



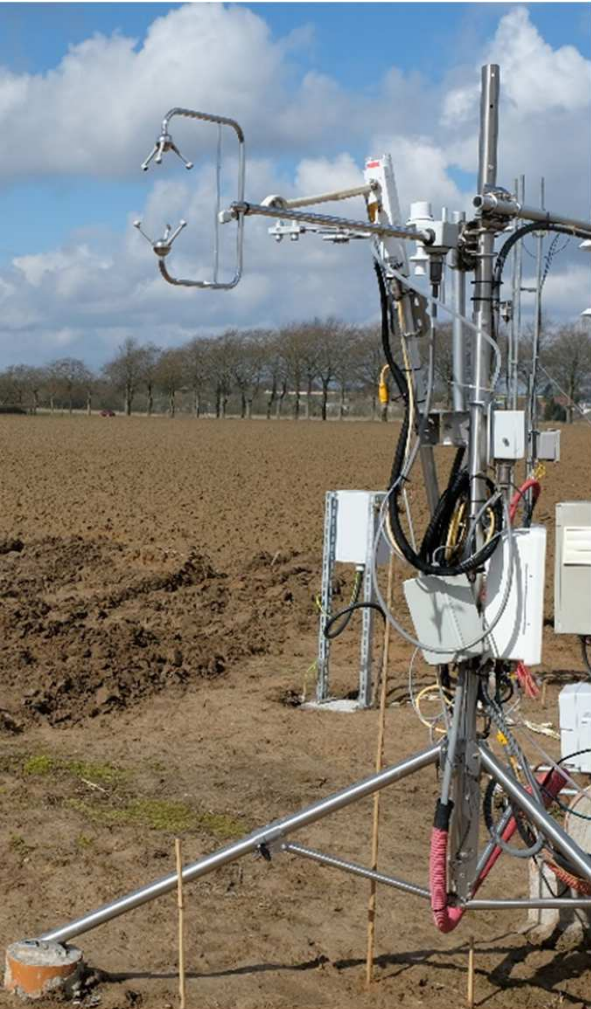
Frequency corrections on EC fluxes

A multi-site comparison of spectral and co-spectral approaches for correction of turbulent gas fluxes with ICOS set-up

Ariane Faurès, Gerardo Fratini, Giacomo Nicolini ,
Dario Papale, Simone Sabbatini, Bernard Heinesch

ICOS MSA, on-line, 21 May 2026

Recap: Frequency corrections

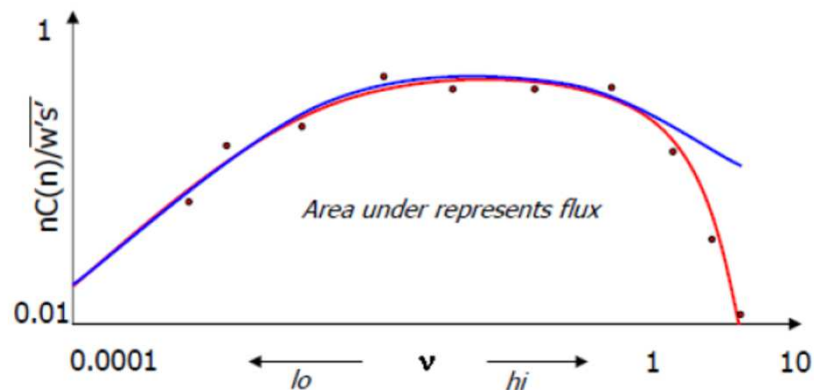


- High-frequency flux attenuation due to:
 - (Sonic path averaging of w and T)
 - (IRGA path averaging of c and h)
 - Sensor separation
 - Air flowing through the rain cap/filter/tube

Recap: Frequency corrections

- Experimental correction strategy :

transfer function (TF)



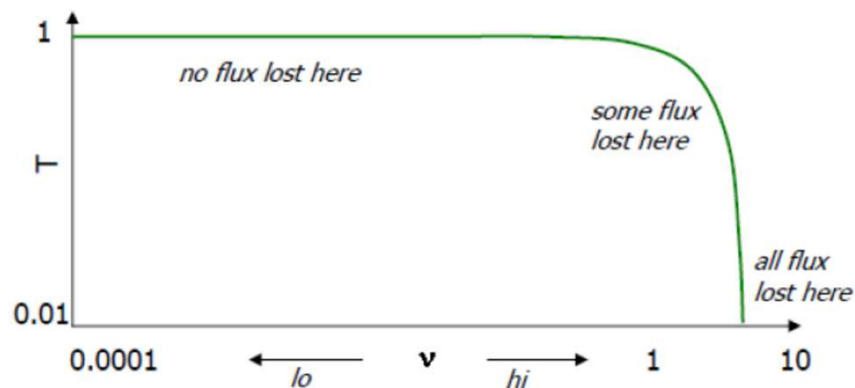
co-spectra:

Ideal (H is close) —

Modeled using
transfer functions —

Actual: H₂O, CO₂, CH₄ •

Scales: logarithmic



Total transfer function:

T=1 – no flux lost at
these frequencies

T=0.5 – 50% flux lost
at these frequencies

T=0 – 100% flux lost
at these frequencies

correction factor (CF)

$$CF = \frac{\int_0^{\infty} C_{wT}(f) df}{\int_0^{\infty} TF(f) C_{wT}(f) df}$$

Different strategies

- Experimental (vs theoretical)
- Several choices possible
- Focus on spectra vs cospectra

Pros

Cons

spectra

Pure signal
(not polluted by w)

Needs theoretical description of
sensor separation

Noise removal needed in some cases

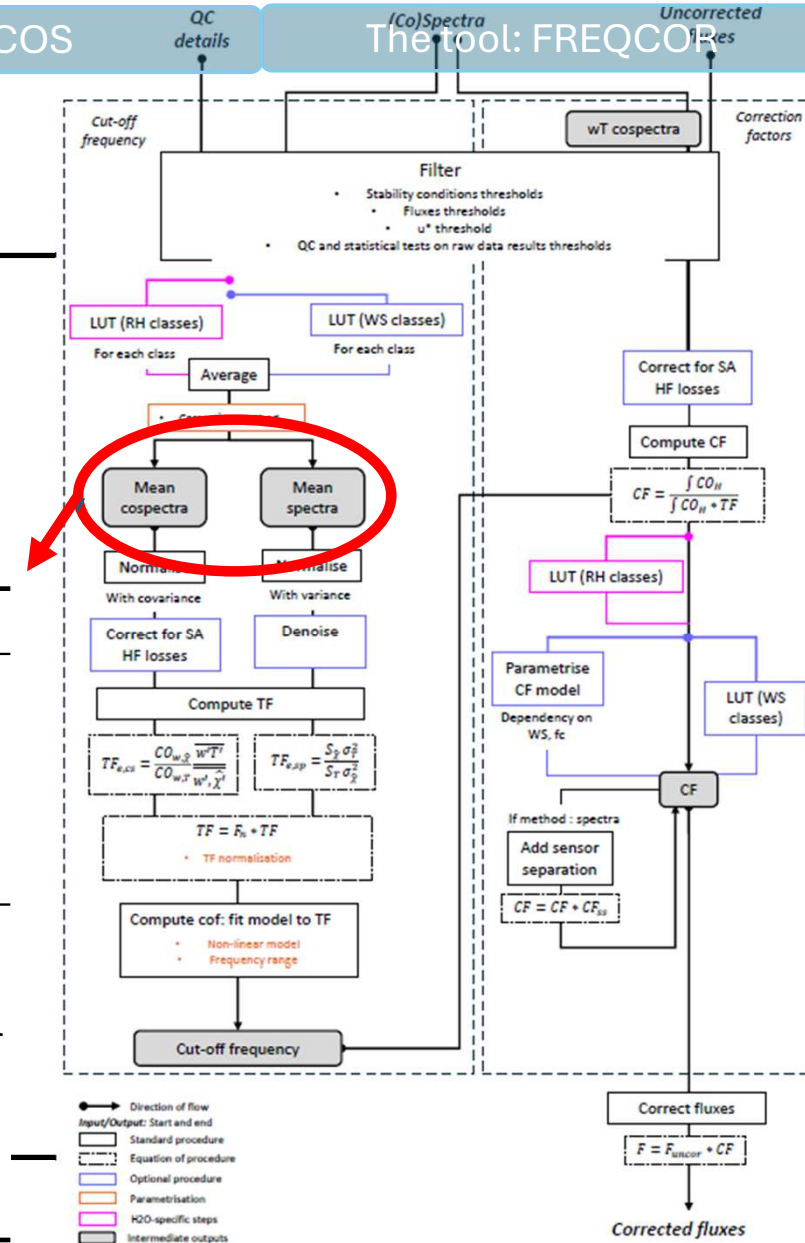
Cospectra

No denoising needed

No sensor separation
description needed

TF determination could be difficult
because of « pollution » of IRGA signal
by w

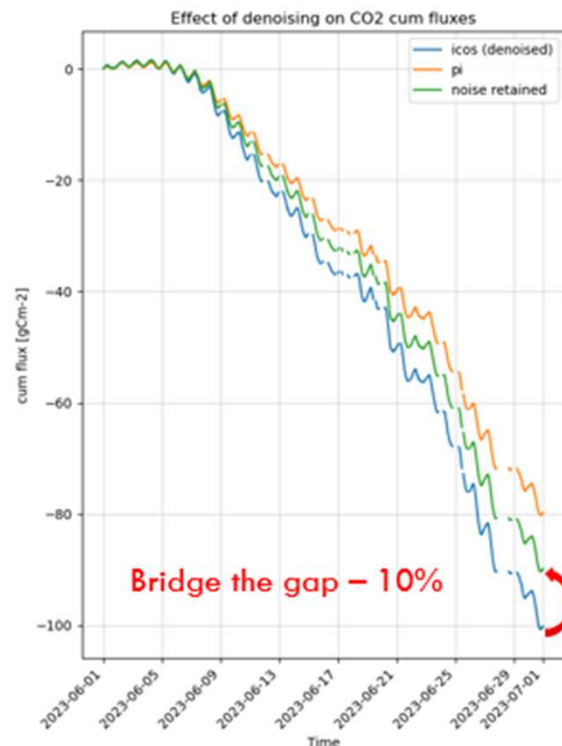
Time lag compensation



Initial motivation

From the ICOS Science conference in Lund (2024):

“Bridging the gap between historical and ICOS ecosystem flux data series”



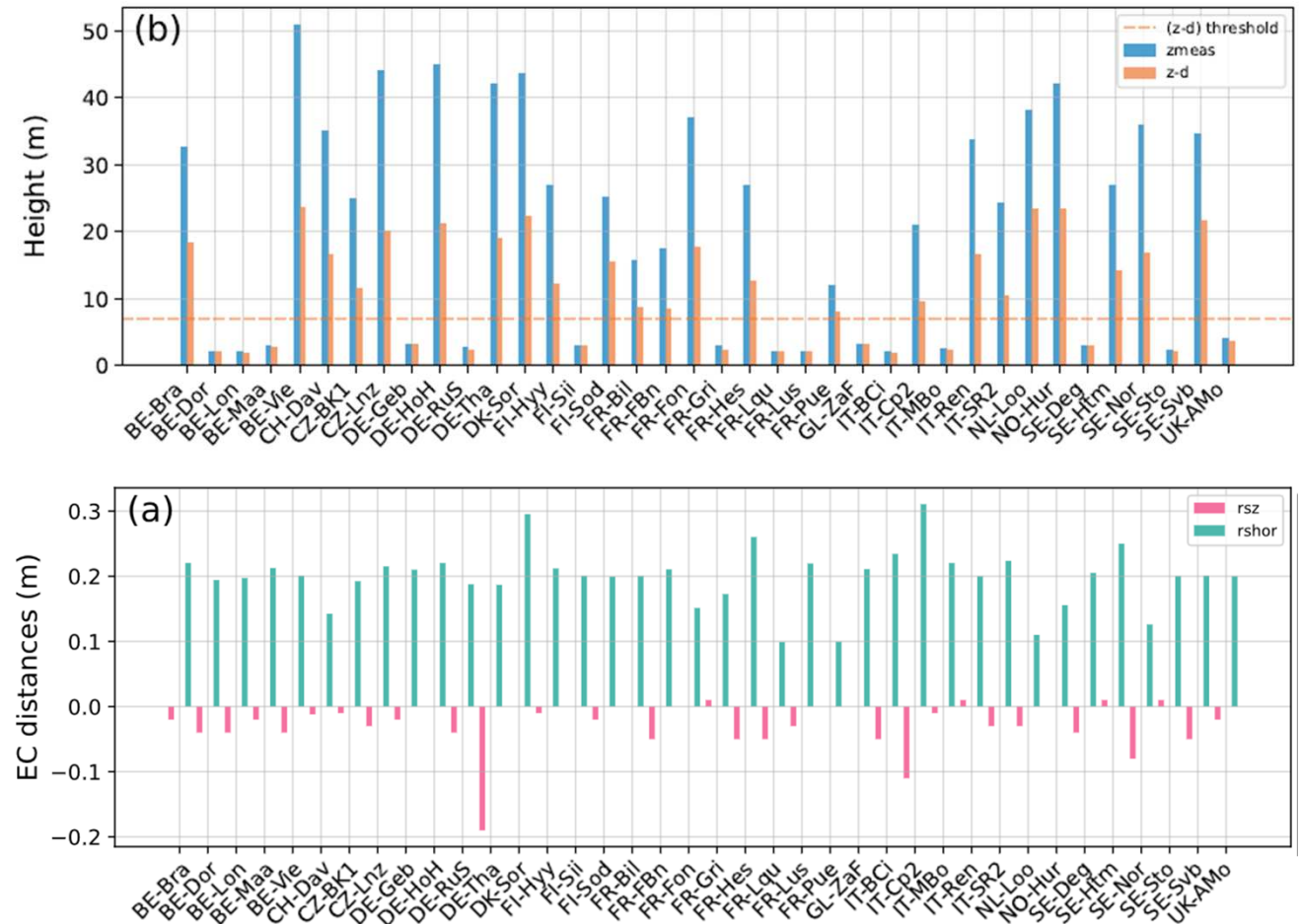
- Excessive denoising on spectra explained half of this discrepancy
- Processing pipeline adapted for the L2 release 2025

Objectives

- 1) How much do spectral and co-spectral methods diverge?
- 2) Under which conditions?
- 3) What is the best practice?
 - limited to the ICOS set-up
 - data-driven, relying on established spectral and cospectral approaches (no new theoretical developments but latest developments included)
 - multi-sites
- 4) How does it compare to the ICOS (EddyPro) implementation of spectral corrections?

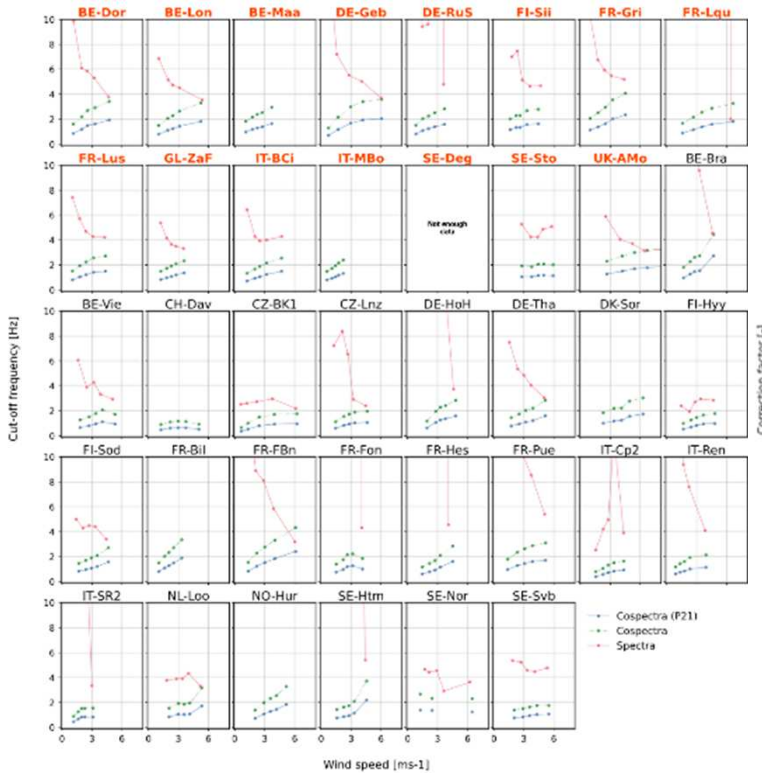
Dataset + M&M

- All 38 ICOS Class 1/2 stations
- One full year (2024)
- Different behaviours observed for “low- and high-measuring sites”
- Implementation of the most up-to-date findings on frequency-corrections (e.g. Aslan 2021, Peltola 2021)
- Use of look-up tables for the dependencies of cut-off frequencies and correction factors on U, RH, WD

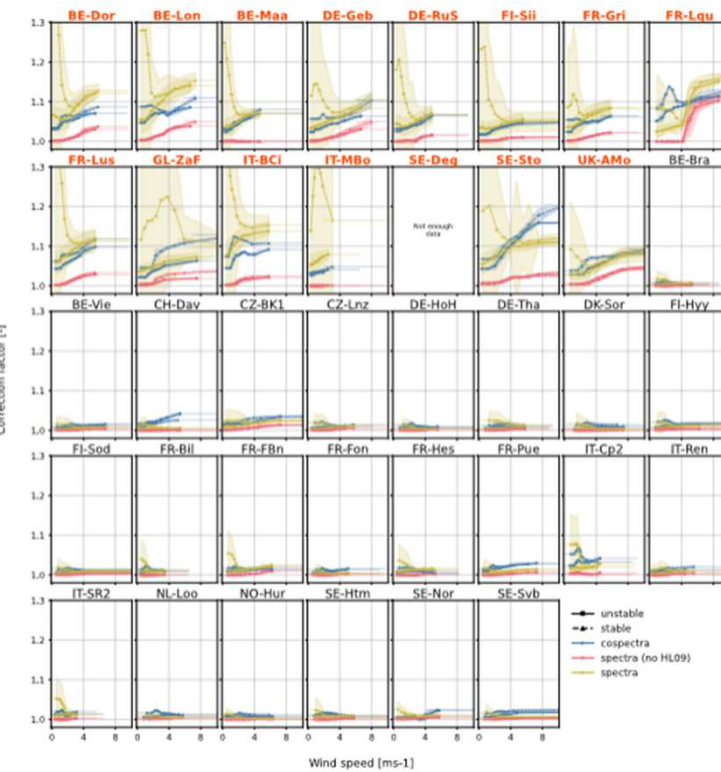


Spectra vs co-spectra (our implementation)

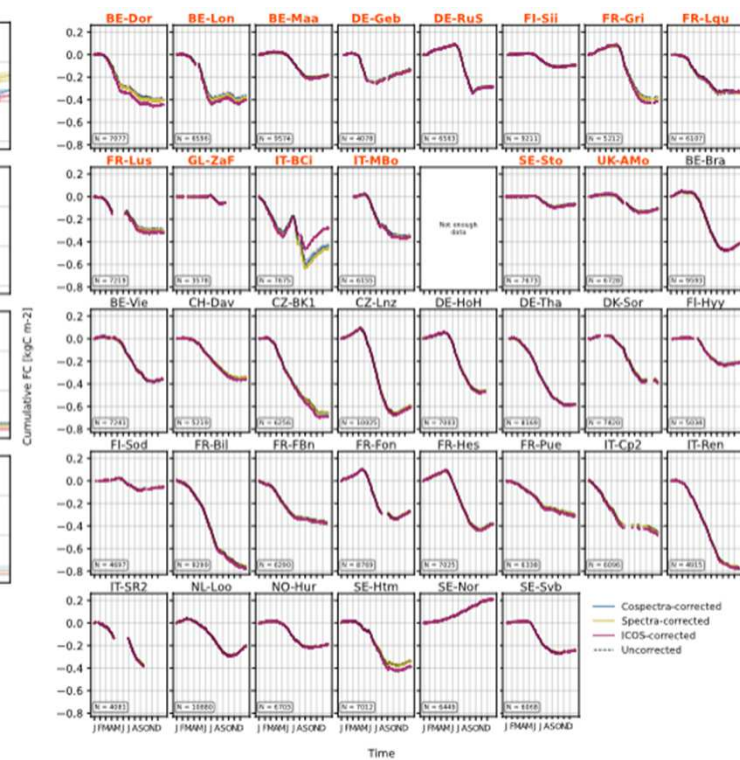
Cut-off frequencies



Correction factors

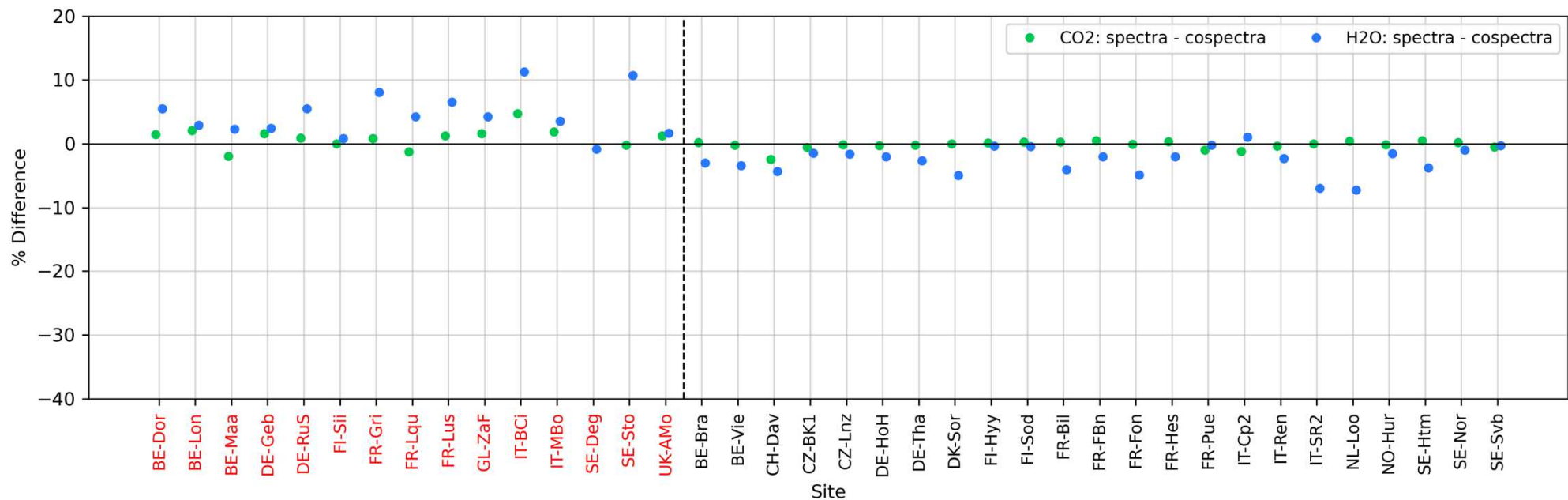
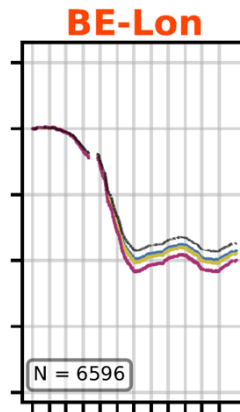


Cumulated fluxes



Spectra vs co-spectra (our implementation)

- Comparison made on cumulative (non gap-filled) fluxes
- Similar for CO₂ (worse is 5.1%), especially for “high measuring sites”
- More divergent for H₂O (can reach 10%)

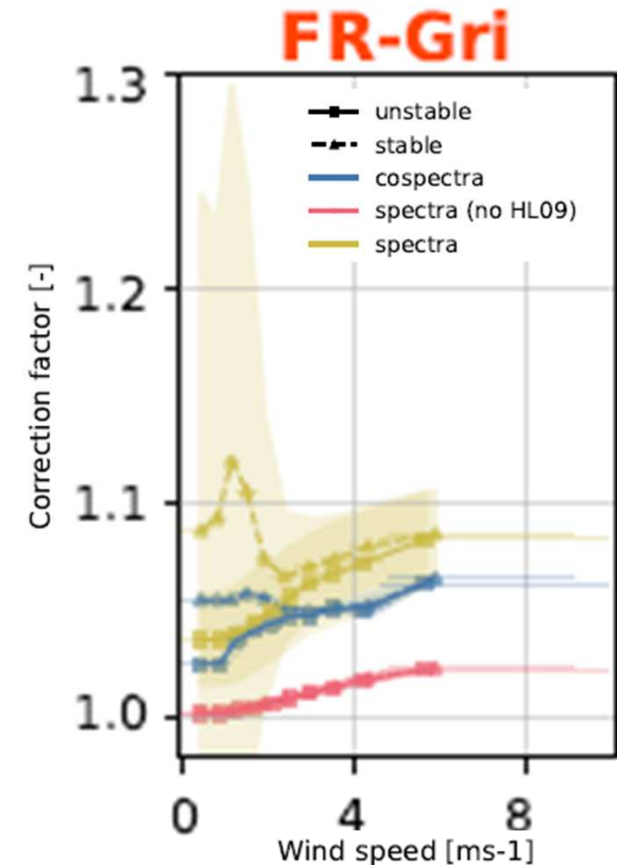


Why these $\neq$?

CO₂ correction factors

- **Spectra** > **Cospectra**
- Sensor separation is largely dominating the correction
Spectra >> **Spectra (no HL09)**
- **Spectra** can reach unrealistically high values (in stable conditions)

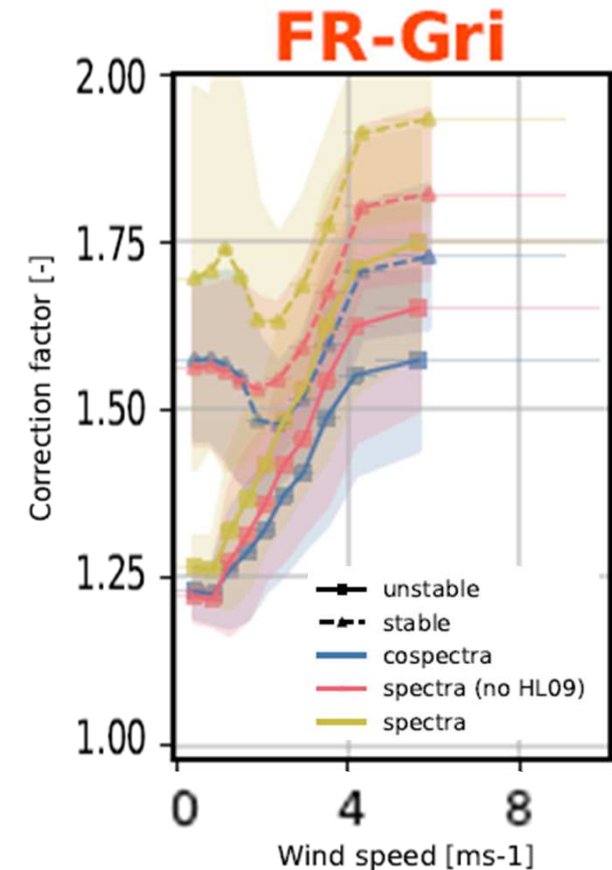
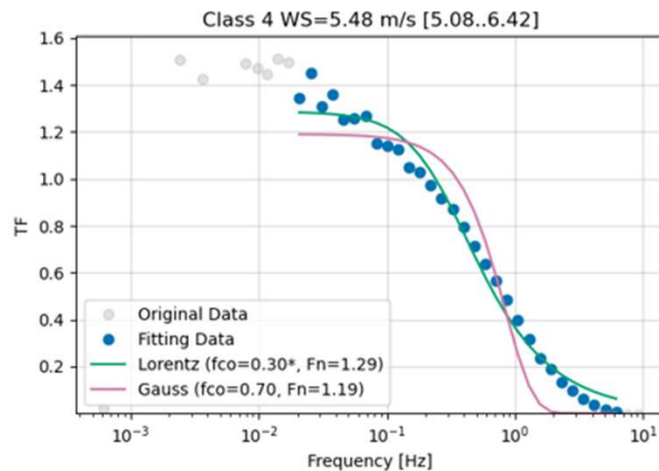
=> we tend to prefer Cospectra
(but impact small and even negligible
over forests)



Why these $\neq$?

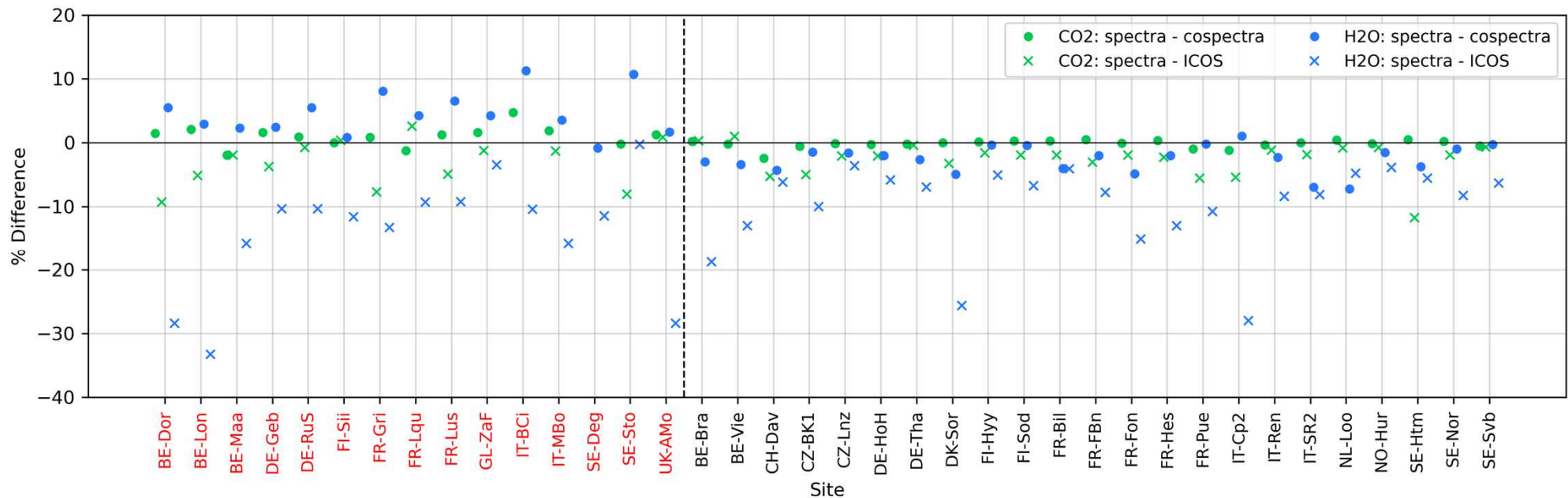
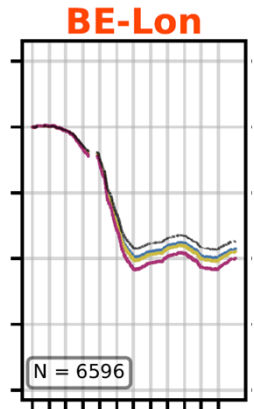
H₂O correction factors

- Spectra > Cospectra
- RH effects dominate (not shown)
- Noise almost always detected
- Problem of spectral similarity, more pronounced on spectra



What about the ICOS fluxes?

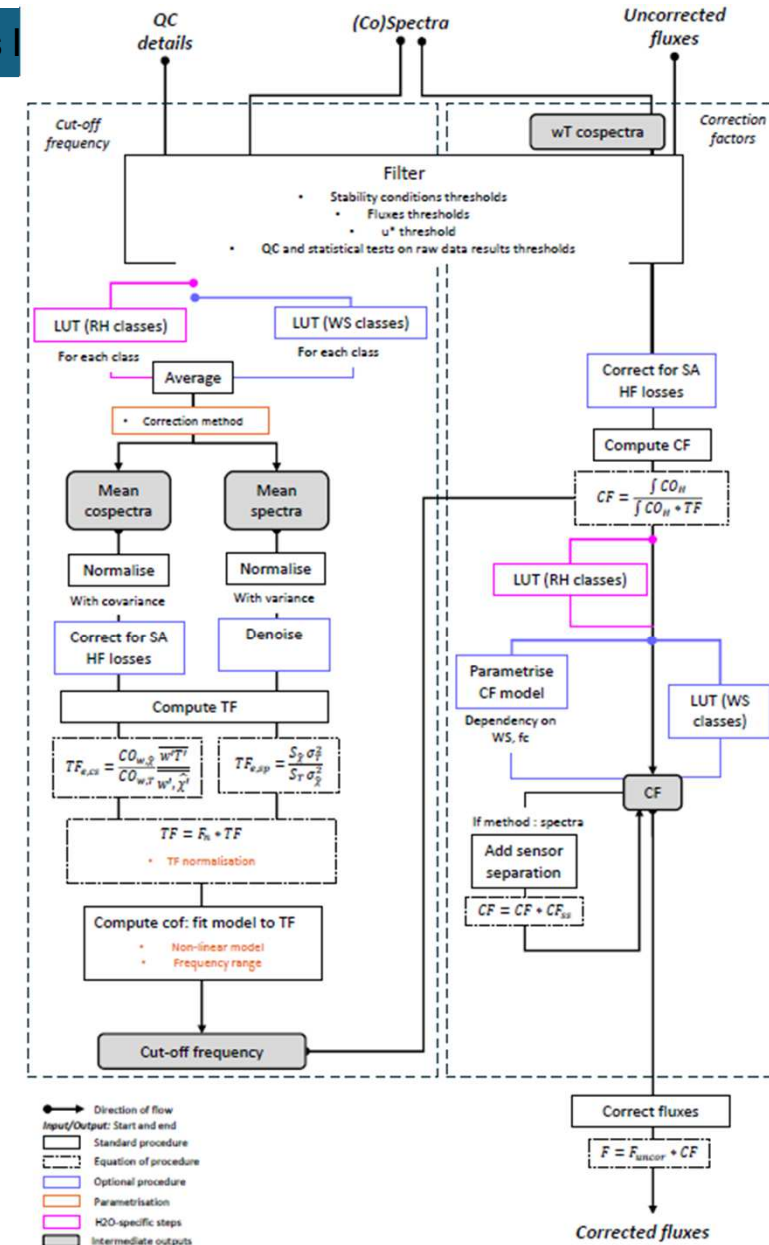
- Comparison made on cumulative (non gap-filled) fluxes
- ICOS uses spectral approach (EddyPro)
- ICOS vs our study (x and x)
- Reaches 11% for CO₂ and 32% for H₂O !



Why these ≠?

- Thresholds for flux filtering and transfer function fitting
- Use of look-up tables for cof and CF dependencies on WS, RH, WD
- Horst and Lenschow equation 13 vs 16
- Denoising systematically unactivated for ICOS but found present and removed in many cases
- Use of $\sqrt{TF}$ according to Peltola 2021

To be investigated further...

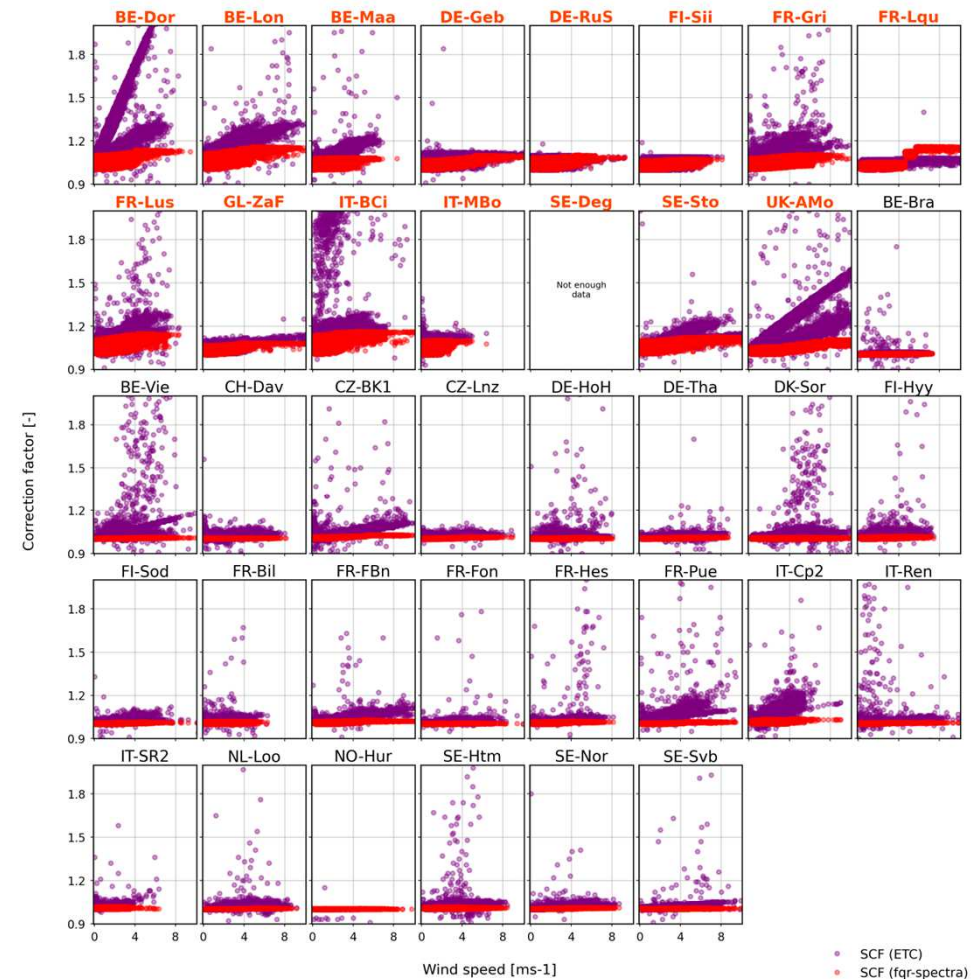


Why these ≠?

- Comparison on CF
 - Ours vs those extracted from the ICOS L2

- SCF (ETC)
- SCF (fqr-spectra)

CO₂

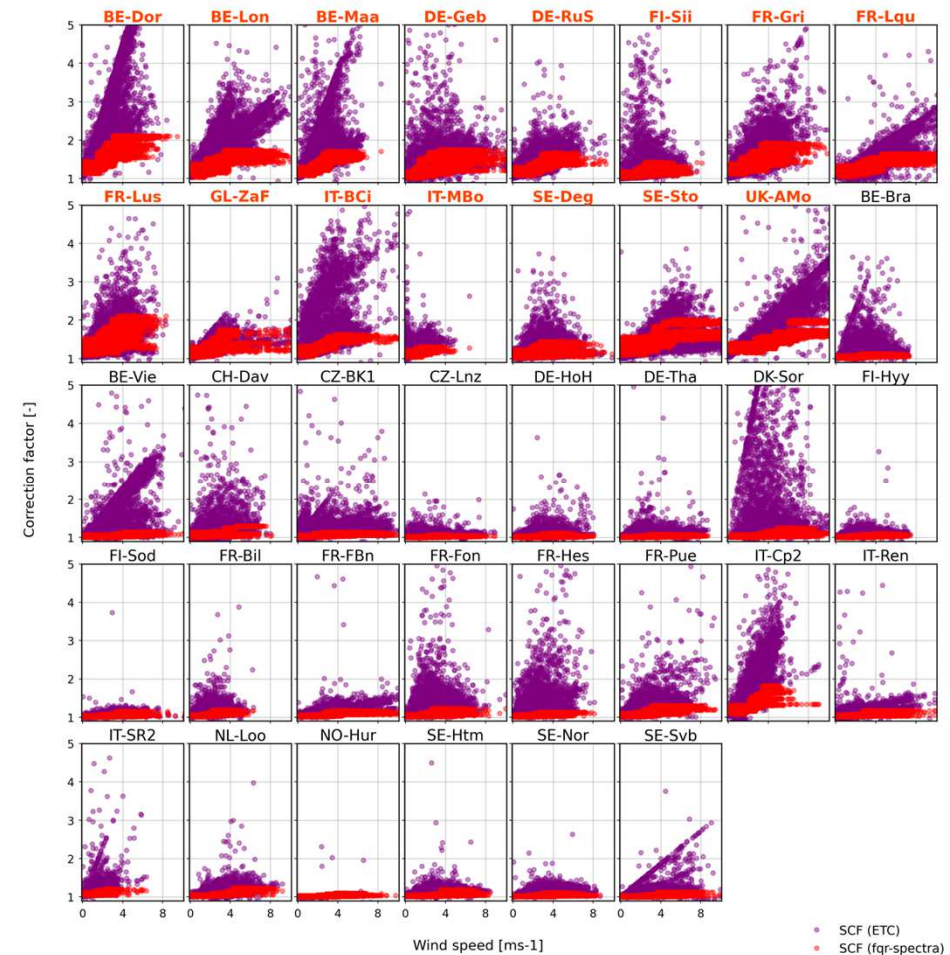


Why these ≠?

- Comparison on CF
 - Ours vs those extracted from the ICOS L2

 H_2O

- SCF (ETC)
- SCF (fqr-spectra)



A python tool : FreqCor

- <https://github.com/BernardHeinesch/FreqCor>

FREQCOR

Search docs

USER GUIDE

- Installation
- Quick Start
- Batch mode (CLI)
- Configuration
- Running the Example
- Outputs
- Contact

PROJECT INFO

- Version History

IMPLEMENTATION DETAILS

- Software Architecture

API REFERENCE

- API Reference

Welcome to FREQCOR Documentation

FREQCOR (**F**REQuency **C**ORrection) is a Python toolbox to compute and apply spectral/cospectral correction factors to eddy covariance fluxes.

It produces:

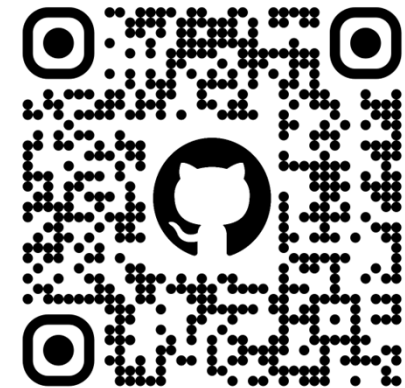
- cut-off frequency look-up tables (LUTs), and
- correction factor LUTs (stable/unstable), which can then be applied to half-hourly flux time series.

Two types of inputs are currently supported: (i) outputs from an EddyPro run (binned (co)spectra and the full_output file), or (ii) outputs from the GEdySoft software, a flux computation toolbox developed by the same research team (<https://github.com/BernardHeinesch/GEdySoft>). Handling of other input formats can be easily implemented by replacing the FREQCOR_Read routine by your own.

The workflow implemented in FREQCOR follows a classical frequency-domain approach:

1. read and quality-screen binned (co)spectra and associated flags,
2. estimate transfer functions and cut-off frequencies from ideal vs real (co)spectra,
3. compute correction factors by integrating degraded vs ideal reference (co)spectra,
4. apply the resulting correction factors.

This tool has been written by Ariane Faurès, from the BioDynE research axis, Gembloux Agro-Bio Tech, University of Liège in Belgium and its version 1.3 has been used in the study "A multi-site comparison of spectral and co-spectral approaches for correction of turbulent gas fluxes with ICOS set-up", to appear soon in the Atmospheric Measurements and Technologies journal peer-review process.



Conclusions

- Spectra vs Co-spectra (our implementation)
 - Similar for CO₂, especially for “high measuring sites”
 - More divergent for H₂O (can reach 10% on cumulated fluxes)
 - ... provided applied with the latest developments
- As PIs, we choose the co-spectral approach, at least for CO₂
- ICOS spectral corrections higher than ours (diff can reach 10% for CO₂ and > 30% for H₂O...)
- Think about Carbon budgets, Energy balance closure, etc...