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ARTICLE INFORMATION

Article title

Dataset of dendrometer and environmental parameter measurements of two different species of the group of genera known as eucalypts in South Africa and Portugal.

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Keywords

Temperature; Humidity; Soil moisture; Soil temperature; Dendrometer; Forestry management; Tree growth; Wood formation

Abstract

Eucalyptus plantations are a crucial global resource, offering raw materials for industries across five continents, including renewable energy sources, recyclable fibers, and eco-friendly wood products. To support sustainable management, ten wireless dendrometer and environmental sensor systems were deployed on *Eucalyptus* trees—six in Stellenbosch, South Africa, and four in Leiria, Portugal. These systems measure tree stem growth, air and soil conditions, and transmit data via LoRaWAN to a cloud-based platform (ThingSpeak), with local SD-card backups. Nine systems collect data at 6-minute intervals, while one collects at 11-minute intervals. This data is valuable for maintaining forest health and ensuring resource sustainability. EucXylo, a Research Chair funded by the Hans Merensky Legacy Foundation, focuses on the ecophysiology, growth, and wood formation in

eucalypts. The dataset aids in developing models of tree growth and xylem production, offering high-resolution insights into *Eucalyptus* growth and environmental conditions.

SPECIFICATIONS TABLE

Subject	Concurrent measurements of radial growth and environmental conditions of eucalypts in South Africa and Portugal.
Specific subject area	Forestry and Wood Science, Environmental Science, Electronic Engineering
Data format	Raw .xlsx file including sheets for codebook, metadata, and data in CSV format.
Type of data	Tables containing measurement data (with accompanying metadata and flags) for tree stem growth, air temperature, humidity, soil temperature, and moisture levels.
Data collection	Data collected from ten wireless dendrometer and environmental sensor systems installed on eucalypts—six systems at Stellenbosch University and four in Leiria, Portugal. Measurements include tree stem growth at breast height (1.37m above ground), air temperature and humidity as close as possible to the canopy, soil temperature and moisture 5cm below the soil surface. Data is sent via LoRaWAN to a gateway and stored in the cloud on ThingSpeak, with local SD-card backups available.
Data source location	*Eucalyptus* plantations at Stellenbosch University, South Africa (33.9321° S, 18.8612° E) and in Leiria, Portugal (39.7594° N, 8.5563° W).
Data accessibility	Mendeley Repository Repository name: Cross Regional *Eucalyptus* Growth and Environmental Data Data identification number: 10.17632/2m9rcy3dr9.2 Direct URL to data: https://data.mendeley.com/datasets/2m9rcy3dr9/3 Data collection was ongoing at the time of publication. The Mendeley repository may be updated, and readers should download the latest version. This paper references Version 2 of the repository.

VALUE OF THE DATA

- The dataset provides comprehensive measurements of tree stem growth, offering valuable insights into the growth rates, patterns, and overall health of *Eucalyptus* plantations. This detailed data allows researchers to track how trees develop over time and how they respond to different environmental conditions.
- The dataset is instrumental in developing and refining models that simulate tree growth and xylem production. These models are crucial for predicting wood formation and quality, which can lead to advancements in the production and utilization of *Eucalyptus* wood products.
- By collecting data from both South Africa and Portugal, the dataset allows for comparative studies of *Eucalyptus* growth across different geographical regions and climates. This comparison can reveal how regional environmental conditions influence tree growth and health, contributing to more informed global forestry practices. The trees in the different regions are also at different ages and sizes.
- The dataset's high-resolution measurements provide detailed and accurate insights into the environmental conditions affecting *Eucalyptus* trees. This precision enhances the ability to analyse and understand complex interactions between tree growth and environmental factors.
- The dataset serves as a valuable resource for future research in forestry, environmental science, and agricultural studies. It offers a solid foundation for further investigations and practical applications in these fields.
- The use of LoRaWAN technology for near real-time data transmission is a novel feature of this system, providing immediate insights into environmental conditions and tree growth. This capability allows for timely data collection and analysis, which is crucial for dynamic and responsive research and management practices. It also eliminates the needs for cables which are frequently a limiting factor in equipment deployments in large forest experiments

BACKGROUND

Eucalyptus is the most widespread hardwood in the world and plantations have emerged as a critical global resource, spanning nearly 20 million ha globally [1]. Eucalypts supply essential raw materials for various industries, including renewable energy, pulp and paper production, and the manufacturing of durable, eco-friendly wood products [2]. Eucalypts are of great economic significance, and their energy potential offers opportunity of socio-economic growth [3, 4]. As the demand for these resources grows, it becomes increasingly important to monitor and manage *Eucalyptus* forests sustainably [5]. Effective monitoring can provide valuable insights into tree growth patterns, environmental impacts, and overall forest health, which are crucial for optimising resource use and maintaining ecosystem services.

A dendrometer is a device used to measure variations in tree stem diameter over time, including both short-term diurnal fluctuations and long-term growth trends [6]. To understand what a dendrometer measures, it is necessary to grasp the principle of tree water dynamics. During the day, stomata in the leaves open, allowing for transpiration, the process by which water is lost from the tree to the atmosphere. Due to the development of negative pressures in the conductive xylem (wood), as the rate of water loss often exceeds the rate of water uptake from the roots, this loss of water causes a temporary reduction in stem diameter. At night, when the stomata close, the tree can equilibrate with the soil, leading to a re-expansion of the stem diameter.

In this study, a generic point dendrometer was developed to measure these diurnal variations. Figure 1 shows a week's worth of data for one of the nodes used in this study, named GWD7. On the y-axis, the diurnal stem variation is depicted. Local minima indicate stem shrinkage, while local maxima reflect the tree regaining lost water (also known as recovery) [7]. The graph also displays a general growth trend, where the increase in the peak-to-peak values of local maxima signifies incremental stem growth.

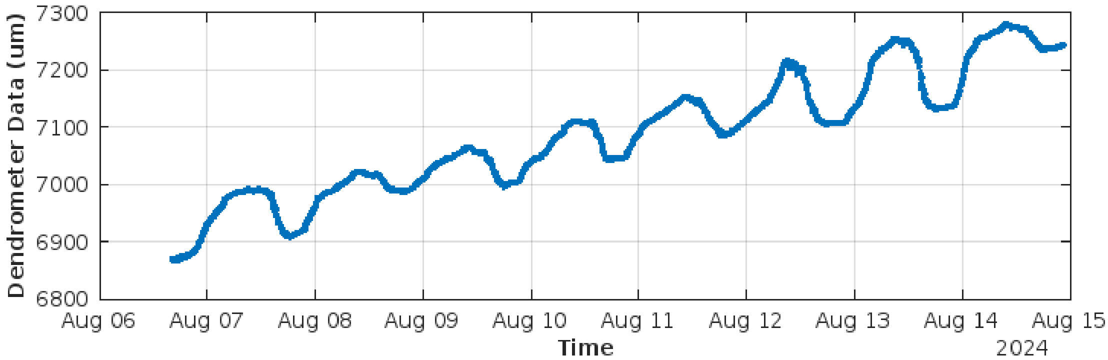

Figure 1: High-resolution dendrometer data captured over one week. Local minima represent stem shrinkage due to transpiration, while local maxima indicate rehydration. The increase in peak-to-peak values reflects overall stem growth.

DATA DESCRIPTION

The dataset is contained in a .xlsx file named "eucalyptus_growth_environment_data_V2.xlsx", which comprises fifteen sheets. The "Codebook" sheet details the index, values, and descriptions of each field within the dataset. Table 1 shows an adaption of the codebook sheet. The sheet named “ALL NODES” include the actual measurements of all devices totalling 102,916 data points, and subset sheets "GWD1" to “GWD10” include the measurements of each respective node. The naming convention includes the abbreviation of “Generic Wireless Dendrometer”, and the device ID, 1-10, accounting for 10 trees (or 10 nodes).

Table 1: Adaption of codebook and description of parameters in the dataset, as of 2 August 2024, Version 2.

Index	**Value Type**	**Unit**	**Description**
Date	[yyyy/mm/dd]	[yyyy/mm/dd]	The date when the measurement was taken.
Time	(UTC+02:00) [HH:MM:SS]	(UTC+02:00) [HH:MM:SS]	The specific time of the measurement.
Device ID	String	-	Unique identifier for each measurement device.
Dendro	Numeric	µm	Measurement of the tree stem variation in micrometres, at breast height (DBH), 1.37 m above ground.
Air Temp	Numeric	°C	Air temperature near the canopy in degrees Celsius. Measured at the start of the canopy.
Air Hum	Numeric	%	Relative humidity near the canopy, expressed as a percentage. Measured at the start of the canopy.
Soil Temp	Numeric	°C	Soil temperature at the measurement location in degrees Celsius. Measured 5cm below soil surface.
Soil Moisture	Numeric	% VWC	Soil moisture level at the measurement location, expressed as percentage volumetric water content (VWC). Measured 5cm below soil surface.
Battery Level	Numeric	%	Battery percentage of the device at the time of measurement.

The sheet named “metadata” contains all relevant metadata regarding information about each node, such as species, initial diameter, location, measurement frequency, battery specifications, and irrigation status. This metadata helps in identifying and distinguishing the nodes and their specific attributes. An adapted extract from this sheet is provided in Table 2.

Table 2: Adaption of metadata, which corresponds to dataset Version 2.

Node	**Species**	**Initial Diameter**	**Location**	**Measurement Frequency**	**Battery**	**Irrigation**
GWD1	E. grandis x urophylla	<10cm	Stellenbosch, South Africa	6 minutes	5000mAh 3.7V Li-Po	Unirrigated
GWD2	E. grandis x urophylla	<10cm	Stellenbosch, South Africa	11 minutes	5000mAh 3.7V Li-Po	Unirrigated
GWD3	E. grandis x urophylla	<10cm	Stellenbosch, South Africa	6 minutes	5000mAh 3.7V Li-Po	Unirrigated
GWD4	E. grandis x urophylla	<10cm	Stellenbosch, South Africa	6 minutes	5000mAh 3.7V Li-Po	Irrigated
GWD5	E. grandis x urophylla	<10cm	Stellenbosch, South Africa	6 minutes	5000mAh 3.7V Li-Po	Irrigated
GWD6	E. grandis x urophylla	<10cm	Stellenbosch, South Africa	6 minutes	5000mAh 3.7V Li-Po	Irrigated
GWD7	E. globulus	>20cm	Leiria, Portugal	6 minutes	5000mAh 3.7V Li-Po	Unirrigated

GWD8	E. globulus	>20cm	Leiria, Portugal	6 minutes	5000mAh 3.7V Li-Po	Unirrigated
GWD9	E. globulus	>20cm	Leiria, Portugal	6 minutes	5000mAh 3.7V Li-Po	Unirrigated
GWD10	E. globulus	>20cm	Leiria, Portugal	6 minutes	5000mAh 3.7V Li-Po	Unirrigated

All nodes operate using LoRaWAN. Occasionally, the dataset experiences intermittent data streams due to connectivity issues between the gateway and the nodes. Some data gaps are a result of maintenance activities or experimental procedures. The sheets titled “Missing Data Intervals”, and “Missing Intervals Distribution” enclosed in this dataset provide detailed information on these gaps, including the start and end dates and times when data was not uploaded to ThingSpeak. They also indicate the total duration of each missing interval, the number of missing datapoints, and the reasons behind the missing datapoints.

EXPERIMENTAL DESIGN, MATERIALS AND METHODS

Data collection for this study took place at Stellenbosch University, South Africa (33.9321° S, 18.8612° E) and in Leiria, Portugal (39.7594° N, 8.5563° W). The trees measured in Stellenbosch (GWD1-GWD6) are ramets of a hybrid clone of *E. grandis* x *E. urophylla* and the trees in Leiria (GWD7-GWD10) belong to the species *E. globulus.* Figure 2 show satellite images of the nodes in their respective locations, and their relative position to the closest LoRaWAN gateway. To demonstrate what effect irrigation might have on the growth patterns of the trees in Stellenbosch (Fig. 2a), GWD4-GWD6 was irrigated, while GWD1-GWD3 remained unirrigated. It is notable, however, that over the period (winter in South Africa) of monitoring, rainfall was high, and even not unirrigated trees were never water-limited. GWD7-GWD10, the nodes in Leiria, Portugal, remained unirrigated throughout the data collection timeline.

a) Stellenbosch University [6] *b) Leiria, Portugal [7]*

Figure 2: Aerial view of the trees in their respective locations.

Table 3 specifies the sensing modules integrated into the environmental sensing system and dendrometer. Ten systems were designed, manufactured, and deployed, each programmed with a unique node identifier (GWD1-GWD10).

Table 3: Sensing module specifications.

Parameter	Sensor Module	Resolution	Accuracy	Unit
Dendro	Generic Digital Dendrometer	0.0763 µm	± 4.5%	µm (microns)
Air Temp	DHT22	0.1°C	±0.5 °C	°C
Air Hum	DHT22	0.1%	±1%	%
Soil Temp	18B20	0.0625°C	±0.5 °C	°C
Soil Moisture	Capacitive Soil Moisture sensor V1.2	0.25%	± 6%	% VWC (Volumetric Water Content)
Battery Level	Lolin ESP32-S2 Mini Analog to Digital Converter (ADC)	13-Bit	±1%	%

According to the LoRa Alliance Fair Use Policy, any end device (or node) may not exceed 30 seconds of airtime per 24 hours [8]. Systems GWD1 and GWD3-GWD7 transmit a payload of 18 bytes every 6 minutes at a Spreading Factor of 7 (SF7) and a bandwidth of 125 kHz. This results in a Time on Air (ToA) of 71.9 ms per payload and 17.26 seconds per node per day, which is well within the bounds of the LoRa Fair Use Policy

WD2 transmits a payload of 128 bytes, which is significantly larger than that of the other nodes. Despite the increased size, transmitting 128 bytes every 11 minutes using SF7 and a 125 kHz bandwidth complies with the LoRa Fair Use Policy, resulting in a Time on Air (ToA) of 27.68 seconds per day. The larger payload size is due to the use of a Sentek Series III Drill and Drop Probe for creating a calibration baseline for the Capacitive Soil Moisture Sensors V1.2. The Sentek Series III measures six temperature values, six soil moisture values evenly spaced along the length of the probe (into the soil depth), and a single supply voltage value.

Hardware Setup

Figure 3 illustrates the various sensor placements with respect to the tree. Each dendrometer is placed at the diameter at breast height (DBH) location, the standard for measuring trees, approximately 1.3 m above the ground [9]. The dendrometer measures radial growth of the tree stem. Air temperature and relative humidity is measured at the closest point to the bottom of the canopy, which differs from tree to tree. Soil moisture and soil temperature sensors are placed approximately 5cm below the surface of the ground.

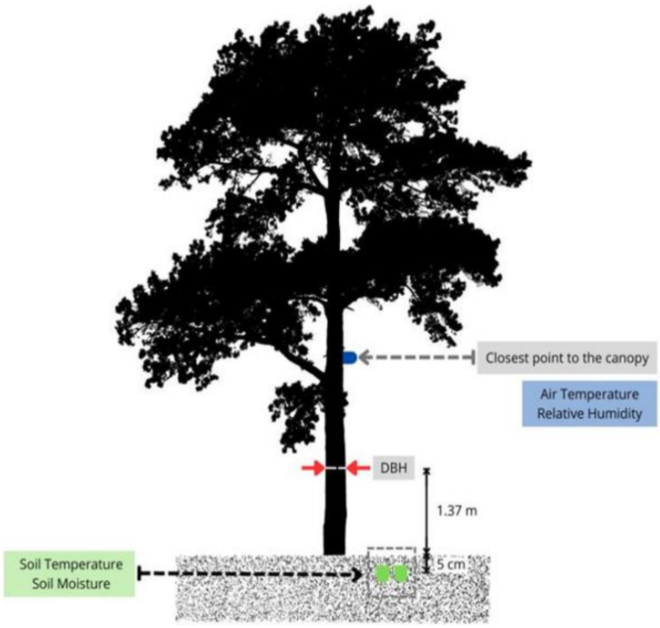

Figure 3: Illustration of measurement locations with respect to the tree.

The system is controlled by a Lolin ESP32-S2 Mini Microcontroller, with an RFM95W transceiver module enabling LoRa communication (Figure 4a). Sensor modules are connected to the system through screw terminals. The entire setup is powered by a 3.7V 5000 mAh Li-Po battery, supplemented by a Seeed Studio 0.5W solar panel (Figure 4b). A detailed power analysis estimates that each node can operate for approximately 48 days on a single battery charge without sunlight. In the presence of sunlight, the system can run indefinitely, assuming no technical faults occur. Figure 4b shows the node GWD9 strapped to a tree, housed in an off-the-shelf IP56 enclosure with the solar panel and antenna mounted externally. Figures 5a through 5c illustrate the various sensor modules and placements, as previously mentioned in reference to Figure 3.

a) The electronics of the generic datalogger, and sensor module connection points

b) GWD9 strapped to a eucalypt in Leiria, Portugal. Equipped with a solar panel and a 3dBi antenna.

Figure 4: Typical installation of the generic datalogger on the tree and the electronics designed to integrate the various sensor modules.

a) The 18B20 Temperature sensor and Capacitive Soil Moisture Sensor V1.2 Placed 5cm deep into the soil.

b) The DHT22 enclosed by a 3D-printed Stevenson screen, strapped as close as possible to the start of the canopy.

c) The Generic Digital Dendrometer, attached to the eucalypt.

Figure 5: Typical installation of sensing modules.

Capacitive Soil Moisture Sensor Calibration

The Capacitive Soil Moisture Sensor V1.2 (SKU: SEN0193, DFROBOT, Shanghai, China) is a generic analogue device. A datasheet is available only for its predecessor, version 1.0 [10]. Due to its low cost and generic nature, specific details about its resolution and accuracy are not provided. However, studies [9,10] have demonstrated a strong correlation between the gravimetric water content level (GWC level) and the output voltage of this module. Nevertheless, the sensor's accuracy is highly dependent on the specific soil composition, making calibration necessary for each particular use case.

Furthermore, in this study, the Capacitive Soil Moisture Sensor V1.2 units, connected to GWD1-GWD6, were calibrated using a Sentek Series III Drill and Drop probe [13]. The Sentek Series III Probe is a capacitance-based soil moisture monitoring device that provides accurate, multi-depth measurements of soil moisture and temperature. With a moisture resolution of 1:10,000 and a precision of ±0.03% vol, it serves as a reliable baseline for sensor calibration. Figure 6 shows the calibrated measurement of the Capacitive Soil Moisture Sensor V1.2 compared to the Sentek Series III Drill and Drop probe.

In this study, a linear function was used to fit the output of the Capacitive Soil Moisture Sensor V1.2 to the Sentek Series III Probe, expressed as:

$$VWC_{cal}\% = (1.59 \times \frac{1}{V} - 0.59) \times 100\%$$

Where $VWC_{cal}\%$ is the calibrated measurement of the volumetric water content percentage, and V (in volts) is the voltage output of the sensor. The linear calibration function results in a RMSE of 1.87, an R^2 equal to 0.81, indicating a reasonably good fit between the sensor output and the reference measurements.

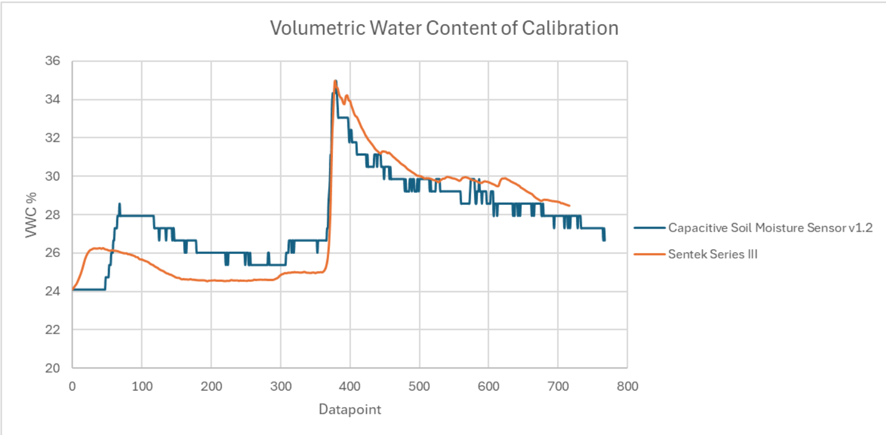

Figure 6: Volumetric Water Content % (VWC %) of the Sentek Series III and the Capacitive Soil Moisture Sensors v1.2 after calibration.

The soil moisture sensor modules of nodes GWD7-GWD10 remain uncalibrated at present. Future work may involve calibrating these sensors to account for varying soil compositions using the gravimetric method, potentially enhancing accuracy across different soil types.

Dataset Composition

Data collection began in June 2024, capturing a wide range of environmental and dendrometer measurements across distinct species and locations (Table 4).

Table 4: Dataset Composition by filter and classification.

Filter	Classification	Data Days	Data Points	Weight [%]
Location / Species	Stellenbosch, South Africa / E. grandis x urophylla	54	67068	45.8%
	Leiria, Portugal / E. globulus	40	35848	24.5%
Irrigation Status	Irrigated	54	43406	29.7%
	Unirrigated	44	102916	70.3%

An increase in data volume occurred after June 21, 2024, due to the deployment and activation of GWD7 through GWD10 at the demonstration site in Leiria, Portugal (Figure 7). Additionally, GWD3 shows no data between June 18 and June 27, 2024. This gap occurred because the microcontroller unit in this device was faulty, leading to the node being taken down for maintenance and replacement of the microcontroller.

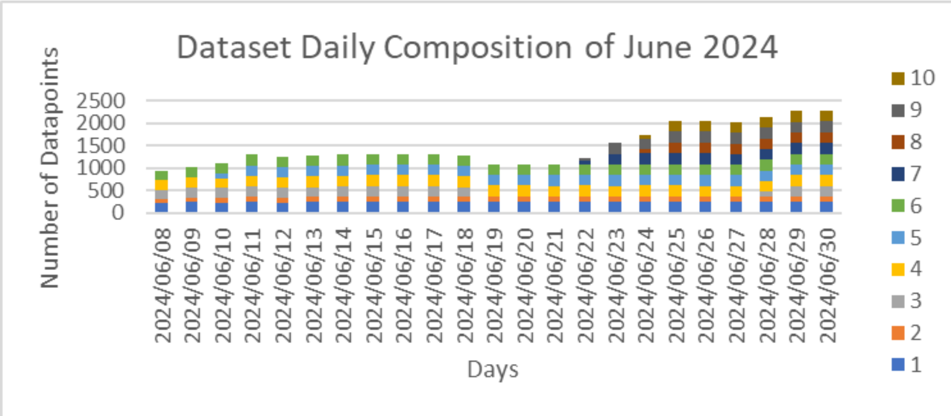

Figure 7: Dataset daily composition for the month of June, 2024.

Similarly, Figure 8, which presents the dataset distribution for July, shows a decrease in data points for GWD7 between July 9 and July 11, 2024. This decrease occurred because the device was taken down for LoRa range experimentation.

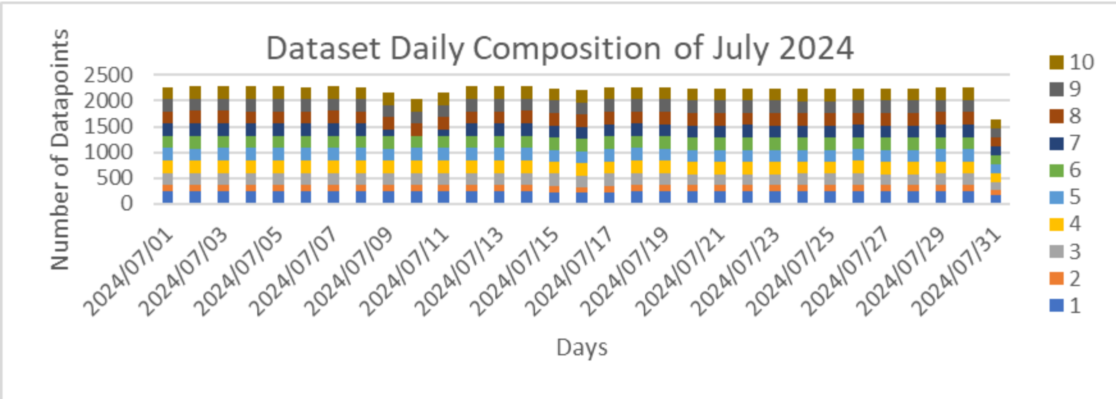

Figure 8: Dataset daily composition for the month of July, 2024.

SOFTWARE CONSIDERATIONS

The provided R code named “Simple_Dendro_Imputation_and_Analysis.R” is a comprehensive analysis workflow that processes and analyses Eucalyptus growth and environmental data from the "eucalyptus_growth_environment_data_V2.xlsx" dataset. The script begins by loading necessary libraries, setting the working directory, and reading the data from the specified Excel sheet. It then combines date and time information into a unified DateTime format and performs data type conversions for relevant columns. The analysis focuses on a specified device, allowing for the selection of neighbouring devices for imputation of missing data. A loop checks for gaps in the time series and fills in missing intervals based on a defined threshold, followed by a function that imputes missing values using the average from nearby devices. Outliers are identified and managed through linear interpolation. The code further calculates vapor pressure metrics and applies temperature corrections to the dendrometer data. Finally, it saves the cleaned and processed data into a new Excel file while conducting dendrometer analysis using the dendRoAnalyst package [14], which includes visualizations and calculations of daily growth metrics and correlations with environmental factors such as vapor pressure deficit (VPD).

LIMITATIONS

At times, transmissions from end devices containing payloads did not reach the ThingSpeak dashboard due to poor weather conditions, errors in the sensing devices, or power loss to the gateway. The building housing the gateway for the setups at Stellenbosch University occasionally underwent electrical maintenance during which electricity was cut, causing transmissions to be received by a more distant gateway, unbeknownst to the authors, which led to some data loss. The total number of missing values across the entire data collection period is 5,312 data points (Figure 9). Considering that the expected number of data points is 108,229, the total number of missing values accounts for 4.9% of the expected dataset. While this may seem significant at first glance, 38% (2,012 data points) of these missing values resulted from GWD3 being offline. All data is backed up locally on SD cards for redundancy; however, the SD cards must be retrieved manually, and additional processing is required to align data points and recover missing values.

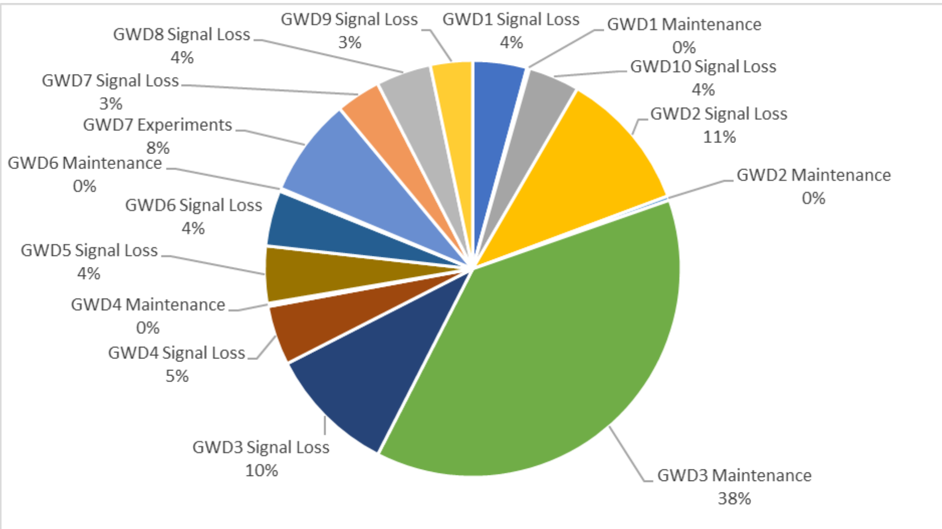

Figure 9: Distribution of missing datapoints, classified by type.

ETHICS STATEMENT

The authors confirm that the ethical requirements for publishing data in Data in Brief have been read and understood and further confirm that the data collected does not involve human subjects, animal experiments, nor data collected from social media platforms.

CRediT AUTHOR STATEMENT

C.S. Erasmus: Sensor development and deployment, data acquisition, data curation, data processing, visualisation, methodology, writing.
D. Drew: Supervision, conceptualisation, funding, methodology, analysis, editing.
M.J. Booysen: Supervision, conceptualisation, funding, methodology, analysis, editing.

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DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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