

Climate Monitoring Guide

Design

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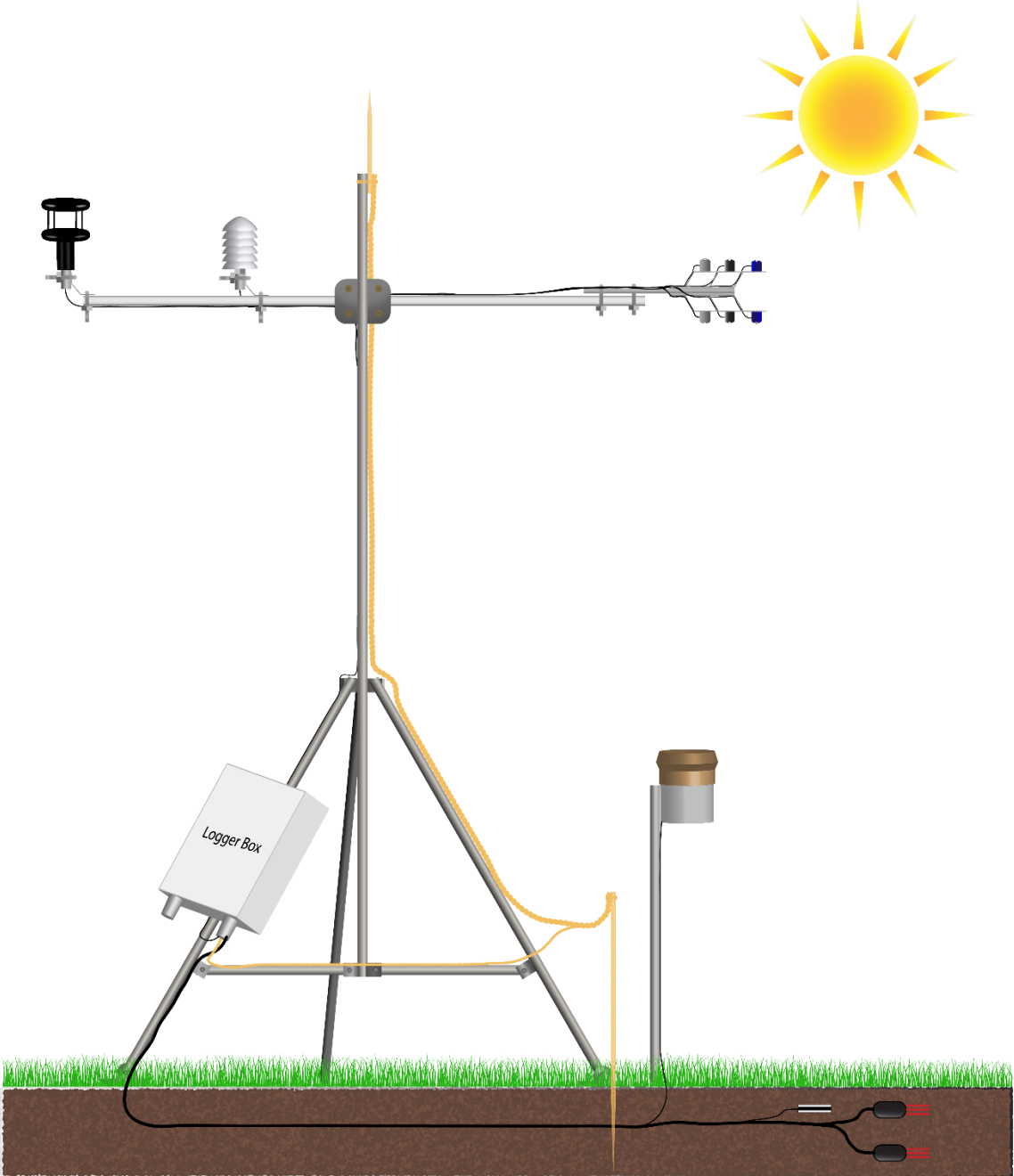


Table of Contents

Table of Contents.....i

List of Tablesi

Table of Figures..... ii

Design..... 1

 Introduction 1

 1.1 Sensor and datalogger compatibility2

 1.2 Power consumption calculation.....7

 1.3 Power sources (off-grid and on-grid) 10

 1.3.1 Off-grid power..... 10

 1.3.1.1 Battery 11

 1.3.1.2 Solar panels..... 13

 1.3.2 On-grid power..... 15

 1.4 Lightning protection 17

 1.5 Mounting infrastructure..... 18

List of Tables

Table 1. Assessment of datalogger channel (analog and digital) and measurement voltage ranges. 4

Table 2. List of data access solutions.....5

Table 3. List of important electrical terms..... 7

Table 4. List of variables names, sensors, channel requirements, voltage measurement range and current draw (power consumption).....9

Table 5. Calculation of site-specific battery bank capacity based on climate station power consumption..... 12

Table 6. Calculation of site-specific solar panel capacity based on climate station power consumption..... 13

Table 7. List of items needed to construct a off-grid solar source..... 14

Table 8. Common mounting infrastructure for climate monitoring stations. 18

Table of Figures

Fig. 1. Illustration of a climate monitoring station powered by an off-grid solar/battery system. The climate variables measured at this station include wind speed, wind direction, air temperature, precipitation, soil heat flux density, volumetric water content, soil temperature, relative humidity, shortwave radiation (incoming and outgoing), longwave radiation (incoming and outgoing) and photosynthetically active radiation (incoming and outgoing).2

Fig. 2. Panel a) is open-source electronics prototyping platform (Arduino; By SparkFun Electronics from Boulder, USA - Arduino Uno - R3, CC BY 2.0, <https://commons.wikimedia.org/w/index.php?curid=26785892>) which relies on open-source programming and peer-to-peer sharing. Panel b) is a proprietary datalogger platform (model Cr6 Campbell Scientific Inc.; <https://www.campbellsci.com/cr6>) which is supported by the company’s manufacturers. In general, panel b) is the best choice for project teams that has limited experience with dataloggers.3

Fig. 3. Illustration of a logger enclosure box (i.e., a protective case that holds sensitive electronics) with a data logger power distribution system, air temperature sensor (thermocouple) and a volumetric water content sensor (time-domain reflectometer) with an embedded soil temperature sensor (thermistor). The connection terminal block, connection terminal disconnect and the DIN-rail are crucial components to organize both power distribution and sensor connections (see.....6

Fig. 4. Illustration of off-grid power system (solar and battery system). Note how a connection terminal disconnect is situated between all electrical components to protect them against power surges. The connection terminal block, connection terminal disconnect and the DIN-rail are crucial components to organize both power distribution and sensor connections (see 11

Fig. 5. Panel a) is a battery (DC power storage) with enough capacity (79 Ah) to operate the climate station. Panel b) is an illustration a battery (DC power storage) with enough capacity (100 Ah) to operate the climate station. 13

Fig. 6. Illustration of a off-grid power system and logger box enclosure. 15

Fig. 7. Example of a compact AC-DC converter (taken from <https://www.digikey.ca/en/products/detail/tdk-lambda-americas-inc/DRB50121/4696210>). 15

Fig. 8. Illustration of AC powered climate station. In this example power is drawn from an AC wall receptacle inside a building. The power system is protected with a surge protector. The 120 V AC is converted to 12 V DC and then distributed to logger (not shown). Note how a connection terminal disconnect is situated between all electrical components to protect them against power surges. Illustration not to scale. 16

Fig. 9. Illustration of climate station infrastructure and lightning protection equipment necessary to ground the climate station 17

Fig. 10. Panel a) is an illustration of the lightning protection components required at the top of the climate station. Panel b) is an illustration of the lightning protection components required to

establish contact between the climate station electronics and the ground (where electrical potential is dissipated). Note how 1) the main conductor extending from the top of the climate station and 2) the datalogger are both connected to the grounding rod..... 18

Fig. 11. Example of climate station supported by a tripod.....20

Fig. 12. Example of climate station supported by a scaffold tower.21

Fig. 13. Example of climate station supported by a triangular tower.22

Fig. 14. Example of climate station supported by a telescoping tower.....23

Fig. 15. Example of climate station supported by a folding utility tower (taken from <https://galvanizeit.org/project-gallery/folding-utility-tower>)24

Design

Introduction

Planning and designing a climate station (**Fig. 1**) early in a project lifetime has the potential to decrease data loss, material waste, maintenance cost associated with equipment and time spent performing repairs. Aside from sensor selection (discussed in [ICBCM_Climate_Guide_1_Planning.pdf](#)), the basic elements of a climate station that must be considered include:

1.1 Sensor and datalogger compatibility

The datalogger in a climate station (the “brain”) is a crucial electrical component for communicating with sensors, controlling site power distribution, storing climate data and facilitating telemetry (transfer of data from remote to central locations). The datalogger chosen must be compatible with the project teams design requirements.

1.2 Site power consumption calculation

The total power consumption of a climate station is the sum each components power consumption. Although many analog sensors do not consume power, digital sensors do. In addition, site cameras, telecommunications and other electronics (i.e., site PC’s, additional dataloggers) consume power. Therefore, in order to design a power supply that will operate a climate station, the power consumption of the whole station must be calculate, by summing the power consumption of its individual components.

1.3 Site power sources (off-grid and on-grid)

Based on the power consumption needs of a climate station the project team must design a power supply solution that will operate the climate station during the measurement period (spring, summer, fall, winter, year-round etc.). Although on-grid (i.e., grid-tied) power is reliable and preferred, climate monitoring is often performed in remote locations and off-grid power systems (e.g., solar panel and battery system) are often required.

1.4 Lightning protection

Installing lightning protection infrastructure for a climate station has the potential to 1) prevent damage to electrical equipment and 2) maintain equal electrical potential (i.e., equal-potential) across all of the climate stations electrical components.

1.5 Mounting infrastructure

There are many solutions available for mounting sensors, datalogger boxes and power supply components and each must be chosen based on project specific design and needs.

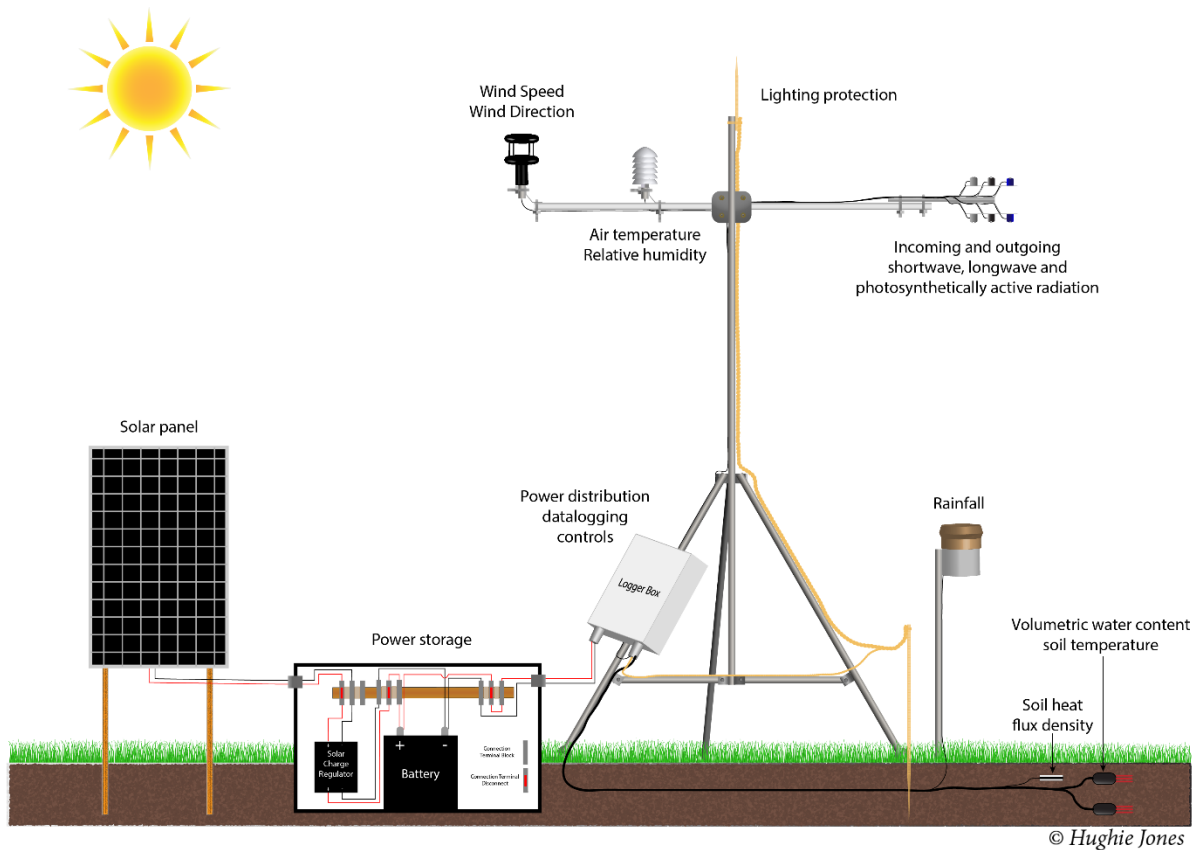


Fig. 1. Illustration of a climate monitoring station powered by an off-grid solar/battery system. The climate variables measured at this station include wind speed, wind direction, air temperature, precipitation, soil heat flux density, volumetric water content, soil temperature, relative humidity, shortwave radiation (incoming and outgoing), longwave radiation (incoming and outgoing) and photosynthetically active radiation (incoming and outgoing).

1.1 Sensor and datalogger compatibility

A data acquisition and control system (i.e., datalogger) is an electrical device that is critical for a climate monitoring station because it permits continuous data collection and storage. In general, all climate monitoring stations require an on-site datalogger for:

- measuring and processing signals from sensors (i.e., analog and digital)
- distributing power to system components (e.g., sensors, relays (switches), cameras)
- controlling system components (i.e., switching power on/off)
- Performing calculations on-site
- Storing data
- Facilitating data transfer off-site (via radio, WIFI, cellular modem)

a)



b)



Fig. 2. Panel a) is open-source electronics prototyping platform (Arduino; By SparkFun Electronics from Boulder, USA - Arduino Uno - R3, CC BY 2.0, <https://commons.wikimedia.org/w/index.php?curid=26785892>) which relies on open-source programming and peer-to-peer sharing. Panel b) is a proprietary datalogger platform (model Cr6 Campbell Scientific Inc.; <https://www.campbellsci.com/cr6>) which is supported by the company's manufacturers. In general, panel b) is the best choice for project teams that has limited experience with dataloggers.

Although each climate station has specific needs there are three questions which can help you decide which datalogger is best suited for your specific needs:

Step 1 Which, and how many, sensors you using in your project?

In this guide, the datalogger chosen for this project must support all the sensor listed in **Error! Reference source not found.**. In order to assess sensor and datalogger compatibility it is necessary to quantify:

- The number of channels needed to wire the sensors (i.e., digital and analog channels)
- The measurement voltage ranges (e.g., 0-2500 mV) for analog sensors
- Sensor excitation, for analog sensors
- Sensor power requirements, for digital sensors
- The compatibility of communications protocols (e.g., SDI-12) for digital sensors

All of the information above can be found in the user manual of each sensor you are considering. Add the information into a table (**Table 1**).

Table 1. Assessment of datalogger channel (analog and digital) and measurement voltage ranges.

Variable name	Chosen sensor	Analog channels (SE ¹ , DIFF ² , EXC ³ , PULSE ⁴)	Digital Channels	Sensor output voltage range (mV)
Air temperature/Water vapour density	https://www.campbellsci.ca/hmp60	2 SE	-	0-1000 mV
Precipitation	https://www.campbellsci.com/te525mm-l	1 PULSE	-	N/A
Wind speed/Wind direction	http://gillinstruments.com/products/anemometer/windsonic.htm	-	1 SDI-12 ⁵	N/A
Incoming shortwave radiation	https://www.campbellsci.com/cs320	-	1 SDI-12	N/A
Outgoing shortwave radiation	https://www.campbellsci.com/cs320	-	1 SDI-12	N/A
Incoming longwave radiation	https://www.apogeeinstruments.com/sl-510-ss-pyrgeometer-upward-looking/	1 DIFF, 1 SE, 1 EXC	-	-23.5-23.5 mV (thermopile), 0-2500 mV (thermistor)
Outgoing longwave radiation	https://www.apogeeinstruments.com/sl-610-ss-pyrgeometer-downward-looking/	1 DIFF, 1 SE, 1 EXC	-	-23.5-23.5 mV (thermopile), 0-2500 mV (thermistor)
Incoming photosynthetically active (PAR) radiation	https://www.apogeeinstruments.com/full-spectrum-quantum-sensor/	-	1 SDI-12	N/A
Outgoing PAR radiation	https://www.apogeeinstruments.com/full-spectrum-quantum-sensor/	-	1 SDI-12	N/A
Soil temperature	https://www.campbellsci.com/107	1 SE, 1 EXC	-	-
Volumetric Soil water content		-	-	-
Soil heat flux density	https://totech.com/product/hp-127-1-0-1-3-71/	1 DIFF	-	0-5000mV
Totals		3 DIFF, 5 SE, 1 PULSE, 3 EXC	5 SDI-12	-

¹SE – single ended analog channel, ²DIFF – differential analog channel, ³EXC – excitation channel (for analog sensors), ⁴PULSE – pulse port channel (for analog sensors), ⁵SDI-12 - digital communication protocol (serial digital interface at 1200 baud)

Step 2 What environmental conditions will the datalogger be exposed to (e.g., temperature, humidity, vibration)?

It is important to consider the environment in which your climate monitoring station will be installed. Typically, air temperature and humidity are the two most common environmental indicators that need consideration when considering a logger.

Air temperature – Operating outside a dataloggers temperature range can decrease the accuracy of your measurements. Whenever possible, access local historical climate data near your project site to determine the temperature range your datalogger will need to withstand.

Humidity - Condensation can cause damage to dataloggers. Since dataloggers are mounted inside enclosures which are nearly air-tight, water vapor can be absorbed inside the enclosure using desiccant (e.g., silicon beads).

Step 3 How often do you require access to data (e.g., half-hourly, daily, weekly, monthly) collected by the datalogger?

Data acquisition/access is crucial to climate monitoring. Project teams must choose an acceptable data-loss that determines the method of data retrieval and the datalogger required to support data access. Some climate monitoring stations require only on-site data storage (e.g., typically inside the datalogger) and others require continuous remote data access (**Table 2**). Remote data access has the potential to reduce data loss and improves a project teams’ ability to troubleshoot sensor issues (e.g., failures, soiling) before data-loss increases above the data-loss threshold.

Table 2. List of data access solutions

Accessibility	Method	Examples
Onsite data access	Internal datalogger memory	
	On-site PC or laptop	
	microSD cards	
Remote data access	WIFI	https://www.campbellsci.ca/cr6
	WIFI booster	https://www.ui.com/airmax/nanostation-ac/
	Radio	https://www.campbellsci.ca/narrow-band-uhf-vhf-radios
	Satellite	
	Cellular modem	https://www.campbellsci.ca/cellular-communications
	LoRaWAN	https://lora-alliance.org/

An example of a data logger that would fulfill the requirements mentioned above are shown in Fig. 2.



Fig. 2. Examples of commonly used dataloggers to support climate station data acquisition, storage and remote data-transfer (model CR1000X Campbell Scientific Inc., <https://www.campbellsci.com/cr1000x>; model Cr6 Campbell Scientific Inc.; <https://www.campbellsci.com/cr6>).

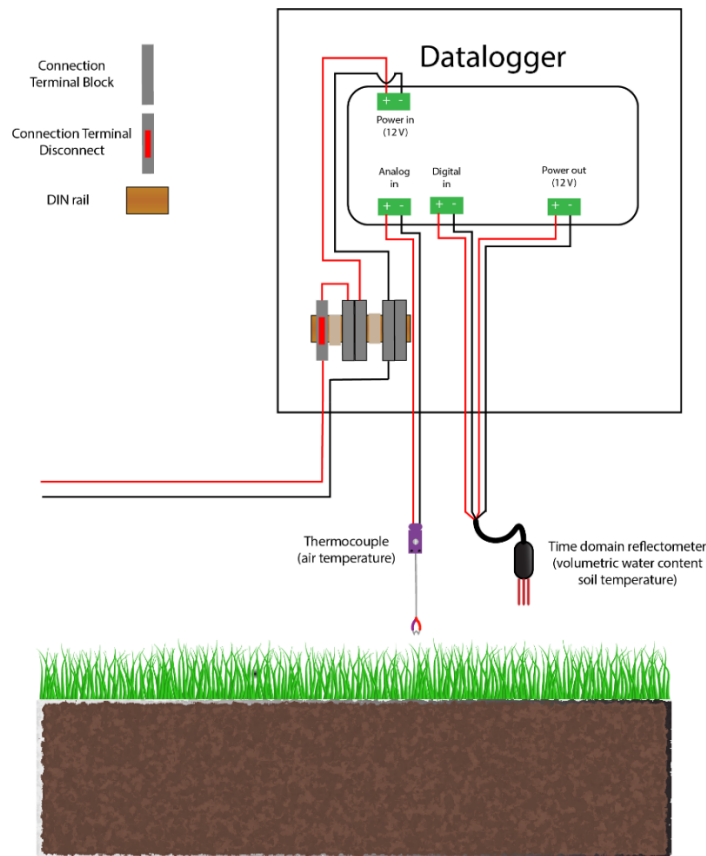


Fig. 3. Illustration of a logger enclosure box (i.e., a protective case that holds sensitive electronics) with a data logger power distribution system, air temperature sensor (thermocouple) and a volumetric water content sensor (time-domain reflectometer) with an embedded soil temperature sensor (thermistor). The connection terminal block, connection terminal disconnect and the DIN-rail are crucial components to organize both power distribution and sensor connections (see

Table 7). Illustration not to scale.

1.2 Power consumption calculation

Calculate the power consumption of a climate station in order to design a power source for operating the climate station. In order to discuss power consumption, awareness of basic electrical terms is required (Table 3)

Table 3. List of important electrical terms.

Terms	Definition
Electrical circuit	is a closed path/loop in which electrons are transmitted
Voltage (V)	electrical potential between two points
Electric current (<i>I</i>)	the rate of flow of electric charge past a point
Amperes (A)	The unit of electric current measured in charge (coulombs; C) per time (seconds; s) (i.e., C s ⁻¹)
Resistance (R)	a measure of a materials opposition to electric current
Power (VA)	Is the rate of electrical energy transfer, per unit time (watts; W)
Alternating current (AC)	electric current which reverses direction and changes its magnitude continuously with time. AC powers household items such as lights, televisions, toasters and fridges. AC is efficient at transmitting electrical energy over long distances (> 25 feet)
Direct Current (DC)	electrical current that flows in one direction. Batteries are a very common source of DC power. DC is efficient at transmitting electrical energy over short distances (<= 25 feet)

Steps for estimating the site power consumption (**Table 4**):

1. List all electrical components (i.e., sensors, WIFI boosters, dataloggers) in the climate station
2. Search inside the user manual of each electrical component and find the value for current consumption or current draw. This value is often found under the section titled **Specifications** or **Power requirements** and will have units of milliamperes (mA) or amperes (A). Many electrical components will have a range of values depending on their operation. Choose the highest value for current consumption listed to avoid underestimating the site current consumption.
3. Once the current consumption for each electrical component is listed, add them together, while ensuring the units of the current consumption are consistent (e.g., 1 A = 1000 mA). The final value is the total number of amperes the climate station draws from the electrical grid.

Table 4. List of variables names, sensors, channel requirements, voltage measurement range and current draw (power consumption).

Variable name	Chosen sensor	Analog channels (SE, DIFF, EXC, PULSE)	Digital Channels (SDI-12)	Voltage Range (mV)	Current draw (mA)
Air temperature/Water vapour density	https://www.campbellsci.ca/hmp60	2 SE	-	0-1000 mV	5 mA
Precipitation	https://www.campbellsci.com/te525mm-1	1 PULSE	-	N/A	0 mA
Wind speed/ Wind direction	http://gillinstruments.com/products/anemometer/windsonic.htm	-	1 SDI-12	N/A	44 mA
Incoming shortwave radiation	https://www.campbellsci.com/cs320	-	1 SDI-12	N/A	30 mA
Outgoing shortwave radiation	https://www.campbellsci.com/cs320	-	1 SDI-12	N/A	30 mA
Incoming longwave radiation	https://www.apogeeinstruments.com/sl-510-ss-pyrgeometer-upward-looking/	1 DIFF, 1 SE, 1 EXC	-	-23.5-23.5 mV (thermopile), 0-2500 mV (thermistor)	16 mA
Outgoing longwave radiation	https://www.apogeeinstruments.com/sl-610-ss-pyrgeometer-downward-looking/	1 DIFF, 1 SE, 1 EXC	-	-23.5-23.5 mV (thermopile), 0-2500 mV (thermistor)	16 mA
Incoming photosynthetically active (PAR) radiation	https://www.apogeeinstruments.com/full-spectrum-quantum-sensor/	-	1 SDI-12	N/A	2 mA
Outgoing PAR radiation	https://www.apogeeinstruments.com/full-spectrum-quantum-sensor/	-	1 SDI-12	N/A	2 mA
Soil temperature	https://www.campbellsci.com/107	1 SE, 1 EXC	-	-	0 mA
Soil water content (gravimetric and volumetric)	https://www.metergroup.com/environment/products/teros-11/	-	-	-	16 mA
Soil heat flux density	https://totech.com/product/hp-127-1-0-1-3-71/	1 DIFF	-	0-5000mV	0 mA
Totals		3 DIFF, 5 SE, 1 PULSE, 3 EXC	5 SDI-12	-	161 mA ¹

¹ Additional site components that were not considered in the power consumption include, but not limited to, communications hardware (i.e., modem, WIFI booster), site camera, lights (for buoys).

1.3 Power sources (off-grid and on-grid)

It is crucial to design a climate stations power supply to match the power requirements of the monitoring station. The section discusses some basic considerations for powering a climate station with on-grid (i.e., grid-tied) or off-grid power sources.

1.3.1 Off-grid power

Off-grid power is distributed as DC. Therefore, no conversion from AC to DC is required. Nevertheless, depending on the output voltage (e.g., 6V, 12V, 24V, 48V) of the off-grid power source (e.g., solar, wind, water turbine) a DC-DC converter may be necessary to achieve the voltage required to power the climate station components (i.e., datalogger, instruments, communications) (**Fig. 4**). Often, 12V DC is required.

Some advantages and disadvantages of off-grid power are:

Advantages:

- Ability to operate in remote locations.
- Infrastructure is relatively mobile.
- No electricity cost (\$).

Disadvantages:

- Cost (\$) to acquire and install new infrastructure (i.e., armoured wires, labour and equipment) is relatively low, depending on site-specific needs (i.e., number of batteries required).
- Batteries can be very expensive if high capacity is needed
- Non-fixed infrastructure increases climate station mobility.

The design of the power system is determined by the site-specific requirements which are determined based on the total site power consumption (detailed in Section 3). The solar-power system will have the following components:

- Solar panels
- Solar charge regulator
- Battery
- Battery box (container to holder electrical components)
- Connection terminal disconnects (i.e., fused switches)
- Connection terminal blocks
- Electrical wires

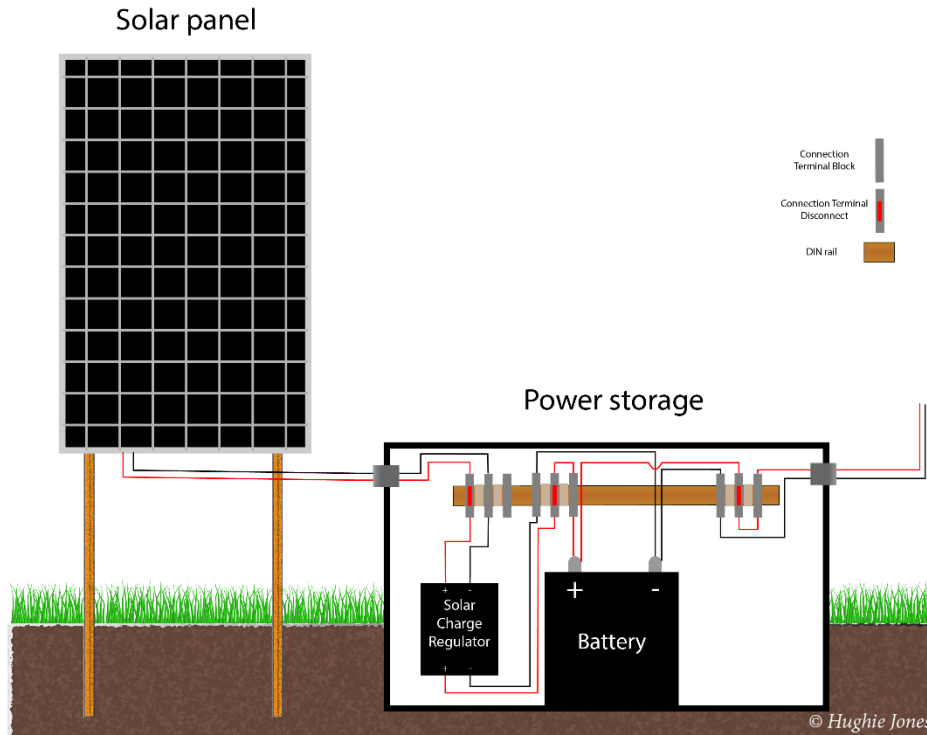


Fig. 4. Illustration of off-grid power system (solar and battery system). Note how a connection terminal disconnect is situated between all electrical components to protect them against power surges. The connection terminal block, connection terminal disconnect and the DIN-rail are crucial components to organize both power distribution and sensor connections (see

Table 7). Illustration not to scale.

1.3.1.1 Battery

The capacity of the battery bank (i.e., Ah) is determined based on the power consumption of the climate station. Battery bank capacity will change depending on project-specific requirements (e.g., site-visit frequency, data loss threshold, desired operating days). **Table 5** provides a step-wise scenario for calculating power requirements for the climate station under consideration in the guide. In general:

- 1) Only 50% of the total battery bank capacity should be considered useable. Therefore, if the total battery bank capacity is 80 Ah, only 40 Ah of capacity should be considered useable to power the site.
- 2) The battery bank capacity should be able to power the site 50% longer than the time between site visits. For example, if site visits occur every 7 days the battery bank capacity should power the site for approximately 10 - 11 days, this approach will decrease data loss.

Table 5. Calculation of site-specific battery bank capacity based on climate station power consumption.

Questions	Answers	notes
What is the climate station “current draw”?	161 mA	The current draw from Section 3.
What is the climate station input voltage?	12V DC	Input voltage for site electrical components (datalogger and instruments)
How many Ah does the climate station consume each day?	$0.161 \text{ A} \times 24 \text{ h} = 3.9 \text{ Ah}$	Total current (i.e., amperes (A)) used by the site each day (24 h)
How many days of power are required in my battery bank?	10 days	If you visit the climate stations once every week (7 days) 10 days of battery supply provides a buffer.
How many amp hours (Ah) does the battery bank require to power the climate station for 10 days?	$2 \times (24 \text{ h day}^{-1} \times 10 \text{ days} \times 0.161 \text{ A}) = 77.2 \text{ Ah}$	The “2 x” in front of the bracket’s accounts for the fact that you only want to use 50% of your battery capacity

Based on the calculation in **Table 5.** Calculation of site-specific battery bank capacity based on climate station power consumption. the battery required to safely power the off-grid climate station must have a capacity greater than 77.2 Ah. The battery if Fig. 2.6 is a 12V deep cycle battery with a capacity of 79 Ah that can be purchased at major department stores.

a)



b)

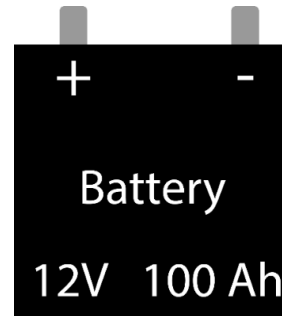


Fig. 5. Panel a) is a battery (DC power storage) with enough capacity (79 Ah) to operate the climate station. Panel b) is an Illustration a battery (DC power storage) with enough capacity (100 Ah) to operate the climate station.

1.3.1.2 Solar panels

Solar panels generate electrical energy from incoming solar radiation and charge the battery bank. Since solar panels only charge the battery bank periodically (i.e., daytime) and the climate station uses power continuously (i.e., daytime and nighttime) the solar panels capacity (**Table 6**) to generate electrical energy must be large enough to:

1. Supply enough power to the battery to offset site power consumption during the daytime and nighttime.
2. Offset battery charge loss during periods when solar radiation is systematically low (i.e., rainy season, low solar radiation season)

Table 6. Calculation of site-specific solar panel capacity based on climate station power consumption.

Questions	Answers	notes
What is the daily total power consumption of the climate station?	4 Ah	Taken from Table 5
What is the average annual number of “peak sun hours” in my location?	6 h (Edmonton, AB)	https://www.currentresults.com/Weather/Canada/Cities/sunshine-annual-average.php
What is the minimum target daily total recharge?	4 Ah x 6 = 24 Ah	
Required solar panel current	24 Ah / 6 h = 4 A	

Since the flux density ($W M^{-2}$) of solar radiation (i.e., sunlight) changes throughout the day, the number of hours each day which allow for maximum solar charging are less than the day length (defined as the time between sunset and sunrise). The number of hours where maximum solar charging occurs is referred to as “peak solar hours”. The number of peak solar hours will vary based on site-specific factors including

1. sky view factor (visibility of sky at site).
2. latitudinal position (e.g., Texas, TX or Calgary, AB).
3. time of year and atmospheric clarity (e.g., cloudiness, smokiness, dustiness).

It is helpful to list the components needed for a off-grid solar power source (

Table 7).

Table 7. List of items needed to construct a off-grid solar source.

Item	Purpose	example
Battery	Storing electrical charge	
Solar charge regulator	Regulating charging of batteries	
Solar panel	Producing electrical charge	
Battery box	Protect battery, solar charge controller and switches from environment (i.e., rainfall, condensation, falling objects, thieves)	
Terminal rings	Provide secure connections on battery terminals	
DIN rails	Mounting hardware	
Connection terminal disconnect	Switch, with replaceable fuse, needed to 1. protect electronic and 2. allow power shutoff	
Connection terminal block	Allows current to feed through	
Fuses	Positioned inside the connection terminal disconnect. Fuses rupture when electrical current exceeds their specific rating (e.g., 1A). This protects electronics.	

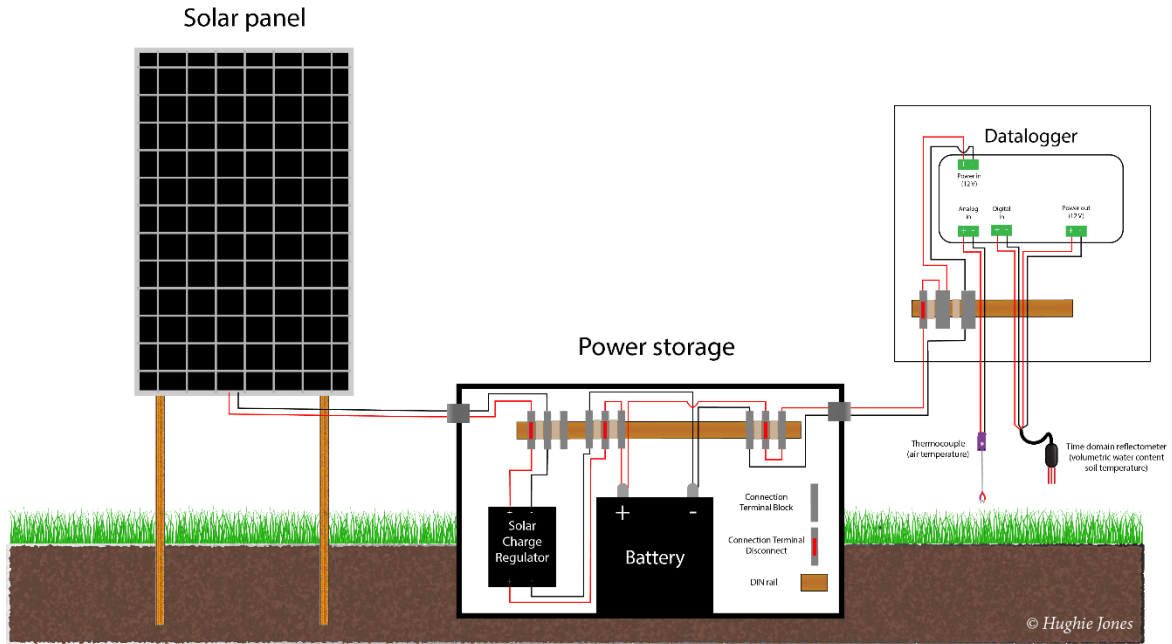


Fig. 6. Illustration of a off-grid power system and logger box enclosure.

1.3.2 On-grid power

Household on-grid power is distributed as alternating current (AC) (e.g., typically at 120V AC), but almost all climate station equipment is powered with direct current (DC) (e.g., typically at 12V DC). Therefore, an AC-DC converter is required to transform AC power into DC power (Fig. 7 and Fig. 8).



Fig. 7. Example of a compact AC-DC converter (taken from <https://www.digikey.ca/en/products/detail/tdk-lambda-americas-inc/DRB50121/4696210>).

Some advantages and disadvantages of on-grid power are:

Advantages:

- Low probability of power loss (unless local power outage occurs)
- Low maintenance

Disadvantages:

- Cost (\$) to acquire and install new infrastructure (i.e., armoured wires, labour and equipment) can be high, particularly in locations that are far from AC power sources
- Fixed power sources decrease climate station mobility

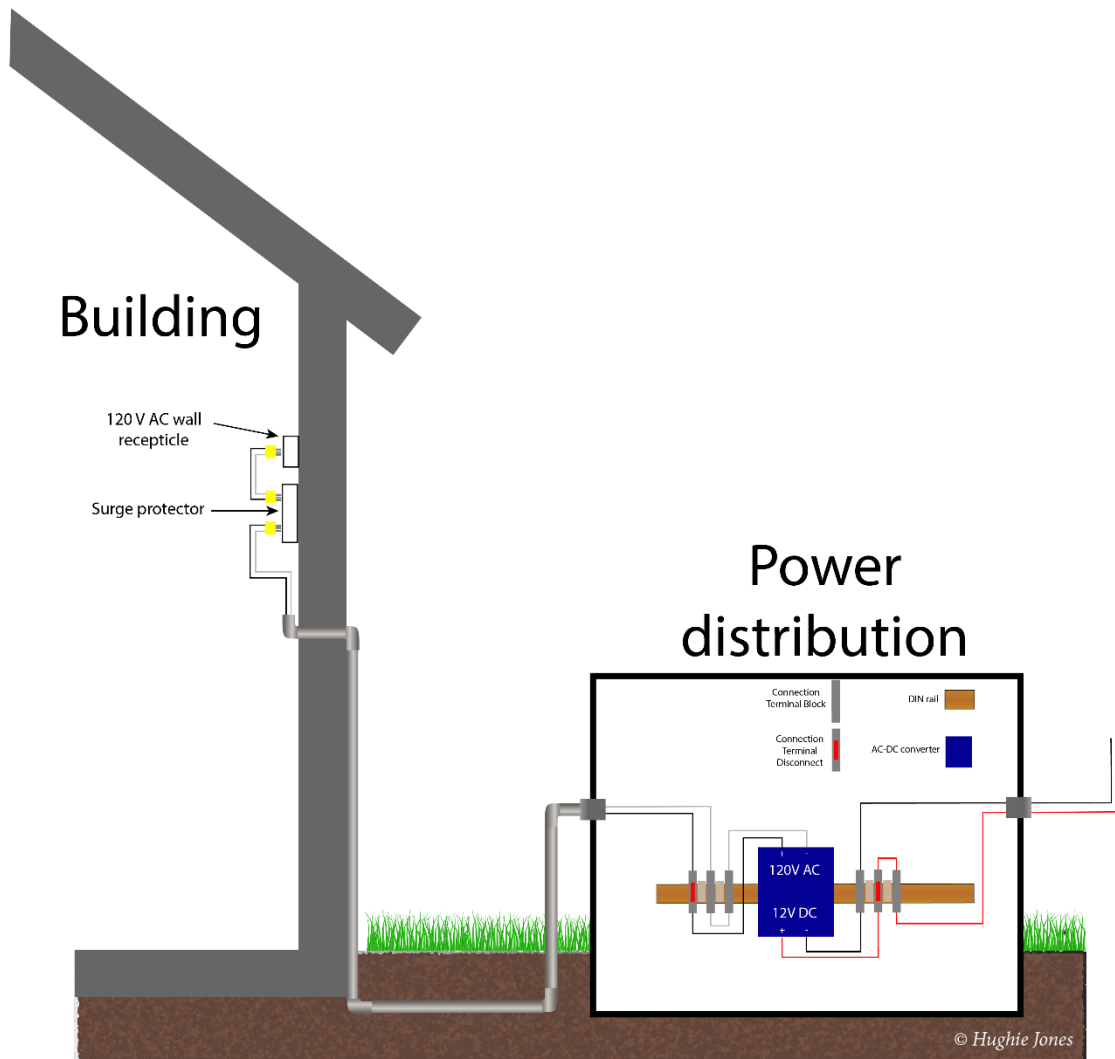


Fig. 8. Illustration of AC powered climate station. In this example power is drawn from an AC wall receptacle inside a building. The power system is protected with a surge protector. The 120 V AC is converted to 12 V DC and then distributed to logger (not shown). Note how a connection terminal disconnect is situated between all electrical components to protect them against power surges. Illustration not to scale.

1.4 Lightning protection

Warning: all lightning protection installations should be performed by certified professionals.

Lightning protection on climate stations has the potential to:

1. Provide a common electrical ground reference point to ensure all electronics within a climate station setup remain at an equal electrical (i.e., equa-potential).
2. Provide an efficient path for electrical static and surges (e.g., atmospheric or electrical-grid related) to the ground to protect electrical components (i.e., sensors) and people.

Lightning protection systems include (**Fig. 9** and **Fig. 10**):

- Air terminals
- Air terminal base
- Conductors (i.e., cooper wires)
- Grounding rod
- Surge protectors



Fig. 9. Illustration of climate station infrastructure and lightning protection equipment necessary to ground the climate station

Infrastructure name	Advantages	disadvantages
Tripod tower (Fig. 11)	<ul style="list-style-type: none"> • Easy to install (1-person) • Low weight • Semi-portable • Stable (requires minimal guy-wire) • Low maintenance 	<ul style="list-style-type: none"> • Low stability for large instrumentation loads • Require ladder for optimal instrument access
Scaffold (Fig. 12)	<ul style="list-style-type: none"> • Stable (often require guy-wire assistance) • Easy access for staff (staircases) • Support heavy instrumentation 	<ul style="list-style-type: none"> • Difficult to install (3 persons) • Immobile • Occupy large area • Maintenance intensive
Triangular tower (Fig. 13)	<ul style="list-style-type: none"> • Occupy small area (require guy-wire support) • Able to reach increased height (20 – 50 m) • Support heavy instrumentation 	<ul style="list-style-type: none"> • Difficult to install (4-5 persons) • Require trained and experienced staff to ascend • Maintenance intensive
Telescoping tower (Fig. 14)	<ul style="list-style-type: none"> • Occupy small area • Ability to raise and lower for access • Ability to change instrument height quickly • Semi-mobile 	<ul style="list-style-type: none"> • Low stability for large instrumentation loads • Difficult to install in remote locations • Limited height (5 m)
Folding utility tower (Fig. 15)	<ul style="list-style-type: none"> • Cannot support heavy instrumentation • Able to reach increased height (20 – 50 m) • Trained climbing staff not required 	<ul style="list-style-type: none"> • Difficult to install (4-5 persons) • Maintenance intensive

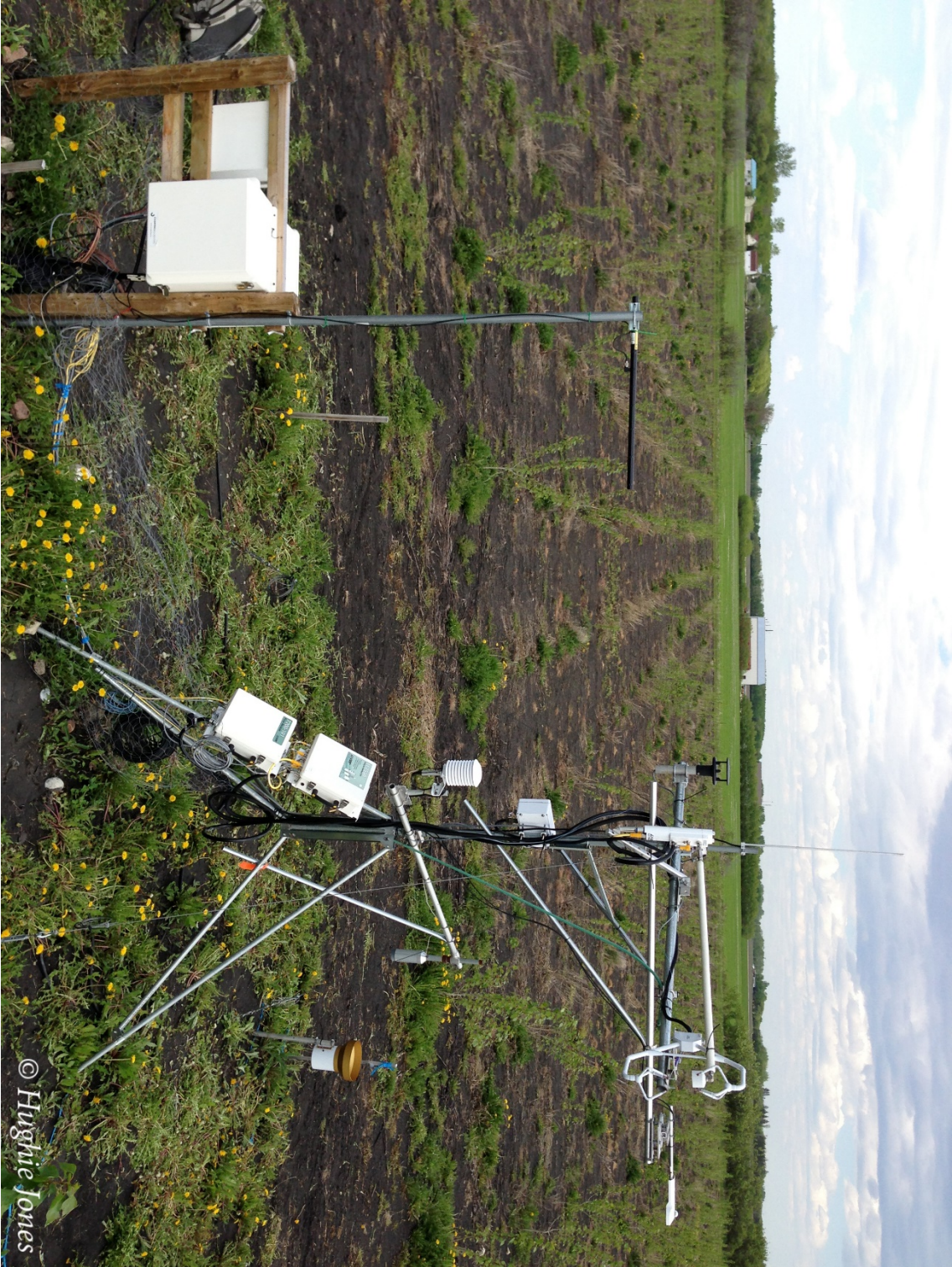


Fig. 11. Example of climate station supported by a tripod.



Fig. 12. Example of climate station supported by a scaffold tower.



Fig. 13. Example of climate station supported by a triangular tower.



Fig. 14. Example of climate station supported by a telescoping tower.



Fig. 15. Example of climate station supported by a folding utility tower (taken from <https://galvanizeit.org/project-gallery/folding-utility-tower>)