

**Eco**matik



we make your plants talk!

# Product Catalogue

[www.ecomatik.de](http://www.ecomatik.de)

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# Dendrometer: well-proven measuring instruments in ecological research

## Efficient tools for new applications in modern precision agriculture

As highly precise and robust measuring instruments, electronic dendrometers are used to continuously record changes in the size of different parts of plants (e.g. trunk, branch, root and fruit of trees, as well as herbaceous plants). The micrometer-accurate dendrometer data obtained provides valuable information on vitality and growth dynamics, as well as on the water status of the plant. They can be used under all growth conditions (tropics, polar regions, underground, under snow or underwater). Their wide range of application, reliability and low maintenance, as well as extremely low power consumption make Ecomatik dendrometers a versatile and cost-effective tool in the fields of ecological research and agriculture.

### Advantages

- Monitoring of plant growth processes
- Studies exploring how environmental factors influence plant growth
- Precise dating of the beginning and end of the growing season
- Precise dating of frost events Monitoring of plantwater status, e.g. in the context of:
  - ecological research
  - automated irrigation
  - construction activities
- Plant water content and water storage estimations
- Monitoring of static characteristics and stability of entire trees or individual branches, e.g. in forests, on roads or in parks
- Data-based crop yield forecasts
- Monitoring of water loss from fruits and vegetables during storage.
- Measurements: radius, diameter, circumference, fruit, vegetables, vertical changes

### Technical features

- More than 20 years, Ecomatik dendrometers are successfully used in more than 60 countries worldwide (polar regions, tropics, high mountains)
- Very high measurement resolution up to 0.2  $\mu\text{m}$  (depending on the respective data logger)
- Extremely low power consumption with several years of battery life, e.g. in IoT applications
- Special sensor design for minimal temperature drift
- Compatible with almost all common data loggers and microcontrollers with analog voltage input channels (e.g. also Arduino)

## DR Radius Dendrometer



DR1



DR1W



DR2



DR3 Single Point Installation

### Description

The DR series dendrometers are used for high-precision and continuous measurement of stem diameter changes. These devices are suitable for long-term use in outdoor conditions. Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications. DR dendrometers are specially designed for tree trunks with medium to very large diameters (> 8 cm; or DC3, > 5 cm). DR dendrometers are mounted with one (DR3, DR3W) or two special screws (DR1, DR2, DR1W) anchored in the tree stem. The changes outside the trunk wood correspond to then radial growth and the daily variation of the trunk diameter, which is associated with tree water status. Screw-mounting ensures extreme stability for long-term measurements with limited maintenance options. DR dendrometers are available in five different versions:

1. **DR1:** with standard mounting frame and measuring range from of 11 mm for species with slow and average growth rates
2. **DR1W:** hermetically sealed to withstand extreme environmental conditions (under snow cover, underwater, elevated exposure to dust and corrosive agents), with standard mounting frame, measuring range of 11 mm for species with slow and average growth rates
3. **DR2:** with standard mounting frame and larger measuring range of 25 mm for fast-growing species
4. **DR3:** quick assembly frame with only 1 screw, suitable for treediameters >5 cm, measuring range of 11 mm for species with slow and average growth rates
5. **DR3W:** hermetically sealed to withstand extreme environmental conditions (under snow cover, underwater, elevated exposure to dust and corrosive agents), quick assembly frame with only 1 screw, for tree diameters >5 cm, measuring range of 11 mm for species with slow and average growth rates

## DR Radius Dendrometer

### Advantages

- Suitable for large stem diameters (> 8cm)
- Minimal contact pressure on tree trunk surface
- Maximum stability against wind, snow, falling branches and fruit
- Ideal for long-term measurements with limited maintenance work

#### Specific to the DR2 model:

- Extended measuring range; reduced maintenance effort (i.e. longer time interval between readjustment of the dendrometer frame) for fast-growing species

#### Specific to the DR3 & DR3W models:

- Quick mounting frame with only one screw
- Can be used for trunk diameters >5 cm

#### Specific to the DR1W & DR3W models:

- Hermetically sealed to withstand extreme environmental conditions: e.g. high humidity, underwater, below snow cover, near the ground surface, elevated exposure to dust or corrosive agents (e.g. coastal sands, volcanic ash), etc.

### Scope of delivery

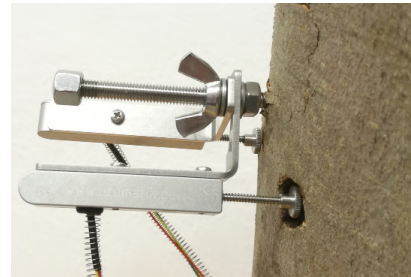
- Sensor with all required parts
- 5 m standard cable length: bare ended, or stereo plug for Mini System logger

### Options

- Cable extension up to 100 m

### Limits

- Drilling and installing the anchoring screws in the trunk may injure the tree (the damage can be minimized by using wound closure resin)
- Not suitable for small trunk diameters ( $w < 8$  or  $< 5$  cm)



DR3 Dual Point Installation



DR3W Single Point Installation

### Required accessories

- Suitable data logger or IoT node: e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

## 1. Dendrometer

Sensor model name	Radius dendrometer Type DR1 and DR1W (hermetically sealed)	Radius dendrometer Type DR2	Radius dendrometer Type DR3 and DR3W (hermetically sealed)
Scope of application	Slow/average growth rates	Fast-growing	slow/normal growth rates
Suitable for diameter	> 8 cm	> 8 cm	> 5 cm
Special features/limitations	2x trunk screws for mounting	Extended measurement range for fast-growing species, 2x trunk screws for mounting	Only 1 trunk screw for mounting, less invasive; dual point installation possible: separate measurement of wood and bark (requires 2 DR3 sensors)
Measurements range	11 mm linear	25,4 mm linear	11 mm linear
Resolution	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$	Data logger dependent e.g.: CR300 series: 0.03 $\mu\text{m}$ Dendrometer logger DL 18: 0.5 $\mu\text{m}$	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$
Accuracy	Dendrometer dependent: max. $\pm 4.5\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value $+0.3 \mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value $+0.45 \mu\text{m})$	Dendrometer dependent: max. $\pm 1.97\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value $+0.6\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value $+1 \mu\text{m})$	Dendrometer dependent: max. $\pm 4.5\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value $+0.3 \mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value $+0.45 \mu\text{m})$
Output signal	Analogue, 0V to Vex (excitation supply voltage)		
Temperature drift of the sensor	< 0.2 $\mu\text{m}/^\circ\text{C}$ in the whole measurement range		
Linearity	< 1%	< 0,7%	< 1%

## 1. Dendrometer

Sensor model name	Radius dendrometer Type DR1 and DR1W (hermetically sealed)	Radius dendrometer Type DR2	Radius dendrometer Type DR3 and DR3W (hermetically sealed)
Operational conditions	<p><b>All Models:</b> normal outdoor field conditions, -25 to -70 °C, 0 to -100% relative air humidity;</p> <p><b>Hermetically Sealed Model DR1W:</b> even under extreme environmental conditions (underwater, below snow cover, under exposure to strongly corrosive substances e.g. saltwater, ash, aggressive agricultural chemicals)</p>	<p><b>All Models:</b> normal outdoor field conditions, -25 to 70 °C, 0 to 100% relative air humidity</p>	<p><b>All Models:</b> normal outdoor field conditions, -25 to 70 °C, 0 to 100% relative air humidity;</p> <p><b>Hermetically Sealed Model DR3W:</b> even under extreme environmental conditions (underwater, below snow cover, under exposure to strongly corrosive substances e.g. saltwater, ash, aggressive agricultural chemicals)</p>
Weight (sensor without cable)	13 g (DR1), 17 g (DR1W)	33 g	13 g
Power supply	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 µWh per measurement	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 µWh per measurement	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 µWh per measurement
Material	Stainless steel and aluminium		
Sensor cable length	5 m, extendable on request to max. 100 m		
Data logger requirements & sensor output signal	<p><b>Minimum logger requirements:</b> 1 single ended channel, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex</p>		

## DD-S Diameter Dendrometer Small



DD-S1



DD-S2

### Description

The DD-S series dendrometers are used for high-precision and continuous measurement of stem diameter changes. These devices are suitable for long-term application in outdoor conditions. Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications. DD-S dendrometers are specially designed for small trees and branches as well as agricultural plants (diameter < 5 cm). The optimized device mounting enables stable installation without exerting excessive pressure on the measuring point. DD-S dendrometers thus deliver stable readings even on very small and herbaceous plants. DD-S dendrometers are available in three versions:

1. DD-S1: with standard mounting frame
2. DD-S2: with quick-mount frame
3. DD-S2W: with a quick-mounting frame and hermetically sealed to withstand extreme environmental conditions (under snow cover, underwater, elevated exposure to dust and corrosive agents)

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended, or stereo plug for Mini System logger

### Required accessories

- Suitable data logger or IoT node:
- e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

### Options

- Cable extension up to 100 m
- Customized frame size (only DD-S1)



## DD-S Diameter Dendrometer Small

### Advantages

- Suitable for small trees and branches as well as agricultural plants with a diameter < 5 cm-Lightweight sensor
- Plants do not have to bear the weight of the sensor (requires a separate support accessory for very small and sensitive plants)
- Injury-free installation, minimal pressure on the plant
- Stability against wind, snow, falling branches and fruits

### Specific to the DD-S2 & DD-S2W models

- Quick mounting frame for fast, easy and tool free installation of the measuring object

### Specific to the DD-S2W model:

- Hermetically sealed to withstand extreme environmental conditions: e.g. high humidity, underwater, below snow cover, near the ground surface, elevated exposure to dust or corrosive agents (e.g. coastal sands and salt, volcanic ash), etc.

### Limits

- Not suitable for diameters > 5 cm (see type DD-L)

### Specific for the DD-S1 & DD-S2 models:

- Not suitable for operation under extreme environmental conditions: e.g. high humidity, underwater, below snow cover, near the ground surface, elevated exposure to dust or corrosive agents (e.g. coastal sands, volcanic ash), etc. (see model DD-S2W)

## 1. Dendrometer

Sensor model name	Diameter Dendrometer Small Type DD-S1	Diameter Dendrometer Small Types DD-S2 and DD-S2W (hermetically sealed)
Scope of application	Slow/average growth rates	
Suitable for diameter	0 to 5 cm	
Special features/limitations	Fixation with a standard mounting frame	Fixation with quick-mount frame, much easier and faster installation, DD-S2W: sealed to withstand with a wide range operational conditions; see below
Measurements range	11 mm linear	
Resolution	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$	
Accuracy	Dendrometer dependent: max. $\pm 4.5\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value +0.3 $\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value +0.45 $\mu\text{m})$	
Output signal	Analogue, 0V to Vex (excitation supply voltage)	
Temperature drift of the sensor	< 0.2 $\mu\text{m}/^\circ\text{C}$ in the whole measurement range	
Linearity	< 1%	
Operational conditions	<b>All Models:</b> normal outdoor field conditions, -25 to -70 $^\circ\text{C}$ , 0 to 100% relative air humidity	<b>All Models:</b> normal outdoor field conditions, -25 -70 $^\circ\text{C}$ , 0 to 100% relative air humidity;  <b>Hermetically Sealed Model DR1W:</b> even under extreme environmental conditions (underwater, below snow cover, under exposure to strongly corrosive substances e.g. saltwater, ash, aggressive agricultural chemicals)

## 1. Dendrometer

Sensor model name	Diameter Dendrometer Small Type DD-S1	Diameter Dendrometer Small Types DD-S2 and DD-S2W (hermetically sealed)
Weight (sensor without cable)	13 g	15 g /DD-S2), 25g (DD-S2W)
Power supply	Vex (! stabilized!) 0.5 to 10 VDC, Power consumption max. 0.28 $\mu$ Wh per measurement	
Material	Stainless steel and aluminium	
Sensor cable length	5 m, extendable on request to max. 100 m	
Data logger requirements & sensor output signal	<p><b>Minimum logger requirements:</b>            1 single ended channel, providing a switched reference voltage (Vex)            Resolution: 12 bits in the measuring range from 0 to Vex            All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements            Sensor output signal: analogue DC voltage in the range from 0 to Vex</p>	

## DD-L Diameter Dendrometer Large



DD-L1



DD-L1W



DD-L2



DD-L3

### Description

The DD-L series dendrometers are used for high-precision and continuous measurement of stem diameter changes. These devices are suitable for long-term application in outdoor conditions. Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications.

DD-L dendrometers are specially designed for small- to medium-sized stems and branches (with diameters ranging from 3 to 30 cm; DD-L1W, max. 20 cm diameter). DD-L dendrometers are fixed to the measuring object with two UV-resistant elastic bands. This simple and very stable mounting method fixes the sensor at the desired measuring point without exerting excessive pressure on the trunk surface. DD-L dendrometers are available in four versions:

1. **DD-L1:** with a measuring range of 11 mm for species with slow and average growth rates.
2. **DD-L2:** larger measuring range of 25 mm for fast-growing species.
3. **DD-L3:** larger measuring range of 50 mm for very fast-growing species. DD-L1W (previously DDW): hermetically sealed to withstand extreme environmental conditions, e.g. high humidity, underwater, below snow cover, near the ground surface, elevated exposure to dust or corrosive agents (e.g. coastal sands, volcanic ash), etc. The DD-L1W is (suitable for trunk diameters between 3 and 20 cm).

## DD-L Diameter Dendrometer Large

### Advantages

- Suitable for small to medium stems and branches with diameters between 3 and 30 cm (DD-L1W, 3 – 20 cm)
- Lightweight sensor
- Injury-free installation, minimal pressure on the plant
- Maximum stability against wind, snow, falling branches and fruit
- Diameter-specific frame size available for diameters ranging from 3 – 30 cm

### Specific to the DD-L2 & DD-L3 models:

- Extended measuring range; reduced maintenance effort (i.e. longer time interval between readjustment of the dendrometer frame) for fast-growing species

### Specific to the DD-L1W model

- Hermetically sealed to withstand extreme environmental conditions: e.g. high humidity, underwater, below snow cover, near the ground surface, elevated exposure to dust or corrosive agents (e.g. coastal sands and salt, volcanic ash), etc.

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger

### Options

- Cable extension up to 100 m
- Customized frame size

### Limits

- Not suitable for diameters > 30 cm (or > 20 cm DD-L1W), (see types DC and DR for diameters > 30 cm)

### Specific to the DD-L1, DD-L2 & DD-L3 models:

- Not suitable for operation under extreme environmental conditions: e.g. high humidity, underwater, below snow cover, near the ground surface, elevated exposure to dust or corrosive agents (e.g. coastal sands, volcanic ash), etc. (see model DD-L1W)

### Required accessories

- Suitable data logger or IoT node: e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

## 1. Dendrometer

Sensor model name	Diameter Dendrometer large Types DD-L1 and DD-L1W (hermetically sealed)	Diameter Dendrometer large Type DD-L2	Diameter Dendrometer large Type DD-L3
Scope of application	Slow/average growth rates	Fast-growing	Very fast growing
Suitable for diameter	DD-L1: 3 – 30 cm; DD-L1W: 3 – 20cm	3 – 30 cm	3 – 30 cm
Special features/limitations	DD-L1W: sealed to withstand a wide range of operational conditions, see below	Extended measurement range for fast-growing species,	Extended measurement range, for very fast-growing species
Measurements range	11 mm linear	25,4 mm linear	50,8 mm linear
Resolution	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$	Data logger dependent e.g.:CR300 series: 0.03 $\mu\text{m}$ Dendrometer logger DL 18: 0.5 $\mu\text{m}$	Data logger dependent e.g.: CR300 series: 0.05 $\mu\text{m}$ Dendrometer logger DL18: 1 $\mu\text{m}$
Accuracy	Dendrometer dependent: max. $\pm 4.5\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value + 0.3 $\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value + 0.45 $\mu\text{m})$	Dendrometer dependent: max. $\pm 1.97\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value + 0.6 $\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value + 1 $\mu\text{m})$	Dendrometer dependent: max. $\pm 0.98\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value + 1.2 $\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value + 2 $\mu\text{m})$
Output signal	Analogue, 0V to Vex (excitation supply voltage)		
Temperature drift of the sensor	< 0.2 $\mu\text{m}/^\circ\text{C}$ in the whole measurement range		
Linearity	< 1%	< 0,7%	< 0,5%

## 1. Dendrometer

Sensor model name	Diameter Dendrometer large Types DD-L1 and DD-L1W (hermetically sealed)	Diameter Dendrometer large Type DD-L2	Diameter Dendrometer large Type DD-L3
Operational conditions	<p><b>All Models:</b> normal outdoor field conditions, -25 to 70 °C, 0 to 100% relative air humidity;</p> <p><b>Model DD-L1W:</b> even under extreme environmental conditions (underwater, below snow cover, under exposure to strongly corrosive substances e.g. saltwater, ash, aggressive agricultural chemicals), Hermetically Sealed</p>	<p><b>All Models:</b> normal outdoor field conditions, -25 to 70 °C, 0 to 100% relative air humidity</p>	<p><b>All Models:</b> normal outdoor field conditions, -25 to 70 °C, 0 to 100% relative air humidity;</p>
Weight (sensor without cable)	13 g	33 g	43 g
Power supply	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 µWh per measurement		
Material	Stainless steel and aluminium		
Sensor cable length	5 m, extendable on request to max. 100 m		
Data logger requirements & sensor output signal	<p><b>Minimum logger requirements:</b> 1 single ended channel, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex</p>		

## DD-RO Diameter Dendrometer Root/Underwater



DD-RO

### Description



The DD-RO series dendrometer is used for the high-precision and continuous measurement of plant diameter changes. This device is suitable for long-term application in outdoor conditions (underground and underwater). Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications. The DRO dendrometer is specially designed to measure roots, aquatic plants

and installations with ground contact, e.g. on ground cover plants. Sealed by a soft, yet resilient rubber coating protects the entire sensor and the sensor rod from the ingress of water and particles; the device is water- and dustproof. An additional metal bracket protects the signal-receiving sensor from pressure that may be exerted when buried under soil in subterranean installations. The specific weight of the entire device is similar to that of water. In underwater installations, the device's buoyancy compensates for its own weight so that no additional load is exerted on the measurement tool.

### Advantages

- Waterproof, suitable for subterranean, aboveground, and underwater applications
- Low pressure at the measuring point
- No additional load on underwater measuring objects
- Ideal for long-term measurements

### Limits

- Only suitable for diameters smaller than 2 cm (for root diameters > 2 cm on request)

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger

### Required accessories

- Suitable data logger or IoT node:
- e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

### Options

- Cable extension up to 100 m
- Customized frame size



## 1. Dendrometer

<b>Sensor model name</b>	<b>Root/Underwater Dendrometer Type DD-RO (hermetically sealed)</b>
Scope of application	Slow/average growth rates
Suitable for diameter	0 – 2 cm (> 2 cm on request)
Special features/limitations	Sealed to withstand with a wide range of operational conditions; see below.
Measurements range	11 mm linear
Resolution	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$
Accuracy	Dendrometer dependent: max. $\pm 4.5\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value +0.3 $\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value +0.45 $\mu\text{m})$
Output signal	Analogue, 0V to Vex (excitation supply voltage)
Temperature drift of the sensor	< 0.2 $\mu\text{m}/^\circ\text{C}$ in the whole measurement range
Linearity	< 1%
Operational conditions	<b>Hermetically Sealed Model DD-RO:</b>  normal outdoor field conditions, -25 to 70 $^\circ\text{C}$ , 0 to 100% relative air humidity, even under extreme environmental conditions (underwater, below snow cover, under exposure to corrosive substances e.g. salt water, ash, aggressive agricultural chemicals)
Weight (sensor without cable)	30 g
Power supply	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 $\mu\text{Wh}$ per measurement
Material	Stainless steel and aluminium
Sensor cable length	5 m, extendable on request to max. 100 m
Data logger requirements & sensor output signal	<b>Minimum logger requirements:</b> 1 single ended channel, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex

## DC Circumference Dendrometer



DC1



DC3



DC4

### Description

The DC series dendrometers are used for high-precision and continuous measurement of changes in stem circumference. These devices are suitable for long-term use in outdoor conditions. Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications.

Changes in stem circumference are recorded by a metal cable that wraps around the stem. This cable is comprised of a special alloy with the lowest possible coefficient of thermal expansion. Friction and pressure between the cable and the stem surface are minimized by special slide rings.

The simplest model in the DC series, the DC1, is attached to the measuring object by the tension of the spring-loaded cable. The tension force is imparted tangentially, and the circumferential signal is recorded directly via the metal cable.

DC3 and DC4 are improved versions of the DC series. The tension force exerted by the sensor spring is transmitted to the measuring wire in radial, and not tangential (cf. DC1), direction. This patented, special design of the DC3 and DC4 dendrometers significantly improves the comparability of the measurement data from objects of different diameters. Additionally, this design ensures a consistently stable installation on objects with both small and very large diameters (more information on our website: difference between the various circumferential dendrometers).

## DC Circumference Dendrometer

### Advantages

- Maximum stability against wind, snow, falling branches and fruits
  - Easy and injury-free installation
- Specific to the DC3 & DC4 models:**
- Suitable for all stem diameters (> 5 cm)
  - Improved data comparability between measurements on tree diameters
  - Exact measurements (even with very large trees)

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger
- Standard lengths of 1 m invar wire and 2 m rubber belt for fixation (sufficient for stem diameters < 30 cm)

### Options

- Cable extension up to 100 m
- Extension of invar wire & rubber belt

### Limits

- Not suitable for measurements underwater nor under snow cover

#### Specific to the DC1 model:

- Measurement data between trees with very different diameters are usually not comparable.
- Measurement values on trees with increasing diameter may be problematic due to the decreasing contact pressure between cable and trunk surface.

#### Specific to the DC3 & DC4 models:

- Raw measurement data must be converted to circumference in mm (Excel program available)
- The cross-section of the measurement object should be approximately circular

### Required accessories

- Suitable data logger or IoT node:
- e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

## 1. Dendrometer

Sensor model name	Circumference Dendrometer 1 Type DC1	Circumference Dendrometer 3 Type DC3	Circumference Dendrometer 4 Type DC4
Scope of application	Slow/average growth rates	Slow/average growth rates	Fast-growing
Suitable for diameter	5 – 32 cm	> 5 cm	> 5 cm
Special features/ limitations	Confined comparability with different trunk diameters	Comparability for different trunk diameters	Comparability for different trunk diameters
Measurements range	11 mm linear $\pm$ 11 mm circumference	25.4 mm linear $\pm$ circumference (diameter-dependent): 50 mm (at $\varnothing$ 10 cm) 35 mm (at $\varnothing$ 50 cm) 28 mm (at $\varnothing$ 100 cm)	50.8 mm linear $\pm$ circumference (diameter-dependent): 107 mm (at $\varnothing$ 10 cm) 80 mm (at $\varnothing$ 50 cm) 65 mm (at $\varnothing$ 100 cm)
Resolution	Data logger dependent e.g.: CR300 series: 0.01 $\mu$ m Dendrometer logger DL18: 0.2 $\mu$ m	Data logger dependent e.g.: CR300 series: 0.03 $\mu$ m Dendrometer logger DL 18: 0.5 $\mu$ m	Data logger dependent e.g.: CR300 series: 0.05 $\mu$ m Dendrometer logger DL18: 1 $\mu$ m
Accuracy	Dendrometer dependent: max. $\pm$ 4.5% of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm$ (0.04% of the measured value + 0.3 $\mu$ m) Dendrometer logger DL18: $\pm$ (0.1% of the measured value + 0.45 $\mu$ m)	Dendrometer dependent: max. $\pm$ 1.97% of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm$ (0.04% of the measured value + 0.6 $\mu$ m) Dendrometer logger DL18: $\pm$ (0.1% of the measured value + 1 $\mu$ m)	Dendrometer dependent: max. $\pm$ 0.98% of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm$ (0.04% of the measured value + 1.2 $\mu$ m) Dendrometer logger DL18: $\pm$ (0.1% of the measured value + 2 $\mu$ m)
Output signal	Analogue, 0V to Vex (excitation supply voltage)		
Temperature drift of the sensor	< 0.2 $\mu$ m/ $^{\circ}$ C in the whole measurement range		
Temperature coefficient of the stem embracing cable wire	< $1.4 \times 10^{-6}/K$		
Linearity	< 1%	< 0,7%	< 0,5%

## 1. Dendrometer

Sensor model name	Circumference Dendrometer 1 Type DC1	Circumference Dendrometer 3 Type DC3	Circumference Dendrometer 4 Type DC4
Linearity	< 1%	< 0.7%	< 0.5%
Operational conditions	Normal outdoor conditions, -25 to 70 °C, 0 to 100% relative air humidity; unsuitable underwater and below snow cover		
Weight (sensor without cable)	13 g	37 g	47 g
Power supply	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 µWh per measurement		
Material	Stainless steel and aluminium		
Sensor cable length	5 m, extendable on request to max. 100 m		
Data logger requirements & sensor output signal	<p><b>Minimum logger requirements:</b></p> <p>1 single ended channel, providing a switched reference voltage (Vex)</p> <p>Resolution: 12 bits in the measuring range from 0 to Vex</p> <p>All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements</p> <p>Sensor output signal: analogue DC voltage in the range from 0 to Vex</p>		

## DF Fruit and Vegetable Dendrometer



DF4



DF5



DF6

### Description

The DF series dendrometers are used for high-precision and continuous measurement of fruit and vegetable growth. These devices are suitable for long-term application in outdoor conditions. Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications.

DF fruit and vegetable dendrometers are specially designed to measure on fruit bodies of different sizes and shapes. This design allows for stable fixation of the fruit in the dendrometer frame without affecting fruit growth. Depending on the model and conditions of installation, the dendrometer frame can be flexibly attached to the branch/shoot from which a fruit hangs. This installation prevents any straining on the branch/shoot, thus avoiding damage to the fruit being measured.

The DF series comprises four different models:

The models DF5 and DF6 come with a quick-mount fruit holder in which the fruit is easily installed and measured. Fruit growth is directly measured without mechanical magnification of the respective measuring range (11 and 25 mm). The fruit growth data collected by these models are precise to the nearest micrometer and are therefore suitable for tracking even the finest growth responses.

The DF4 model, on the other hand, comes with a completely different measuring and installation method. Instead of being fixed in a frame, the fruit is clamped in a movable claw. The advantages of this movable claw include quick, easy installation and a notable mechanically magnified measuring range of up to 130 mm. This range is suitable for many types of fruit and thus allows maintenance-free, absolute measurement of a fruit throughout the growth and ripening process.

The advantages of this movable claw include quick, easy installation and a notable mechanically magnified measuring range of up to 130 mm. This range is suitable for many types of fruit and thus allows maintenance-free, absolute measurement of a fruit throughout the growth and ripening process.

1. **DF4:** easy installation and maintenance-free measurement through a claw mechanism, large measuring range of 130 mm for large and fast-growing fruits (e.g. apple, orange, peach, tomato, ...)
2. **DF5:** with a measuring range of 11 mm for small fruits (e.g. cherries, grapes).
3. **DF6:** larger measuring range of 25 mm for medium-sized and fast-growing fruits (e.g. plums, nuts, tangerines, apricots)

# DF Fruit and Vegetable Dendrometer

## Advantages

- Suitable for diameters from 0 to 3 cm (DF5), 0 to 5 cm (DF6), or 0 to 13 cm (DF4)
- Solutions for larger diameters on request
- No extra weight load on the fruit
- Record ripening in softening fruits
- Injury-free installation
- Minimal pressure on the measuring point
- Maximum stability against wind, falling branches and fruit

### Specific to the DF5 & DF6 models:

- Direct micrometer-precise measurement, without mechanical magnification of the respective measuring range (11 and 25 mm).
- DF6 with extended measuring range; reduced maintenance effort (i.e. longer time interval between readjustment of the dendrometer frame) for fast-growing species

### Specific to the DF4 model:

- Mechanically magnified measuring range of up to 130 mm, maintenance-free measurement of the absolute fruit diameter throughout the entire fruit growth.

## Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger

## Options

- Cable extension up to 100 m

## Limits

- Not suitable for fruits that are too soft (e.g. ripe raspberries)

## Required accessories

- Suitable data logger or IoT node:
- e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

## 1. Dendrometer

Sensor model name	Fruit & Vegetable Dendrometer Type DF4	Fruit & Vegetable Dendrometer Type DF5	Fruit & Vegetable Dendrometer Type DF6
Scope of application	Medium-/large-sized and fast-growing fruit	small-sized fruit	Small- to medium-sized, fast-growing fruit
Suitable for fruit diameter	10 – 130 mm	5 – 30 mm	5 – 50 mm
Special features/limitations	<p>Quick and easy installation with the fruit gripper</p> <p>Mechanically greatly magnified measuring range of 130 mm</p> <p>Maintenance-free (no readjustment necessary) measurement of the absolute fruit diameter</p>	<p>Quick and easy installation with quick-mount fruit holder</p> <p>Extended measuring range for medium-sized, fast-growing fruits</p> <p>Direct, micrometer-accurate measurement of fruit growth</p>	<p>Quick and easy installation with quick-mount fruit holder</p> <p>Extended measuring range for medium-sized, fast-growing fruits</p> <p>Direct, micrometer-accurate measurement of fruit growth</p>
Measurements range	130 mm linear (full scale, FS)	11.0 mm linear	25.4 mm linear
Resolution	Data logger dependent e.g.: CR300 series: 0.15 $\mu\text{m}$ Dendrometer logger DL18: 2.5 $\mu\text{m}$	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$	Data logger dependent e.g.: CR300 series: 0.03 $\mu\text{m}$ Dendrometer logger DL18: 0.5 $\mu\text{m}$
Accuracy	<p>Dendrometer dependent: max. <math>\pm 0.8\%</math> of the measured value (stable offset)</p> <p>Data logger dependent e.g.: CR300 series: <math>\pm (0.1\%</math> of the measured value + 3.5 <math>\mu\text{m})</math></p> <p>Dendrometer logger DL18: <math>\pm (0.1\%</math> of the measured value + 5.5 <math>\mu\text{m})</math></p>	<p>Dendrometer dependent: max. <math>\pm 4.5\%</math> of the measured value (stable offset)</p> <p>Data logger dependent e.g.: CR300 series: <math>\pm (0.04\%</math> of the measured value + 0.3 <math>\mu\text{m})</math></p> <p>Dendrometer logger DL18: <math>\pm (0.1\%</math> of the measured value + 0.45 <math>\mu\text{m})</math></p>	<p>Dendrometer dependent: max. <math>\pm 1.97\%</math> of the measured value (stable offset)</p> <p>Data logger dependent e.g.: CR300 series: <math>\pm (0.04\%</math> of the measured value + 0.6 <math>\mu\text{m})</math></p> <p>Dendrometer logger DL18: <math>\pm (0.1\%</math> of the measured value + 1 <math>\mu\text{m})</math></p>
Output signal	Analogue, 0V to 80% of Vex (excitation supply voltage)	Analogue, 0V to Vex (excitation supply voltage)	Analogue, 0V to Vex (excitation supply voltage)
Temperature drift of the sensor	< 0.015% of FS/ $^{\circ}\text{C}$ in the whole measurement range	< 0.2 $\mu\text{m}/^{\circ}\text{C}$ in the whole measurement range	< 0.2 $\mu\text{m}/^{\circ}\text{C}$ in the whole measurement range



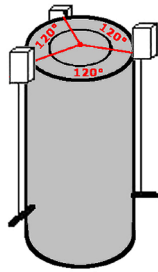
## 1. Dendrometer

Sensor model name	Fruit & Vegetable Dendrometer Type DF4	Fruit & Vegetable Dendrometer Type DF5	Fruit & Vegetable Dendrometer Type DF6
Linearity	< 1%	< 1%	< 0.7%
Operational conditions	<b>All Models:</b> Normal outdoor conditions, -25 to 70 °C, 0 to 100% relative air humidity; unsuitable underwater and below snow cover		
Weight (sensor without cable)	48 g	15 g	33 g
Power supply	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 µWh per measurement		
Material	Stainless steel and aluminium		
Sensor cable length	5 m, extendable on request to max. 100 m		
Data logger requirements & sensor output signal	<b>Minimum logger requirements:</b> 1 single ended channel, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex		

## DV Dendrometer



DV



DV schematisch



### Description

The DV dendrometer is used for high-precision and continuous measurement of vertical changes (not growth) in dimension and/or curvature of tree stems. This device is suitable for long-term in outdoor conditions. Due to their extremely low power consumption, Ecomatik dendrometers are ideal for battery-powered solutions, e.g., in IoT applications.

Tree stems and their respective sections vary in length and curvature, according to water status (short- to mid-term), wind direction and wind speed (short-term to permanent), snow and fruit load (mid-term to permanent), and unbalanced growth or loss of crown parts (long-term). Information of parallel measurements with three vertical dendrometers in three different cardinal directions, provide valuable information on water status and static properties of the instrumented tree.

### Advantages

- Stress-strain relationship computation
- Maximum stability against wind, snow, falling branches and fruit
- Ideal for long-term measurements

### Limits

- Installation (drilling and screwing in the anchoring screws) damages the tree trunk (which could be minimized with wound closure resin).
- Only suitable for diameters > 8 cm

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger
- Standard lengths of 1 m invar

### Required accessories

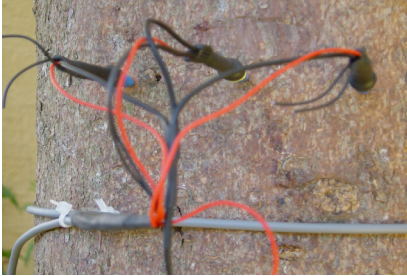
- Suitable data logger or IoT node:
- e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

### Options

- Cable extension up to 100 m

Sensor model name	Vertical Dendrometer Type DV
Scope of application	Stems or branches
Suitable for diameter	> 8 cm
Special features/limitations	2x trunk screws for mounting
Measurements range	11 mm linear
Resolution	Data logger dependent e.g.: CR300 series: 0.01 $\mu\text{m}$ Dendrometer logger DL18: 0.2 $\mu\text{m}$
Accuracy	Dendrometer dependent: max. $\pm 4.5\%$ of the measured value (stable offset) Data logger dependent e.g.: CR300 series: $\pm (0.04\%$ of the measured value +0.3 $\mu\text{m})$ Dendrometer logger DL18: $\pm (0.1\%$ of the measured value +0.45 $\mu\text{m})$
Output signal	Analogue, 0V to Vex (excitation supply voltage)
Temperature drift of the sensor	< 0.2 $\mu\text{m}/^\circ\text{C}$ in the whole measurement range
Temperature coefficient of the stem embracing cable wire	< $1.4 \times 10^{-6}/\text{K}$
Linearity	< 1%
Operational conditions	Normal outdoor field conditions, -25 to 70 $^\circ\text{C}$ , 0 to 100% relative air humidity; unsuitable underwater and below snow cover
Weight (sensor without cable)	13 g
Power supply	Vex (! stabilized !) 0.5 to 10 VDC, Power consumption max. 0.28 $\mu\text{Wh}$ per measurement
Material	Stainless steel and aluminium
Data logger requirements & sensor output signal	<b>Minimum logger requirements:</b> 1 single ended channel, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex

## SF-G / SF-L Granier Sap Flow Sensors



SF-L



SF-G

### Description

Sap flow sensors are used to continuously measure water uptake in woody plants. The SF-G model corresponds to the classic, two-needle model developed in 1985 by André Granier.

Our four-needle SF-L sensor is an updated Granier sensor. The patented improvements correct the naturally occurring and time-varying vertical temperature gradients in the sapwood. Without correction (i.e. the original Granier sensor, SF-G) and despite isolation, these natural temperature gradients can lead to a temporary over- or underestimation of the measured sap flow values of up to 50% in extreme cases (cf. Do, F., & Rocheteau, A., 2002). Additional temperature measurements with the SF-L sensor enable a correction of the measured sap flow values, which prevents errors caused by the natural vertical stem temperature gradients. This results in a significantly higher accuracy and a stabler zero-point ( $\Delta T_{max}$ ) of the xylem (sap) flow.

A dendrometer can be used in order to continuously measure the water saturation level of the tree body, to exactly determine zero sap flow conditions: sap flow = 0 if the relative humidity in the crown at 100% and the tree body is 100% saturated with water (no change in diameter). The improved SF-L sensor combined with dendrometer-aided precise determination of zero flow conditions enables the recording of a nocturnal xylem flow.

### Advantages

#### Specific to the SF-G model:

- Suitable for tree diameters > 1 cm

#### Specific to the SF-L model:

- Greater measurement accuracy
- Correct determination of the xylem flow zero point when supplemented with dendrometer measurements
- Allows measurement of nocturnal xylem flow
- Additional information about tree growth provided by installing supplementary dendrometers

### Limits

#### Specific to the SF-G model:

- The measured values are superimposed by naturally occurring vertical temperature fluctuations in the trunk (up to +/- 2.5 ° C). This leads to measurement errors greater than 50% and may impact the reliability of measurement results
- Nocturnal sap flow cannot be measured.

#### Specific to the SF-L model:

- Not suitable for trees with a diameter < 8 cm
- 3 logger channels are required per sensor

## SF-G / SF-L Granier Sap Flow Sensors

### Scope of delivery

- Sensor with all required parts for one installation (no tools)
- 5 m standard cable length: bare ended (extendable up to 20 m on requests)

### Required accessories

- Suitable data logger or IoT node:
- e.g. Maxi System, or other logging device (please contact us to check compatibility)
- Constant current source (CCS)
- installation tools

Sensor model name	Sap Flow Sensor Type SF-G	Sap Flow Sensor Type SF-L
Scope of application	For continuous measurement of the sap flow in wood plants	For continuous measurement of the sap flow in wood plants
Suitable for diameter	> 1 cm	> 8 cm
Number of sensor needles	2	4
Sensor dimensions	Needle diameter: 1.5 mm; Needle length//length heated in mm, available versions: 18//10; 33//20; 43//20; 63//20	
Output signal	Analog, DC voltage -100 $\mu$ V to +800 $\mu$ V	
Required logger channels	1x differential, resolution better than 10 $\mu$ V	3x differential, resolution better than 10 $\mu$ V
Power supply	Sap flow sensors must be supplied via a constant current source (CCS). A CCS supplies up to 3 SF-G and / or SF-L sensors and continuously needs 85 mA x 12 V. This corresponds to 2.1 amps x hour / day	
Sensor cable length	5 m, extendable to max. 20 m	
Data logger requirements & sensor output signal	<b>Minimum logger requirements:</b> 1 (SF-G) or 3 (SF-L) differential analog channels per sensor, Resolution: 10 $\mu$ V or better in the measuring range from -100 to 1000 $\mu$ V All loggers of Campbell Scientific, meet these requirements. Sensor output signal: analogue DC voltage in the range from -100 to 1000 $\mu$ V.	

## Temperature broad leaf (LAT-B3)



LAT-B3

### Description



Leaf-to-Air-Temperature sensors (LAT-B3) are used for direct, continuous and high-precision temperature measurements. The ultra-light, magnet-mounted sensor measures temperatures of the leaf surface ( $T_{\text{leaf}}$ ) and leaf-surrounding ambient air ( $T_{\text{air}}$ ), allowing the calculation of the temperature difference between leaf surface and ambient air ( $\Delta T_{\text{leaf-to-air}}$ ) with high-precision due to its factory-matched dual probe.

These devices are suitable for long-term application in outdoor conditions. Due to their extremely low power consumption,

Ecomatik LAT sensors are ideal for battery-powered solutions, e.g., in IoT applications.

### Advantages

- Direct, continuous and highly accurate measurement of blade temperature ( $T_{\text{leaf}}$ ), air temperature ( $T_{\text{air}}$ ), and leaf-air temperature difference ( $\Delta T_{\text{leaf-to-air}}$ )
- Small, lightweight and flexible sensors to minimize loading on and damage to the measurement object
- Easy installation
- Maximum stability against wind and rain; specifically designed for field conditions
- Customizable size

### Limits

- Not suitable for leaves with a length of less than 1.4 cm and a width of smaller than 0.8 and not suitable for leaves with a thickness of  $> 0.7$  mm

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger

### Required accessories

- Suitable data logger or IoT node:
- e.g. Mini System, Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

### Options

- Cable extension up to 50 m

<b>Sensor model name</b>	<b>Leaf temperature sensor for broad leaves Type LAT-B3</b>
<b>Scope of application</b>	For continuous measurement of leaf surface (Tleaf), surrounding ambient air temperature (Tair), and leaf-to-air temperature difference ( $\Delta$ tleaf-to-air)
<b>Suitable for leaf dimensions</b>	Leaf length > 1.4 cm, leaf width > 0.8 cm (other dimensions on request), stable magnet attachment to leaves with a thickness of up to 0.7 mm.
<b>Special features/limitations</b>	Measurement of the absolute temperatures of leaf surface and ambient air, high accuracy in leaf-to-air temperature difference (individually matched probes) Dual-probe spacing: User-configurable distance between Tleaf and Tair probes between 0 to max. 35 mm
<b>Measurements range</b>	-25 to +70 °C
<b>Resolution</b>	Theoretically infinite depending on the data logger used e.g. CR300-Logger (at 25°C): < 0,000025 °C DL 18 Logger (at 25°C): < 0,00035 °C
<b>Accuracy</b>	<b>Sensor dependent:</b> Tolerance of absolute Tair & Tleaf ± 0,4 °C in temperature range between +5°C to +40°C ± 0,8 °C in temperature range between -25°C to +70°C  <b>Tolerance of Leaf-to-Air-Temperature difference (<math>\Delta</math>TLeaf-Air):</b> ± 0,2° in temperature range between -25°C to +70°C  <b>Logger dependent, e.g.:</b> CR300-Logger (at 25°C): ± 0,01 °C DL 18 Logger (at 25°C): ± 0,03 °C:
<b>Power supply</b>	VEX (! Regulated!) 0.5 to 2.5 VDC, required excitation interval time max. 100 ms. Power consumption negligibly low, max. 16.5 nWh per measurement
<b>Operational conditions</b>	Air temperature: -25 to 70 ° C, rel. humidity: 0 to 100%
<b>Size &amp; Weight</b>	Diameter sensor 12mm, weight 0.9g (only sensor, without cable)
<b>Sensor cable length</b>	0.5m + 4.5m pluggable extension, plug extension up to max. 50 m possible
<b>Data logger requirements &amp; sensor output signal</b>	<b>Minimum logger requirements:</b> 2 single ended channels, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex

## SMT100 Soil moisture and soil temperature



SMT100



SMT100

### Description

The SMT100 soil sensor allows for easy, inexpensive soil moisture and temperature measurements. This device enables both the precise analysis of the soil water balance and the determination of plant soil water availability. The SMT100's integrated temperature sensor additionally provides important data on ground temperature. The device's numerous applications range from data collection for scientific purposes to irrigation control in commercial agriculture and horticulture.

Through its special design and optimized measuring principle, the SMT100 combines the advantages of low-cost FDR sensors with the accuracy of TDR measurements. This way the SMT100 takes reliable measurements even in dense clay and salty soils. Sensor and cable are maintenance-free, robust, waterproof and frost-resistant. The SMT100 is therefore ideal for continuous operation, or point measurements."

### Advantages

- Accurate determination of soil water content
- Integrated temperature measurement
- Suitable for every soil type
- Easy installation (ongoing measurement) and insertion (manual measurement with handset) into soil
- Cost-effective
- Compatible with almost every logger system (interface options: Analogue Volt Signal, RS-485, SDI-12)

### Required accessories

- Suitable data logger or IoT node:
- e.g. Maxi System, Multi-IoP LoRa node, or other logging device (please contact us to check compatibility)

### Scope of delivery

- Sensor with all required parts
- 10 m standard cable length: bare ended

### Options

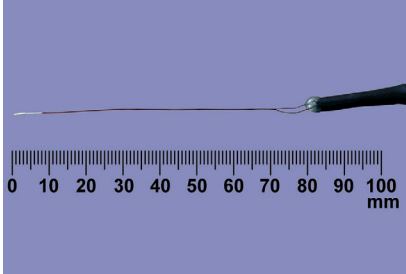
- Cable extension up to 50 m



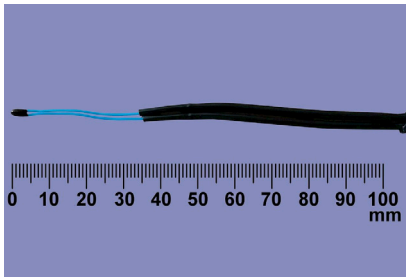
## 4. Soil Moisture and Temperature

<b>Sensor model name</b>	<b>Soil moisture and soil temperature sensor Type SMT100</b>
<b>Scope of application</b>	For continuous (permanent installation) or manual (insertion with handset) measurements of the volumetric water content of soil (SWC)
<b>Suitable for diameter</b>	All soil types
<b>Special features/ limitations</b>	<b>Special feature:</b> read out of additional information possible: »Raw data, dielectric permittivity  <b>Limitation:</b> Use for manual point measurements in highly abrasive technosols is not recommended
<b>Measurements range</b>	<b>SWC:</b> 0 to 60% volumetric water content (up to 100% volumetric water content with restricted accuracy)  <b>Temperature:</b> Temperature: -40 to + 80 ° C (analogue version -40 to + 60 ° C)
<b>Resolution</b>	0.1% SWC 0.01 ° C (analogue version 0.2 ° C)
<b>Accuracy</b>	<b>Volumetric water content (SWC):</b> <ul style="list-style-type: none"> <li>• at factory calibration up to <math>\pm 3\%</math> (SWC) in mineral soil types with medium salinity of 0 to 50% VW</li> <li>• for soil-specific calibration up to <math>\pm 1\%</math> (SWC)</li> </ul> <b>Temperature:</b> <ul style="list-style-type: none"> <li>• typical <math>\pm 0.2</math> ° C, max. <math>\pm 0.4</math> ° C over the entire measuring range (analogue version <math>\pm 0.8</math> ° C)</li> </ul>
<b>Logger requirements and sensor output signal</b>	All data loggers with suitable power supply and RS485 Interface (TBus, Modbus, ASCII), SDI-12 or Analogue input 0 – 10 V (other voltage ranges on request)
<b>Power supply</b>	4 – 24 V DC, up to 40 mA peak during measurement (Analogue version 12 – 24 V DC for 0 – 10 V output signal) Measuring time digital versions: less than 50 ms Measuring time analogue versions: less than 500 ms
<b>Operational conditions</b>	Air temperature: -25 to 70 ° C, rel. air humidity: 0 to 100%
<b>Size &amp; Weight (sensor without cable)</b>	18.2 cm x 3 cm x 1.2 cm; about 80 g without cable
<b>Sensor cable length</b>	10 m, can be extended on request

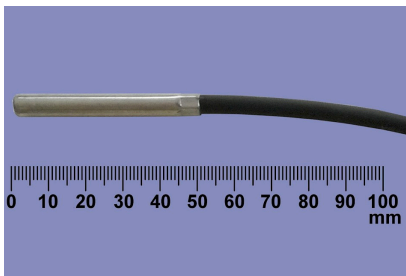
## T-Tissue: Tissue temperature, T-Surface: Surface temperature, T-Soil: soil or underwater temperature



T-Tissue



T-Surface



T-Soil

### Description

The T-series sensors are used for direct, continuous and high-precision temperature measurements. The various T-series models are designed specifically to record internal temperatures (T-Tissue), outer/surface temperatures (T-surface) on plants and other measurement objects, or for soil/water temperature (T-soil). These devices are suitable for long-term application in outdoor conditions. Due to their extremely low power consumption, Ecomatik T-sensors are ideal for battery-powered solutions, e.g. in IoT applications.

**T-Tissue model:** Small, light, and flexible, especially for minimally invasive installation within measurement object

**T-Surface model:**

- Robust, yet small, light, and flexible

**T-Soil model:**

- Hermetically sealed in metal sleeve, for long-term operation in soil or under water

### Advantages

- Easy installation
- Robust; designed for use under outdoor conditions
- Direct, continuous and highly accurate temperature measurements
- Sensor signal documented in mV, recordable with most common data loggers
- Extremely low power consumption, suitable for IoT applications

### Limits

**Specific to the T-Tissue model:**

- Not suitable for measurement objects < 4 mm

### Scope of delivery

- Sensor with all required parts
- 5 m standard cable length: bare ended or stereo plug for Mini System logger

### Options

- Cable extension up to 50 m

## 5. Temperature Sensors

Sensor model name	Temperature sensor type T-Tissue	Temperature sensor type T-Surface	Temperature sensor type T-Soil
Scope of application	Internal measurements, e.g. inner tissues	Measurements on surfaces	Measurements below-ground or underwater
Suitable for	Tree bud, cambium, fruit temperature	Tree bark, fruit, or other surface areas	Soil and water temperature
Special features/limitations	Minimally invasive microprobe	Small but robust; for permanent outdoor use	Hermetically sealed in robust metal sleeve for permanent operation belowground or underwater
Measurements range	-40 to 70°C		
Resolution	Theoretically infinite depending on the data logger used e.g. CR300 logger (at 25 °C): < 0.001 °C DL 18 Logger (at 25 °C): < 0.002 °C		
Accuracy	Sensor-dependent: max. ± 0.2 °C Logger dependent: e.g. CR300 logger (at 25 °C): ± 0.03 °C DL 18 Logger (at 25 °C): ± 0.07 °C		
Linearity	< 1%	< 0,7%	< 0,5%
Power supply	VEX (! Regulated!) 0.5 to 2.5 VDC, required excitation interval time max. 100 ms  Power consumption negligibly low, max. 8.3 nWh per measurement		
Operational conditions	Temperature: -25 to 70 °C, rel, air humidity: 0 to 100%		
Size and Weight	Spherical shape, diameter 0.9 mm, weight 0.1 g (sensor only, cable not included)	Spherical shape, diameter 2 mm, length 3.3 mm, weight 0.3 g (sensor only, cable not included)	Form cylindrical, diameter 6 mm, length 50 mm, weight 5 g (sensor only, cable not included)
Material	Glass	Epoxid	Epoxid, Aluminium
Sensor cable length	5 m, extendable to max. 50 m		
Data logger requirements & sensor output signal	<b>Minimum logger requirements:</b> 1 single ended channel, providing a switched reference voltage (Vex) Resolution: 12 bits in the measuring range from 0 to Vex All loggers of Campbell Scientific, as well as the DL 18 logger meet these requirements Sensor output signal: analogue DC voltage in the range from 0 to Vex		

## Mini-Systems with Data Logger DL 18 or DL 18 - BLE



DL-18



### Description

Our Mini-Systems are based on the data loggers DL 18 (interface: USB to PC with Windows or MacOS) or DL 18-BLE (interface: Bluetooth Low Energy to Windows PC, or Tablet / Smartphone with Android or iOS).

Both loggers feature 4 precise and high-resolution measuring channels (temperature-compensated, 16 bits) for connecting various analogue sensors, such as dendrometers, soil moisture sensors, temperature probes (T-soil, T-surface, T-Tissue), leaf temperature sensors (LAT-B2), and T/RH air sensor. A possible sensor combinations would be for example: 1x dendrometer + 1x T/RH air sensor (this sensor type occupies 2 channels) + 1x soil moisture sensor (max. number of soil moisture sensors per DL 18 is 1 piece, due to the higher power consumption of this sensor type).

Our mini measuring system can operate independently due to their robustness (weather resistant protective box and metal roof are included); battery-operative, extremely low power consumption (2 replaceable AAA batteries, lifetime > 1 year); as well as their large internal memory (1,900,000 data points). Mini-Systems are thus ideal for long-term measurements in outdoor conditions with a spatially decentralized distribution of the measuring points.

## Mini-Systems with Data Logger DL 18 or DL 18 - BLE

### Advantages

- Small, robust, weatherproof
- User friendly: easy sensor connection with stereo plug, easy configuration and data readout via PC or smartphone/tablet, control buttons for the most important functions directly on the logger device, LCD display can be turned off (displayable information includes current measurement values, recording status, alarms, battery status, memory usage)
- Extensive measurement functions: average, event-controlled burst-measurements, measurement-value-controlled alarms, etc.
- Precise and high-resolution measurements
- Low power consumption, powered by 2 AAA batteries; very long battery life
- Large measurement data memory

### Specific to the DL 18-BLE model:

- Wireless configuration and data transmission via Bluetooth Low Energy to Windows-PC, Tablet or Smartphone with Android or iOS

### Limits

- Only 4 channels
- On the logger itself, linear conversions of the raw readings can be programmed and carried out; however, complex conversions must be performed post-hoc, after data download of the raw measured values (e.g., in a spreadsheet program)

## 6. Data Capture and Measurement Systems

Logger Type	Mini Logger DL 18	Mini Logger DL 18-BLE
Scope of application	Battery-powered data recording in outdoor conditions	Battery-powered data recording in outdoor conditions. Bluetooth data transfer to smartphone/tablet particularly advantageous if logger accessibility is difficult (e.g., if attached to a greater height in the tree)
Compatible Sensors	Sensors with analogue output signal: <ul style="list-style-type: none"> <li>- Dendrometer (all models)</li> <li>- Temperature sensors (T-Series)</li> <li>- Leaf temperature sensor (LAT-B3)</li> <li>- T/RH air sensor (EM 14)</li> <li>- Soil moisture sensor (SMT100)</li> <li>- Light sensors (Par: EM 20; Pyranometer: EM 25)</li> </ul>	
Special features/limitations	Small; robust, weatherproof metal box; cost-effective; easy to use; long battery life	Small; robust, weatherproof plastic box; wireless communication with mobile devices via Bluetooth; cost-effective; easy to use; long battery life
Number of measuring channels & measuring range	4 channels for 0 to 2.5 V	
Recording interval	Adjustable between 1 sec and 18 hours (averaging possible)	
Storage capacity	4 MB (max. 1,900,000 measured values) e.g. For 4 channels and 30 minutes recording interval sufficient for 7,900 days	
Resolution	40 $\mu$ V e.g.: Dendrometer, depending on the model: 0.2 to 1 $\mu$ m T-Series, LAT-B3: $1.6 \cdot 10^{-3}$ °C	
Accuracy	$\pm 0.1$ mV $\pm 0.1\%$ of measured value	

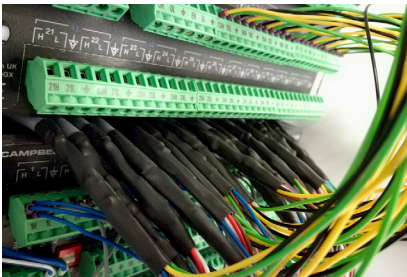
## 6. Data Capture and Measurement Systems

Logger Type	Mini Logger DL 18	Mini Logger DL 18-BLE
By the logger supplied sensor excitation voltage	2.5 V (switched, stabilized)	2.5 V (switched, stabilized)
Logger powering & battery life	2x AAA cell, user-replaceable  Battery life: typically 1 year with a logging interval of 1 minute	2x AAA cell, user-replaceable  Battery Life: typically 1 year with a logging interval of 1 minute and activated Bluetooth
Interface	USB to PC (Windows or MacOS)	Bluetooth Low Energy to Windows- PC, tablet or smartphone (Android or iOS); range up to 30 m line-of- sight
Operational conditions	Normal outdoor conditions, recording -20 to 70 ° C, 0 to 100% relative air humidity	
Size and Weight	17x13x8 cm, 725 g (complete in met- tal protection with mounting plate)	17x13x8 cm, 600 g (complete in plas- tic protection with mounting plate)

## Maxi-Measurement Systems, Customized System Integration



Maxi-Measurement System



Maxi-Measurement System

### Description

You know what to measure, we know how:

Each project is different. This is especially true in the scientific field.

A simple and cost-effective standard solution may be ideally suited to one case, whereas another case may require a more complex and individually designed measurement infrastructure.

In this context, our customers benefit from our years of experience, individually designing and implementing complete measuring systems. We are happy to assist you in any stage of your project, e.g. with a rough sketch required for initial planning or the project application, the concrete implementation at the start of a project, or when expanding a pre-existing measuring system.

With you and your project in mind, we determine which system optimally and most cost-effective fulfils your requirements. Important planning aspects include, for example:

Type and scope of the sensors (plant, weather, soil or optical sensors, webcams, etc.)

Energy supply source: power supply via grid connection or off-grid solar power system

Spatial distribution of sensors and logger systems: centralized or decentralized

Data transmission from logger to computer: manual data download or automatic data transmission via Ethernet, WiFi, LoRa, cellular network, satellite, etc.

Optional: notification and alarm function service through e-mail and/or SMS

Optional: data cloud service with user account management

Optional: online data visualization internally for your team, or presented as data dashboard with open access

Optional: maintenance of your running stations.

### Advantages

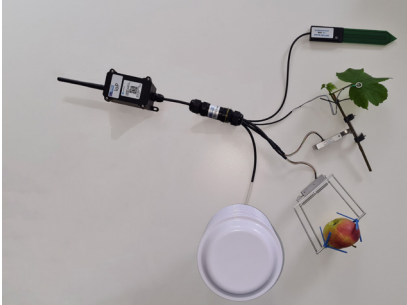
- Our open and modular systems are highly flexible and can be progressively extended in the course of your growing project: almost all sensors or other peripheral devices (such as a webcam) can be integrated.
- Various data transfer options (wired, Ethernet, WiFi, LoRa, cellular network, satellite, etc.) directly to your server.

### Limits

- Practically none



## Ecomatik IoP Measurement Systems



IoP Measurement System

### Description



Intelligent algorithms and machines, smart home, smart city, smart agriculture and the Internet of Things - modern communication technology, data processing and automation permeate all areas of human activity.

Our plant sensor technology, in combination with the latest technology for energy-saving, long-range data transmission creates a new type of interface, connecting you to the **Internet of Plants (IoP)**, opening the door to an entire world of new possibilities and applications.

With the Ecomatik IoP products, information on a wide variety of plant vitality parameters and plant growth conditions can be continuously recorded and fed into further, subsequent information processing. The basis for a clear online data visualization for more efficient monitoring of vitality and growth behavior, simply from your desk or on the go on your mobile device, as well as further automation and optimization of your work-flow and production processes.

Small, energy-saving and with a large number of connection options, the IoP LoRa node together with our Multi-Interface is a real all-rounder:

If both devices are combined to form a Multi-IoP node, almost all Ecomatik sensors, but also many sensors from other manufacturers, can be integrated and result in a lean and cost-efficient solution for recording and transmitting the most relevant plant data and environmental parameters. Our IoP nodes can be connected to your existing LoRa WAN network or via The Things Network. If you do not yet have an existing LoRa network, we will be happy to find a gateway solution for your application.

One of the many different sensor equipment options of a Multi-IoP node would be for example:

- 1x soil moisture and soil temperature sensor
- 1x trunk dendrometer
- 1x fruit dendrometer
- 1x LAT-B3 leaf temperature sensor
- 1x Air humidity, air temperature and air pressure sensor

You are very welcome to receive more individual configuration options on request.

It's Ecomatik.  
We make your plants talk!

## Ecomatik IoP Measurement Systems

### Advantages

- Small, robust, weatherproof
- High transmission ranges of more than 10 km possible (i.a. depending on the environment and the gateway used).
- Compatible with a wide range of sensors with analog or digital outputs (SDI-12, I2C)
- User-friendly: Sensor combination of the respective Multi-IoP node is customizable. Nodes are delivered fully pre-configured for the connected sensors.
- Customizable programming of the measuring functions possible: e.g. calculation of different parameters from raw values of connected sensors, averaging of several connected individual sensors, etc.
- Precise and high-resolution analogue measurements
- Low power consumption, battery-operated with internal, replaceable 8500 mAh battery, very long battery life (depending on the connected sensors and transmission interval)

### Scope of delivery

- Complete LoRa telemetry node with attached Multi-Interface
- Multi-Interface with all sensors pre-connected, as ordered

### Options

- Analog sensors: e.g. all dendrometers models, LAT-B3 leaf temperature, light sensors, etc.
- Digital sensors (SDI-12, I2C): e.g. SMT100 soil sensor, air temperature, humidity & pressure sensors, light sensors, etc.

### Limits

- 4 analog input channels only
- Without an external battery, not suitable for energy-intensive sensors (systems with external energy supply on request)

### Required accessories

- LoRa Gateway with connection to the internet (via ethernet, W-lan or cellular network)

Device name	Multi-IoP (IoP LoRa Node + Multi-Interface)
Application	Battery-powered sensor measurements with remote data transmission under outdoor conditions
Compatible Sensors	<p><b>Sensors with analog output signal, e.g.:</b></p> <ul style="list-style-type: none"> <li>- Dendrometer (all models)</li> <li>- Temperature probes (T series)</li> <li>- Leaf temperature sensor (LAT-B3)</li> </ul> <p><b>Sensors with digital output signal (SDI-12 &amp; I2C), e.g.:</b></p> <ul style="list-style-type: none"> <li>- SMT100 soil moisture and temperature sensor</li> <li>- T/RH air sensor</li> <li>- light (PAR, pyranometer)</li> </ul>
Special Features	small, robust in a weatherproof housing, inexpensive, easy to use, long battery life
Number of Input Channels	4 analog input channels, 1x SDI-12, 1x I2C
Measurement & Transmission Interval	Adjustable, depending on the connected sensor types. Suitable for most applications are intervals of 10 to 30 minutes
Transmission characteristics	<ul style="list-style-type: none"> <li>• LoRaWAN v1.0.3 Class A</li> <li>• <b>Available frequency bands (please specify when ordering):</b></li> <li>• CN470/EU433/KR920/US915/EU868/AS923/AU915/IN865</li> </ul>
Analog Measurement Resolution (noise-free, for ratiometric measurements)	16.6 bits Dendrometer, depending on the model: 0.15 to 0.6 $\mu\text{m}$ T-Series, LAT-B3: 0.0002 $^{\circ}\text{C}$ (at measuring temperature 25 $^{\circ}\text{C}$ )
Accuracy	$\pm 0.1\text{mV} \pm 0.1\%$ of reading
Provided Sensor Supply-voltage for analog and digital Sensors	3.3 V or 5 V (switched, regulated)
Power & Battery Life	8500mAh Li-SOCI2 battery Battery life: typically > 1 year, depending on the measurement and transmission interval, connected sensors and radio signal strength at the gateway
Configuration interface	Programmable via AT commands in a serial terminal using a TTL serial adapter to connect node to PC with Windows or macOS operating system and via downlink. (If required nodes will be supplied pre-programmed)
Operating conditions & Protection class	normal outdoor conditions, IP67, temperature -20 to 70 $^{\circ}\text{C}$ , 0 to 100% relative humidity
Size & Weight	6x10x5 cm (only node housing), 320 g (only LoRa IoP nodes with multi-interface, without connected sensors)

## Online data management & Data Visualization - Advantages

### Availability –

Your data is where you are

### Efficiency –

more time and money for your actual work

### Automation –

your computer should do what it does best , quickly and without careless mistake

### Visibility –

A data graphic is worth a thousand values

### Shareability –

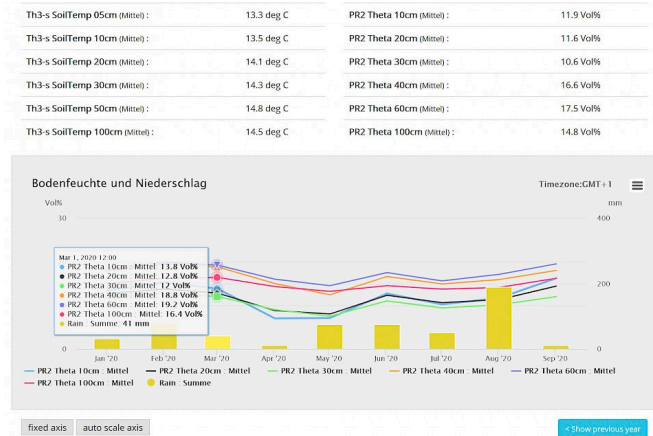
Everyone gets what he or she needs: user - account - controlled and task-specific

### Security –

Better safe than sorry. With us you don't have to worry about data loss anymore.

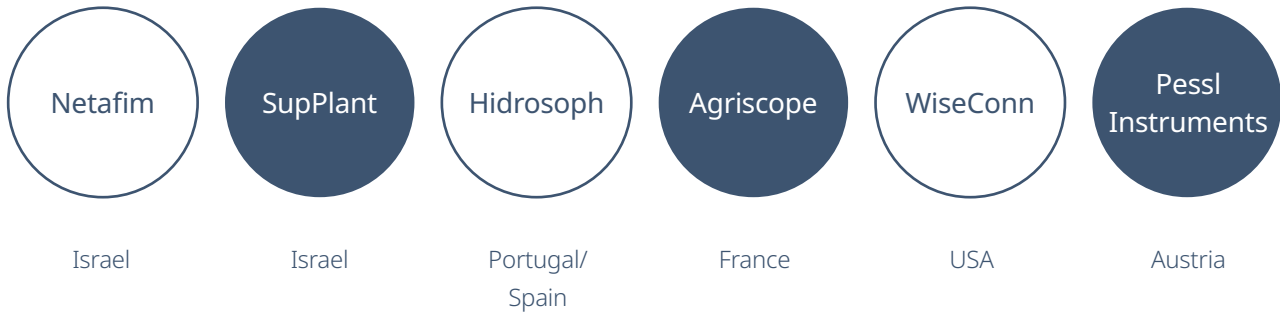
### Customizability –

Special requirements, special solutions.

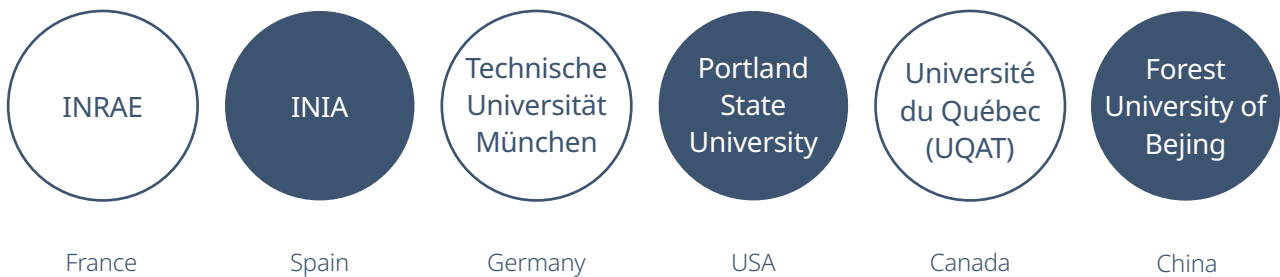


## Some of our customers

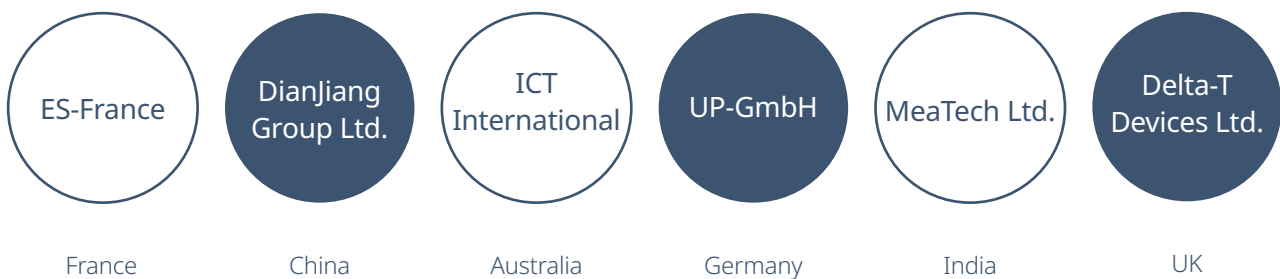
### AgTech



### Research



### Trader of measurement instruments



## Selected publications

### Dendrometers

last update: 2018

- Atay, E., Hucbourg, B., Drevet, A., & Lauri, P. E. (2016). Growth responses to water stress and vapour pressure deficit in nectarine. In D. Milatovic, D and Milivojevic, J and Nikolic (Ed.), III BALKAN SYMPOSIUM ON FRUIT GROWING (Vol. 1139, pp. 353–357). PO BOX 500, 3001 LEUVEN 1, BELGIUM: INT SOC HORTICULTURAL SCIENCE.
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- Hiltner, U., Bräuning, A., Gebrekirstos, A., Huth, A., & Fischer, R. (2016). Impacts of precipitation variability on the dynamics of a dry tropical montane forest. *Ecological Modelling*, 320, 92–101.
- He, M., Yang, B., Wang, Z., Braeuning, A., Pourtahmasi, K., & Oladi, R. (2016). Climatic forcing of xylem formation in Qilian juniper on the northeastern Tibetan Plateau. *TREES-STRUCTURE AND FUNCTION*, 30(3), 923–933.
- Hu, L., & Fan, Z. (2016). Stem radial growth in response to microclimate in an Asian tropical dry karst forest. *Acta Ecologica Sinica*, 36(5), 401–409.
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- Lindén, J., Fonti, P., & Esper, J. (2016). Temporal variations in microclimate cooling induced by urban trees in Mainz, Germany. *Urban Forestry & Urban Greening*, 20, 198–209.
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- Spannl, S., Volland, F., Pucha, D., Peters, T., Cueva, E., & Braeuning, A. (2016). Climate variability, tree increment patterns and ENSO-related carbon sequestration reduction of the tropical dry forest species *Loxopterygium huasango* of Southern Ecuador. *TREES-STRUCTURE AND FUNCTION*, 30(4), 1245–1258.
- Wang, W., Zhang, F., Yuan, L., Wang, Q., Zheng, K., & Zhao, C. (2016). Environmental Factors Effect on Stem Radial Variations of *Picea crassifolia* in Qilian Mountains, Northwestern China. *FORESTS*, 7(10).
- Zhang, R., Yuan, Y., Gou, X., Zhang, T., Zou, C., Ji, C., ... Li, X. (2016). Intra-annual radial growth of Schrenk spruce (*Picea schrenkiana* Fisch et Mey) and its response to climate on the northern slopes of the Tianshan Mountains. *DENDROCHRONOLOGIA*, 40, 36–42.
- Jiang, Y., Wang, B.-Q., Dong, M.-Y., Huang, Y.-M., Wang, M.-C., & Wang, B. (2015). Response of daily stem radial growth of *Platycladus orientalis* to environmental factors in a semi-arid area of North China. *Trees*, 29(1), 87–96.
- Oberhuber, W., Kofler, W., Schuster, R., & Wieser, G. (2015). Environmental effects on stem water deficit in co-occurring conifers exposed to soil dryness. *INTERNATIONAL JOURNAL OF BIOMETEOROLOGY*, 59(4), 417–426.
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### Sap flow sensors

last update: 2018

Gu, D., Zhen, F., Hannaway, D. B., Zhu, Y., Liu, L., Cao, W., & Tang, L. (2017). Quantitative Classification of Rice (*Oryza sativa* L.) Root Length and Diameter Using Image Analysis. *PLOS ONE*, 12(1), e0169968.

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Schmidt, M. W. T., Schreiber, D., Correia, A., Ribeiro, N., Surový, P., Otieno, D., ... Pereira, J. S. (2009). SAP FLOW IN CORK OAK TREES AT TWO CONTRASTING SITES IN PORTUGAL. *Acta Horticulturae*, (846), 345–352.

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Otieno, D. O., Kurz-Besson, C., Liu, J., Schmidt, M. W. T., Do, R. V.-L., David, T. S., ... Tenhunen, J. D. (2006). Seasonal variations in soil and plant water status in a *Quercus suber* L. Stand: roots as determinants of tree productivity and survival in the mediterranean-type ecosystem. *PLANT AND SOIL*, 283(1–2), 119–135.

## Selected publications and more customers

### Sap flow sensors

Wieser, G., Gigele, T., & Pausch, H. (2005). The carbon budget of an adult *Pinus cembra* tree at the alpine timberline in the Central Austrian Alps. *European Journal of Forest Research*, 124(1), 1–8.

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### more customers

last update: 2018

#### Argentina

CONICET-INTA EEA Bariloche, Grupo de Ecología Foresta, Bariloche  
IANIGLA-CONICET, Mendoza

#### Australia

PlantSensors, Nakara

#### Austria

Universität Innsbruck, Institut für Botanik, Innsbruck  
BFW, Abt Ökophysiologie der Alpenen Waldgrenze, Innsbruck  
Universität Wien, Department of Geography and Regional Research UZA II, Wien  
Pessl Instruments GmbH, Weiz

#### Belgium

Vrije Universiteit Brussel, WE-DBIO-APNA, Brussels  
Vrije Universiteit Brussel, Toegepaste Ecologie & Milieubiologie, Gent  
Vrije Universiteit Brussel, ETRO Department Building Ke, room Ke.3.22, Brussels  
Laboratory for Wood Biology and Xylarium, Royal Museum for Central Africa, Tervuren

#### Brasil

Fundacao de Desenvolvimento Cientifico E Curtural-Fundecc, Campus da Univesidade Federal de Lavras  
Tecnal Ltda.

#### Canada

Direction de la recherche forestière, Ministère des Ressources naturelles et de la Faune, Québec  
McGill University, Department of Natural Resource Sciences, Québec  
University of Western Ontario, Department of Geography, London  
Macdonald Campus of McGill University, Department of Natural Resource Sciences, Québec

#### Chile

MorpH2O SA Latinoamerica S.A, Buin

#### China

LICA United Technology Limited Beijing  
Beijing Channel Scientific Instruments Co., Ltd. Beijing  
Chinese Academy of Forestry, Research Institute of Forest Ecology, Environment and Protection, Beijing  
Xishuangbanna Tropical Botanical Garden (CAS), Yunnan

#### Denmark

University of Aarhus, Faculty of Agricultural Sciences, Dept. of Agroecology and Environment, Tjele

#### Ecuador

Sistemas Tecnológicos, Quito

#### France

Agriscopie Lunel  
O3HP St Michel l'Observatoire  
INRA-EPHYSE, Site de Recherches Forêt Bois de Pierroton, CESTAS Cedex

#### Germany

Universität Bochum, Geographisches Institut, Bochum  
Universität Cottbus, Institut für Rekultivierung  
Universität der Bundeswehr München, Institut für Tiefbau, Neubiberg  
Universität Freiburg, Institut für Forstbotanik und Baumphysiologie, Freiburg  
Universität Freiburg, Institut für Bodenkunde und Waldernährungslehre, Freiburg  
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