

## Do tree stems shrink and swell with the tides?

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Received July 6, 1999

Zürcher et al. (1998) reported that the stem diameters of two young Norway spruce (*Picea abies* L. Karst.) trees grown in containers at a controlled temperature in continuous darkness fluctuated with the tide. They attributed these changes to a rhythmic reversible flow from symplast to apoplast that is “influenced by the Moon.” This claim is remarkable, as one would expect stem diameter to vary with only the tissue osmotic potential or the tension in the xylem and phloem, the latter being closely linked to the transpiration rate and thus varying diurnally (Kozłowski 1976). To explore the periodicity of stem fluctuations in relation to the gravitational influence of the Moon, we applied Fourier analysis to data on variations in stem and xylem widths of Scots pine trees (*Pinus sylvestris* L.) collected over periods of 1 to 4 months. No indication of tidal influence on stem diameters was found.

Diameter variations were measured at the SMEAR II station (southern Finland, 61°51' N, 24°17' E) (Vesala et al. 1998) and in Devilla forest (central Scotland, 56°2' N, 3°43' W) (Irvine et al. 1998). In Finland, the trees were 12 m high and mean diameter at breast height was 13 cm. In Scotland, the corresponding values were 15 m and 20 cm. In both Finland and Scotland, a rigid steel frame, housing a sensitive displacement transducer (Sylvac Inc., Switzerland, and an LVDT, Schlumberger Industries, U.K., respectively) was mounted around the circumference of each tree. In Finland, measurements were taken both above and below the bark. For whole-stem measurements, the loose bark was removed, and for xylem measurements, tiny screws were attached directly to the xylem. In Scotland, small windows in the bark, cambium and phloem were made so that the LVDT rested on the xylem. Corrections were made for the thermal expansion of the frame (coefficient of linear expansion used was  $10 \times 10^{-6} \text{ K}^{-1}$  and  $20 \times 10^{-6} \text{ K}^{-1}$  in Finland and Scotland, respectively) and the change in linear dimensions of fresh wood ( $-4 \times 10^{-6} \text{ K}^{-1}$ ). Data were collected from May to September (1996–1998) and April to September (1995) in Finland and Scotland, respectively. The calculated gravimetric curves (variations in gravity detectable as variations in acceleration due to it) for the loca-

tions of the stands were supplied by the Finnish Geodetic Institute. Figure 1 presents an illustrative sample of data sets for gravimetric tide and diameter variations.

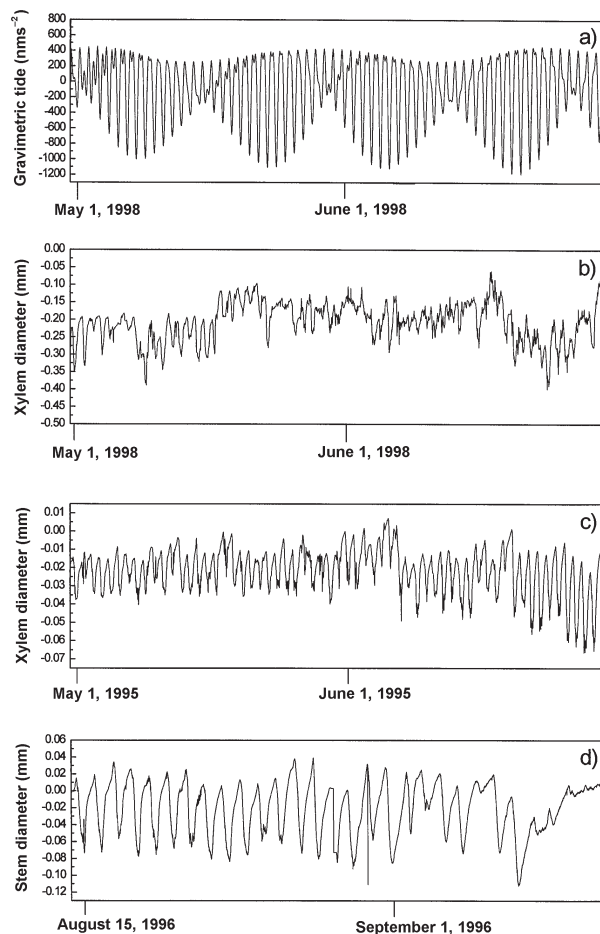


Figure 1. (a) Variation in acceleration due to gravity (caused by the heavenly bodies) in Finland, (b) xylem diameter in Finland, (c) xylem diameter in Scotland, and (d) stem diameter in Finland.

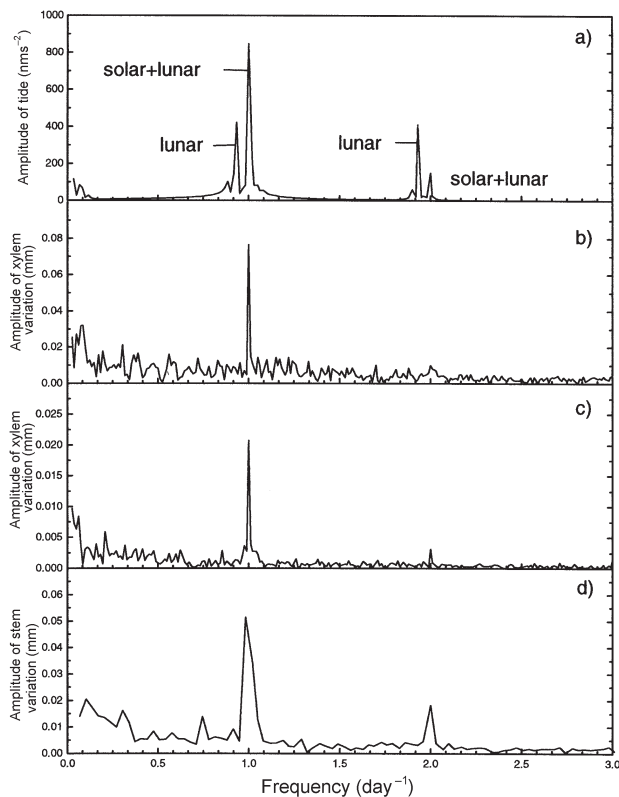


Figure 2. The amplitudes of various frequencies (a) in gravimetric tide, (b) in xylem diameter variations in Finland, (c) in xylem diameter variations in Scotland, and (d) in stem diameter variations in Finland, revealed by Fourier analysis. Square roots of power spectra are shown. The plots in (a) and (b) are based on the data for May–August (1998) and that in (c) based on the data for May–June (1995) and that in (d) for mid-August–mid-September (1996). The tidal spectrum shows the influence of both the Sun and the Moon. For the xylem and stem diameters, only the diurnal frequency is shown. In (a) the peaks occur in frequencies of  $f_e - 2f_m$ ,  $f_e$ ,  $2f_e - 2f_m$ , and  $2f_e$ , where  $f_e = 1.0 \text{ day}^{-1}$  and  $f_m = 0.0352 \text{ day}^{-1}$ . Higher frequencies correspond to harmonics of the fundamental frequencies.

To detect periodicities in the time series, Fast Fourier Transform (FFT) was performed on the data sets, which were detrended before computing FFT so that a straight line was fitted by least squares and subtracted from the original data. No windowing functions were applied. According to Figure 2a, the principal part of the diurnal tides appears as four prominent peaks resulting from the luni-solar and lunar periods. (Note that Zürcher et al. (1998) erroneously report 24 h 49 min for the lunar period although it is 25 h 49 min and the scale of their Figure 1b should be  $\mu\text{Gal}$ , not  $\text{mGal}$ .) In the diameter spectra, there was only one significant frequency per day (Figures 2b–d). This frequency is explained by variation of the amount of water in the xylem, which is caused by the diurnal rhythm in transpiration. The amplitude of the variation (0.01–0.1 mm) is consistent with known transpiration and water transport rates and stem elasticity (Irvine and Grace 1997). The background noise was estimated to be less than 0.001 mm

for the xylem spectra and less than 0.01 mm for the stem spectra. Should there be any tidal effects, the amplitudes of such frequencies must be below these noise levels; otherwise, the peaks would be visible.

Our results contradict those of Zürcher et al. (1998), who detected daily diameter fluctuations of amplitudes typical of field experiments. The contribution of the gravitational potential to the total water potential is about 10 kPa for every 1 m of height; thus, a tidal change of  $1 \mu\text{m s}^{-2}$  in acceleration should lead to a water potential change of  $10^{-3} \text{ Pa m}^{-1}$ . Diameter variations caused by such a small change due to the direct physical force are many orders of magnitude too small to be observed independently. We also considered the possibility of a biological response. Generally, higher plants are able to sum up stimuli that are below the threshold value (Perbal et al. 1997). Therefore gravitropic stimuli are measured in terms of  $g$  multiplied by presentation time. In plants, the most sensitive known response to  $g$  is exhibited by roots of seedlings. According to Perbal et al. (1997), the minimal detectable response of the sensing mechanism to a gravitational force of 1  $g$  needs a presentation time of 30–300 s and tests have shown that this principle operates between 0.08 and 58  $g$ . For a cycle of 12 h, the presentation time is 43–200 s and the required  $g$  force to get the minimal detectable response is about 0.0007–0.007  $g$ , which is much larger than the change exerted by tides. The local tide may differ from the theoretical one (calculated from the coordinates and masses of the heavenly bodies) because of the impact of the ocean, which might maximally increase the tide by a factor of 1.2.

Measuring the diameter variations is a highly demanding task, requiring delicate equipment. It is conceivable that the vertical or horizontal tidal components could induce the equipment, together with the tree stem, to act as a gravimeter: then the readings would not be related to true diameter changes at all. Thermal expansion (Irvine and Grace 1997) and barometric changes might also cause apparent diameter variations. Fourier analysis should be applied to check the amplitude and phase of the critical frequencies.

In conclusion, variation in tree diameter comparable with that observed by Zürcher et al. (1998) could not be observed in our study of trees growing in natural conditions. Our analyses suggest that the fluctuations observed by Zürcher et al. (1998) are unlikely to have been caused by gravitational signal. However, it is possible that, in the absence of transpiration-induced diurnal rhythm, there are rhythmic variations in the osmotic strength of living cells that cause variation in diameter. These types of circadian rhythms, which are associated with cell shrinking and swelling, have been observed in leaf movements of some leguminous trees (Taiz and Zeiger 1991). These rhythms could easily coincide with tidal periodicity, because the natural periodicities of transpiration and tide are closely related.

#### Acknowledgments

Anthony Trewavas is acknowledged for his comments.

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