

Advancing Heliostat Performance Through Precision Angle Measurement

Current Research Progress at the University of Nevada, Las Vegas (UNLV)



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Team Members



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- **Adiba Azam**, UNLV, PhD Student

Outline

- ❑ Introduction – Center for Energy Research
- ❑ Operating Surface Angle Measurement System
- ❑ Sensor Development
- ❑ Heliostat Field Test

Research at CER-UNLV

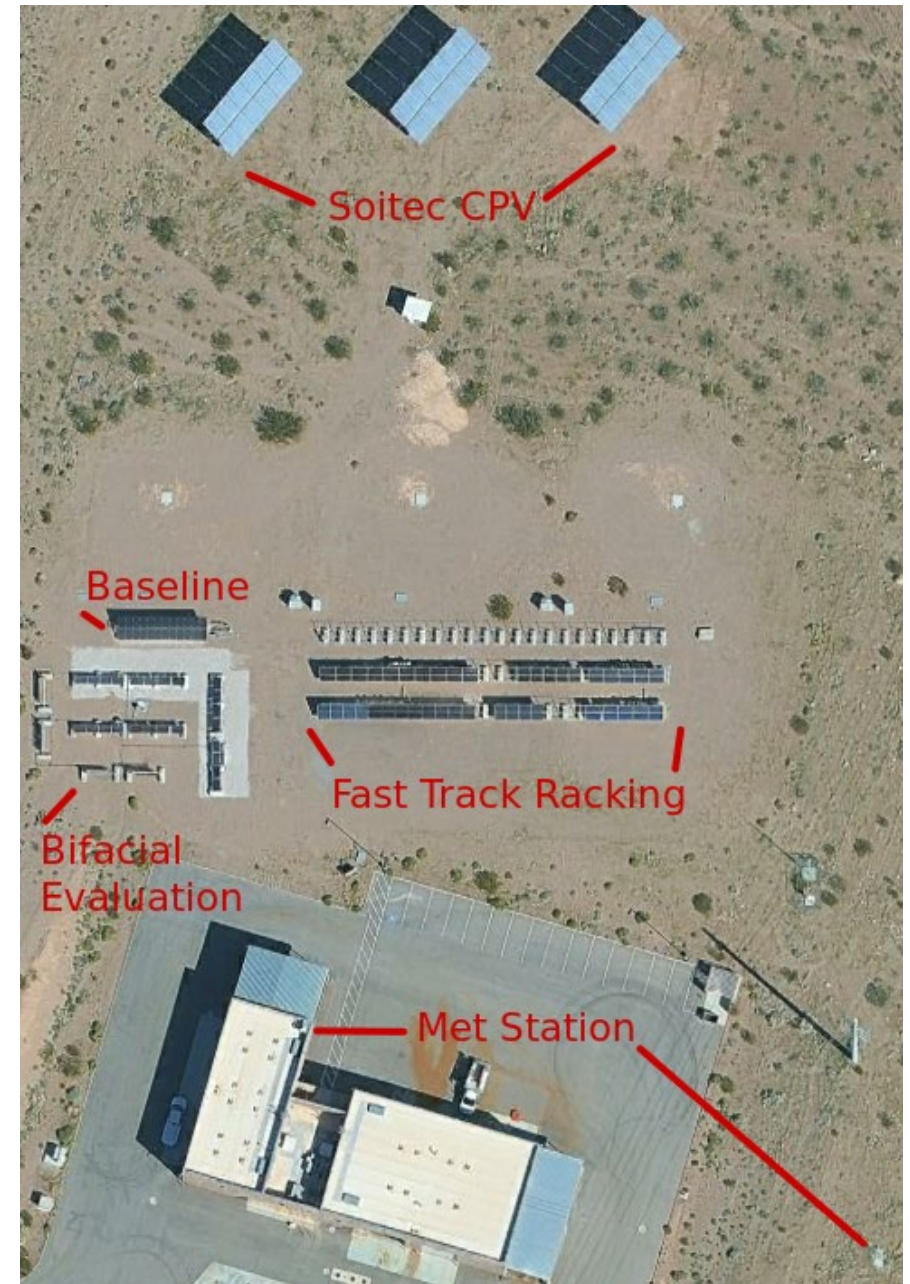
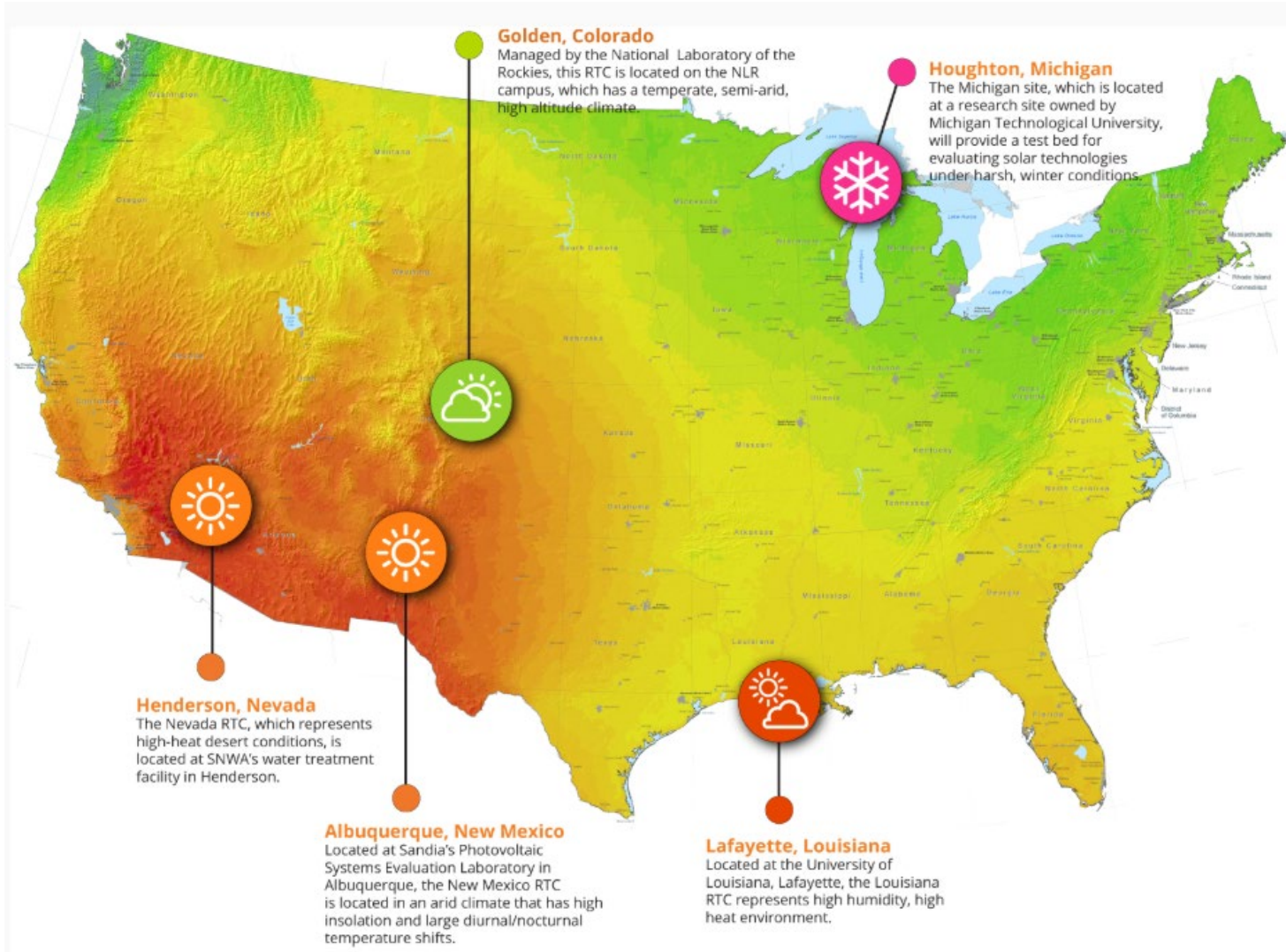
Center for Energy Research

- Solar Research - Concentrating and Flat Plate Photovoltaic Systems, Concentrating Trough Plants, Solar Stills, Solar Water Heaters, Hybrid Solar Lighting, and Solar Resource Assessment
- Energy Efficient Buildings and Homes
- Wind Resource Assessment
- Hydrogen Research-Renewable Hydrogen Generation, Vehicle Conversions, Solar Hydrogen Generation, Systems Modeling and Performance



Current Research at CER-UNLV

Nevada Regional Test Center



Past Research at CER-UNLV

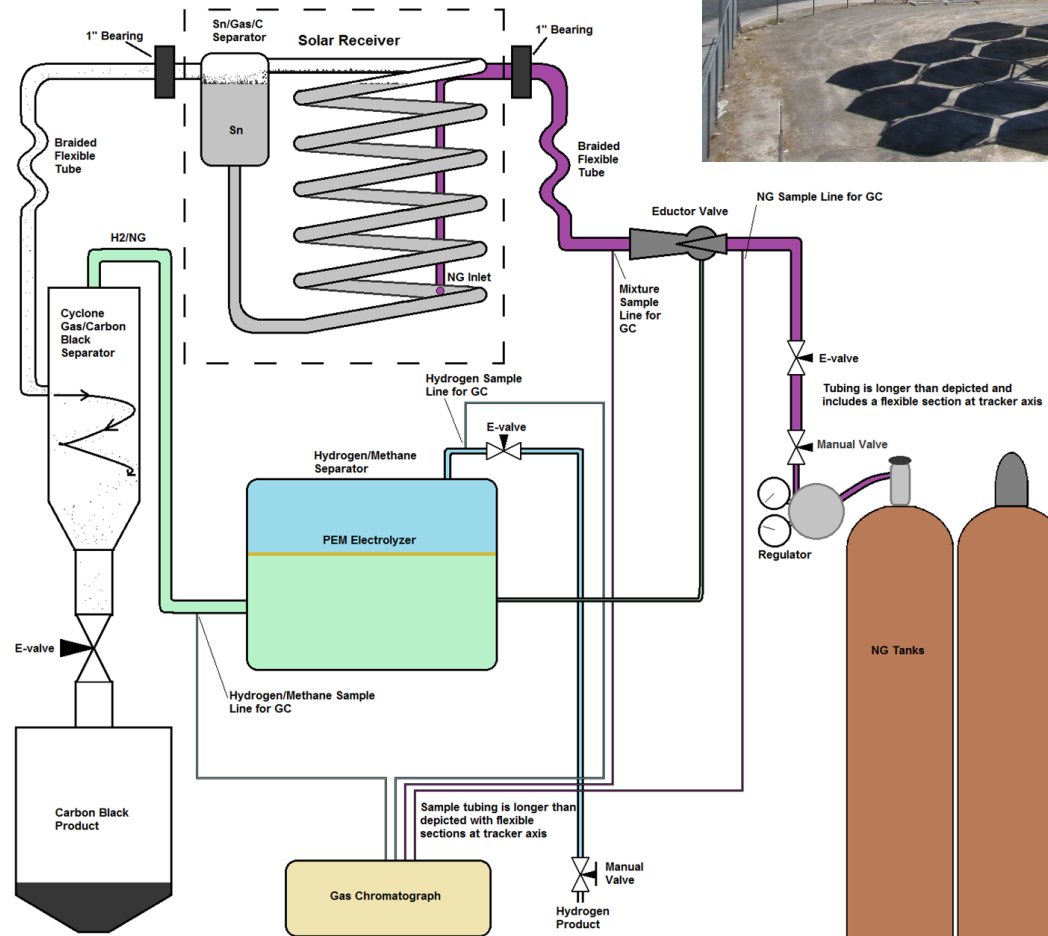
Building Energy Efficiency

- Villa Trieste Project - Reduce utility peak demand because this causes high priced power to be used in summer
- 185 houses specially built for this project:
 - Energy efficient home construction with roof-integrated PV system
 - Direct communication of instantaneous pricing to consumer
 - Demand Side Management – or demand response—using an “Intelligent Agent” approach developed at UNLV
 - Load shifting with a Battery Energy Storage System (BESS)
- Promise to decrease peak demand by 60% over code-built houses



Future Research at CER-UNLV Hydrogen

- Design and build a Solar Powered Natural Gas to Hydrogen Pyrolysis Process
 - Existing UNLV solar dish concentrator
 - Produces Hydrogen from Natural Gas without producing CO₂ using Polymer Exchange Membrane (PEM) electrolyzer
 - Black Carbon powder (commercial product) as only byproduct



Outline

- ❑ Introduction – Center for Energy Research
- ❑ **Operating Surface Angle Measurement System**
- ❑ Sensor Development
- ❑ Heliostat Field Test

Project Overview

Project Goals

Project Title:

Precision Angle Measurement System for Enhanced Heliostat Performance and Cost Reduction

Project Goals:

1. Develop a high-precision Operating Surface Angle Measurement System (OSAMS) to enhance heliostat design, validation, and field performance, thereby improving optical accuracy and reducing costs for better techno-economic outcomes.
2. Provide industry accessibility through publicly available educational modules, collaborative testing at national labs, and open dissemination of sensor specifications, calibration procedures, and analytical tools via NREL and SNL.

Project Overview

Project Objectives

✓ What problem are you addressing?

For open-loop or closed-loop tracking systems

- Improve open loop tracking by estimating tracking errors
- Measuring/modeling reflective surface deflections that affect reflective surface angle

✓ What capability are you creating?

A precision diagnostic tool for heliostat systems

- Compact, multiple, easy-to-install sun sensors
- Multiple sensor measurements taken at same time
- High-resolution tracking and angle error detection
- Ability to measure surface curvature and cant angle
- Structural sensitivity to wind speed, gravity, temperature

✓ What is the solution?

A real-time, multi-point accurate sun angle measurement system

- Sensors placed at key points on the heliostat reflective surface
- Surface angle errors measured during normal operating conditions
- Data analyzed to identify error sources and magnitude

✓ How does this support HelioCon's mission?

Direct contribution to performance and cost

- Increased tracking accuracy leads to increased energy – lower LCOE
- Verify heliostat meets design reflection requirements under normal operating conditions
- Increased heliostat performance models can be used to optimize LCOE

Project Overview

Project Objectives

There are four components to OSAMS

- Development of 2-axis sun sensors
- Program that will use measured data from sensors to determine sources and values of errors in the tracking system (e.g. pedestal tilt, gravity bending, etc)
- Tracking software uses measured errors to point accurately at sun
- Program calculates the reflective surface normal at key locations with respect to a reference location over the day under normal operating conditions

Outline

- ❑ Introduction – Center for Energy Research
- ❑ Operating Surface Angle Measurement System
- ❑ **Sensor Development**
- ❑ Heliostat Field Test

Sensor Development

Previous Sensor Work

A previous sun sensor was developed in 2010's which was designed for CPV.

- ± 1.5 degree field of view
- 5 lbs weight
- Built in rechargeable battery
- 0.003 degree accuracy
- Synchronization ability with cable
- Serial communications with cable



Sensor Development

Error Measurement with Previous Sensor

Three of the previous sensors were mounted to Soitec Unit 2 at the Nevada Regional Test Center



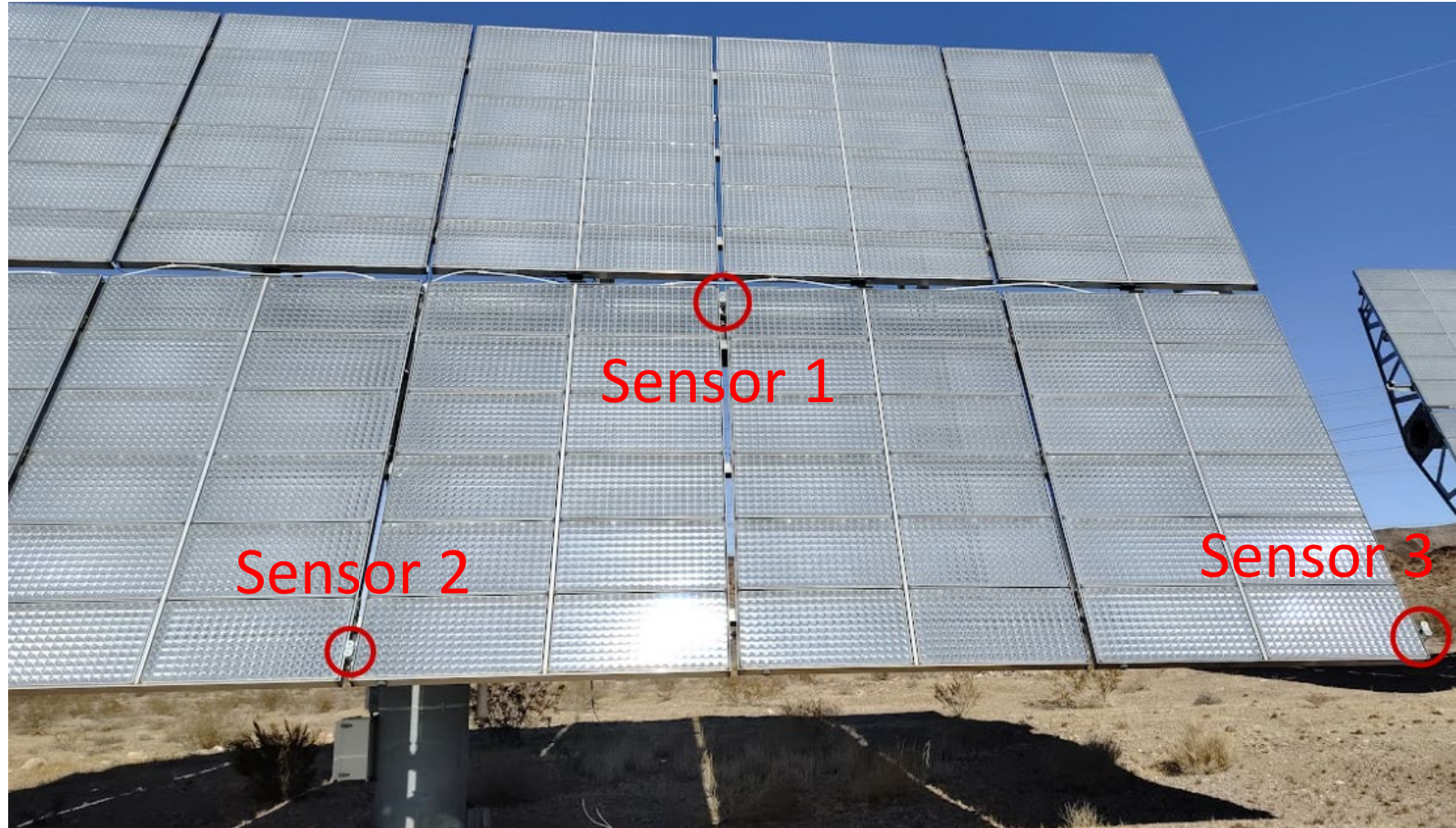
Sensor Development

Error Measurement with Previous Sensor

Ideal location for master sensor is in the center. Unfortunately there wasn't enough clearance between the two modules.

Over 77,000 measurements were taken between December 2024 and March 2025

Differences between sensors provide structural bending data



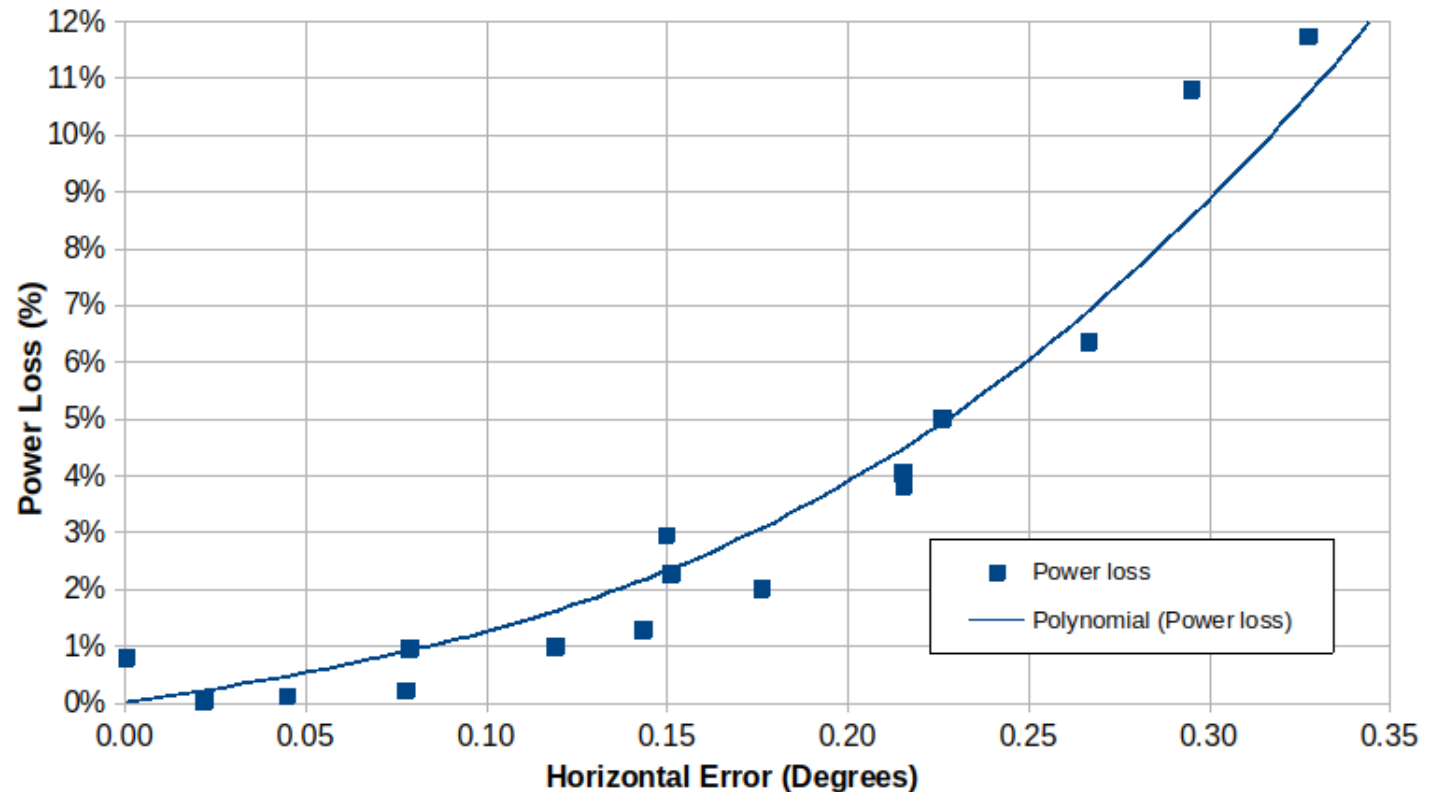
Sensor Development

Error Measurement with Previous Sensor

Power loss measurement of Soitec Unit 2 as a function of tracking error.

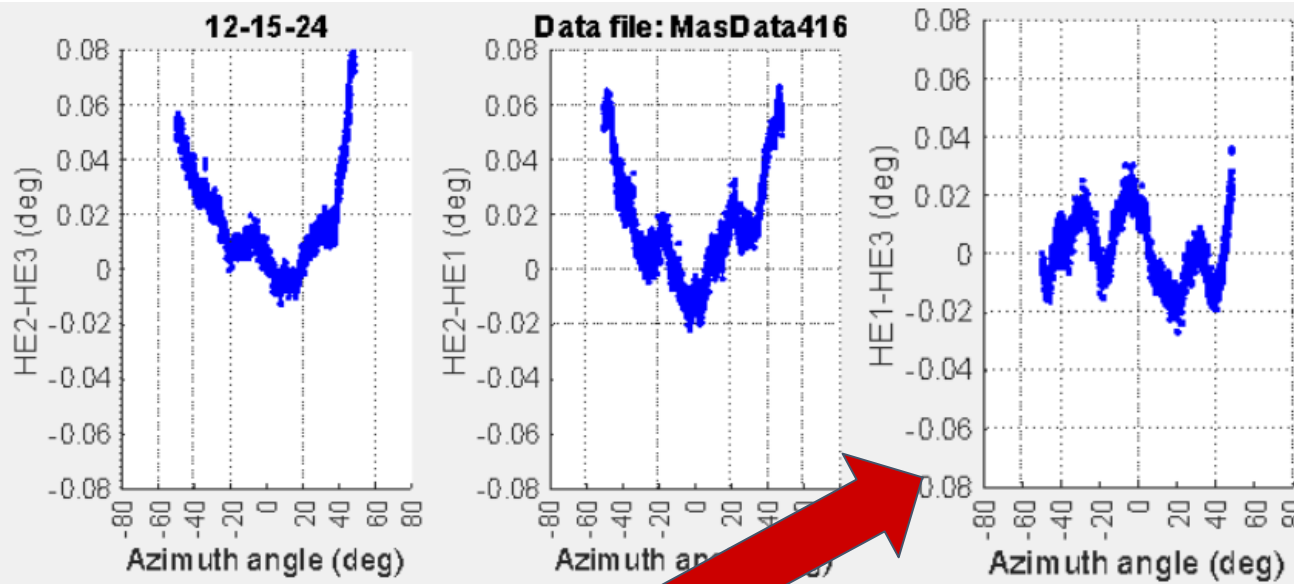
4% loss at 0.2 degrees of tracking error

~1% loss at 0.1 degrees of tracking error

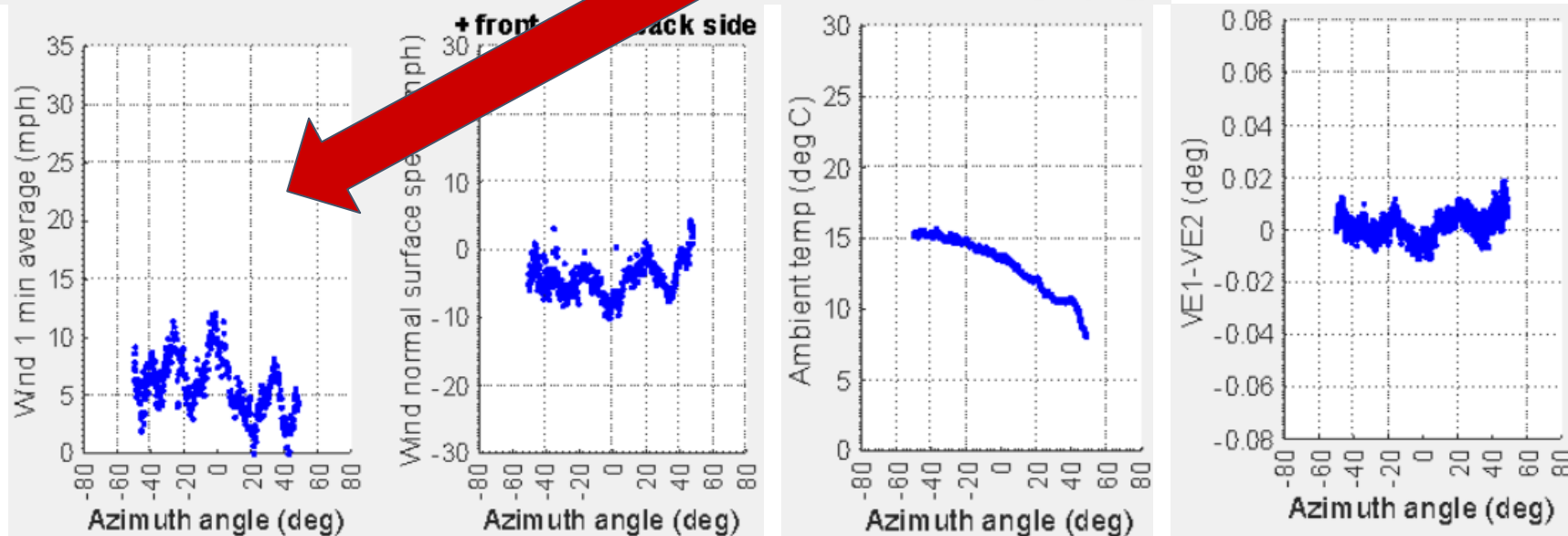


Sensor Development

Error Measurement with Previous Sensor

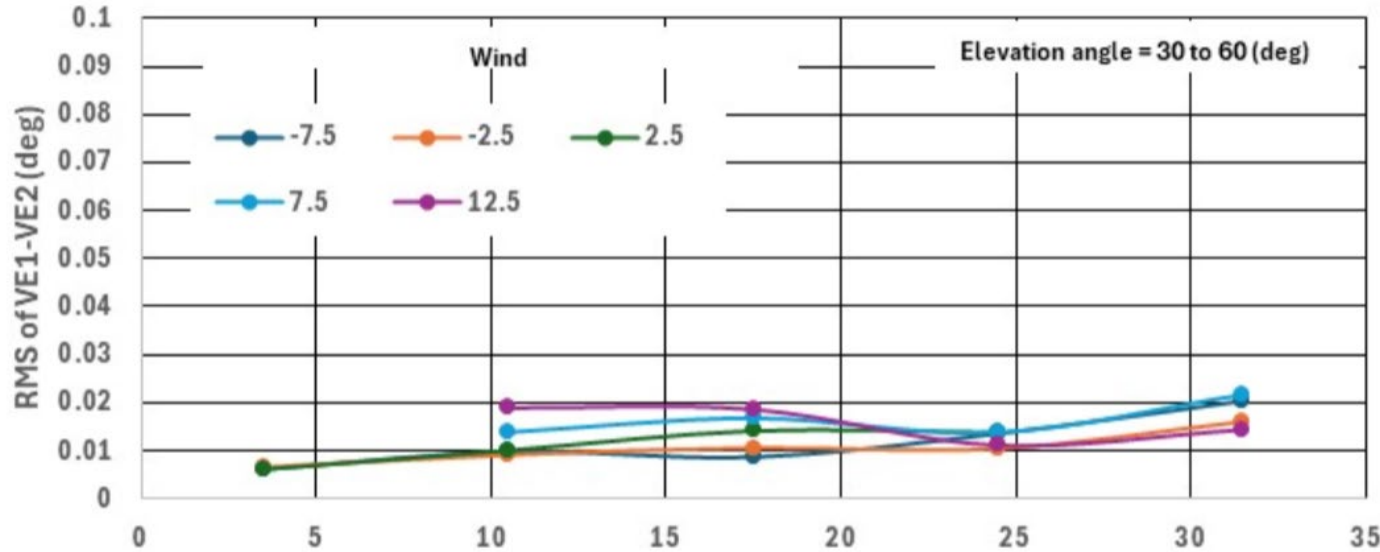


Even under low wind conditions, sensor measures deflections as low as 0.02 deg and show a direct relationship to wind speed



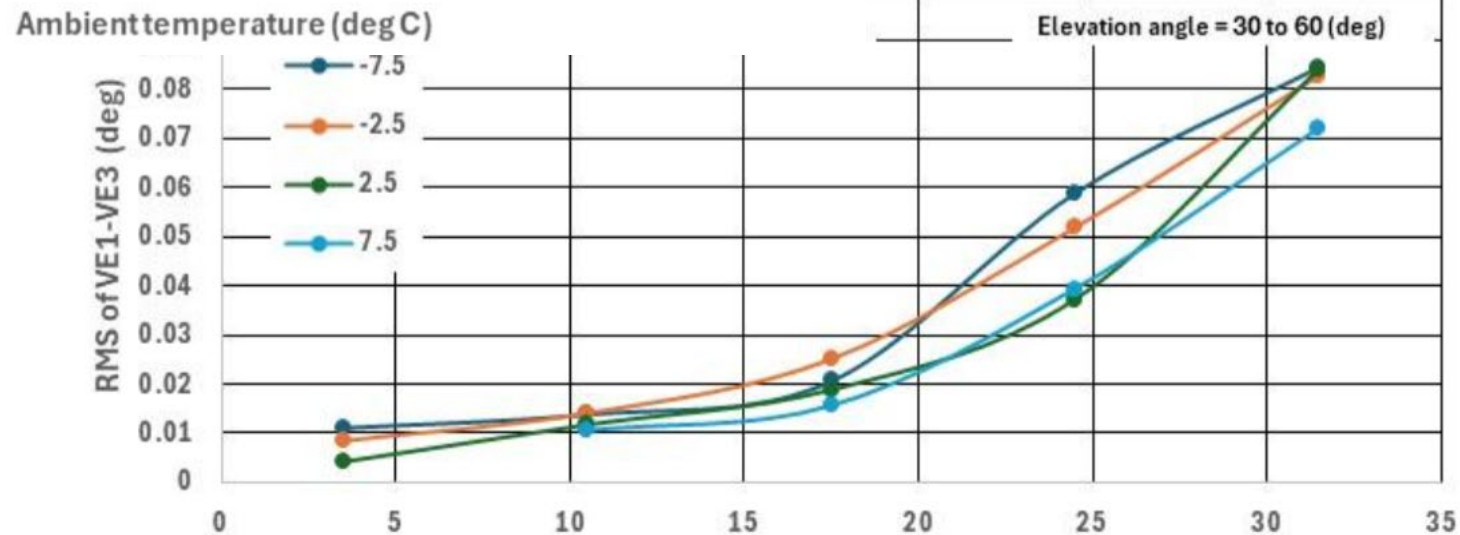
Sensor Development

Error Measurement with Previous Sensor



Analysis of data show an unexpected structural deflection between VE1 and VE3 that was very sensitive to ambient temperature and could result in 1% power loss

Data: MasData05192025



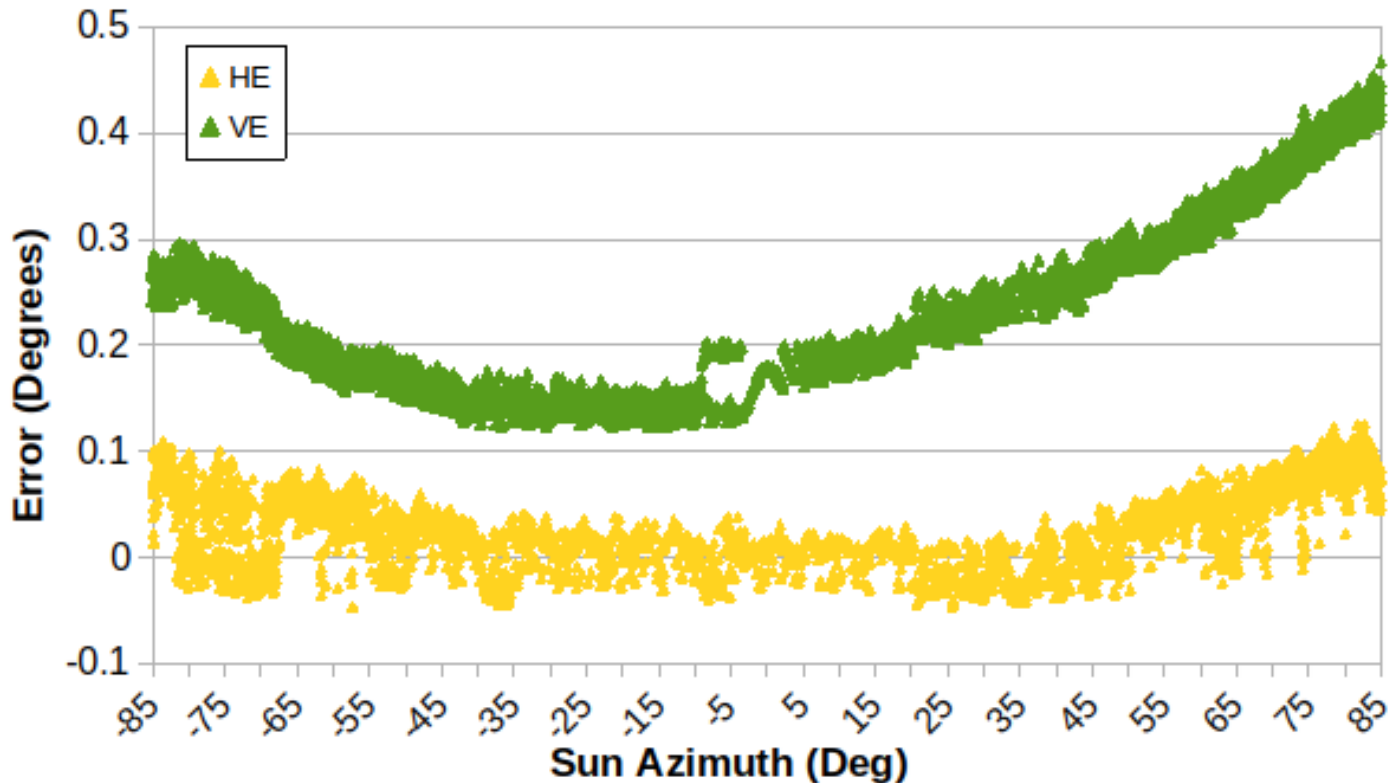
Data: MasData05192025

Ambient temperature (deg C)

Sensor Development

Error Measurement with Previous Sensor

Soitec Unit 2 Open Loop Tracking Error 8/29/25



Determination of the tracking system errors requires the system to track in open loop.

Since the center position of the array would not allow for placement of a sun monitor, the cross-elevation axis from the second sun monitor was used and the elevation (vertical) axis was used from sun monitor 1

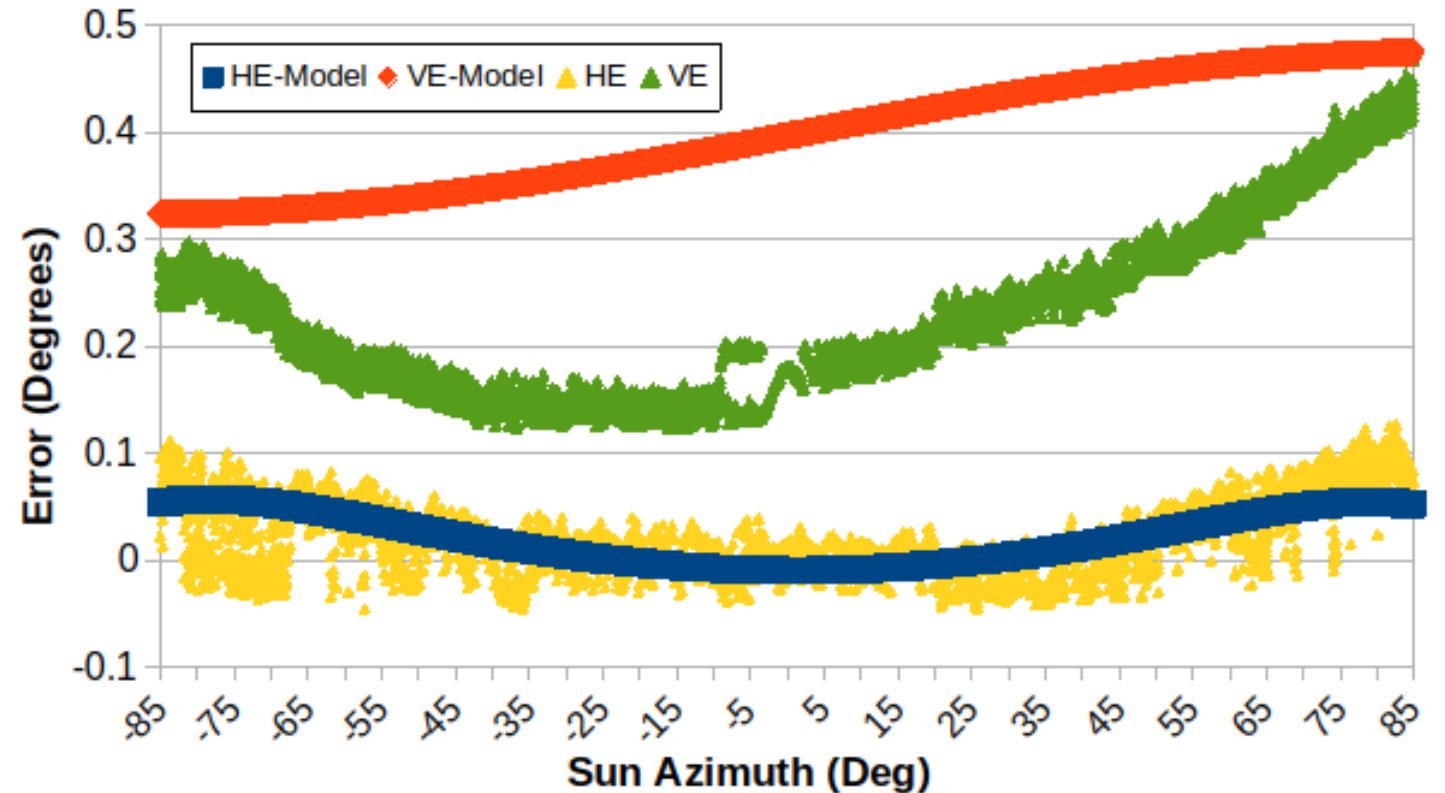
Sensor Development

Error Measurement with Previous Sensor

The Vertical error is solved for first by solving for Gamma 1, Gamma 2, and Sle. Differences between the modeled VE and the measured data are assumed to be due to gravity bending.

Delta 1, Delta 2, and FEE are solved for and the modeled cross-elevation (HE) is found.

Soitec Unit 2 Open Loop Tracking Error 8/29/25



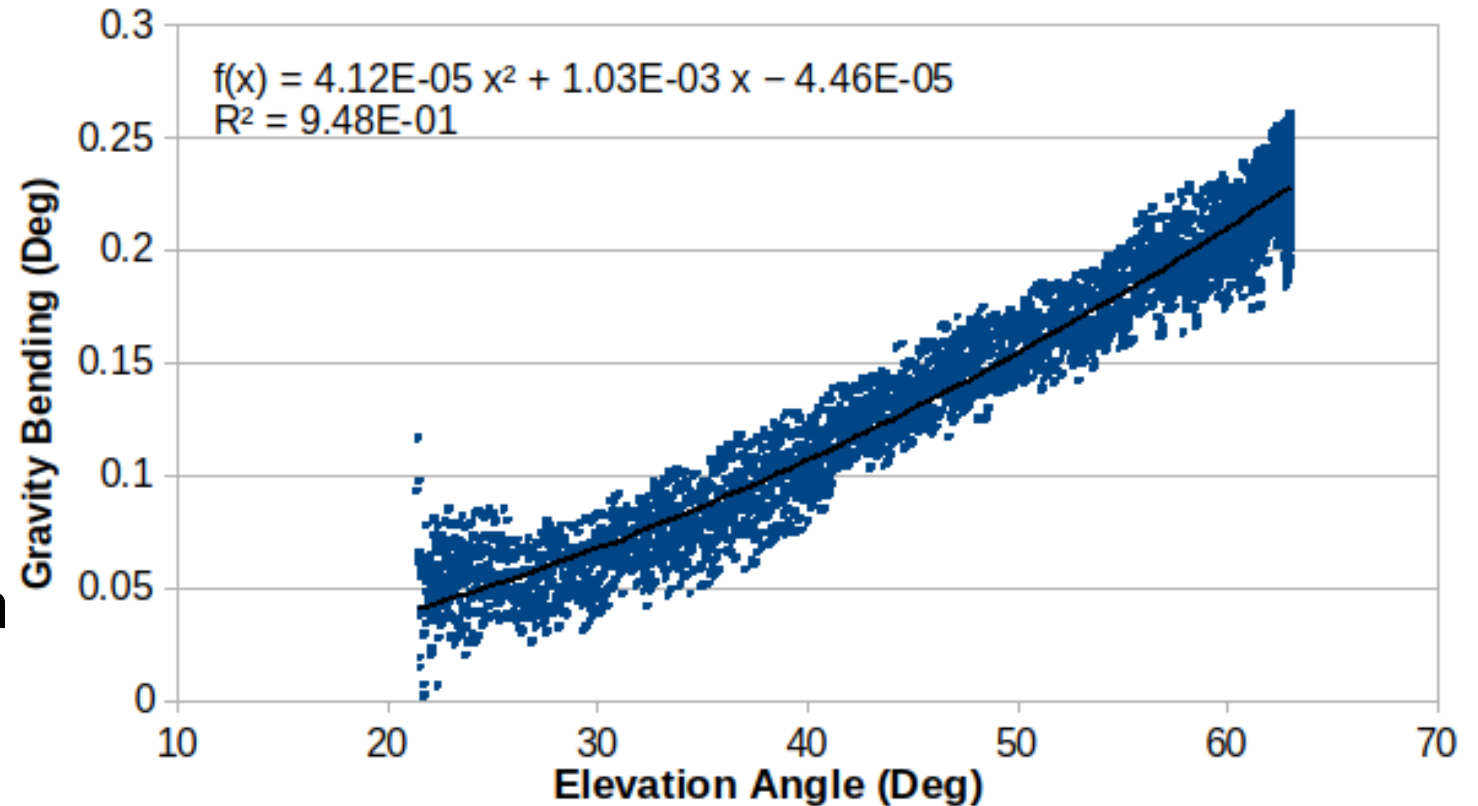
Sensor Development

Error Measurement with Previous Sensor

Differences between the modeled VE and the measured data are assumed to be due to gravity bending.

The results seem reasonable. The final VE model subtracts the gravity bending result from the previous VE equation.

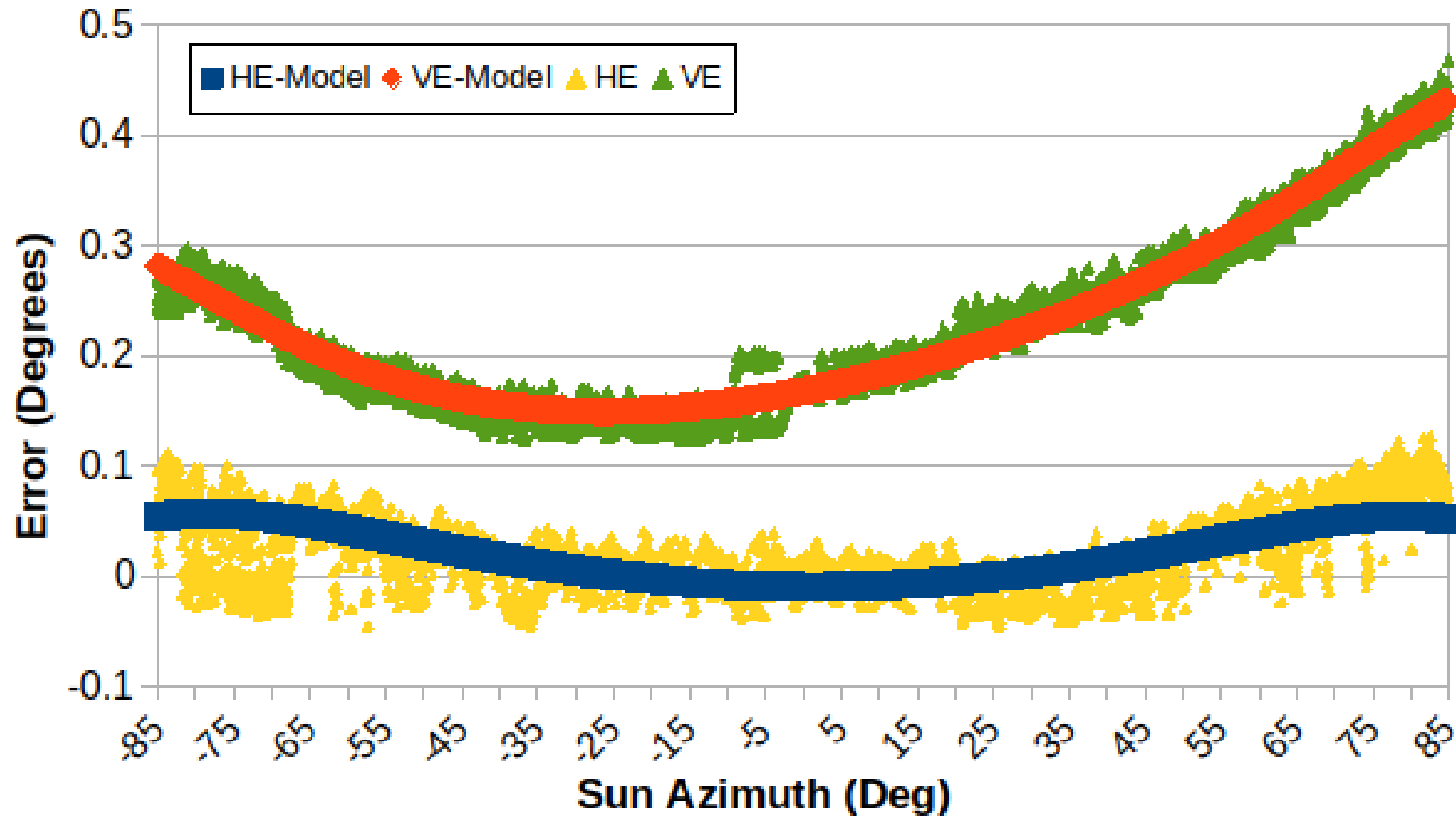
Soitec Unit 2 Assumed Gravity Bending 8/29/25



Sensor Development

Error Measurement with Previous Sensor

Soitec Unit 2 Open Loop Tracking Error with Models 8/29/25



Sensor Development

Error Measurement with Previous Sensor

Measurement of Gamma 1 and Gamma 2 with Inclinometers



Two inclinometers were placed on the top of the drive of Soitec Unit 2

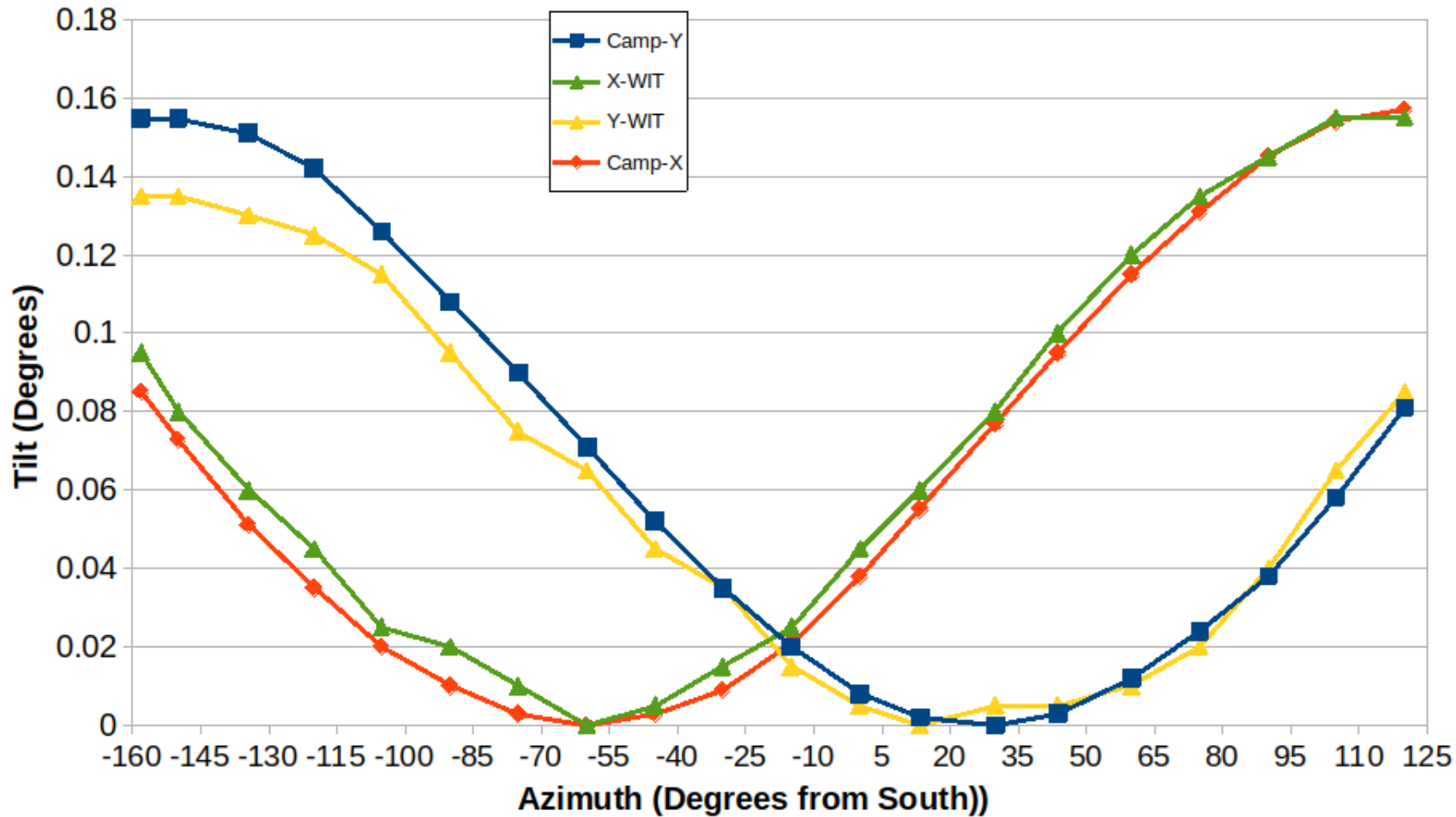
The system was placed in a vertical position and rotated from one Azimuth limit to the other Azimuth limit. with measurements recorded at 15 degree increments.

The larger sensor was more sensitive with a smaller signal range (± 10 degrees)

Sensor Development

Error Measurement with Previous Sensor

Measurement of Gamma 1 and Gamma 2 with Inclinometers



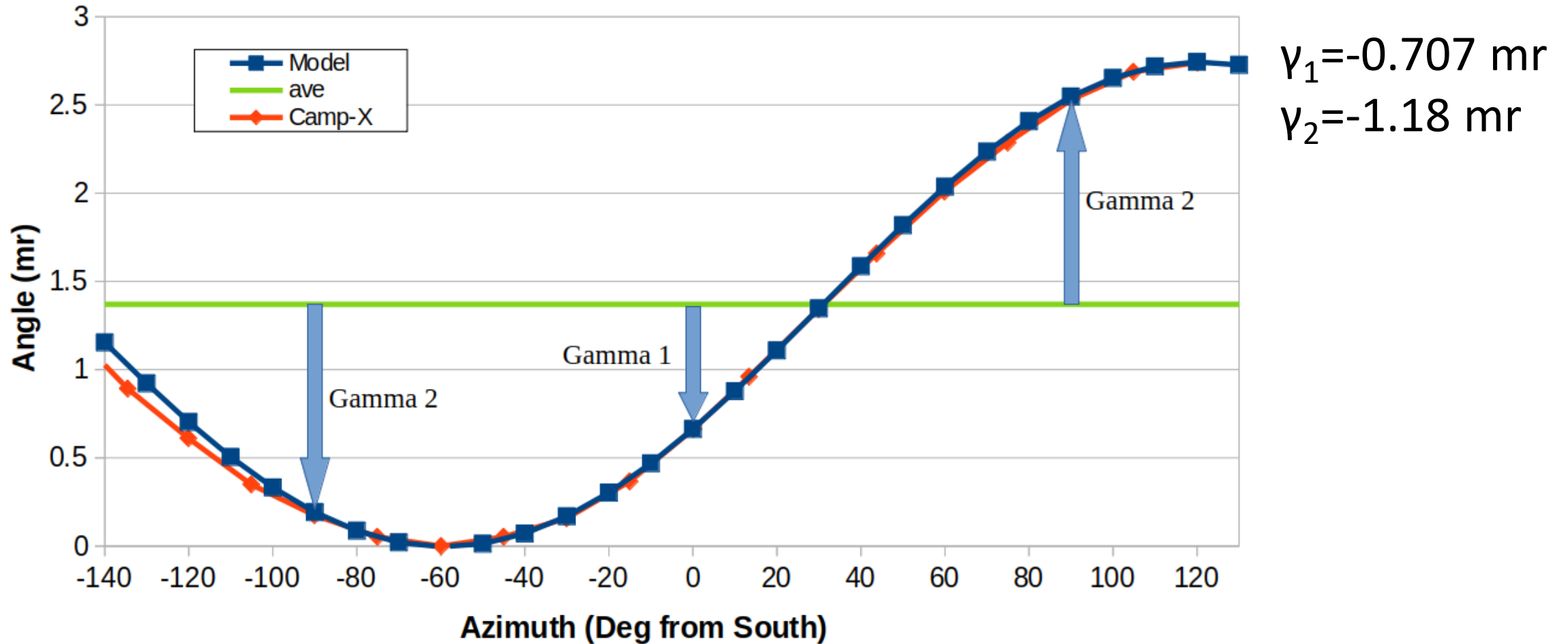
Y is aligned with the elevation axis

X is perpendicular to the elevation axis

Sensor Development

Error Measurement with Previous Sensor

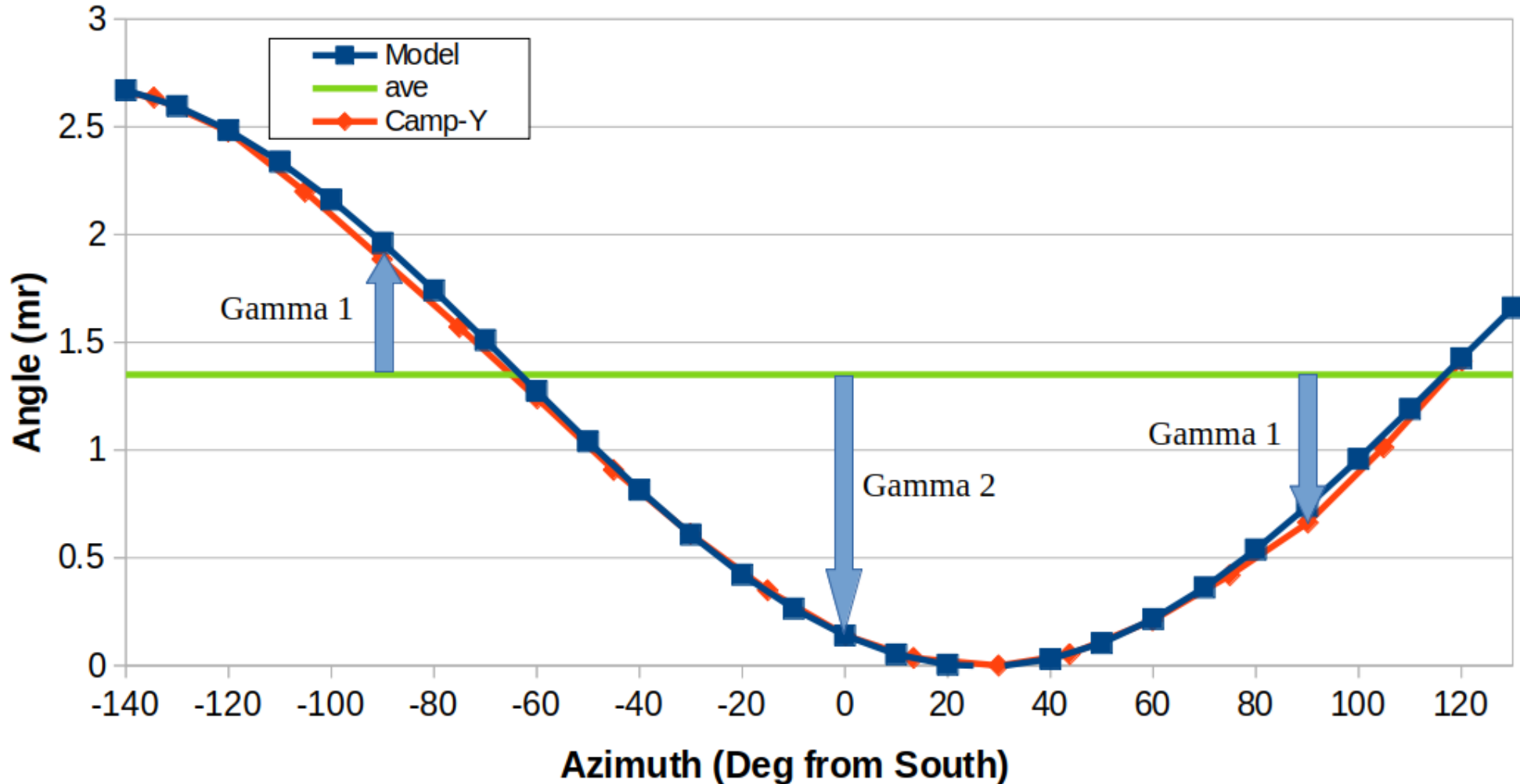
Measurement of Gamma 1 and Gamma 2 with Inclinometers



Sensor Development

Error Measurement with Previous Sensor

Measurement of Gamma 1 and Gamma 2 with Inclinometers



$$\gamma_1 = -0.611 \text{ mr}$$
$$\gamma_2 = -1.21 \text{ mr}$$

Sensor Development

Error Measurement with Previous Sensor

Measurement of Gamma 1 and Gamma 2 with Inclinometers

Inclinometer:

Average $\gamma_1 = -0.659$ mr

Average $\gamma_2 = -1.195$ mr

Sun monitors:

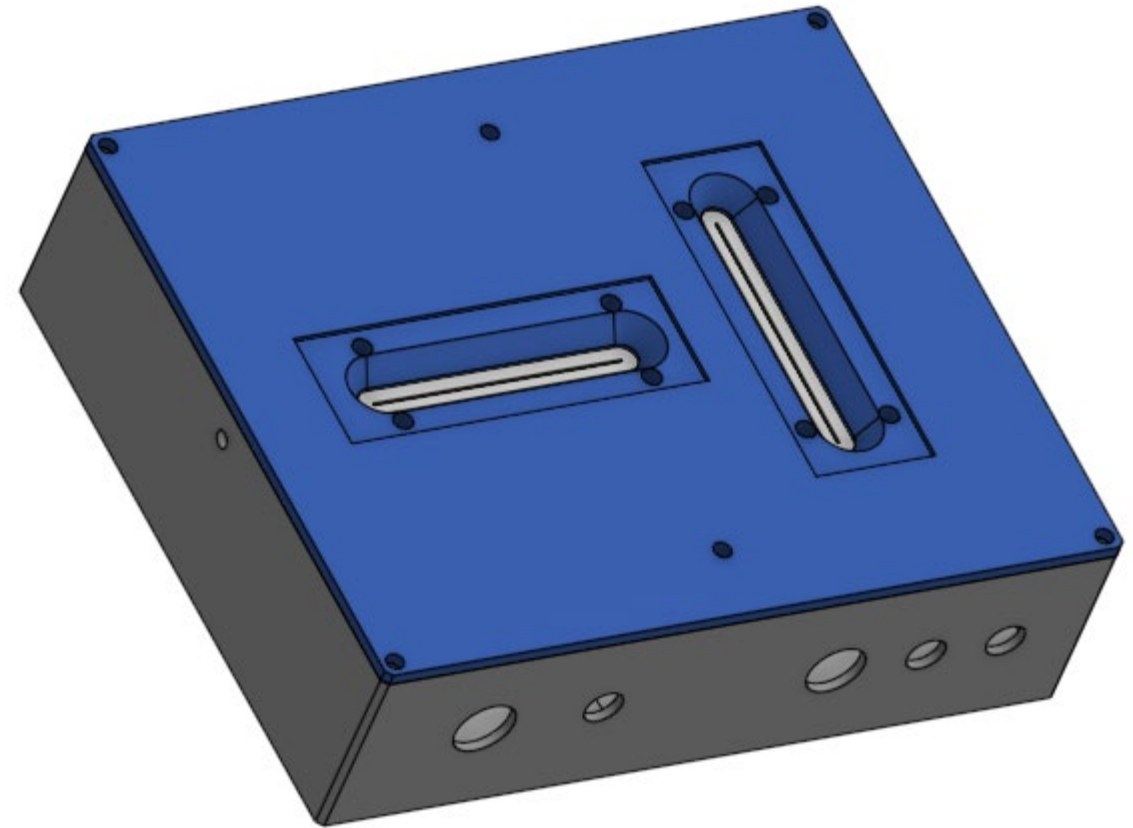
$\gamma_2 = -1.1$ to -1.32 mr (very good agreement)

$\gamma_1 = -0.04$ to 0.4 mr (not good agreement) - still investigating

Sensor Development

New Sensor Design

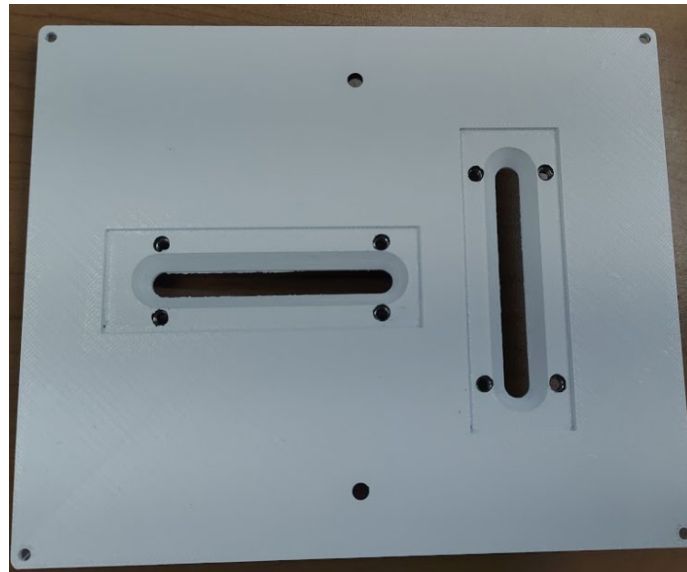
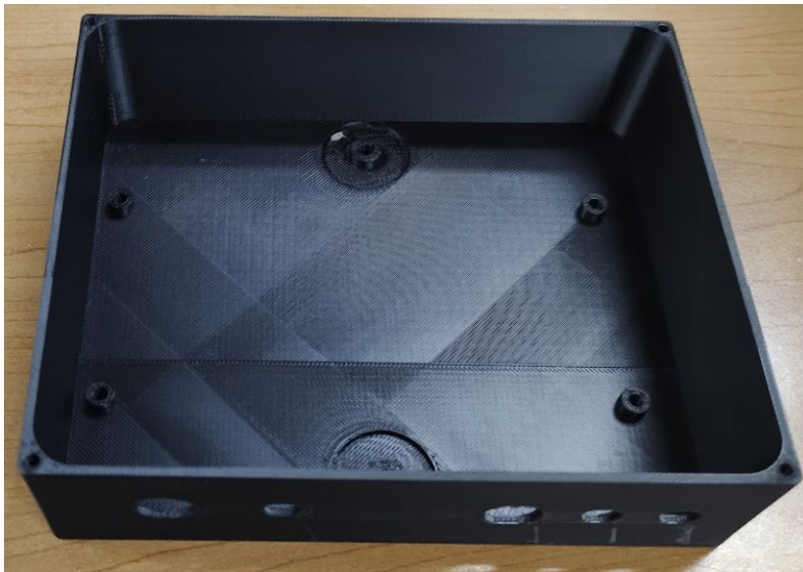
- Larger field of view
- <1 lbs weight (current is 0.94 lbs)
- Smaller package-6.25"x5.25"x1.75"
- Magnetic mounting
- External rechargeable battery
- 0.003 degree accuracy
- Wireless synchronization ability
- Wireless communications with PC



Sensor Development

New Sensor Design

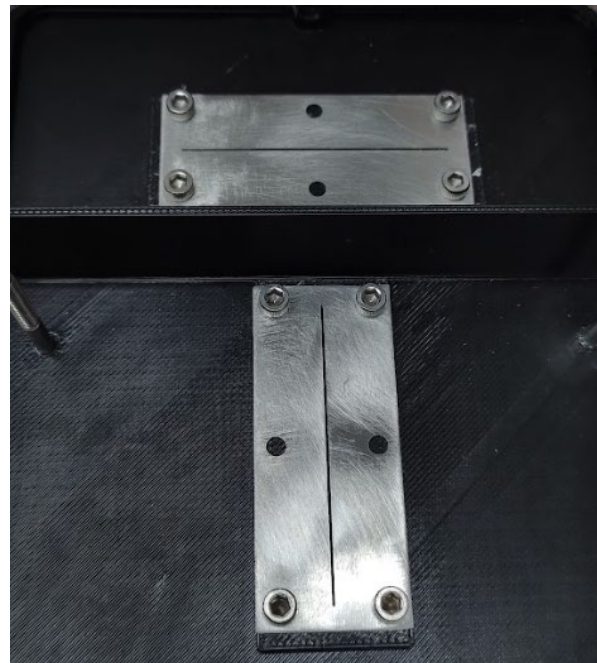
- 3D printed from Acrylonitrile Styrene Acrylate (ASA)
- Ceramic coating paint on exterior surfaces
- Silicone O-ring on top plate
- Helicoils used to strengthen screw holes



Sensor Development

New Sensor Design

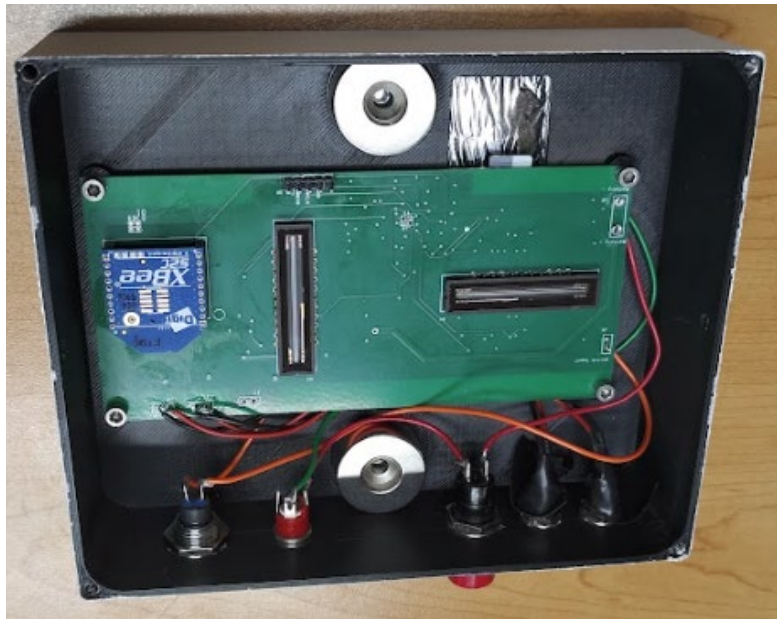
- Microscope slide glass
- Laser cut stainless steel slits
- Plastic welding filters



Sensor Development

New Sensor Design

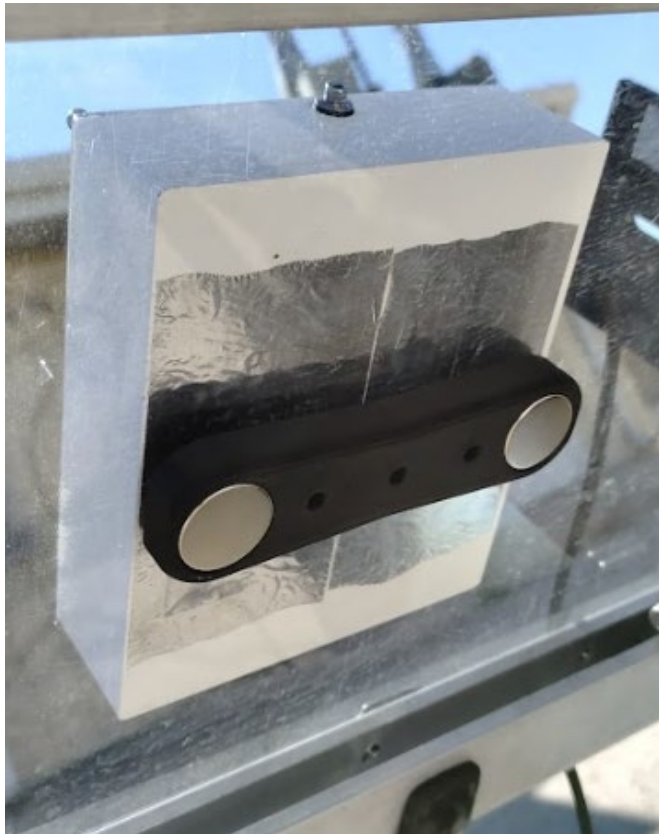
- Internal ring neodymium magnets
- External magnet holder
- Zigbee module
- Linear arrays



Sensor Development

Sensor Testing

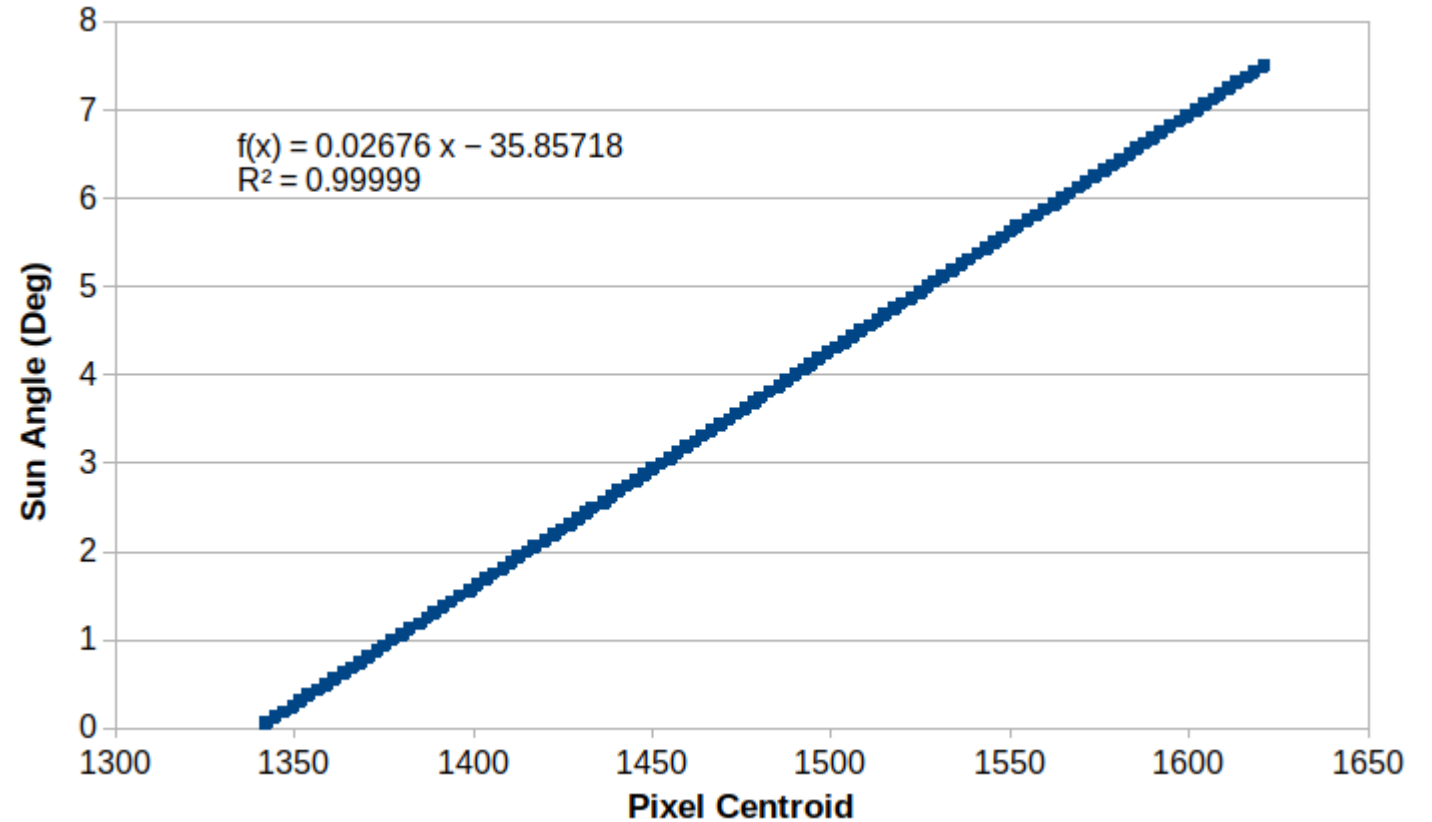
- Calibration and Testing
 - Losmandy G-11 tracker



Sensor Development

Sensor Testing

- Calibration and Testing
 - Preliminary measured accuracy - 0.0072 deg 1σ
 - Preliminary field of view ± 30 degrees
- Exploring method for increasing accuracy



Outline

- ❑ Introduction – Center for Energy Research
- ❑ Operating Surface Angle Measurement System
- ❑ Sensor Development
- ❑ **Heliostat Field Test**

Heliostat Field Test

Plans for Field Testing

- Calibrated sensors will be placed on Soitec Unit 2 for comparison with old sensors
- After checkout of sensors and software they will be mounted on a heliostat, possibly at Ivanpah
- Measurement of mirror curvature and cant angle and the change in these parameters with wind, gravity, and temperature.
- May measure the change when another heliostat is shining on the back side



Questions?

