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## What fluxes are telling us so far ? A naïve reanalysis of CO<sub>2</sub> fluxes over the past 18 years

Virginie Moreaux, Paul Berbigier, Daniel Berveiller, Jean-Marc Bonnefond,  
Christophe Chipeaux, Nicolas Delpierre, Olivier Darsonville, Eric Dufrene,  
André Granier, Richard Joffre, et al.

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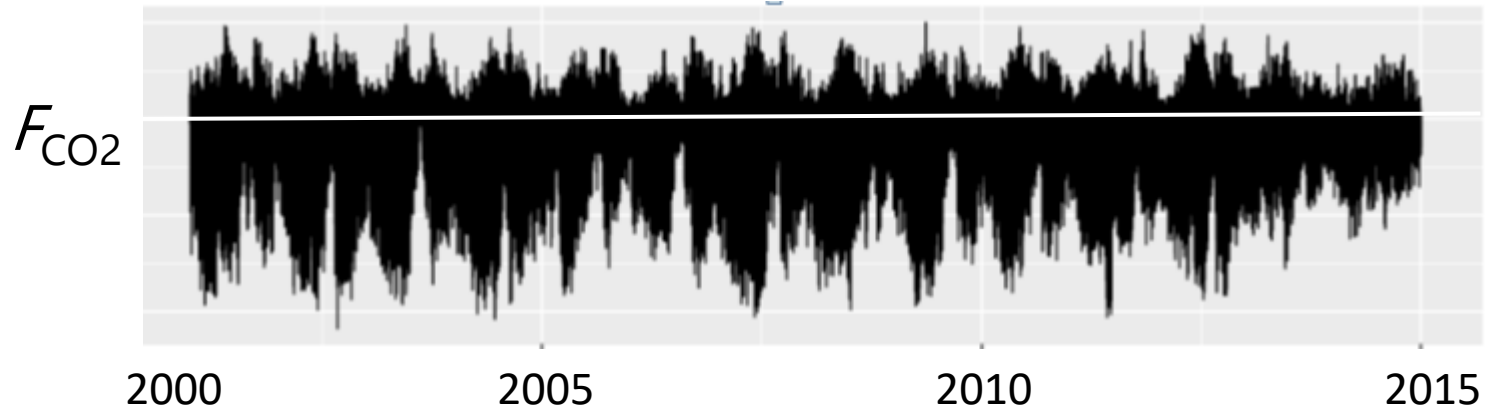
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1996 - 2035

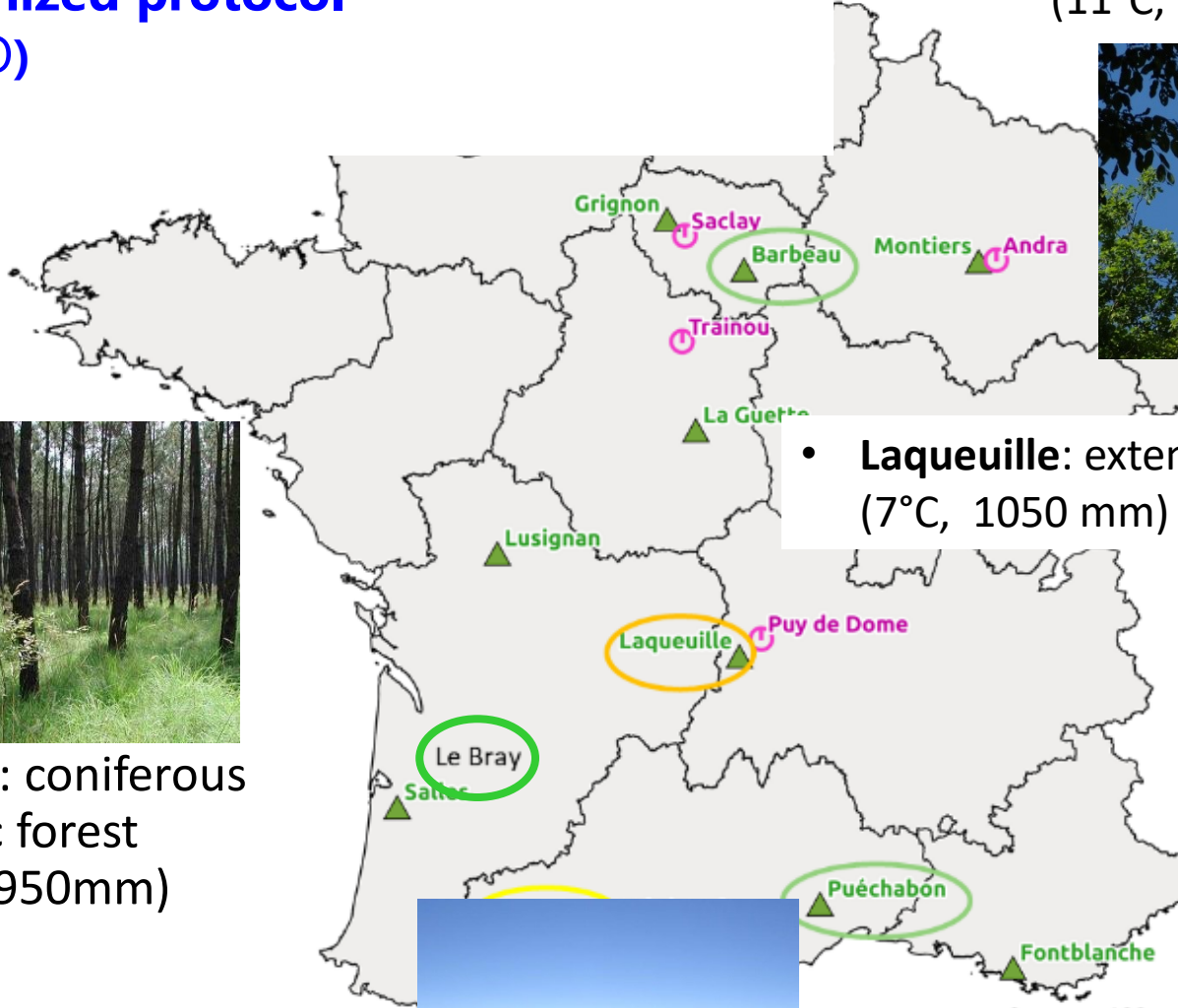


At half the way: what is still to be achieved ?

# Sites with minimal management

## Data filtered & processed using homogenized protocol (EddyPRO)

- **Barbeau** : old growth mixed broadleaved forest (11°C, 690mm)



- **Laqueuille**: extensive grassland (7°C, 1050 mm)

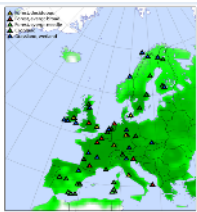


- **Le Bray**: coniferous Atlantic forest (13°C, 950mm)

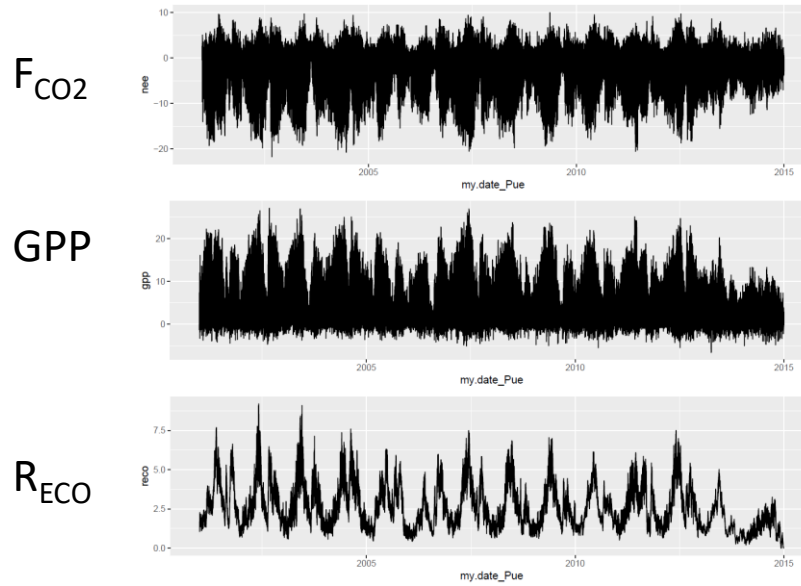


- **Puechabon**: old-growth evergreen Quercus coppice (14°C, 910 mm)

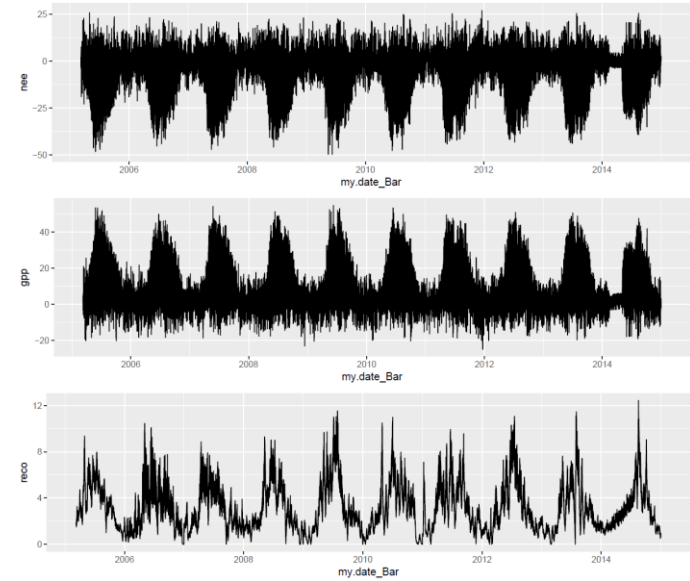
# Time series analysed



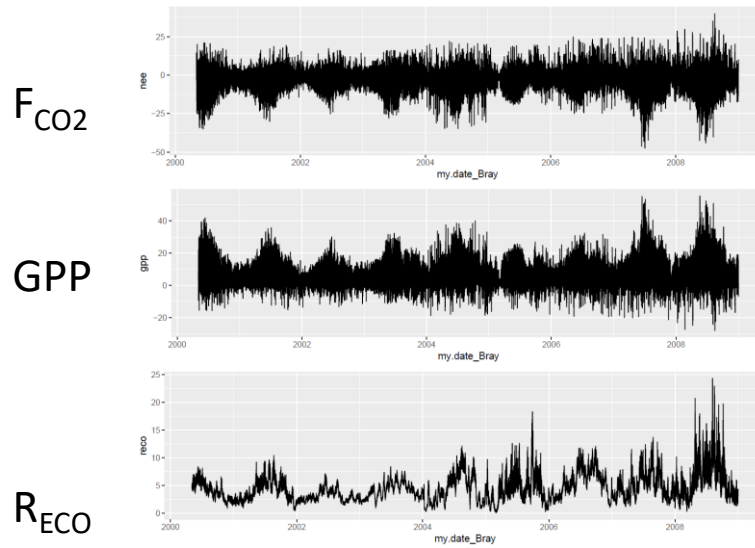
## Puechabon



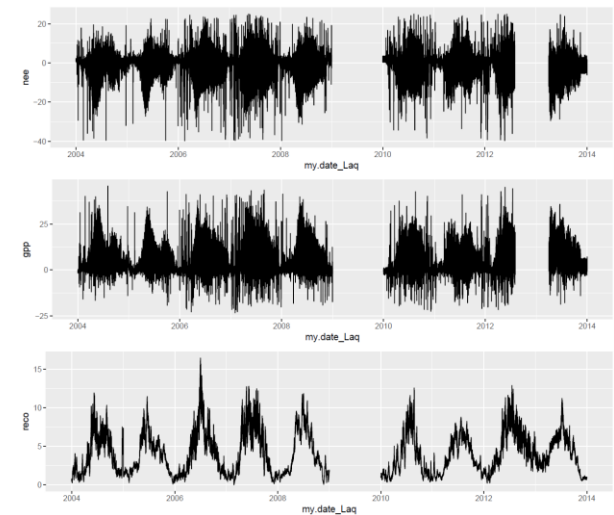
## Barbeau



## Le Bray



## Laqueuille



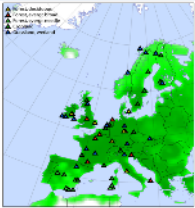
# What fluxes are telling us so far ?

A naïve reanalysis of CO<sub>2</sub> fluxes over the past 18 years

Berbigier P., Berveiller D., J.-M. Bonnefond, Chipeaux C., Delpierre N., Darsonville O.,  
Dufrene E., A. Granier Joffre R., Klump K., Lafont S., Limousin J-M., Longdoz B.,  
Loustau D., Ourcival J.-M., Piquemal K., Pontailler J.-Y., Rambal S. , Soussana J.-F.

Moreaux V.





# CO<sub>2</sub> fluxes and environmental factors across sites and frequency-time scales

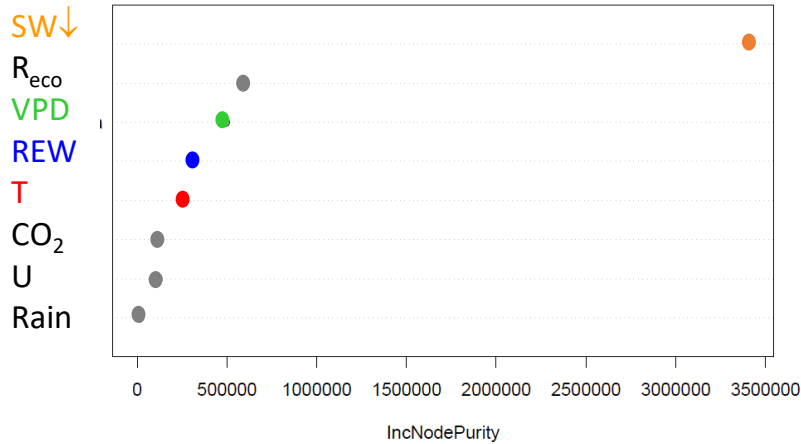
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- ⇒ 1. High frequency classification approach: Random Forest analysis (Breiman, 2001)
- ⇒ 2. Across frequency domain: Cospectra analysis with wavelet theory
  - Torrence C & Compo GP, 1998
  - Stoy et al. 2005, 2009
  - Vargas et al. 2010, 2011
  - Fares et al. 2013
- ⇒ 3. Inferential statistics ( linear/non linear regression analysis)
- ⇒ 4. Low frequency trends. Detection, attribution.

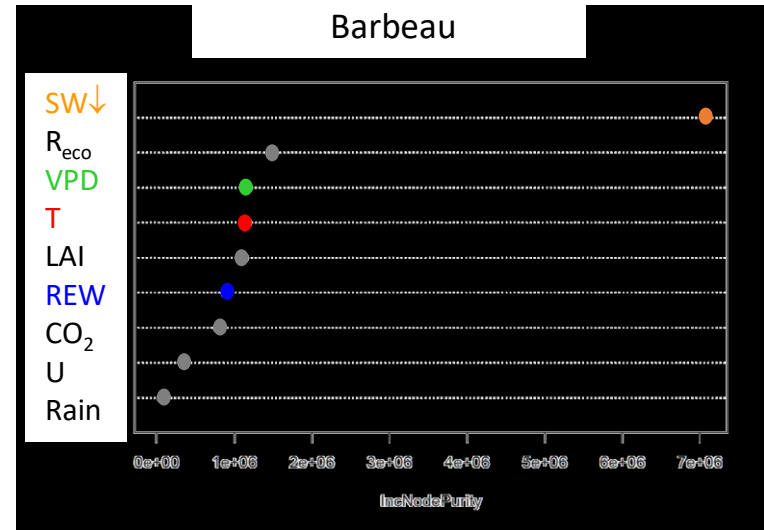
# 1. Classification of environmental factors : ecosystem photosynthesis (GPP)

- Random forest analysis at 1/2h time scale

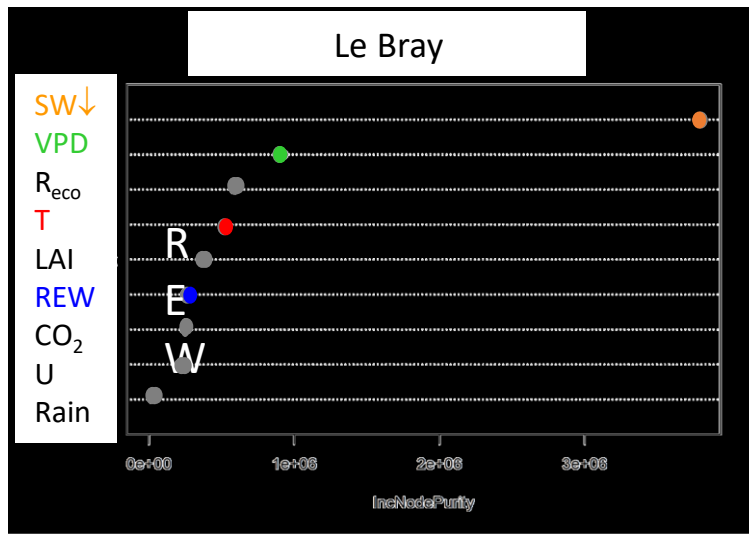
Puechabon



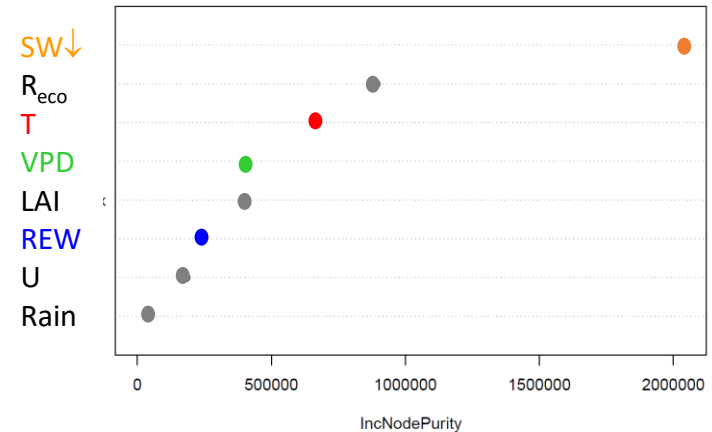
Barbeau



Le Bray



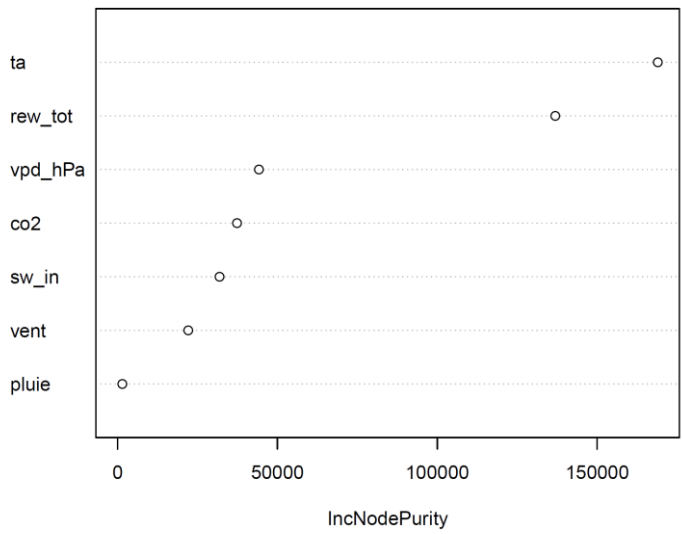
Laqueuille



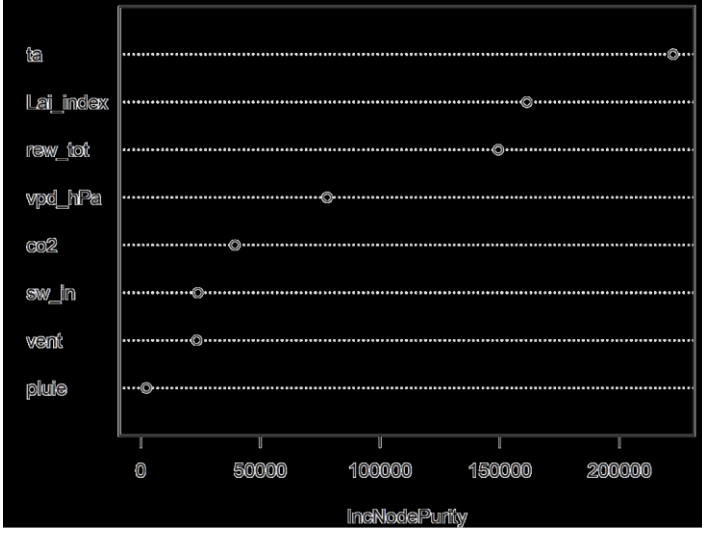
# 1. Classification of environmental factors : ecosystem respiration ( $R_{ECO}$ )

- Random forest analysis at 1/2h time scale

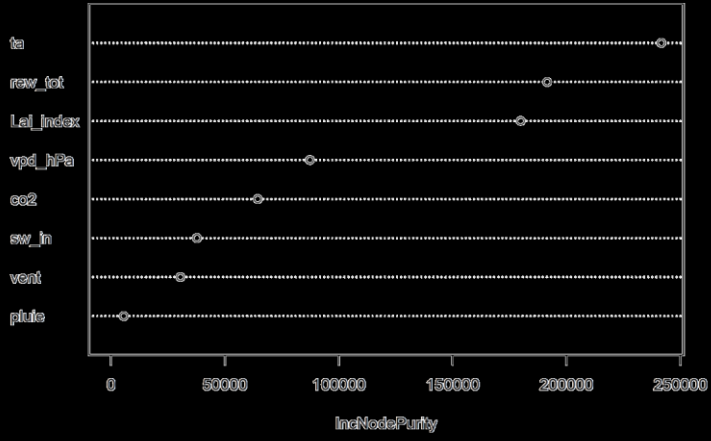
Puechabon



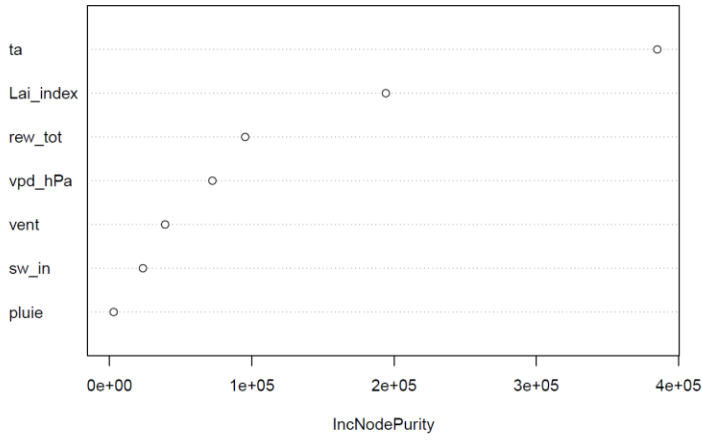
Barbeau



Le Bray



Laqueuille





# 2. Continuous time series analysis

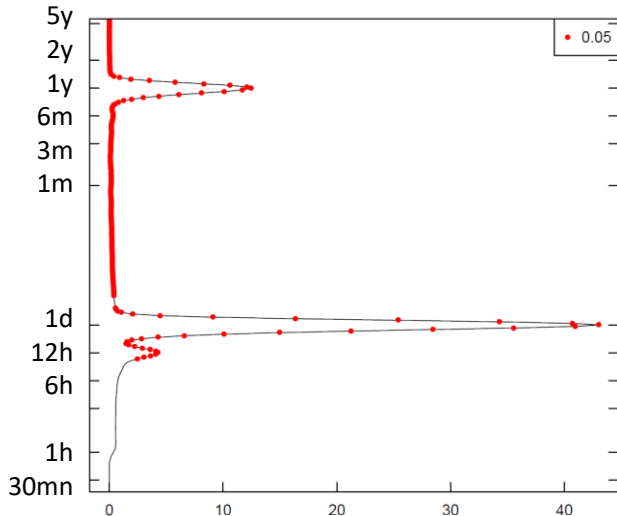
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## Wavelet analysis: scalogram and average cross-coherence graphs

- Appropriate to nonstationary and heteroscedastic time series
- Single and cross-spectra in time or frequency domains
- Assess synchrony and phasing (advance/delay between signals at given frequencies)

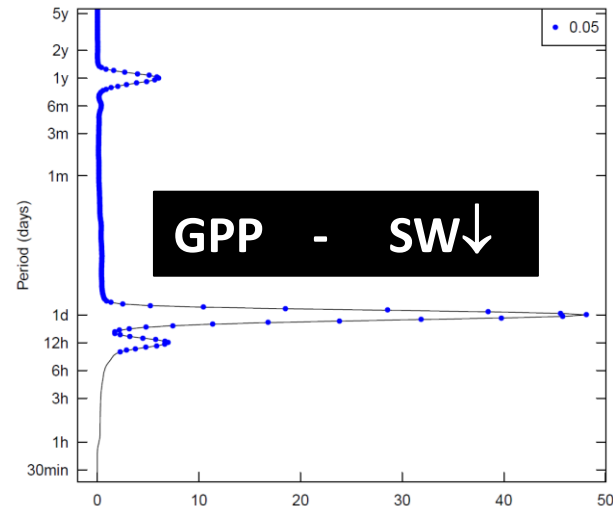
# Cross correlograms of GPP, SW↓ and Soil Water (REW)

Barbeau



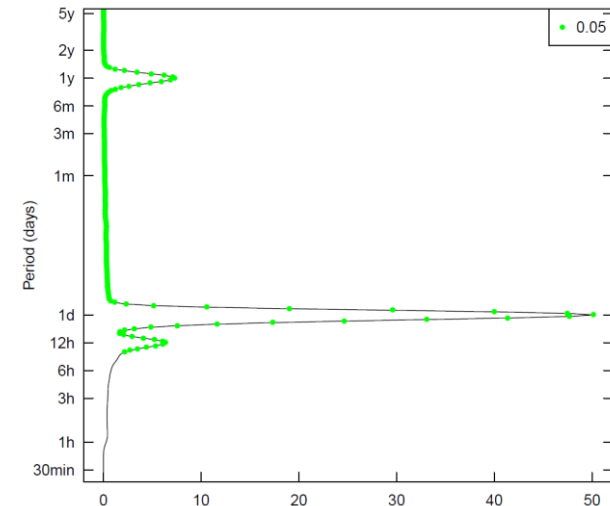
Average cross wavelet power

Puechabon

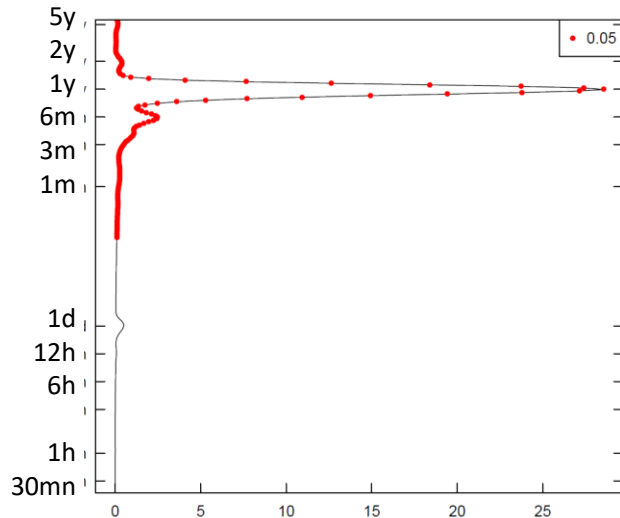


Average cross wavelet power

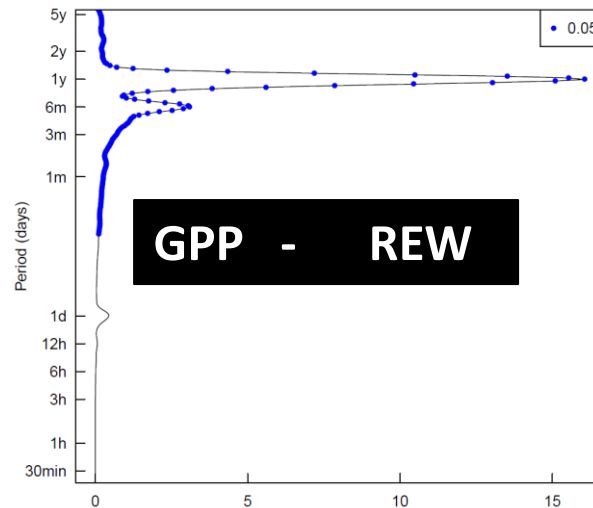
Le Bray



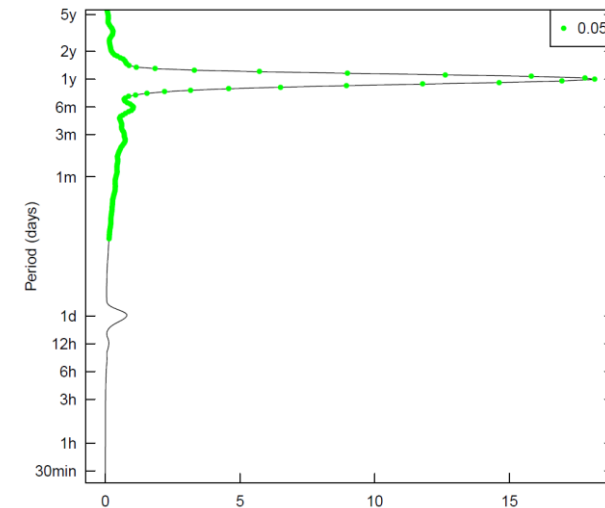
Average cross wavelet power



Average cross wavelet power



Average cross wavelet power

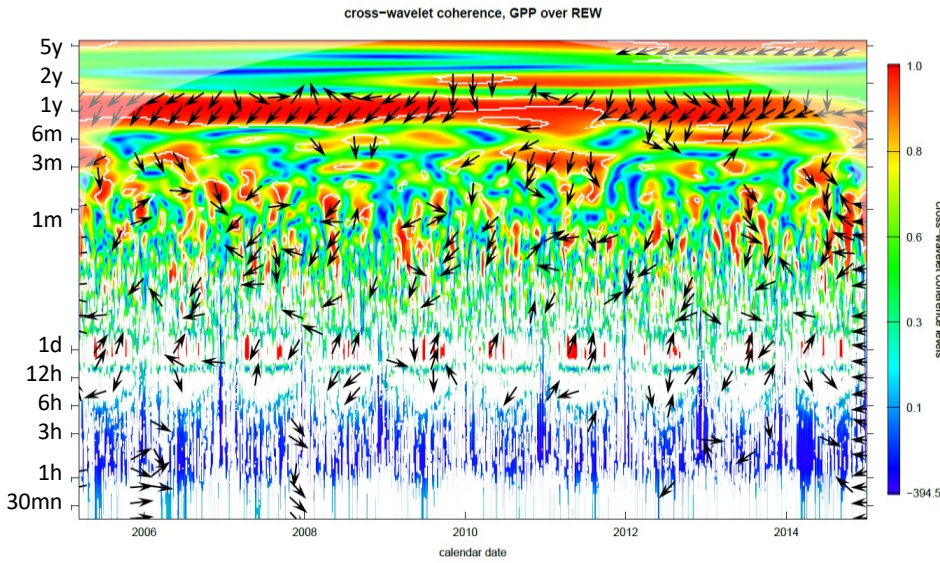


Average cross wavelet power

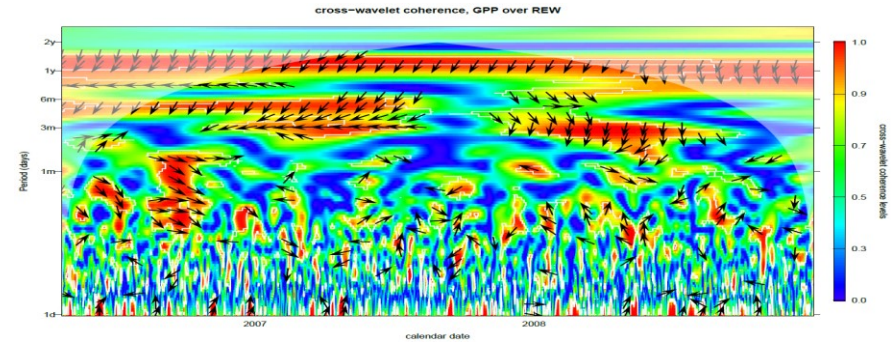
# Selected scalograms:

# GPP - REW

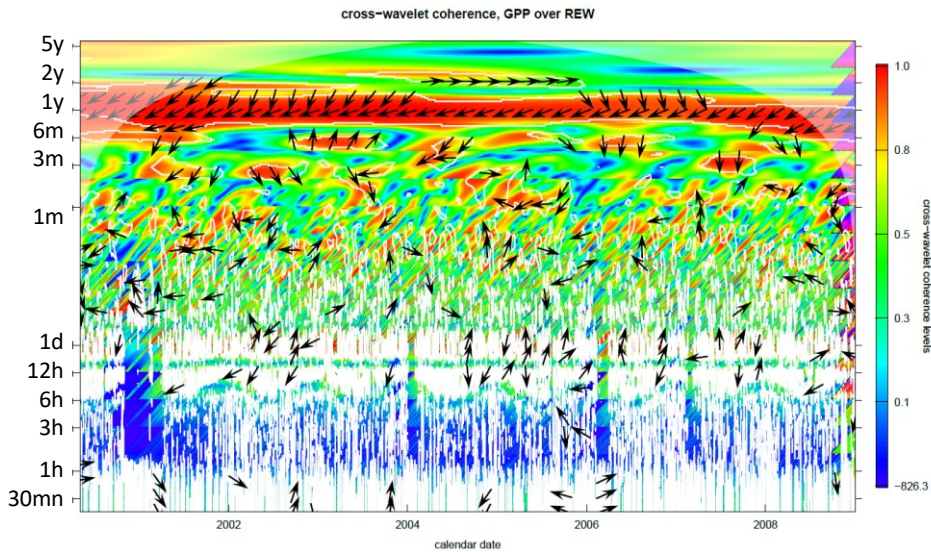
## Temperate deciduous broadleaf forest (FR-Fon)



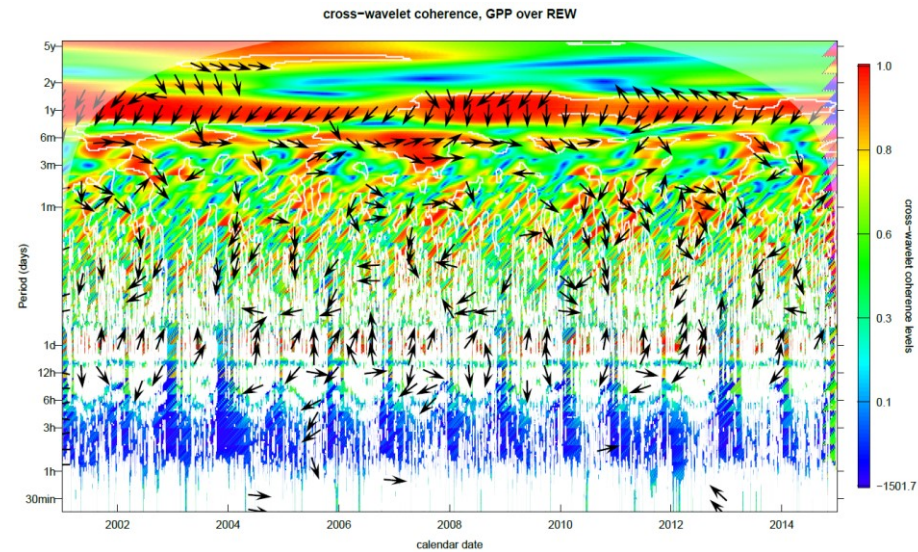
## Extensive grassland (FR-Laq)



## Temperate coniferous forest (FR-LBr)



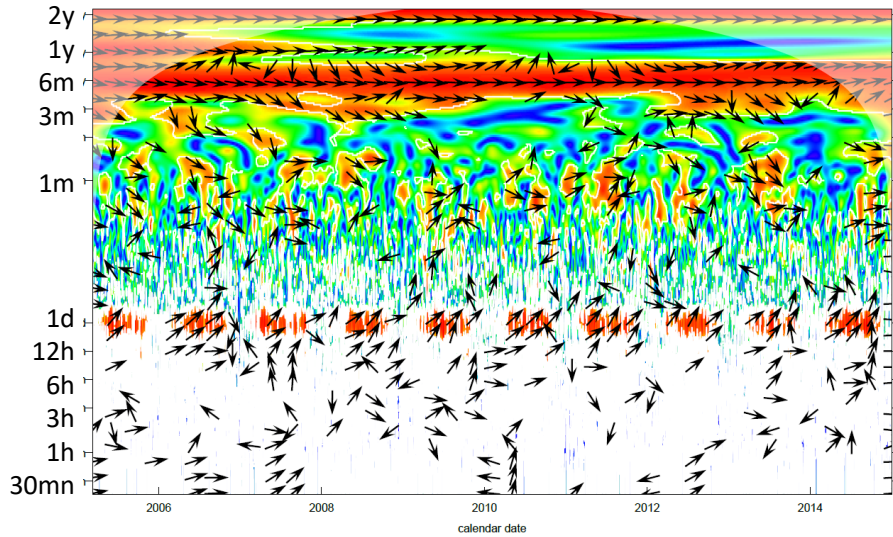
## Mediterranean evergreen broadleaf forest (FR-Pue)



# Selected scalograms: GPP - $R_{ECO}$

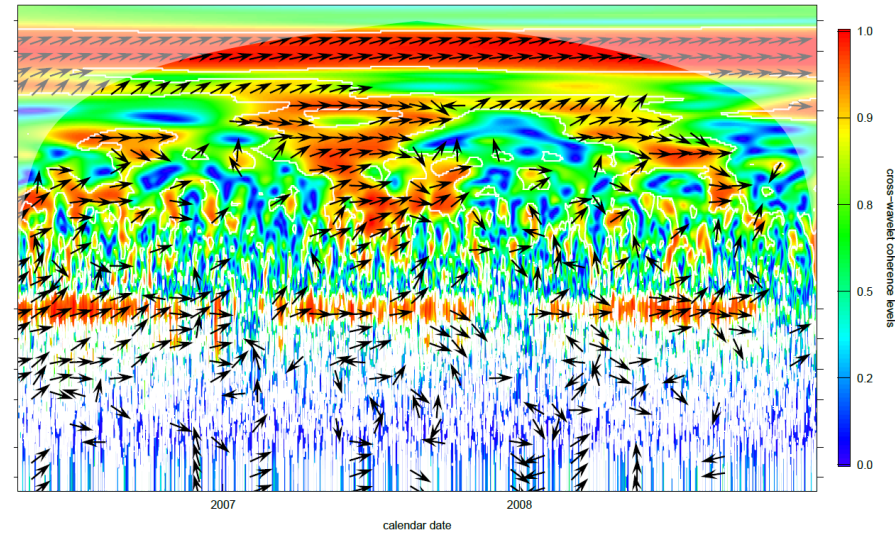
## Temperate deciduous broadleaf forest (FR-Fon)

cross-wavelet coherence, GPP over Reco



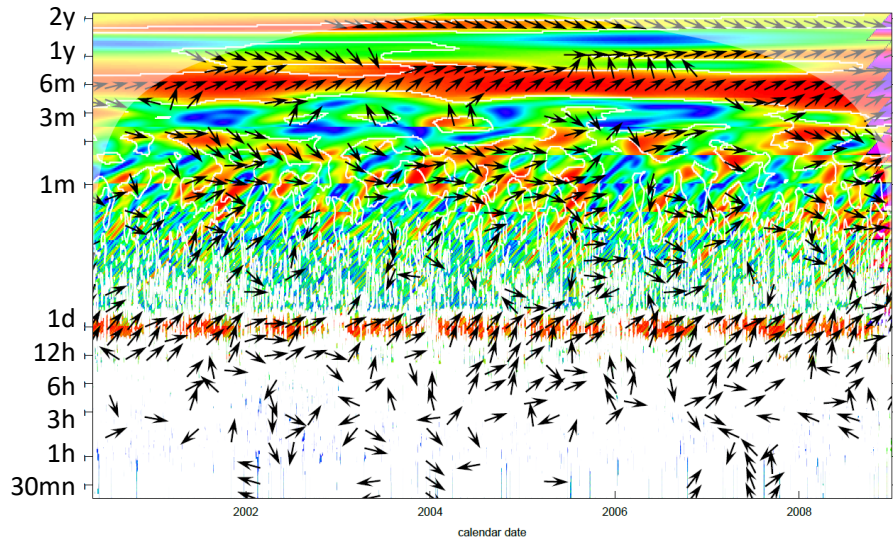
## Extensive grassland (FR-Laq)

cross-wavelet coherence, GPP over Reco



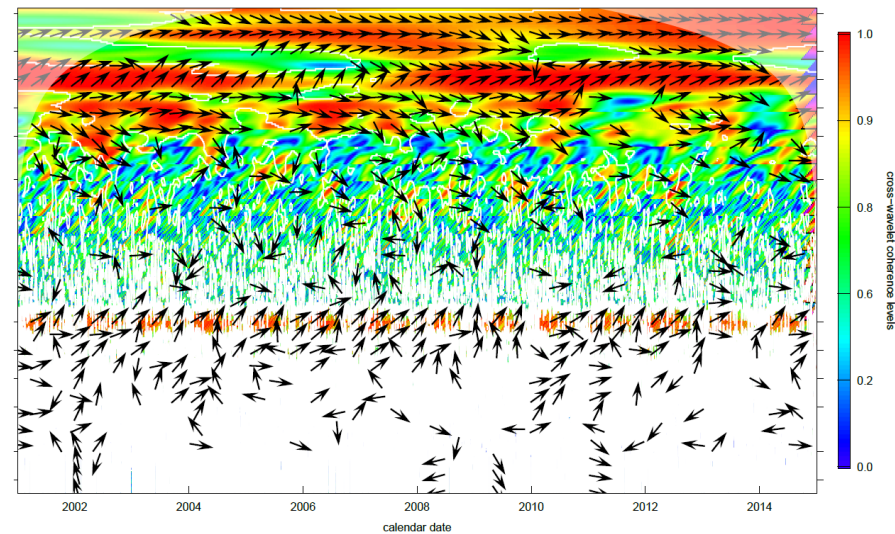
## Temperate coniferous forest (FR-Bra)

cross-wavelet coherence, GPP over Reco



## Mediterranean evergreen broadleaf forest (FR-Pue)

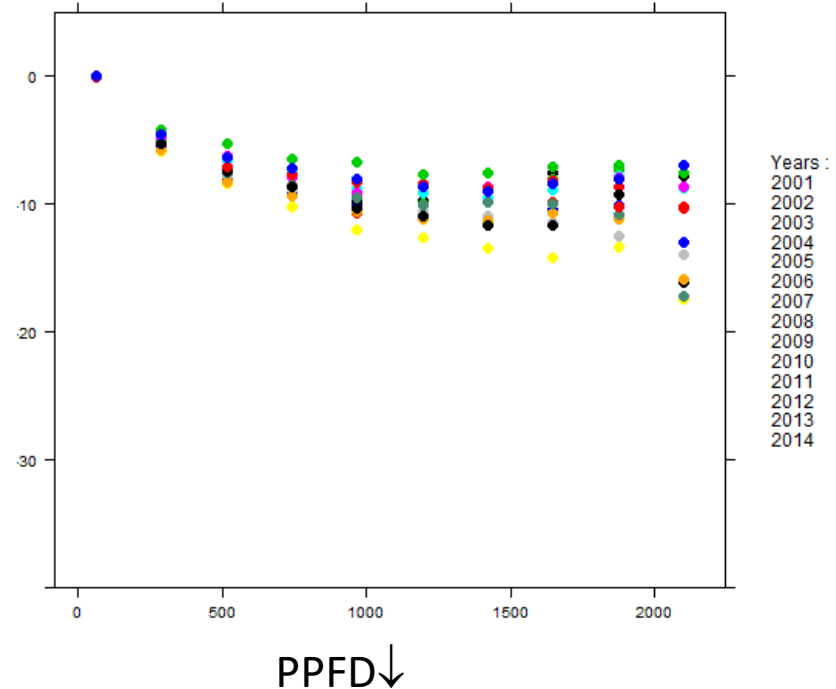
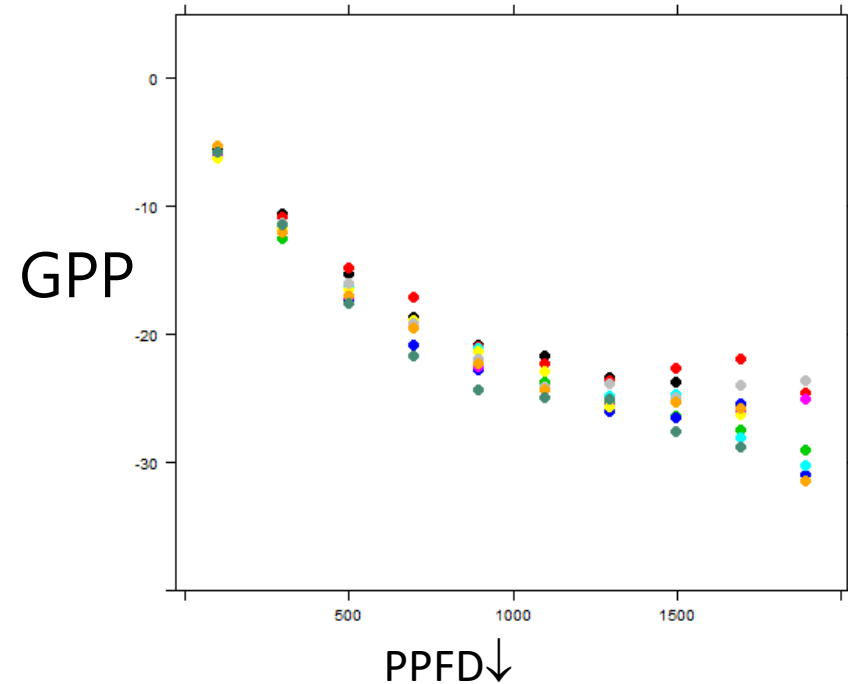
cross-wavelet coherence, GPP over Reco



# 3. Regression analysis: GPP response to environmental parameters: PPFD↓

Temperate deciduous forest (FR-Fon)

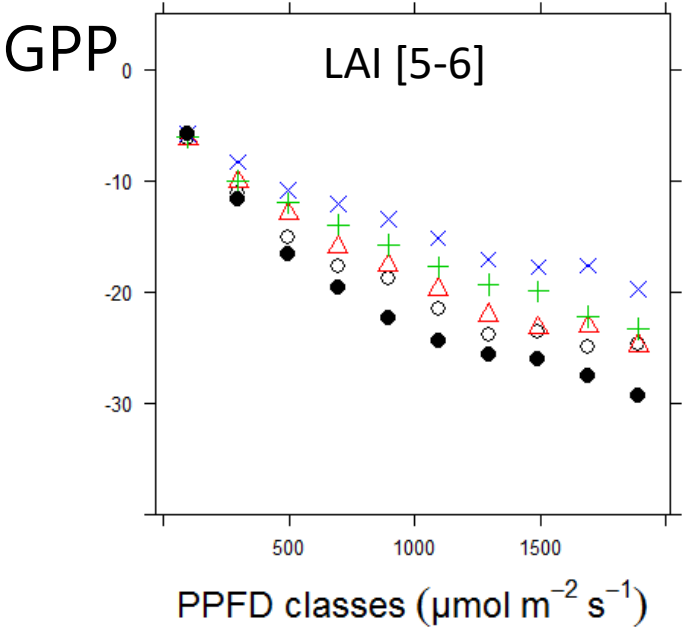
Mediterranean evergreen forest (FR-Pue)



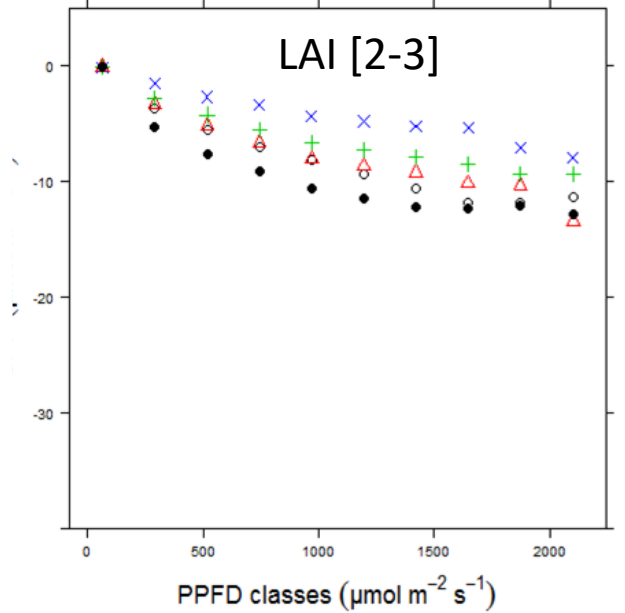
Similar response of ecosystem photosynthesis/LAI to PPFD among sites and between years.

# 3. Regression analysis: GPP response to environmental parameters: PPFD ↓

Temperate deciduous forest (FR-Fon)



Mediterranean evergreen forest (FR-Pue)

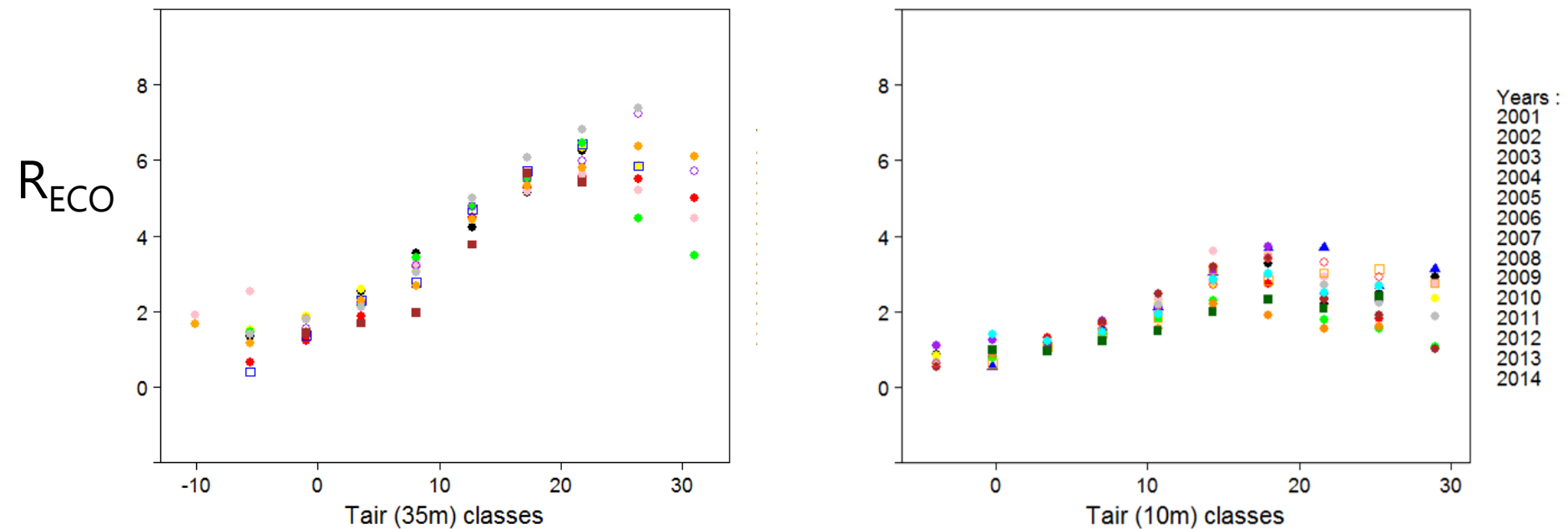


The response of ecosystem photosynthesis/LAI to PPFD x VPD is similar among sites.

# 3. Regression analysis: $R_{ECO}$ response to temperature

Temperate deciduous forest (FR-Fon)

Mediterranean evergreen forest (FR-Pue)



Same response of ecosystem respiration to temperature among sites and between years.

### 3. Time series re-analysis: naive conclusions

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Large similarities among all sites - years.

- Photosynthesis correlated with:

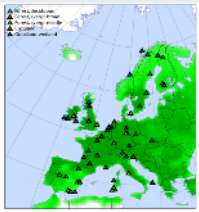
$SW\downarrow > \text{Air VPD} > \left\{ \begin{array}{l} \text{Air Temperature (Fr-Laq FR-LBr)} \\ \text{Soil water (Fr-Fon, Fr-Pue)} \end{array} \right.$

- Respiration correlated with:

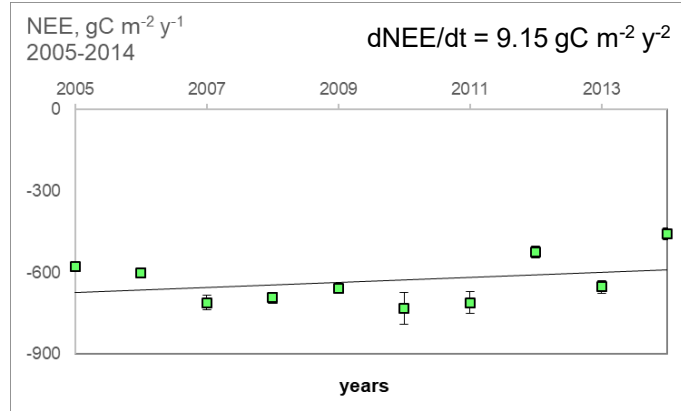
Temperature > Air VPD > soil water content



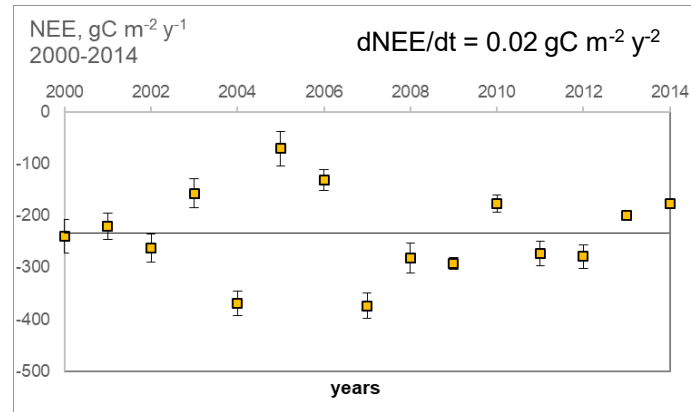
# 4. Low frequency changes



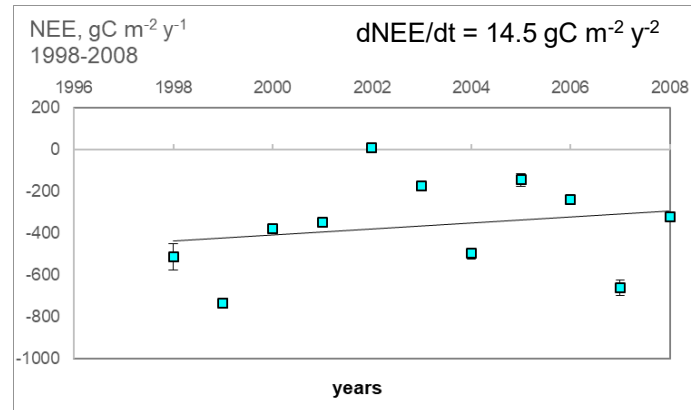
FR-Fon

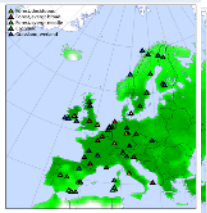


FR-Pue



FR-LBr



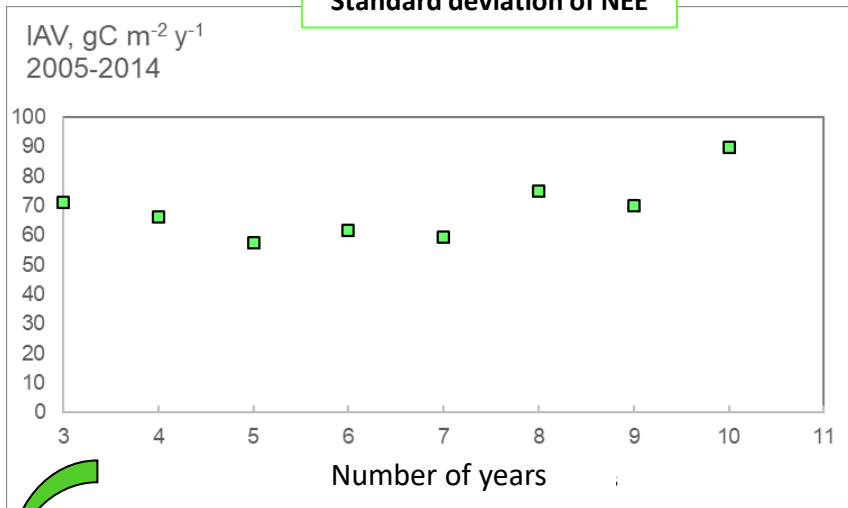


# 4. Low frequency changes: are they significant ?

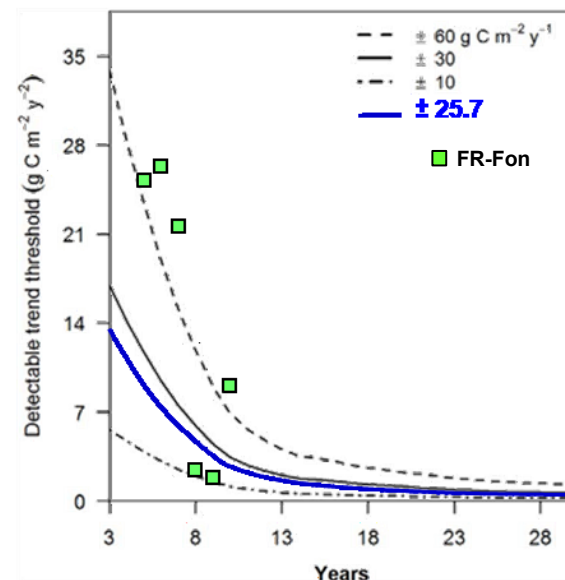
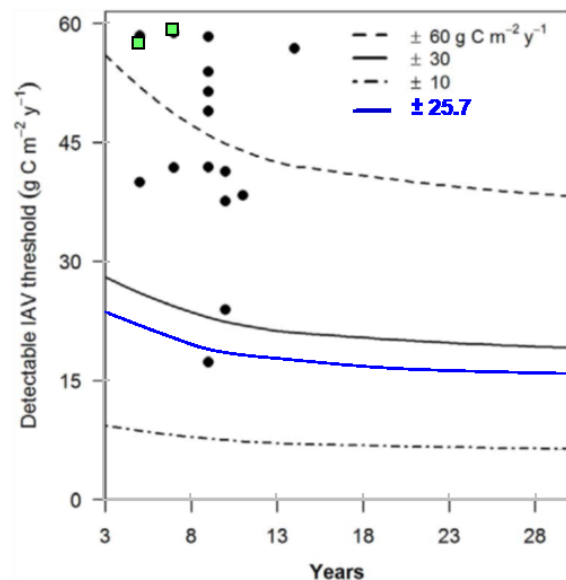
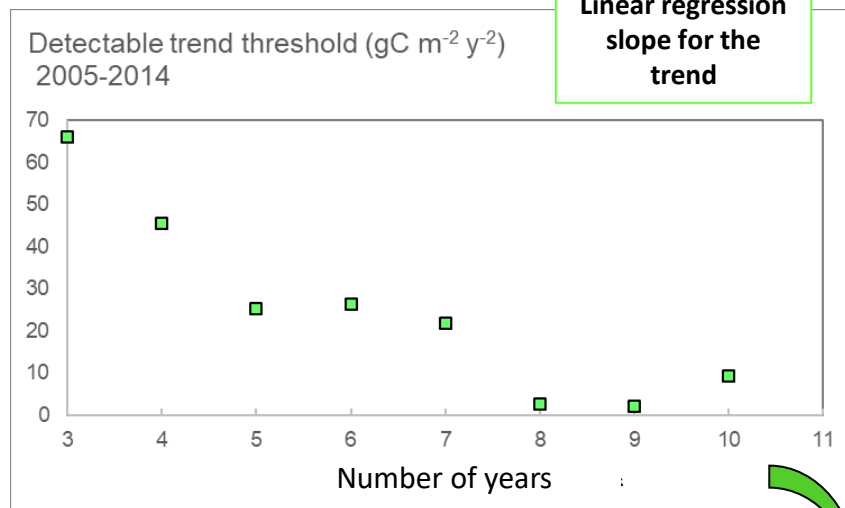
Longterm trend analysis: **Example of Barbeau: FR-Fon**

after *Baldocchi et al. 2018*

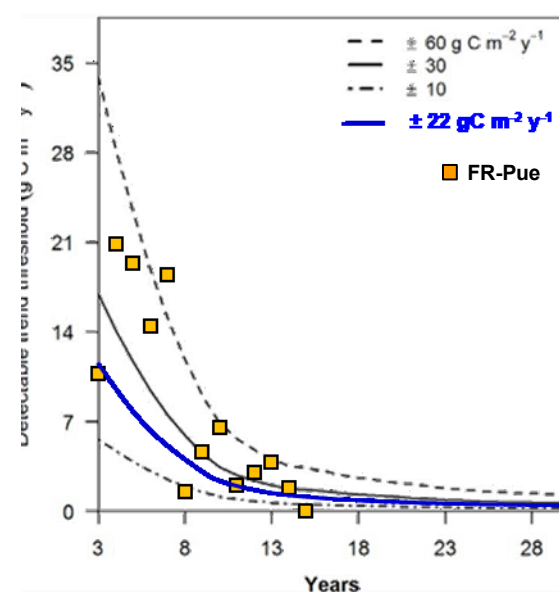
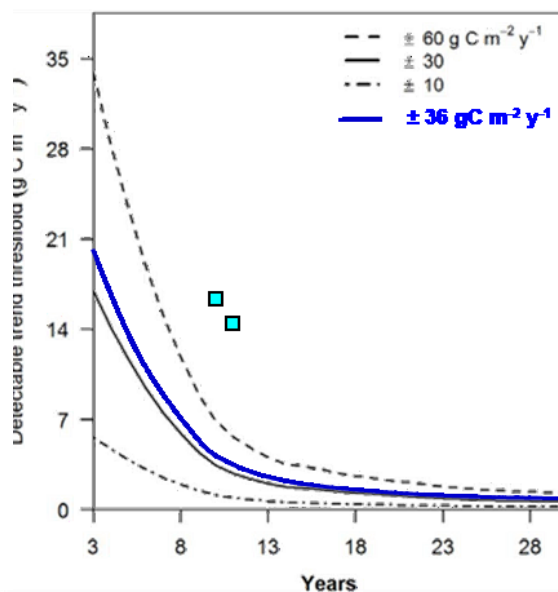
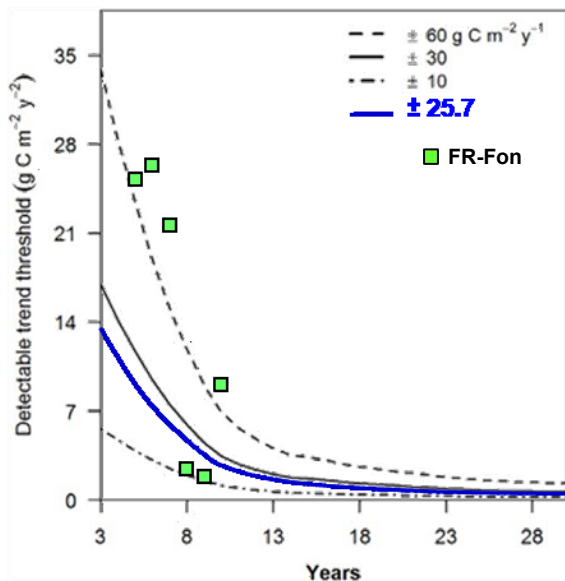
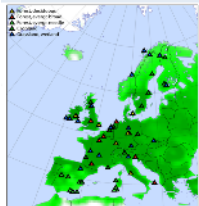
Standard deviation of NEE



Linear regression slope for the trend



# 4. Low frequency changes: are they significant ?



Temporal trends across sites: significant but not consistent

# Few thoughts to share together

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- Climate drivers of CO<sub>2</sub> exchanges are strikingly similar among a range of ecosystems
  - SW↓, Tair, Soil Water, air water vapour saturation deficit
- Respiration is coupled more tightly with GPP in ecosystems with lesser biomass and soil carbon stocks
  - Faster transfer of C from foliage to soil
  - Larger fraction of autotrophic respiration
- Cumulative effects of drifting variables (e.g. CO<sub>2</sub>) are barely visible.
  - Uncertainty and lack of temporal consistency still too large
  - Confounding effects (growth, age,...) are dominant
- Obtained time series so far:
  - numerical analysis of fluxes data say little about ecosystem functioning
  - long for scientists but short for the ecosystems !

# And few thoughts for future research

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From naive statistical correlations to causal attribution of biogeochemical fluxes:

- Transform ecosystem stations, « Flux towers » into terrestrial biogeochemical observatories where :
  - Monitoring of environmental drivers completed (Ozone, Ndeposition, ...)
  - Fluxes measurements can be better ascribed to processes
- In-depth, knowledge-guided time series investigations
- Develop plant growth processes modelling !!

Plant growth drives photosynthesis !

But what is driving plant growth ?

# Acknowledgements

- Sites :
  - Berbigier P., J.-M. Bonnefond, Chipeaux C., Loustau D.
  - Berveiller D., Delpierre N., Dufrene E., Pontailier J.-Y.,
  - Darsonville O., Falcimagne R., Klump K., Soussana J.-F.
  - Cuntz M., Granier A., Gross P., Lily J.-B., Longdoz B.
  - Joffre R., Limousin J.-M., Ourcival J.-M., Piquemal K., Rambal S.
  - Buysse P., Cellier P., Loubet B.
  - Brut A., Ceschia E., Tallec T.
- Data analysis:
  - Moreaux V., Brut A., Delpierre N., Dufrene E., Klump K., Lafont S., Limousin J.-M., Longdoz B., Loubet B., Loustau D., Tallec T.
- CESEC project: Cross-comparison of Reco and GPP in response to environmental parameters: synthesis over French forest ecosystems (ADEME)
- RINGO project: Long term trends and variability on carbon fluxes: uncertainties and detection ability of heterogeneous network. (H2020 / INFRAIA, TASK 3.5)