Turbulent transport extraction and high time resolution flux estimation using wavelet analysis

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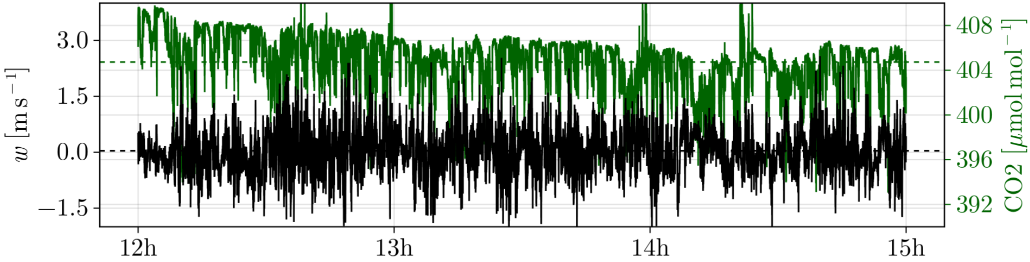
INRAE

Context and Goal

- *Context:* Study of forest ecosystem dynamics at fine temporal resolutions of 1 minute to 1 hour (e.g. the dynamic of canopy conductance)
- **Require high time resolution fluxes**
- *Goal:* estimation of ecosystem fluxes carried by local turbulent transport at a rate of ~1min
- *Data:* Using FR-Hes flux tower measurements, forest ecosystem, (30m tall tower, 20m tall canopy)

Limits of standard eddy-covariance

$$\overline{(w - \overline{w})(s - \overline{s})}$$



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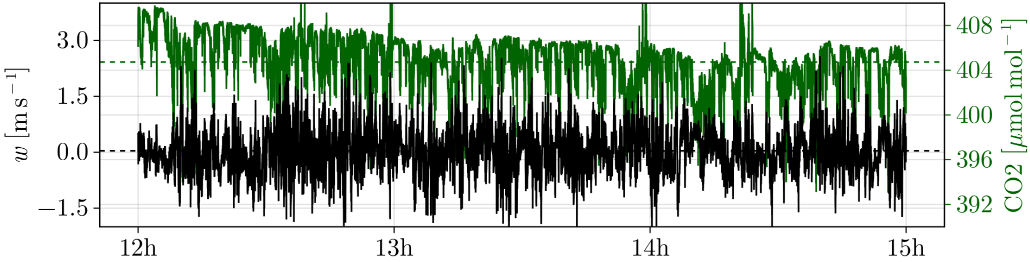

Limitations

- Averaging length cannot be modified without risking biased estimation
- Quality tests only flag periods with trends or under-developed turbulence

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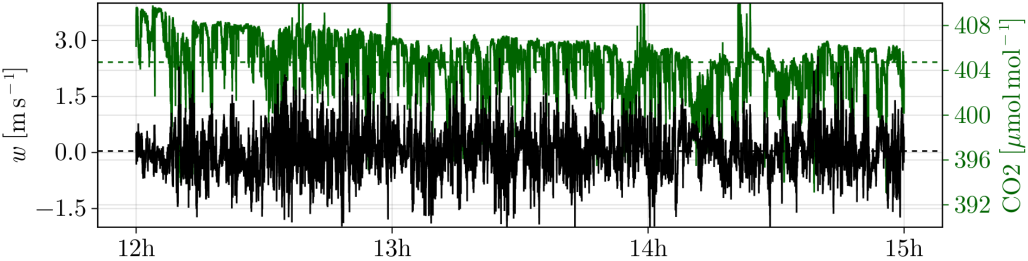

Limitations

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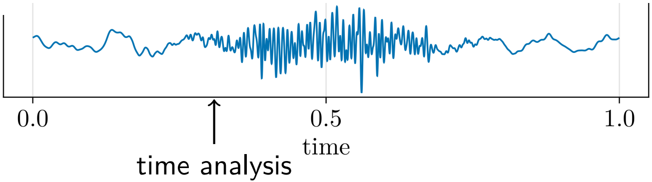
Standard Eddy-Covariance cannot separate scales in non-stationnary settings

Dealing with Non-Stationnarity and Scales Separation: An illustration



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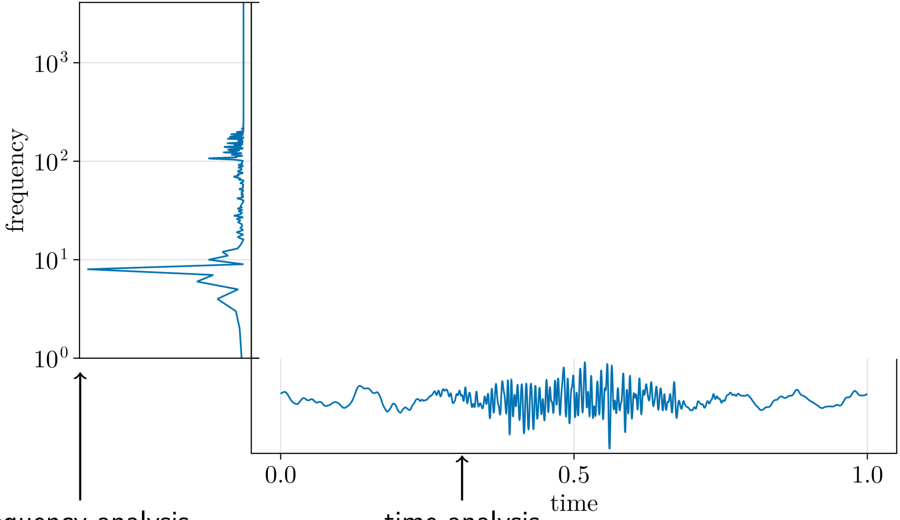
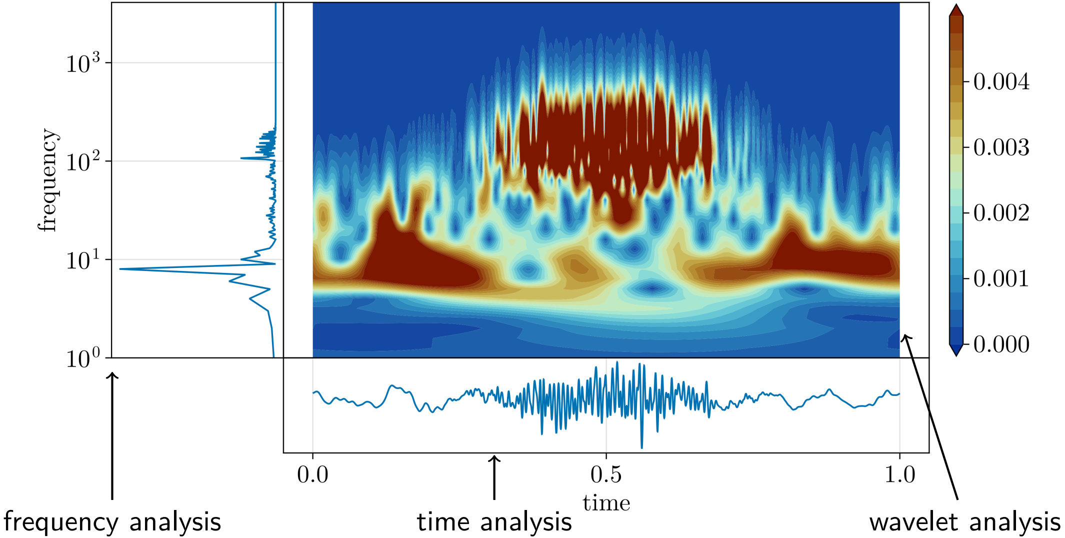


frequency analysis

time analysis

Dealing with Non-Stationnarity and Scales Separation: An illustration with wavelet analysis



Dealing with Non-Stationnarity and Scales Separation: Proposed Methodology

Main problem in flux estimation carried by turbulent transport

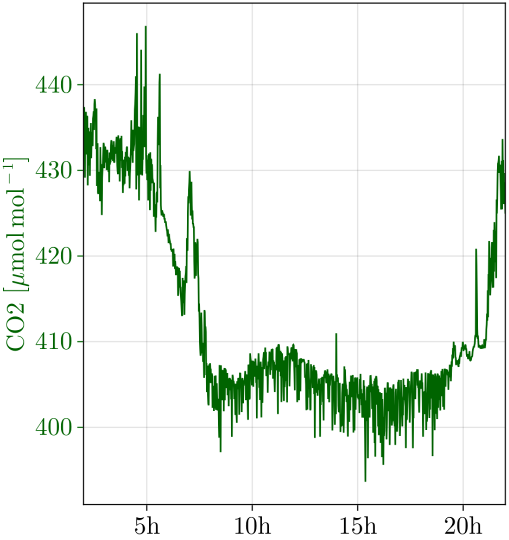
- Separation of scales in non-stationnary conditions

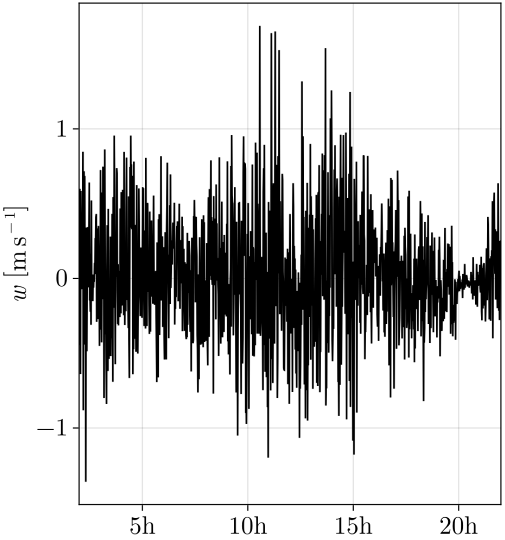
Wavelet Transforms as a basic tool to circumvent that problem

Proposed methodology

A. Time-Frequency decomposition of fluxes
B. Identification of turbulent transport in time-frequency space
C. Integration of a high time resolution flux given A. and B.

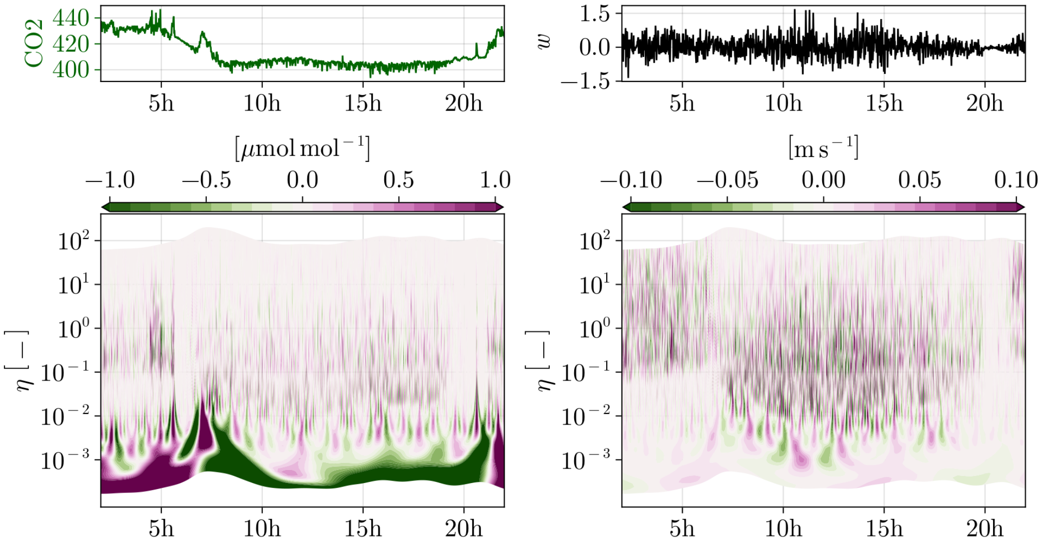
A. Time-Frequency Decomposition of Fluxes





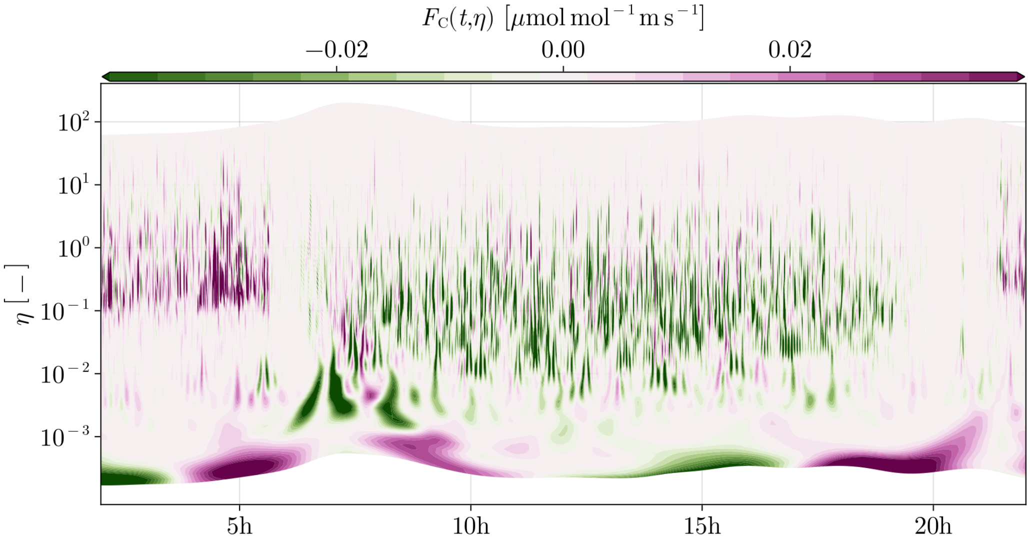
A. Time-Frequency Decomposition of Fluxes

With Norm. Freq. $\eta(t, f) = \frac{(z-d)f}{|u|(t)} \simeq \frac{\text{Ref. height}}{\text{Eddy Size}}$



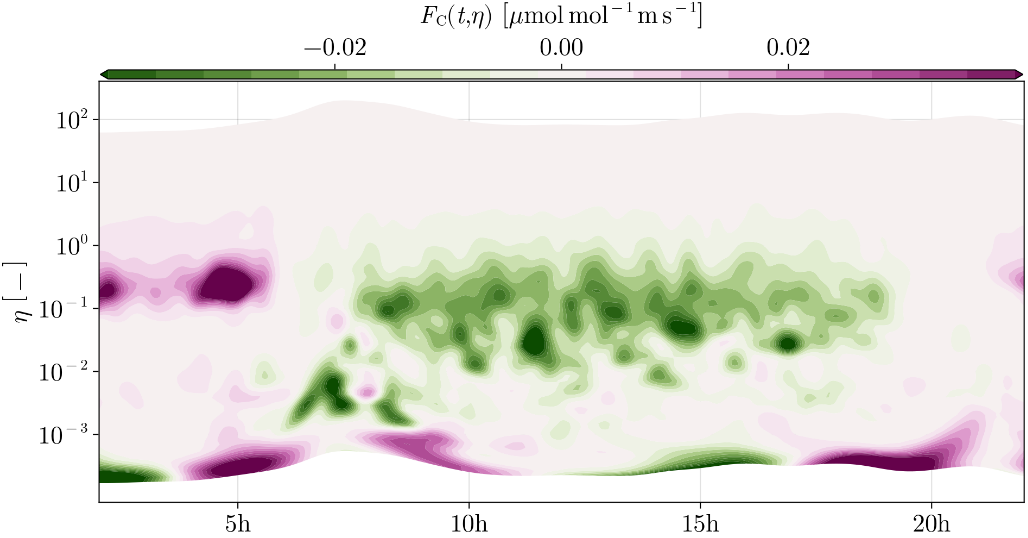
A. Time-Frequency Decomposition of Fluxes

Product of decompositions



A. Time-Frequency Decomposition of Fluxes

Product of decompositions + time averaging (e.g. 10min Gauss. window.)



B. Identification of Turbulent Transport in Time-Frequency Space

$$\begin{pmatrix} \overline{u'^2} & \overline{u'v'} & \overline{u'w'} \\ & \overline{v'^2} & \overline{v'w'} \\ & & \overline{w'^2} \end{pmatrix}$$

B. Identification of Turbulent Transport in Time-Frequency Space

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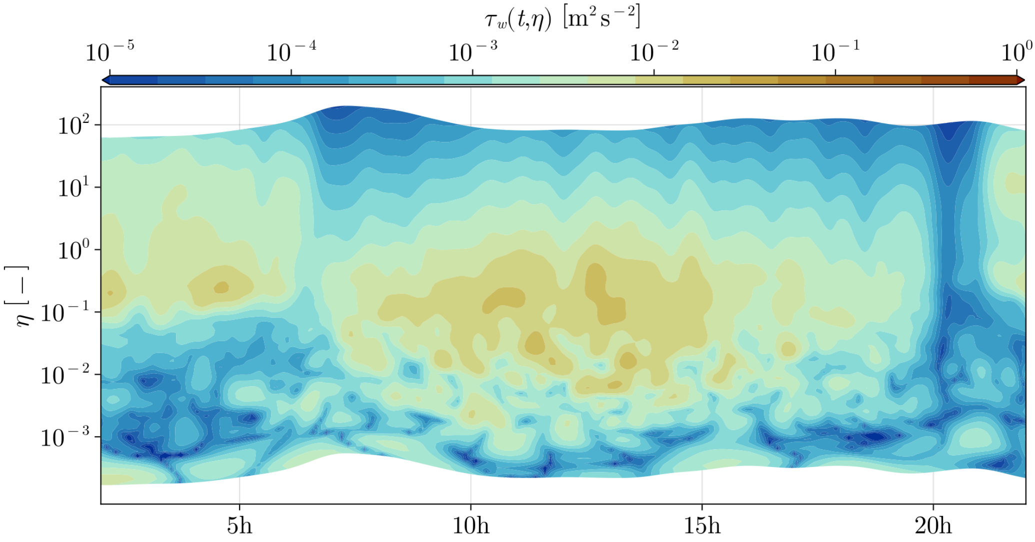
... but in time-frequency space !

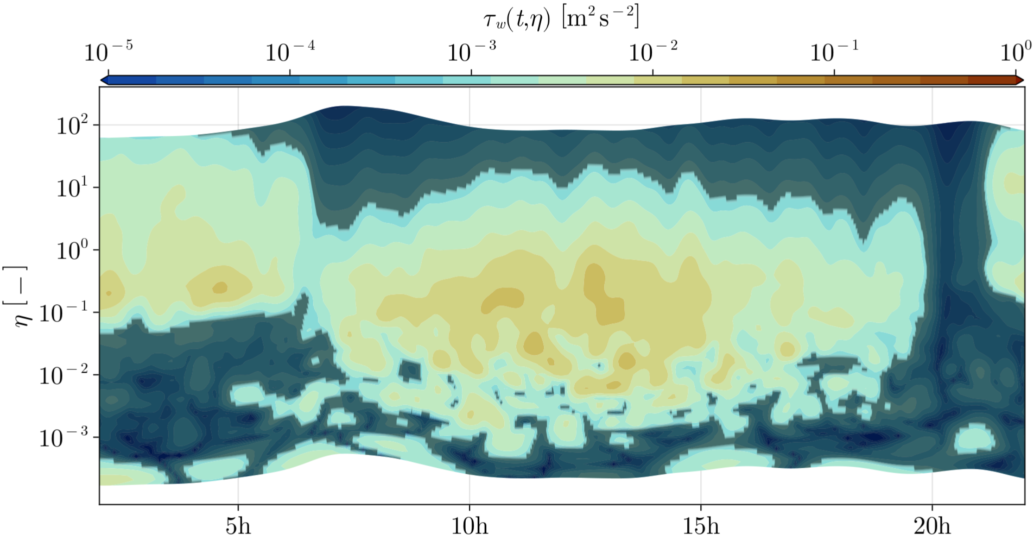
B. Identification of Turbulent Transport in Time-Frequency Space

τ_w

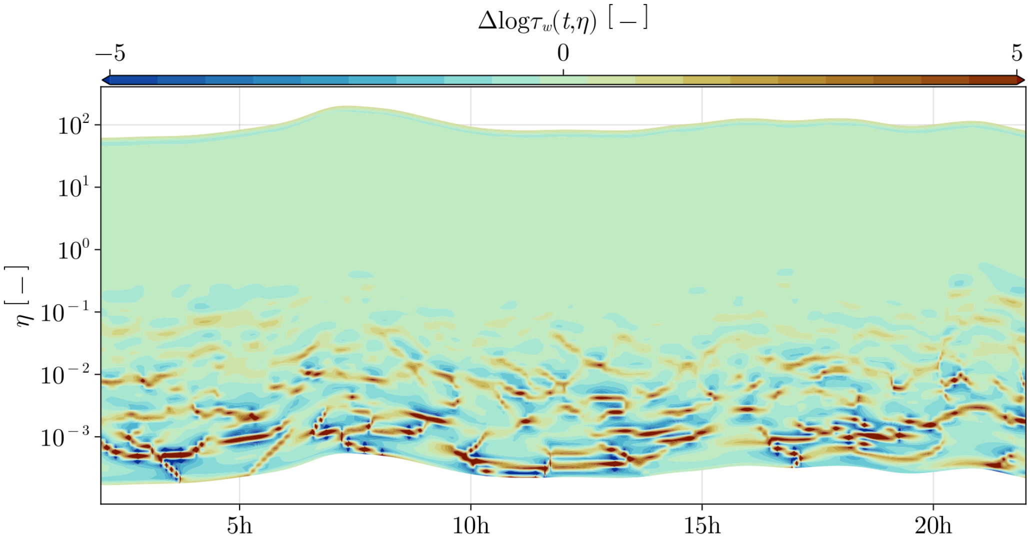


B. Identification of Turbulent Transport in Time-Frequency Space

τ_w + thresholding



Laplacian of τ_w



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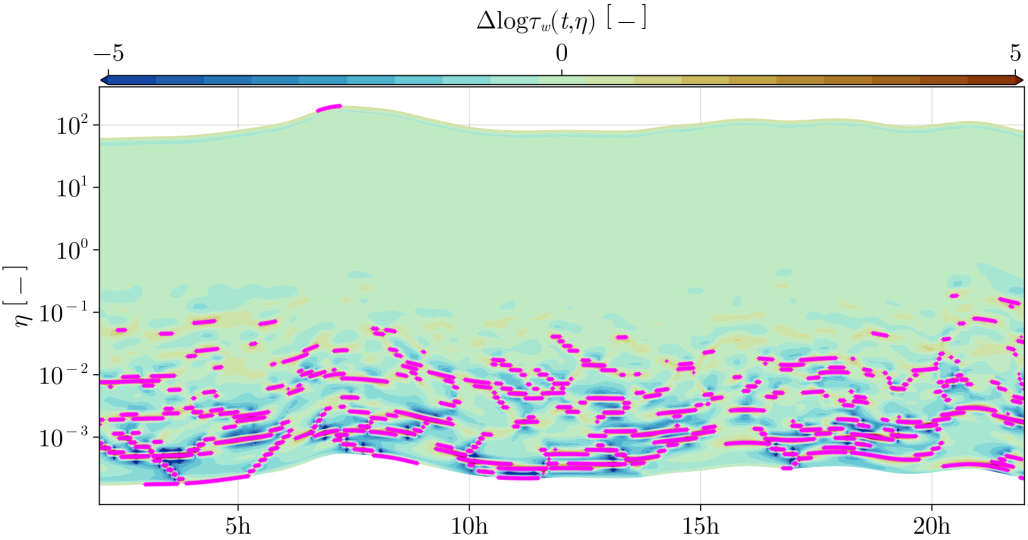
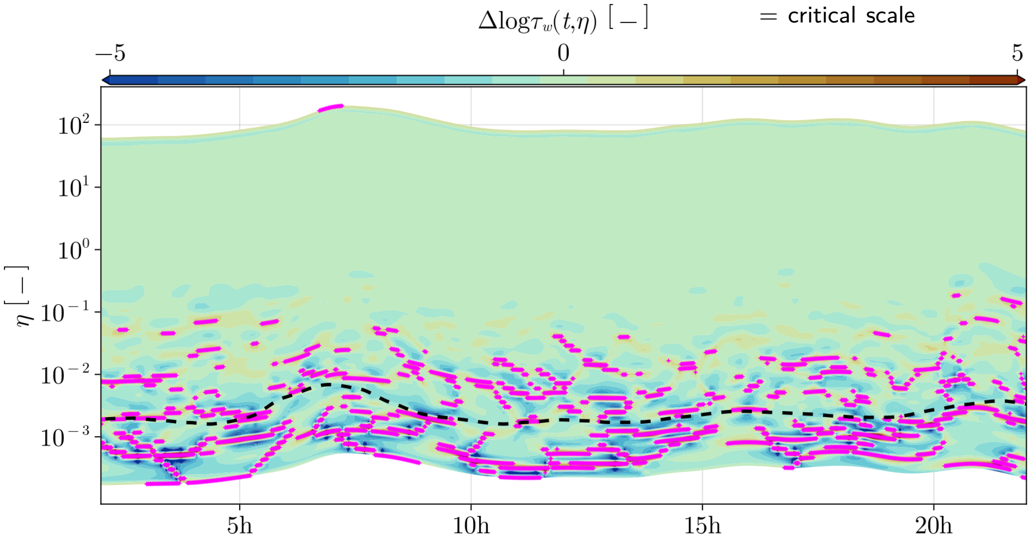
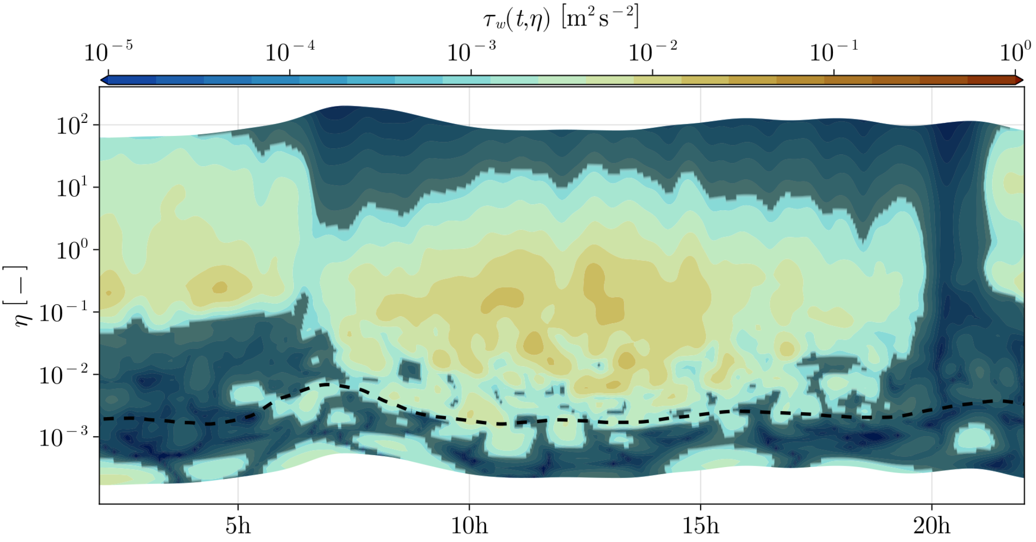


B. Identification of Turbulent Transport in Time-Frequency Space

Laplacian of τ_w + thresholding + linear weighted regression = critical scale

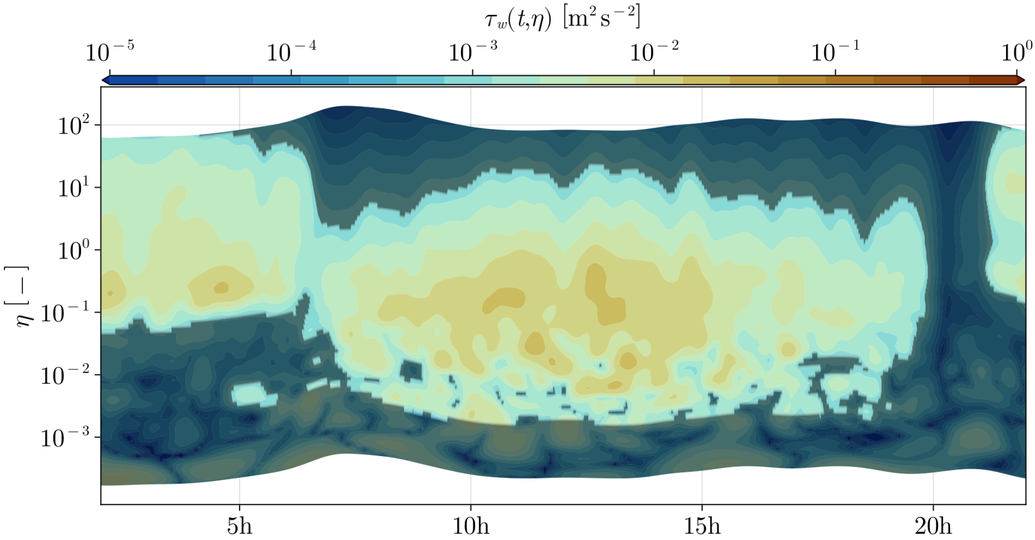


τ_w + thresholding + critical scale

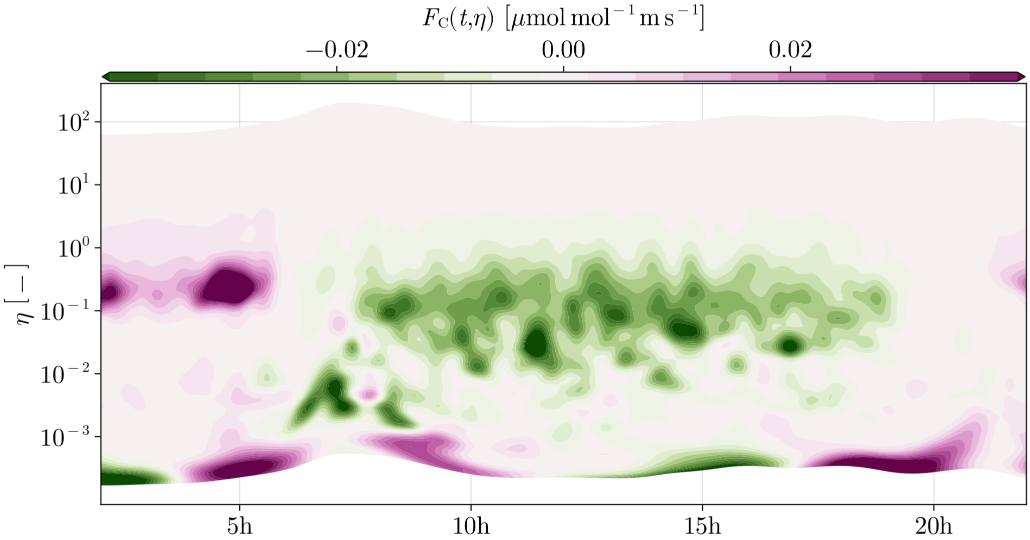


B. Identification of Turbulent Transport in Time-Frequency Space

τ_w + thresholding + critical scale
= turbulent transport mask

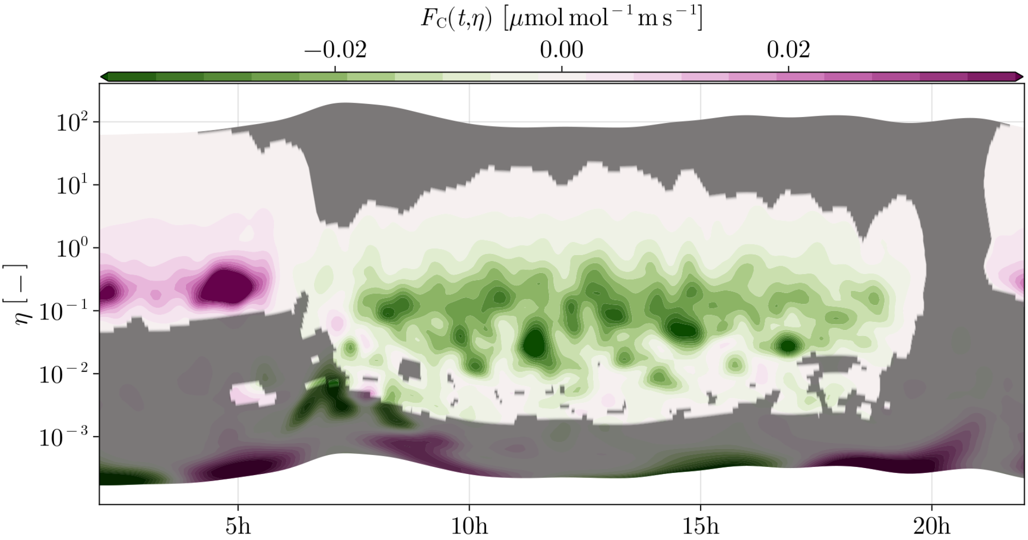


Decomposed flux



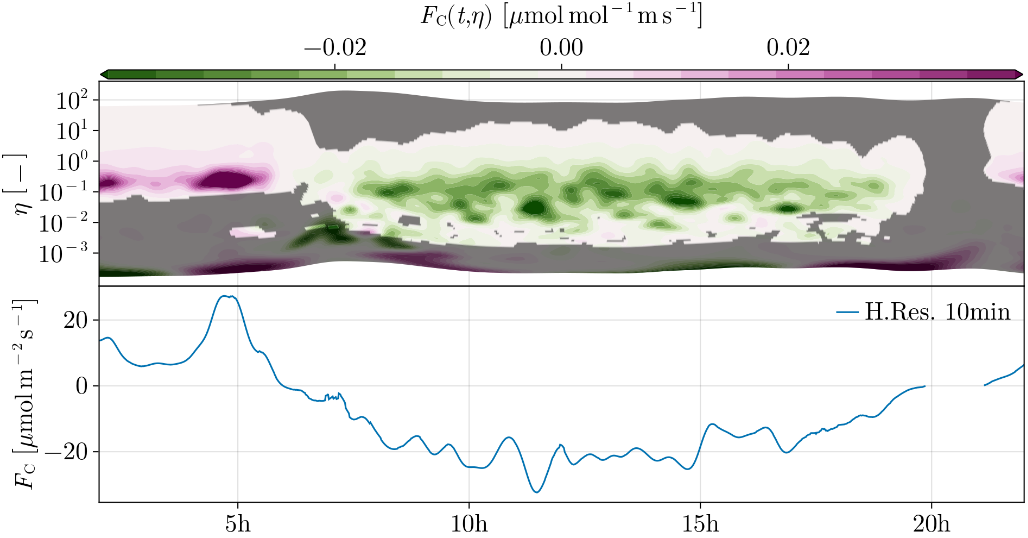
C. High Time Resolution Flux Integration

Decomposed flux + turbulent transport mask



C. High Time Resolution Flux Integration

Decomposed flux + turbulent transport mask + integration along freq. = flux



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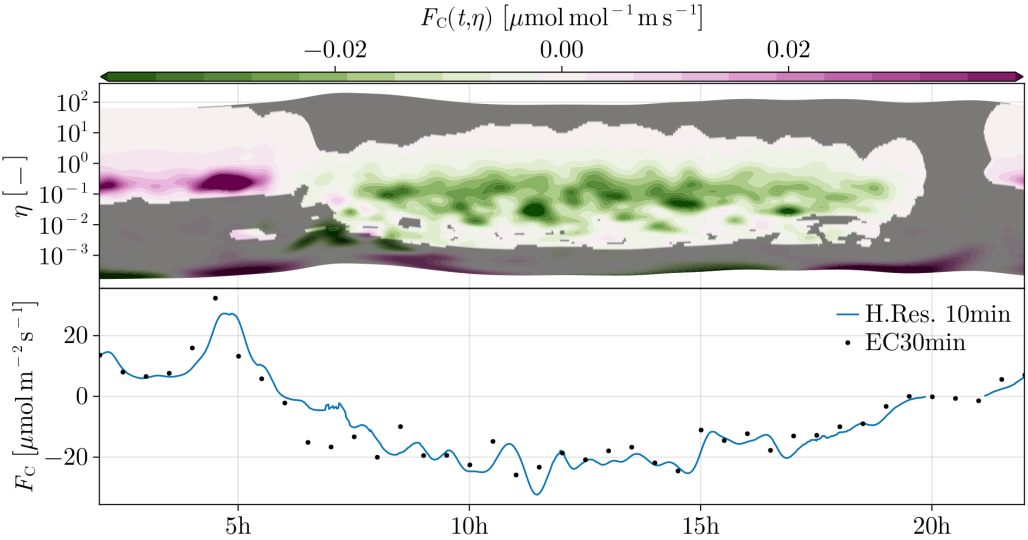

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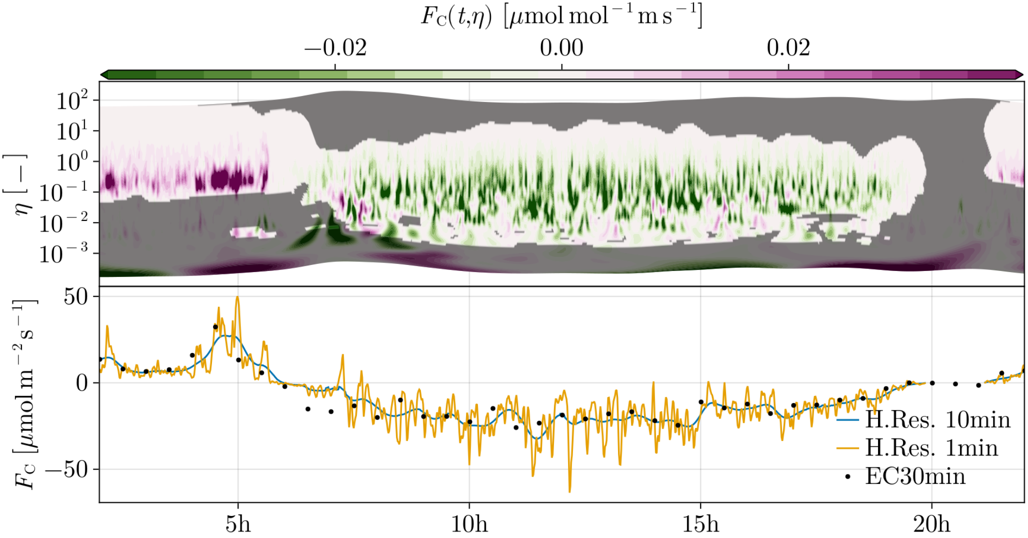
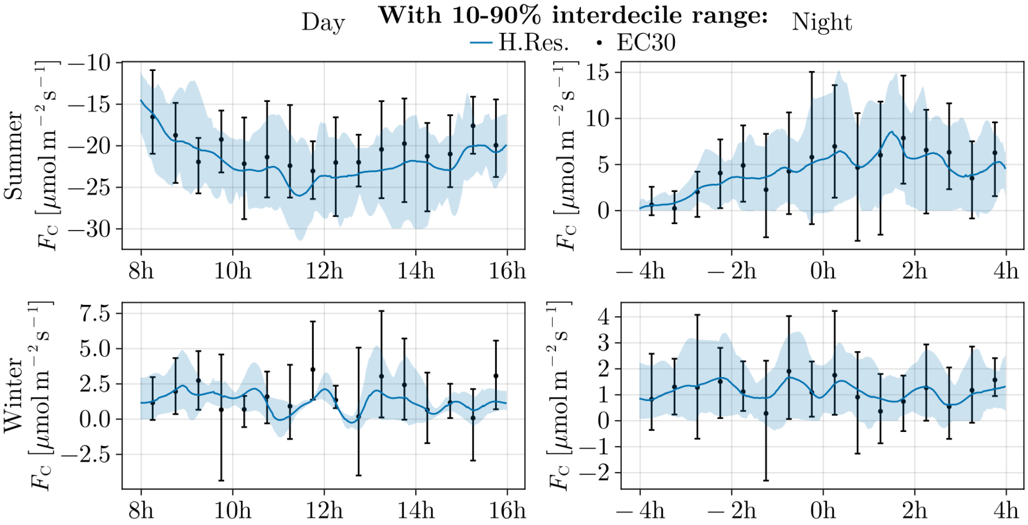


Statistics ($\sim$ 10 day periods)

Conditions: sunny consecutive days w/o precipitation



Conclusion and Perspectives

Take-Away

- High temporal resolution flux from local turbulent transport with adjustable rate
- Fast: 24-hour flux at 1-minute resolution from 20Hz data in less than 2 minutes

Comparison with standard Eddy-Covariance

- Handles non-stationnarity and tests for developed turbulence
- More consistent predictions

Comparison with other wavelet-based approaches

- Use a parametrized superfamily of wavelets (Generalized Morse Wavelets)
- Continuous Wavelet transform and averaging kernel designed to conserve global flux
- Wavelet coefficients filtering (thresholding) not solely based on energy criteria

Conclusion and Perspectives

Perspectives

- Test in different ecosystems and with taller towers
- Study of ecosystem response time using differentiability of estimated fluxes

Ressources available

- Paper in preparation
- `TurbulenceFlux.jl` julia package with data samples and notebook will be available on github

Statistics (∼ 10 day periods)

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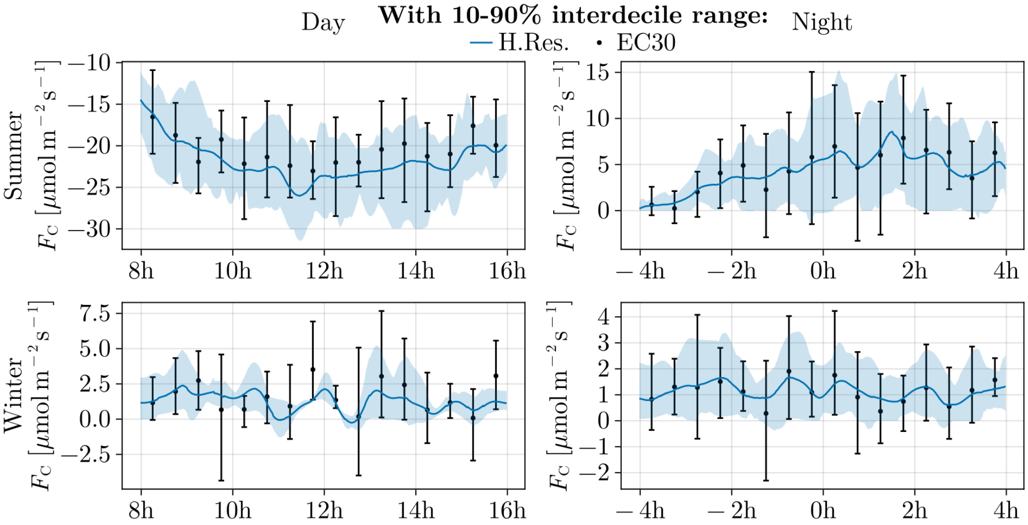

Thank you ! **Contact:** `gabriel.destouet@inrae.fr`