# Supplementary information

## SI-1 Data treatment process

The raw strain data go through four processing steps before hourly maxima are selected. These steps are described below and data and scripts to apply the techniques described are available online.

1. The data are calibrated according to the size of the strain gauge caliper and the calibration coefficient of the strain gauge.
2. Next, the data are re-projected from the angles at which the strain calipers were placed on the tree to the Northward and Eastward directions.
3. The strain gauge responds to environmental factors and tends to develop an offset over time. This is partly corrected for in the field by adjusting a variable resistor in the wheat-stone bridge circuit, but it is necessary to further reduce this offset at the post-processing stage (Hale et al., 2012). We subtract a 5000-point (20.8 minute) running mode in this study.
4. The maximum strain on the circumference of the trunk at 1.3 m is calculated at each timestep, assuming the trunk is cylindrical.

At this point hourly maxima are selected. We tested a subsampling method (Cook 1986; Palutikof, Brabson & Lister 1999) for selecting maximum strain but found no increased accuracy over a simple maximum, although this led to systematically lower maximum strain values and correspondingly higher CWS estimates. We performed a sensitivity analysis on the parameters and choices involved in the process of CWS estimation from field data and found that the maximum strain selection method is by far the most important factor. Variations in offsetting window length make a small and uniform difference across the trees we studied.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Range** | **ΔCWS** |
| Offset window length (minutes) | 4 🡪 20 | 2% |
| Maxima selection method | Simple 🡪 robust | 68% |

Table SI-1 – Data treatment parameters and the sensitivity of CWS estimates to changes in these parameters.

## SI-2 Wind measurements and choice of time-resolution

In this study we used hourly maximum wind speeds from the local meteorological station since these data were readily available and easily comparable to our model output. We experimented with varying resolutions (i.e. using a one-minute mean wind speed and maximum strain) but found that this merely increased the noise without adding additional accuracy. Using an hourly value selects the outer envelope of the wind-strain relationship, which is the most relevant for wind-damage. Previous large scale critical wind speed estimates use the ten-minute mean wind speed multiplied by a gust factor (GF) to account for the higher resolution wind effects (Hale et al., 2015). Using maximum wind speed avoids the need for a gust factor. Using wind data from the meteorological station, instead of the data collected as part of this study, increased the number of hours of data available and avoided complications due to the change in wind regime in summer, since the anemometer is situated outside the forest.



Figure SI-2 – A - Mean wind speed against maximum strain at varying temporal resolution. B – Vertical wind speed profiles in summer and winter, as measured from anemometers at 5, 10 and 15 m on the canopy walkway. The dashed lines represent the power law function used to model the vertical variation in wind speed, only the winter data was used in this study. C – Mean hourly wind speed against maximum wind speed, measured at 5 s resolution at the ECN weather station. D – Hourly mean wind speed inside and outside the canopy, in summer and winter.

## SI-3 Modelling the effect of gravity

The trees were scanned on calm days. The force of gravity is acting on the branches and their stiffness is keeping them in equilibrium by creating an equal and opposite force. In the finite element analysis, gravity must be defined as an external forcing. There are three options:

1. Run the simulations without gravity. In this case the trees do not experience self-weight or the additional force from their displaced crown as they lean in each direction.
2. Apply gravity directly to the model. This deforms the branches away from their scanned position slightly. This is small displacement and does not have a significant effect on the dynamics of the tree under wind forcing, but it is not fully realistic. Also, tree whose main stem leans significantly in the TLS scan could be deformed significantly by this forcing.
3. Apply a reversed gravity force, which causes the branches to deform upwards. These deformed positions are then saved and the analysis restarted using the deformed position. The restarted analysis then applies gravity according to option 2, which returns the branches to their resting position while maintaining the gravity load throughout all subsequent analysis. This is the most realistic option, although it does not take into account the non-uniform maturation strains which allow the branches to oppose the force of gravity normally. This is also the most computationally taxing approach since it requires two simulations per tree as well as a user defined subroutine to extract the deformed nodal positions.

The choice of treatment of gravity does not make a significant difference to the five-minute high-resolution simulation. However, the difference between option 1 (no-gravity) and options 2 and 3 (with gravity) is noticeable in both the frequency extraction and the critical wind speed estimation. As the tree bends in the wind, its centre-of-mass is displaced leading to an increased moment. This becomes significant at high displacements and can be seen as a slight deviation from the strict square law relationship between wind and strain.

To summarize, option 2 and 3 are similarly accurate for all the trees we tested, whereas option 1 produces less physical results in the case of large displacements. Option 3 is preferable since it more closely resembles the underlying physics and is therefore more likely to be applicable across trees.