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(ISO 9001:2015 certified)

Data measured with dendrometers

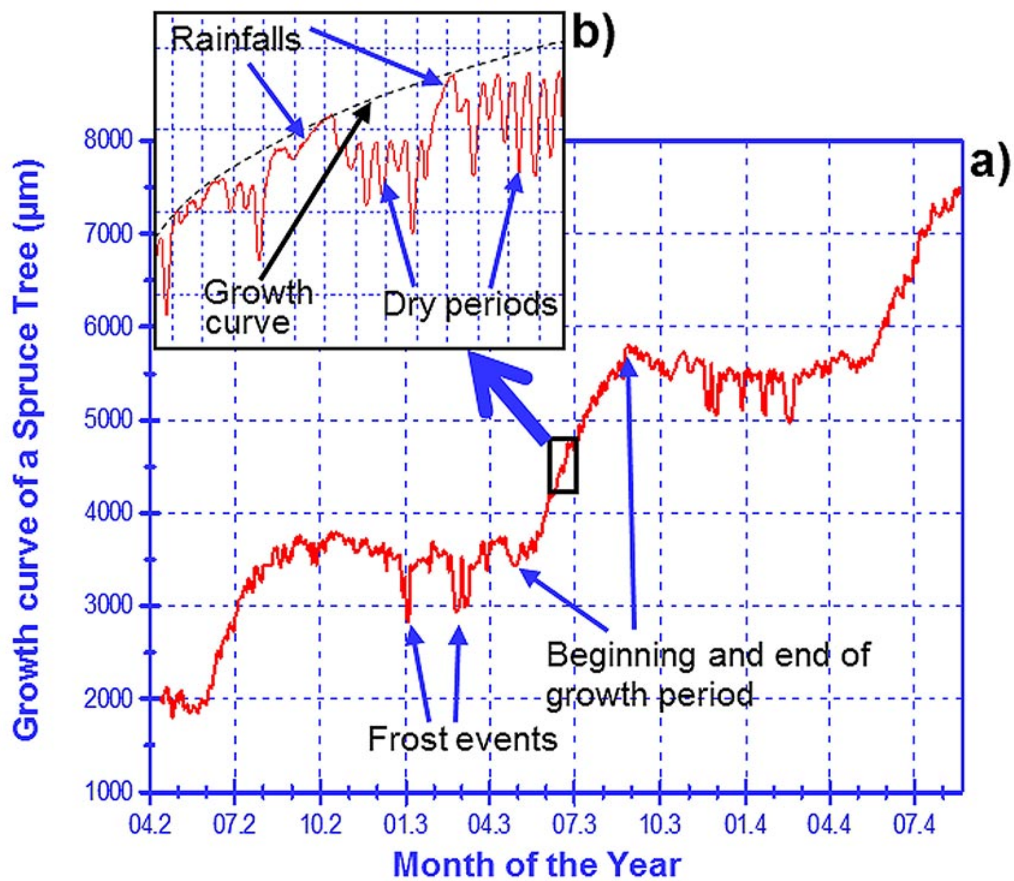

Fig. 1: How a typical dendrometer curve of a perennial plant looks like and what it tells us:
At the monthly time scale (Fig. a), continuous data reveals intra- and inter-annual differences in dynamics of diameter growth, i.e. beginning and end of the growth period and the speed of diameter growth (slope). At the diurnal time scale (Fig. b) the course of diameter variation reveals periods of high transpirational water demand with significant depletion of stem water storage (during dry periods) as indicated by strong shrinking and swelling of the trunk (high diurnal diameter amplitudes).

ΔLA-B (ΔT Leaf-to-Air-Broadleaf type)
ΔLA-C (ΔT Leaf-to-Air-Conifer type)
Data Logger

During rainfalls transpirational water consumption is marginal and water storage pools are replenished as indicated by completely dampened diurnal amplitudes and the return of the diameter to the growth curve (black, dashed graph). (For further reading klick: 1, 2, 3, 4, 5). The occurrence of frost events is indicated by strong transient diameter decreases during winter (Fig. a).

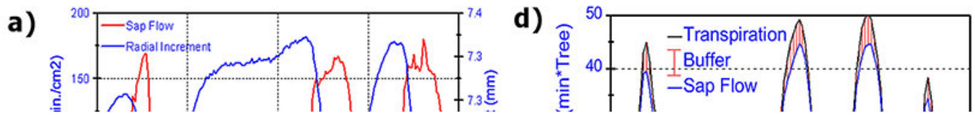

Fig. 2: Whole tree transpiration can be reconstructed with data from xylem sap flow and stem diameter fluctuations
a) Measurements with the SF-L sap flow sensor from ECOMATIK – dendrometer-assisted determination of ΔTCmax –
The SF-L sensor records the sap flow of the tree (red graph). Special feature of the SF-L sensor: correction for background temperature gradients within the sapwood via additional reference thermocouples. The dendrometer monitors the filling state of the tree's stem water storage (blue graph). ΔTCmax is the absolute maximum temperature difference between the heated and the reference part of the sensor, when sap flow is zero. In contrast to the approach of Granier, zero sap flow does not occur every night. For the correct determination of ΔTCmax, two prerequisite conditions must be met:
1. The tree is saturated and stops to absorb water. This condition of the tree can be identified during humid weather periods by the absence of diurnal swelling and shrinking, the dendrometer curve forms a plateau.
2. The air humidity is about 100%, inhibiting transpiration.
b) Relationship between total weight of a cut 40-years old Norway spruce tree (y-axis) and its stem diameter (x-axis) during air-drying
For three years, the growth of a 40-year old spruce tree (Picea abies) was continuously recorded with a DR Dendrometer at breast height (1.3m). Relevant parameters (weather, soil moisture, sap flow) were assessed in

parallel every 30 minutes. At the end of the measurement period the well-watered tree had been cut with the dendrometer still attached. By slowly air-drying the tree, its decreasing fresh weight was plotted against the shrinking diameter continuously. The relationship reflects the proceeding depletion of stored water within the trunk of the tree (buffer) and the corresponding shrinkage in diameter. A shrinkage of 250 µm from the saturated state (0 to -250 µm) means 12 liters of water loss, while the next 250 µm shrinkage (-250 to -500 µm) causes only 2 liters loss of water.

c) Sap flow and use of stored water within the trunk of the tree (buffer) as complemental components of whole tree transpiration

Actual whole tree transpiration (black graph) was calculated from sap flow (blue graph) and diameter fluctuations in combination with the derived relationship between diameter and water storage consumption (i.e. buffer, red shaded areas). The calculated transpiration is shown for consecutive 5 days. During this period, the water storage of the tree is clearly visible. The tree body behaves like a storage reservoir for water. It replenishes overnight, whereas during the day it supplies water in periods of high transpirational demand. Depending on the daytime, buffering accounts for up to 50% of transpiration. On average, the buffering makes 6% of transpiration

d) Continuous data of stomatal conductance at the whole tree level

Stomatal conductance at the whole tree scale (i.e. canopy conductance), has been modelled based on data of temperature and humidity of the air in the canopy, the needle surface area and whole tree transpiration. Highest conductance was determined during humid days (cf. 15th of July).

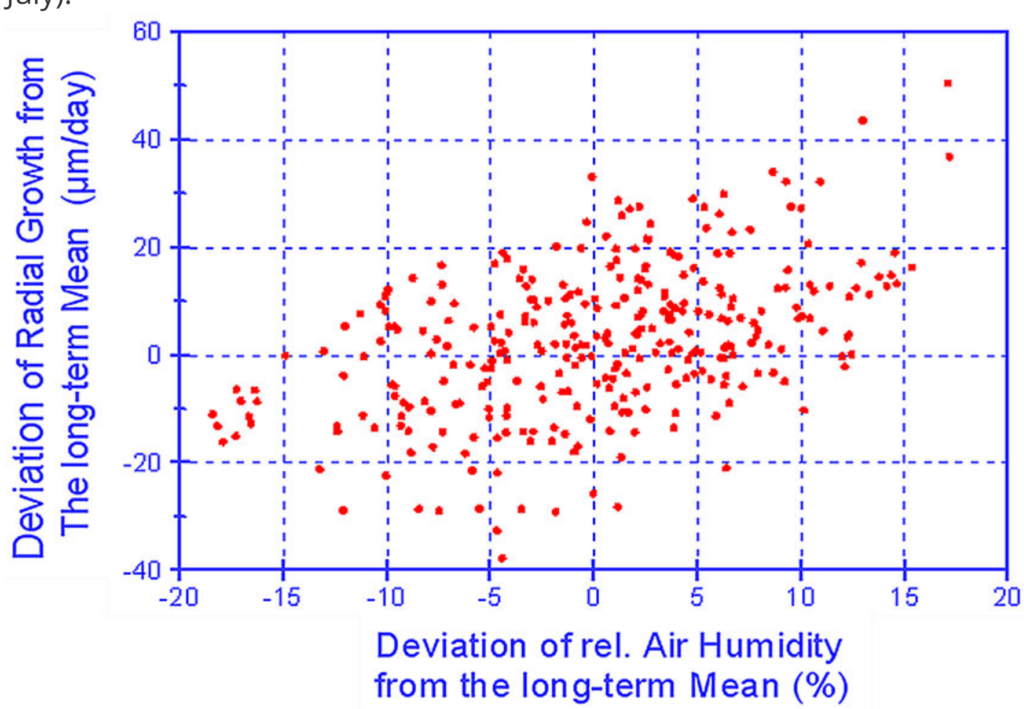

Fig. 3: Correlation between deviations of radial increments (Gdev)

and air humidity (Wdev) from their respective long-term DOY mean during the growing season (May 1 – Sept. 30).

Here we introduce a method to derive climate-growth relationships based on dendrometer measurements. This approach allowed us to evaluate the influence of weather conditions on tree growth at daily resolution. In our approach, we assumed that in a limited period of time (Link for further reading: 1)

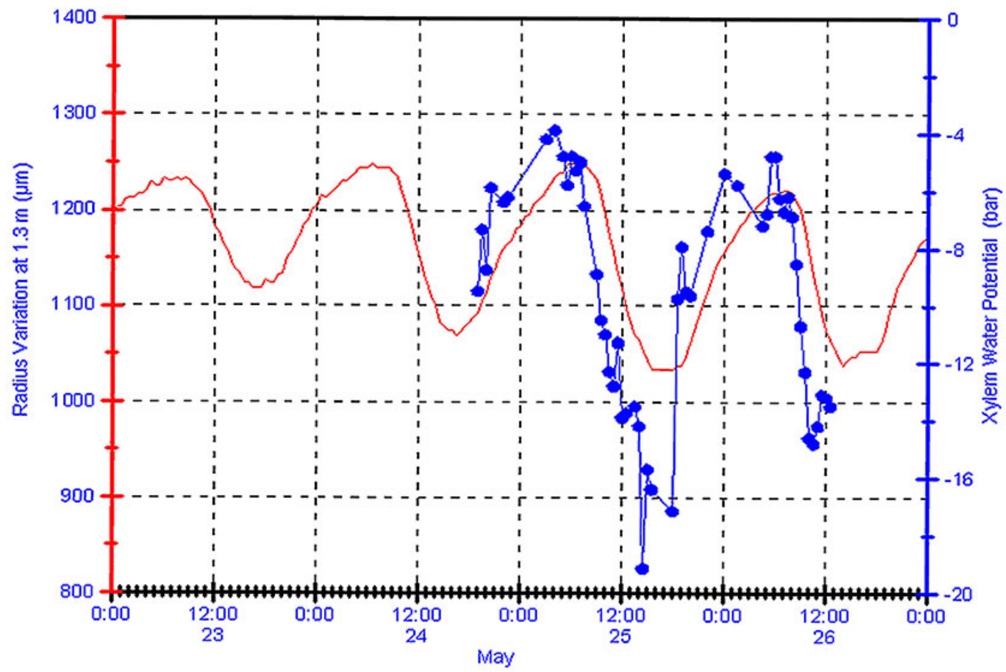

Fig. 4: Diurnal diameter variation as continuously measurable index for whole plant water status.

The main component that causes diurnal diameter amplitudes (red graph), i.e. shrinking and swelling of the trunk, is caused by variations in cell pressure (turgor) of living parenchymatic cells in the cortex. Under conditions of deficient soil water supply (dry periods), high amplitudes correspond to high transpirational water demand around midday, causing significant variations in stem water storage and hence xylem water potential (blue graph, a physiological parameter which directly indicates the plant water status). The diurnal information in the dendrometer signal can hence serve as non-invasive method to index plant water status (-> Link further reading: 1, 2, 3, 4, 5, 6). This is of special interest, as alternative methods to determine xylem water potential itself are typically invasive (parts of the plant have to be cut, or stem has to be injured), labor-intensive (single point measurements, e.g. with a Scholander pressure bomb) and error-prone (stem psycrometers) procedures.

Fig. 5: Growth dynamics and diurnal diameter fluctuation of stem and root in an 80-year-old spruce tree (Picea abies).
Measurements were conducted on a mature spruce tree at the experimental site “Kranzberger Forst” of TU Munich. The stem was equipped with a circumference dendrometer (DC1) at a height of 1.3 m (diameter=44 cm). A root with a diameter of about 5 mm in a depth of 5 cm in the mineral soil was equipped with a root dendrometer (DRO). After installation, the small pit was refilled with the original soil. The measurement started at the end of March 2013 and ended in January 2014. The water-tight root dendrometer remained buried in the soil, during the whole time of investigation of more than nine months. Apart from interruptions in June and July due to a failure of the data logger, both dendrometers worked without any problems.
Left: Growth dynamics of trunk (blue line, right scale) and root (Φ 5 mm, red line, left scale). Before July 2013, the root showed a similar growth pattern to that of the trunk. In the beginning of the measurements in March 2013, both tree parts showed a reduction of the diameter. This phenomenon can be attributed to changes in the osmotic regulation of cells, which adjusts the freezing point of cells in the course of the year (Gross et al., 1980). Radial growth started in mid-April. By the end of June, the root grew in diameter by 200 µm, while the trunk increased its diameter by 2000 µm. While the trunk showed significant growth activities during the entire growth period, the root shrank from July 2013 drastically by about 50 µm and remained until the end of the measurement with only minimal changes. Drought especially affects roots in the upper soil layers. Based on the results, we hence conclude that the root had died during the summer drought event which occurred in July/August 2013.
Middle: During moist periods, stem and root showed similar daily variations. During the day, the diameter shrank with increasing transpiration of the crown leading to water loss of the parenchyma cells

of the living bark. At night, the water loss was compensated by uptake from the soil and the diameter of root and stem increased. Maximum values were observed between 4 to 6 o'clock in the morning.

Right: During dry periods (e.g. April 24th to 27th), a time shift between the diurnal diameter fluctuations of stem and root could be observed. The stem reached its daily maximum just before sunrise, whereas the maximum of root diameter occurred much earlier. The tree benefits from its entire root system and is able to refill the water storage pool in the stem during the whole night by accessing water resources in deeper soil regions. The water status of individual roots near to the surface, by contrast, appears to be dependent on local water availability in the upper soil layers and is hence strongly affected by drought events. Exposed to the dry conditions in the upper soil layer, the superficial root has already taken up the small amount of available water near midnight.

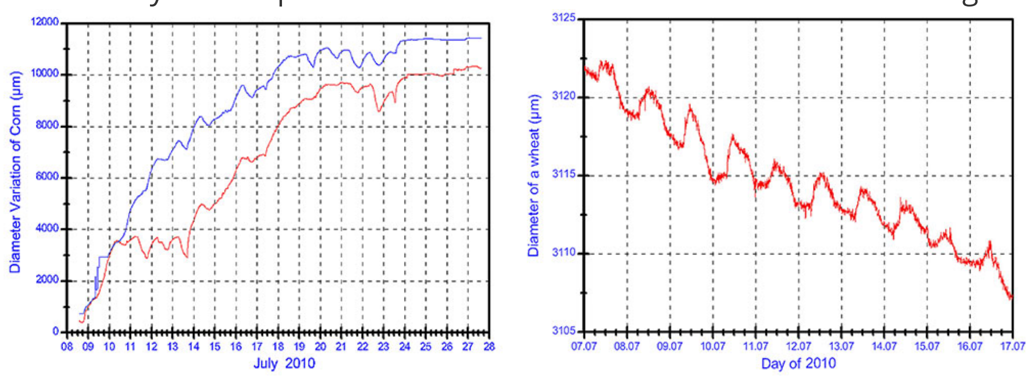

Fig. 6: Diameter variation of growing corn (left) and drying wheat (right), measured with a Diameter Dendrometer (DD-S)

Left: Growth of two corn plants under always well-watered conditions (blue) and with transient water deficit (red; water deficit 10th to 14th). Compared with the wellwatered Plant, even the short transient water shortage led to a permanent deficit in plant size.

Right: Measured during a dry period, the pattern of shrinking during the afternoon and swelling during the night and the morning hours indicates the diurnal depletion and subsequent refilling of the internal water storage pools of the wheat plant. Nevertheless, the overall shrinking of wheat during that period indicates an overall negative water balance. Without irrigation, the plant will desiccate.

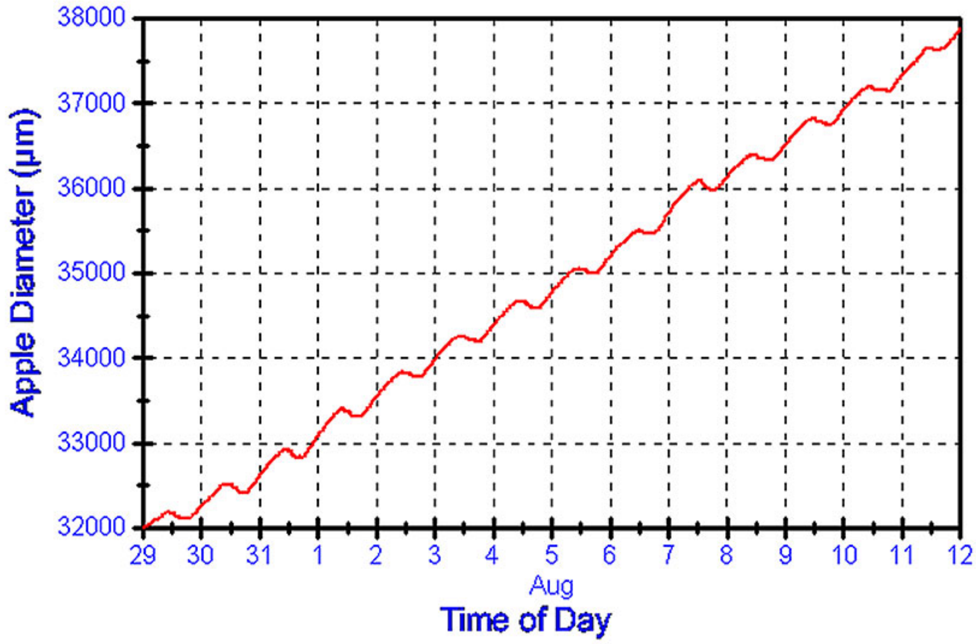

Fig. 7: Diameter change of a growing apple under well-watered conditions, measured by means of a Fruit Dendrometer (DF)

Analog to the diurnal swelling and shrinking at the stem level, we observe the similar pattern in the diameter change of the fruit. Deficient irrigation during fruit expansion can cause limitations to fruit growth and hence losses in production.

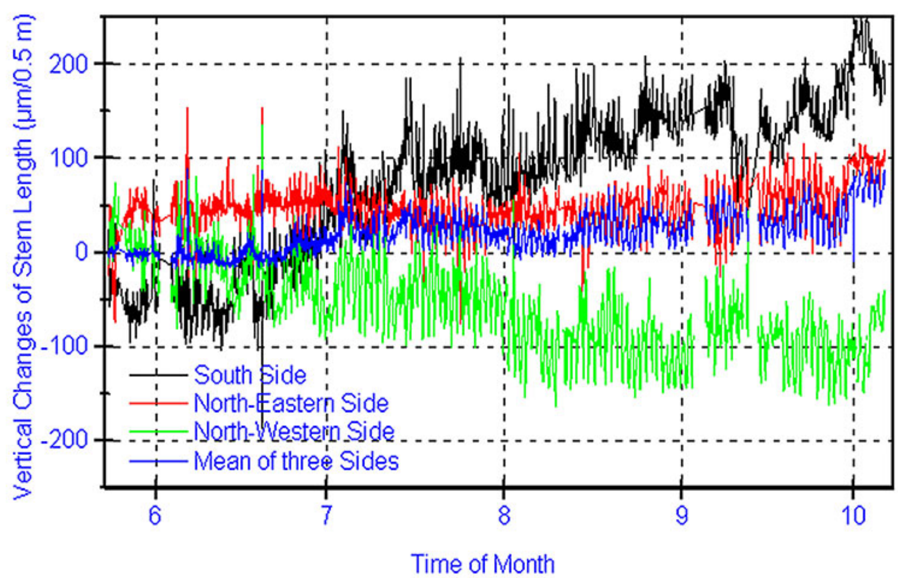

Fig. 8: Changes in the axial dimension of the trunk, measured by means of three vertical dendrometers (DV)

The different graphs show the vertical changes (i.e. the length) of the regarded stem section (1.0 to 1.5 m height -> 0.5 m) in three different cardinal directions (S: black; NE: red; NW: green). The overall mean is shown by the blue graph. At the short-term scale (i.e. seconds to minutes), variations in the signal of a single sensor are indicative for direction and intensity of a momentary horizontal strain (e.g. wind), that leads to a bending of the trunk. At the mid-term scale (days to months), variations can serve as indicator for longer-lasting imbalances within the crown (e.g. snow load, unbalanced fructification). At the long-term scale (months to years) the signal indicates constitutive changes in tree static (e.g. unbalanced growth after thinning, unbalanced loss of crown parts). At all three time scales the DV sensors provide specific data on the static conditions of a tree and can serve as basis of information for related risk assessments and studies. Variations in the overall signal (blue graph) are related to vertical swelling and shrinking of the trunk, indicating changes in water status of the tree.

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