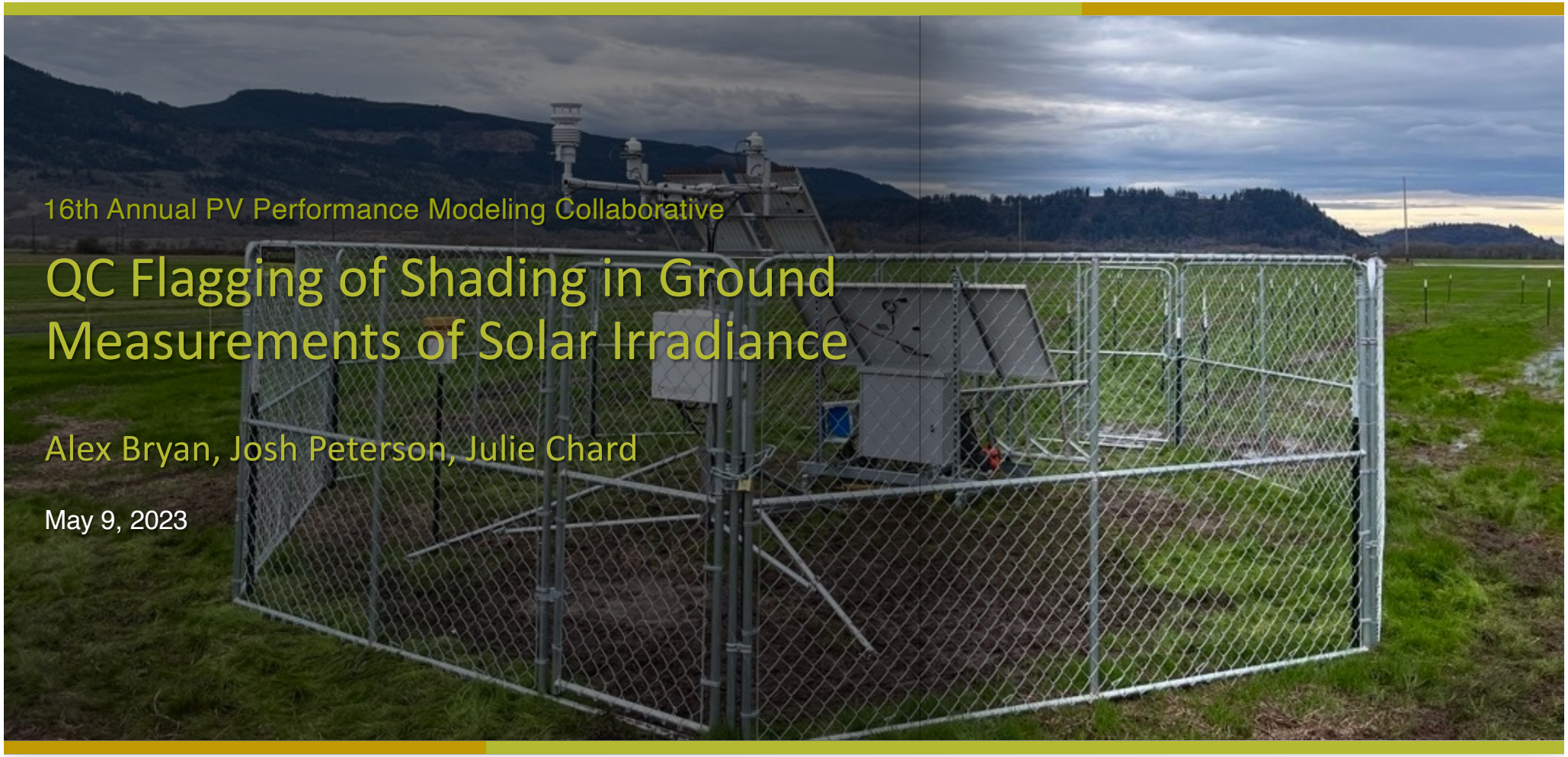


16th Annual PV Performance Modeling Collaborative

# QC Flagging of Shading in Ground Measurements of Solar Irradiance

Alex Bryan, Josh Peterson, Julie Chard

May 9, 2023

# GROUNDWORK'S SITING PROTOCOL AIMS TO AVOID SHADING

GroundWork

GroundWork Renewables, Inc.

GroundWork

Rey MET System Siting Information & Requirements

To ensure a smooth and successful installation, GroundWork requires a clear understanding of site conditions prior to field work. Your cooperation in completing this form in a detailed and timely manner is greatly appreciated. Please secure land control and any required permits before project scheduling.

Safety is our number one priority. For this reason, our client is responsible for identifying and disclosing to GroundWork any job site hazards and considerations, including but not limited to underground utilities, hunting activity, and electrified fencing.

**Please include this completed form upon delivery of the project KMZ.** The KMZ should include property boundaries and preferred and alternate coordinates, if available. Please contact your dedicated project manager with any questions.

General information:

The Rey meteorological (MET) system is a stand-alone, self-powered, rugged weather system which provides solar meteorological data for solar resource assessment. The system includes the MET tripod with a battery power unit (Figure 1) and may include an albedometer tripod (Figure 2).

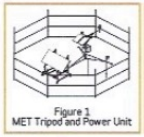


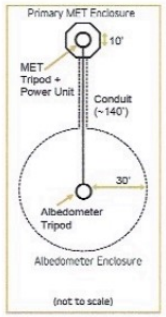
Figure 1
MET Tripod and Power Unit

Figure 2
Albedometer Tripod

Footprint of the MET System

- The MET tripod and power unit will typically be enclosed within an octagonal chain link fence with panels that are 10 feet in length and 6 feet high.
- The albedometer will be mounted on a separate tripod, approximately 140 feet from the main MET enclosure, typically to the south. The albedometer is connected to the MET tripod by an above-ground cable, jacketed in a flexible conduit, and is surrounded by a low-impact fence.
- A wire and t-post enclosure will be installed in a 30-foot radius, centered on the albedometer and running along either side of the conduit.

  For high growing crops such as corn, a 40-foot radius enclosure will be installed. For livestock, 3-strand barbed wire fencing will be installed in place of visibility tape.
- Sensors on the MET tripod are mounted at a height of approximately 8 feet, while the albedometer sits at a height of approximately 5 feet.




Proprietary & Confidential

Q: Would the landowner like a courtesy call in advance of our field team's arrival? If so, via text or phone call?
A: Yes. Contact landowner with a phone call.

Q: Are there access restrictions such as locked gates? The local technician will require weekly access. If yes, will codes/keys be provided? We can provide a shared padlock with code for both parties to use if needed.
A: NO

Q: Is the location accessible year-round? Please advise if 4-wheel drive is recommended.
A: Yes

Q: Is the area prone to theft or vandalism? If so, installation in a location that his highly visible to passing traffic should be avoided for security purposes.
A: No

Q: Does the area have cellular service through Verizon?
A: NO

Q: Are there possible hazards pertaining to ground penetration such as gas lines, waterlines, or utilities? If so, please make necessary calls to 811 ten (10) business days prior to our arrival.
A: Not to my knowledge

Q: Is there susceptibility to flooding or drainage, or proximity to bodies of water?
A: No

Q: Are there transmission/powerlines and poles near the site that may not be visible on the KMZ?
A: No

Q: What are the current groundcover conditions? Tall grass, tumbleweeds, etc.
A: Short grass

Q: Are there any nearby structures which could cause potential shading? Newly built structures, etc.
A: Storage



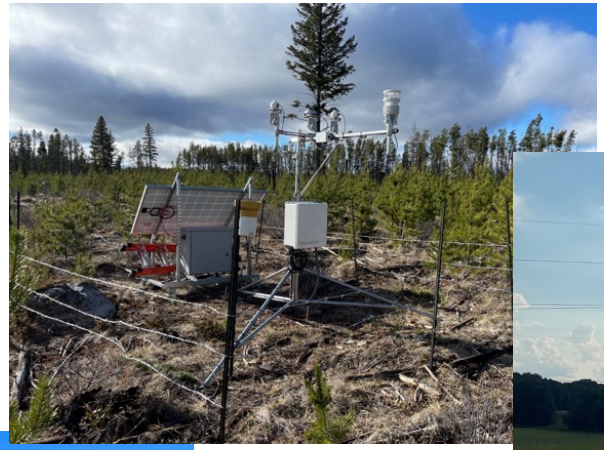


Siting Documentation & Questionnaire

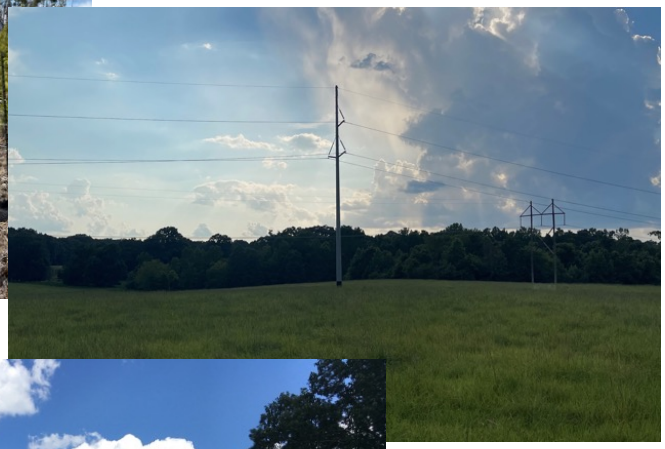
Siting photos & supplement solar pathfinder image

# SOME SHADING IS UNAVOIDABLE . . .

*Mountain ridges*



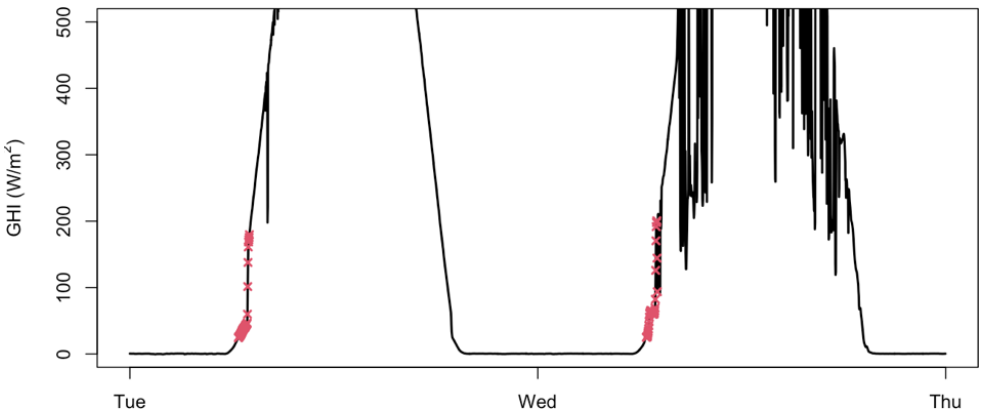
*Trees, power poles, cell towers, etc*



*Forest edge*

# THE GOAL: FLAG SHADED DATA

> *… Shading should only occur within a half hour of sunrise or sunset [1] …*




*We need a way to flag shading such that it is not considered in satellite tuning for solar resource assessment!*

[1] IEC 61724-1:2021 *Photovoltaic system performance - Part 1: Monitoring*. Section 8.2.3.
Available at https://webstore.iec.ch/publication/70170

## QC Flagging of Shading in Ground Measurements of Solar Irradiance

01 Challenges to Overcome

02 Tools to Overcome Them

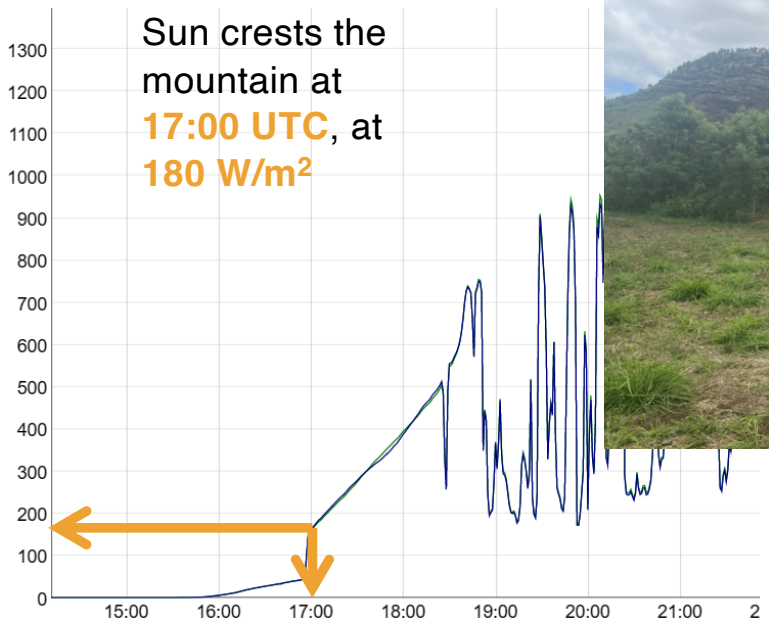
03 Application to 3 Diverse Shading Sources

## *Handling Temporal Data*

## *Handling Temporal Data*

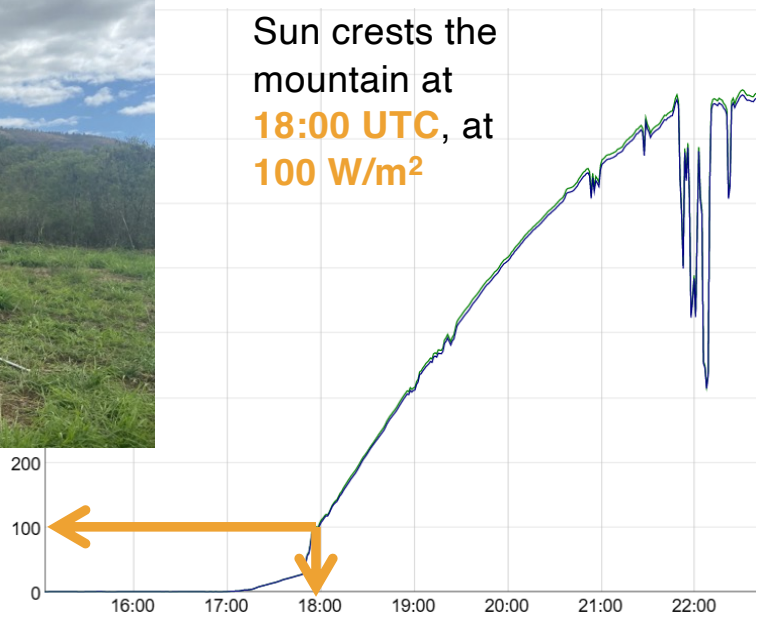
**Summer**

Sun crests the mountain at **17:00 UTC**, at **180 W/m²**

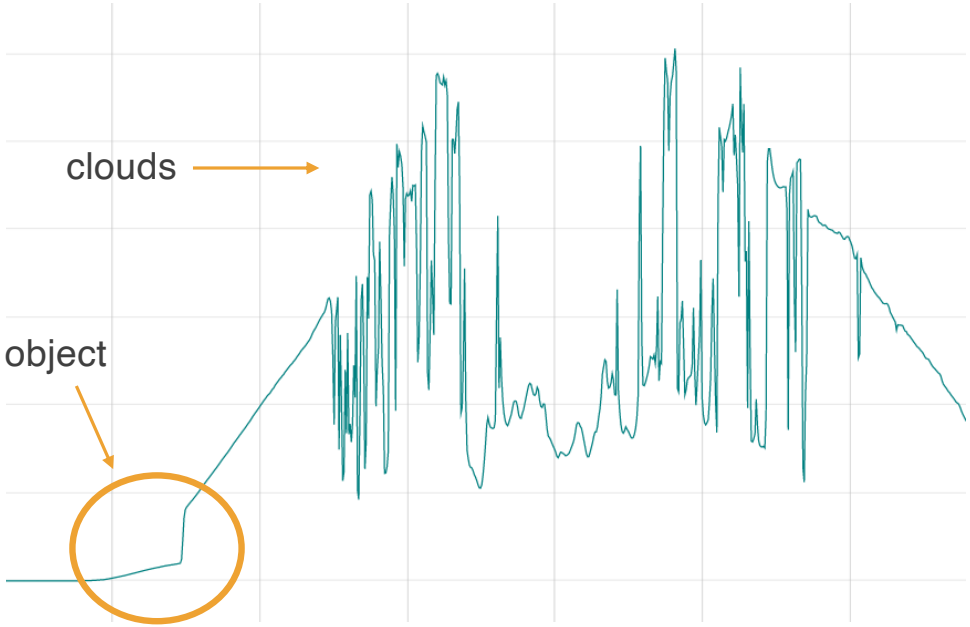


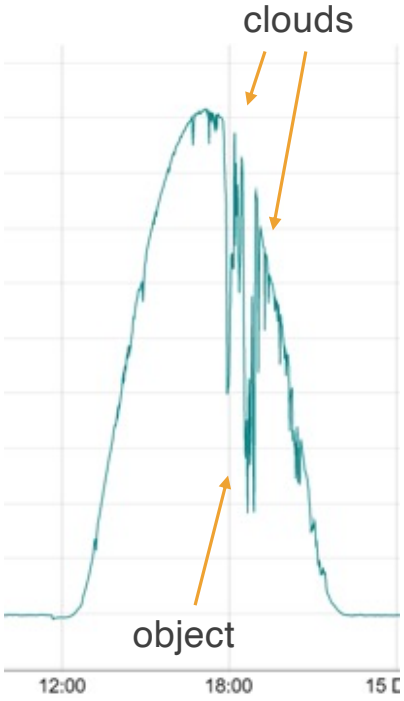

**Winter**

Sun crests the mountain at **18:00 UTC**, at **100 W/m²**



*Distinguishing clouds from objects*

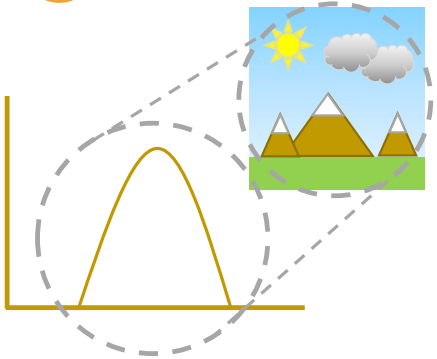


# TOOLS TO OVERCOME THEM

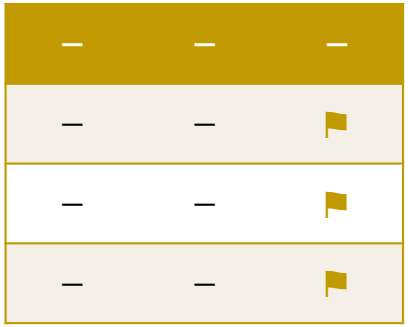
GroundWork

1 *Map out the sky*



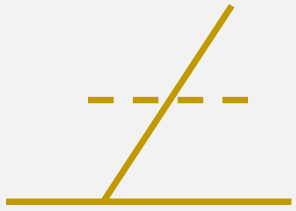
2 *Build polygon*

3 *Flag*



*A toolbox of other tools, as needed*

*Elevation Dependence Removal*

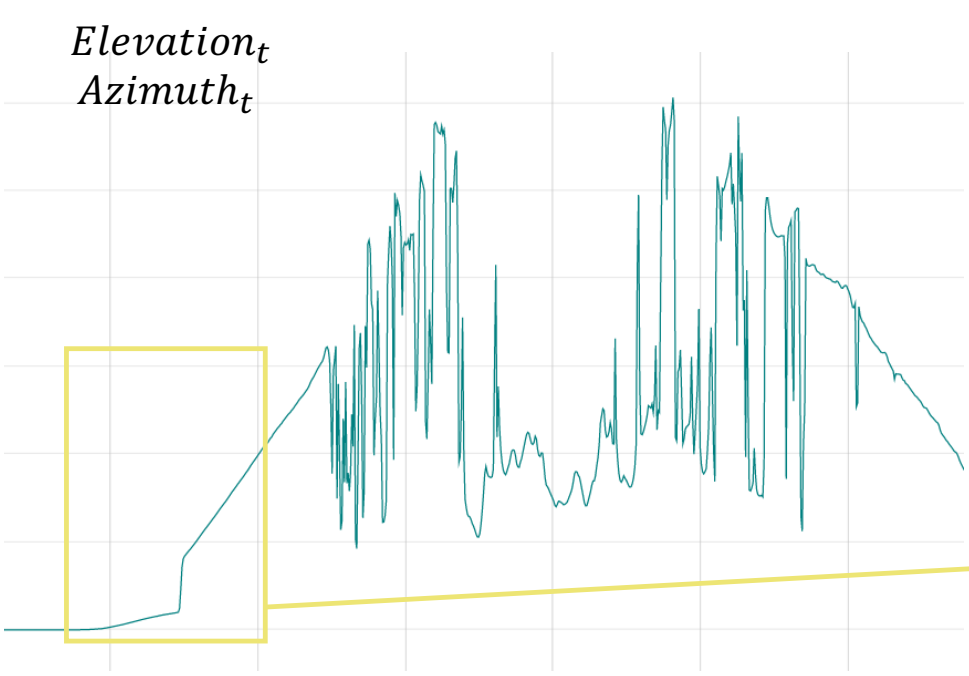


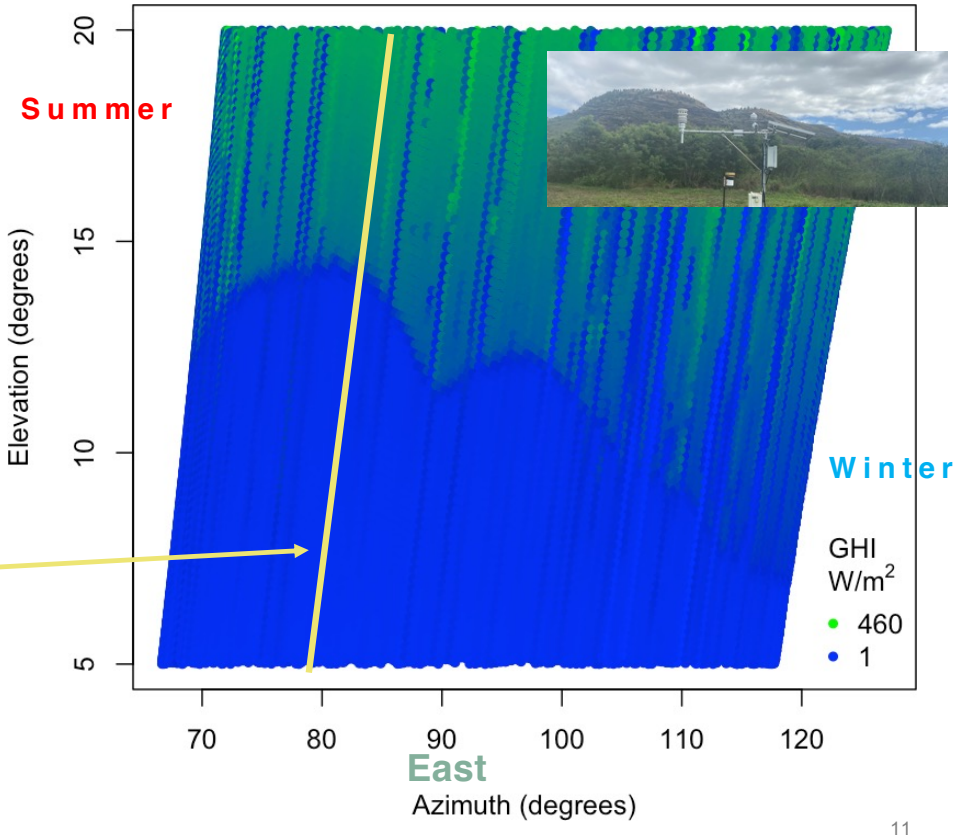
*Cloud filtering*

*Gaussian smoothing*

Calculate **solar position (elevation, azimuth)** at each **time** using a solar position calculator. [1]

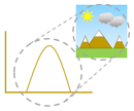
Plot each data point with respect to **elevation** (solar height) and **azimuth** (position in the sky; E, W, N, S).

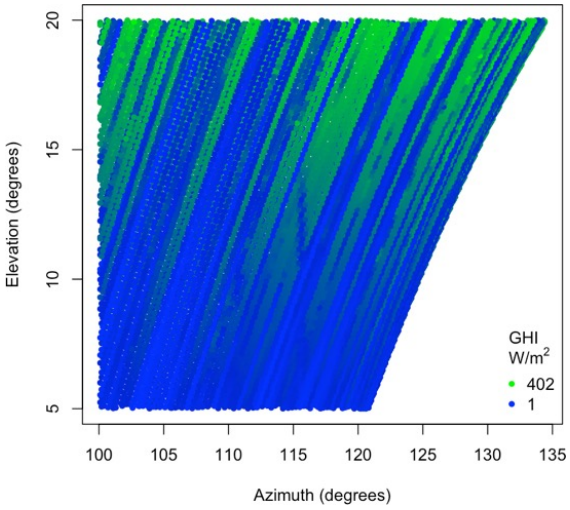


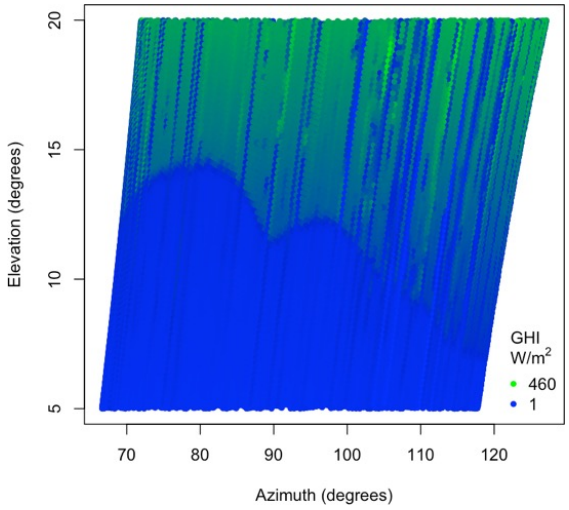



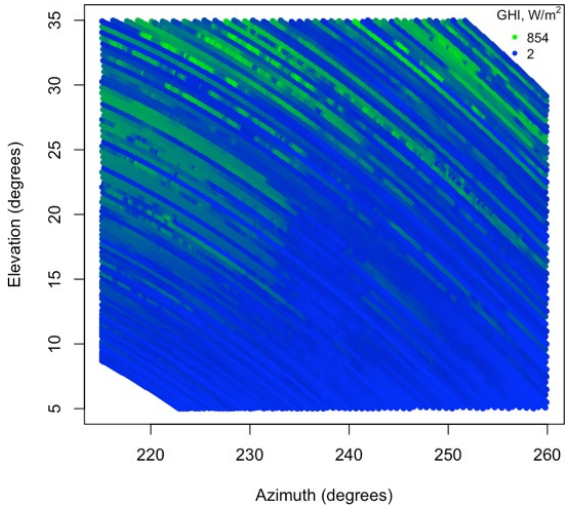

[1] Campbell Scientific on-board datalogger solar position calculator based on Solpos algorithm developed by NREL. See https://help.campbellsci.com/crbasic/cr1000x/Content/Instructions/solarposition.htm.

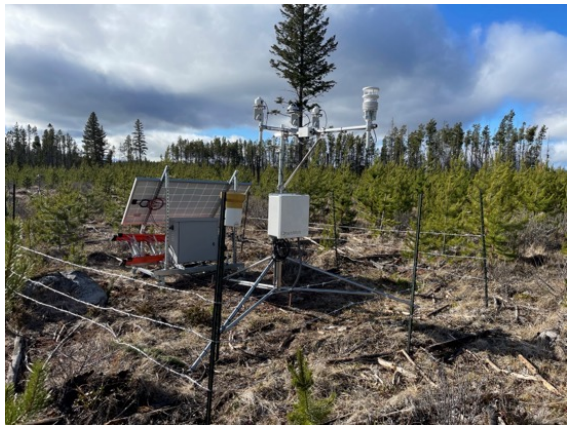
# 1. MAP OUT THE SKY





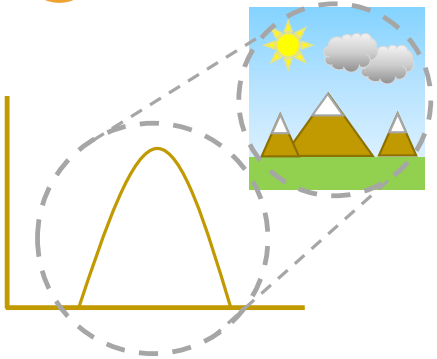



# TOOLS TO OVERCOME THEM

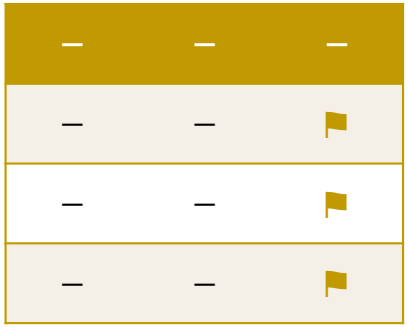
GroundWork

1 *Map out the sky*



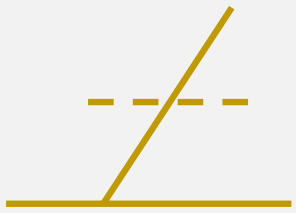
2 *Build polygon*

3 *Flag*



*A toolbox of other tools, as needed*

*Elevation Dependence Removal*



*Clear/cloudy normalization*

*Gaussian convolution*

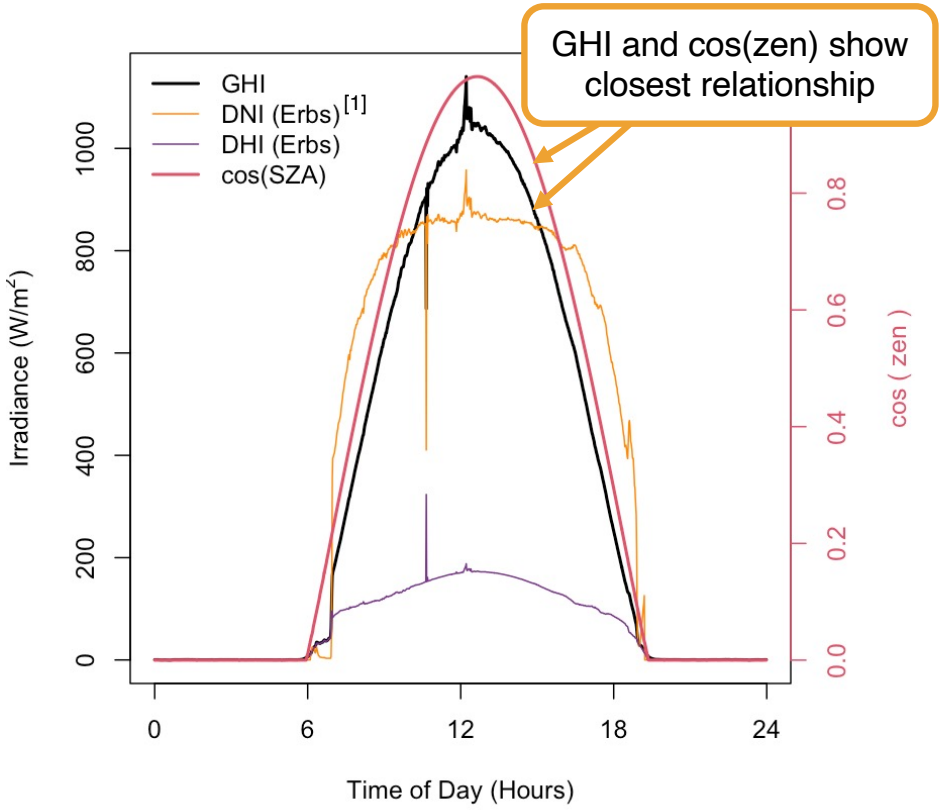
## Unify color distribution by removing elevation dependence

- Elevation dependence of GHI is linked to cosine of the zenith angle applied to DNI

$$GHI = DNI * \cos(zen) + DHI$$

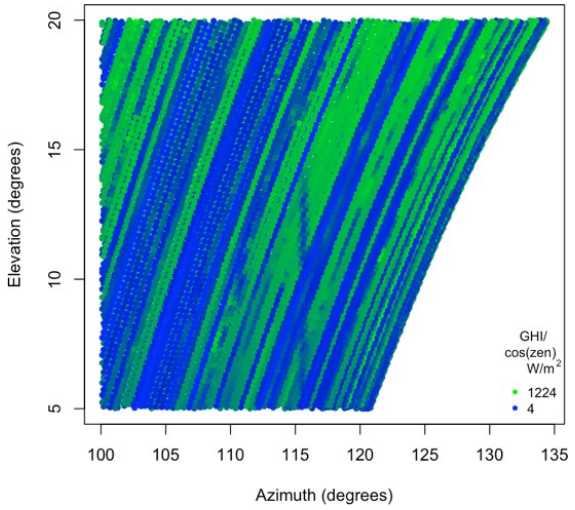
Global Direct Diffuse

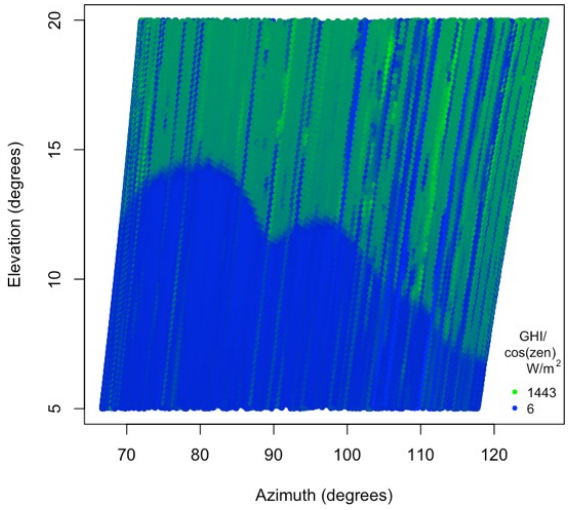
$$\frac{GHI}{\cos(zen)} = DNI + \frac{DHI}{\cos(zen)}$$

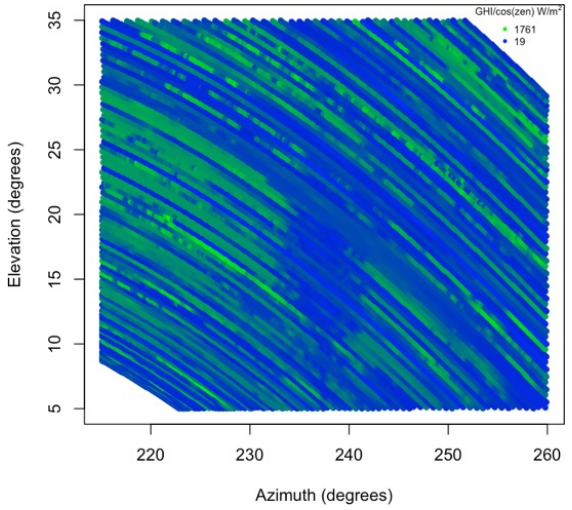



[1] Erbs, D. G., Klein, S. A., and Duffie, J. A., (1982). 'Estimation of the diffuse radiation fraction for hourly, daily and monthly-average global radiation', Solar Energy 28(4), pp 293-302.

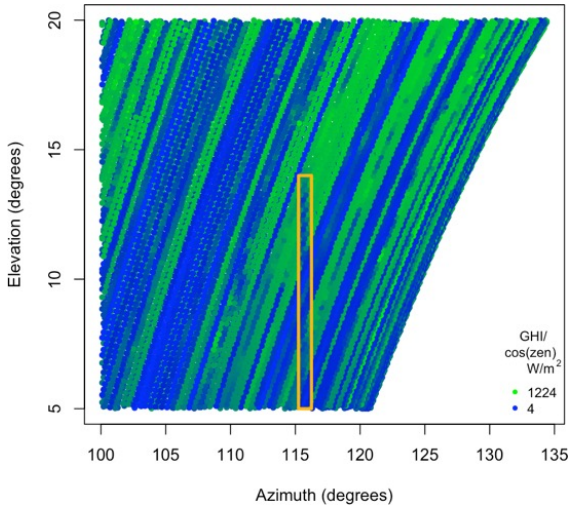
# ELEVATION DEPENDENCE REMOVAL

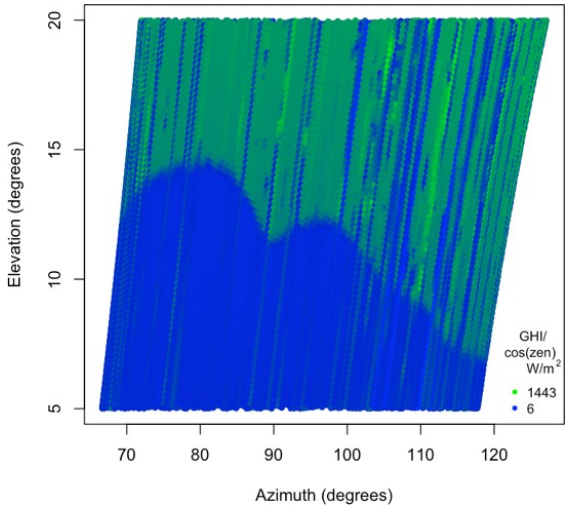


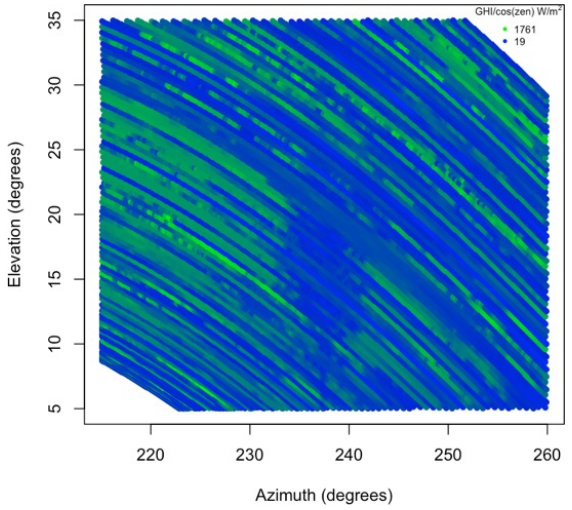



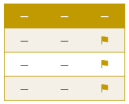

# 2. BUILD POLYGON



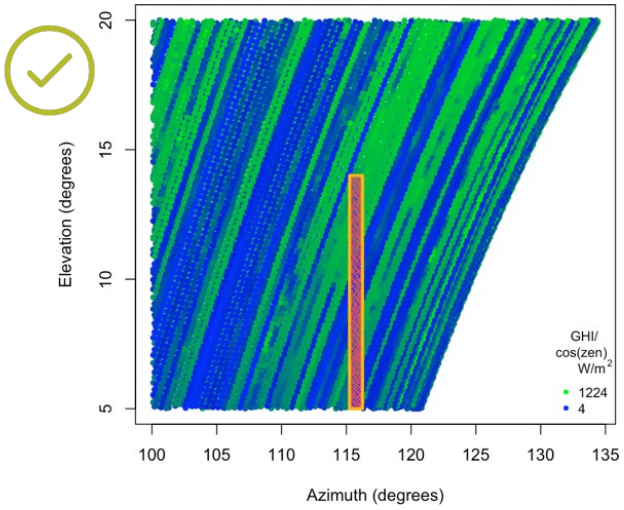



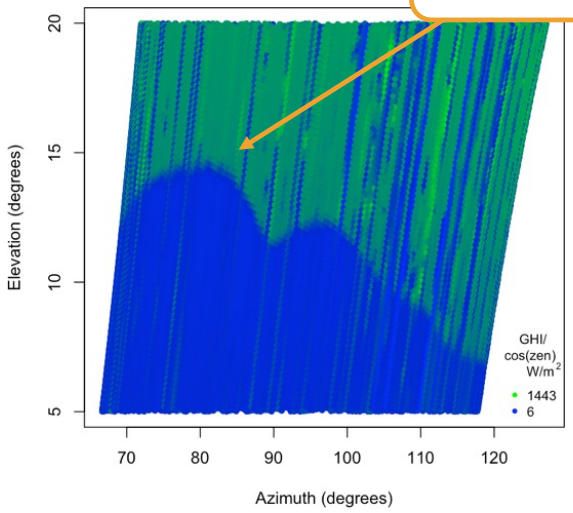



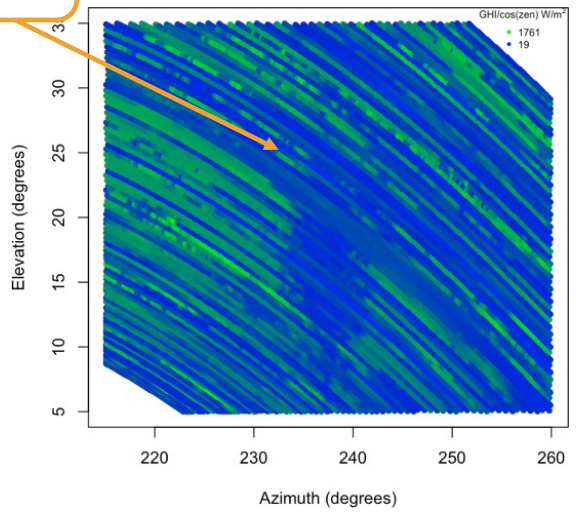

# 3. FLAG

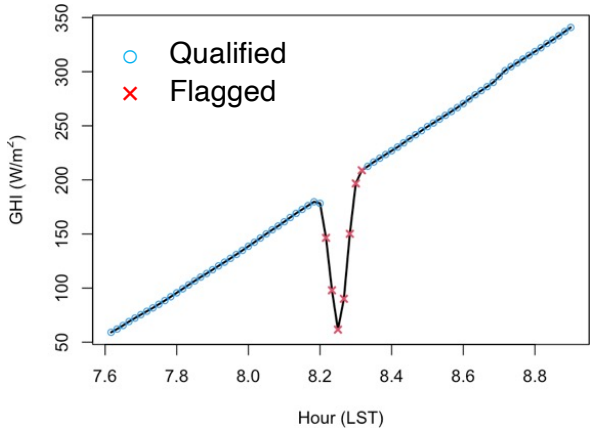


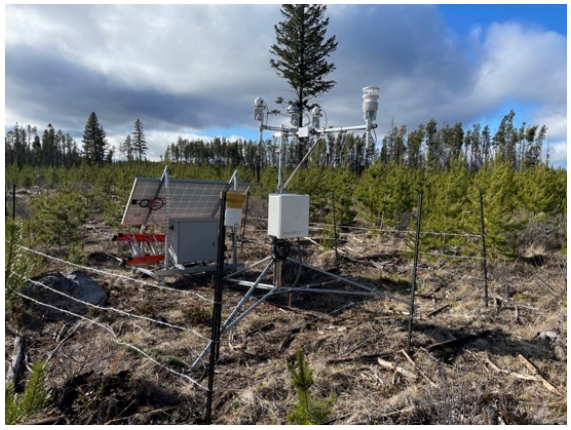
Not easily able to draw a box



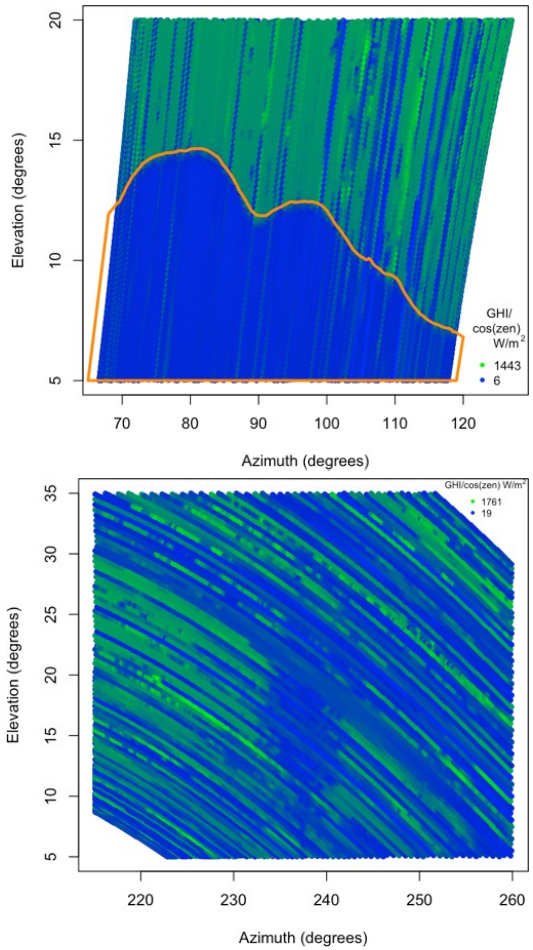



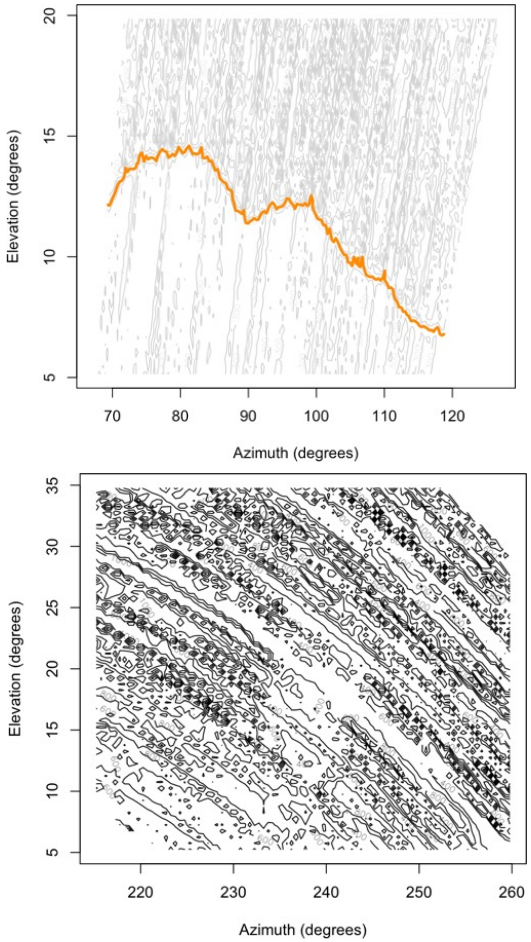



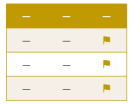



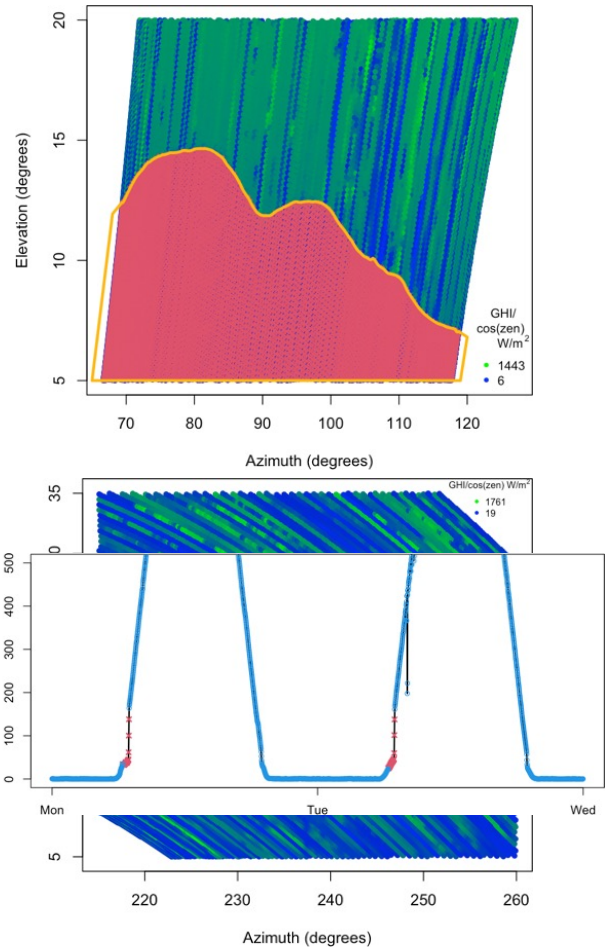
# 2. BUILD POLYGON ONTOUR MAPPING)



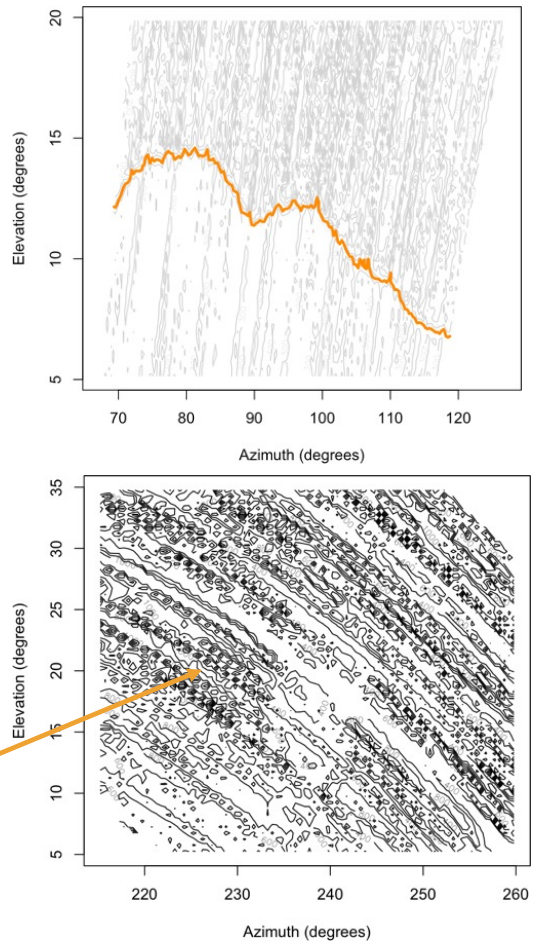



# 3. FLAG






Not easily able to draw a contour

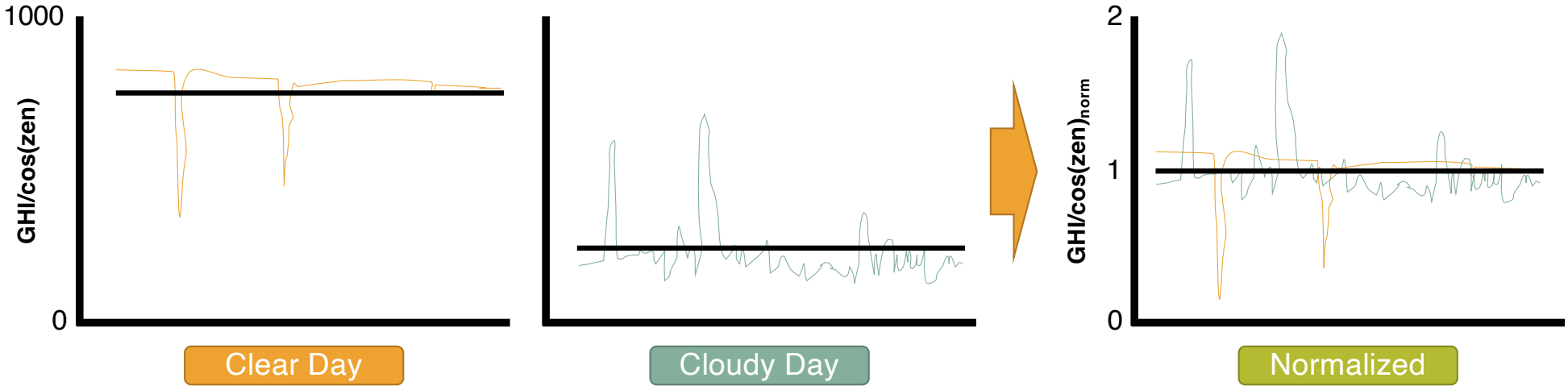


# CLEAR/CLOUDY NORMALIZATION

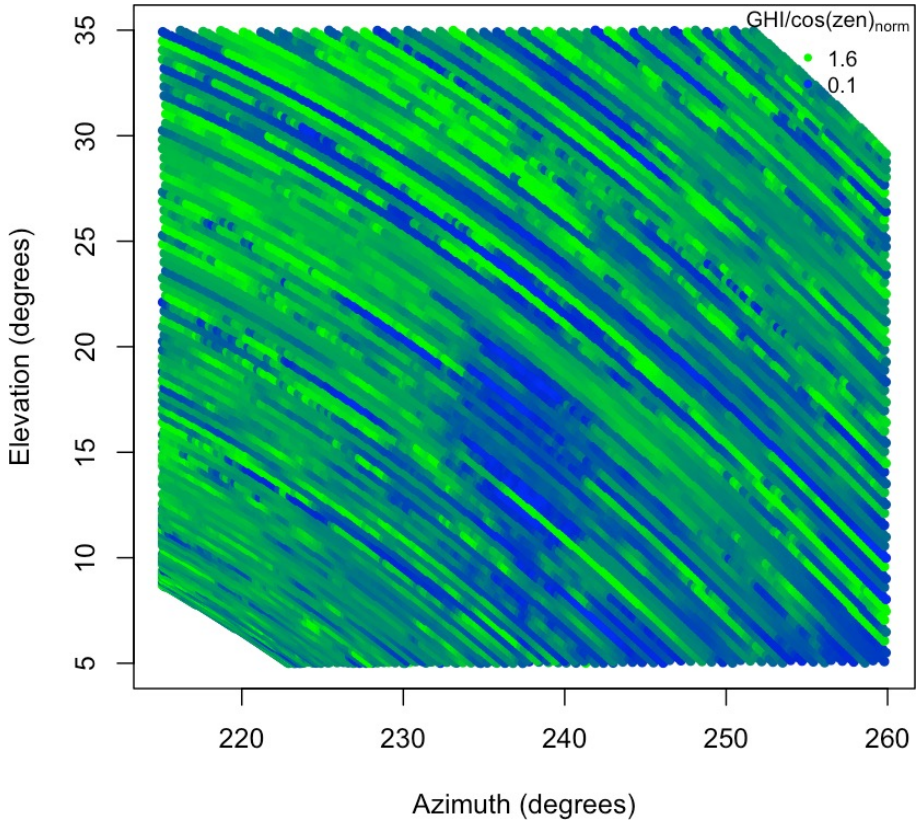
- Two steps . . .
  1. Normalize by the *daily mean* GHI/cos(zen) to merge cloudy and clear days onto one plane.

**Normalized GHI/cos(zen)**

$$\frac{GHI}{\cos(zen)_{norm}} = \frac{\frac{GHI}{\cos(zen)_{i,day}}}{\frac{GHI}{\cos(zen)_{day}}}$$



## After clear/cloudy normalization



# GAUSSIAN CONVOLUTION

- Two steps . . .
  1. Normalize by the *daily mean* GHI/cos(zen) to merge cloudy and clear days onto one plane.
  2. Smooth the remaining partly cloudy days and sunsplash events using a 2D Gaussian smoothing.
     - → Grid data into two dimensions
     - → Apply Gaussian smoothing algorithm

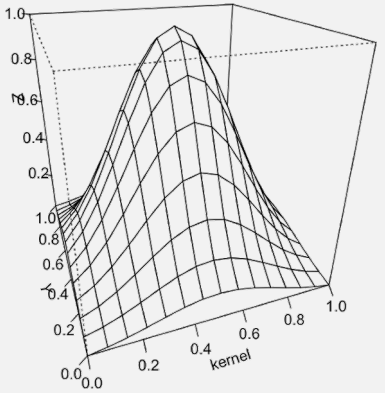
**Gaussian Distribution**

$$f(x) = ae^{-\frac{(x-b)^2}{2c^2}}$$

*a* = peak height

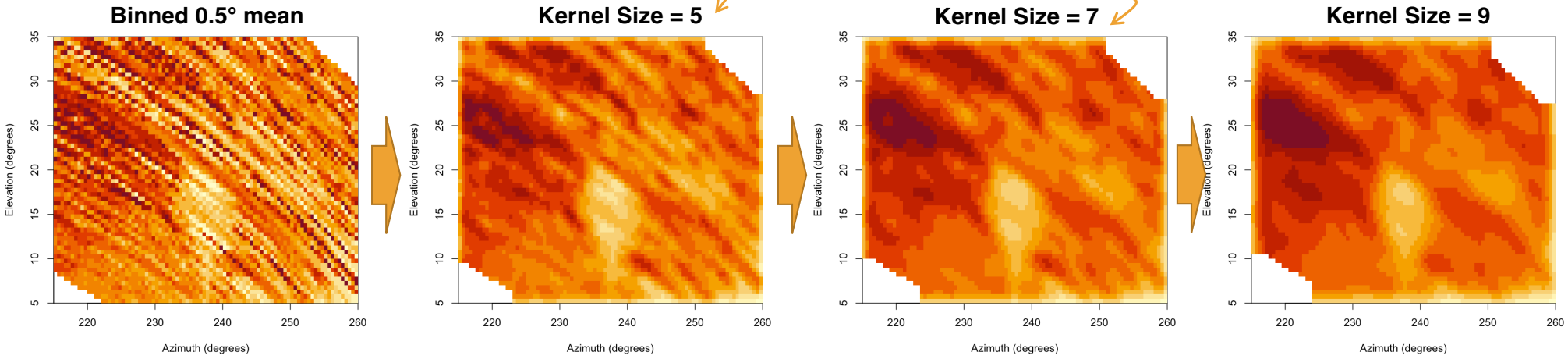
*b* = peak center

*c* = standard deviation

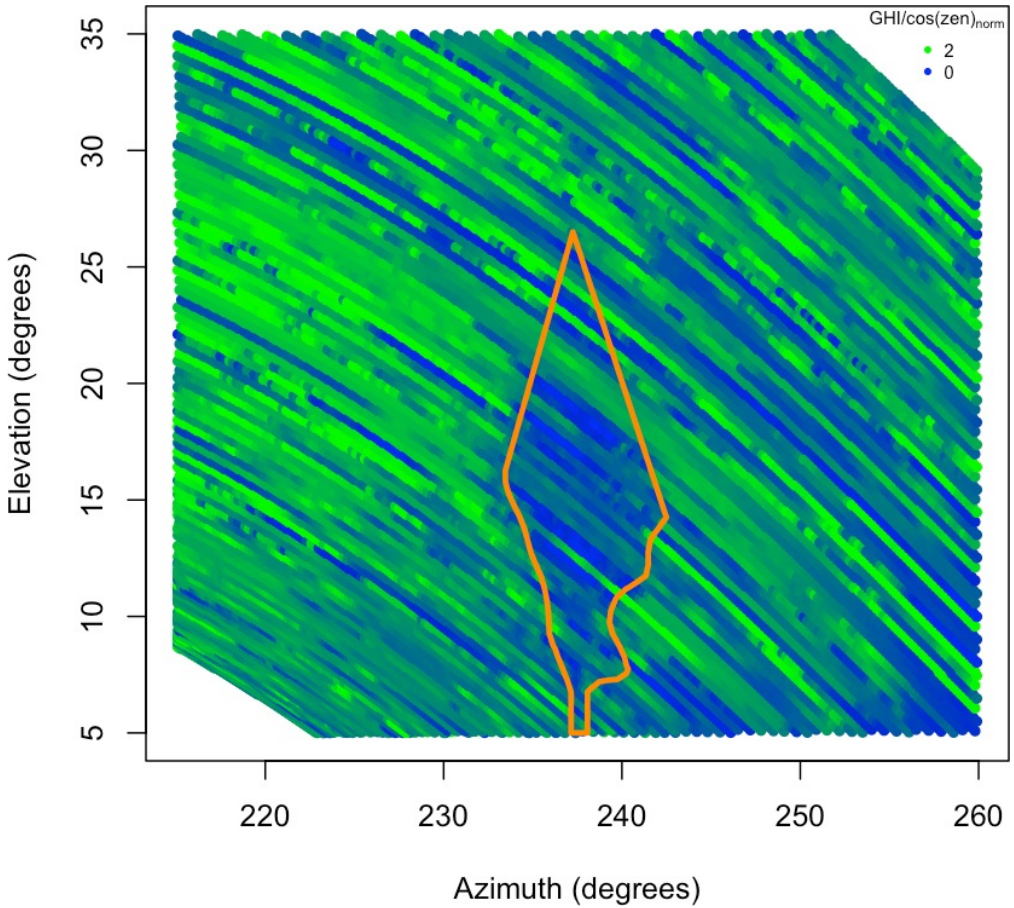



**5 × 0.5° bins = 2.5°**

**Optimal size = 7**



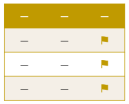
## 2. BUILD POLYGON (CONTOUR MAPPING)

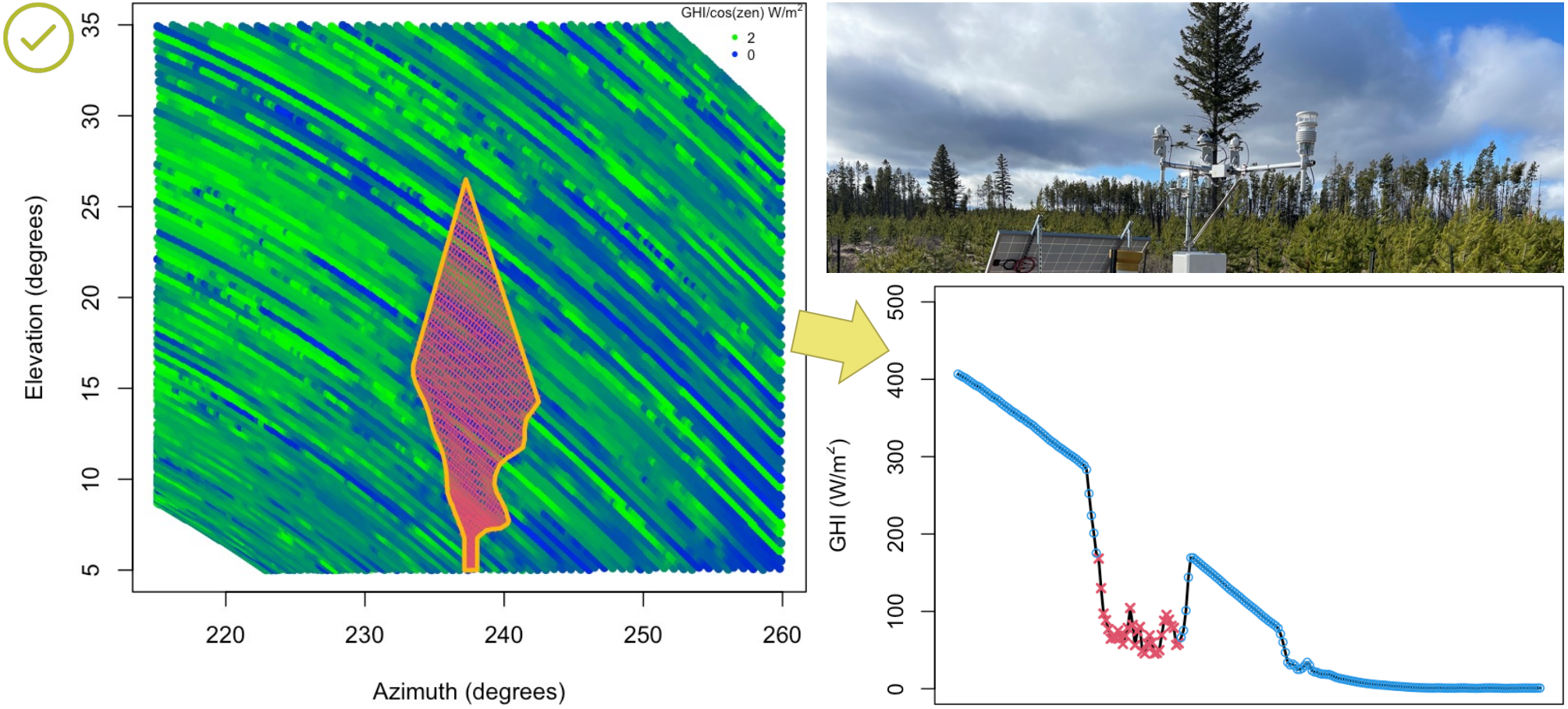



- Select a contour, and refine

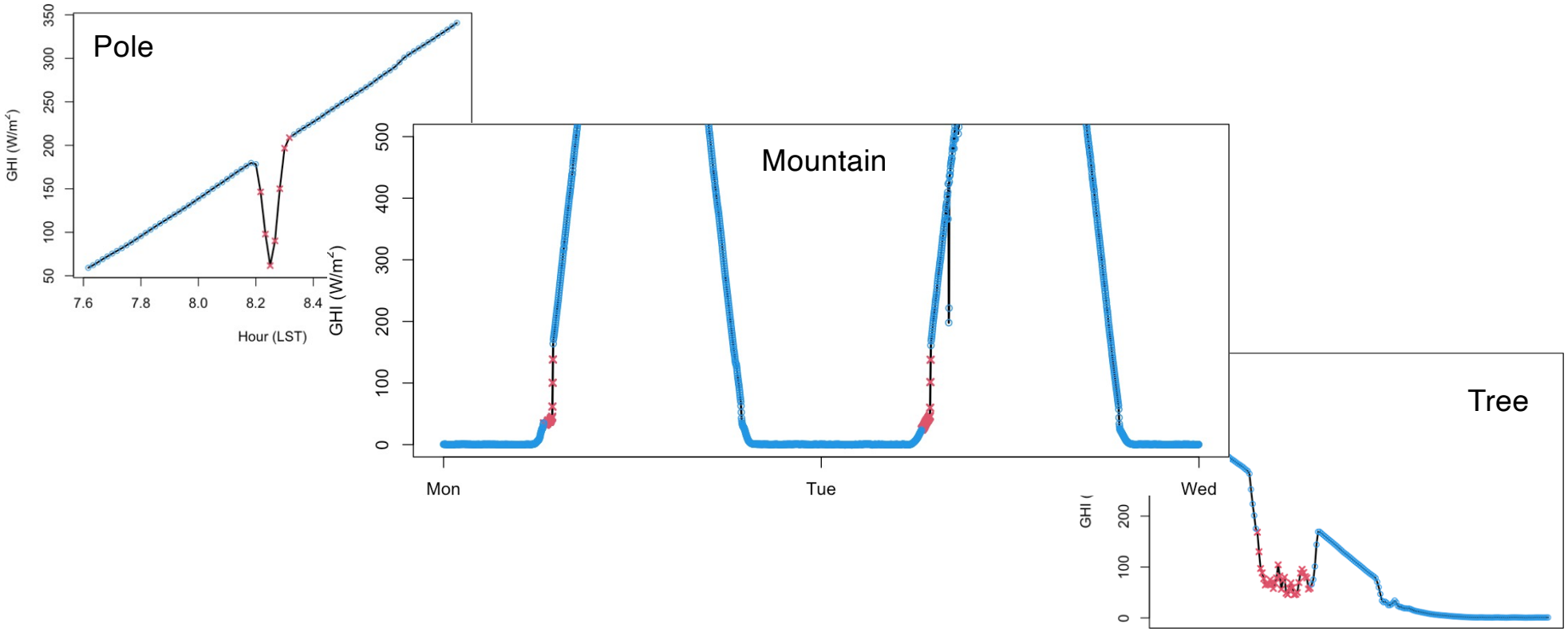
$$\frac{GHI}{\cos(zen)_{norm}} = 0.82$$

# 3. FLAG

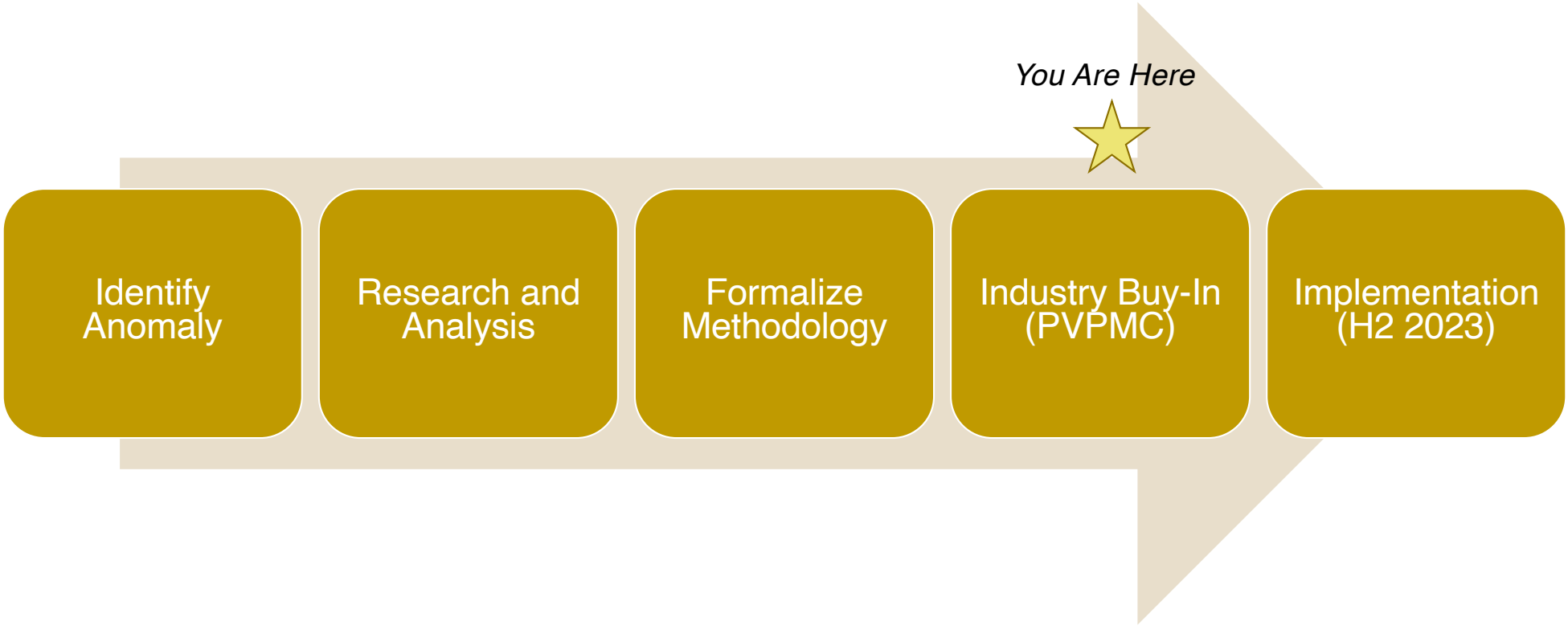




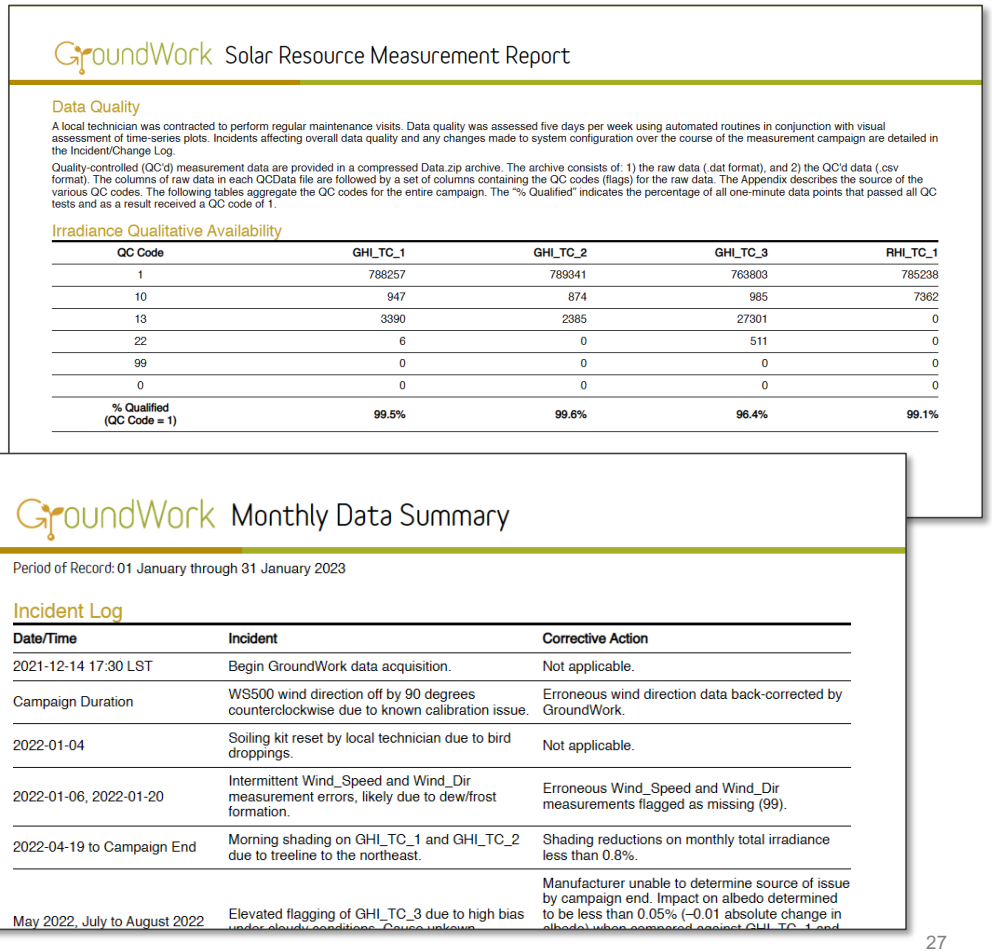
## Proper filtering significantly improves the quality of solar resource data.



## GROUNDWORK'S CONTINUOUS INNOVATION



- Shading analyses to be incorporated into QC flagging for Ground Data Packages (reports and data)
  - → New QC code
  - → Anticipated release of **H2 2023**



GroundWork Solar Resource Measurement Report

Data Quality

A local technician was contracted to perform regular maintenance visits. Data quality was assessed five days per week using automated routines in conjunction with visual assessment of time-series plots. Incidents affecting overall data quality and any changes made to system configuration over the course of the measurement campaign are detailed in the Incident/Change Log.

Quality-controlled (QC'd) measurement data are provided in a compressed Data.zip archive. The archive consists of: 1) the raw data (.dat format), and 2) the QC'd data (.csv format). The columns of raw data in each QCData file are followed by a set of columns containing the QC codes (flags) for the raw data. The Appendix describes the source of the various QC codes. The following tables aggregate the QC codes for the entire campaign. The "% Qualified" indicates the percentage of all one-minute data points that passed all QC tests and as a result received a QC code of 1.

Irradiance Qualitative Availability

| QC Code | GHI_TC_1 | GHI_TC_2 | GHI_TC_3 | RHI_TC_1 |
|---|---|---|---|---|
| 1 | 788257 | 789341 | 763803 | 785238 |
| 10 | 947 | 874 | 985 | 7362 |
| 13 | 3390 | 2385 | 27301 | 0 |
| 22 | 6 | 0 | 511 | 0 |
| 99 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| **% Qualified (QC Code = 1)** | **99.5%** | **99.6%** | **96.4%** | **99.1%** |

GroundWork Monthly Data Summary

Period of Record: 01 January through 31 January 2023

Incident Log

| Date/Time | Incident | Corrective Action |
|---|---|---|
| 2021-12-14 17:30 LST | Begin GroundWork data acquisition. | Not applicable. |
| Campaign Duration | WS500 wind direction off by 90 degrees counterclockwise due to known calibration issue. | Erroneous wind direction data back-corrected by GroundWork. |
| 2022-01-04 | Soiling kit reset by local technician due to bird droppings. | Not applicable. |
| 2022-01-06, 2022-01-20 | Intermittent Wind_Speed and Wind_Dir measurement errors, likely due to dew/frost formation. | Erroneous Wind_Speed and Wind_Dir measurements flagged as missing (99). |
| 2022-04-19 to Campaign End | Morning shading on GHI_TC_1 and GHI_TC_2 due to treeline to the northeast. | Shading reductions on monthly total irradiance less than 0.8%. |
| May 2022, July to August 2022 | Elevated flagging of GHI_TC_3 due to high bias | Manufacturer unable to determine source of issue by campaign end. Impact on albedo determined to be less than 0.05% (–0.01 absolute change in |

# THANK YOU!

**Q** Questions?

**A** Contact me: abryan@grndwork.com