PHYSICAL REVIEW E **94**, 067001 (2016)

Comment on "Critical wind speed at which trees break"

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(Received 23 March 2016; published 13 December 2016)

Virot *et al.* [E. Virot *et al.*, Phys. Rev. E **93**, 023001 (2016)] assert that the critical wind speed at which $\geqslant 50\%$ of all trees in a population break is ≈ 42 m/s, regardless of tree characteristics. We show that empirical data do not support this assertion, and that the assumptions underlying the theory used by Virot *et al.* are inconsistent with the biomechanics of trees.

DOI: 10.1103/PhysRevE.94.067001

Virot *et al.* [1] report results on (i) the breakage of brittle rods of dry wood with various geometry and (ii) extend these results to predict wind speeds for trunk breakage in forests. Our comments deal with part (ii). In this part of their work they developed minimal scaling arguments combining linear theory of rod brittle breakage under static bending (small perturbations and Griffith's criterion) with the "elastic similarity" scaling of tree slenderness (Ref. [39] in [1]). This predicts that the critical wind speed for trunk breakage is ≈ 42 m/s, with low if any dependency on tree height and material properties. This prediction was compared to reprocessed data from storm Klaus (24th January, 2009). If correct, this work would have important implications about the key factors controlling the critical strength of trees against the wind, as well as for forest and urban tree management (as shown by numerous reports on [1] in the popular science and arboricultural press).

However, there are several physical and mechanical reasons why we think that the claim of Virot *et al.* [1] cannot be substantiated.

(1) Given the meteorological variability of storms and the biological variability of trees, observations after a single storm event do not provide a sound basis for generalization and validation of stem breakage models. Moreover, an evaluation of the model using the data from storm Klaus (24th January, 2009) has serious problems because only 16% of all damage in this storm was due to trunk breakage (see Ref. [26] in [1]). Thus Virot *et al.* [1] evaluated their model against an inadequate data set. It would have been beneficial if the authors had investigated storm damage from forests with high levels of stem breakage, for example from the large body of data on forest wind damage accumulated by the plant biomechanics research community (e.g., [2,3]).

(2) The experiments of Virot *et al.* [1] employed dry wooden rods and the authors use the properties of dry wood in their calculations. Unfortunately the material properties of dry wood, being stiff and brittle, differ significantly from those of green, living wood, which is more flexible and less brittle [4]. Wood in tree stems also has a large radial variation in mechanical properties, which is an essential adaptation of trees living in a windy environment [5]. Therefore, Eq. (4) in Virot *et al.* [1], which was derived for dry wood, cannot be applied to the green, living wood in tree trunks.

(3) Virot *et al.* [1] treat the wind loads on trees as those on tree trunks modeled as point-loaded, cylindrical nontapered rods with uniform material properties. This model is not consistent with the biomechanics of trees [6]. In particular, Virot *et al.* [1] made the unrealistic assumption that tree trunks are nontapered, homogeneous in composition, and entirely pruned by high winds before stem breakage. Each of these assumptions is unfounded; e.g., total branch pruning is a very rare event (in the vast majority of cases a tree's branched crown is the major source of wind drag) [7].

(4) The conclusion reached in Virot *et al.* [1] depends on the assumption of the interspecific scaling relationship $H \propto D^{2/3}$ (wherein $H =$ height and $D =$ trunk diameter), which emerges from the hypothesis of elastic self-similarity [6,8]. However, elastic self-similarity is based on buckling under self-weight, which is almost unheard of in the natural world except in the case of extremely slender trees growing under unusual circumstances [9]. In addition, comparisons with broad datasets have shown that this scaling holds true only for trees of exceptionally tall stature, many of which emerge above the canopy of the surrounding forest (i.e., tree champions). Specifically, this scaling relationship does not hold for even-aged

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single species stands [6,10], which are typical of the maritime pine forest dataset presented by Virot *et al.* [1]. Indeed, the size, shape, and material properties of all plants including trees are responsive to wind-induced mechanical loads during their growth, a phenomenon called thigmomorphogenesis [11–13]. Thus, trees growing in sheltered conditions differ in height, trunk diameter, and wood mechanical properties from their counterparts growing in windy sites [14]; and tree form is also influenced by the amount of competition for growing space and by silvicultural practices [15]. Consequently, no single scaling relationship for tree height in relationship to trunk diameter holds true even for trees belonging to the same species.

(5) The model by Virot *et al.* [1] is static. However, previous comparisons between static models and experimental data have revealed that dynamic effects linked to wind turbulence (wind gusts) cannot be neglected [16]. This led Virot *et al.* [1] to apply an additional "gust factor" of 2 for the wind loading. However, wind-tunnel and field measurements (e.g., [16]) have obtained values many times greater than 2 (typically 6–10) and have shown that these values depend on the ratio of tree height to tree spacing.

These and other concerns (e.g., damage propagation during storms [17], growth prestresses [18], and mechanical fatigue [19]) are not compatible with the assertion of a constant critical wind speed for tree failure. However, we do believe that the most rapid advance in understanding the interaction between trees and the wind will come from close collaboration among scientists from diverse disciplines such as physics, meteorology, biomechanics, forestry, and plant biology and we hope our commentary on Virot *et al.* [1] will encourage debate and further work on this complex subject.

[1] E. Virot, A. Ponomarenko, É. Dehandschoewercker, D. Quéré, and C. Clanet, Phys. Rev. E **93**, 023001 (2016).

[2] B. Gardiner, K. Blennow, J.-M. Carnus, P. Fleischer, F. Ingemarson, G. Landmann, M. Lindner, M. Marzano, B. Nicoll, C. Orazio, J.-L. Peyron, M.-P. Reviron, M.-J. Schelhaas, A. Schuck, M. Spielmann, and T. Usbeck, *Destructive Storms in European Forests: Past and Forthcoming Impacts*, Final Report to European Commission, DG Environment (European Forest Institute, Pierroton, France, 2010), http://ec.europa.eu/environment/forests/fprotection.htm.

[3] B. Gardiner and C. Quine, For. Ecol. Manage. **135**, 261 (2000).

[4] I. Burgert, A. Bernasconi, K. J. Niklas, and D. Eckstein, Holzforschung **55**, 449 (2001).

[5] *Size- and Age-Related Changes in Tree Structure and Function*, edited by F. C. Meinzer, B. Lachenbruch, and T. E. Dawson (Springer, Dordrecht, Netherlands, 2011).

[6] K. J. Niklas and H.-Ch. Spatz, *Plant Physics* (The University of Chicago Press, Chicago, IL, 2012).

[7] D. Lopez, S. Michelin, and E. de Langre, J. Theor. Biol. **284**, 117 (2011).

[8] T. A. McMahon, Science **179**, 1201 (1973).

[9] B. Gardiner, P. Berry, and B. Moulia, Plant Sci. **245**, 94 (2016).

[10] M. S. Watt and M. U. F. Kirschbaum, Ecol. Modell. **222**, 3910 (2011).

[11] M. J. Jaffe, Planta **114**, 588 (1973).

[12] F. W. Telewski, Am. J. Bot. **93**, 1466 (2006).

[13] E. Badel, F. W. Ewers, H. Cochard, and F. W. Telewski, Front. Plant Sci. **6**, 266 (2015).

[14] V. Bonnesoeur, T. Constant, B. Moulia, and M. Fournier, New Phytol. **210**, 850 (2016).

[15] E. Valinger, Scand. J. For. Res. **7**, 219 (1992).

[16] B. Gardiner, B. Marshall, A. Achim, R. Belcher, and C. Wood, Forestry **78**, 471 (2005).

[17] S. Dupont, D. Pivato, and Y. Brunet, Agric. For. Meteorol. **214-215**, 243 (2015).

[18] B. Moulia and M. Fournier, J. Exp. Bot. **60**, 461 (2009).

[19] M. F. O'Sullivan and R. M. Ritchie, Forestry **66**, 69 (1993).