Turbulent transport extraction in time and frequency and the estimation of eddy fluxes at high resolution

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Dear reviewers, thank you very much for your very stimulating questions, comments and suggestions. We did our best to address them appropriately in the revised version of the manuscript, and by doing so to improve the quality of the presented research.

The remarks and comments are enumerated and denoted in font **R#.C#**. We use blue to refer to sections and figures in the revised manuscript.

For each reviewer, we provide the same general response addressing a global concern that both reviewers appear to have raised. This is followed by a specific response to the reviewer, and then we address each of their comments individually.

Reviewer 2 (R2)

General comments

The manuscript "Turbulent transport extraction in time and frequency and the estimation of eddy fluxes at high resolution" by Gabriel Destouet et al. (egusphere-2024-3243) presents a method for determining if the turbulence is sufficiently developed considering time and the eddy scale.

The manuscript is clear. I appreciated the progressiveness of the introduction that guides well the reader and found that the technical parts in the methods are well explained. It is in Atmospheric Measurement Techniques' scope and it brings clear contributions to the flux community. A few points could be clearer, please see my major concerns below [...] The scientific approach and methods applied are valid and the results and discussion well based on it. Overall, I believe that this manuscript represents a significant contribution to the field of atmospheric measurement techniques and I recommend it for publication in Atmospheric Measurement Techniques.

We would like to thank the reviewer for their review and positive feedback on our manuscript. Below, you will find our general response addressing common remarks made by the reviewers, as well as a specific response to the reviewer's detailed comments on our work.

General response: One of the primary issues in our initial version was the lack of emphasis on the distinction between "technical" and "physical" time resolutions. The former refers to the time step of the estimations, while the latter relates to the averaging time. We acknowledge that we have not been differentiating clearly enough these concepts in the original paper, which may have obscured the understanding of the proposed approach.

Our motivation for the method arose from studying eddy-fluxes with a faster rate of change. Specifically, we aimed to increase the "physical" time resolution of the flux estimations by reducing the averaging time. However, the standard eddy-covariance method does not allow for adjusting the averaging time without affecting the filtering of perturbative scales. To address this, we propose decoupling the filtering of perturbative scales from the flux calculations. This led us to develop a method based on time-frequency analysis, particularly wavelet analysis, that enables:

1. Identifying turbulent coherent structures by tracking turbulent spectra across the time-frequency domain.
2. Freely adjusting the averaging time, allowing for estimation of eddy fluxes with high time resolution.

The first point involves creating a time-frequency map of the turbulent structures by analyzing the Reynold's tensor and establishing the turbulent mask. The second point follows from the first; with accurate isolation of turbulent structures, one can adjust the averaging time to correctly resolve their contribution to turbulent transport.

Additionally, since our method allows for high "technical" resolution, we suggested it could enhance data availability after applying standard quality tests. However, as both reviewers noted, the standard eddy-covariance method can also achieve high "technical" resolution, although this is less common in standard implementations. We have removed any references to increasing the "technical" resolution from the original paper and focused solely on our original motivation: increasing the "physical" resolution without compromising the quality of flux estimations.

Specific Response: As the reviewer mentioned, our method is based on previous research on the wavelet analysis of turbulence. In this paper, we aimed to address some of the common mathematical and technical challenges that come up with wavelet transforms, especially when it comes to energy conservation and practical use. We think that the proposed framework, which uses generalized Morse wavelets, will be a great addition to the community. It offers both the flexibility and the physical guarantees needed for future research to dive deeper into analyzing and isolating turbulent structures.

R2.C1: The manuscript seems to suggest an innovation is calculating fluxes at smaller time periods. Estimating fluxes at high resolution can be done using standard eddy-covariance. The time and frequency average are commonly the same but there is no reason why not to calculate the instantaneous deviation (c') using the 30-min average and then averaging w'c' every 1 min. Conserving thus lower than 1-min frequency while having the 1 min fluxes calculated. Also calculating 1 min flux using continuous wavelets has been done in Schaller et al. (2017).

$\Longrightarrow$ We agree with the reviewer. We have removed the claim from the manuscript that the method produces fluxes with shorter time steps. The abstract, discussion, and conclusion have been revised to focus on the two main features we consider important: (1) the identification of turbulent transport and (2) the ability to change the averaging time without impacting the filtering.

R2.C2: The fact that Schaller et al. (2017) have used wavelets for addressing short turbulent events could be cited in the introduction when enumerating the uses of wavelets. The authors justify choosing the Generalised Morse Wavelets to avoid making an arbitrary choice of a particular family of wavelets such as Mexican hat or Morlet wavelets. Then it presents the parameters used. It seems the Generalised Morse Wavelet is of a "more flexible use", but once you define its parameters, it is hard to understand how different this is from choosing another particular wavelet.

$\Longrightarrow$ The revised manuscript now also references the work of Schaller et al. (2017) for identifying short turbulent events.

One of the primary challenges with wavelet transforms is the variability that can arise from switching between different wavelet families and the associated implementation costs. The advantage of Generalized Morse Wavelets lies in their flexibility, Their spectrum can be easily adjusted to various forms by tweaking their parameters. This flexibility also allows us to see how estimations are affected by wavelet parameters, which could lead to new research paths for studying turbulent transport and improving the estimation process.

The proposed framework is not restricted to using this specific wavelet family. It is sufficiently general to use any set of filters that can decompose frequencies and separate different scales. In this study, we employ Generalized Morse Wavelets as we find that they currently offer the most practical approach for implementing the proposed framework.

R2.C3: The manuscript would benefit from showing clearly an equation stating how to calculate the global flux from wavelets. The result from using eq. 15-17 together I imagine.

$\Longrightarrow$ The manuscript now includes a brief paragraph in Sec. 2.6 summarizing the steps to calculate the flux at a time t from the time-frequency decomposition of the flux.

R2.C4: The terms "smoothing" and "local smoothing" are used several times in the manuscript and

seems to be one of the key concepts. Once it includes a citation "The local smoothing of cross-scalograms (Mauder et al., 2007)", however the authors in Mauder et al. (2007) do not employ the term themselves. In the manuscript it seems to be simply a time average, so how does it differ from it and is it really relevant to employ this wording? The risk is to lose the reader with too technical terms.

⟹ The term originates from the work of Torrence and Compo (1998) on the analysis of turbulence using wavelets. Mauder et al. (2007) built upon this work, which led us to retain the term "smoothing" as defined in Section 5 of Torrence and Compo (1998). The term "smoothing" is more general, encompassing various averaging windows beyond the traditional rectangular one. In Fig. 2 of the revised manuscript, a difference can be seen, where EC30 is using a rectangular window while HRTM uses a Gaussian window with $\sigma = 30$ min. The estimation with the Gaussian window has fewer high-frequency components.

R2.C5: The figures showing the time and frequency decomposed fluxes with a mask on top are well-appreciated. They are clear and intuitive. In the conclusion, the authors state that the proposed method "opens up new research perspectives, in particular the analysis of ecosystem response to rapid environmental changes (< 1 hour)." This is an important point, but it could be expanded upon. The sentence seems to suggest the advantage of calculating fluxes for shorter time periods, but this is not the innovative part of the manuscript (see major comment 1). The main contribution lies in doing the analysis in the frequency domain and considering the changing conditions for turbulence flagging.

⟹ Thank you for the positive feedback on the figures. Regarding the conclusion, we appreciate your insight and have revised it to better highlight our core contributions. Specifically, we emphasize two key aspects: the decoupling of the filtering process from flux calculations, and the ability to localize turbulent coherent structures across time and frequency. Please see our general response above for further details.

Minor comments

R2.C6: l.12, 1 min is mentioned but is not shown in the rest of the manuscript.

⟹ We now show the diffrent averaging time used in the paper including the 1 min.

R2.C7: In p.5 l.124-125, the sentence may not be rigorously all correct. In standard eddy covariance, although we commonly only refer to a single averaging time, in reality we do two. One to calculate the instant deviation and another to pass from 10/20Hz to 30-min. See major comment 1.

⟹ Please see our general response. In the revised manuscript, regarding the "time resolution" of the estimates, we insist on the ability to vary the averaging time and not on the ability to decrease the time-steps of the estimations.

R2.C8: In p.5 l.125-127, The sentence does not refer to standard eddy covariance anymore, rephrasing may help avoid misunderstanding. Such as by adding "Alternatively" in the beginning or some other alternative.

⟹ Thank you for the proposed reformulation.

R2.C9: In p.5 l.141, the term "fluxes" repeats 3 times. I suggest to reformulate as such "The advective term is decomposed into turbulent eddy fluxes and other fluxes, encompassing those generated by large-scale processes and noise.".

⟹ Thank you for the proposed reformulation.

R2.C10: In p.8 l.211, is K defined?

⟹ The number of frequency bands K is determined during the initialization of the wavelet bank. The definition of K depends on the criterion used to reject poorly sampled wavelets. In our case, we set a low-frequency bound and reject any wavelets whose peaks fall below it.

R2.C11: In p.8 l.213-214, is it possible that peaks at low frequencies may represent real information and thus be acceptable?

⟹ Our assumption is that these are not considered eddy fluxes, as their scales are too large for the study area. Separating the small turbulent scales from the larger ones seems reasonable. The proposed approach still allows for later analysis to assess whether the lower scales contribute to local turbulent transport.

R2.C12: In p.10 l. 293, "less smoothing" seems imprecise.

⟹ Corrected

R2.C13: In p. 14, l.357, "dotted" should be "dashed".

⟹ Corrected