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Biogeosciences Discussions

Interactive comment on "The motion of trees in the wind: a data synthesis" *by* Toby D. Jackson et al.

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Dear reviewer, thank you again for taking the time to comment on our manuscript. I have discussed your comments with co-authors and respond to them below. I believe most of the smaller issues were dealt with in my previous reply, so this response deals only with issues arising from the interpretation of the slope of the tree motion power spectrum (Sfreq).

I have broken down your major concern b) into three parts, which I will address in turn:

Reviewer comment b.1)

I find the meaning of the slope of the tree energy spectrum not clear in the paper. In lines 94-95, it is written that "the slope of the power spectrum (Sfreq) can be used as an overall measure of energy transfer between wind and tree at different frequency

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ranges (van Emmerik et al., 2018; Van Emmerik et al., 2017)". I am not sure to agree with this statement that Sfreq represents the energy transfer between wind and tree. In my opinion, it is more representative of the tree energy transfer (cascading) or damping from f0 to high frequencies.

Author response b.1)

Thanks for raising this issue. We agree with you that Sfreq will be influenced by the damping and related to the stiffness of the tree. However, unlike typical building structures, the stiffness and damping of the system will change with wind speed (particularly the aerodynamic damping), as the tree changes shape and the whole system deforms.

The spectral response of the tree is essentially the spectra of the wind modified by the tree response (close to a lumped mass damped harmonic oscillator for conifers). This is described in equation 27 in Gardiner 1992. This is also presented in Mayer (1987), Kerzenmacher and Gardiner (1998) and Sellier et al (2008). It seems that many of your criticisms stem from this difference in interpretation and it would be useful if you could provide some references to support your view.

We appreciate that the current wording may be unclear we suggest revising this to: 'the tree spectrum is essentially the wind spectrum modified by the tree response. Therefore, the slope of the tree spectrum (Sfreq) is the result of the energy transfer between wind and tree as well as the energy transfer within the tree itself'.

Reviewer comment b.2)

Indeed, f0 is usually located at the level of the inertial subrange of the wind velocity spectrum (see Figures S6 and S7), i.e. at frequencies larger than the frequencies of the main eddy motions at canopy top. I would think that the energy transfer between wind and tree occurs mainly at lower frequencies than f0, where the tree power spectra exhibit the same distribution with frequency as the wind spectra. I think Sfreq reflects how the tree damps/transfers its energy independently of the wind. Maybe a way to

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verify which flow motions are involved in tree motions is to look at the momentum flux cospectrum, assuming that the momentum flux at canopy top is totally absorbed by the trees. For example, if you look at Figs 4 and 6 of Dupont et al. (2018, Agric Forest Meteorol., 262, 42-58), you can see that most of the canopy-top momentum flux occurs at frequencies lower than f0. Smaller eddies than the dominant canopy-top eddies may transfer as well energy to the tree but I would think it mainly concerns branches and less the trunks where the measures presented in this paper have be done. Branch motions are not necessarily in phase with the trunk motions.

Author response b.2)

The aim of our manuscript is not to identify which frequency ranges are most important, but to study the similarities / differences between trees. This helps contextualize the more detailed, single site studies. As explained in my previous response, the fact that this study contains a number of diverse data sets (which is its strength) precludes the analysis you suggest, which would require high resolution wind data for all sites.

All frequencies in the wind spectra necessarily stimulate tree motion, albeit rather unequally (this response is called the mechanical transfer function or admittance function). Previous studies have analysed which frequencies contribute most to this energy transfer (e.g. Dupont et al. 2018 and Gardiner 1995, Schindler 2008, Schindler and Mohr 2019). It is true that the dominant motion is triggered by the coherent turbulent structures in the wind (Schindler and Moher, 2019) but this does not mean there is no response at other frequencies. The wind drag will be primarily on the leaves / needles, resulting in their motion which will transfer to the stem. Motion also passes from the trunk back to the branches and to the leaves and is then dissipated as vortex shedding from the leaf tips (Spatz and Theckes, 2013). This leads to a spectral short-cut in the wind spectra inside the canopy (Finnigan, 2000). Therefore, although the spectral shape of the tree displacement does reflect this energy transfer, it is mixed with the direct response to the wind at all frequencies. We observe, therefore, a superposition of tree fundamental mechanical response and a supplementary response due to the

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transfer of energy between different frequencies that overall leads to a transfer from low frequency motion to high frequency needle / leaf waving.

Reviewer comment b.3)

The lower Sfreq for broadleaves than for conifers may just reflect their difference in architecture. I would think that Sfreq is representative of the tree properties, but not representative of the wind. Is it really new/surprising to observe differences between tree species in energy cascading/damping knowing that this mechanism depends on the tree properties (architecture, stiffness: : :)?

Author response b.3)

We agree with you that some (or even most) of the differences between trees arise from their different architectures. To our knowledge, no study has compared tree motion spectra across multiple species and different genera and growing conditions before. Our aim was not to produce surprising results, but to test whether or not different trees behaved in different ways. Perhaps the surprising part (and not what we expected initially) is the degree of similarity across such a diverse data set. Sfreq is rather consistent across all trees and decreases to a value of -3 at around 4 m/s in most cases. We do not speculate in the paper what this indicates but it might suggest a convergent evolutionary response to the danger of wind loading and an efficient method for dissipating energy.

Reviewer comment c)

Third, the Authors seem surprised and present as a result the fact that below a threshold wind speed value, Sfreq decreases with wind speed (Figures 4c-d). In my opinion, this decrease of Sfreq reflects the increasing noise of the tree data at high frequencies as the wind diminishes. With decreasing wind, the frequency of the main canopy motions gets lower. Consequently, f0 is shifted to the bottom (high frequencies) of the inertial subrange of the wind velocity spectrum, where there is much less energy. The

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high-frequency trunk motions become negligible. I am, therefore, not surprise to see that Sfreq decreases with wind speed, its evaluation becomes irrelevant and should not be presented.

Author response c)

We do not have a good explanation for this change and do not present it as a key result (L385). However, we do not think that this is simply due to a declining signal-to-noise ratio. Even at relatively low wind speeds, many trees have large motions orders of magnitude larger than the sensitivity of the sensors. Obviously, our study contains a wide range of sensors and some of them may be noisy, but it also contains some extremely high-quality data sets which exhibit the same pattern. For example, accelerometers are extremely sensitive and the strain gauges are able to monitor the tiny diurnal fluctuations (few millimetres) in stem swelling as the trees stop respiring at night (Duperat et al, 2020).

Specific comments.

I will not copy and paste each comment below, instead I refer to them by number. I only respond to those not previously addressed.

7) The tree spectrum is essentially the wind spectrum modified by the tree response. Sfreq is the slope of the tree spectrum. If either the wind spectrum or the tree response changes (due to increased wind speed or streamlining, respectively) we expect Sfreq to change. As for the direction, an increasing wind speed should lead to more energy at higher frequencies.

8) As discussed above, the tree spectrum is essentially the wind spectrum modified by the tree response. We state explicitly that Sfreq will depend on the wind spectrum because different sites may have different spectra (i.e. a uniform conifer forests compared to a multi-layered tropical forests or an open-grown tree in a park).

11) This is the same issue as comment (8). I will clarify this at the revision stage.

12) We presented this mechanism as a possible explanation for our observations, it is purely speculative. We are happy to delete this speculation from the discussion.

15) The value of Sfreq does depend on tree properties, we can see this in our comparison across trees (Fig 2b). We are arguing that the lack of changes in Sfreq suggests there are no substantial changes in the tree response, such as additional damping mechanisms or resonant effects.

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