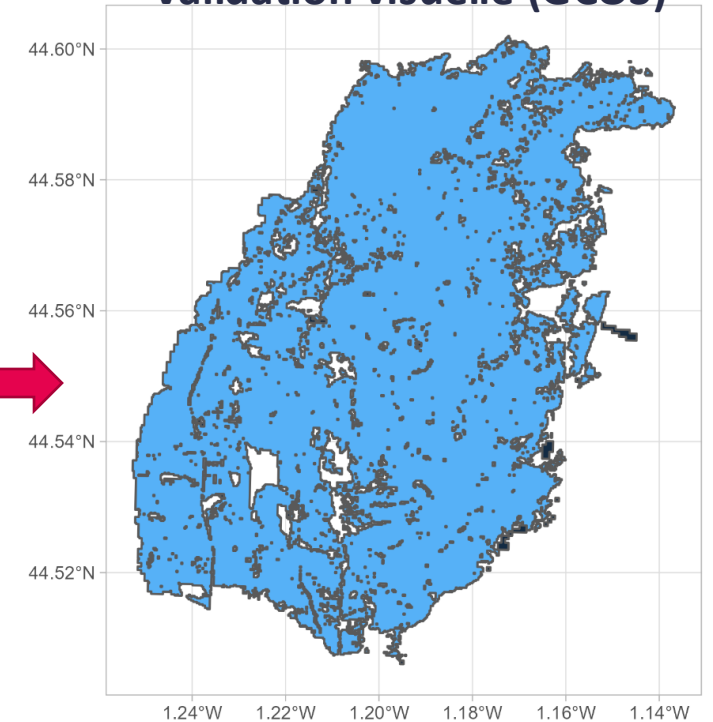


BAMT semi-automatic method (Roteta et al. 2020)

Zone d'entraînement  
=> Random Forest



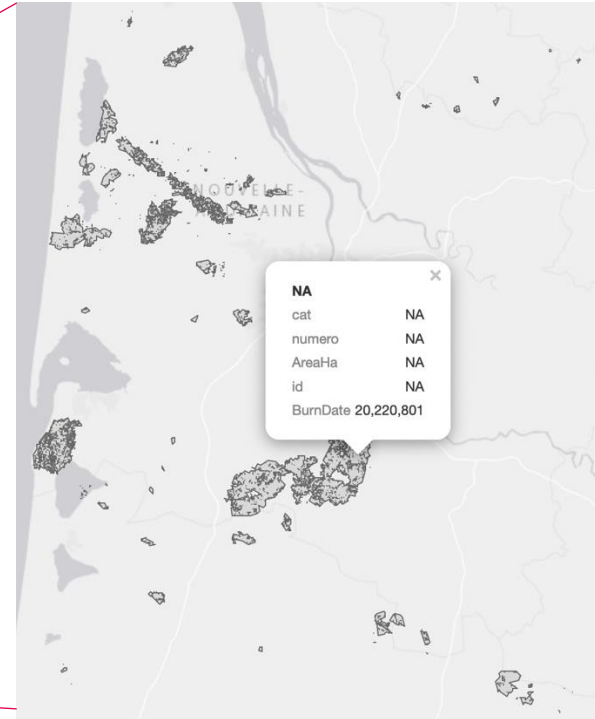
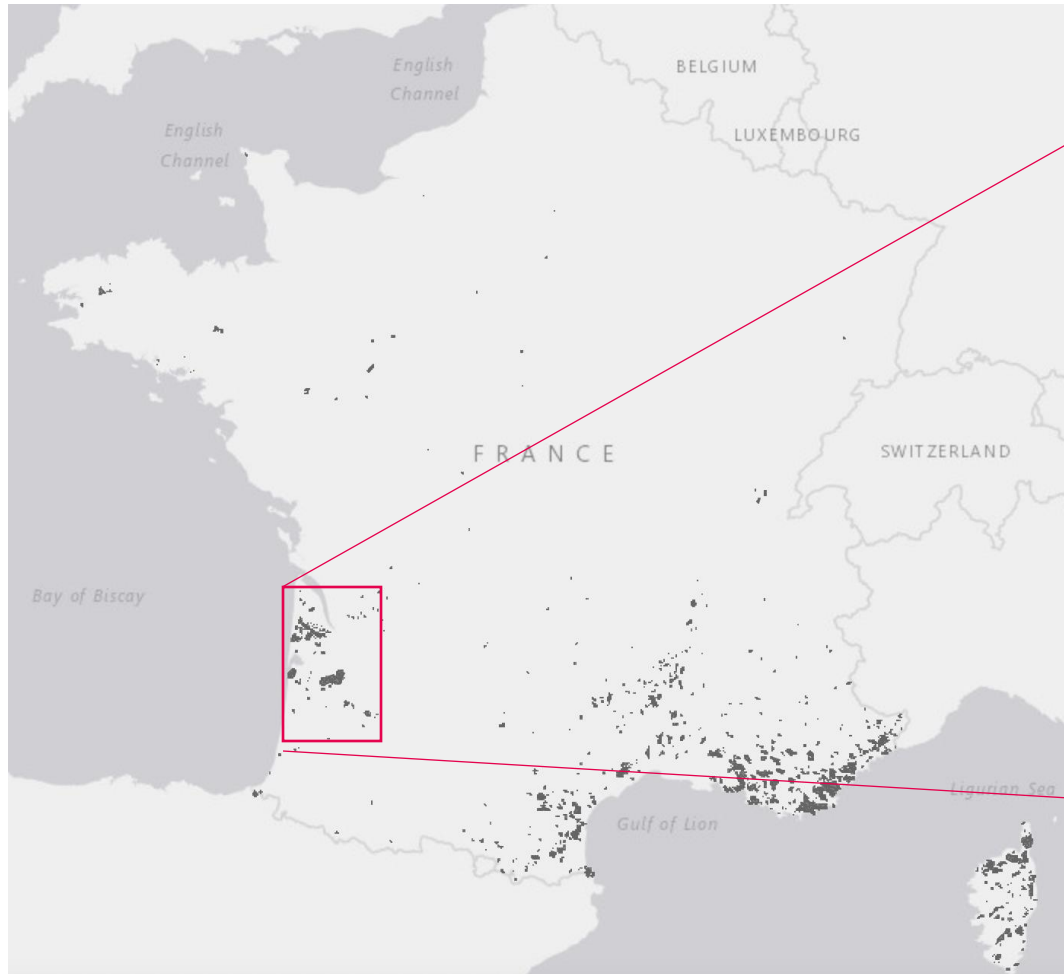
Polygone de feux  
Validation visuelle (GCOS)





# Emissions de C en France...nouveaux développements

## 3.1. Les surfaces brûlées (S): vers une donnée spatialement explicite haute résolution



<https://data.oreme.org/fire/home>

>1500 polygones

1984-2022

Feux > 50ha

Validation visuelle GCOS

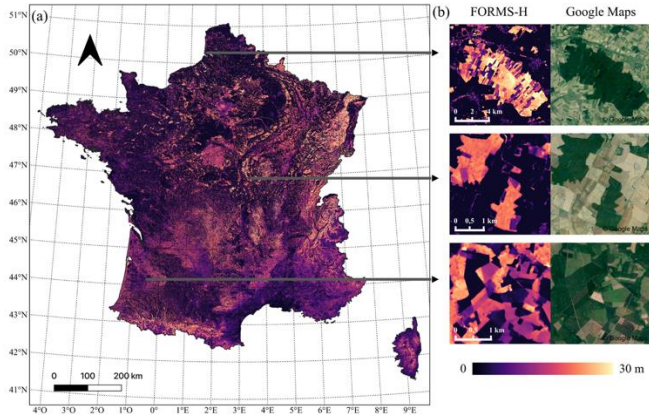
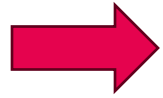
Date, surface

# Emissions de C en France...nouveaux développements

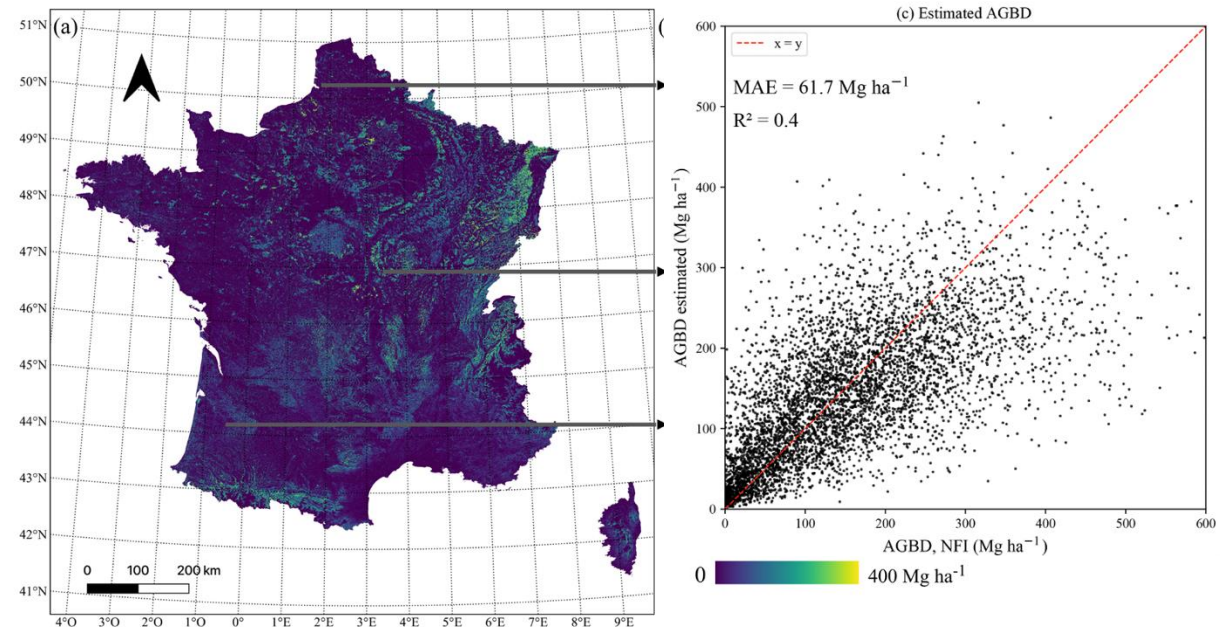
## 3.2 La biomasse (B): de l'IFN à la haute résolution LIDAR

GEDI / Sentinel

IFN



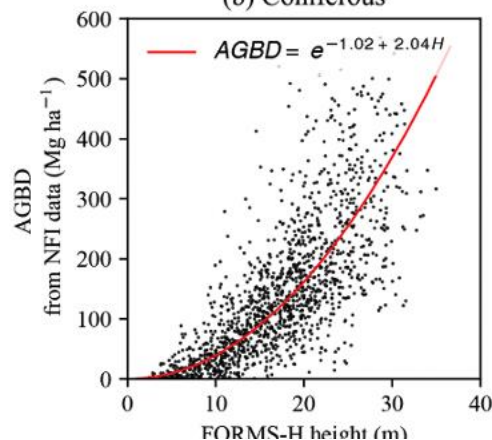
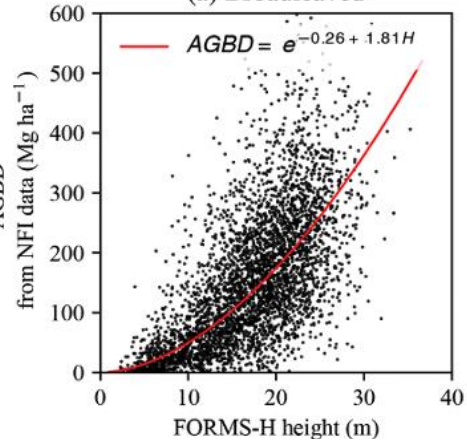
FORMS: hauteurs, volume, biomasse 10m resolution  
Schwartz et al. (2023)



Allometrie Hauteur/biomasse

(a) Broadleaved

(b) Coniferous



11/10/2024

Sauvons le Climat, Florent MOUILLOT, Incendies et impact Carbone



# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol? Négligée malgré les évidences 2022...



Landiras (33), 2022.



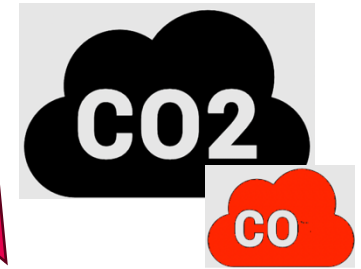
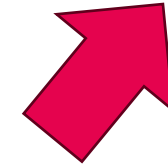
# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: mise en évidence par les tours Atmosphériques ICOS

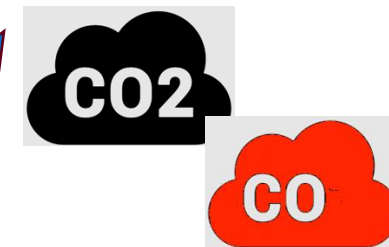
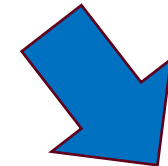


$$MCE = \frac{[CO_2]}{[CO_2] + [CO]}$$

Combustion de flamme  
(Flaming F)



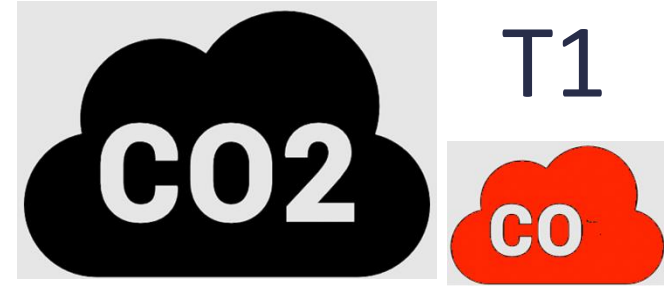
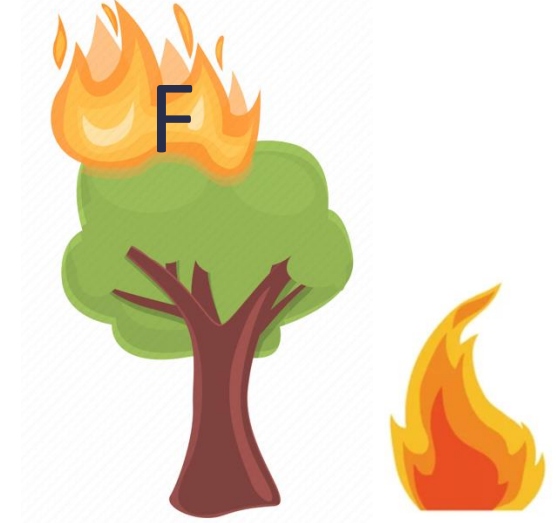
Combustion étouffée  
(Smoldering S)





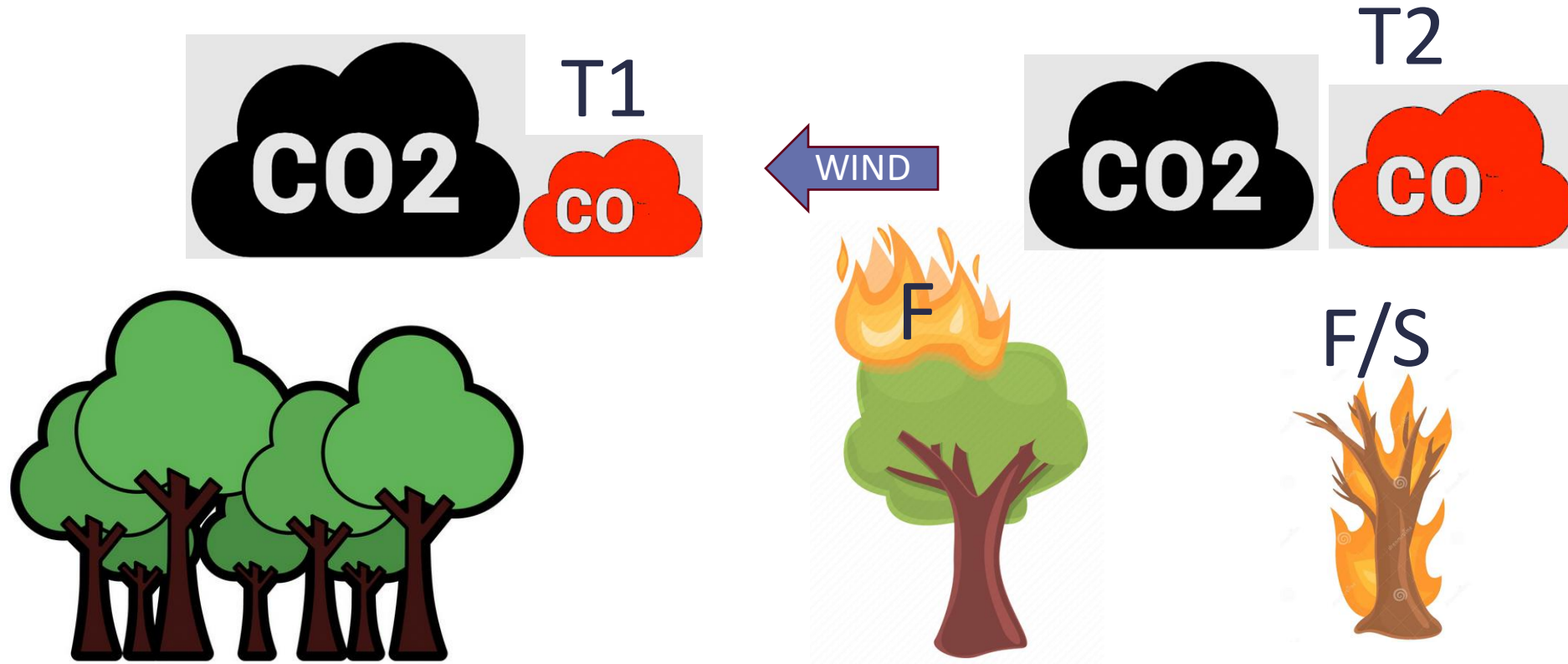
# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: mise en évidence par les tours Atmosphériques ICOS



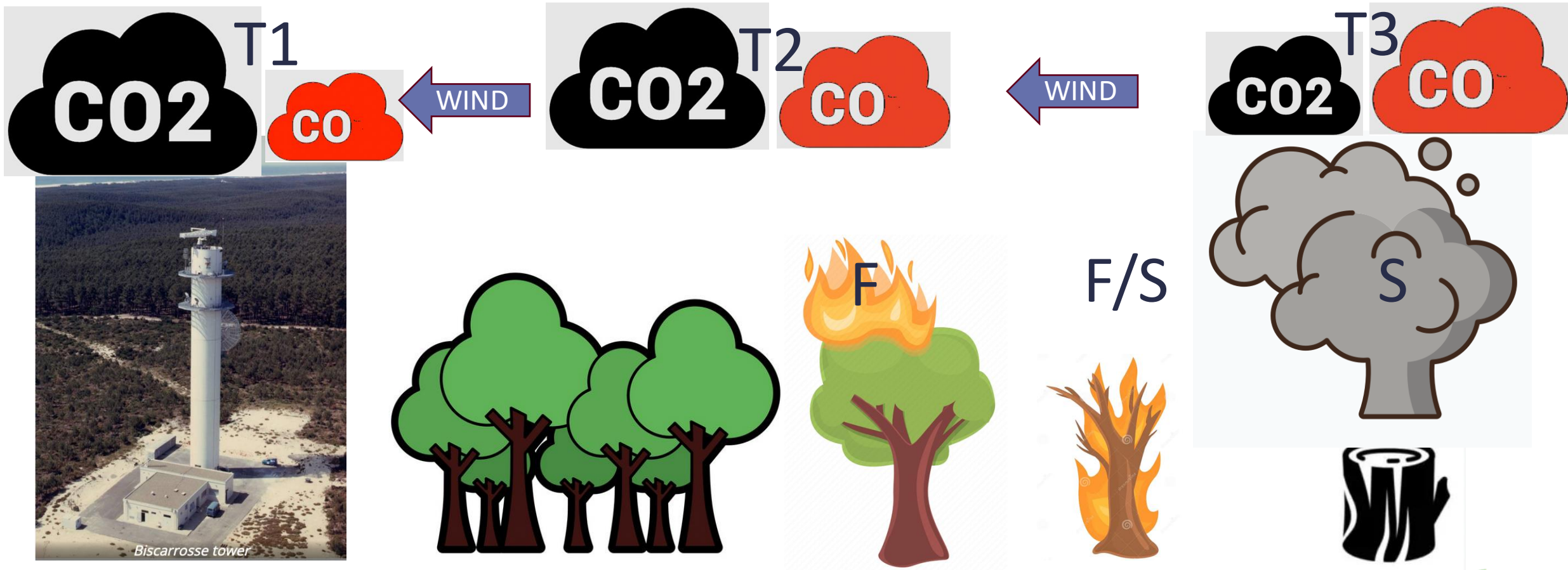
# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: mise en évidence par les tours Atmosphériques ICOS



# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: mise en évidence par les tours Atmosphériques ICOS

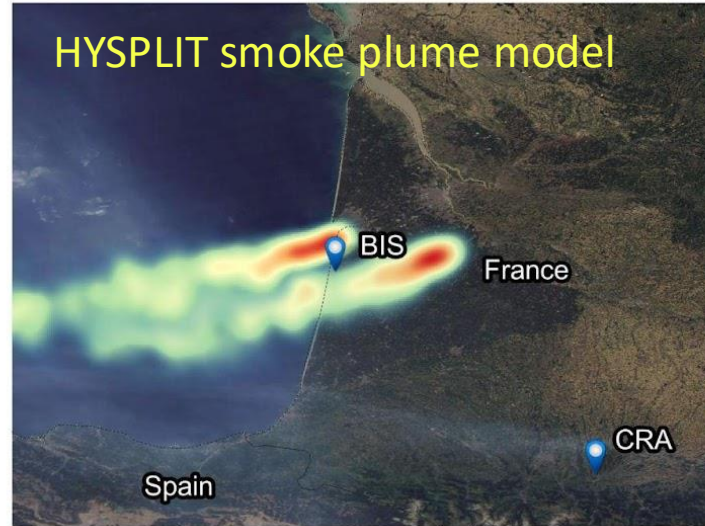
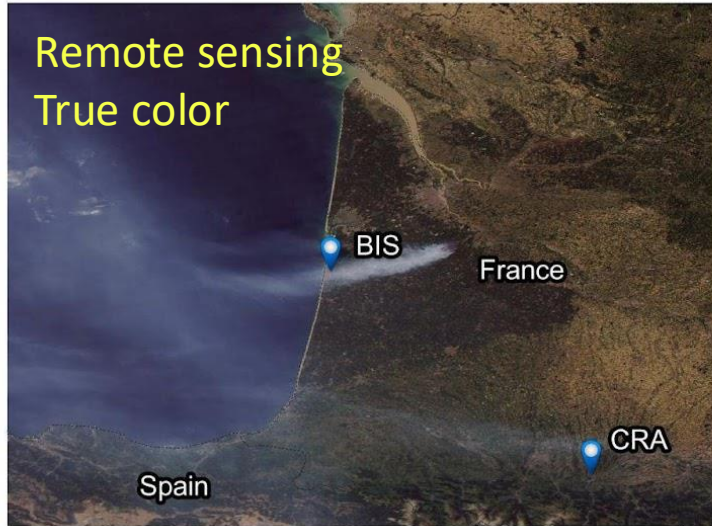




# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: mise en évidence par les tours Atmosphériques ICOS

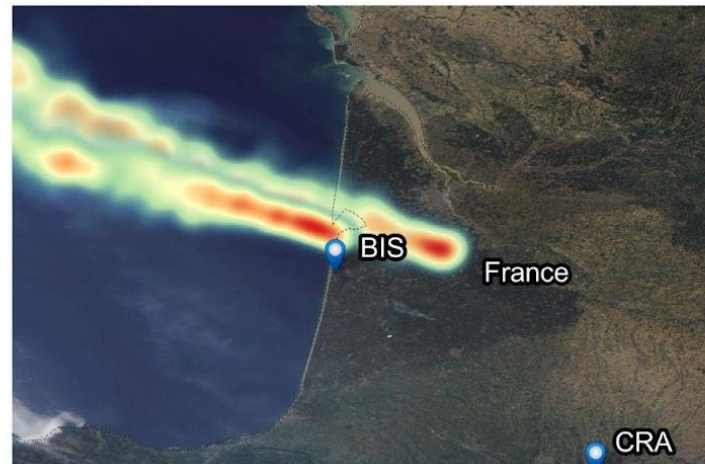
2022-07-16



Mesures ICOS:

- Filtrage des jours dans le panache
- simulation de panache HYSPLIT

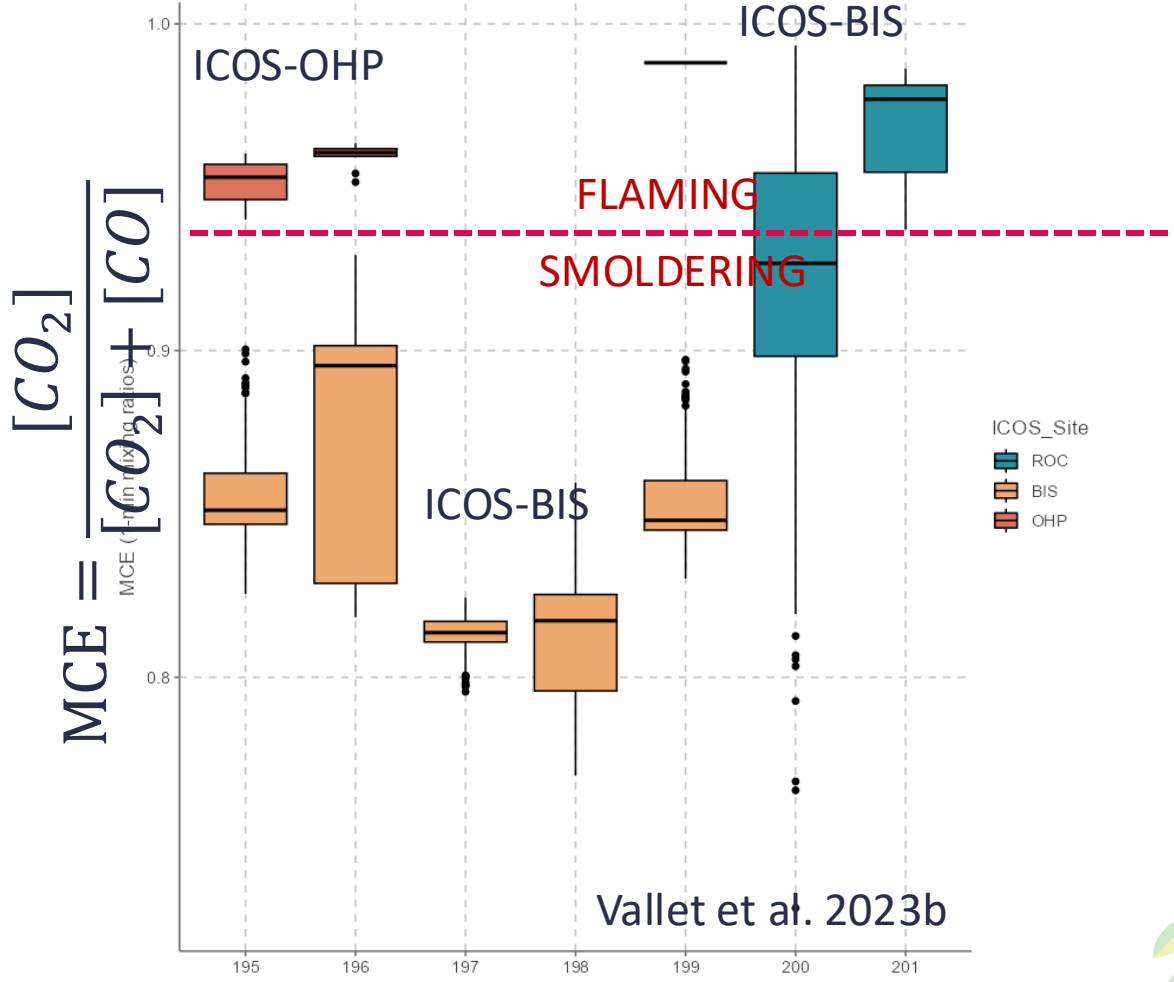
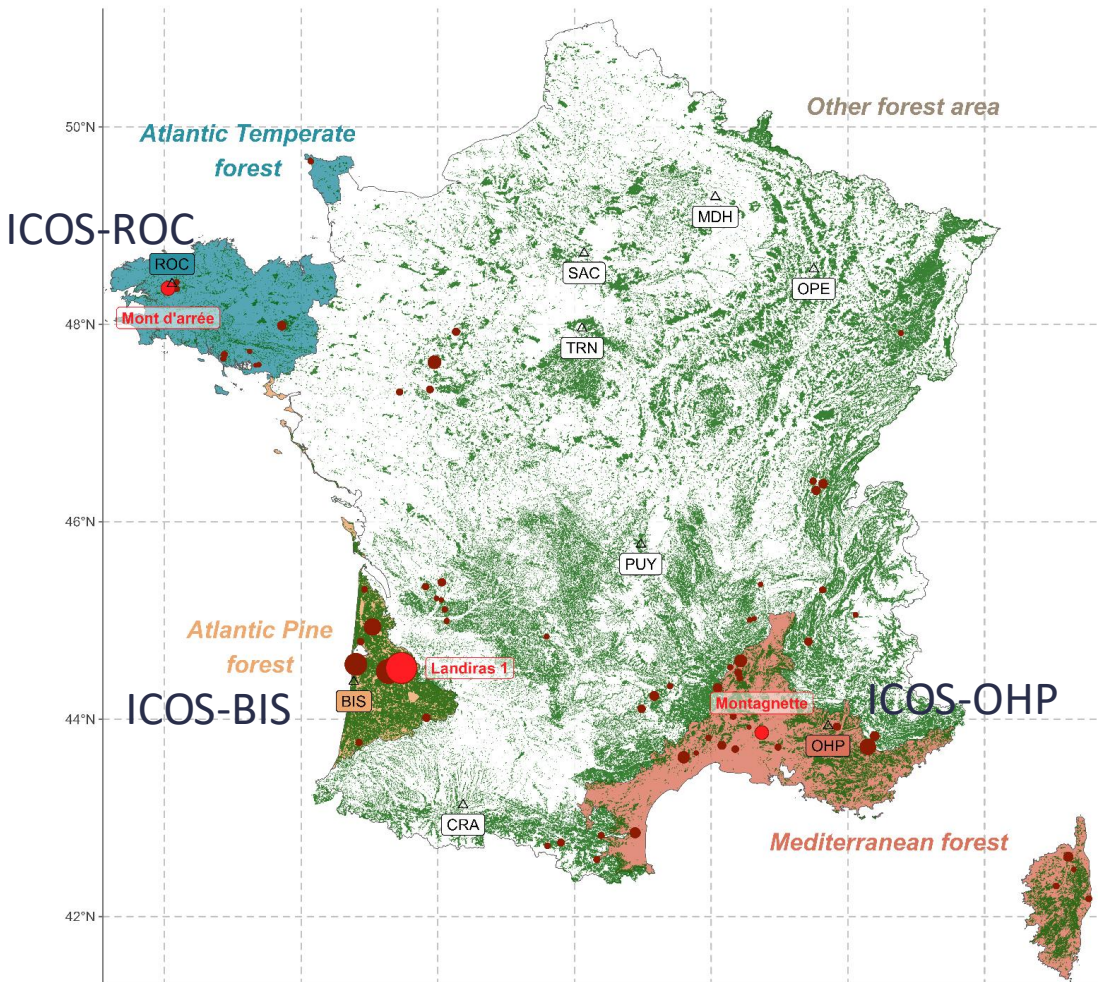
2022-07-18



Vallet et al. 2023b

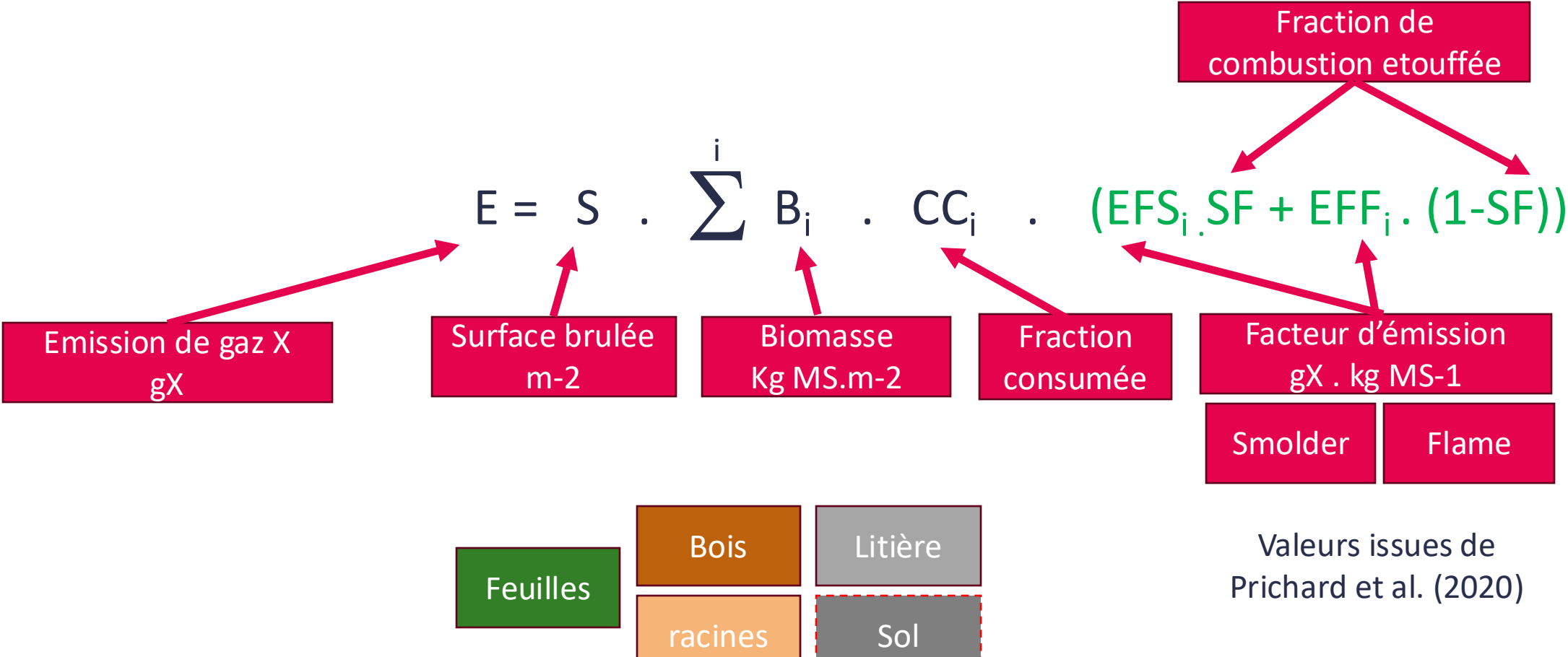
# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: mise en évidence par les tours Atmosphériques ICOS



# Emissions de C en France...nouveaux développements

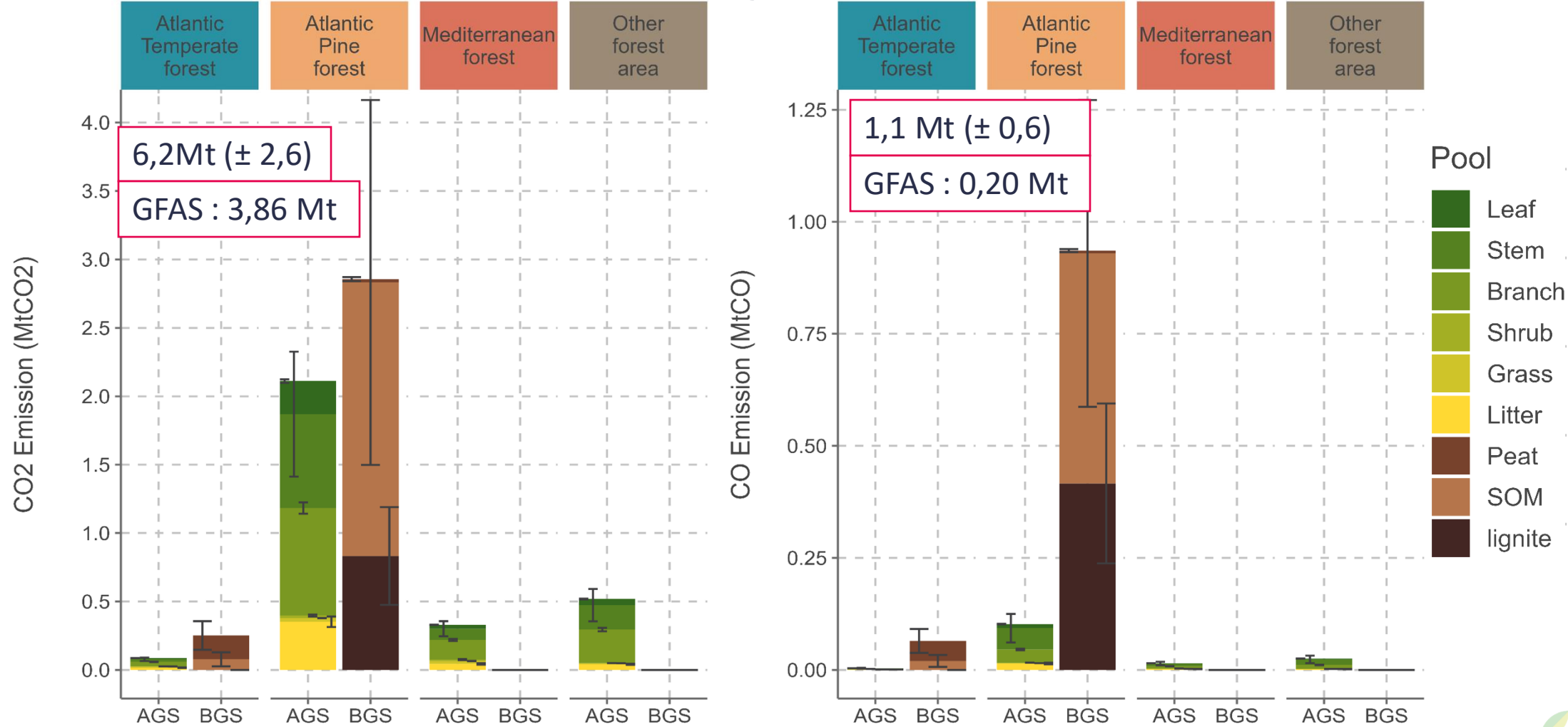
## 3.3 La combustion du sol: vers un nouvel algorithme





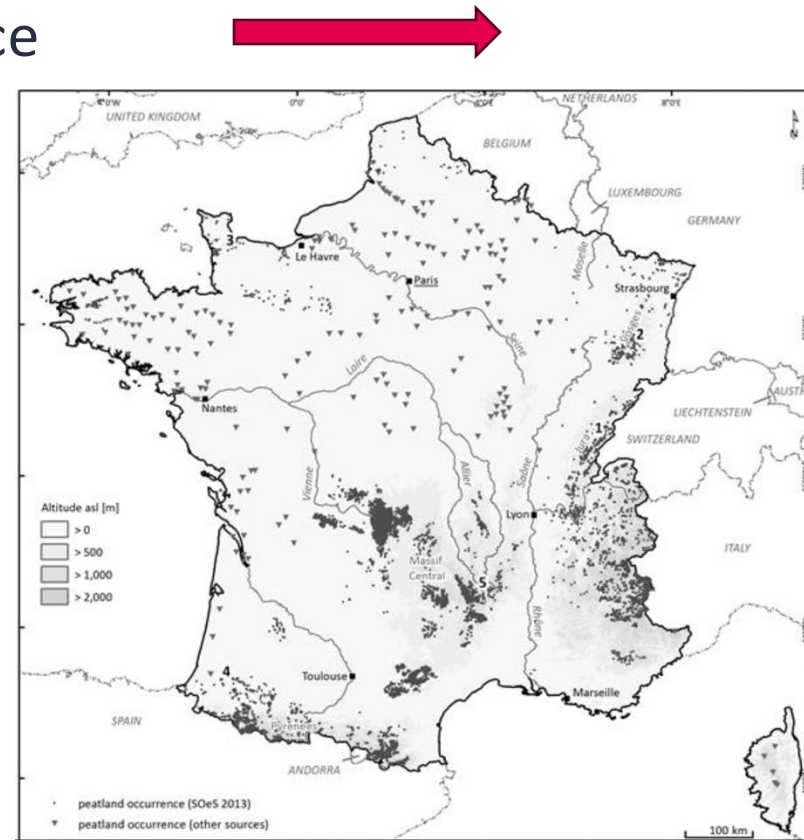
# Emissions de C en France...nouveaux développements

## 3.3 La combustion du sol: vers un nouvel algorithme



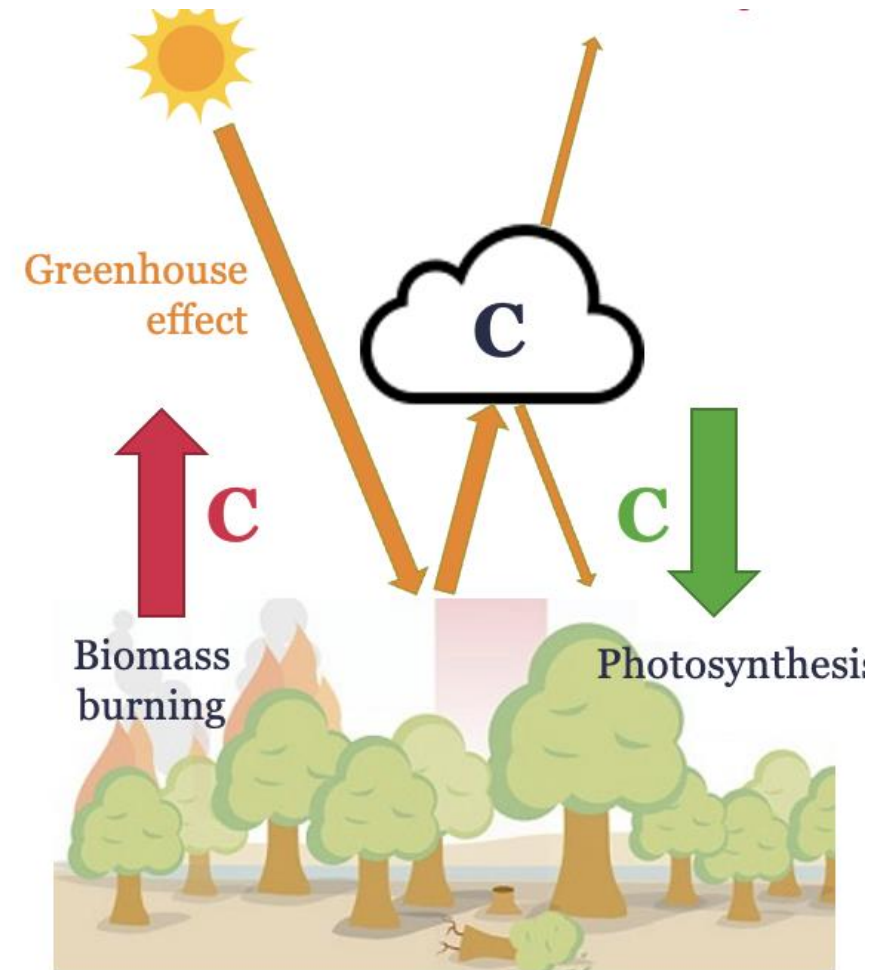
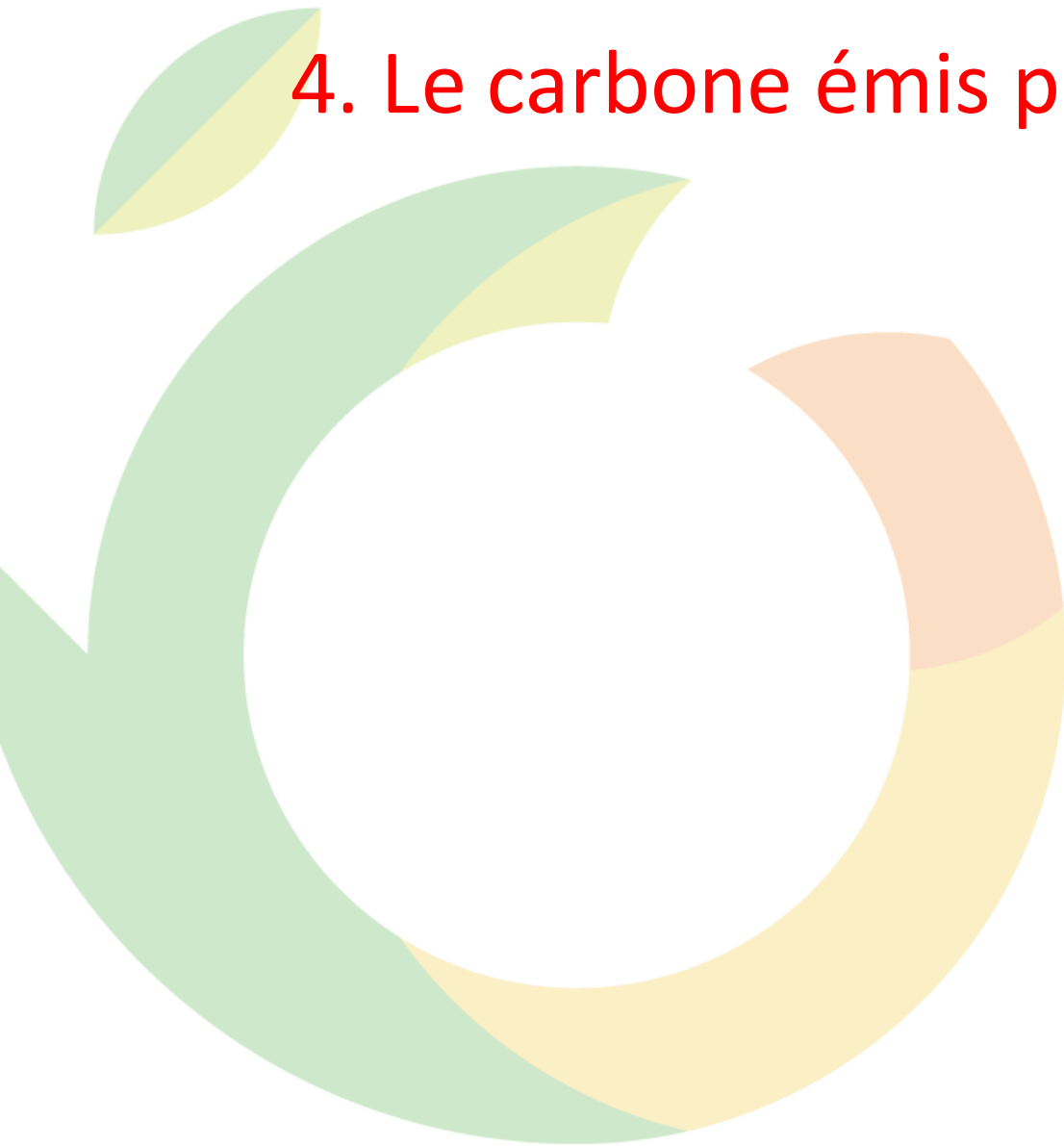
# Perspectives

- Intégration de la combustion de sols tempérés  
=> facteurs d'émission (EF)? (Prichard et al. 2020 US)
- Vulnérabilité des stocks de Carbone en France  
=> intégrer C sol et tourbières



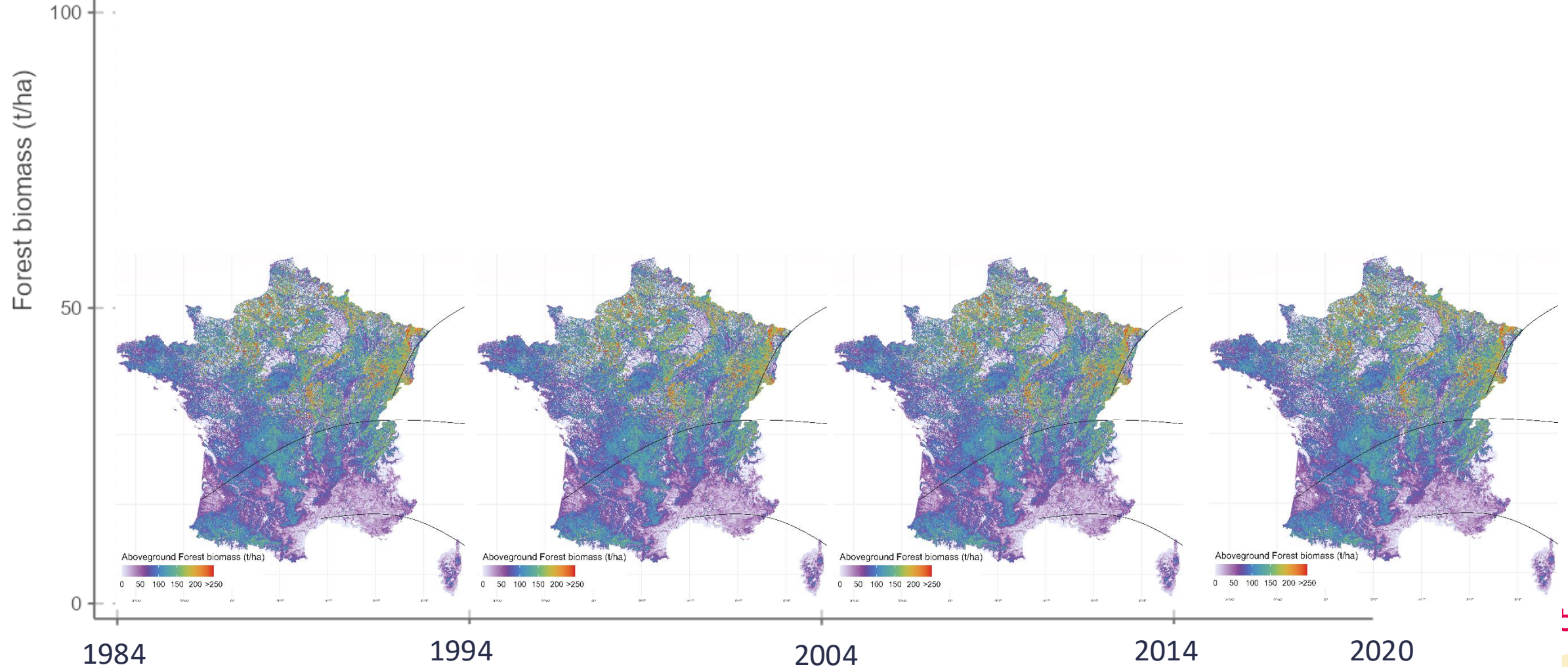
Muller et al. 2018

## 4. Le carbone émis par les incendies est-il récupérable?

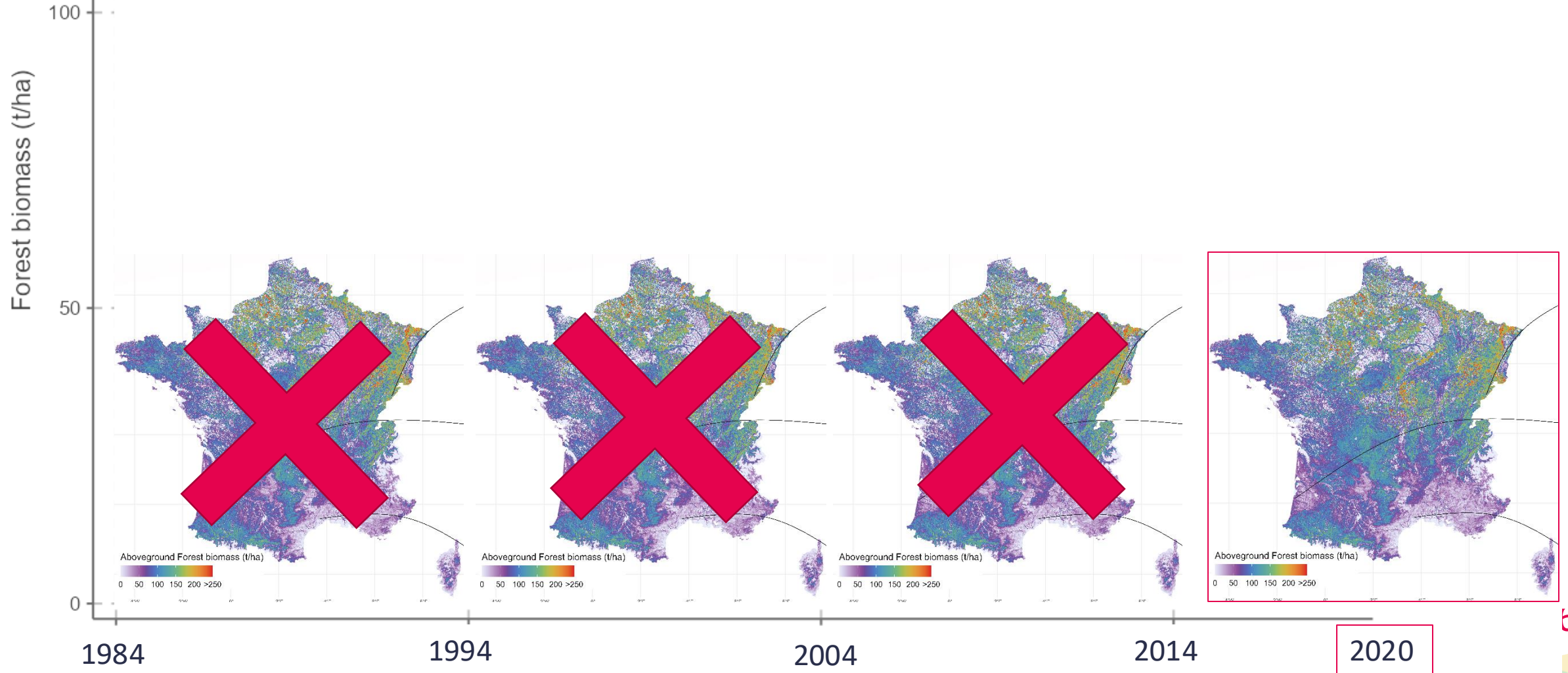




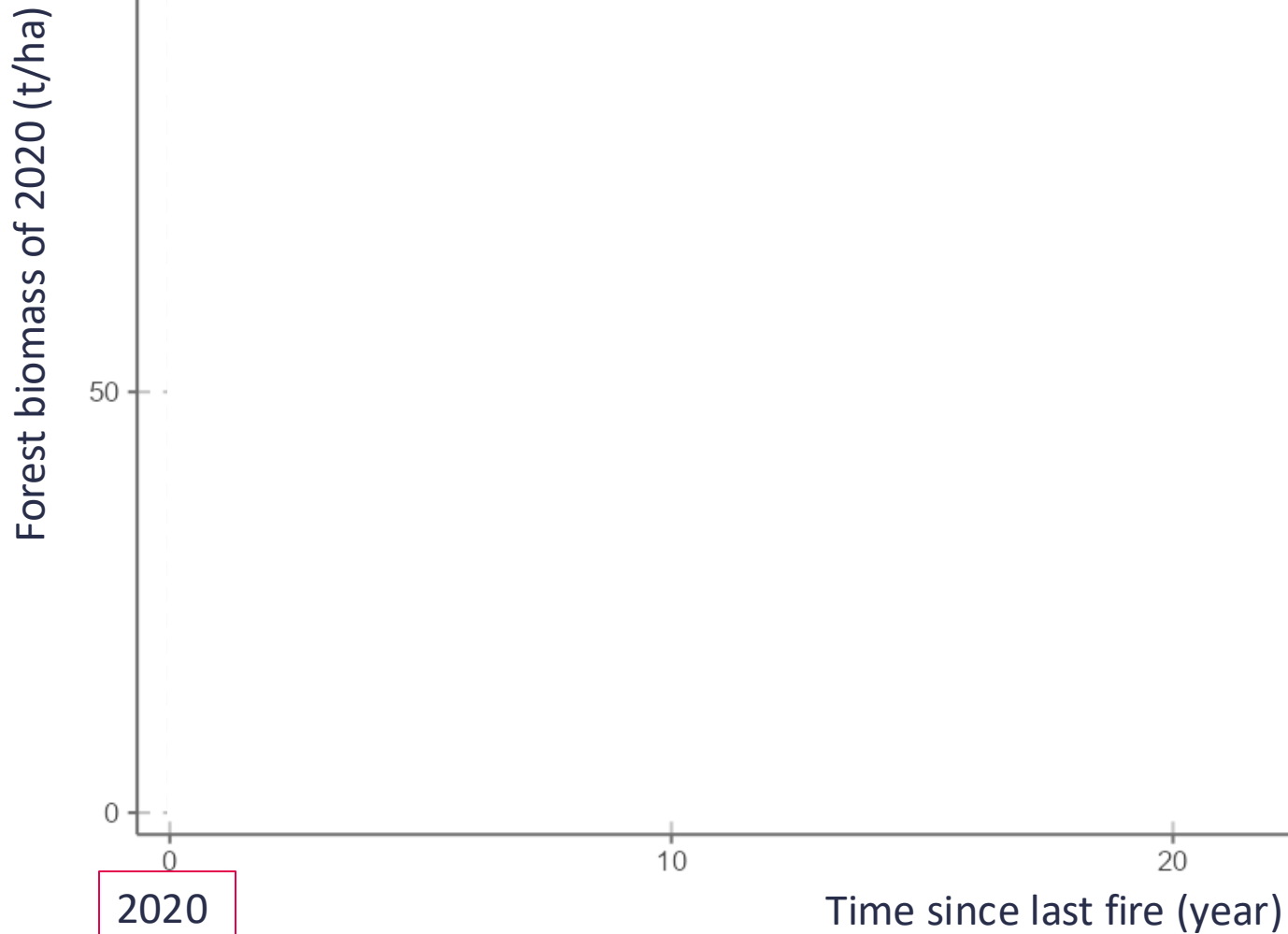
# Post-fire biomass dynamics



# Post-fire biomass dynamics

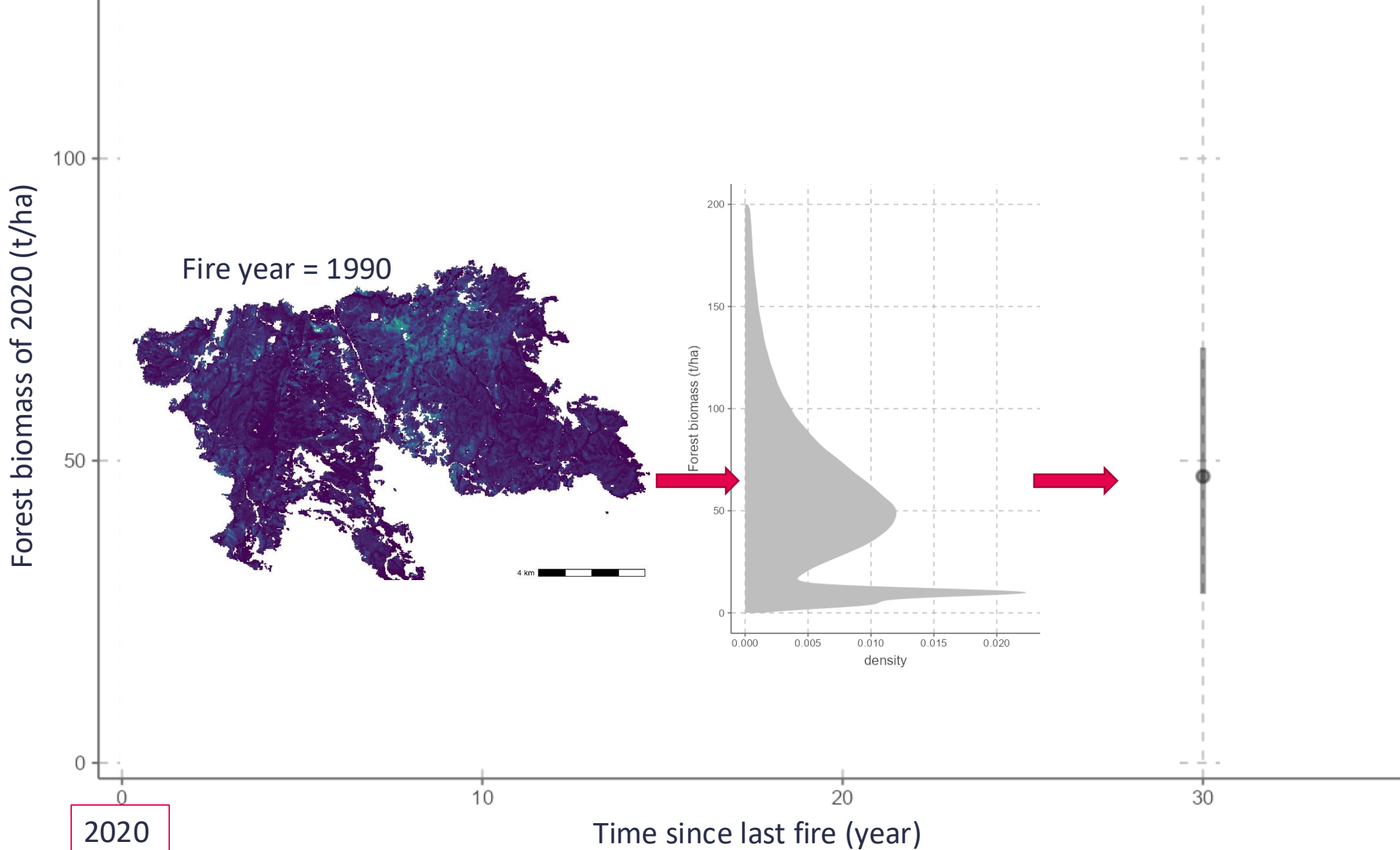


# Post-fire biomass dynamics



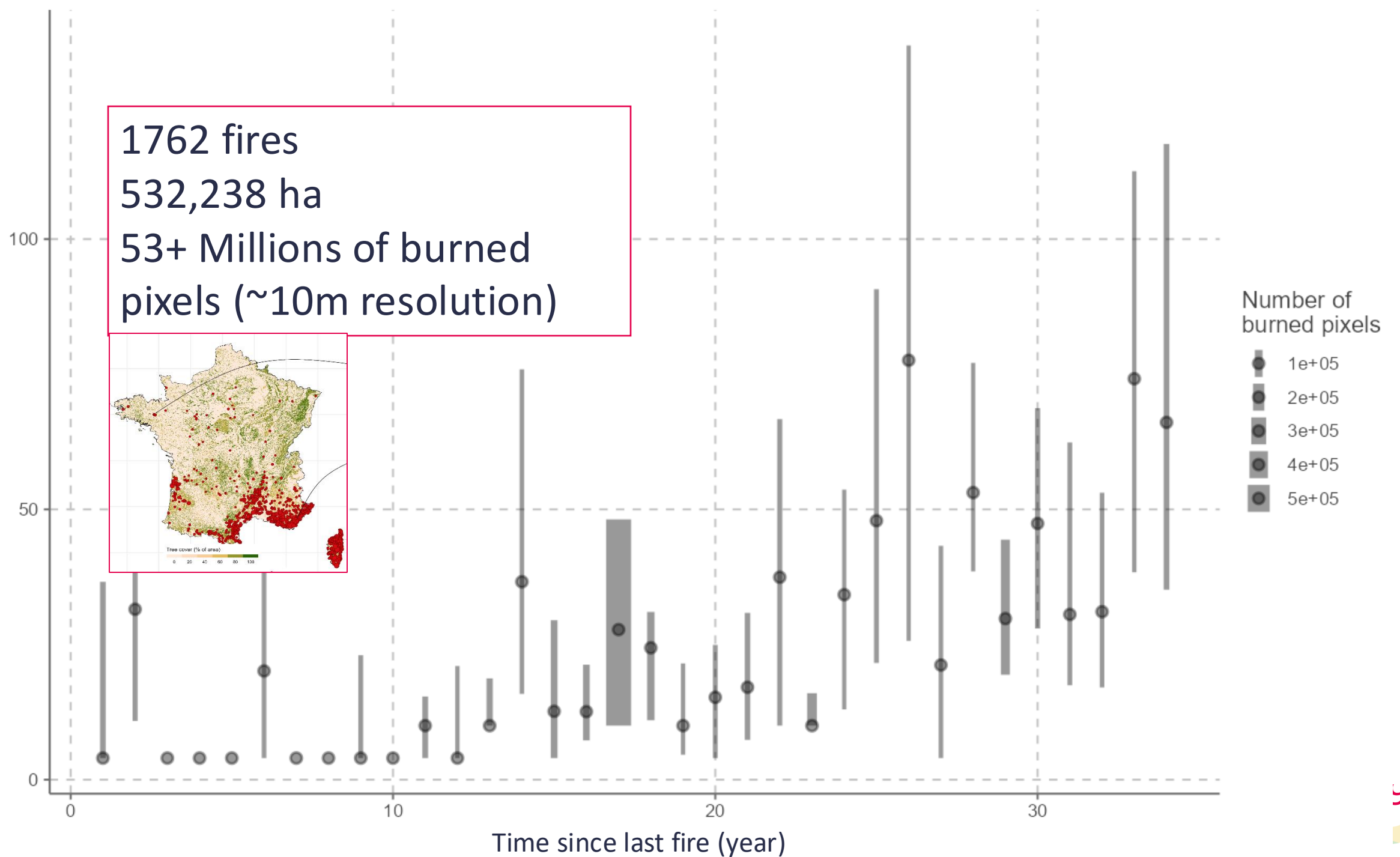
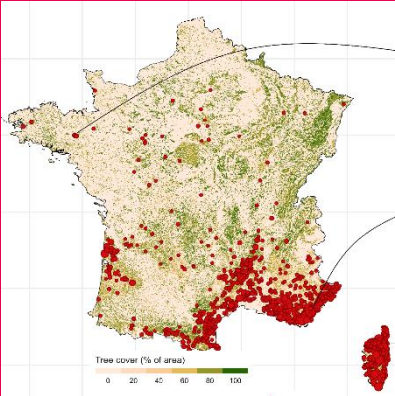


# Post-fire biomass dynamics



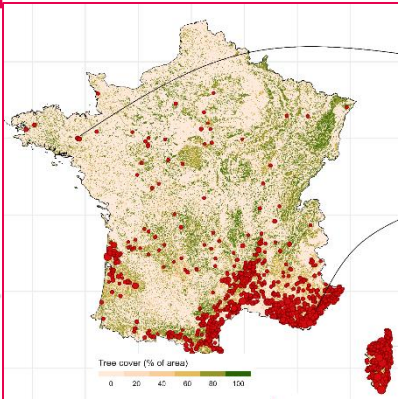
Forest biomass of 2020 (t/ha)

1762 fires  
532,238 ha  
53+ Millions of burned  
pixels (~10m resolution)



Forest biomass of 2020 (t/ha)

1762 fires  
532,238 ha  
53+ Millions of burned  
pixels (~10m resolution)



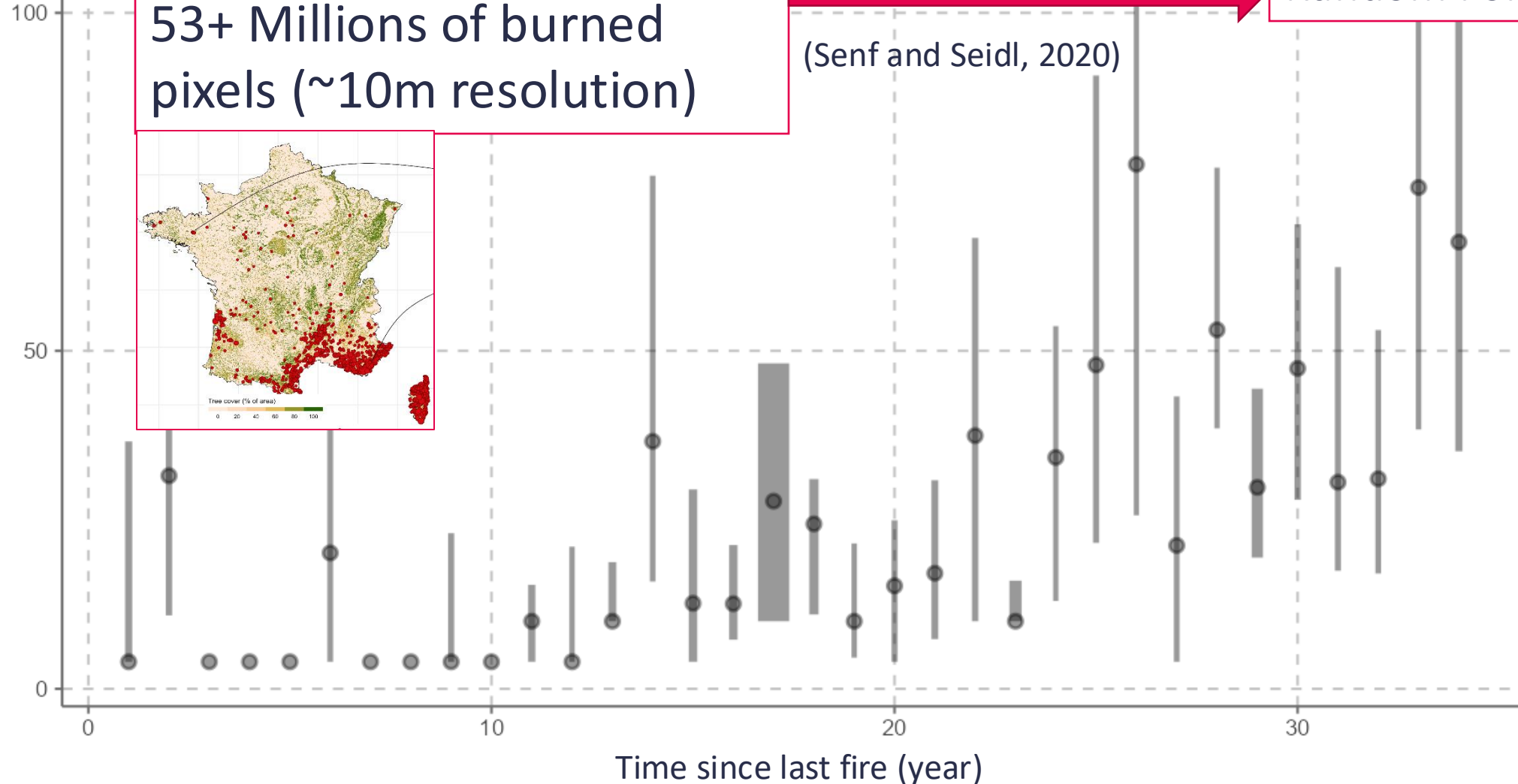
Spatial filtering on burned pixel

(Senf and Seidl, 2020)

Random Forest Model

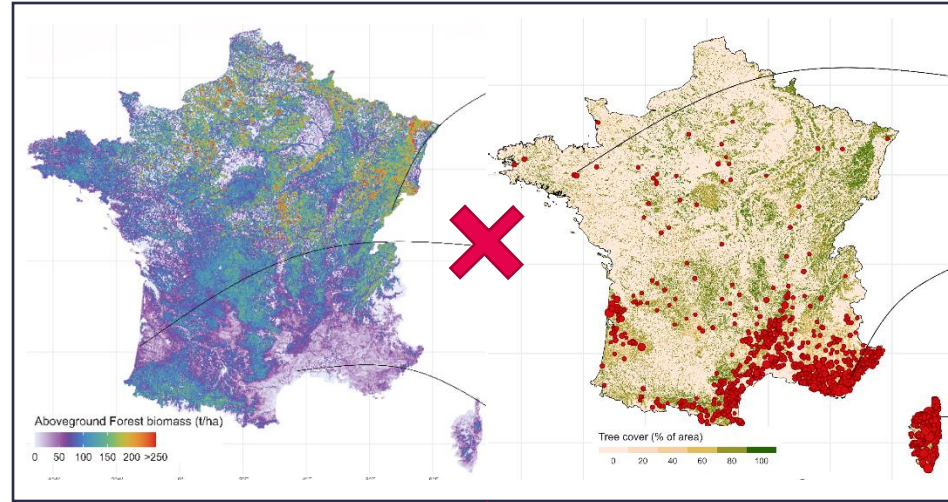
Number of  
burned pixels

- 1e+05
- 2e+05
- 3e+05
- 4e+05
- 5e+05





# Vers une modélisation de la dynamique C post-feu

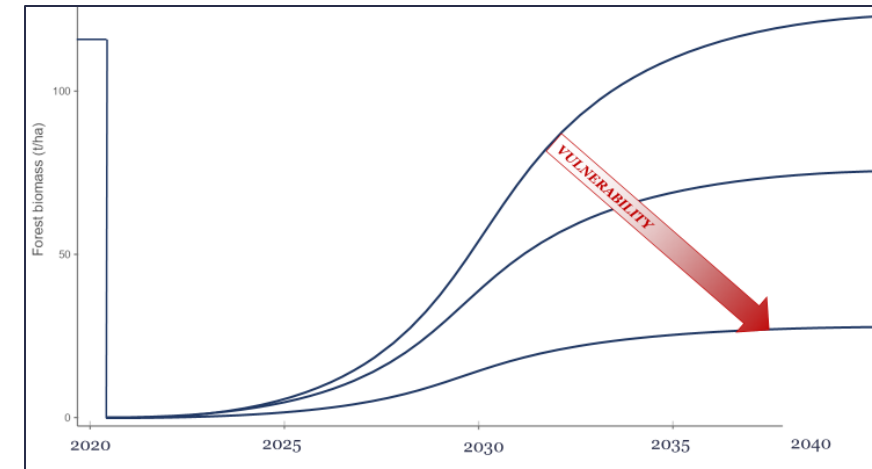


Training  
90%

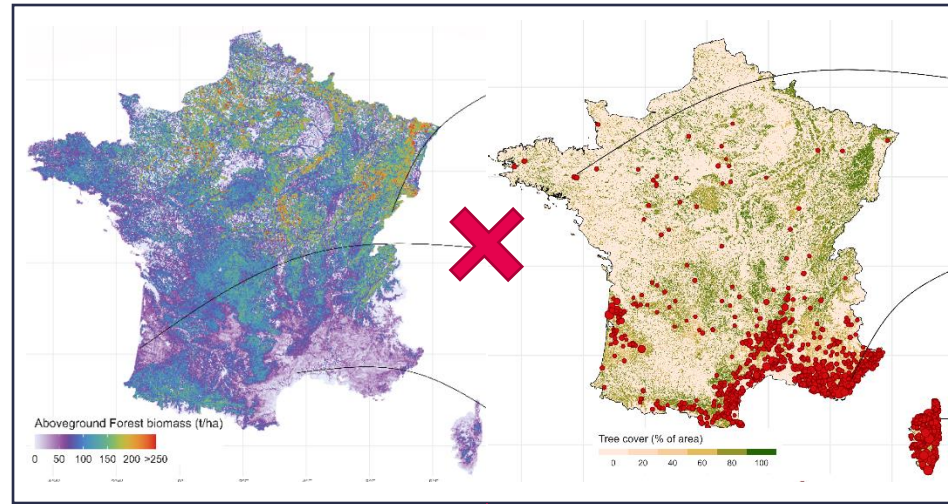
## Variables category

- #1  Climate drivers
- #2  Species traits
- #3  Disturbance characteristics
- #4  Topographic variables

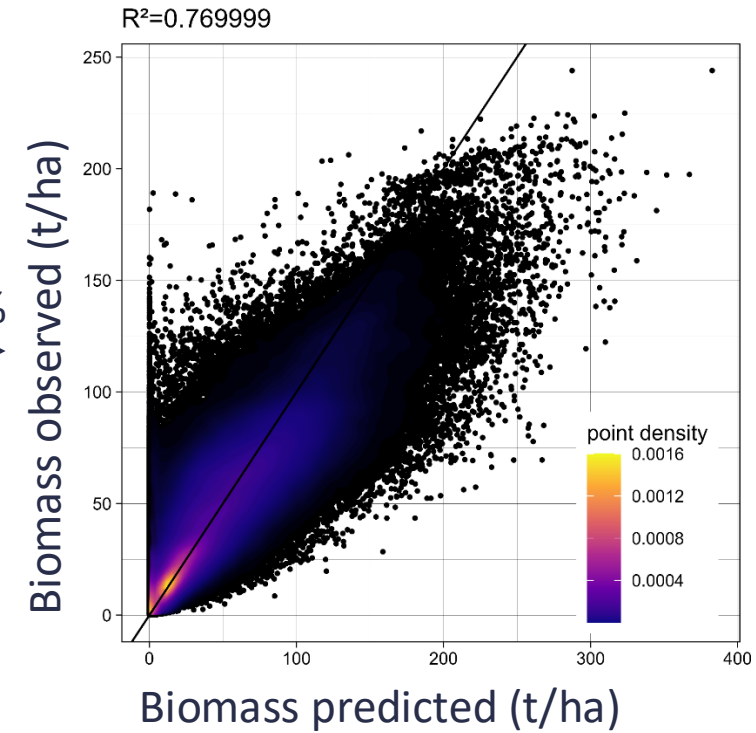
Random Forest  
Model



# Vers une modélisation de la dynamique C post-feu



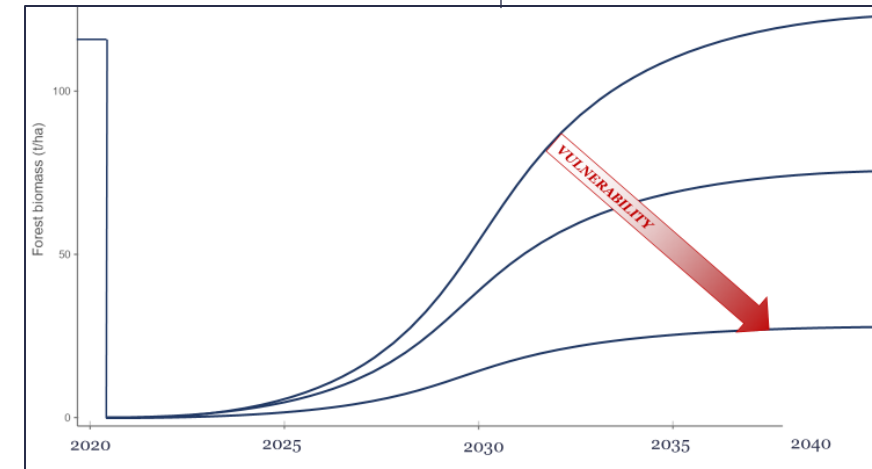
Test 10%



Variables category

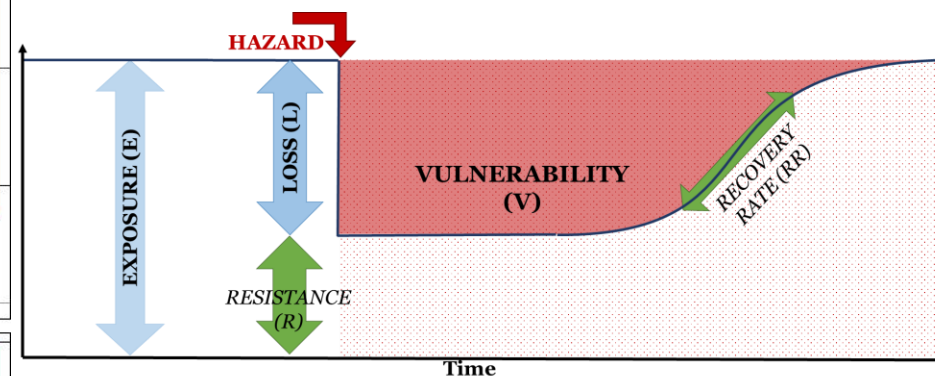
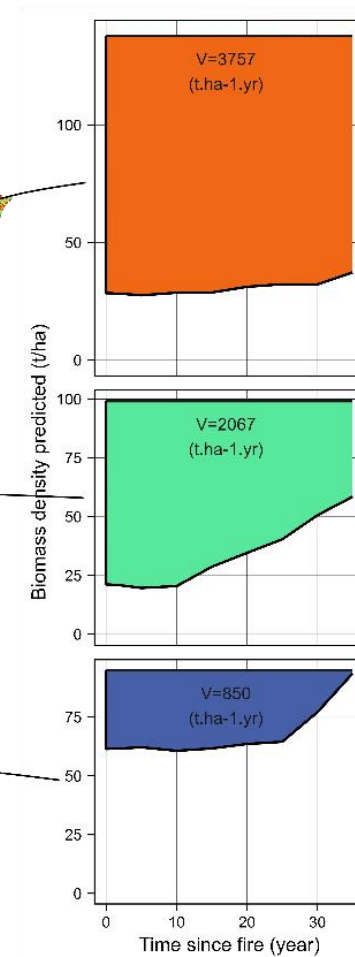
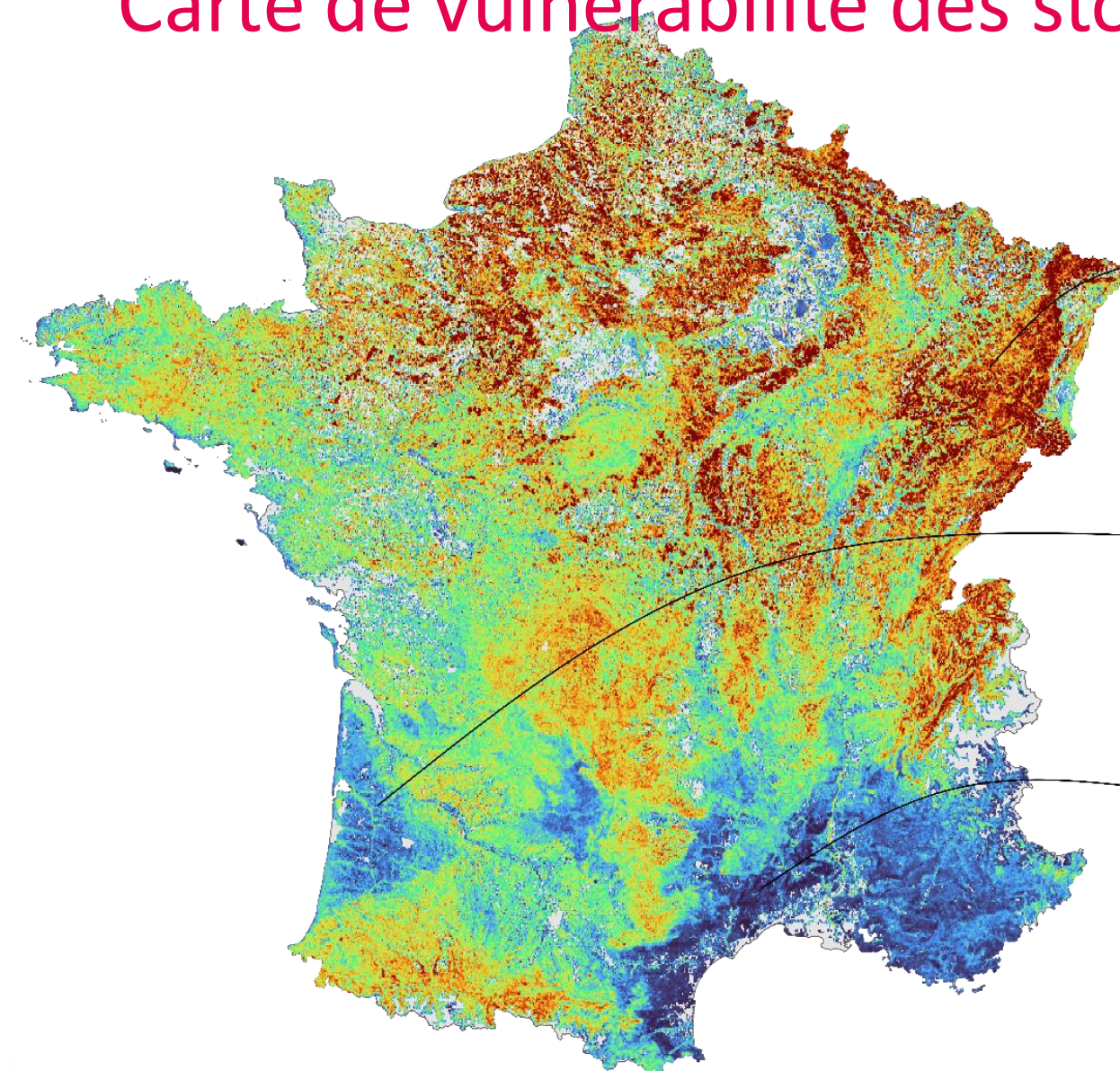
- #1  Climate drivers
- #2  Species traits
- #3  Disturbance characteristics
- #4  Topographic variables

Random Forest Model





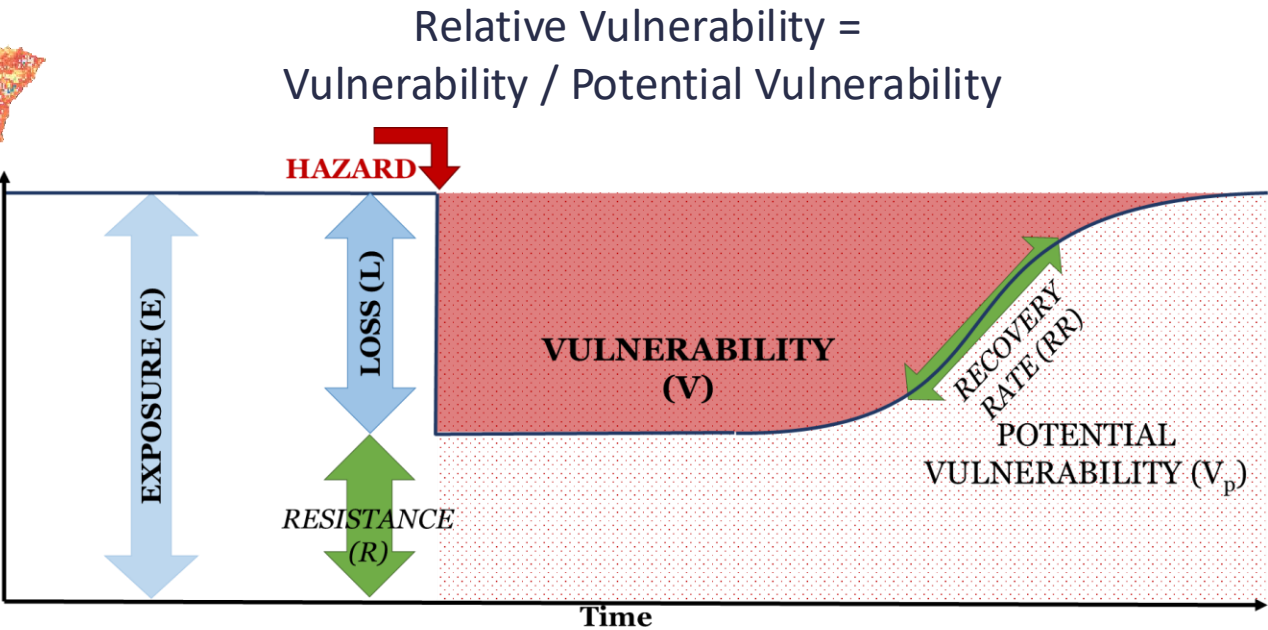
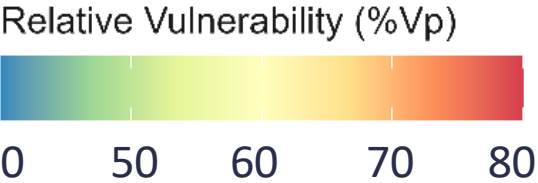
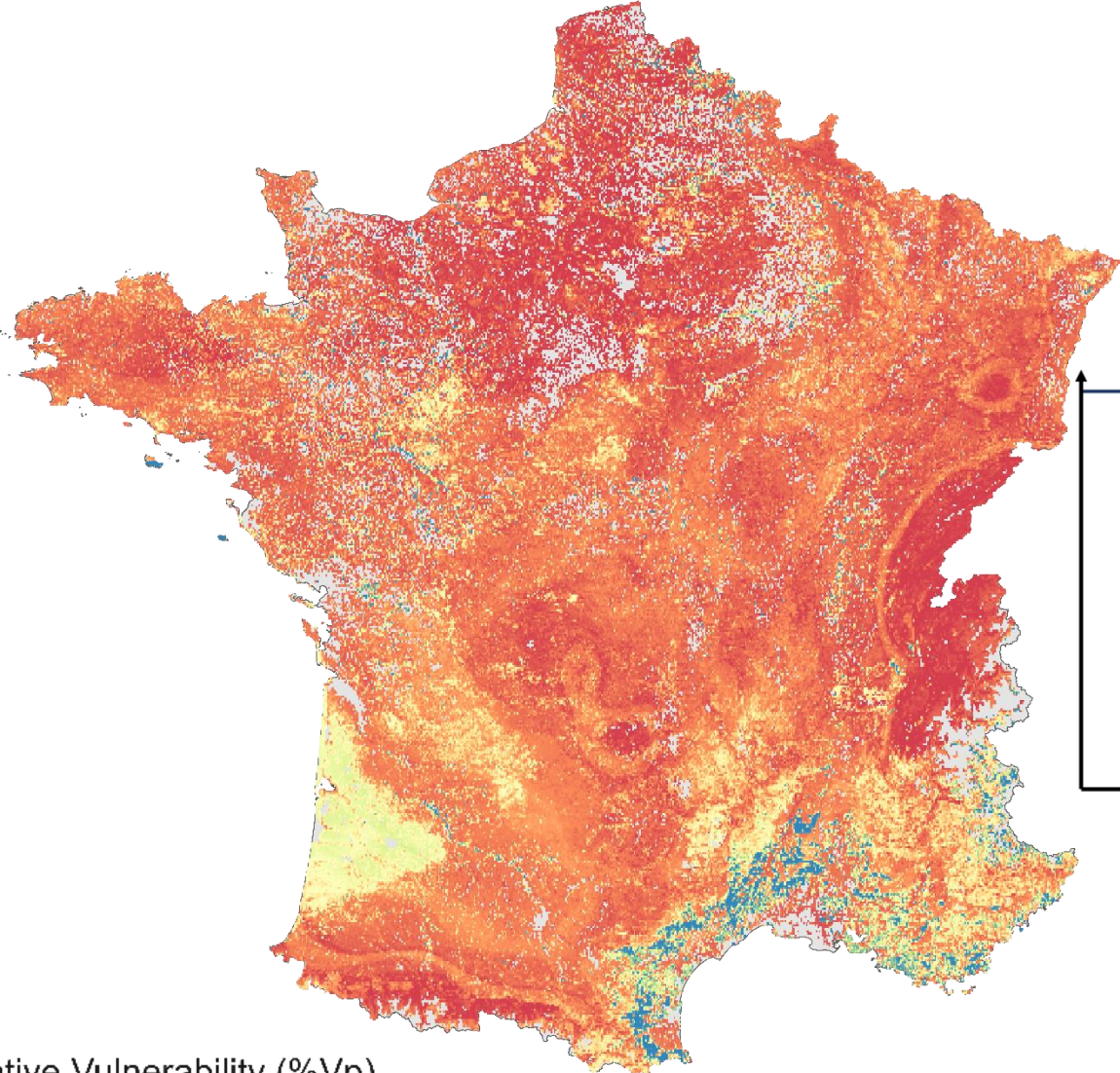
# Carte de vulnérabilité des stocks de C forestiers au feu



Vulnerability : Lack of biomass over time  
- 35 years -  
*Noon et al. 2022*

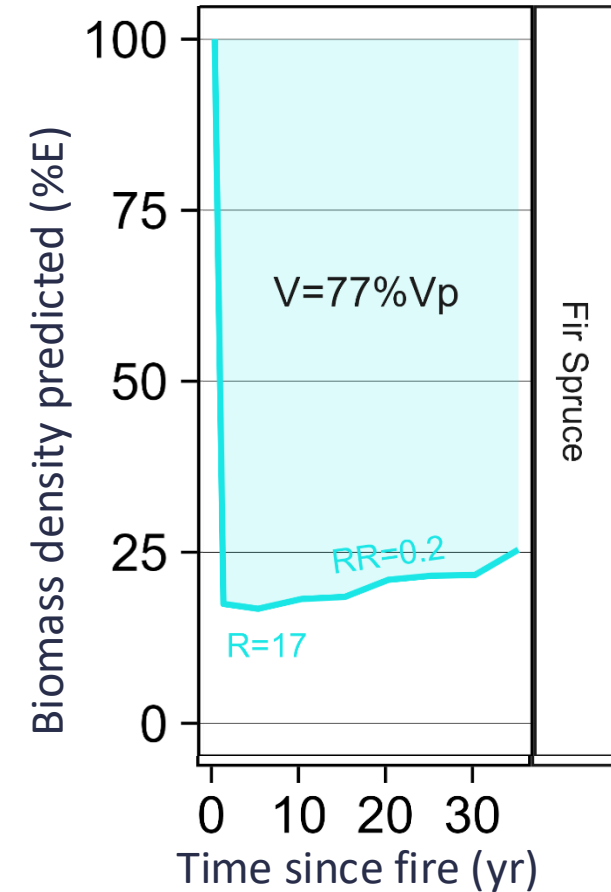
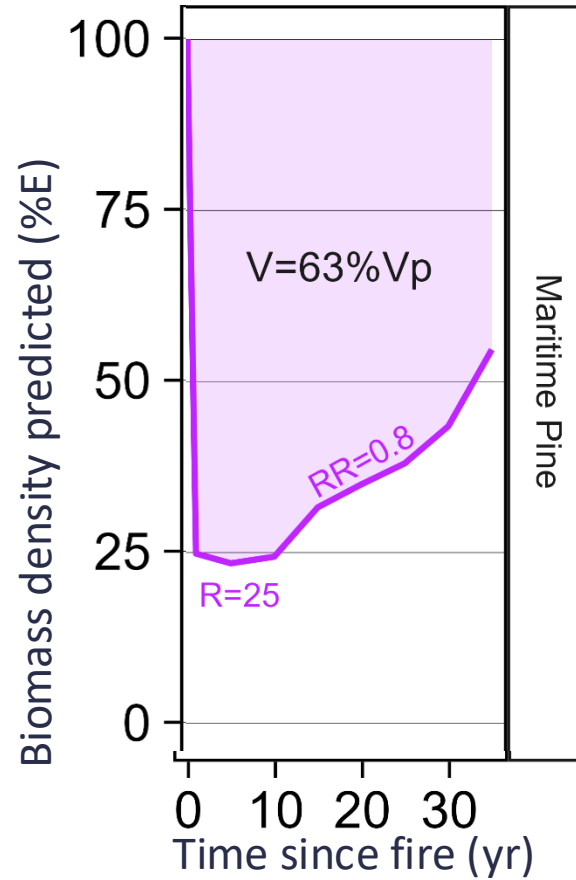
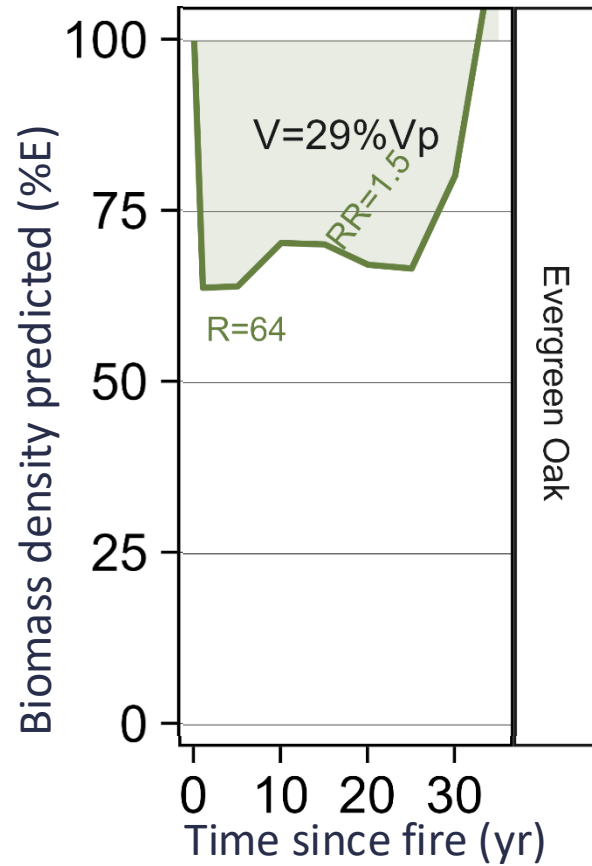


# Carte de vulnérabilité relative des stocks de C au feu

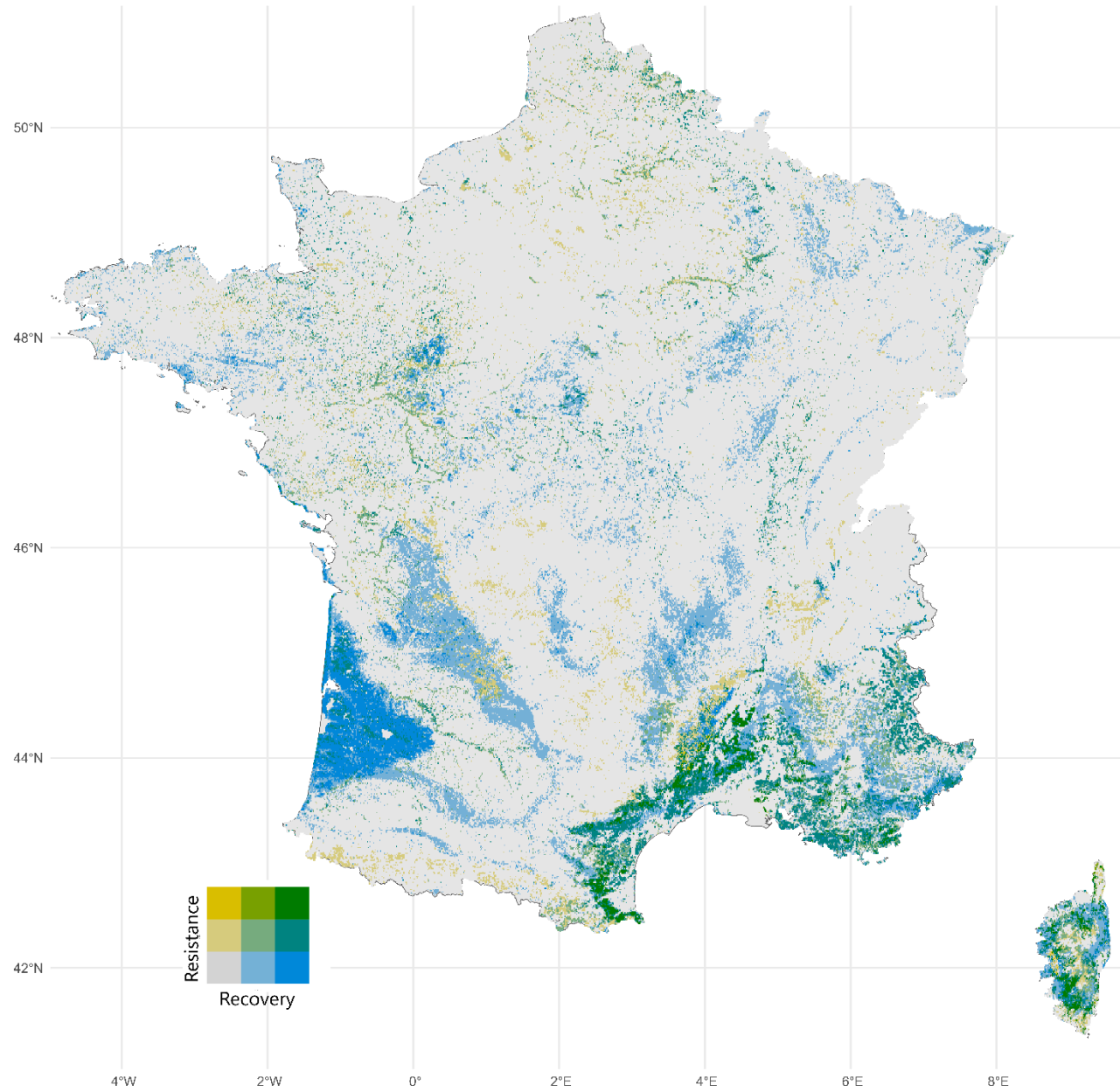




# Pourquoi une telle variabilité?



# Pourquoi une telle variabilité? La réponse des arbres au feu

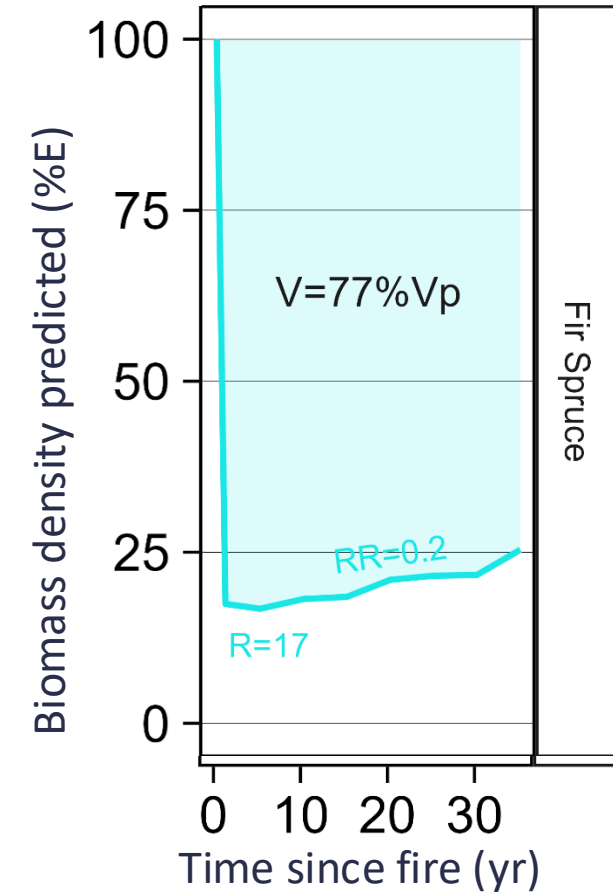
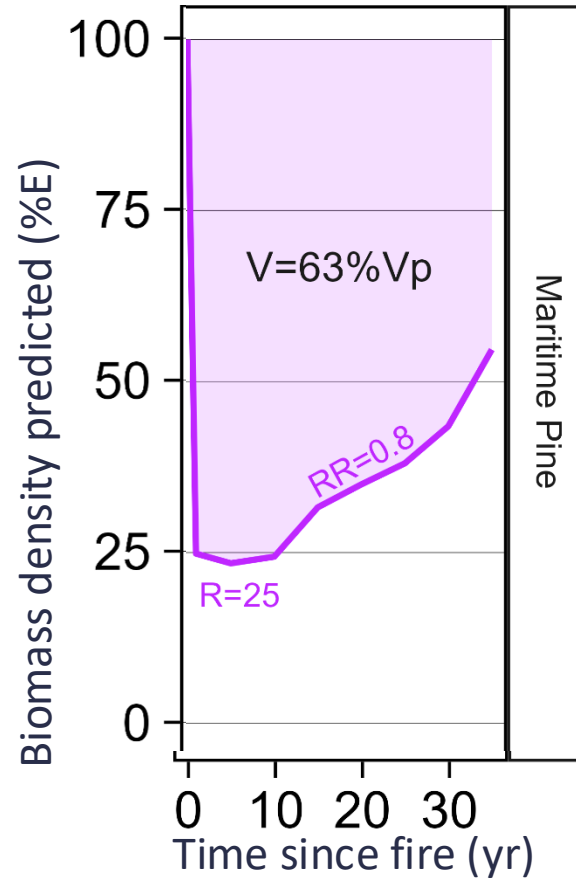
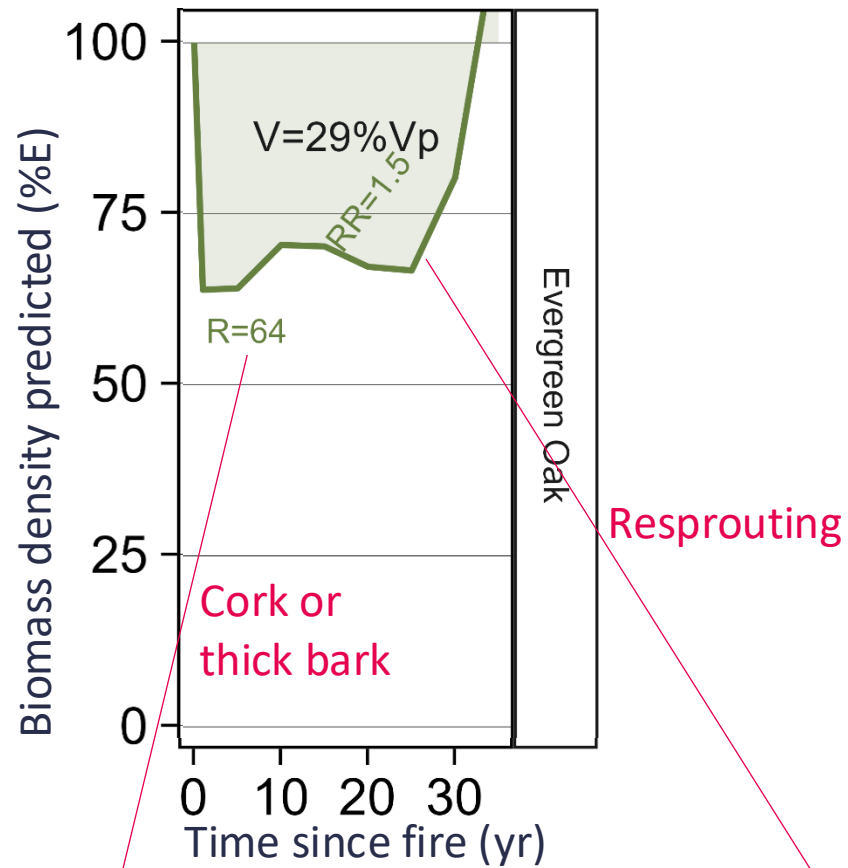


Résistance au feu

Régénération

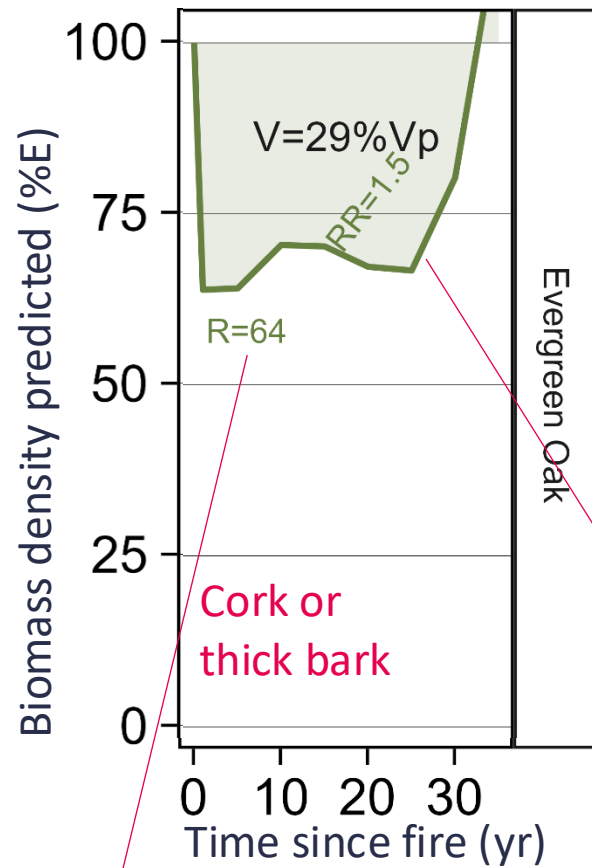
Croissance

# Pourquoi une telle variabilité? La réponse des arbres au feu

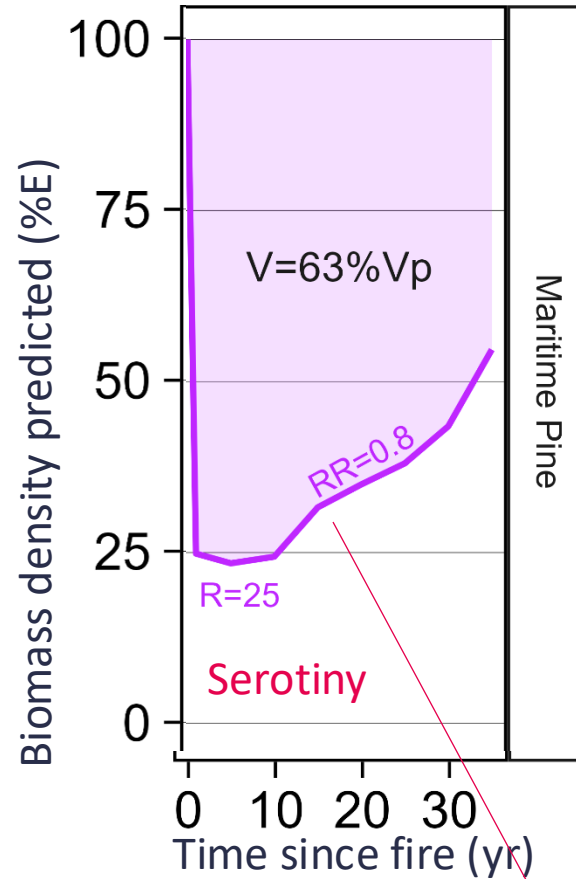




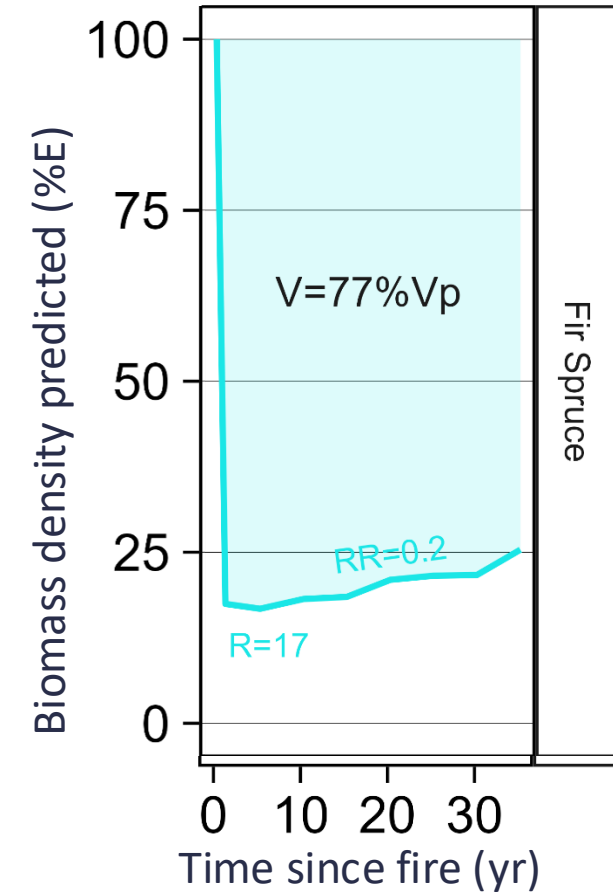
# Pourquoi une telle variabilité? La réponse des arbres au feu



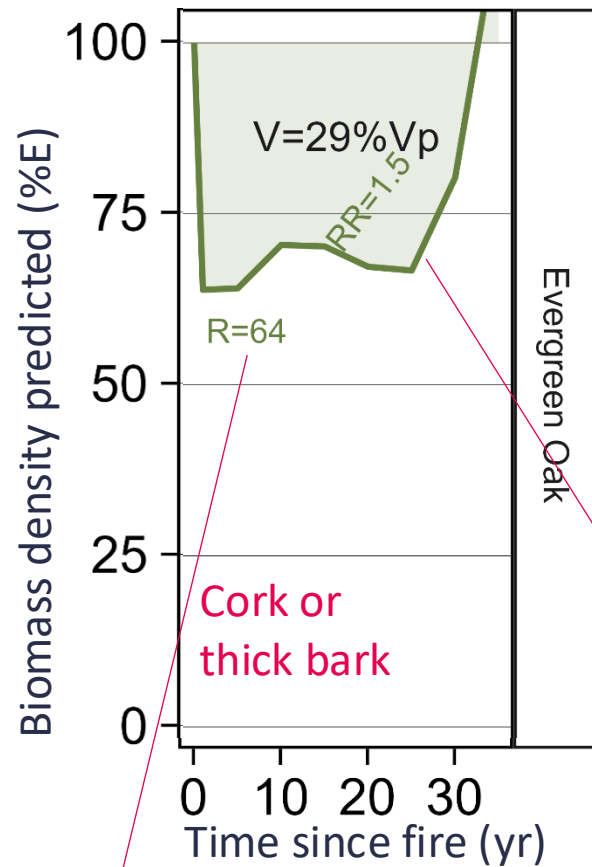
Resprouting



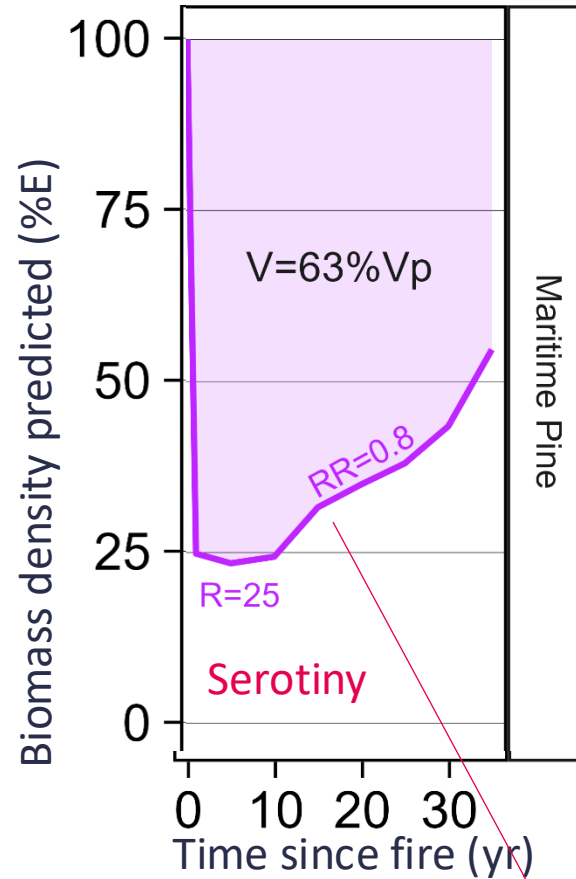
Serotiny



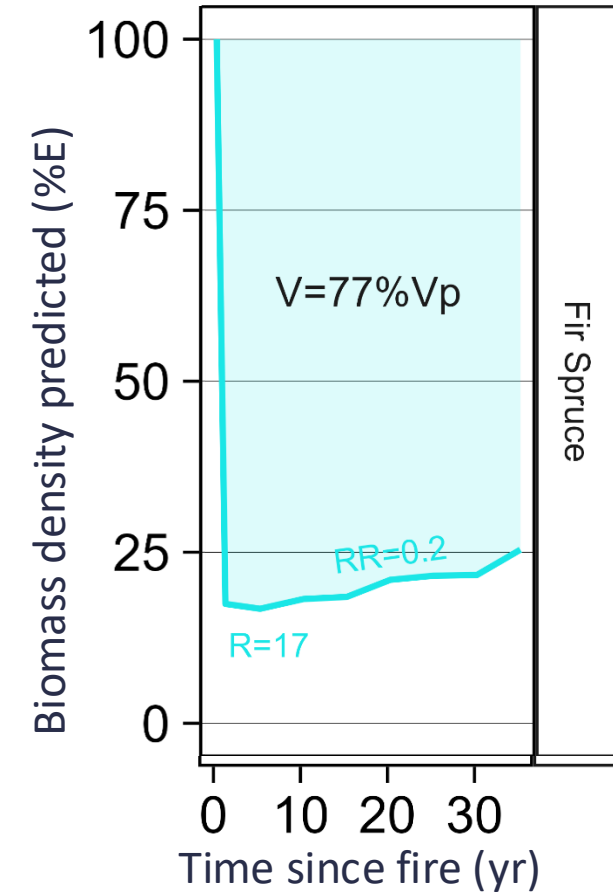
# Pourquoi une telle variabilité? La réponse des arbres au feu



Resprouting



Serotiny



No fire-adapted traits



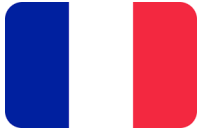
# Conclusion



7,95 MtCO<sub>2</sub>e émis par les feux de forêts en France en 2022



~ 2 fois les estimations par les modèles globaux (GFAS : 4,18 MteqCO<sub>2</sub>e)



~ 2% des émissions de gaz à effet de serre de la France (403,8 MtCO<sub>2</sub>e)



~ 30% du pouvoir de séquestration annuelle des forêts françaises (27 MtCO<sub>2</sub>e/an)



# Conclusion



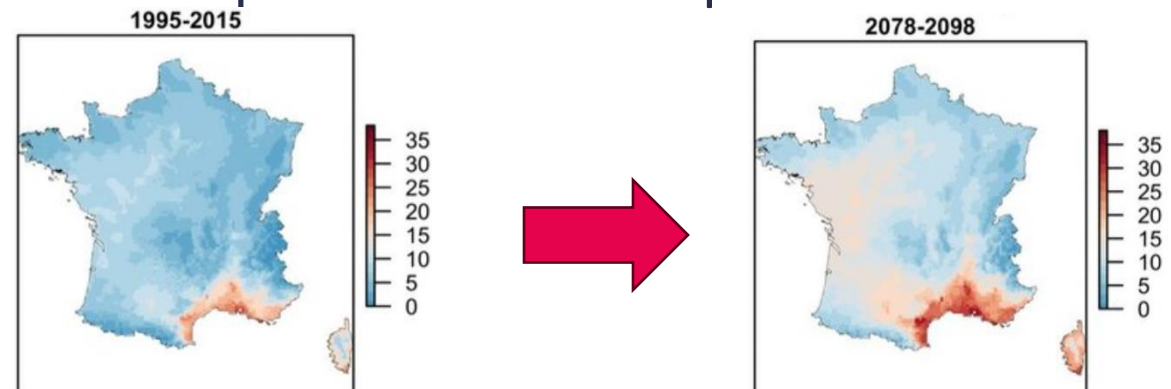
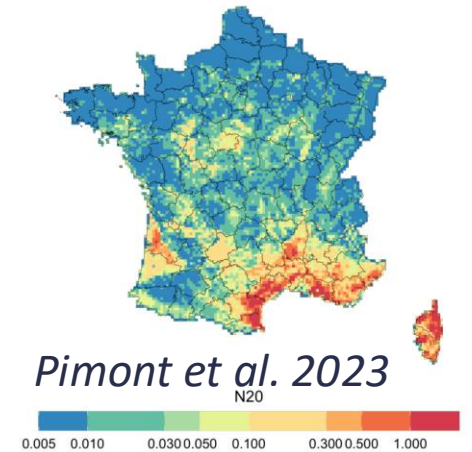
Les forêts méditerranéennes sont les plus affectées par les feux....  
...mais les plus résistantes et résilientes (V=29% sur 30 ans)



La gestion forestière peut être un levier d'action (V=60%)



Les forêts tempérées sont les moins adaptées au feu mais pourraient être affectées dans le futur.



# MERCI A VOUS MERCI A EUX:

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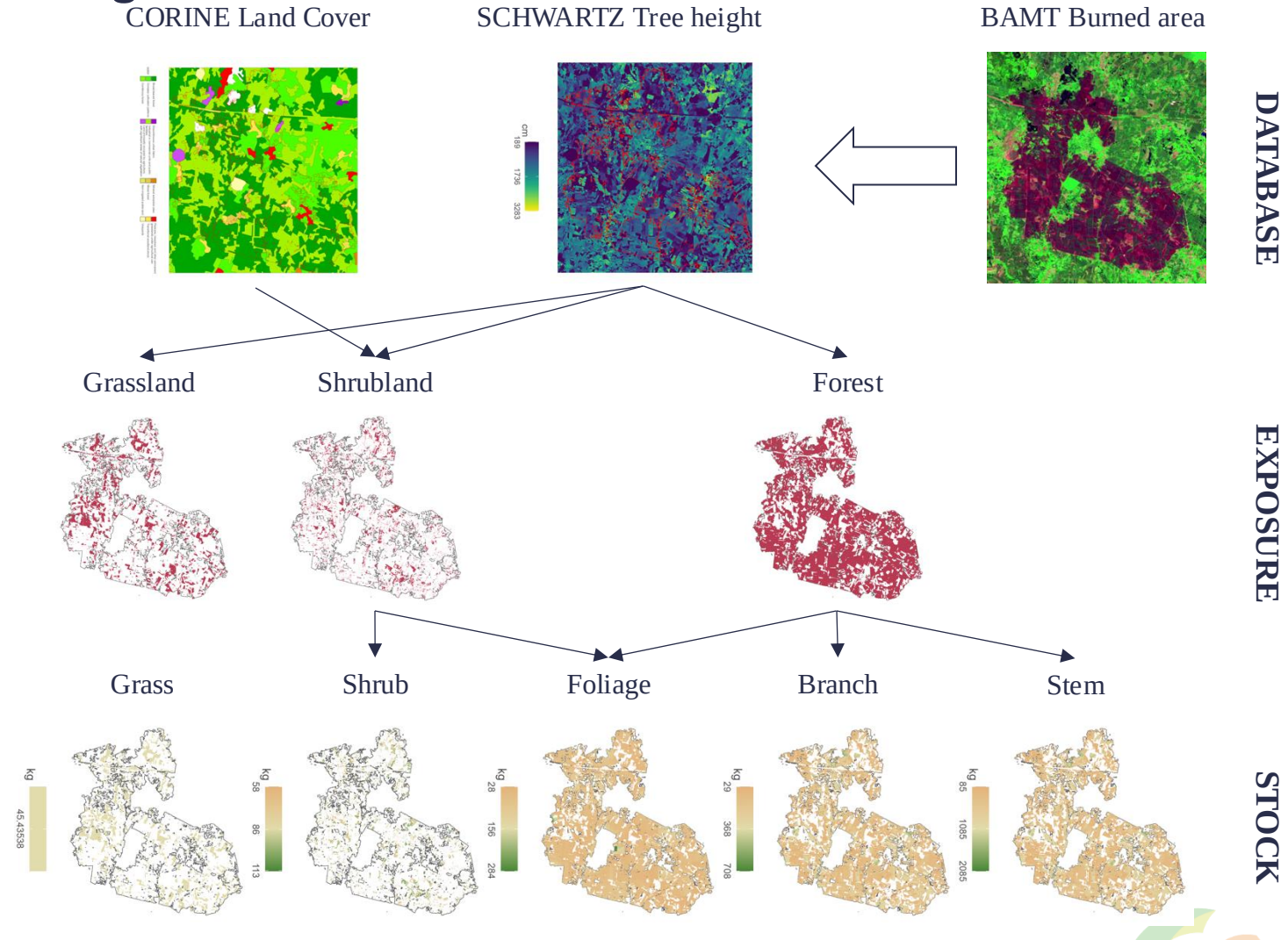
## ***References:***

*Vallet et al. (2023b), Soil smoldering in temperate forests : A neglected contributor to firecarbon emissions revealed by atmospheric mixing ratios. Biogeosciences, <https://doi.org/10.5194/egusphere-2023-2421>*

*Vallet et al. (2024), High-resolution data reveal a surge of biomass loss from temperate and Atlantic pine forests, contextualizing the 2022 fire season distinctiveness in France. Biogeosciences, 20, 3803–3825, <https://doi.org/10.5194/bg-20-3803-2023>*

# Emissions de C en France...nouveaux développements

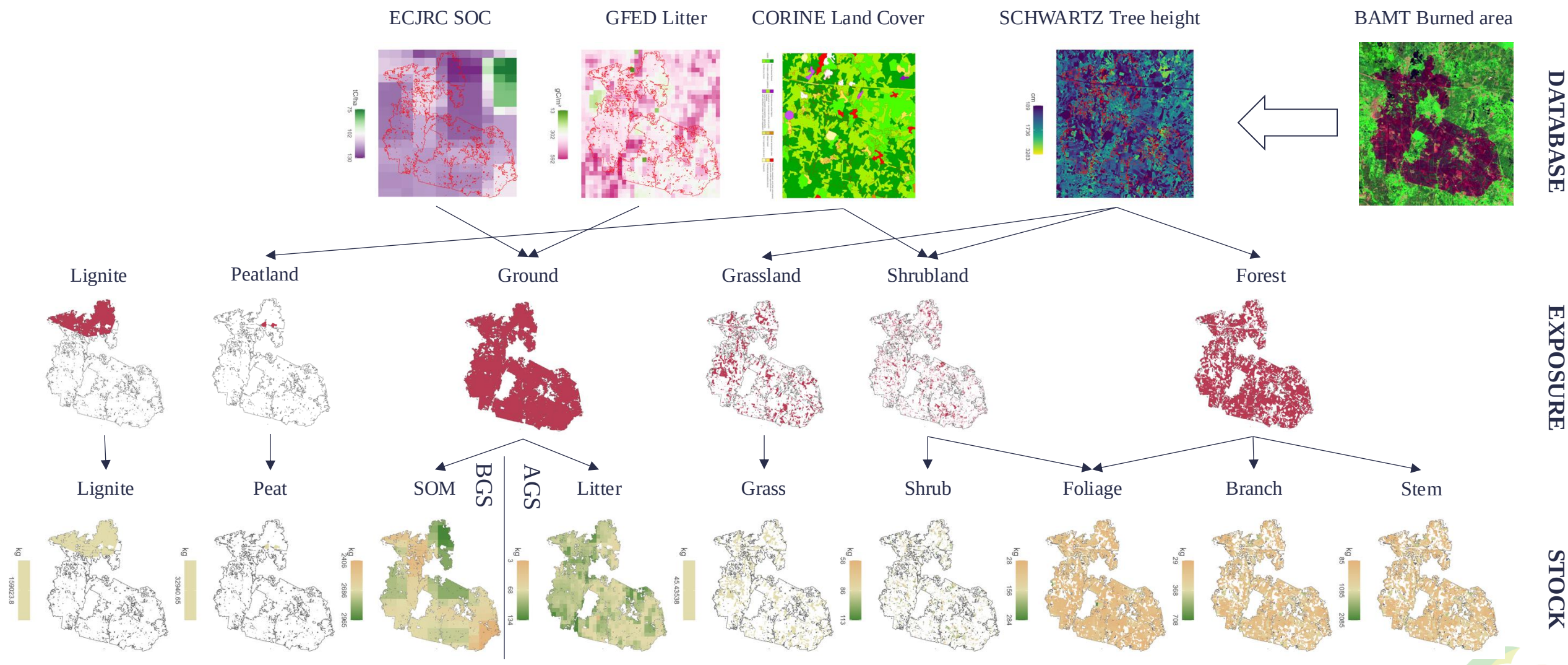
## 2.5 La combustion du sol: vers un nouvel algorithme des émissions de C





# 2) Combustion de sol et Emissions carbone

AGS : AboveGround Stock  
BGS : BelowGround Stock



# 2) Combustion de sol et Emissions carbone

AGS : AboveGround Stock  
BGS : BelowGround Stock

