User Manual

Portable L-band Radiometer Rev. 5

PoLRa5

Drone-based Version

Last modified October 2025
TerraRad Tech AG, Zurich, Switzerland.
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1. What's in the box

TerraRad™ PoLRa 5 Sensor

Back

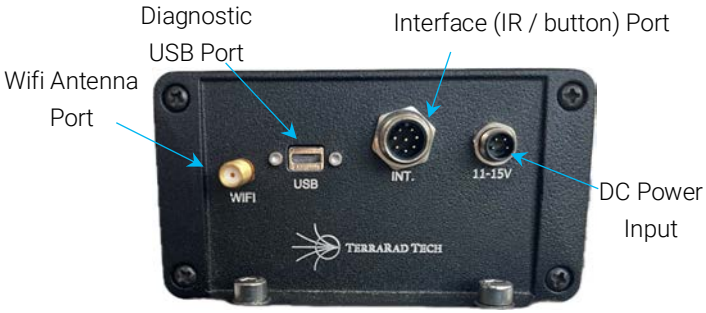
Front

GPS Antenna

Power Cable

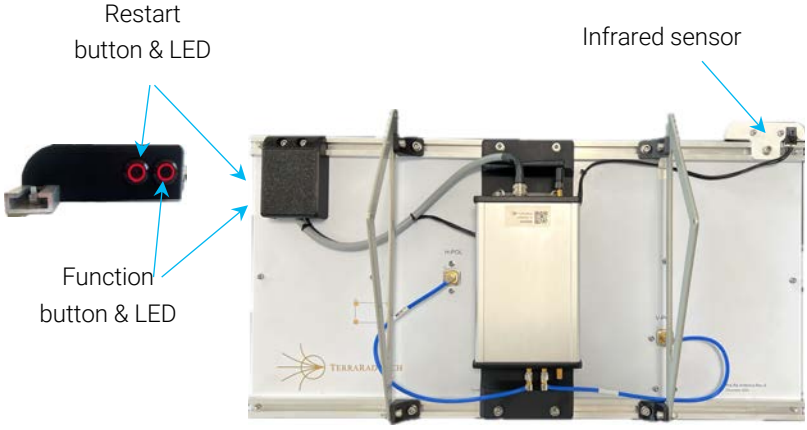
Mount Hardware

2. Sensor Details



Top

Bottom



Back

3. Specifications

Weight	2.2 kg
Dimensions	30 x 60 x 10 cm
Power Requirement	4 W[1]
Field of View	35º Horizontal and Vertical symmetric[2]
Polarization	Dual Linear (Horizontal & Vertical)
Sample Rate	10 Hz[3]
Radiometric Resolution	0.14 K at 1 sec integration
Absolute Calibration Uncertainty	0.6 K at 200 K
Soil Moisture Accuracy	≈ 2% Vol.
Interference Immunity	>60 dB out of band[4]
Operating Band	1400-1427 MHz
Transmit Power	0 mW (passive only sensor)
Connectivity	Wifi and Bluetooth (CE and FCC certified unit)
Antenna Efficiency	>99%[5]
Power Supply	11-15 VDC
Data Rate	11 MB / hr[6]
Software	PoLRa Cloud© WebApp

[1]Extremely low power consumption prolongs flight time or allows operation on small solar panel

[2]Symmetric antenna pattern measures the same footprint at both polarizations, which is not the case with other systems

[3]Includes time for measuring both polarizations and internal calibration loads

[4]Out-of-band rejection/immunity is critical for low-power passive sensing. TerraRad's unique use of bandpass filters in front of the amplifier chain ensures that interference signals do not saturate the detector

[5]TerraRad's patented antenna is highly efficient, meaning that detected microwave power originates from the remote scene and not from the antenna itself

[6]The relatively low data rate means quick transfer and low processing times

4. Connecting the Sensor

1. GPS

Place the GPS antenna on top of the drone in a location where it will have a clear view of the sky. The PoLRa GPS operates independently from your drone for maximum compatibility across platforms

2.Secure GPS

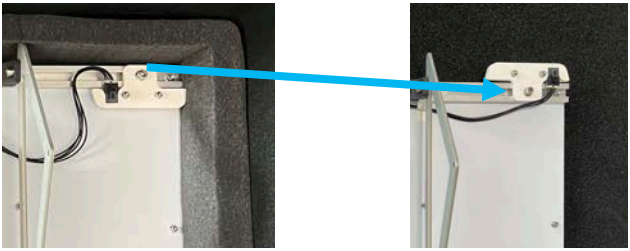
Secure the GPS antenna cable to a location on the drone to keep it tidy and well out of reach of the rotors, using zipties or similar.

3. Power

Connect the provided power cable to the DC power input of the sensor enclosure (4-pin) and the other end (XT-30) to a regulated DC power supply. Although the enclosure calls out 11-15V DC, the 18V DC output under the Matrice 600 (Pro) is acceptable for powering the PoLRa.

Other drones such as the Freefly Alta X provide an optional 12V XT-30 or XT-60 output. XT-60 can be adapted down to XT-30. The PoLRa may also be powered by a standalone 3S LiPo (Lithium Polymer) which can be procured with XT-30 connector directly

4. IR Sensor



The PoLRa ships with the Infrared (IR) sensor reversed for protection while transporting. Use a 4mm allen wrench to loosen the M5 screw securing the sensor holder to the aluminum C-rail. Rotate 180 degrees and resecure.

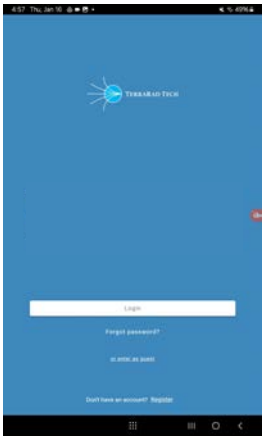
5. Sensor configuration

Please download the TerraRad mobile app from the google play app store (Android only), download and install the app named “TerraRad” NOT app named “turfRad” by TerraRad Tech AG.:

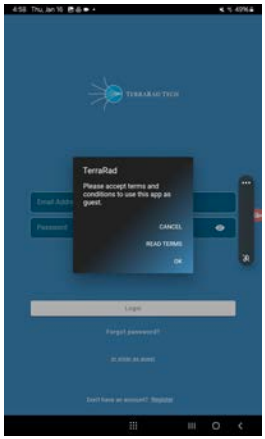
Once you have installed the app, make sure:

1. The sensor has **power** (LED around the around RESTART button is on)
2. The GPS antenna is mounted and connected.
3. You are outside with a clear view of the sky
4. You have access to **WIFI** (hotspots via LTE also work)
5. You have enabled **Bluetooth** on your android phone or tablet
6. Confirm that the LED light around the FUNCTION button is blinking slowly, this confirms that GPS satellite signal has been acquired.

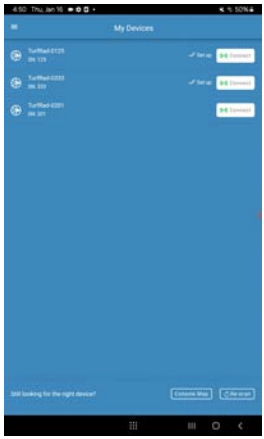
Follow steps 1 – 12 if this is your first time setting up the TerraRad sensor.



1. Login: Register or Enter as Guest



2. Accept the terms and conditions.



3. The app searches on Bluetooth for your TerraRad sensor.

Click the white "Connect" on the right of your sensor name/serial number to start the configuration.

Note: do not Pair or connect to the sensor with the settings of your phone, this app handles that part.

4. If your device was not factory configured to PoLRa mode, you will need to accept the prompt to convert your sensor into a manually operating “Research” TerraRad sensor. Click “Configure”.

5. Allow the sensor to “Pair” with your phone. Select “Pair” to continue.

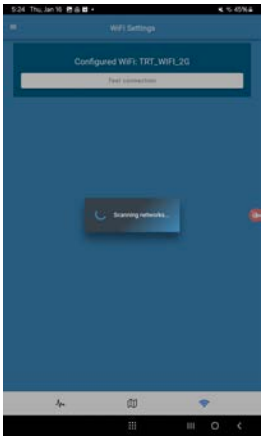
6. You are brought to the default map screen which shows the location of the sensor relative to your mobile device.

Tabs:

	Display and check status of sensor
	View and configure sensor location and facility radius
	Change and test WIFI network settings

Note: If you do not see the sensor icon in step 8:
It can take up to 20 minutes to get GPS signal the first time you power on the sensor. If you only just powered on the sensor wait three to five minutes.

Check that the GPS antenna is properly attached and has a clear view of the sky.



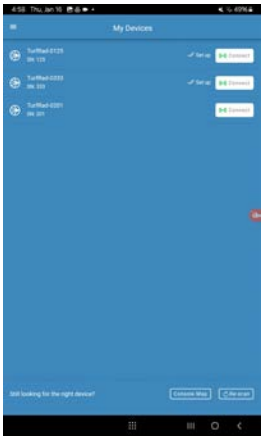
7. The Wifi tab in the app allows you to configure a new or different Wifi network. It will first scan for available networks.

8. The list of available Wifi networks will be provided.

9. Select your Wifi network and enter the password. Once configured you may optionally run the Wifi connection test with the “Test Connection” button near the top of the screen.

10. The Sensor Status tab provides a summary of the sensor details including the pending files, and valid GPS signal.

11. Disconnect the Bluetooth connection to the sensor by selecting the menu icon (top left) and clicking “Disconnect” on the bottom left.



12. You will be brought back to the home / Device list screen.

6. Sensor Operation

6.1. Starting a Measurement

Measurements are started by pressing the Function button when:

- The sensor has already powered up and entered “Idle” state, slow blinking Function LED.
- The sensor has GPS fix, indicated by the slow-flashing Function LED
- Upon bootup, the sensor will attempt to connect to WIFI to upload un-sent (pending) files check for over the air (OTA) firmware updates (fast blink of Function LED within 90 seconds of startup) if the configured WIFI network is not reachable, the sensor will exit WIFI mode and return to “Idle” within ~30 seconds or after 3 attempts.

Pressing the Function will trigger a rising beep sequence, solid Function LED and begin logging measurements.

To stop measurements, press the Function button again. The sensor will connect to WIFI and upload data automatically (fast flashing Function LED).

6.2. Internal Storage

The PoLRa has 32 GB of onboard storage to save data locally. With 1.13 KB/s storage rate, 3.88 MB/hr, you can store roughly 8000 hours of data before uploading, almost 1 year continuously. Files are cleared from internal storage after cloud upload is complete and verified.

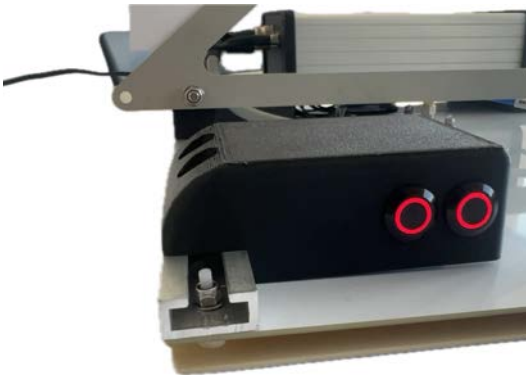
6.3. Internal Battery

Your TerraRad sensor has a small internal battery to allow the sensor to upload data after you turn off the power source.

The battery charges automatically from source power (max 0.4 A current draw) and the sensor turns itself off after 20 minutes, after completing data upload and update check.

6.4. Buttons and LEDs

Your TerraRad PoLRa sensor is equipped with 2 buttons and 2 LED indicator lights to provide you with information on the state of the sensor and allow manual intervention.



Restart button If your sensor is powered, this button restarts your sensor. This can

	occasionally be helpful if experiencing issues with uploads or during any support issues. If the sensor is not powered (on battery) this turns off the sensor.
Function button	This button starts a measurement in “manual” mode. Press the button to start, and press again to stop, data collection.
Restart LED Light	This LED around the Restart button is lit anytime the sensor is powered (or on internal battery power)
Function LED Light	This light has 4 possible states: **Off:** The sensors does not have GPS fix **Constant On:** Data collection in process **Slow Flash:** The sensor has GPS signal lock (location) and is in “idle” mode in the facility. **Quick Flash:** The sensor is connected to WiFi, checking for updates (on power-on) or uploading data.

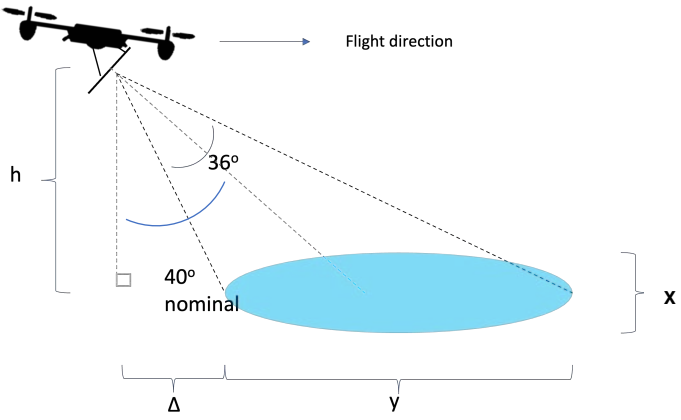
Note: Do not worry if the power LED stays on after you turn off your equipment. The sensor is powering itself from battery power.

6.5. Buzzer / Chirp

The TerraRad sensor has a multitone beep / chirp. Don't be surprised if you hear it beeping at you.

Startup	4 beeps
GPS position lock	2 beeps
Measurement start	4 beeps (low-high-low-high)
Upload complete	3 beeps (high-med-low)

7. Footprint Size



Ground footprint dimensions for various sensor heights above ground (meters):

h (m)	x (m)	y (m)	delta (m)	Footprint Area (m^2)
5	3.2	6.0	3.1	15
7	4.5	8.4	4.4	30
10	6.5	12.0	6.2	61
15	9.7	17.9	9.4	137
20	13.0	23.9	12.5	244
30	19.5	35.9	18.7	550
40	26.0	47.9	25.0	977
50	32.5	59.8	31.2	1526
70	45.5	83.7	43.7	2992
100	65.0	119.6	62.5	6106

Ground footprint dimensions for various sensor heights above ground (feet):

h (ft)	x (ft)	y (ft)	delta (ft)	Footprint Area (ft^2)
10	6.5	12.0	6.2	61.1
20	13.0	23.9	12.5	244.2
30	19.5	35.9	18.7	549.5
50	32.5	59.8	31.2	1526.4
60	39.0	71.8	37.5	2198.1
75	48.7	89.7	46.9	3434.5
100	65.0	119.6	62.5	6105.8
150	97.5	179.4	93.7	13737.9
200	130.0	239.3	125.0	24423.0
300	195.0	358.9	187.5	54951.8

8. Flight Planning

8.1. Planning Software

We recommend using an automatic flight planning software, flying in Waypoint, Grid or Survey mode and NOT FLYING THE DRONE MANUALLY when using the PoLRa. Options include QGroundControl for PixHawk based controllers, and Litchi for DJI open-SDK models. Various other options exist.

As the PoLRa is autonomously operated, the specific planning software or flight application used is independent.

8.2. Grid Spacing

The PoLRa does not stitch images together like many other drone-based remote sensing imagers. The footprint represents a single measurement, sampled 10 times per second, as the drone flies. The ability to interpolate an image comes from the footprint measurements at various GPS locations. If 100% coverage (measurements over complete area of interest) is desired, the width between flight lines should not exceed the footprint width x.

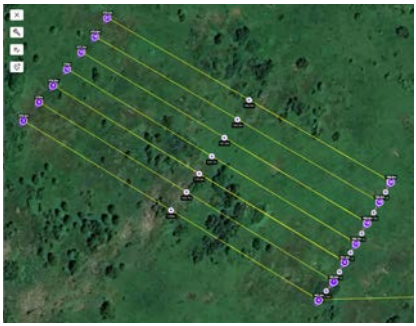
There is a tradeoff between achievable resolution, flight altitude, flight time, and size of the Area of Interest. Achieving high resolution over a large area will require low flight altitude and high flight time.

8.3. Heading

The antenna should always point ahead of or behind the direction of flight. Configuring the flight such that the PoLRa is looking 'sideways' is not advised as the variable pitch angles of the drone will introduce variability in the vertical and horizontal polarization geometry with respect to the ground surface.

Depending on the drone (UAV) platform, landing gear restrictions, etc., the antenna may need to be mounted such that it is not looking in the standard forward flight direction. In this case, it is advised to configure the flight plan with a yaw angle (if possible, e.g. on multicopter drones) such that the PoLRa antenna will be looking in the direction of flight.

8.4. Dual-angle Flights



If setting a constant yaw angle is possible from the drone (UAV) flight planning software, it is also possible to perform measurements at two effective incidence angles. A multicopter drone will pitch up to move forward and pitch down to move backward. By programming flightlines with both a pass with the antenna looking forward and behind relative to the flight direction, incidence angle variation of 15-30 degrees can be achieved providing more 'time on target' and more independent information over each sample area.

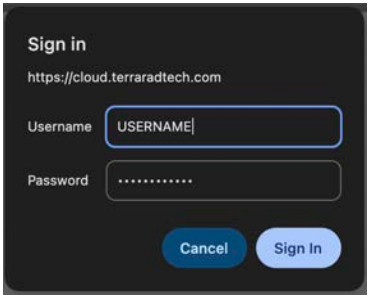
9. Data and Processing

The PoLRa uploads data to a secure and backed-up cloud storage operated by TerraRad Tech AG and hosted by Microsoft Azure.

cloud.terraradtech.com

9.1. Login

First step is getting logged in to the TerraRad cloud platform. Use the Username and Password provided for your institution license. This login may be shared with colleagues and collaborators.



9.2. Select Sensor

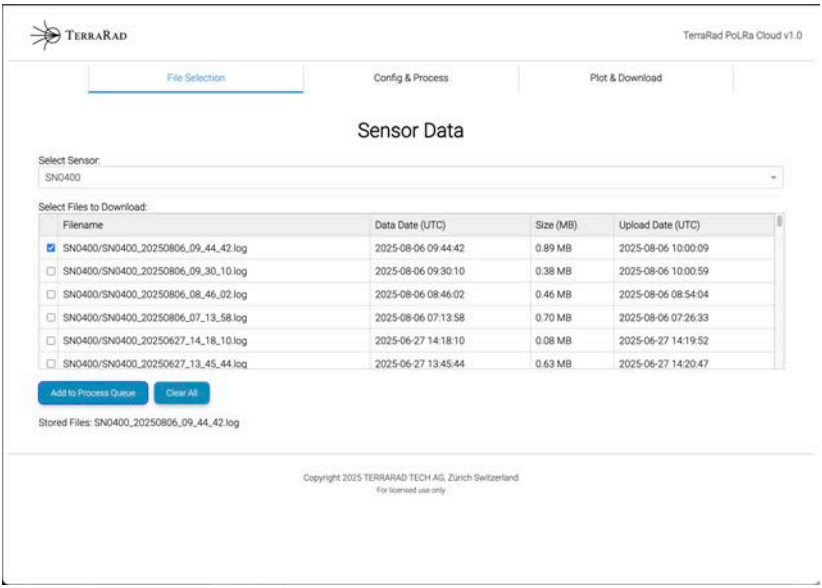
Select your sensor serial number from the “Select Sensor” dropdown.

9.3. File Selection

In the “Select Files to Download” table you will see a listing of data files collected by your PoLRa ordered from newest to

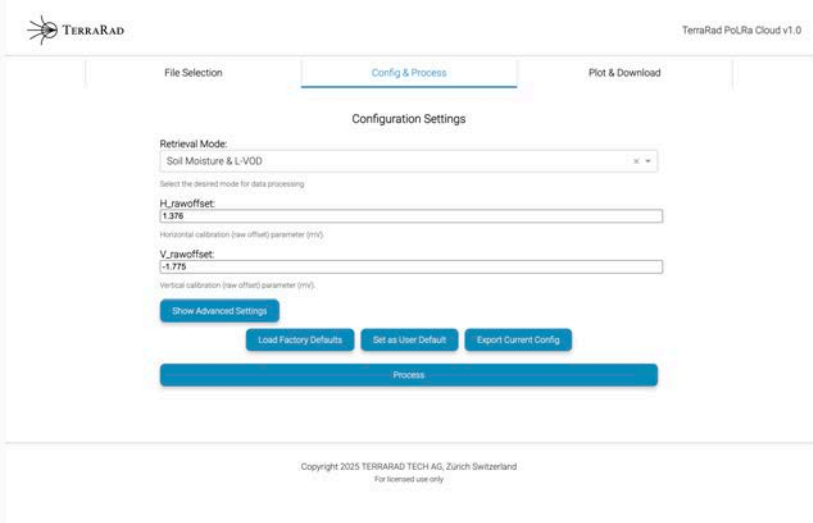
oldest. Place a checkmark on the file(s) you wish to analyze and click “Add to Process Queue”.

Note that if you select multiple files they will be appended to eachother and processed with the same settings. If you would like to apply different configuration settings or visualize the data separately please process one file at a time.



After downloaded the data file from cloud storage to the processing server your data file(s) will be listed in “Stored Files” underneath the table. The files are still in a raw binary format and need to go through processing before downloading directly to your local computer.

9.4. Configuration and Processing



The basic Config & Process tab provides a dropdown for Retrieval Mode, and inputs for raw voltage offsets, calibration parameters.

Retrieval Mode	**Description**
Soil Moisture	Retrieve soil moisture using a fixed L-band Vegetation Optical Depth (L-VOD)
Dielectric Constant	Retrieve raw soil dielectric constant (real part)
Soil Moisture & L-VOD	Dual parameter retrieval of soil moisture and L-VOD

The H_rawoffset and V_rawoffset parameters may be provided from basic factory calibration of your sensor, or they can be determined by cold-sky calibration measurements.

9.5. Config & Process: Advanced Settings

This sections provides a description of each setting in the advanced Configuration Settings menu.

Setting Parameter	Description
int_time	Integration time for single port in seconds
toffset	Time offset in seconds from UTC, use if you want plots in local time
tau	Fixed L-VOD, e.g. 0 for bare soil, 0.03-0.3 for grass, 0.3 – 1.5 for dense forest, this is used in Dielectric and Soil Moisture Retreival Mode, tau is retrieved in Soil Moisture & L-VOD mode
omega	Single scattering albedo from Tau-Omega model
hpars[0], vpars[0]	Slope of Active Cold Source brightness temperature vs Active Cold Source physical temperature (K/K) for H and V pol. respectively
hpars[1], vpars[1]	Offset of Active Cold Source brightness temperature vs Actice Cold Source physical temperature (K) for H and V pol. respectively.
hpars[2], vpars[2]	Cable loss for H and V pol. in -dB
varminw	Minimum constraint for soil moisture or Dielectric Constant in retrieval.
varmaxw	Maximum constraint for soil moisture or Dielectric Constant in retrieval.
H_bias, V_bias	Apply constant brightness temperature bias to H pol./ V pol. (K)
stdthresh	Filter based on subsample voltage standard deviation. This is the maximum value for filter (mV)

cfthresh	Filter based on Cost Function value (residual) from numerical optimization of Tau-Omega model
madfiltbool	Enable Rolling Median Absolute Deviation filter of raw voltages
spikefilterbool	Enable Spike filter (whole file Median Absolute Deviation)
cablecorrbool	Enable cable loss correction for both polarizations
mnwindowsz_cal	Window size for smoothing of calibration voltages
mnwindowsz_miss	Number of required valid values within Window to consider valid sample
modestr	h, v, or dual. Run retrieval on single or dual polarization
imupitchdronebool	Enable using of the incidence angle from the internal sensor IMU, if enabled incidence_angle is ignored. Recommended for drone-based use.
incidence_angle	Fixed incidence angle of sensor to ground from nadir. Default mount is 40 degrees.
soil temp API Boolean	Use 6 cm soil temperature from weather model, Openmeteo API.
vegetation temp from IR	Use infrared temp sensor for vegetation temp. If disabled assumes vegetation temp is equal to soil temp
varmintau	Minimum constraint for L-VOD in retrieval. Used only for Soil Moisture & L-VOD retrieval mode
varmaxtau	Maximum constraint for L-VOD in retrieval. Used only for Soil Moisture & L-VOD retrieval mode
roughness parameter H	Surface roughness parameter H from HQN roughness model, applied to Fresnel reflectivity

roughness parameter Q	Surface roughness parameter Q from HQN roughness model, applied to Fresnel reflectivity
roughness parameter n H pol. / V pol	Surface roughness parameter n from HQN roughness model, applied to Fresnel reflectivity, polarization specific (H pol. or V pol.)
shift sensor footprint by lookdirection	Standard geometry correction to GPS coordinates to geolocate sensor footprint on ground, requires height above ground (flight altitude for drone-based measurements)
use IMU yaw	Uses the yaw angle from the internal IMU to determine the look angle of the antenna.
height of antenna sensor above ground / drone flight altitude	Height of the antenna center above ground surface (drone flight height) in meters (m). Considers flat surface for footprint projection.
direction of antenna relative to direction of motion	Orientation direction of the antenna relative to the direction of motion. Standard for drone-based sensor is front. Can be front, back, left, right.
anglenormbool	Enable pitch / incidence angle normalization using 3rd order fit. Corrects for extreme pitch manoeuvres, recommended for drone-use.
anglenorm	Incidence angle in degrees to normalize to, used if anglenormbool is Enabled.

9.6. Config & Process: Controls

Once Config parameters are set, Pressing the Process button will begin the file processing.

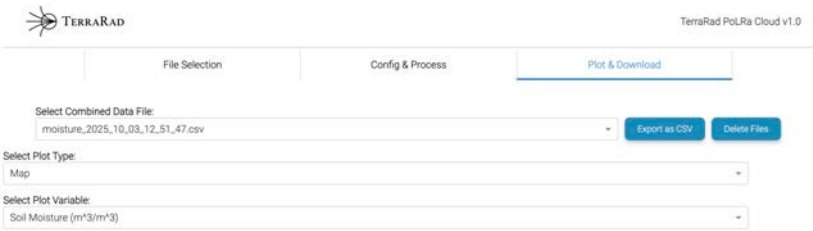
Button	Action
Load Factory Defaults	Return Config settings to factory defaults
Set as User Default	Store current Config parameters as default. Provides a confirmation: ✅ saved as user default
Export Current Config	Export and save current configuration parameters to local file
Process	Start file processing

Config & Process Controls:

Loading bar may take up to 20 min for large data files

9.7. Plot & Download

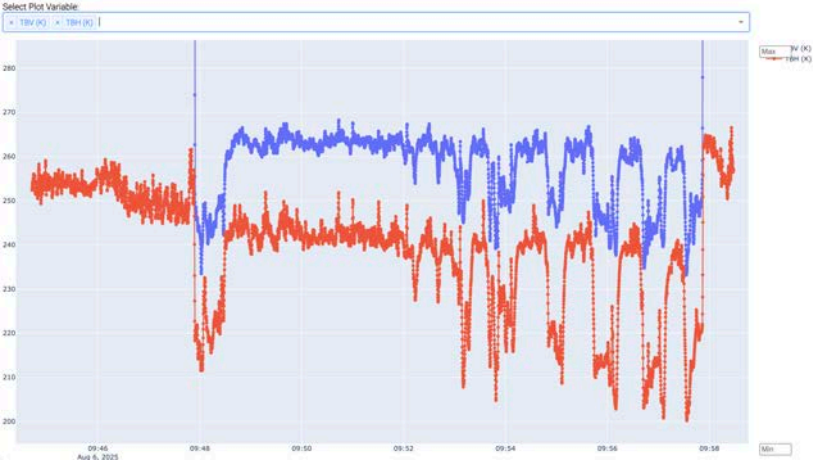
The Plot and Download tab allows you to visualize your result



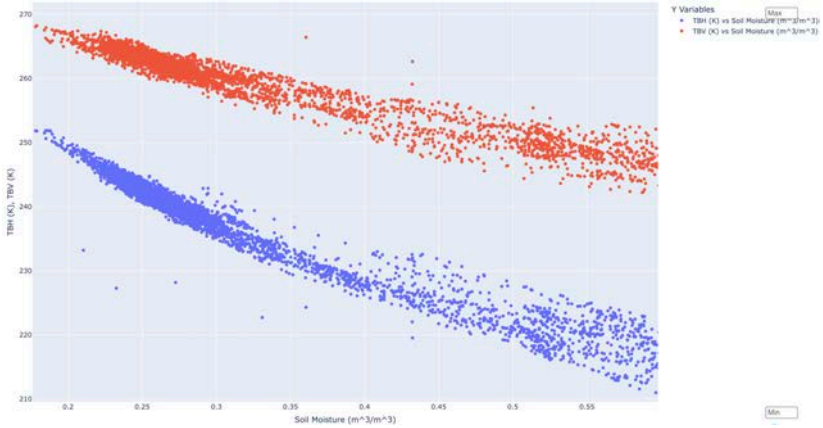
Control	Behavior
Select Combined Data File	Plot data from various processing options. This file takes the timestamp from processing time in UTC.
Export as CSV	Export full data file to csv and download. It may take a few seconds for the download dialogue to appear
Delete Files	Clear all processed files in Select Combined Data dropdown, map will clear
Select Plot Type	Choose plot type between: Map, Timeseries, Scatter
Select Plot Variable	Visualize any of the raw parameters from the data file. Multiple selections allowed in timeseries and scatter type.
Grid Size [m]	Grid size for standard grid
Calculate Gridded Data	Bin and grid data to regular square grid cells of size Grid Size. The interpolated file

Example of Raw Map:

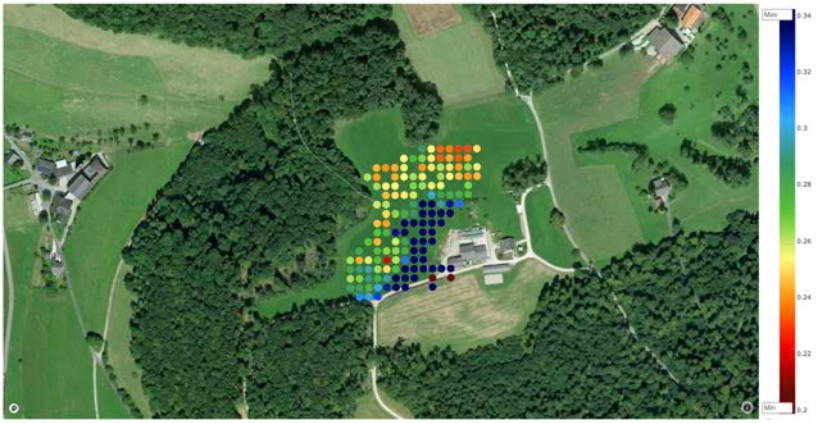
Example of Timeseries:



Example of Scatter:



Example of Gridded Data Map:



Example of Pearson Correlation:

	# pass time	Latitude	Longitude	X	Y	Soil Moisture	TBV (K)	TBH (K)	CF (K^2)	TBV theory (K	TBH theory (K	TBV pitch fit	TBH pitch fit	Pitch angle (	Roll angle (d	Yaw angle (de	Altitude (m)	T_RS
# pass time	1	-0.13	-0.52	-0.52	-0.12	0.03	-0.66	-0.49	-0.68	-0.47	-0.51	-0.23	-0.12	-0.08	0.27	-0.74	0.16	-0.95
Latitude	-0.13	1	0.15	0.16	1	0.15	-0.48	-0.01	-0.52	-0.05	-0.04	-0.18	-0.13	-0.05	0.19	-0.5	0.09	0.26
Longitude	-0.52	0.15	1	1	0.14	-0.32	0.47	0.23	0.48	0.16	0.14	0.19	0.09	0.1	-0.19	0.48	-0.18	0.51
X	-0.52	0.16	1	1	0.15	-0.31	0.46	0.23	0.48	0.16	0.14	0.19	0.09	0.1	-0.19	0.47	-0.18	0.52
Y	-0.12	1	0.14	0.15	1	0.15	-0.48	-0.01	-0.52	-0.05	-0.04	-0.18	-0.13	-0.05	0.19	-0.51	0.09	0.25
Soil Moisture	0.03	0.15	-0.32	-0.31	0.15	1	-0.85	-0.95	-0.78	-0.99	-0.96	-0.16	-0.11	-0.04	0.21	-0.7	0.26	-0.54
TBV (K)	-0.66	-0.48	0.47	0.46	-0.48	-0.85	1	0.7	0.99	0.91	0.95	0.29	0.2	0.08	-0.31	0.93	-0.29	0.53
TBH (K)	-0.49	-0.01	0.23	0.23	-0.01	-0.95	0.7	1	0.6	0.36	0.23	0.08	0.06	0.03	-0.17	0.48	-0.22	0.45
CF (K^2)	-0.68	-0.52	0.48	0.48	-0.52	-0.78	0.99	0.6	1	0.85	0.91	0.3	0.21	0.09	-0.32	0.95	-0.28	0.53
TBV theory (K	-0.47	-0.05	0.16	0.16	-0.05	-0.99	0.91	0.36	0.85	1	0.99	0.19	0.04	0.01	-0.1	0.44	-0.11	0.39
TBH theory (K	-0.51	-0.04	0.14	0.14	-0.04	-0.96	0.95	0.23	0.91	0.99	1	0.22	0.05	-0.01	-0.07	0.45	-0.06	0.42
TBV pitch fit	-0.23	-0.18	0.19	0.19	-0.18	-0.16	0.29	0.08	0.3	0.19	0.22	1	0.36	0.54	-0.08	0.3	-0.05	0.2
TBH pitch fit	-0.12	-0.13	0.09	0.09	-0.13	-0.11	0.2	0.06	0.21	0.04	0.05	0.36	1	-0.51	-0.19	0.2	-0.05	0.12

9.8. Export as CSV

When you export the data as CSV (comma delimited ASCII file), you will get a csv with between 34-37 columns, depending on config settings. The below table details each header parameter and column in the exported CSV. This csv can be imported into various softwares and IDEs including QGIS, ArcGIS, Excel, Python, Matlab, R, etc., for further processing or analysis.

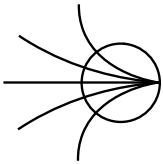
Header Variable	Description
posix time	Timestamp in POSIX format (seconds since Unix epoch).
datetime	Human-readable timestamp in ISO 8601 format.
Latitude	Geographic latitude in decimal degrees.
Longitude	Geographic longitude in decimal degrees.
X	UTM Easting (m).
Y	UTM Northing (m).
Soil Moisture (m^3/m^3)	Estimated volumetric soil moisture content.
Tau (-)	Retrieved L-VOD, present for Retrieval Mode Soil Moisture & L-VOD.
Dielectric (-)	Retrieved real part of the relative dielectric constant, present for Retrieval Mode Dielectric.
TBV (K)	Brightness temperature in vertical polarization.
TBH (K)	Brightness temperature in horizontal polarization.
CF (K^2)	Cost Function value (least squares residual).

TBV theory (K)	Modelled theoretical brightness temperature (vertical).
TBH theory (K)	Modelled theoretical brightness temperature (horizontal).
TBV pitch fit (K)	Fit of TBV vs pitch angle.
TBH pitch fit (K)	Fit TBH vs pitch angle.
Pitch angle (deg)	Platform pitch angle in degrees.
Roll angle (deg)	Platform roll angle in degrees.
Yaw angle (deg)	Platform yaw/heading angle in degrees.
Altitude (m)	Altitude of the sensor above WGS-84 reference ellipsoid in meters.
T_RS	Resistive source physical temperature (K).
T_ACS	Active cold source physical temperature (K).
T_IR	Infrared surface temperature (K).
T_Ant	Antenna/Ambient physical temperature (K).
u_RS (mV)	Measured voltage corresponding to resistive source.
u_ACS (mV)	Measured voltage corresponding to active cold source.
u_V (mV)	Measured voltage for vertical polarization channel.
u_H (mV)	Measured voltage for horizontal polarization channel.
STD(u_RS) (mV)	Standard deviation of voltage subsamples; reference source.
STD(u_ACS) (mV)	Standard deviation of voltage subsamples; active cold source.

STD(u_V) (mV)	Standard deviation of voltage subsamples; vertical channel.
STD(u_H) (mV)	Standard deviation of voltage subsamples; horizontal channel.
Kurt(u_RS) (mV)	Kurtosis of reference source subsample voltage distribution.
Kurt(u_ACS) (mV)	Kurtosis of cold source subsample voltage distribution.
Kurt(u_V) (mV)	Kurtosis of vertical channel subsample voltage distribution.
Kurt(u_H) (mV)	Kurtosis of horizontal channel subsample voltage distribution.
Gain (K/mV)	Radiometer calibration gain factor.
Offset (K)	Radiometer calibration offset.

Questions?

Please direct your inquiries to support@terraradtech.com



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