Qualitative Dendrometer Signal Interpretation

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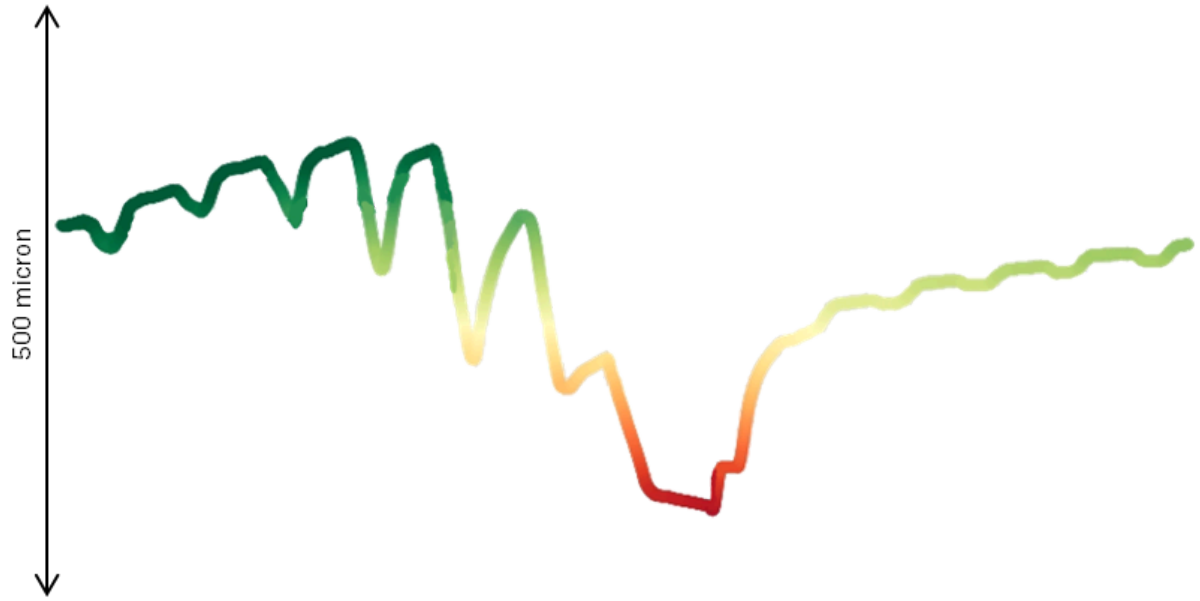
The dendrometer signal provided information on both growth (new, permanent wood) and daily swings related to water supply and demand.



Cacao tree - drought effects over 2 week period
Color is relative TWD (Tree Water Deficit as defined by Dr. Roman Zweifel) The tree ended up suffering from embolism which caused some branches to be lost.

Note: If daily contractions are less than 20µm, it is possible that the tree tag is installed over largely inactive tissue. Consider moving the tag to a different area on the tree.

Note: If growth and contractions seem erratic and don't seem to follow a daily pattern, or are inverted from what you would expect, it is possible that the dendrometer plunger is over too much dead bark. Consider excavating some dead bark under the plunger head.

Growth

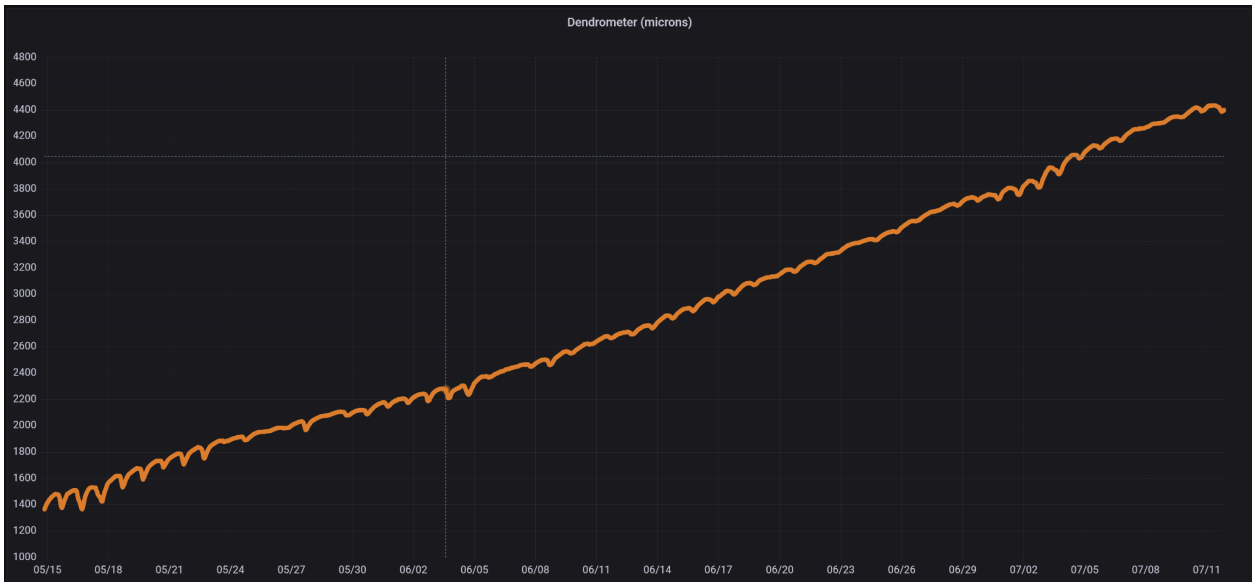
The growth is most noticeable when it has accumulated over several weeks or months, and becomes larger than the daily swings. Growth tends to be either flat/zero or accumulating at varying rates.

Flat/zero growth is usually caused by one or more of the following:

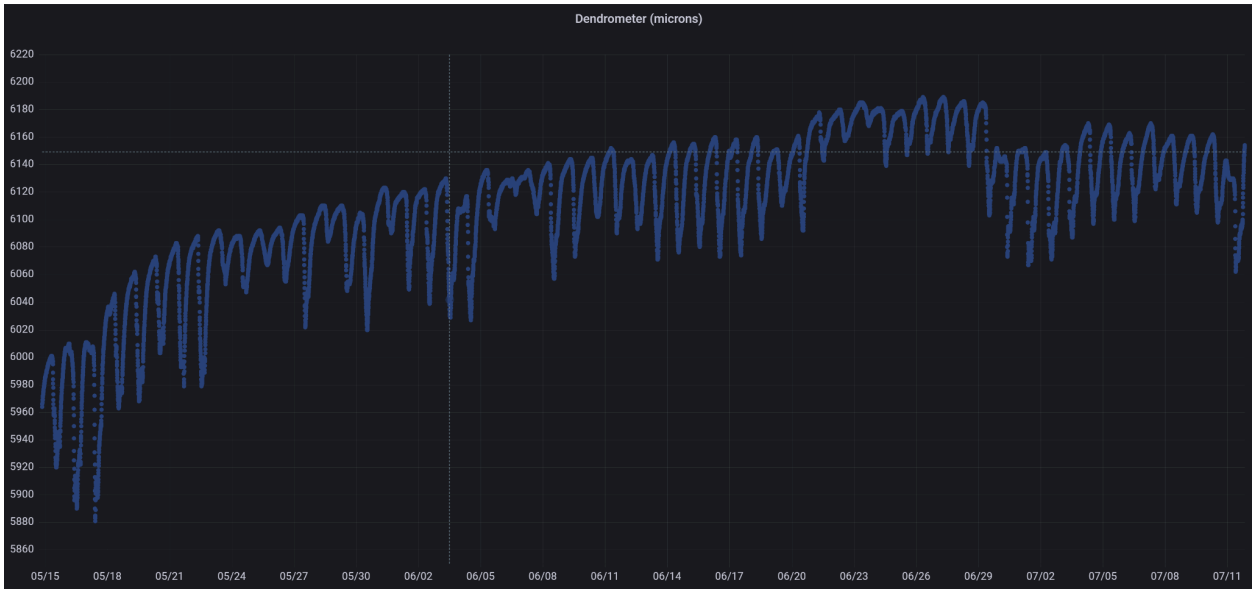
1. Winter dormancy: the tree is not actively producing sugars, and those stored in the tree are saved for energy to allow spring budburst. [show an early season transition]
2. Mid-season carbohydrate limitations. Following longer periods of cloudy weather, the tree might be deficient in stored energy to allow growth. Some species will also divert energy from trunk thickening to focus more aggressively on shoot or root elongation. Fruit production is also energy intensive, and can divert resources away from trunk thickening. If the tree has been growing for some weeks or months, and then stops mid-season, this might be the cause. Observe the tree for shoot or fruit growth to help in this determination. Look for resumed growth after long, cloudy/rainy weather periods.
3. Water stress.
    a. New wood can only be produced when cells are in a relaxed environment. This often only occurs at night when the tree is not actively transpiring water. Very warm and dry nighttime conditions can interrupt growth if these conditions are present.
    b. Similarly, long, hot, and dry days shorten the time at night when the tissue is relaxed and able to support growth. Dry soil during these weather conditions will exacerbate the effect. Irrigation will help alleviate the stress, and growth should begin the next day if it was hindered by soil water limitations.

A small amount of nightly growth is typical of most trees during the active growing season. The rate of growth is highly dependent on species, and can vary based on position of the tree tag. Thus, the growth rate in isolation does not define performance unless it is well characterized, for that specific mounting location, in either other years or under otherwise well understood growing conditions. You might be able to steer growth rates by altering irrigation intervals and quantities.

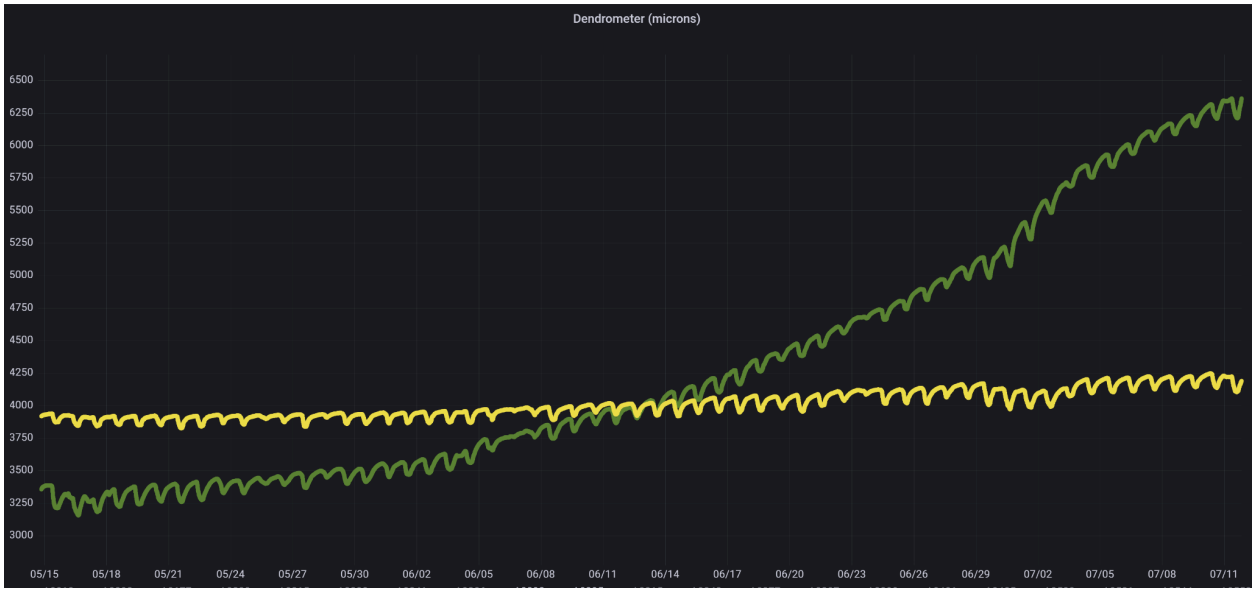
Often, growth rates will taper off over a period of days to weeks due to depletion of soil water. With increasing water stress levels, the tree is less able to grow new tissue at night. The duration of this period is largely dependent on tree size and degree of establishment. Larger trees, especially infrequently or non-irrigated trees, will show a slower decrease in growth rate over time due to soil water limitations, as the effective soil volume is larger and acts as a buffer. If soil water limitations are causing this lessening of growth, irrigation will noticeably reverse the trend, and a large recovery should be noticeable the night following the irrigation. It is possible to observe the effects of irrigation almost instantaneously. If irrigation seems to have little effect on a lessening growth rate, it is possible that the tree is diverting resources away from growth and into other important functions, such as shoot growth or fruit production. This is normal and part of some trees' natural annual cycle. In particular, growth will naturally taper off towards the end of the growing season. Trees adapted to survive closer to the equator will show less variability strictly aligned with time of year, but often go in and out of growth stages as a function of water availability and temperature. Tropical trees tend to be more variable in growth, even when conditions are not adverse. Growth can also be affected directly by temperature. Cooler temperatures cause the vascular cambium, the region under the bark where new tissue is produced, to be less active.



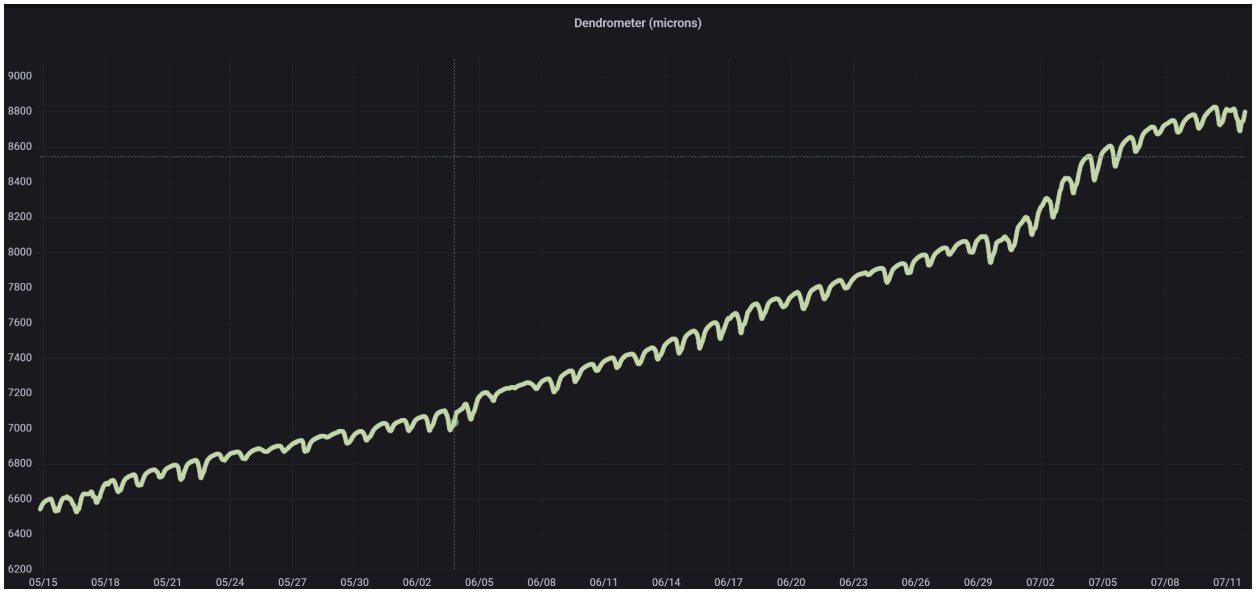
A 10" diameter coast redwood. No irrigation. Typical, healthy growth curve showing a slight depression in growth in late June due to a heat wave. Increased transpiration during warmer weather inhibits the tree's ability to add new wood. Growth resumed after the hot weather passed, indicating soil water is not limiting.



A mulberry in the second growing season after transplant. An irrigation on June 20th allowed for some growth over the next day or two, but largely the growth has stagnated. The late June heat wave set this tree back. It could have used more water for more robust health. For comparison, see the behavior of this same tree a year earlier, towards the end of this document.



Two containerized coast redwoods. Both trees have been on consistent irrigation schedules for 18 months. Yellow tree received water to saturation every six days, green tree every three days. The more frequent irrigation has clearly benefited the more frequently irrigated tree.



A California bay laurel, established, likely 20-30 years old. The Late June warm weather has caused an increase in growth for several days. This tree is not irrigated and it is not water limited.

Contraction Magnitude and Recovery

Contraction magnitude is largely governed by evaporative demand. Hot, dry days create more tension in the sap, and the trees contract more heavily. Similarly, cool, moist days will show small or nonexistent contractions. In this case, there is less driving force for water to exit the

leaves. It is also possible that the tree's leaves have closed their pores (stomata) in cloudy conditions. This is the response of the tree much like that observed at night: there is simply not enough light available for photosynthesis to merit losing water. Closed stomata will largely limit transpiration, the tree relaxes, and you can observe an increase in the dendrometer signal. This effect can be quite pronounced, such as when the sun passes behind a cloud or another tree/building. Shade can induce a night response in some trees, particularly those adapted to full sun. Note that this effect can be reversible: if the sun passes past a blocking tree or building, the stomata re-open and the tree will begin contracting again. If the signal looks jagged throughout the day, it is possible this is the cause. Observe the path of the sun as it relates to exposure of the tree canopy.

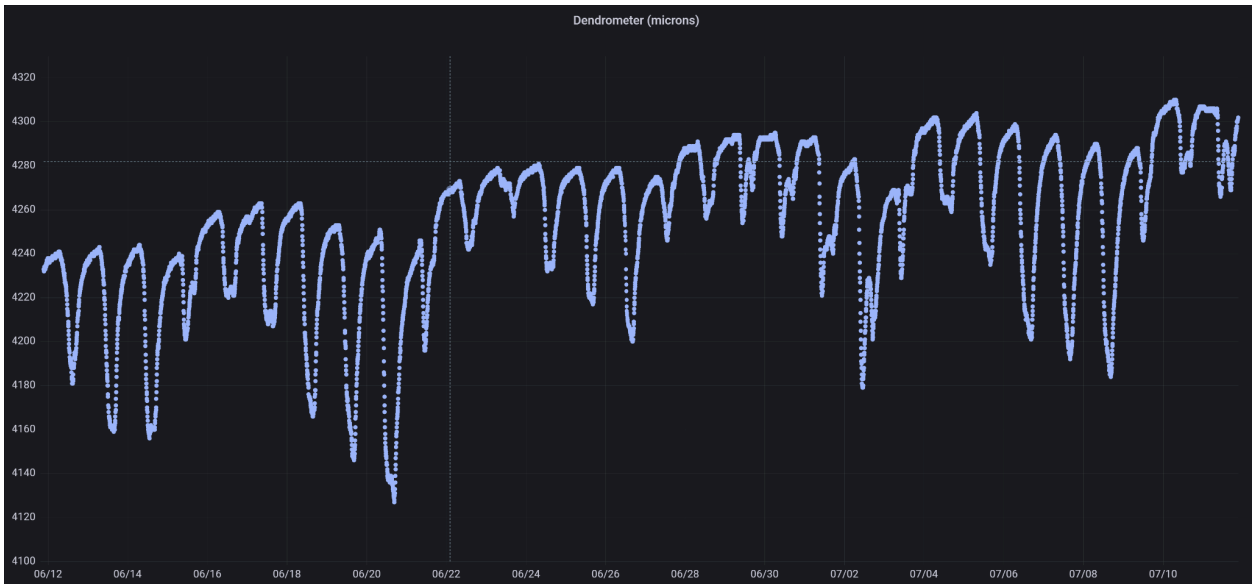
During very hot/dry days, the stomata might also close to limit transpiration. This is a defense mechanism to prevent the sap from supporting too much tension. At a certain level of tension, which is highly species-dependent, the sap can cavitate and form embolisms (gas pockets). In general this is a very serious state that can ultimately kill a tree. Tissue that is embolized can no longer function to transport sap, so trees have evolved mechanisms to deal with the threat. Stomatal closure is one such mechanism. Some trees regulate their stomata gradually throughout hot, dry, or bright conditions, and some do so abruptly, ideally just before cavitation is realized.

While the contraction magnitude is highly dependent on the temperature, humidity, and light around the tree's canopy, soil water limitations will tend to increase the contraction magnitude for a given temperature and humidity. If you notice a steadily increasing contraction magnitude, often accompanied by a decreasing growth rate, it is possible that the soil is becoming depleted of water. Irrigation will reverse the trend if soil water is indeed limited. If irrigation seems to have little effect, consider that the increased contraction magnitude is caused simply by hotter, drier days. At a certain level of soil water depletion, the dendrometer signal will not recover to where it was the previous night. If these conditions are allowed to continue, contraction magnitude will increase even more, eventually reaching a low plateau with small daily fluctuations. At this point, the tree tissue is likely damaged, so it would be good to avoid such extreme water deficits. Some minor deficits can be beneficial if they are carefully monitored, for instance if you are attempting to regulate shoot vigor by withholding water. Fruit size and potentially quality can be manipulated by restricting water at the proper times. The degree of deficit can be quantified by aspects of the dendrometer signal, such as contraction magnitude beyond what is expected for a given temperature and humidity. Another technique would be to only irrigate when the level of non-recovery at night has reached a predetermined threshold.

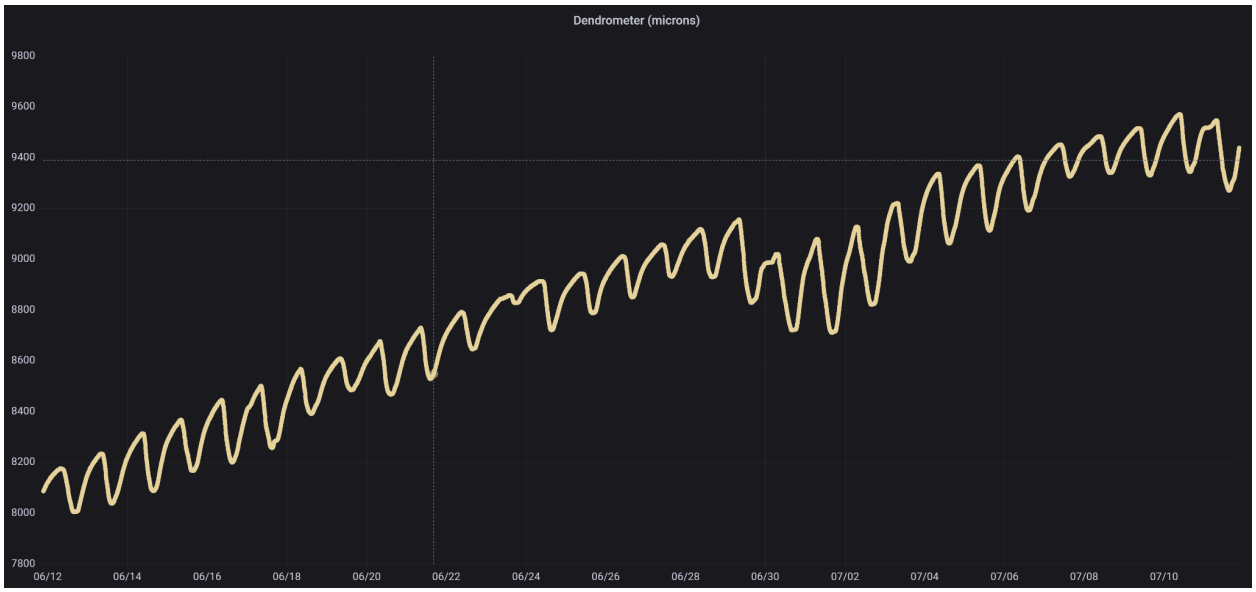
Dendrometer signals represent the combined effect of both soil water limitations and atmospheric demand. You can largely separate the effects by observing the range of contraction magnitude in periods when you know the tree is well watered, as well as observing the signal recovery (or lack thereof) when you irrigate after some period of soil drying. Always keep in mind that each installation location will offer its own range of signal magnitudes, so comparisons are best made over the historical range of that particular installation. The relative changes, which ultimately offer insight into the water status of the tree, will be fairly similar at

most locations on the trunk of the tree. Also bear in mind that trees can change markedly throughout the course of a season, so when comparing the current day's response to those responses in the past, consider limiting the historical comparative window to a few weeks or a month, and pay attention to when the tree might be undergoing certain changes, such as a transition to flowering or fruiting.

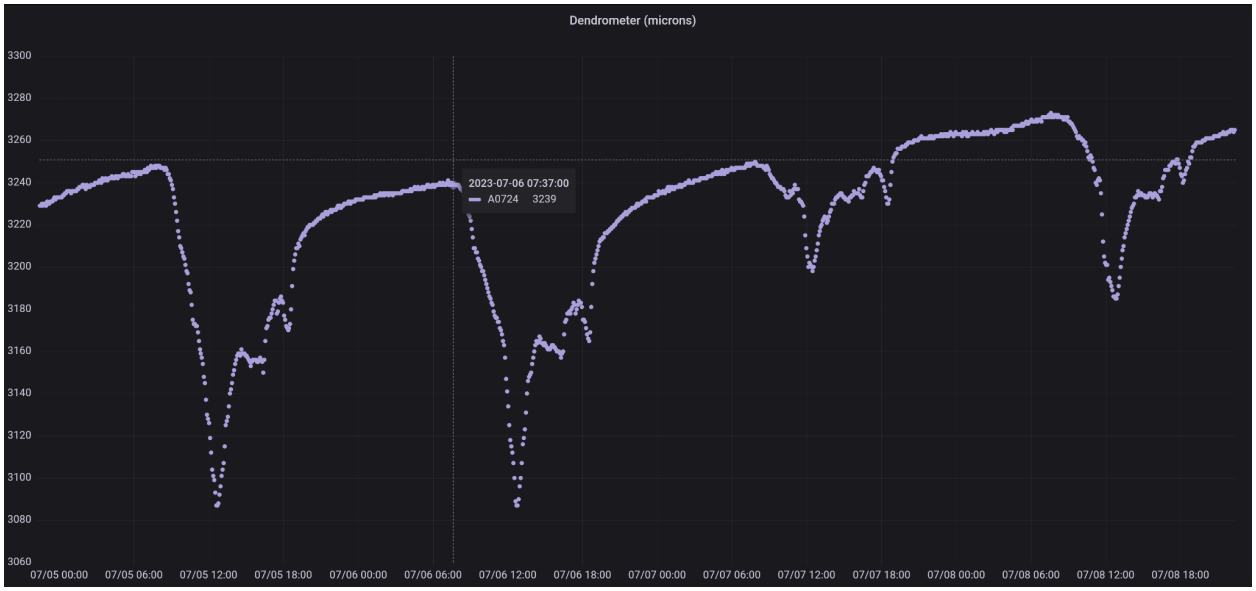
Technical note: The degree of contraction is directly related to sap tension accumulated during the time of contraction. What relates the two is largely the thickness and elasticity of the phloem, the tissue just under the non-living cork/bark. In addition, the nutrient/mineral state of this tissue (and hence osmotic properties of the cells) can affect the degree to which the phloem contracts for a given tension. The tree might alter these properties gradually as a part of its programmed function, but changes can happen abruptly, such as from a sudden influx of fertilizer or other salt from the rootzone.



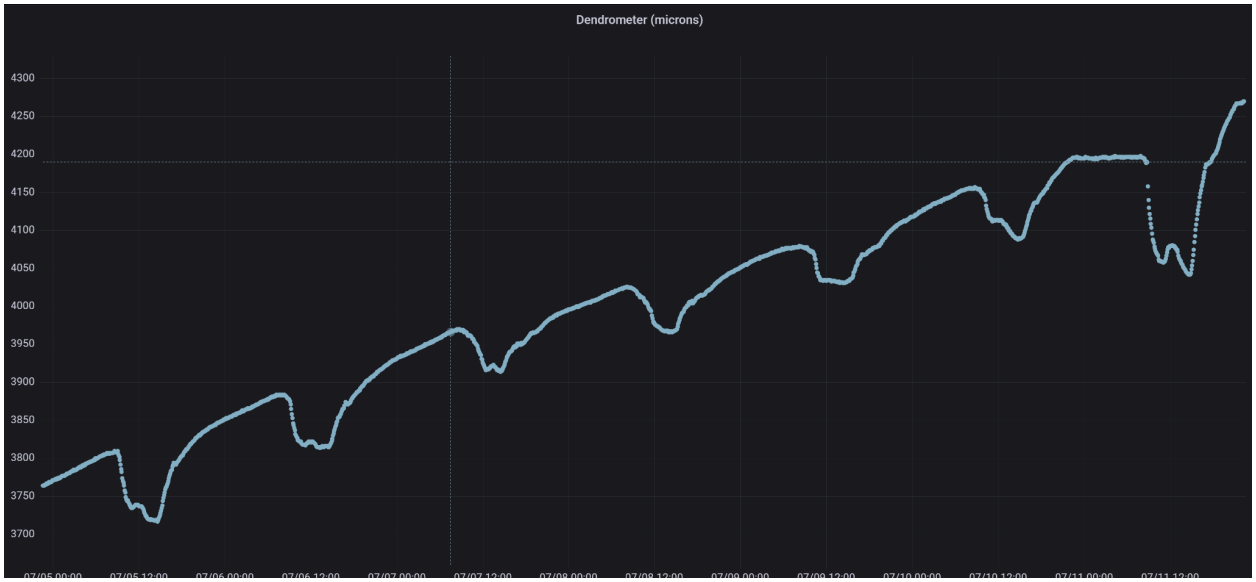
A containerized coast live oak on a six-day irrigation schedule. The six-day pattern is clearly observable. On or abouts the fourth night after irrigation, the tree begins to not recover to its previous nighttime level. This tree could benefit from twice as frequent irrigation.



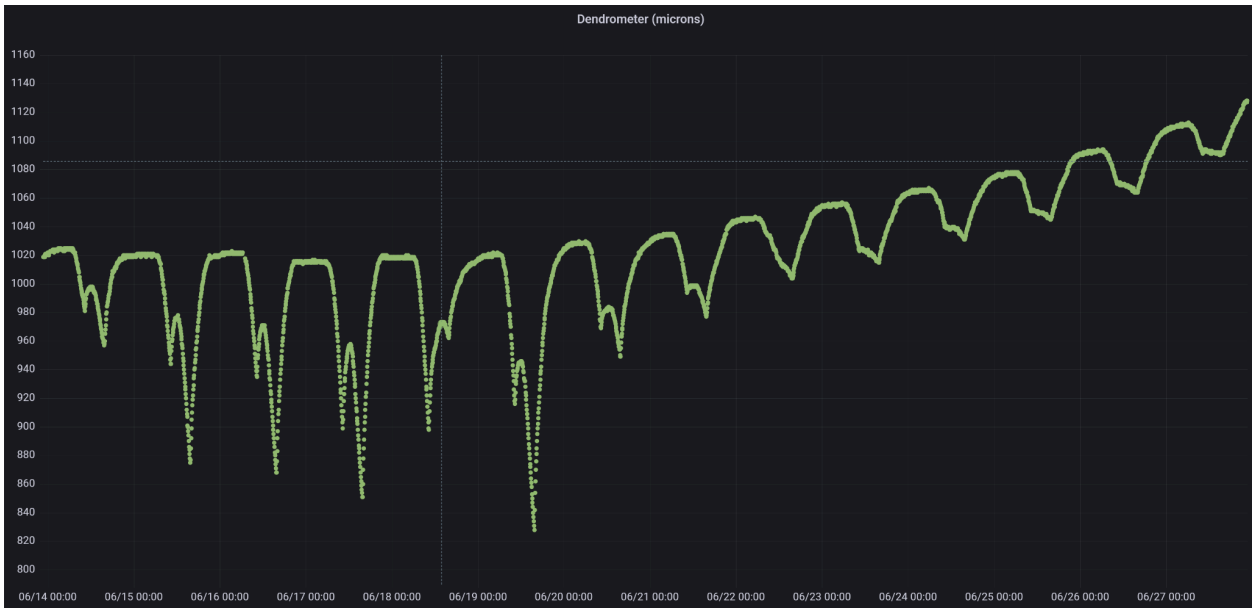
An established, but juvenile western red cedar. The late June heat wave caused this tree to not recover each subsequent night, and contraction magnitude was larger during these hot days. The tree is clearly not closing its stomata as a result of increased evaporative demand, and the tree appears to be water limited. Growth is stagnating towards the end of the plotted time, which is a form of summer dormancy. Indeed, non-irrigated trees of this species, in this environment, and planted around the same time, are all quite stunted for their age.



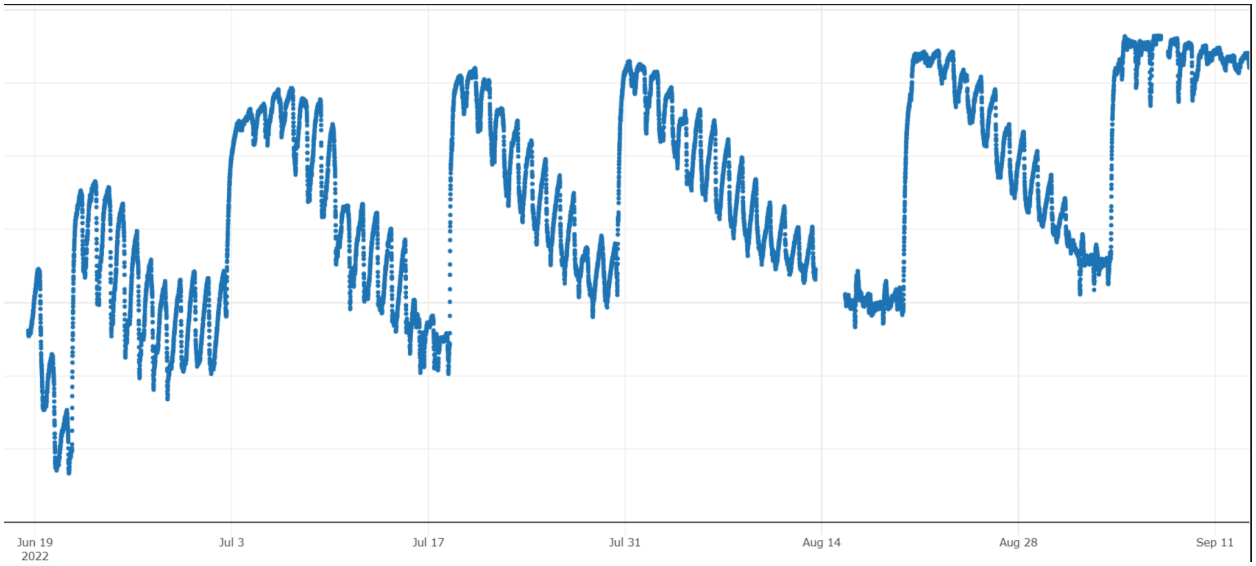
A young (first growing season) Braeburn apple graft. The bumps and dips after noon are the result of the sun passing through a stand of Douglas fir for the rest of the day. The stomata are alternately closing and opening as a function of sun exposure. The first two days were warmer/drier than the second two days, with concomitant changes in contraction magnitude.



A three year old Comice pear tree. The flat bottoms at the base of the contractions are due to the stomata closing to conserve water during midday. This is most apparent in the last day, which was significantly warmer than the previous week.



A containerized cacao tree in a research greenhouse. The double-dips in the first half of the signal are a result of a double-irrigaton - each a few hours apart. The tree was able to match evaporative demand after the first irrigation, but this water was quickly depleted and the tree began to contract again. About midway through this two week period, the greenhouse manager was not happy with this level of deficit, and increased the number of emitters on this tree. Contractions became less severe, and growth resumed.



The same mulberry as above, but a year earlier. The irrigation events are very pronounced due to the two or so weeks between them. The tree almost immediately begins to not recover each night, the contraction magnitudes increase over the next week or so, and begin to decrease *as the phloem is almost fully depleted of water (it can only shrink so much). This tree is spending most of its time in a quite severe water stress state, and should have been irrigated on a three-day schedule rather than the haphazard two week schedule I managed to hit it with. The tree was in its first growing season, but had been growing at another site before I moved it here, so it had a large canopy in comparison to its root-ball, which was severely hacked back when it was dug up. It could have been more severely pruned to limit this effect.*

In Short

1. Observe the tree. What do you expect it to be doing?
2. Observe the effects on the signal from an irrigation. If not much response, consider waiting longer between irrigation events.
3. Observe the path of the sun throughout the day, and how it is incident on your tree's canopy. Are there potential obstructions, such as other trees or buildings?? Can you observe shading events in the dendrometer signal?
4. How does the signal vary naturally with air temperature and humidity? Consider the maximum extent of contraction and the average or maximum temperature and humidity.
5. Pay particular attention when the nighttime recovery does not reach the level of the preceding night. Continued non-recovery will eventually damage the tree. Some level of stress is not detrimental.
6. Have fun learning about your tree!