High-resolution tropical rain-forest canopy climate data

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Abstract

Canopy habitats challenge researchers with their intrinsically difficult access. The current scarcity of climatic data from forest canopies limits our understanding of the conditions and environmental variability of these diverse and dynamic habitats. We present 307 days of climate records collected between 2019 and 2020 in the tropical rainforest canopy of the Yasuni National Park, Ecuador. We monitored climate with a 10-min temporal resolution in the middle crowns of eight canopy trees. The distance between canopy climate stations ranged from 700 m to 10 km. Apart from air temperature, relative humidity, leaf wetness, and photosynthetically active radiation (PAR), measured in each canopy climate station, global radiation, rainfall, and wind speed were measured in different subsets of them. We processed the eight data series to omit erroneous records resulting from sensor failures or lack of the solar-based power supply. In addition to the eight original data series, we present three derived data series, two aggregating canopy climate for valleys or for ridges (from four stations each), and one overall average (from the eight stations). This last derived data series contains 306 days, while the shortest of the original data series covers 22 days and the longest 296 days. In addition to the data, two open-source tools, developed in RStudio, are presented that facilitate data visualization (a dashboard) and data exploration (a filtering app) of the original and aggregated records.

Impact Statement

Climate data from tropical forest canopies are scarce, yet crucial to understanding tropical canopy dynamics. We encourage the use of our high-resolution climate data series as a field-based reference to validate models simulating the microclimate of these canopies. Furthermore, these data series can be used as climate inputs to model small-scale and fast-paced ecological dynamics driven by climate, such as the photosynthesis of canopy-dwelling organisms.

This research article was awarded Open Data and Open Materials badges for transparent practices. See the Data Availability Statement for details.

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1. Introduction

Forest canopy climate is important for the performance of trees (Luo, 2007; O’Grady et al., 2011) as well as for sessile and mobile organisms living in the dynamic canopy habitat (Suggitt et al., 2017). Forest canopies host a wealth of biological diversity (Barker and Pinard, 2001) and canopy climate factors such as temperature, relative humidity, and light intensity drive and constrain the physiological performance, ecology, and fitness of sporadic and permanent inhabitants (Suggitt et al., 2017). In addition to hosting sessile organisms, such as plants and lichens (i.e., epiphytes), canopies host mobile organisms ranging in size from microorganisms and arthropods to all groups of vertebrates (Nakamura et al., 2017). This astonishing diversity is a common descriptor for canopies in mature tropical forests, yet canopy climate records describing the conditions met by these diverse organisms are particularly scarce, despite the expansion of canopy research at tropical latitudes in recent decades (Nakamura et al., 2017). Here, we present >300 days of canopy climate records with high temporal resolution (each 10 min) obtained in the lowland tropical forest surrounding the Yasuní scientific station in Amazonian Ecuador, an iconic biodiversity hotspot (Bass et al., 2010).

The intrinsic difficulty to access forest canopies challenges us while studying canopy climate in forests around the world. Yet, the relevance of canopies for biodiversity maintenance calls for persistence, creativity, and cooperation (Barker and Pinard, 2001). In addition, forest canopies contribute importantly to vegetation-climate feedback (Lin et al., 2010; O’Grady et al., 2011). The exchange of relevant gases between canopies and the atmosphere can be highly dynamic, in dependence of climatic fluctuations above and inside the canopy (Luo, 2007; Lin et al., 2010). However, high-temporal-resolution field measurements of canopy climate remain scarce and scattered, limiting our ability to understand such dynamics (Nakamura et al., 2017). This shortage is especially pronounced in tropical forests. Although a modeling approach can supply estimates for the canopy climate of forests in different parts of the world (Maclean and Klinges, 2021), the robustness and accuracy of those estimates are hard to evaluate in forest types with no or insufficient available field data. Hence, monitoring canopy climate is critical to improving and validating such climate models. In turn, understanding climatic fluctuations in forest canopies is essential to understand and model vegetation-atmosphere interactions, as well as the functional ecology of trees and the incredible diversity of canopy-dwelling organisms found, in particular, in tropical rainforests.

Canopy climate parameters can be estimated from macroclimate with mechanistic models (Maclean, 2020), but akin to other models, calibration and validations demand field measurements (Lembrechts et al., 2020). Recently, a decided leadership and the contribution of a wealth of field measurements resulted in a body of global estimates of high temporal and spatial resolution microclimate for soils and near the soil surface (Lembrechts et al., 2021). This integrative research highlighted the divergence between soil microclimate and macroclimate, summarized consistent patterns across biomes, and incentivized using microclimate to tackle ecological research in the frame imposed by global change. For the canopy, a recent mechanistic model can estimate climate conditions from a climate input and from a series of canopy descriptors (Maclean and Klinges, 2021), however remote and under-described forests configure challenging applications of such models. While extrapolated and modeled macroclimate estimates have supported a generation of studies assessing the effects of climate on organisms and ecosystems (Suggitt et al., 2017), the divergence between macroclimate and climate of specific habitats (Lembrechts and Lenoir, 2020) can obscure the efforts to interpret the impact of climate change on organismal responses (Suggitt et al., 2017; Lembrechts and Lenoir, 2020). Therefore, high-resolution microclimate records constitute a relevant input to unveil ecological nuances of the habitat where they were gathered.

Tropical regions host vast forested areas, like the Amazon, yet detailed canopy climate records for these forests remain scattered (e.g., Löbs et al., 2020). Here, we present a set of climate measurements with high temporal resolution obtained in the canopy of the forest in Yasuní National Park, Ecuador, a global biodiversity hotspot (Bass et al., 2010). Data were collected within the crowns of eight canopy trees, in the Johansson (1974) zone corresponding to the middle canopy. We monitored temperature, relative humidity, photosynthetically active radiation (PAR), and leaf wetness, and we derived the vapor pressure deficit...
(VPD). In selected crowns, we additionally registered precipitation. Solar radiation, and wind speed and direction. Despite several data gaps due to the harsh conditions for electronics in the forest coupled with logistical challenges, we compiled canopy climate series with more than 300 days of data.

We anticipate that these data series will enrich the view and methodological possibilities of ecologists studying the wealth of organisms dwelling in the canopy of this and other tropical lowland forests. Even if the structure of this canopy remains relatively stable despite recent climate warming trends (Nabe-Nielsen and Valencia, 2020), the biology, ecology, and phenology of its inhabitants may lead to new ecological dynamics and emergent properties (Pincebourde et al., 2016). We encourage using these data series to assess organismal responses of specific organism groups to short-term canopy climate. It is likely that a modeling approach can assess how relevant are fine temporal resolution climate patterns for organismal responses (Lembrechts et al., 2019).

The section below corresponds to the Metadata of our climate data series. Given the potential use of these data in ecological studies, the metadata follows the standard descriptors suggested by Michener et al. (1997), excluding non-applicable fields to avoid redundancies while maintaining the suggested numbering system.

2. Metadata

2.1. Class I. Data set descriptors

A. Data set identity:
   High-resolution tropical rain-forest canopy climate data

B. Data set identification codes:
   Suggested Data set Identify Codes.
   “S1R_Canopy_Clima_te_2019–20.csv,” “S1V_Canopy_Clima_te_2019–20.csv,”
   “S2R_Canopy_Clima_te_2019–20.csv,” “S2V_Canopy_Clima_te_2019–20.csv,”
   “S3R_Canopy_Clima_te_2019–20.csv,” “S3V_Canopy_Clima_te_2019–20.csv,”
   “S4R_Canopy_Clima_te_2019–20.csv,” “S4V_Canopy_Clima_te_2019–20.csv,”
   “Ridges_Canopy_Climate.csv,” “Valleys_Canopy_Climate.csv,” and “Yasuni_Canopy_Climate.csv” (DataS1).

C. Data set description
   I. Originators:
      1. Monica B. Berdugo
         University of Marburg, Faculty of Geography, Ecological Plant Geography, Deutschhausstraße 10, D-35032, Marburg, Germany
      2. Maaike Bader
         University of Marburg, Faculty of Geography, Ecological Plant Geography, Deutschhausstraße 10, D-35032, Marburg, Germany
      3. Jörg Bendix
         University of Marburg, Faculty of Geography, Laboratory for Climatology and Remote Sensing, Deutschhausstrasse 12, D-35032 Marburg, Germany.

2.2. Class II. Research origin descriptors

A. Overall project description:
   1. Identity:
      A global approach to analyze the extent of the newly detected Tropical Lowland Cloud Forest (TLCF) based on a large-scale analysis of fog frequency and epiphyte growth, with a special focus on South America
   2. Originators:
      The TLCF project was coordinated by Maaike Bader, lead of the Ecological Plant Geography laboratory, and Jörg Bendix, lead of the Laboratory for Climatology and Remote Sensing; both associated with the Faculty of Geography at the University of Marburg.
3. Period of study:
The project started in 2018 and will end in 2022.

4. Objectives:
Mapping and validating the occurrence of fog and modeled abundance patterns of epiphytes in tropical lowland forest areas using remote sensing, field observations, and modeling.

5. Source of funding:
This research was funded by the German Research Foundation – DFG, grants BA 3843/7-1, BE 1780/48-1, and LE 3990/1-1. Deutsche Forschungsgemeinschaft e.V. Kennedyallee 40, 53175 Bonn, Germany.

B. Specific subproject description

1. Site description
a. Site type: Well-preserved tropical rainforest.
b. Geography: Sites were located near the Yasuní Scientific Station (YSS) in Amazonian Ecuador (Figure 1). The YSS is located in the Orellana province (0°40′27″S 76°23′50″W, ~230 m a.s.l., ~90 ha) to the South of the Tiputini river.
c. Habitat: Medium crown of eight canopy trees (Table 1).
d. Geology, landform: Modestly undulating terrain, where local valleys and ridges differ by less than 100 m of elevation, with poor and clayey soils originated from weathering of dominant materials of the intersection between two geological shields, Andes and Brazilian (stratified clays and sediments of the Curaray formation from the tertiary; Tschopp, 1953).

Figure 1. Study area and stratified study design used to monitor climate with a 10-min temporal resolution in the tropical rainforest canopy of the Yasuní National Park, Ecuador. Large circles represent study sites located at different distances from the Tiputini river (black indicates the largest distance and the lightest grey indicates the shorter distance). Two canopy climate stations were established in each site, one in a valley (blue dot) and the other in a ridge (orange dot) as highlighted by colour-keyed altitudinal belts.
Table 1. Identity and dimensions of the trees supporting the canopy climate stations instrumented a given sensor set to monitor the canopy climate of the tropical rain-forest of the Yasuní National Park, Ecuador.

| Species                  | Family        | DBH (cm) | Tree height (m) | First branch height (m) | Crown (m)  | Canopy cover (%) | Sensor set            | D | T | Station |
|--------------------------|---------------|----------|-----------------|-------------------------|------------|------------------|----------------------|---|---|---------|
| Eschweilera coriacea     | Lecythidaceae | 76.4     | 28.5            | 14.0                    | 6.6        | 14.5             | 79.2, 6.6, 68.1–88.7 | T, RH, PAR, LW, RAD, Wind |    |   | S1V     |
| Trichilia septentrionalis| Meliaceae     | 41.7     | 22.3            | 12.9                    | 4.9        | 9.4              | 82.2, 4.9, 71.1–87.8 | T, RH, PAR, LW, RAD, Wind |    |   | S1R     |
| Byrsonima putumayensis   | Malpigiaceae  | 55.1     | 28.0            | 12.2                    | 8.3        | 15.8             | 78.5, 6.5, 65.9–86.5 | T, RH, PAR, LW, PRE, Wind |    |   | S2V     |
| Virola duckei            | Myristicaceae | 86.3     | 29.9            | 20.0                    | 6.1        | 9.9              | 82.8, 4.7, 72.7–88.6 | T, RH, PAR, LW, PRE, Wind |    |   | S2R     |
| Ficus krukovii           | Moraceae      | 104.5    | 23.0            | 10.0                    | 8.8        | 13.0             | 83.5, 2.6, 78.6–86.9 | T, RH, PAR, LW, PRE |    |   | S3V     |
| Eschweilera coriacea     | Lecythidaceae | 69.7     | 25.3            | 15.0                    | 8.4        | 10.3             | 78.2, 6.7, 66.7–87.2 | T, RH, PAR, LW, PRE |    |   | S3R     |
| Guarea cf. gigantea      | Meliaceae     | 23.9     | 24.8            | 19.5                    | 6.1        | 5.3              | 80.6, 4.8, 71.6–85.9 | T, RH, PAR, LW, PRE |    |   | S4V     |
| Pourouma tomentosa       | Urticaceae    | 55.1     | 26.7            | 19.7                    | 8.5        | 7.0              | 75.9, 3.6, 71.3–82.8 | T, RH, PAR, LW, PRE |    |   | S4R     |

Note. Coloured bars refer to the stratified study design where S indicates sites and T indicates topography (blue represents valley and orange, ridges). Crown radius is an average calculated from three to four measurements. Canopy cover statistics derived processing 10 pictures taken with a mobile phone and processed in Gap Light Analyzer (GLA Version 2.0; Frazer et al., 2008). Crown depth calculated as the difference between Tree height and Fist branch height. Abbreviations: DBH, diameter at the breast height; Wind, digital anemometer; LW, leaf wetness; PAR, photosynthetic active radiation; PRE, Generic rain gauge; RAD, Global radiation; RH, relative humidity; T, temperature.
e. Site history: Forest protected within the Yasuní National Park and distant from active oil well extraction, with the influence of cultural practices of the local indigenous communities belonging to the ethnic group Waorani.

f. Climate: The region corresponds to the Holdridge Life Zone of tropical wet forest (Holdridge, 1947, 1964) with a wet equatorial climate with imperceptible seasonality (Bailey, 2014), a mean annual temperature of ~25°C and an average annual precipitation of ~2,240 mm.

2. Experimental or sampling design

a. Design characteristics: To monitor canopy climate, eight canopy climate stations were established in a stratified sampling design targeting ridges (four stations) and valleys (four stations). Nearby valley and ridge trees correspond to a site (Table 1). Air temperature, relative humidity, PAR, and leaf wetness were recorded by all canopy climate stations, while precipitation, wind, and global radiation were recorded by selected canopy climate stations (Table 1).

b. Data collection period, frequency, etc.: All canopy climate stations measured climate parameters every 30 s and recorded data every 10 min (mean, minimum, maximum, or sampling values of the 20 measurements) between April 2019 and February 2020. However, the different stations and sensors have gaps within this period (Figure 2 and Table 2).

3. Research methods

a. Field/laboratory: We installed eight climate stations, each in the crown of a tree, using adapted climbing techniques (Perry 1978) in the second half of April 2019. These trees belonged to seven species distributed in six botanical families and averaged 64 ± 25.6 cm (mean ± SD) for DBH, 26 ± 2.7 m of height, and 7.2 ± 1.5 m of crown radius (Table 1); we targeted canopy trees, that is, those immersed in the canopy stratum of the forest—excluding sub-canopy and emergent trees. In each tree, the sensor set (Figure 3) was established in the medium section and upper side of crown branches (i.e., in the middle canopy sensu Johansson 1974). We verified the performance of the climate stations in the lab before installation, and from the ground via WIFI after installation, using the interface provided by the datalogger manufacturer (Device Configuration Utility, 2.21.16 by Campbell scientific). Verifications and data downloading from the ground were performed 1 week, 4 months, and 10 months after installation. After the last verification, we removed the climate stations.

Figure 2. Continuity of the climate series recorded by eight canopy climate station established in the tropical rainforest of the Yasuní National Park, Ecuador. For brevity, we aggregated the data at daily resolution. Power failure corresponded to complete gaps in the series while NA occurred for some of the climate parameters. See descriptive statistics in Table 2.
b. Instrumentation: Each canopy climate station consisted of a logger (80 MB CPU drive and 30 MB serial flash storage, configured to host a Wi-Fi network) and its sensor set (Table 1) powered by a solar panel (50 Wp/12VDC, Resun model RSM-50P) and a backup battery (12 V, SunBrigth Battery model 6-FM-20). A controller (Morningstar corporation, model SHS-10) protected the climate station against short circuit, over-current, high voltage, and lightning, and set reverse current at night, that is, shifted the energy source from the solar panel to the battery, charged during light hours. Loggers and sensors (Table 3) were set, programmed, and tested using ShortCut 4.1. (2018) and Device Configuration Utility version 2.21.16 (2019), both by Campbell Scientific. The recording program consisted of registering the different climate parameters every 30 s and logging the data every 10 min. Thus, average, maximum, minimum, standard deviation, and sample values were obtained from 20 measurements.

c. Permit history: The data presented here were collected in the frame of the research permit 003–2019-IC- PNY- DPAO—PUCE issued by the Ministry of Environment of Ecuador in February 2019 and expired in February 2020.

C. Project personnel:
Monica Berdugo (University of Marburg, Faculty of Geography, Ecological Plant Geography, Marburg, Germany) implemented the ecological work package of the TLCF project, in which the climate was recorded, with the support of Karen Suárez (Federal University of Pernambuco, Biology Department, Laboratory of Plant Taxonomy, Recife, Brazil) and Jorge Déleg (Universidad Técnica Particular de Loja, Departamento de Ciencias Naturales,

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Table 2. Percentage of NA due to sensor failure (Failure) or due to values out of the variable or sensor range (Outlier) in the climate series recorded by eight canopy climate station established in the tropical rainforest of the Yasuní National Park, Ecuador.

| Station | Number of records | NA   | T    | RH  | PAR | LW  | PRE | RAD | Wind |
|---------|-------------------|------|------|-----|-----|-----|-----|-----|------|
| S1V     | 16,492            | Failure | <0.01 | 75.9 | 0.2 |
| S1R     | 23,862            | Failure | 79.2  | 79.2 |      |
| S2V     | 34,557            | Failure |       |      | <0.01| |
| S2R     | 41,921            | Failure |       |      | <0.01| 0.1|
| S3V     | 17,705            | Failure |       |      | 0.01 | 0.02|
| S3R     | 3,119             | Failure |       |      | 36.4 | |
| S4V     | 42,588            | Failure |       |      | <0.01| 0.3 |
| S4R     | 23,541            | Failure |       |      | 73.9 | 73.9| 69  |      |

Note. No NA was identified for station S3V, neither for precipitation, recorded with PRE.

Abbreviations: Wind, digital anemometer; LW, leaf wetness; PAR, photosynthetic active radiation; PRE, generic rain gauge; RAD, global radiation; RH, relative humidity; T, temperature.
Figure 3. Set of sensors used to monitor climate with a 10-min temporal resolution in the tropical rainforest canopy of Yasuní National Park, Ecuador. In each station, a radiation shield (a) protected the sensor for temperature and relative humidity from direct sunshine and rain. The leaf wetness sensor (b) and the sensor for photosynthetic active radiation (c) were placed on the upper side of the medium section of a crown branch. Selected canopy climate stations were instrumented with a generic rain gauge (d), a sensor for global radiation (e), or a digital anemometer (f), as indicated in Table 1. Instrument details are provided in Table 3.
2.3. Class III. Data set status and accessibility

A. Status

1. Latest update: December 2021
2. Latest archive date: February 2020
3. Metadata status: August 2020
4. Data verification:
   Data were checked in by the authors. In each data series, a variable of each climate parameter was plotted to identify gaps and suspicious data in the records, suggesting partial or definitive sensor failure. This data exploration was supported by field notes taken at the time of

| Equipment                     | Function                                                                 | Maker                | Model          | Serial numbers                      |
|-------------------------------|--------------------------------------------------------------------------|----------------------|----------------|-------------------------------------|
| Data loggers                  | Implement the program to calculate climate parameters and log the corresponding data | Campbell Scientific | CR300_WIFI | 11807, 13980, 13981, 13982, 13984, 13985, 13986, 13987 |
| Temperature and relative humidity sensor | Record minimum, maximum, average, and the standard deviation of air temperature, and minimum and maximum relative humidity. These sensors were protected in 10 plate radiation shields (Figure 3a) | Campbell Scientific | CS215         | E21628, E21629, E21630, E21631, E21632, E21633, E21634, E21,635 |
| Dielectric leaf wetness sensor (Figure 3b) | Record the average voltage as well as the period length during which the leaf wetness sensor was dry wet or contaminated. A threshold of <274 mV indicates dry leaves and threshold ≥ 284 indicates wet leaves | Campbell Scientific | LWS           | 03-615, 03–620, 03-622, 03–626, 98600–03-240, 98600–03-241, 98600–03-242, 98600–03-243 |
| Photosynthetically active radiation — PAR sensor (Figure 3c) | Record average, maximum, minimum, and total PAR density | Campbell Scientific | CS310 Quantum Sensor | 1664, 1666, 1772, 1773, 1774, 1775, 1776, 1777 |
| Tipping bucket rain gauge (Figure 3d) | Record total precipitation during the recording period (10 min) | ELM Kalyx | | 190847, 190848, 190849, 190850, 190851, 190852 |
| Digital thermopile pyranometer (Figure 3e) | Record average solar radiation, average dew point, and a second measurement for average air temperature and its standard deviation | Campbell Scientific | CS320         | 1835, 1836 |
| Two-dimensional ultrasonic wind sensor (Figure 3f) | Record a sample of wind direction, as well as average, maximum, and minimum wind speed | The Gill WindSonic4 | | 18480149, 18500164, 18500165, 19480151 |
removing the stations (e.g., “rain gauge clogged with canopy debris,” “rain gauge broken; the rain collector is absent,” “climate station box colonized by termites,” “logger under water within the climate station box”). To ease comparisons among stations and sites, data series were aligned, and suspicious data were labeled as NA (R script DataCompilation.Rmd). By the end of the data verification process, the data series contained only trustable data (Figure 4).

Figure 4. Example of a multiplot after the data verification process, corresponding to station S2V, recording climate every 10-min in the tropical rainforest canopy of the Yasuní National Park, Ecuador. Following the suggestions by the sensor maker (Dielectric leaf wetness sensor, Campbell Scientific), we set the threshold $<274 \text{ mV}$ to indicate dry and $> = 284$ to indicate wet leaves.
B. Accessibility
   1. Storage location and medium:
      Data files and R scripts of the developed open-source tools are stored in Dryad (https://datadryad.org/stash/share/saMwQoZF81_wT5Gyxm_W2QGifzqGiaeG9nHOVjfwMT4).
      In addition, raw data are stored in the data warehouse of the Laboratory for Climatology and Remote Sensing (LCRS) at the Faculty of Geography of the University of Marburg.
   2. Contact person(s):
      Monica B. Berdugo, University of Marburg, Faculty of Geography, Ecological Plant Geography, Deutschhausstraße 10, D-35032, Marburg, Germany, phone: +4,906,421 2,824,187, berdugom@staff.uni-marburg.de and biobibiana@yahoo.com.
      Maaike Bader, University of Marburg, Faculty of Geography, Ecological Plant Geography, Deutschhausstraße 10, D-35032, Marburg, Germany, phone: +4,906,421 2,828,952, maaike.bader@uni-marburg.de
   3. Copyright restrictions:
      None
   4. Proprietary restrictions:
      There is no restriction for using data from this data paper, as long as the data paper is cited as the source of the information used.

C. Costs:
   None.

2.4. Class IV. Data structural descriptors
A. Data set file
   1. Identity:
      S1V_Canopy_Climate_2019–20.csv.
      S1R_Canopy_Climate_2019–20.csv.
      S2V_Canopy_Climate_2019–20.csv.
      S2R_Canopy_Climate_2019–20.csv.
      S3V_Canopy_Climate_2019–20.csv.
      S3R_Canopy_Climate_2019–20.csv.
      S4V_Canopy_Climate_2019–20.csv.
      S4R_Canopy_Climate_2019–20.csv.
      Yasuni_Canopy_Climate_2019–20.csv.
      Ridges_Canopy_Climate_2019–20.csv.
      Valleys_Canopy_Climate_2019–20.csv.
      Data_Compilation.Rmd.
      Dashboard_CanopyClimate.Rmd.
      Dashboard_CanopyClimate.html.
      Filtering_CanopyClimate.Rmd.
   2. Size:
      Data size details are presented in Table 4.
   3. Format and storage mode:
      Comma-separated values (.csv), R Markdown scripts (.Rmd) and outputs (.html).
   4. Header information:
      Data series of stations in the same site (e.g., S1V and S1R) share headers (See Table 4 in Section B, Variable information)
   5. Alphanumeric attributes:
      Mixed (See Table 4 in Section B, Variable information).
B. Variable information
   The details of the climatic variables included in the data are summarized in Table 5.
C. Data anomalies:
In the original data series, absent data were filled with NA either by the data logger or during the data verification process, where suspicious data points were replaced by NA. In the derived data series, absent data were filled with NA during the data compilation process.

2.5. Class V. Supplemental descriptors
A. Data acquisition
Automated data loggers.
B. Quality assurance/quality control procedures:
The original data series went through a data verification process while the derived data series resulted from a data compilation process.
The data verification, including the calculation of derived variables, consisted of four steps: (a) visualization and diagnosis of suspicious data, that is, those exceeding the possible values for the climate parameter in the locality or those resulting from sensor failure (for instance, PAR that was above zero during night hours), resulting from malfunctioning of specific sensors; (b) replacement of suspicious data with NA; (c) calculation of derived climate variables (Table 5), average relative humidity as the mean value of the recorded relative humidity variables (maximum and minimum), VPD derived from average relative humidity and average air temperature following Fenton and Frego (2005), calculated dew point (DewPtC) derived from average air temperature and average relative humidity following Lawrence (2005); and transformation of solar radiation data, recorded in kWm2, to W/m2, because this is the most commonly used unit; and (d) creation of fields used to filter data, that is, Date, Hour, and DateHour (Table 4), by using functions of R base (trunc; R Core Team, 2020), and

| File                                | Number of records | Record length (days) | Size (KB) |
|-------------------------------------|-------------------|----------------------|-----------|
| S1R_Canopy_Climate_2019–20.csv      | 16,492            | 115                  | 3,090     |
| S1V_Canopy_Climate_2019–20.csv      | 23,862            | 166                  | 5,591     |
| S2R_Canopy_Climate_2019–20.csv      | 34,557            | 240                  | 7,426     |
| S2V_Canopy_Climate_2019–20.csv      | 41,921            | 291                  | 8,929     |
| S3R_Canopy_Climate_2019–20.csv      | 17,705            | 123                  | 3,242     |
| S3V_Canopy_Climate_2019–20.csv      | 3,119             | 22                   | 564       |
| S4R_Canopy_Climate_2019–20.csv      | 42,588            | 296                  | 6,006     |
| S4V_Canopy_Climate_2019–20.csv      | 23,541            | 164                  | 4,337     |
| Ridges_Canopy_Climate_2019–20.csv  | 44,680            | 302                  | 7,419     |
| Valleys_Canopy_Climate_2019–20.csv | 44,680            | 268                  | 7,852     |
| Yasuni_Canopy_Climate_2019–20.csv  | 44,680            | 306                  | 8,379     |
| Data_Compilation_REDS.Rmd           | —                 | —                    | 35        |
| Dashboard_CanopyClimate_R.Rmd       | —                 | —                    | 31        |
| Dashboard_CanopyClimate_R.html      | —                 | —                    | 12,445    |
| Filtering_CanopyClimateR.Rmd        | —                 | —                    | 28        |

Note. Size of the data series of canopy climate of the tropical rain-forest of the Yasuní National Park, Ecuador along to the size of their companion Markdown scripts.
Table 5. Variable information for the canopy climate data series of the tropical rain-forest of the Yasuní National Park, Ecuador.

| Variable identity | Variable definition | Units       | Range          | Stations series | Aggregated series |
|-------------------|---------------------|-------------|----------------|-----------------|-------------------|
| datetime          | Record date and time (format yyyy-mm-dd hh:mm:ss) |             |                | x x x x x     | x x x x x x x     |
| Date              | Date derived from the datetime field during the data verification to filter or summarize data at the date resolution (format yyyy-mm-dd) |             |                | x x x x x     | x x x x x x x     |
| Hour              | Hour derived from the datetime field during the data verification to filter or summarize data at the hour resolution (format hh) |             |                | x x x x x     | x x x x x x x     |
| DateHour          | DateHour derived from the datetime field during the data verification to filter or summarize data at the hour resolution within a given date (format yyyy-mm-dd hh) |             |                | x x x x x     | x x x x x x x     |
| record            | Consecutive record number according to datalogger |             |                | x x x x x     | x x x x x x x     |
| BattV             | Minimum value of the battery V | V           | 0–14.3         | x x x x x     | x x x x x x x     |
| LWmV_Avg          | Average leaf wetness mV | mV          | 257.7–1,250.0  | x x x x x     | x x x x x x x     |
| LWMDry_Tot        | Period length during which the leaf wetness sensor was dry Minutes | Minutes    | 0–10           | x x x x x     | x x x x x x x     |
| LWMCon_Tot        | Period length during which the leaf wetness sensor was contaminated Minutes | Minutes    | 0–10           | x x x x x     | x x x x x x x     |
| LWMWet_Tot        | Period length during which the leaf wetness sensor was wet Minutes | Minutes    | 0–10           | x x x x x     | x x x x x x x     |
| PAR_Den_Avg       | Average photosynthetically active radiation (PAR) density umol/(s m$^2$) | umol/(s m$^2$) | 0–1,756       | x x x x x     | x x x x x x x     |
| PAR_Den_Max       | Maximum PAR density umol/(s m$^2$) | umol/(s m$^2$) | 0–2,158       | x x x x x     | x x x x x x x     |
| PAR_Den_Min       | Minimum PAR density umol/(s m$^2$) | umol/(s m$^2$) | 0–1,508       | x x x x x     | x x x x x x x     |
| PAR_Tot_Tot       | Total PAR density recorded in 10 min mmol/(s m$^2$) | mmol/(s m$^2$) | 0–1,053.7     | x x x x x     | x x x x x x x     |
| SlrkW_Avg         | Average solar radiation W/m$^2$ | W/m$^2$ | 0–432         | x              | x x x x x x x     |
| Variable identity  | Variable definition                                                                 | Units | Range               | Stations series | Aggregated series |
|--------------------|--------------------------------------------------------------------------------------|-------|---------------------|-----------------|-------------------|
|                    |                                                                                      |       |                     | S1V S2V S3V S4V | RCC VCC YCC       |
| DewPtC_Avg         | Average dew point                                                                    | °C    | 5.1–27.72           | x               | x x x x           |
| LogTC_AVG          | Average temperature of the datalogger                                                | °C    | 19.24–40.67         | x x x x x x     |                   |
| BoxTC_AVG          | Average temperature within the station box (Figure 5)                               | °C    | 18.7–38.59          | x x x x x x     |                   |
| AirTC_Avg          | Average air temperature                                                              | °C    | 17.28–33.96         | x x x x x x x x |                   |
| AirTC_Max          | Maximum air temperature                                                              | °C    | 17.30–34.40         | x x x x x x x x |                   |
| AirTC_TMx          | Date and time at which maximum air temperature was registered                        |       |                     | x x x x x x x x |                   |
| AirTC_Min          | Minimum air temperature                                                               | °C    | 12.84–33.74         | x x x x x x x x |                   |
| AirTC_TMin         | Date and time at which minimum air temperature was registered                        |       |                     | x x x x x       |                   |
| AirTC_Std          | Standard deviation of the air temperature                                             | °C    | 0.000–1.924         | x x x x x       |                   |
| RH_Max             | Maximum air relative humidity                                                         | %     | 26.28–100.00        | x x x x x x x x |                   |
| RH_Min             | Minimum air relative humidity                                                         | %     | 20.01–100.00        | x x x x x x x x |                   |
| CS320.Temp_Avg     | Average air temperature recorded by the pyranometer                                  | °C    | 17.15–33.89         | x               |                   |
| CS320.Temp_Std     | Standard deviation of the air temperature recorded by the pyranometer                | °C    | 0.000–1.341         | x               |                   |
| WindDir            | Sample of wind direction                                                             | °      | 0–359               | x x x x x x x x |                   |
| WS_ms_S_WVT        | Wind speed vector calculated as the mean of the horizontal speed for 10 samples taken during the recording period, using WS Ms as reference wind speed | m/s   | 0.01–3.16           | x               |                   |
| Variable identity       | Variable definition                                                                                                                                 | Units | Range       | Stations series | Aggregated series |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------------|-----------------|-------------------|
| WindDir_D1_WVT          | Wind direction vector calculated as the mean of the horizontal direction for 10 samples taken during the recording period, using WindDir as reference wind direction |       | 0–359       | x               |                   |
| WindDir_SD1_WVT         | Standard deviation vector WindDir_D1_WVT, using WindDir as the reference wind direction                                                                 |       | 0–89.3      | x               |                   |
| WS_ms_Avg               | Average wind speed                                                                                                                                     | m/s   | 0–4.10      | x               | x                 | x                 | x                 |
| WS_ms_Max               | Maximum wind speed                                                                                                                                 | m/s   | 0–12.70     | x               | x                 | x                 | x                 |
| WS_ms_Min               | Minimum wind speed                                                                                                                                 | m/s   | 0–1.60      | x               | x                 | x                 | x                 |
| PCP                     | Total precipitation                                                                                                                                   | mm    | 0–21.6      | x               | x                 | x                 | x                 |
| RH_Avg                  | Average relative humidity calculated as the mean value from the records of RH_Max and RH_Min                                                                 | %     | 26–100      | x               | x                 | x                 | x                 | x                 |
| VPD                     | Vapor pressure deficit calculated as $6.1078 \exp\left(\frac{17.269 \times \text{AirTC}_{\text{Avg}}(237.3 + \text{AirTC}_{\text{Avg}})}{100 - \text{RH}_{\text{Avg}}}\right)$ | hPa   | 0–29.6      | x               | x                 | x                 | x                 | x                 |
| DewPtC                  | Dew point calculated as $\text{AirTC}_{\text{Avg}} - ((100 - \text{RH}_{\text{Avg}})/5)$, following Lawrence (2005)                                                        | °C    | 7.3–27.3    | x               | x                 | x                 | x                 | x                 |

Abbreviations: RCC, derived data series aggregating climate records for ridges; VCC, derived data series aggregating climate records for valleys; YCC, derived data series aggregating climate records for the forest.
“lubridate” (hour; Grolemund and Wickham, 2011) and “chron” (as.chron; James and Hornik, 2020) R packages.

The data compilation consisted of three steps: (a) temporally aligning series for each climate parameter; (b) assigning a value for each climate parameter to each timestep, by either copying the value recorded by a single station or calculating a mean value when two or more stations registered that parameter; absent data were filled with NA; and (c) writing the aggregated data series as an output (in format csv file).

C. Related materials:
None

D. Computer programs and data-processing algorithms:
Data were downloaded using the logger software (Campbell Scientific), while data verification and processing were performed using R (see details in literal B, Quality assurance/quality control procedures, above and in the R scripts: Data_Compilation.Rmd, Dashboard_CanopyClimate.Rmd, and Filtering_CanopyClimate.Rmd).

E. Archiving
1. Archival procedures: Description of how data are archived for long-term storage and access
2. Redundant archival sites: Locations and procedures followed

Figure 5. Appearance of a box station (S2R) used to monitor canopy climate with a 10-min temporal resolution in the tropical rainforest canopy of the Yasuni National Park, Ecuador. Tables 2 and 4 detail equipment and station components.
F. Publications and results: None.

G. History of data set usage
1. Data request history: None.
2. Data set update history: First update in August 2019, second update in February 2020.
3. Review history: None.
4. Questions and comments from secondary users: None.

3. Conclusion
The main practical lesson from this data collection and compilation is that sustaining cooperation with local researchers is critical to strengthen our capabilities toward understanding ecological processes occurring in tropical canopies, as likewise suggested by Haelewaters et al. (2021). This lesson highlights the need for budgeting qualified partners to ensure proper equipment maintenance. Then, relocating a part of the available budget toward qualified colleagues rather than to equipment would likely result in a more complete and clean raw data series. We observed that equipment becomes less reliable as forest growth occurs in or around critical components of sensors and electronics, including the power supply.

Abbreviations
PAR photosynthetically active radiation
VPD vapor pressure deficit

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Data Availability Statement. Data files and R scripts of the developed open-source tools are stored in Dryad (https://datadryad.org/stash/share/samWQoZF81_wT5Gyxn_W2QGfzqGiaeG9nHOVjfWMT4).

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Ethics Statement. The research meets all ethical guidelines, including adherence to the legal requirements of the study country.

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References
Bailey RG (2014) Ecoregions, 2nd Edn. New York: Springer. https://doi.org/10.1007/978-1-4939-0524-9
Barker MG and Pinard MA (2001) Forest canopy research: Sampling problems, and some solutions. Plant Ecology 153, 23–38.
Bass MS, Finer M, Jenkins CN, Kreft H, Cisneros-Heredia DF, McCracken SF, Pitman NC, English PH, Swing K, Villa G, Di Fiore A, Voigt CC and Kunz TH (2010) Global conservation significance of Ecuador’s Yasuni National Park. PLoS ONE 5, e8767. https://doi.org/10.1371/journal.pone.0008767
