Impact of Heat Wave Episodes in Summer 2019 on the Carbon Flux

inferred through modelling from ICOS Ecosystem stations in France

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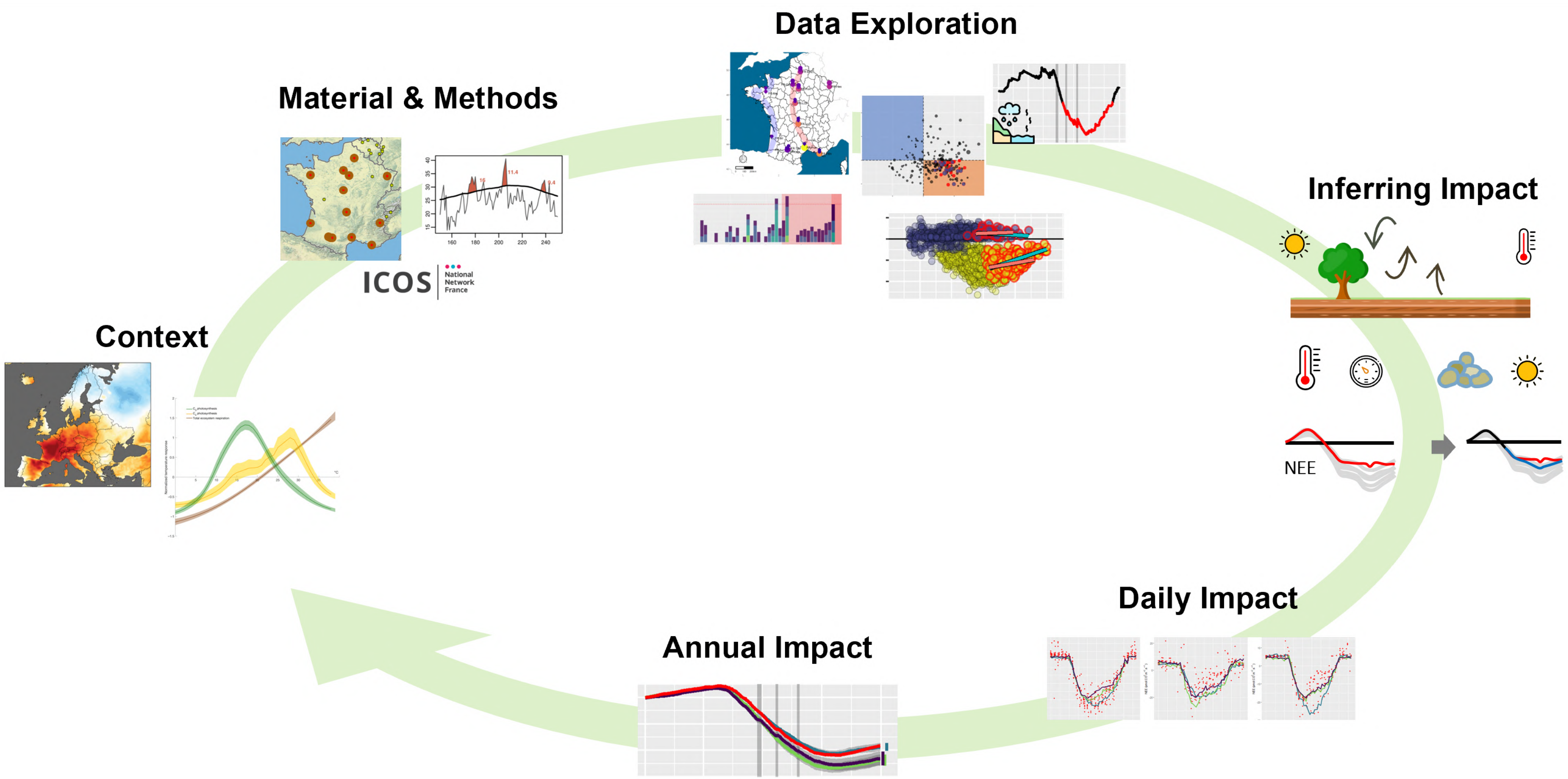
Supervised by P. **Buysse**, B. **Loubet**

Special thanks to G. **Simioni**, S. **Lafont**, D. **Berveiller**, J. **Ruffault**

Outline

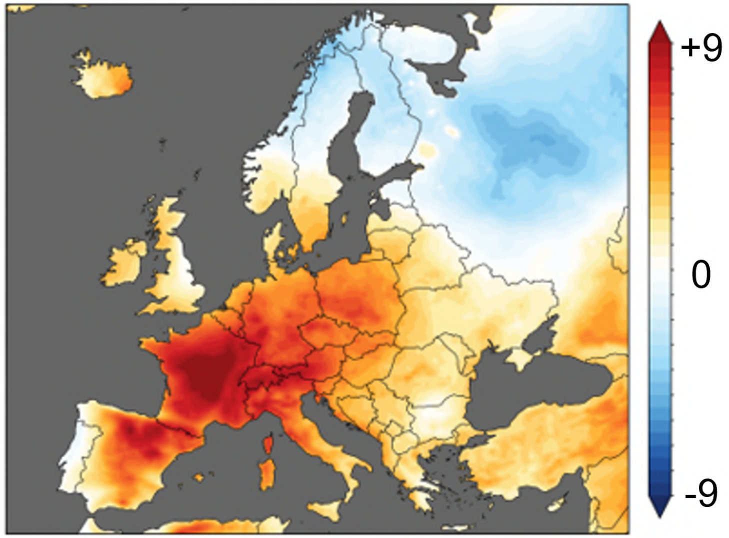


Data Exploration
Material & Methods
ICOS
National Network France
Inferring Impact
Context
NEE
Daily Impact
Annual Impact

Context

2019 Summer Heat Waves in France

Temperature Anomaly (25-29 June 2019)



Anomalies up to +9°C in France.

In central France, equivalent to 2003,

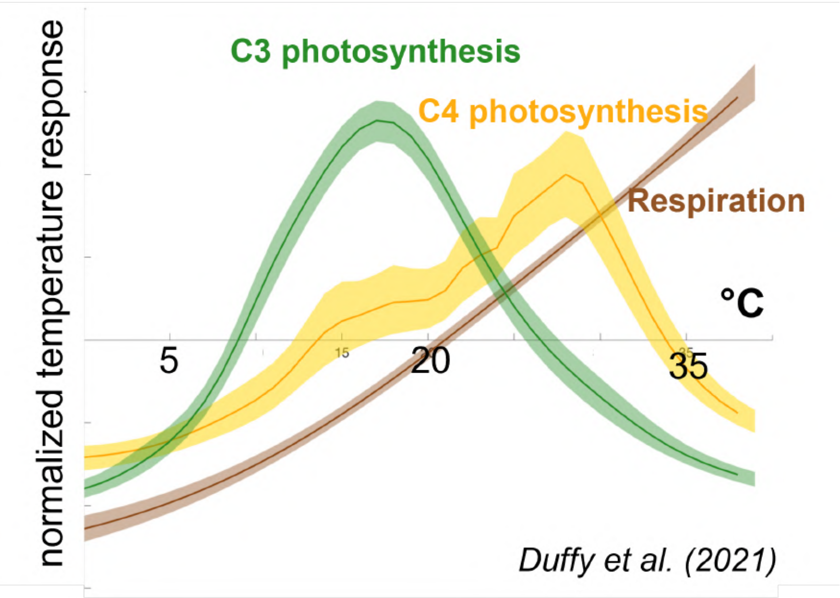
when summer accounted for 70,000 additional deaths in Europe.

(Robine et al., 2008)

In 2019 again, absolute and local temperature records.

Context

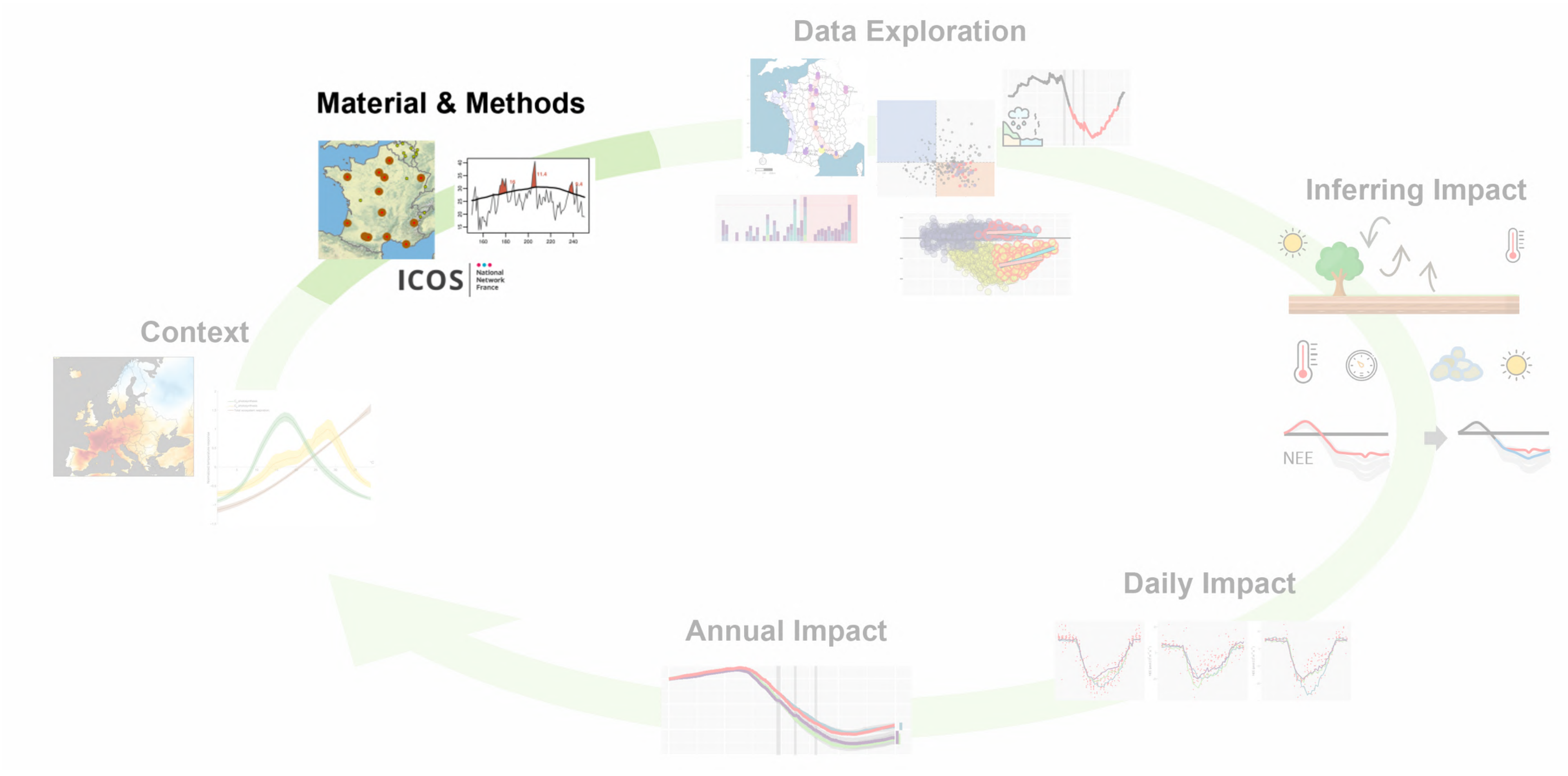
Ecosystem Response to Temperature



- Land carbon sink strength depends on temperature. (Duffy et al., 2021)
- Extreme events are likely ↑ intense and ↑ frequent in the future. (IPCC, 2013)
- Uncertainty on land sink as carbon regulator. (Duffy et al., 2021)

Scientific questions: (1) Do heat waves decrease ecosystems' carbon sequestration capacity? (2) Does the ecosystems kept sequestering less carbon even after heat waves ceased?

Material and Methods



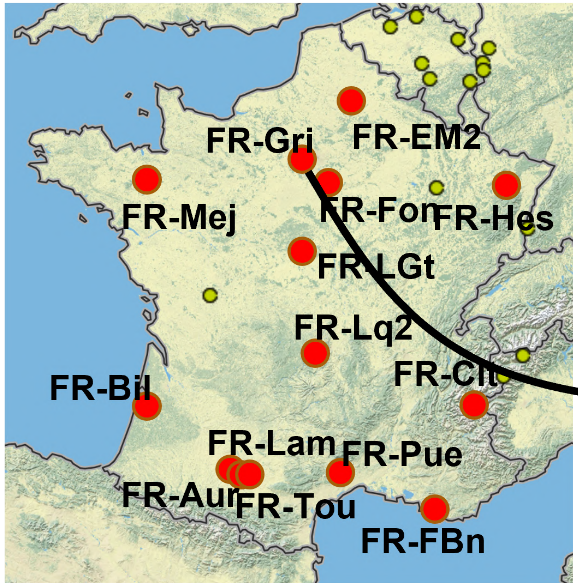
Material and Methods

Observation Sites

ICOS National Network France

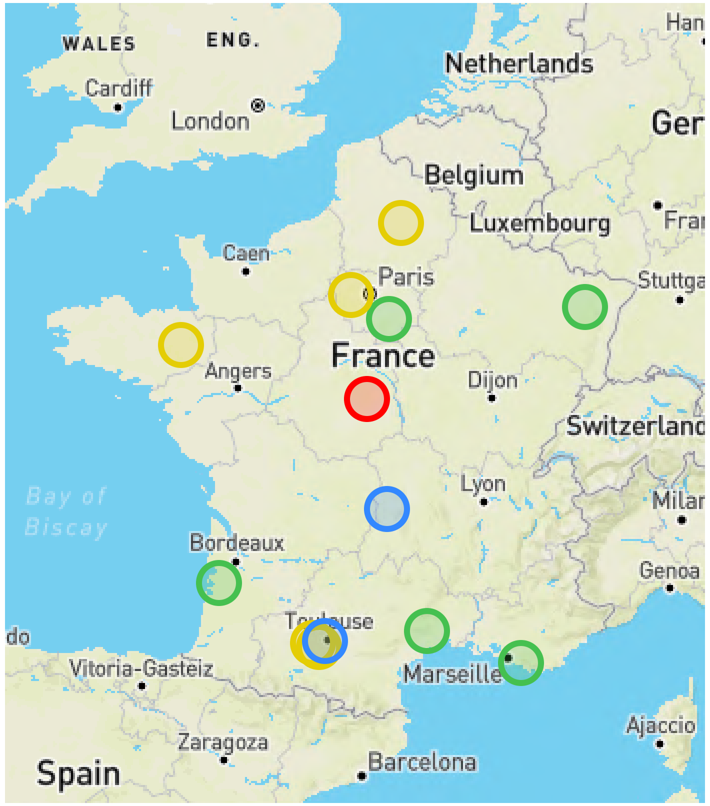
Data from 13 sites

Forests (5)
Cropland (5)
Grassland (2)
Peatland (1)



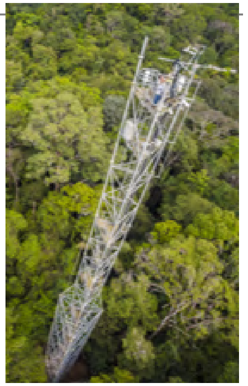
Material and Methods

Observation Sites



ICOS | INTEGRATED CARBON OBSERVATION SYSTEM

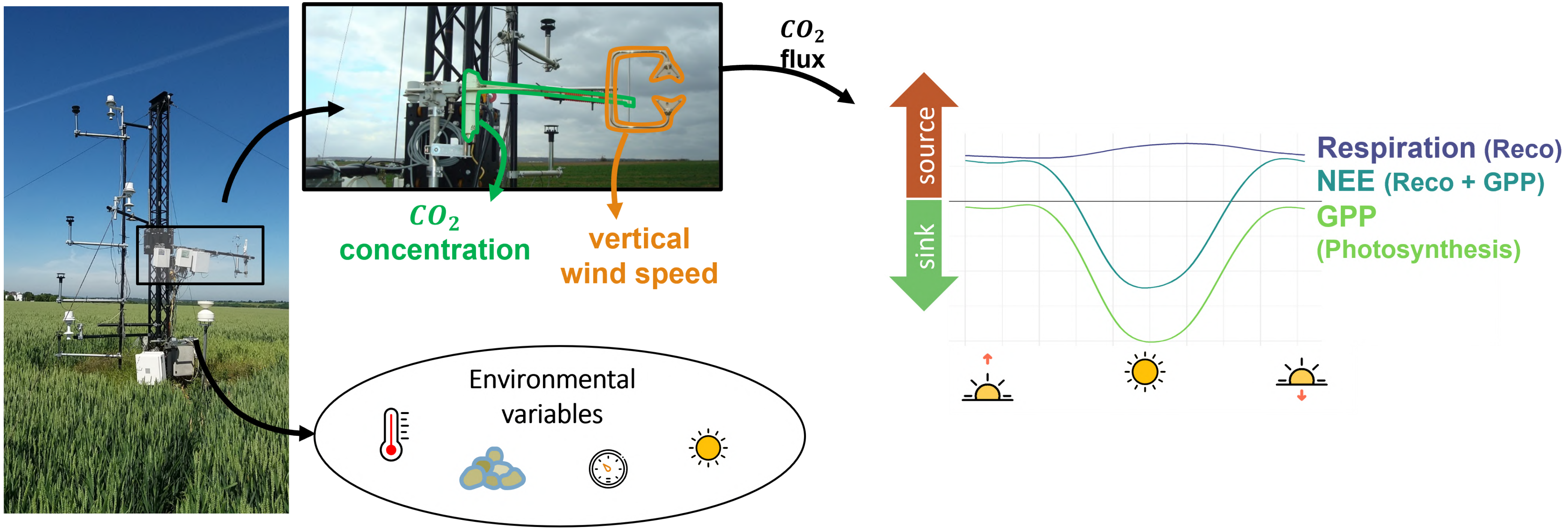
- 5 forest sites
- 5 crop sites
- 2 grassland sites
- 1 peatland site

https://www.icos-cp.eu/

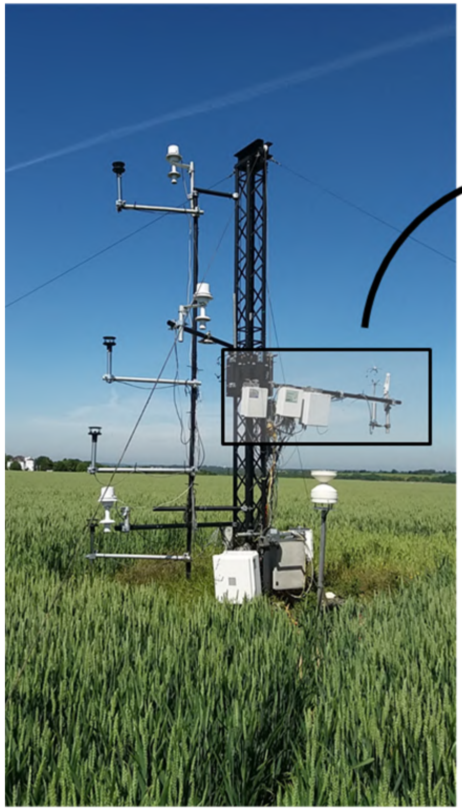
Material and Methods

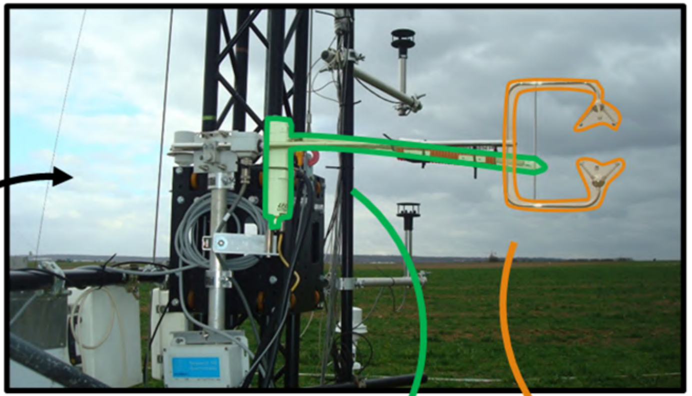
Data Acquisition



Material and Methods

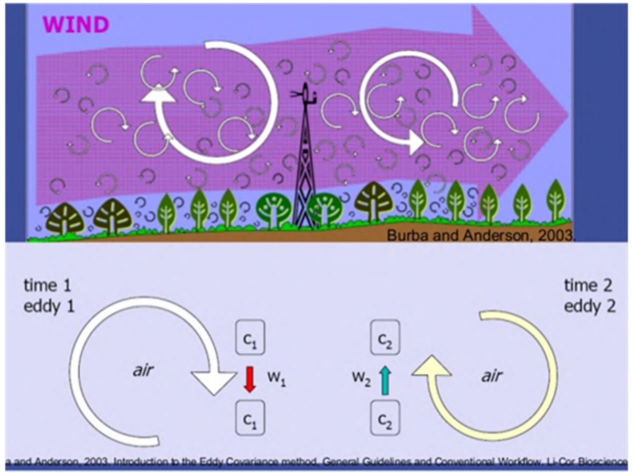
Eddy Covariance





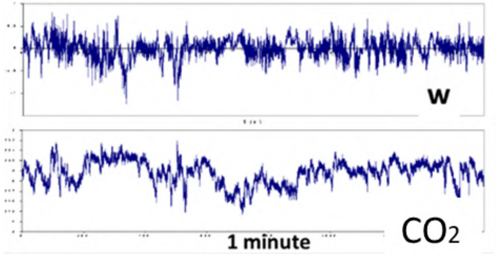
high-frequency (20 Hz) infrared gas analyzer

3D sonic anemometer



Burba, 2013

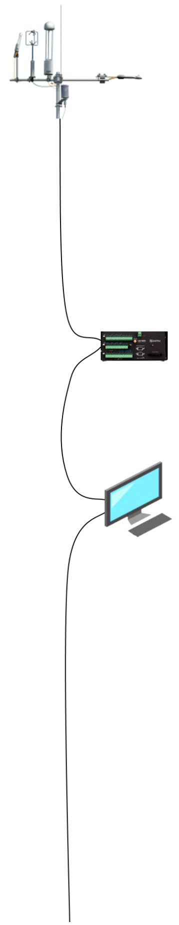
Very high acquisition rate (10 or 20Hz)



eddy-covariance method

Data Handling

from 20 Hz data to Gap filling



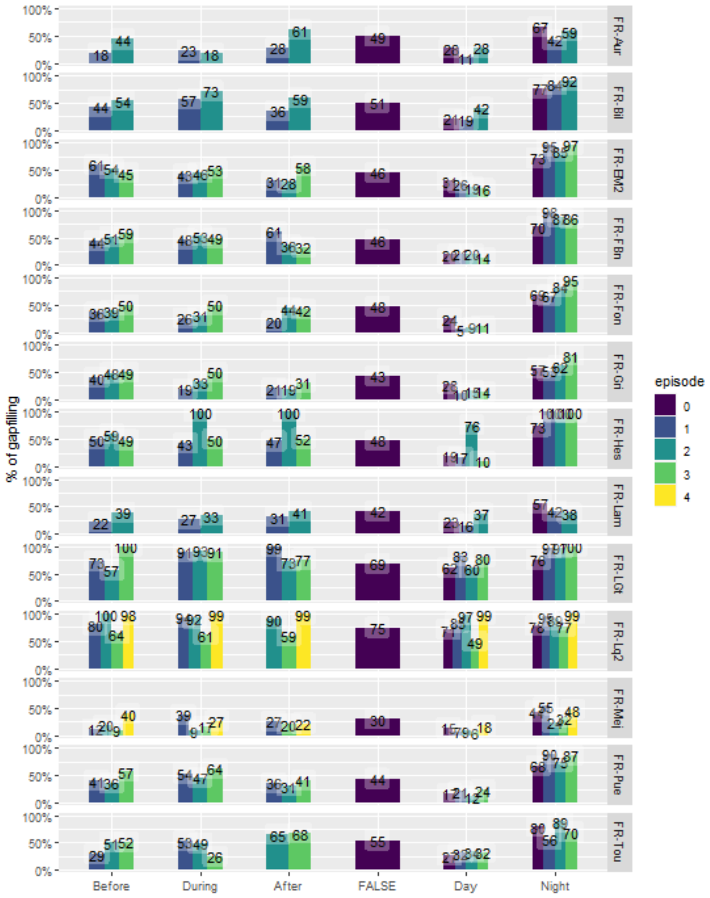
Steps:

1. Measurement (20Hz)
    - Infrared gas analyser.
    - 3D sonic anemometer.
    - ...

2. Datalogger

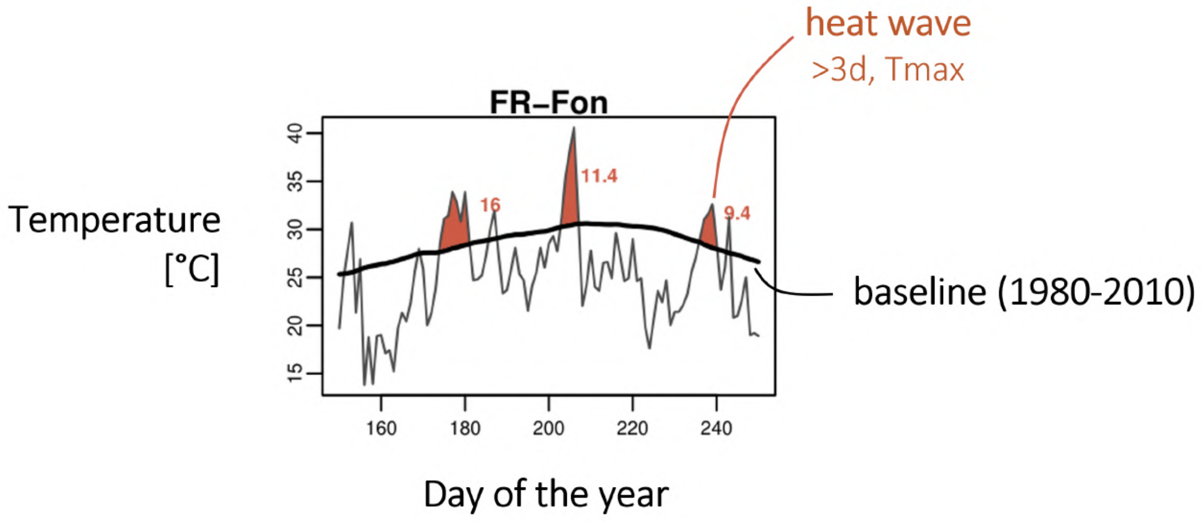
   Sync data from instruments.

3. Processing
    - Corrections.
    - Calculating flux by eddy-covariance method.
    - Gap filling (fig. →).
    - Partitioning.

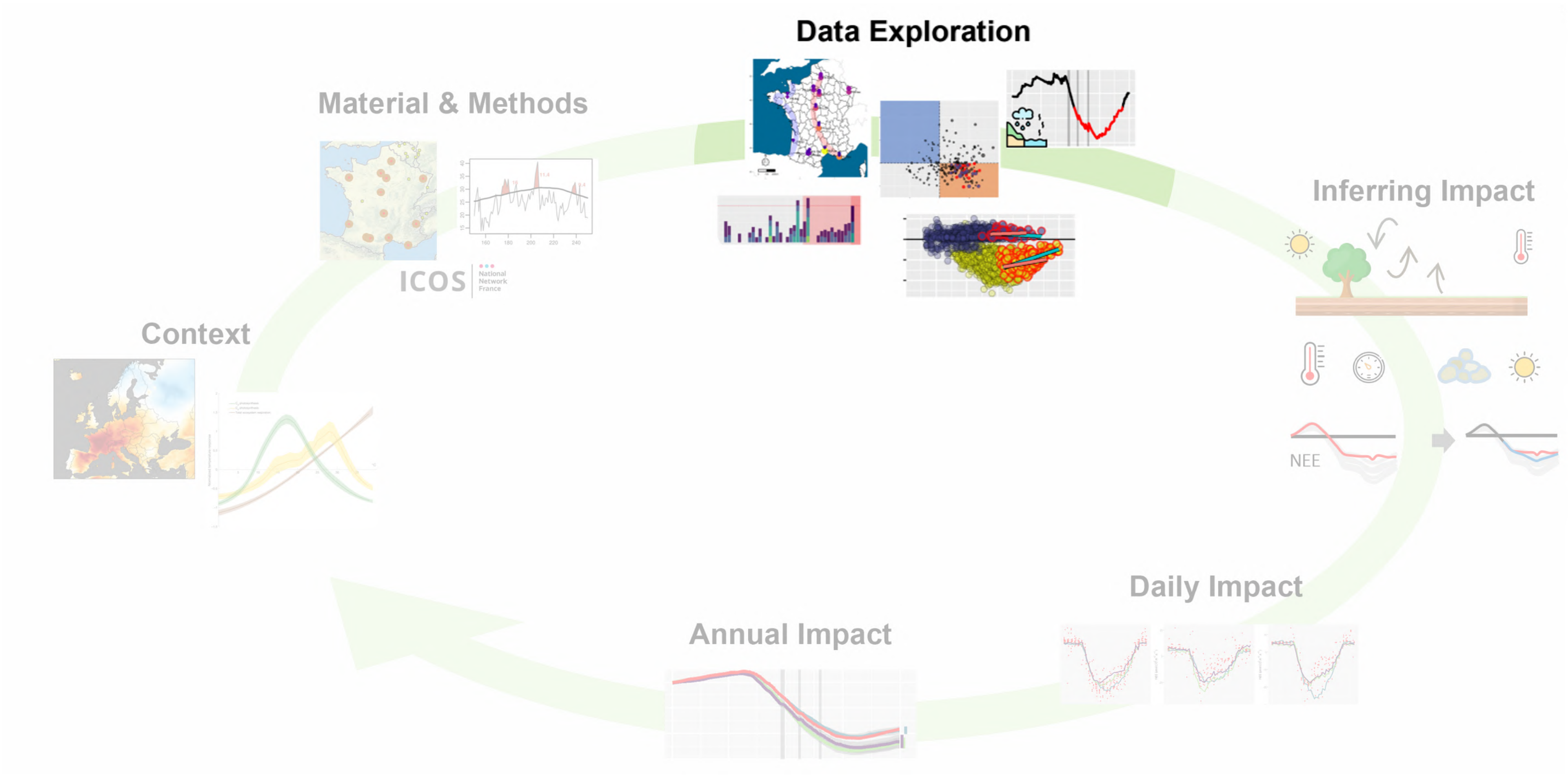


Material and Methods

Identifying Heat Waves



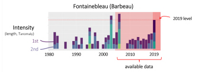
Data Exploration

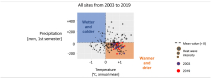


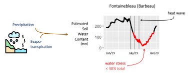
Data Exploration

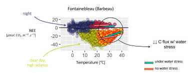
Map of 2019 Heat Waves

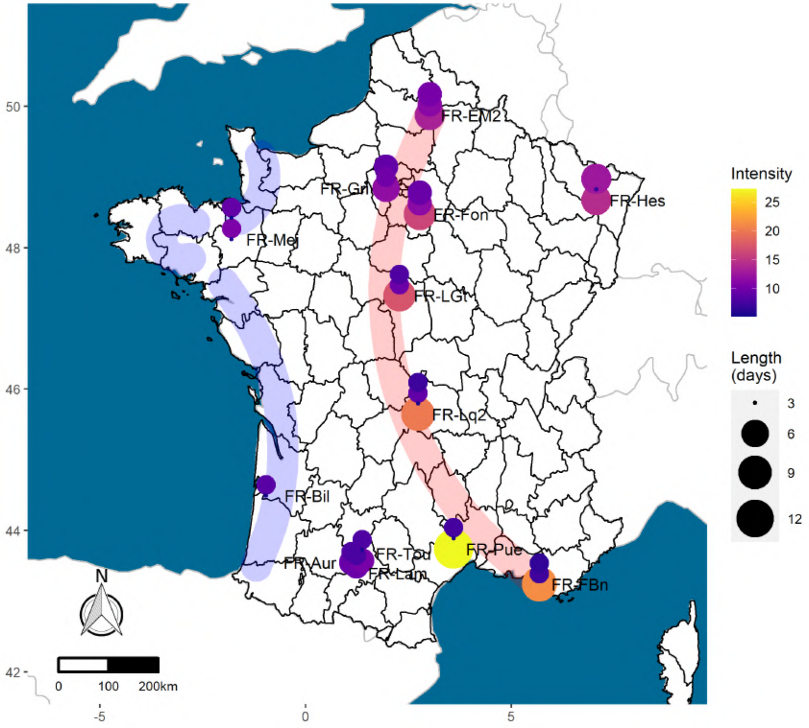
→





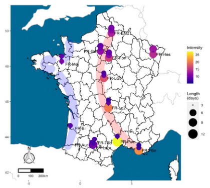






Data Exploration

Historic of Heat Waves



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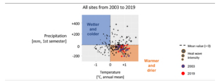
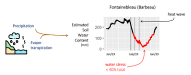
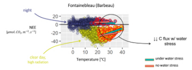
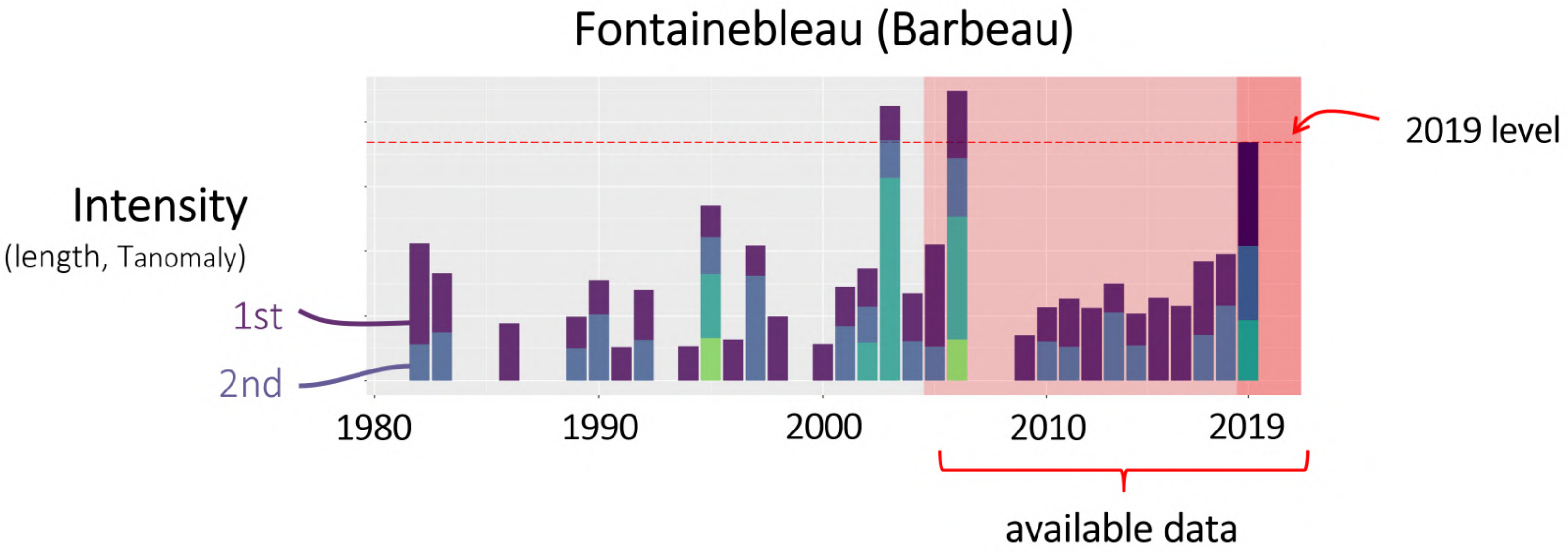


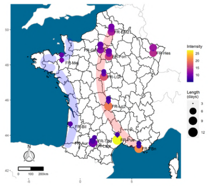


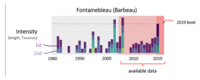




Data Exploration

Heat Waves during Drier and Warmer Years





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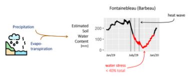
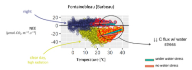
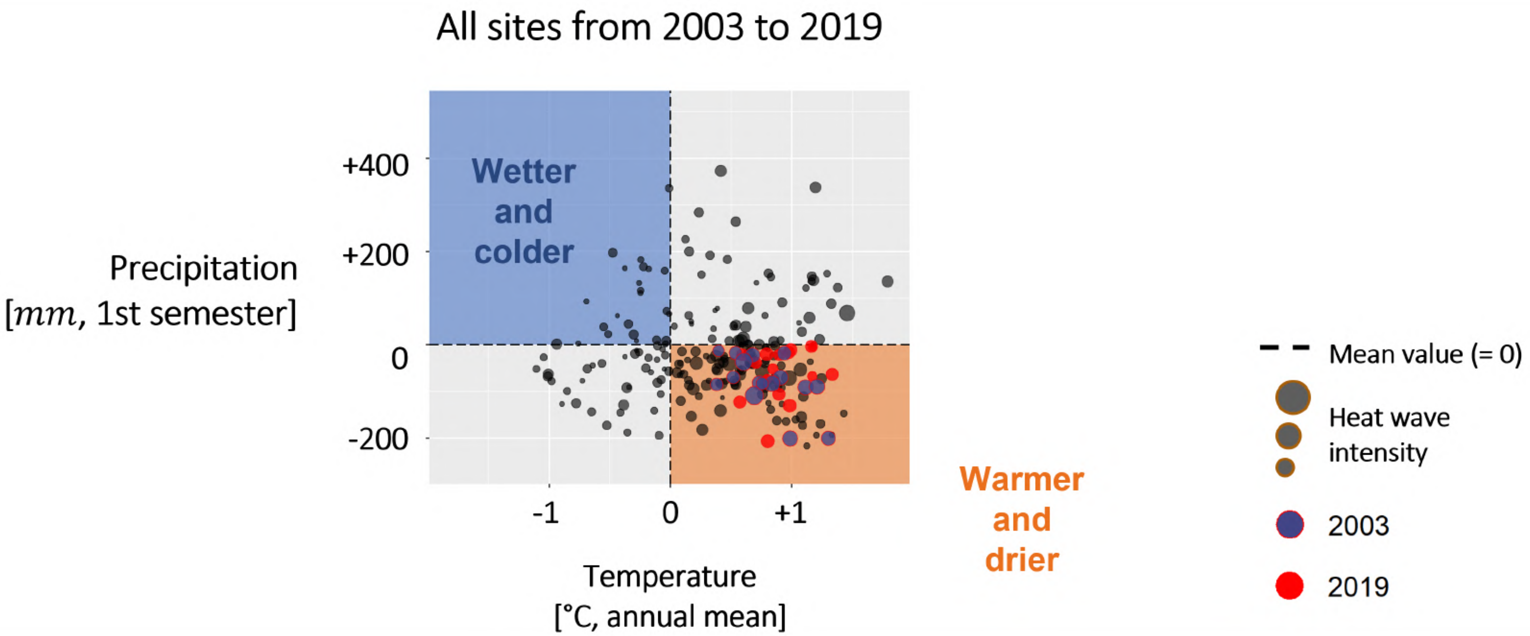
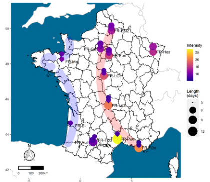


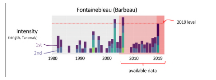


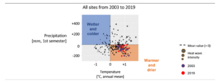


Data Exploration

Water Stress and Heat Waves







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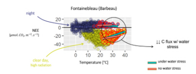
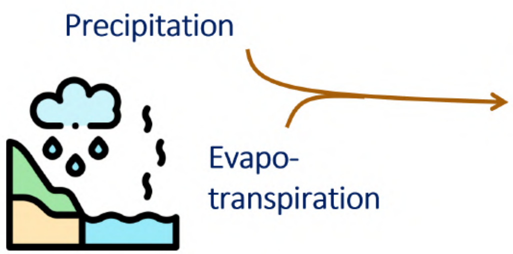
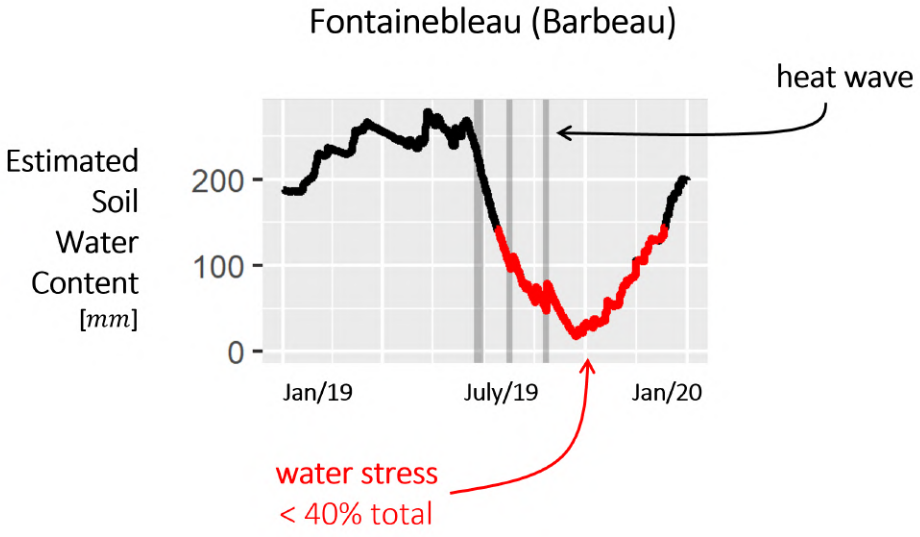






Data Exploration

Estimated Soil Water Content

- Model:

$$initialRU = 0$$

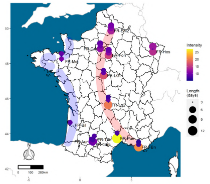
$$SW_t = \begin{cases} RU, & t = 1 \\ SW_{t-1} - ETR_t + P_t, & t > 1 \end{cases}$$

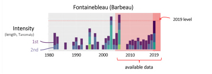
$$\text{if } SW_t > RU : SWt = RU \text{ (lost)}$$
$$\text{if } SW_t < 0 : \text{restart avec } RU + 1$$
$$\text{where, ETR and P are gapfilled data.}$$

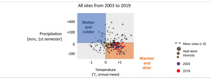
- Water Stress (40% of available water capacity).

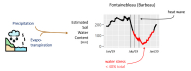
Data Exploration

Water Stress and Carbon Flux









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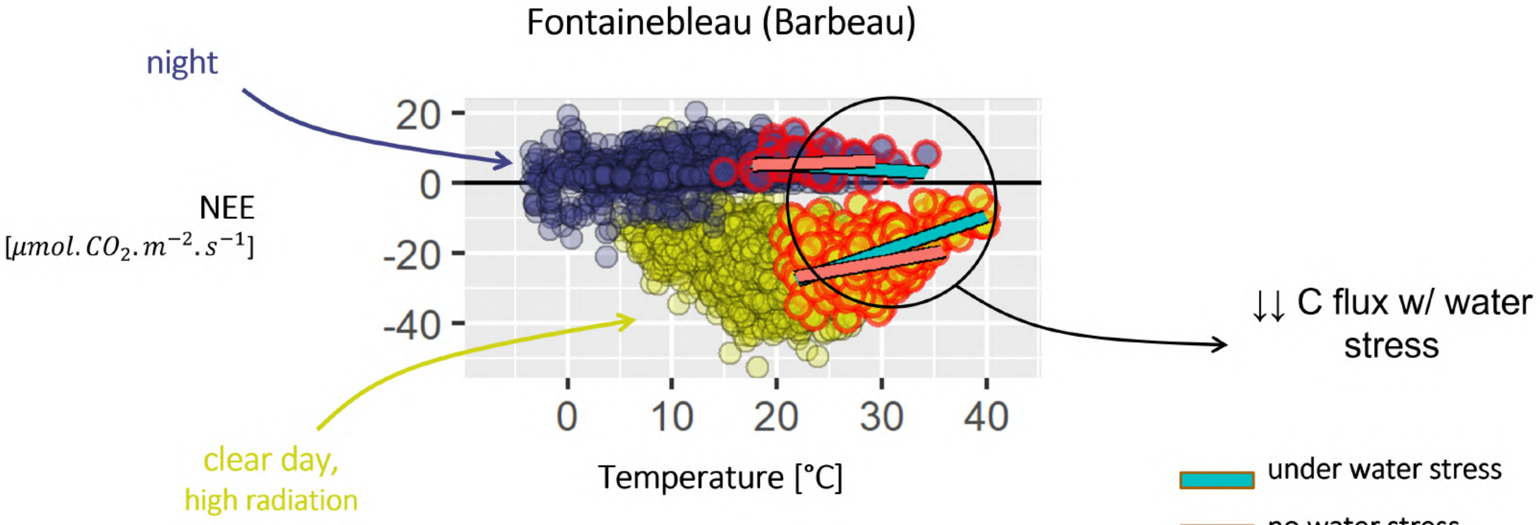
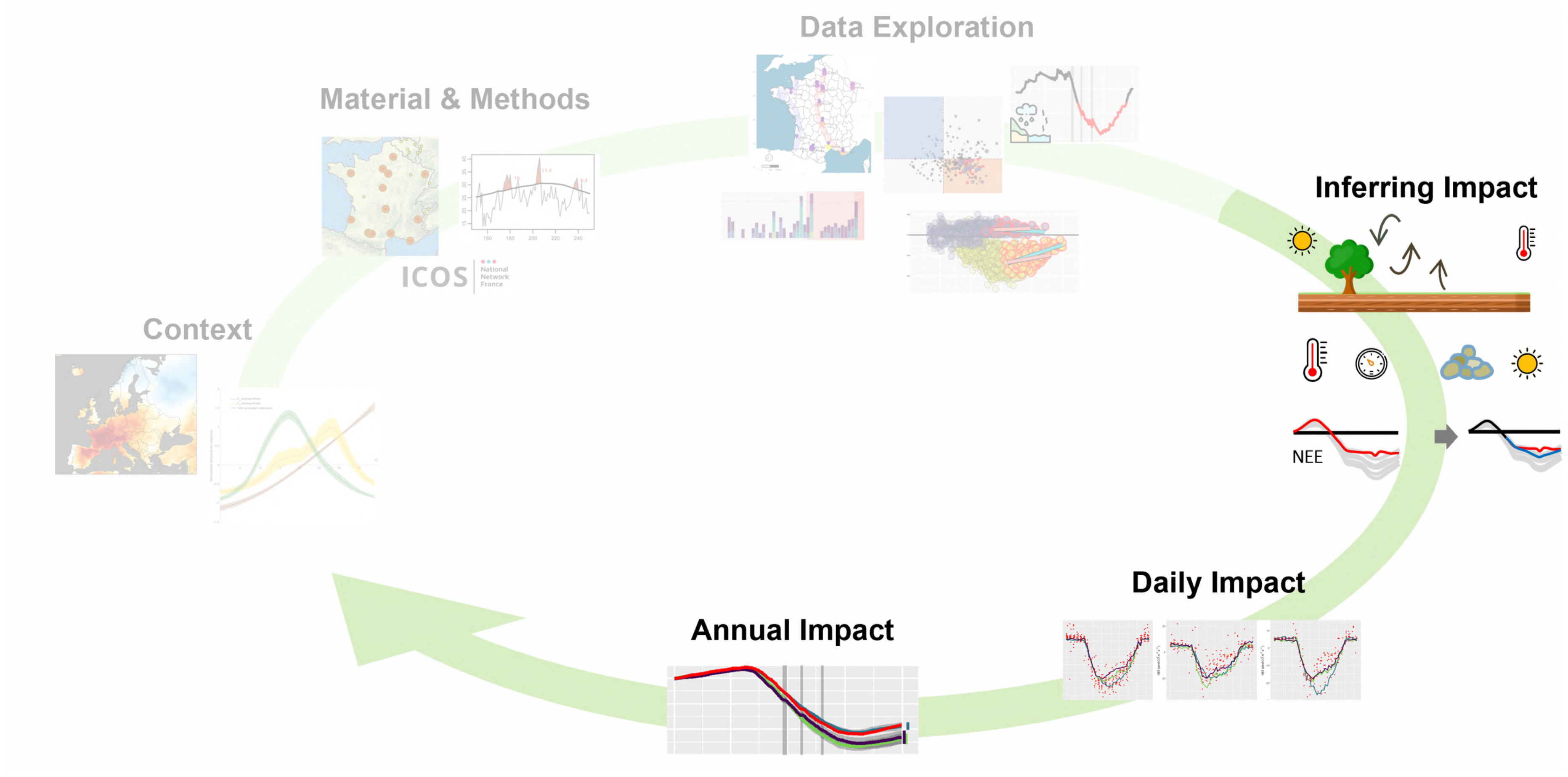
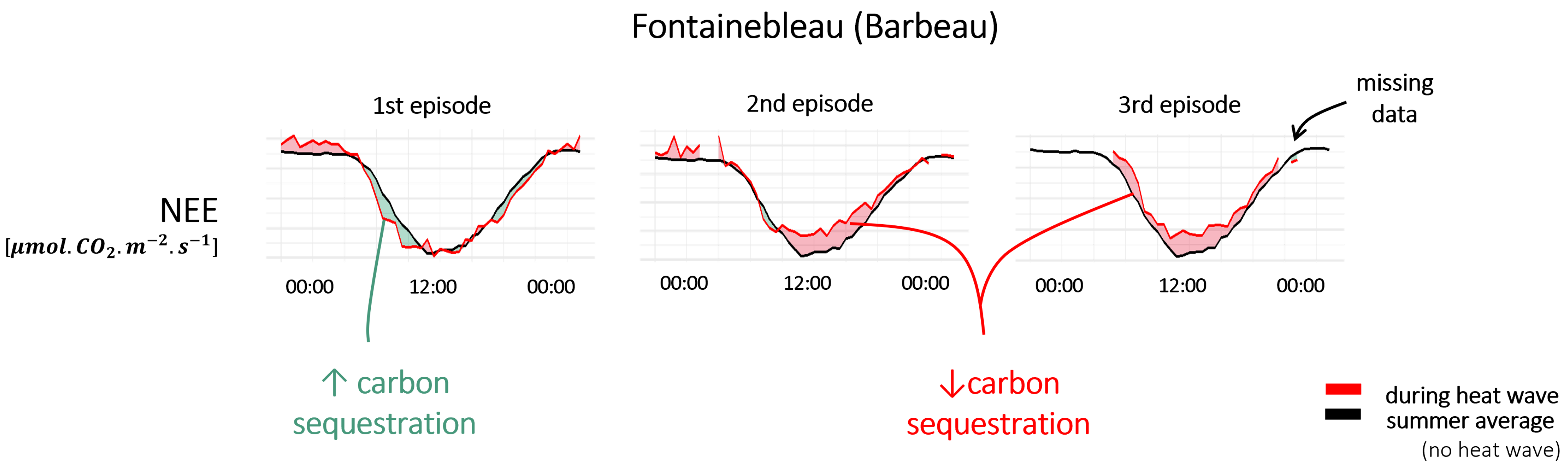


Inferring Impact



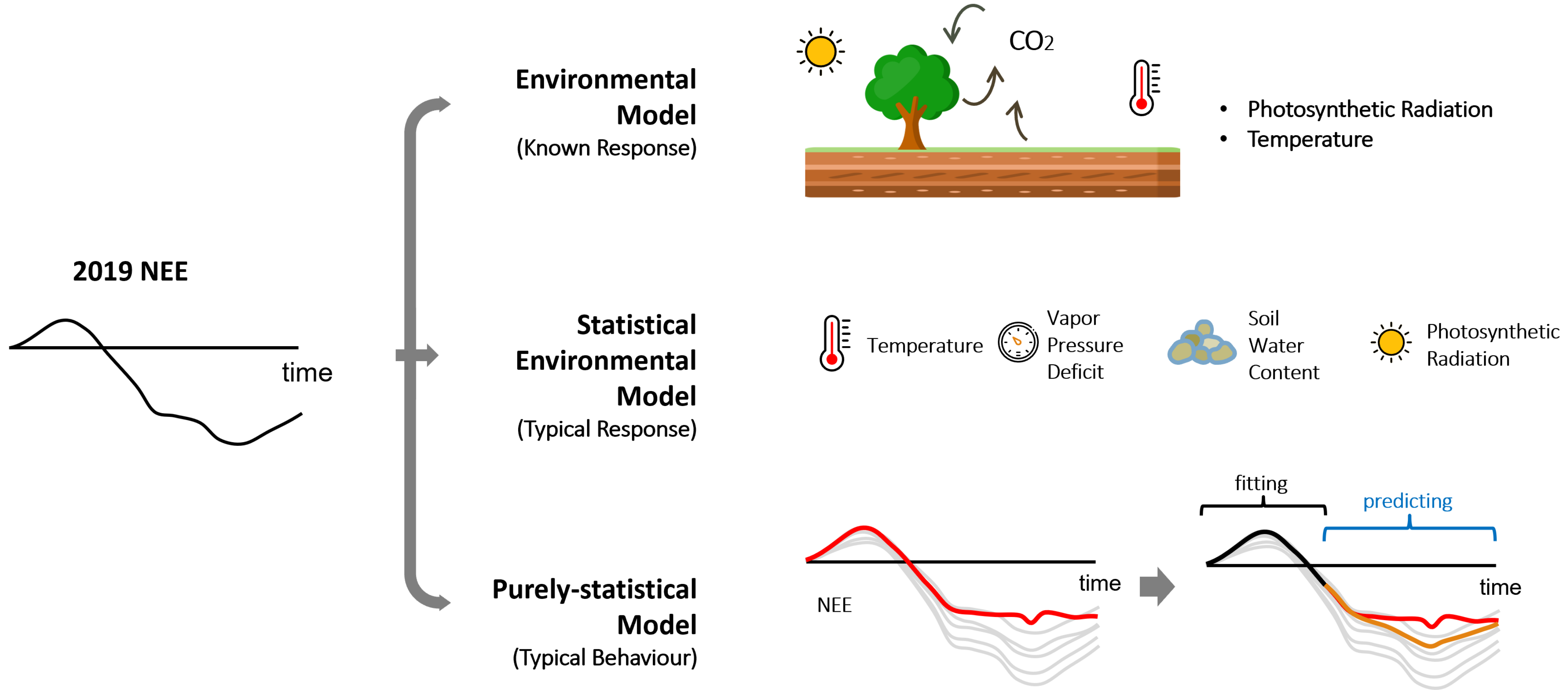
Inferring Impact

Hourly Average



Inferring Impact

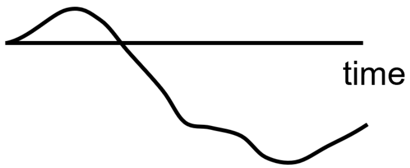
Modelling



Inferring Impact

Modelling

2019 NEE



Environmental Model
(Known Response)

$$NEE = f(\mathrm{T}, \mathrm{PAR})$$

GPP: $f(T, PAR)$, $Farquhar$

R_{eco}: $f(T)$

Statistical Environmental Model
(Typical Response)

$$NEE = \beta_T^i \times T + \beta_{VPD}^i \times VPD + \beta_{SWC}^i \times SWC + \beta_{PAR}^i \times PAR$$

i = week of the year (annual), 30-min (daily)

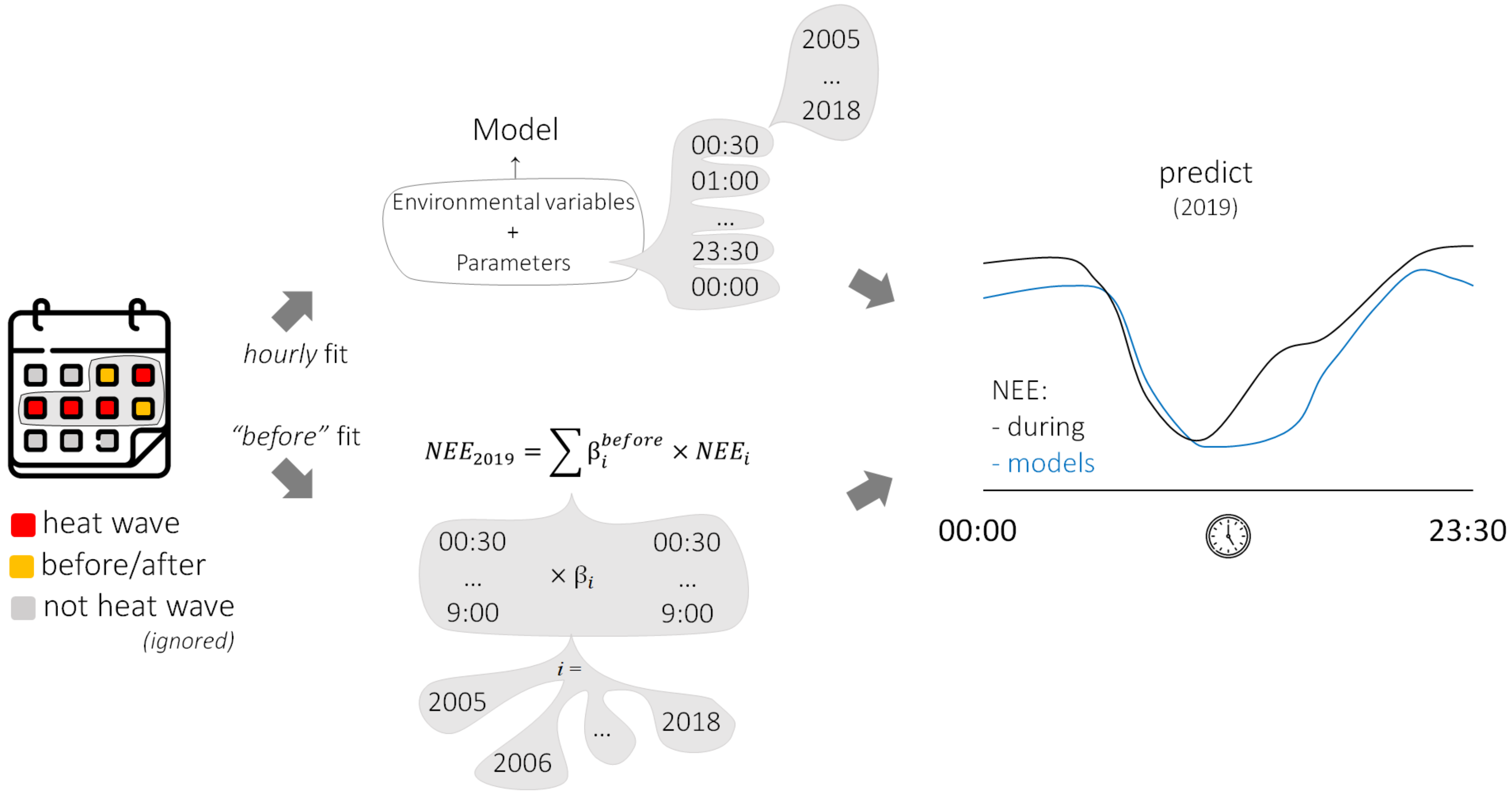
Purely-statistical Model
(Typical Behaviour)

$$NEE_{2019} = \sum \beta_i^{before} \times NEE_i$$

i = control years

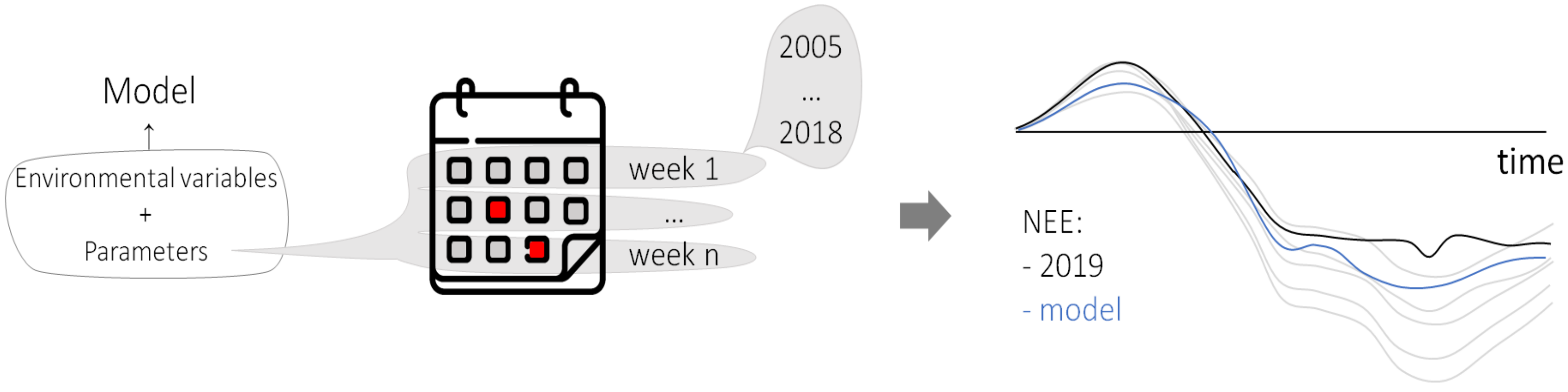
Modelling Daily Impact

parameter optimization

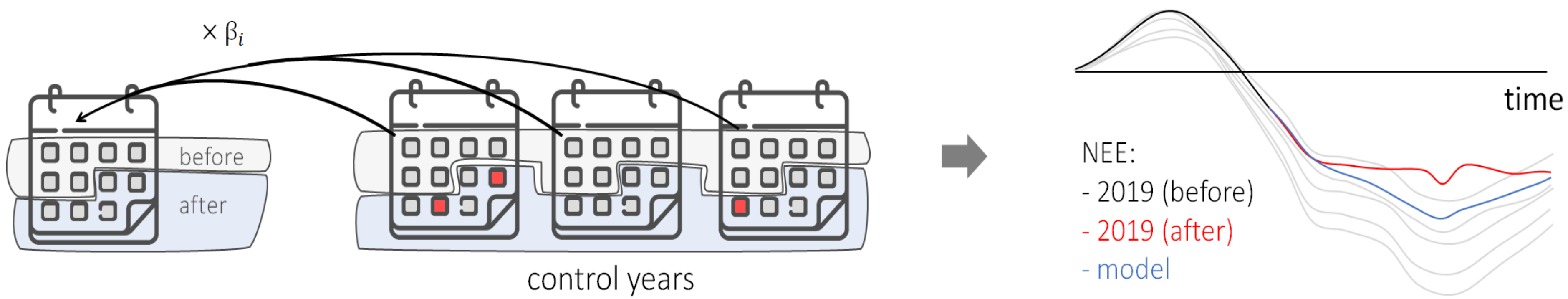


Modelling Annual Impact

parameter optimization



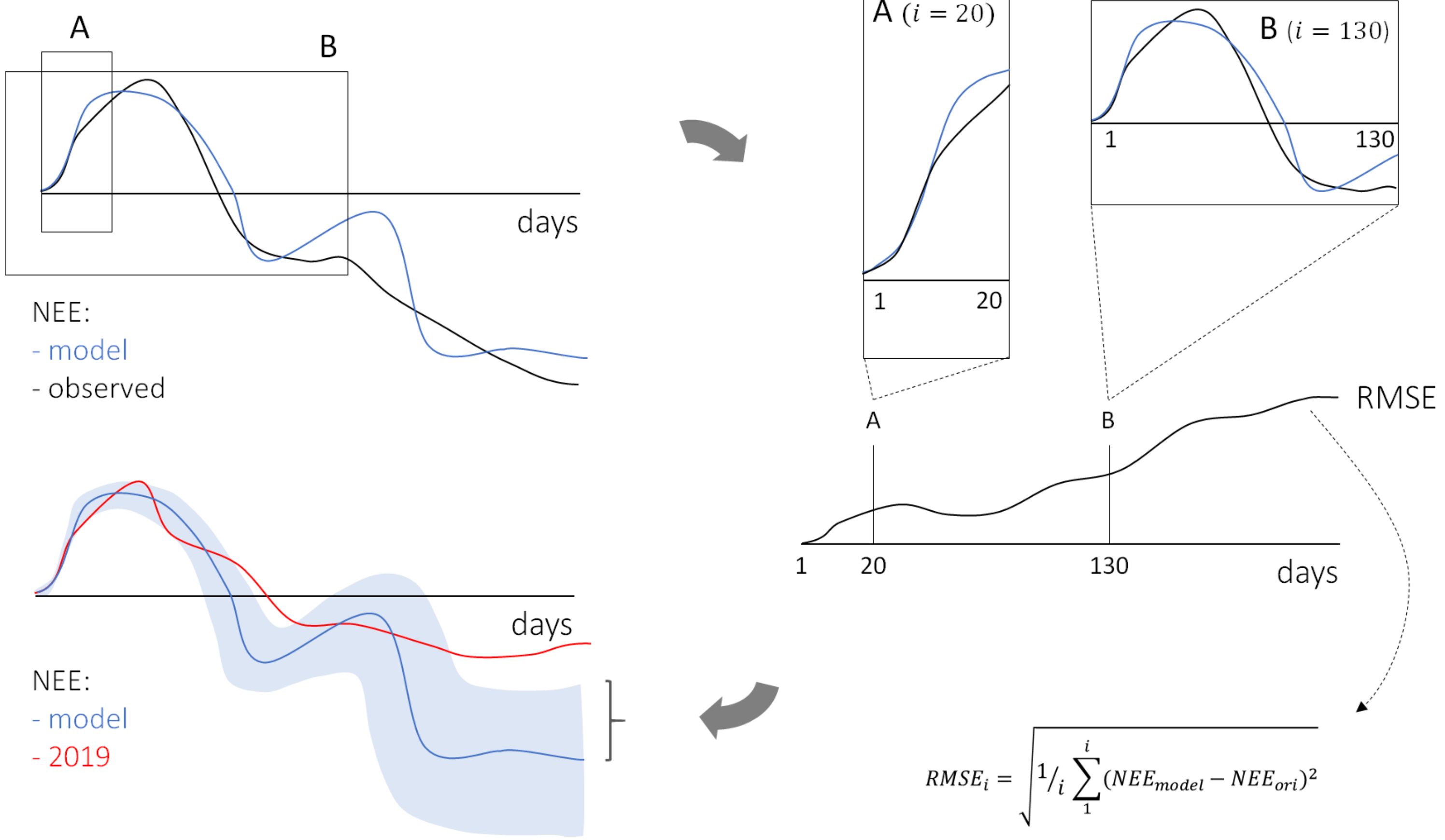
$$NEE_{2019} = \sum \beta_i^{before} \times NEE_i$$



Modelling Annual Impact

uncertainty

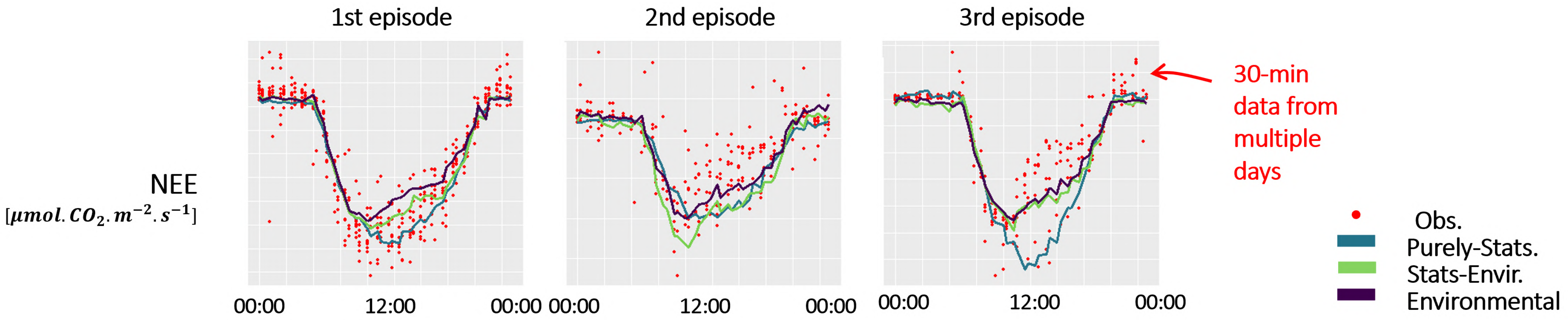
Applied to all control years (2005-2018)



$$RMSE_i = \sqrt{{}^1/_i \sum_{1}^{i} (NEE_{model} - NEE_{ori})^2}$$

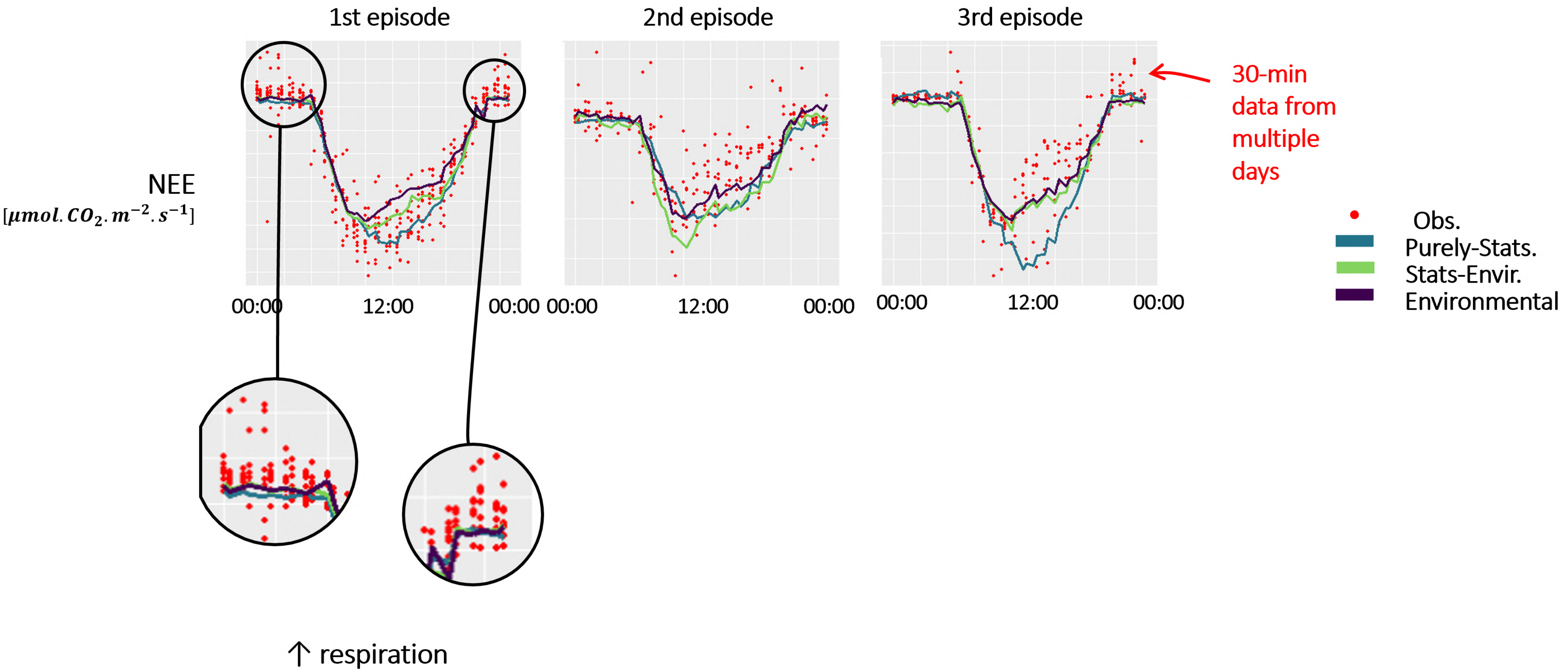
Daily Impact

Fontainebleau (Barbeau)



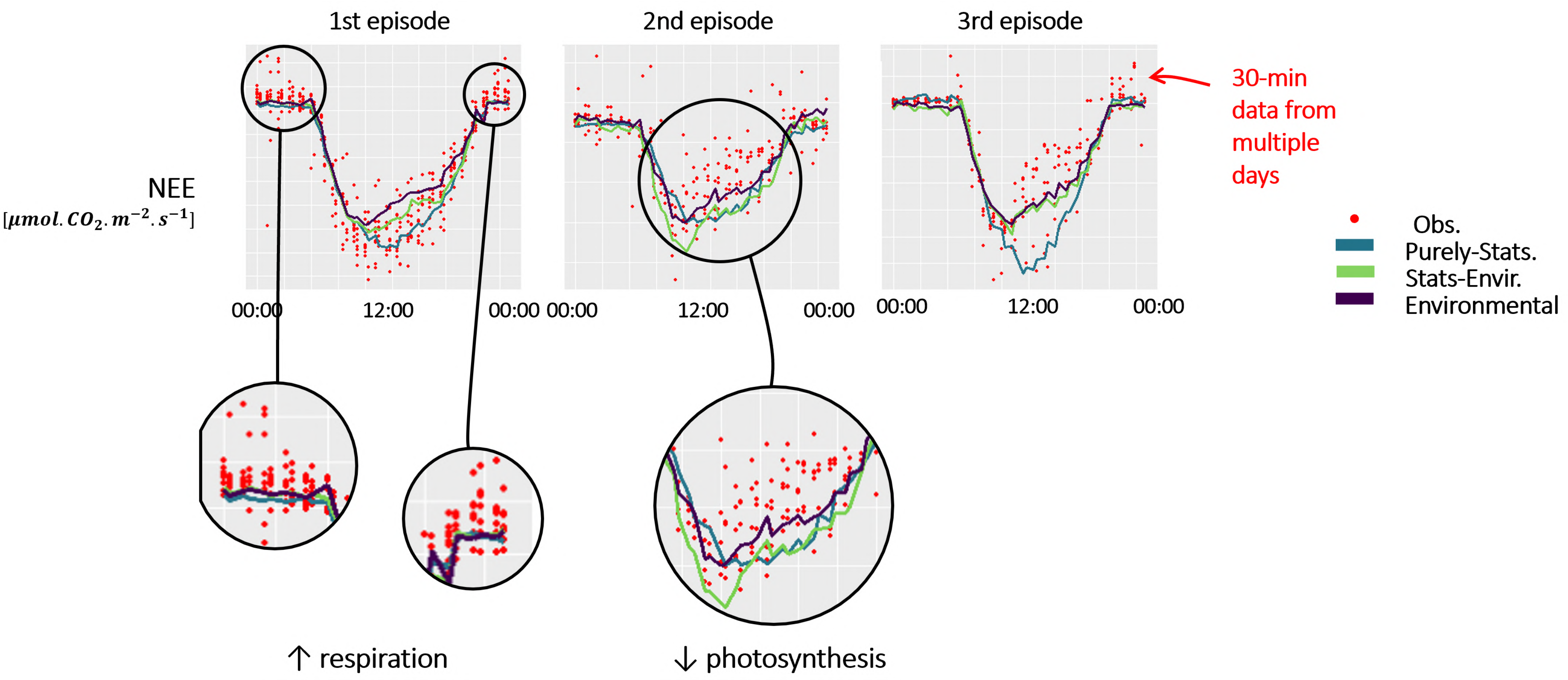
Daily Impact

Fontainebleau (Barbeau)



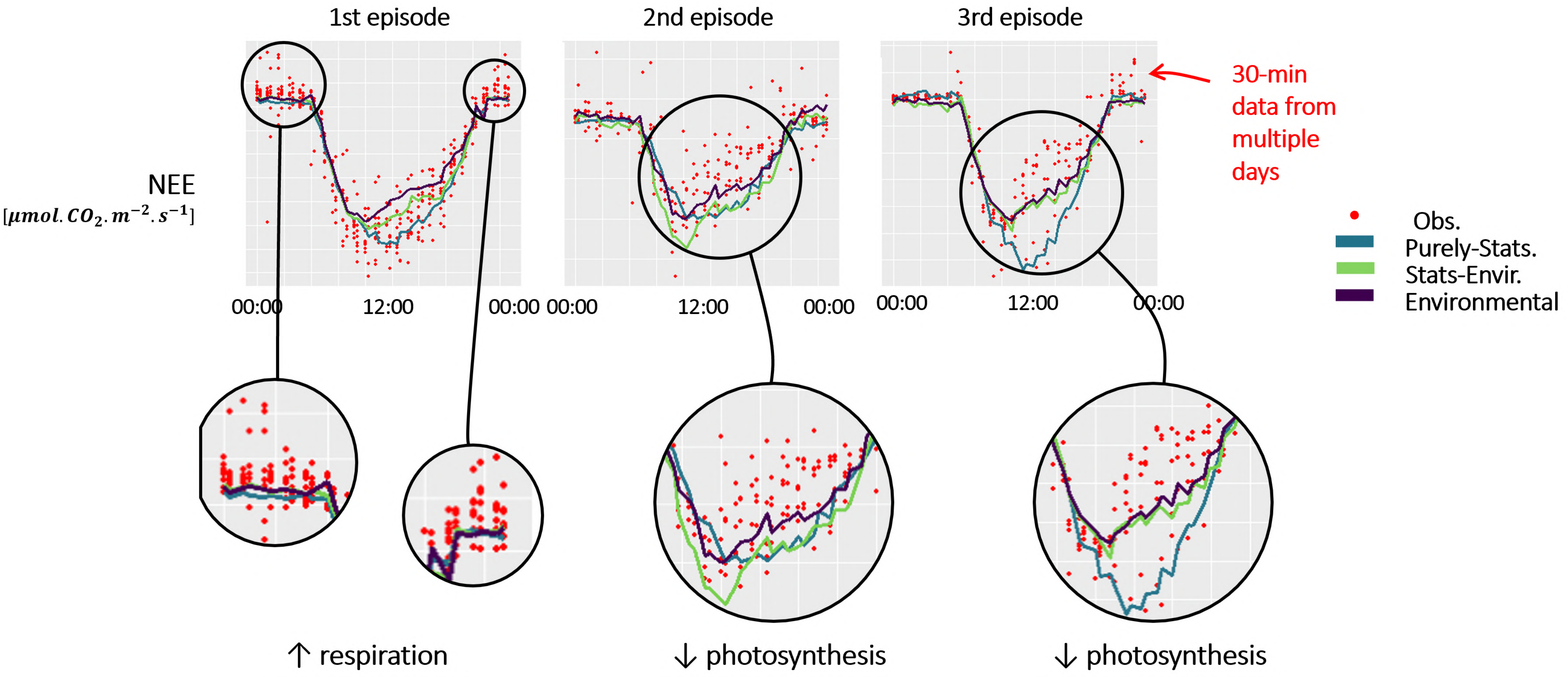
Daily Impact

Fontainebleau (Barbeau)



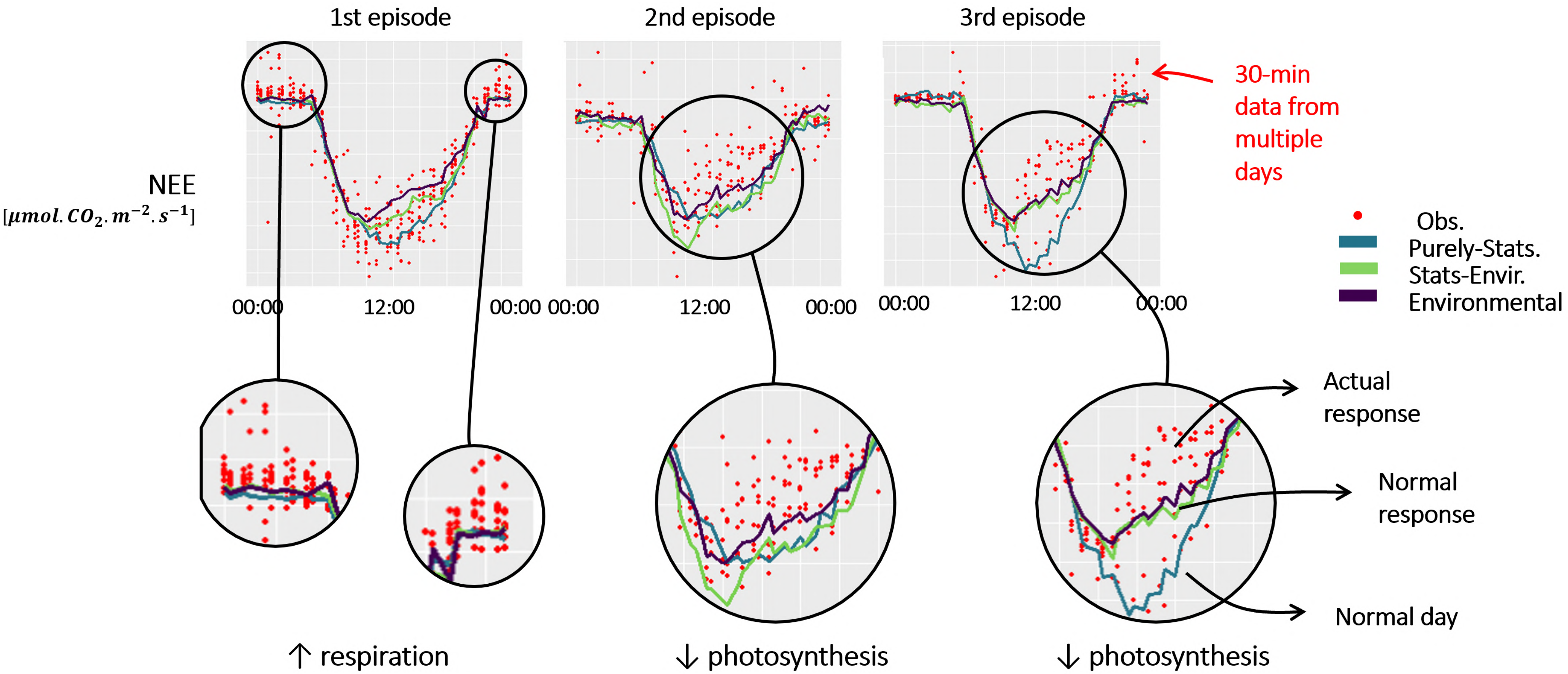
Daily Impact

Fontainebleau (Barbeau)



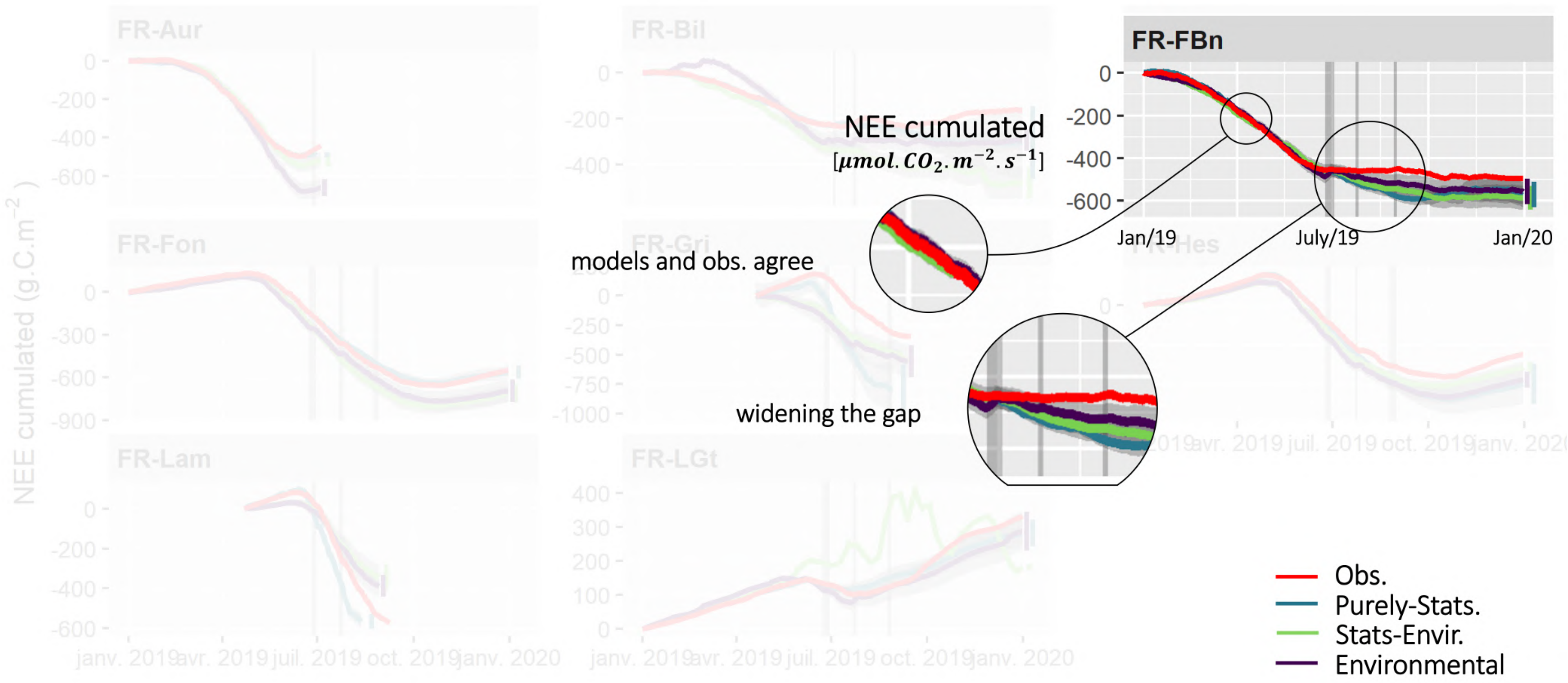
Daily Impact

Fontainebleau (Barbeau)



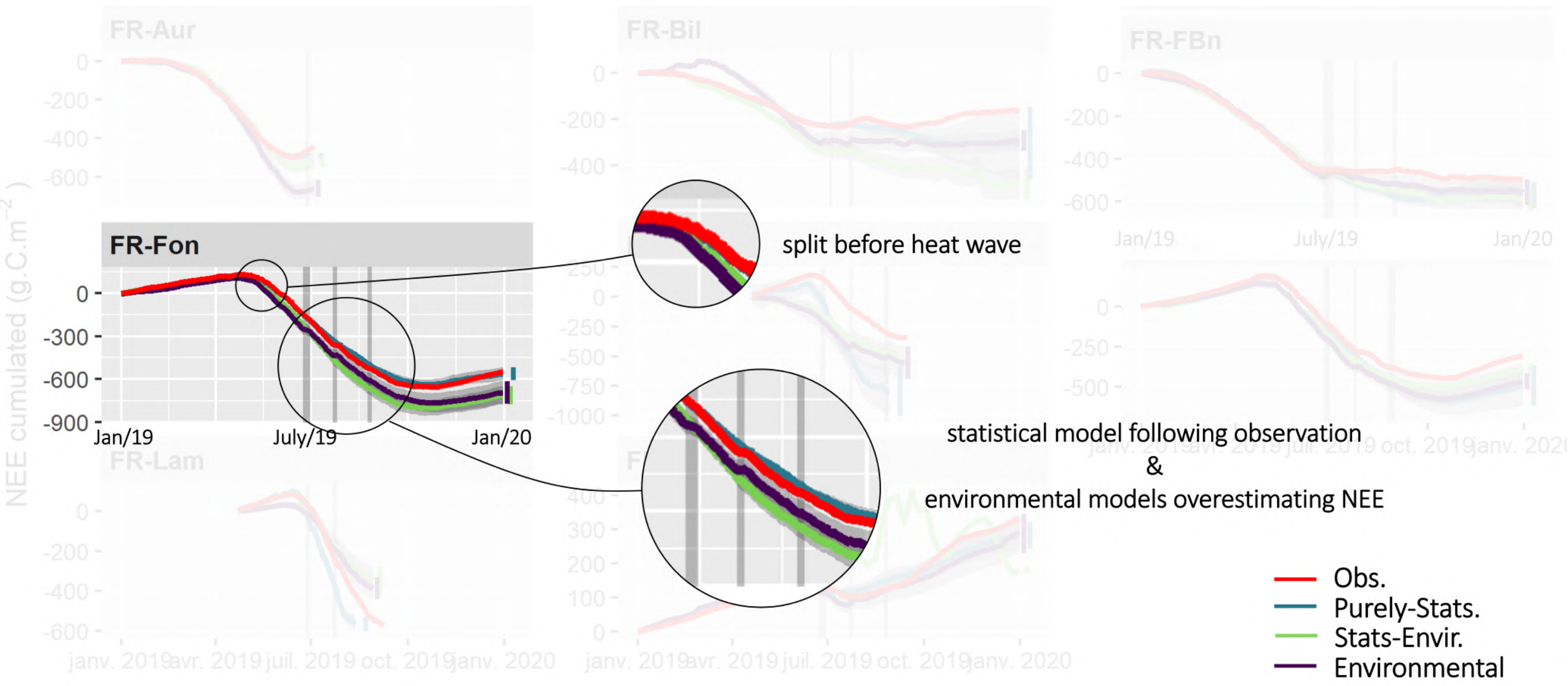
Annual Impact

Font-Blanche



Annual Impact

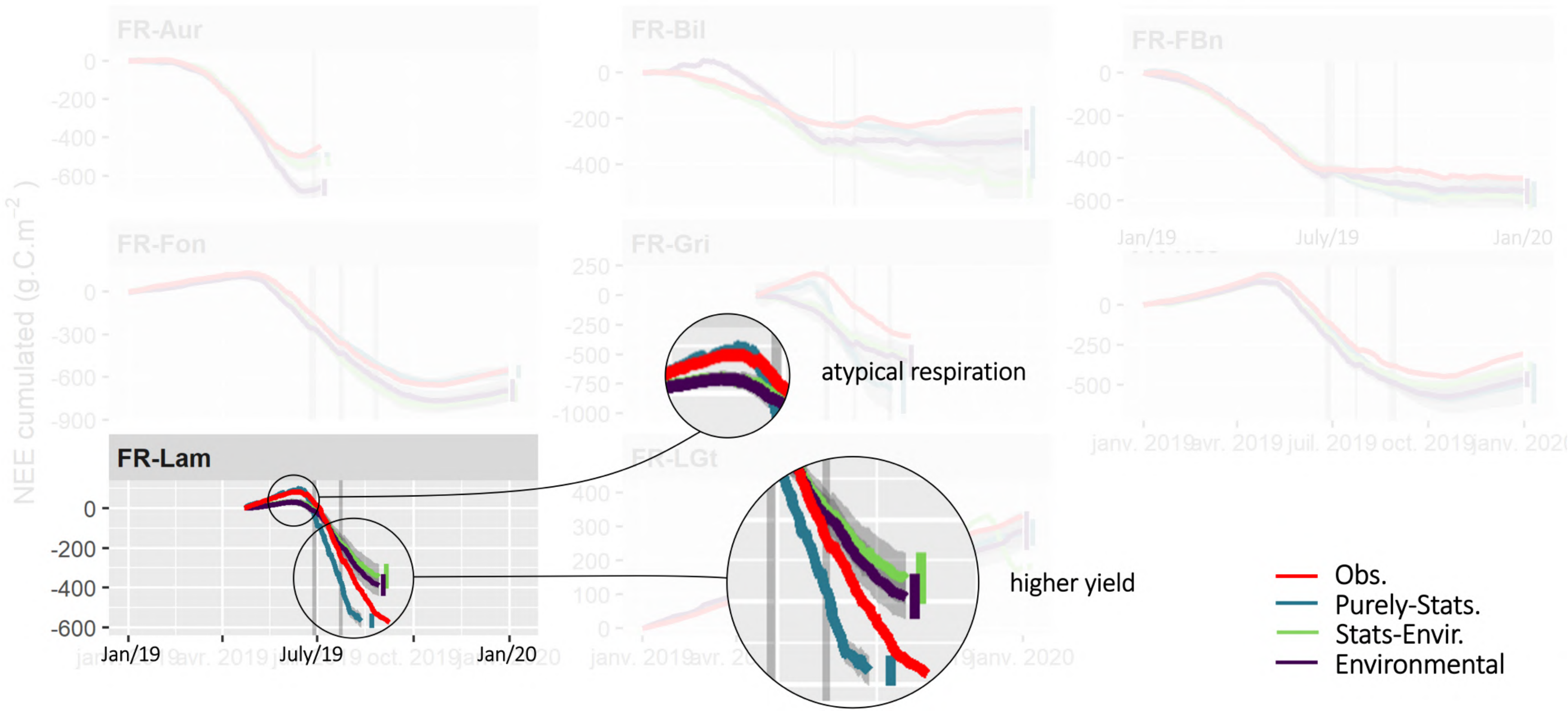
Fontainebleau (Barbeau)



all sites:

Annual Impact

Lamasquère



all sites:

Discussion

- Sites where heat waves happened during a period of water stress consistently reduced carbon sequestration.
- Irrigation for agricultural sites may prevent decrease in carbon sequestration.
- Forests sites sequestered 15 ~ $316g.C.m^{-2}.yr^{-1}$ less than predicted (w/ uncertainty ± 34 ~ $157g.C.m^{-2}$.
- In 2018, drought-induced decline of carbon flux for forests $182 \pm 42g.C.m^{-2}.season^{-1}$ (Fu et al., 2020)

Take-home messages

- Models can be useful in identifying periods when the site is underperforming in terms of carbon sequestration and apply appropriate tools to mitigate the impact.

- Reduction of ecosystem carbon sink behavior, as induced by higher temperatures, was found to be linked to water stress.

- In agricultural sites results suggest that irrigation can prevent negative impacts.
  This may lead to higher water demand in the future.

- Due to climate change, the frequency and intensity of heat waves (and droughts) is expected to increase.
  In the absence of any process faster than it, we are partially loosing the help of these ecosystems in the fight against it.

Thank you