Temperature and Heat Flux Errors Associated with Thin Film Thermometry

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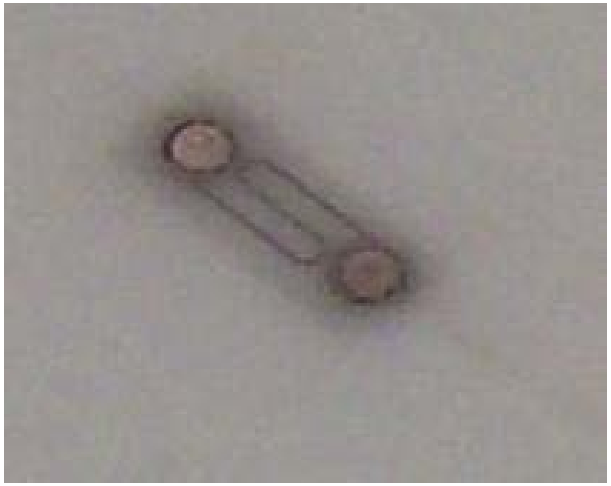
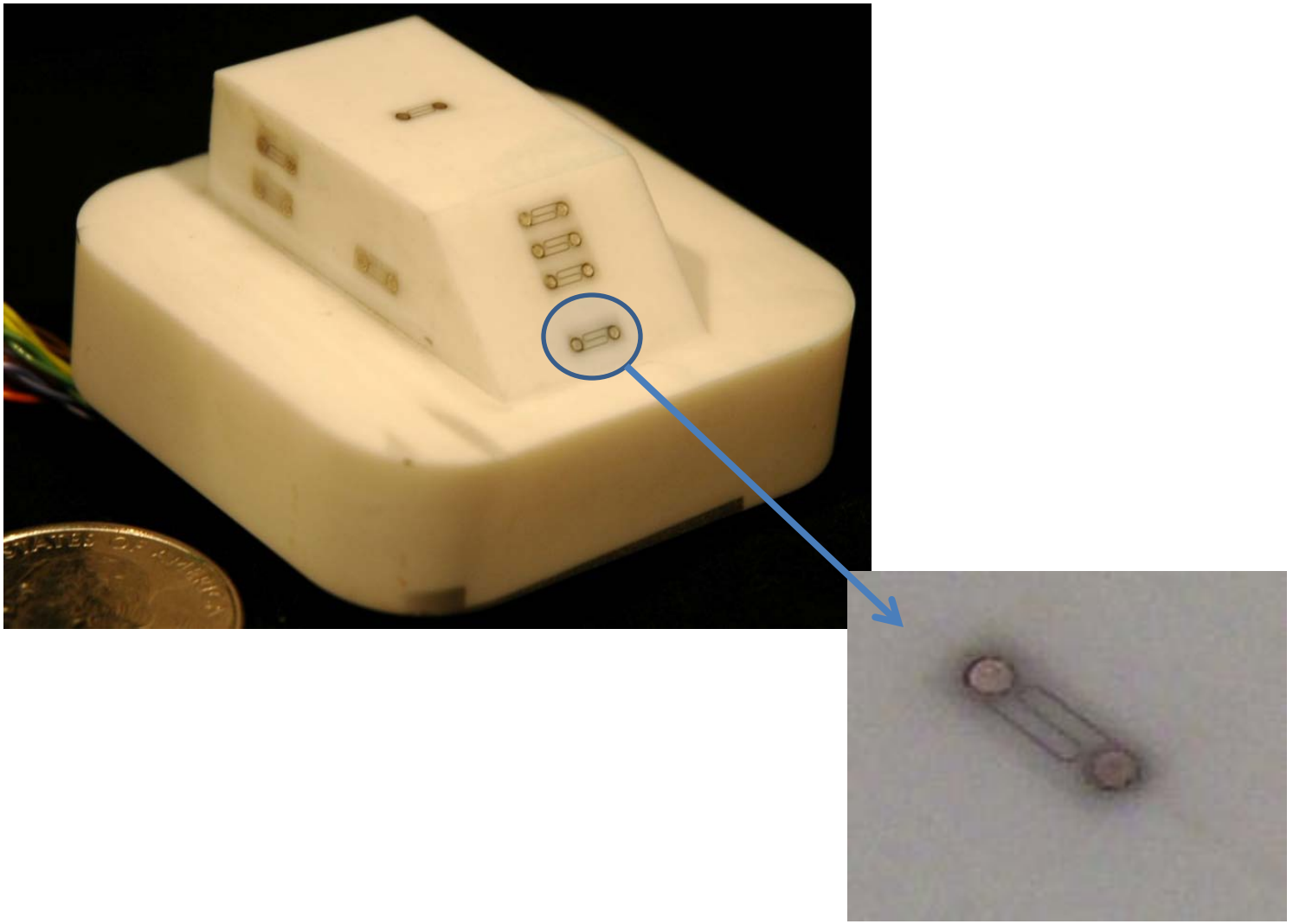
Platinum Resistance Thermometers

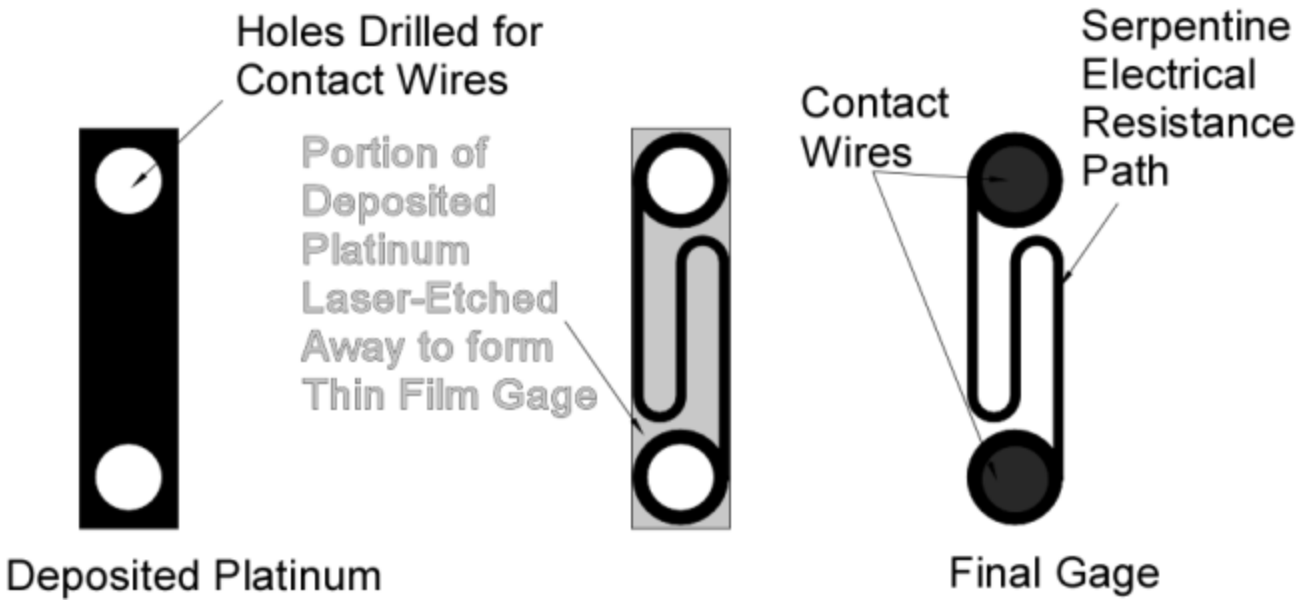
- Platinum resistance thin film sensors are frequently used in wind tunnel experiments to measure surface temperatures and subsequently calculate surface heat fluxes



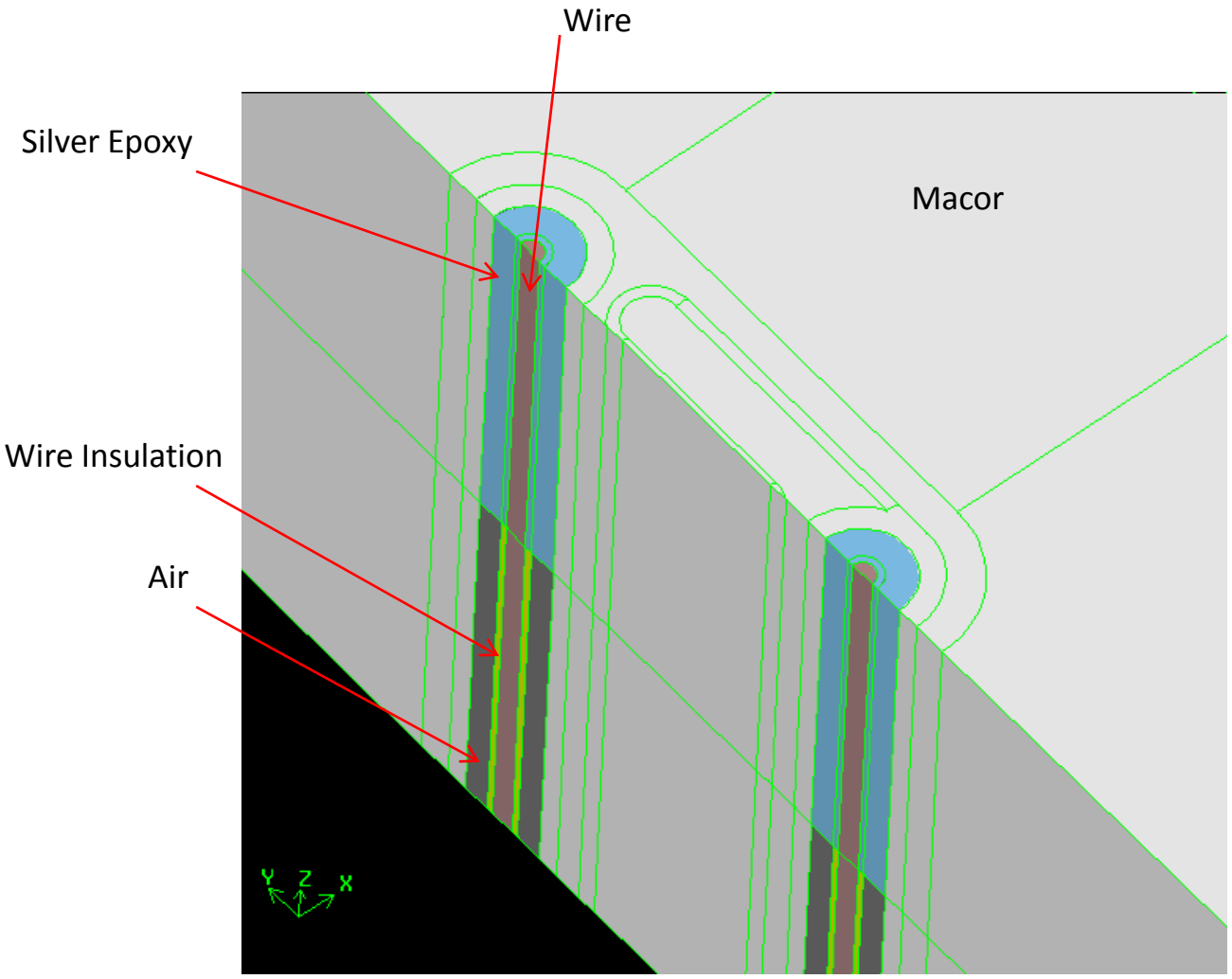
Hypothetical Installation



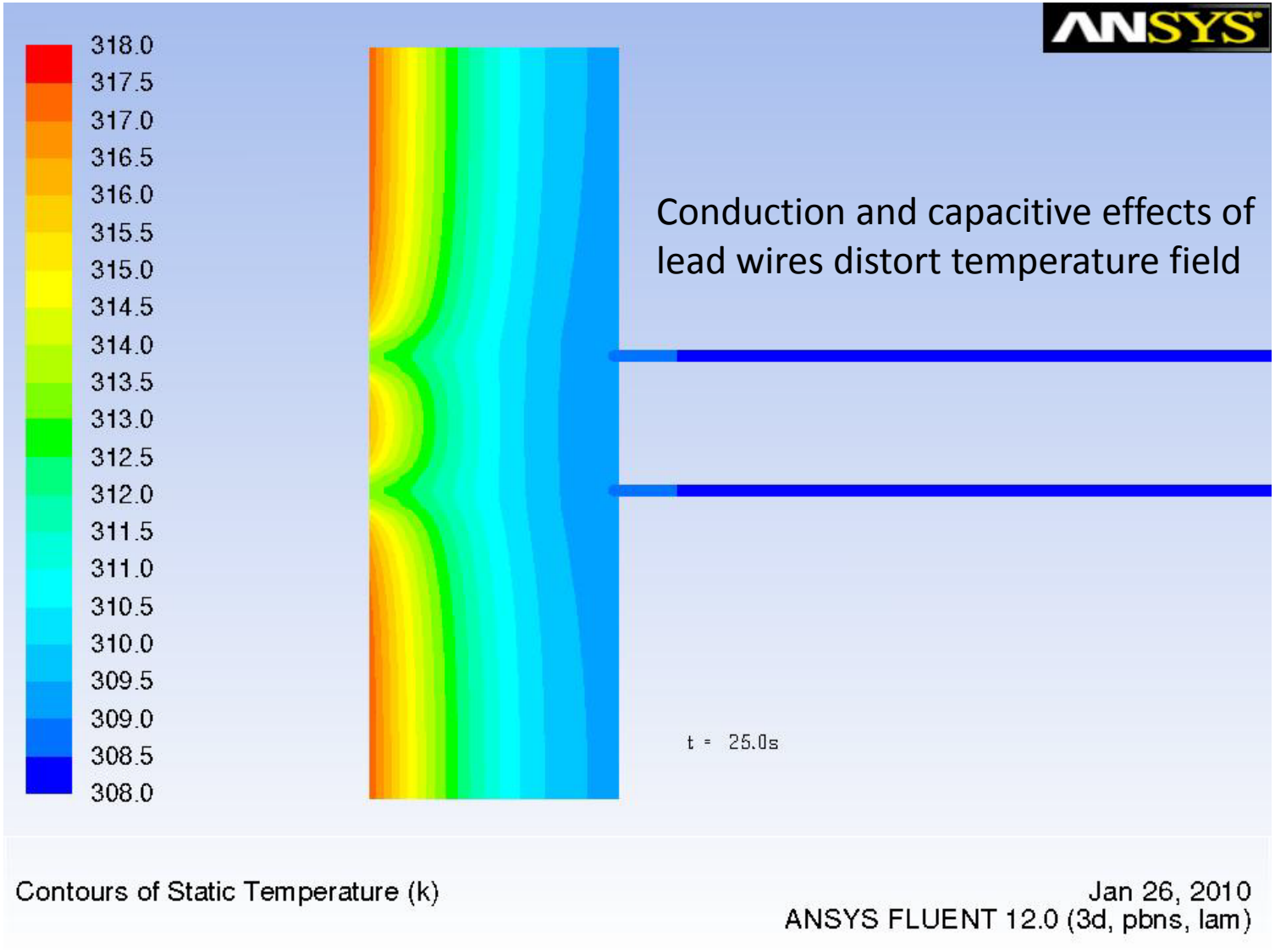
Sensor Construction

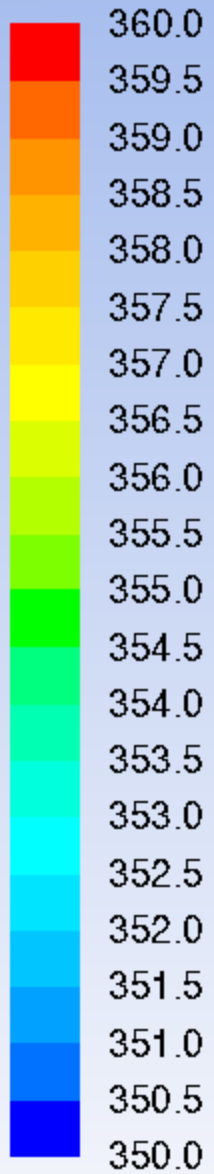


Thin Film Sensor Model - Construction

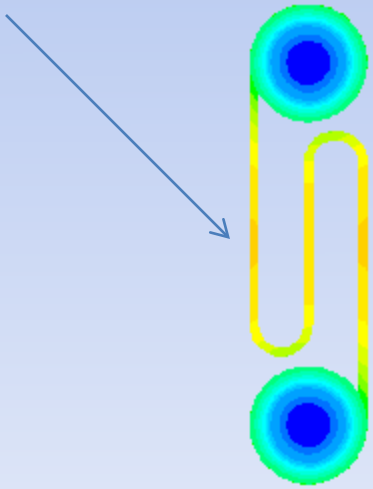


Temperature Field - Split View





"Measured" temperature will be the average temperature of the serpentine platinum film

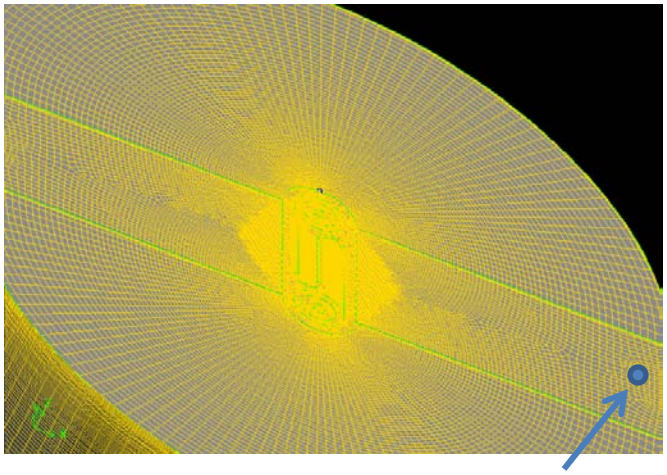


Contours of Static Temperature (k)

Jan 15, 2010
ANSYS FLUENT 12.0 (3d, pbns, lam)

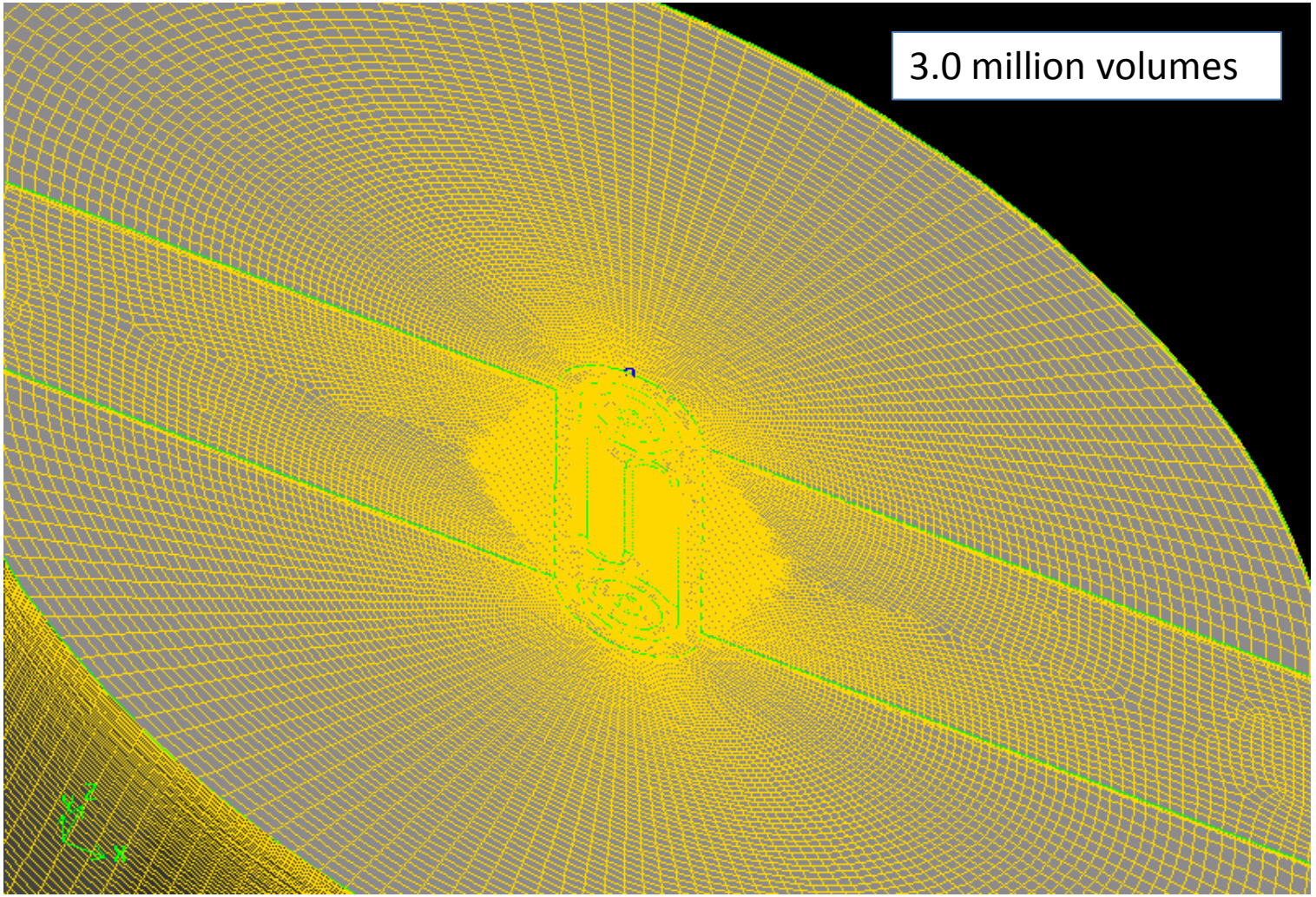
Error

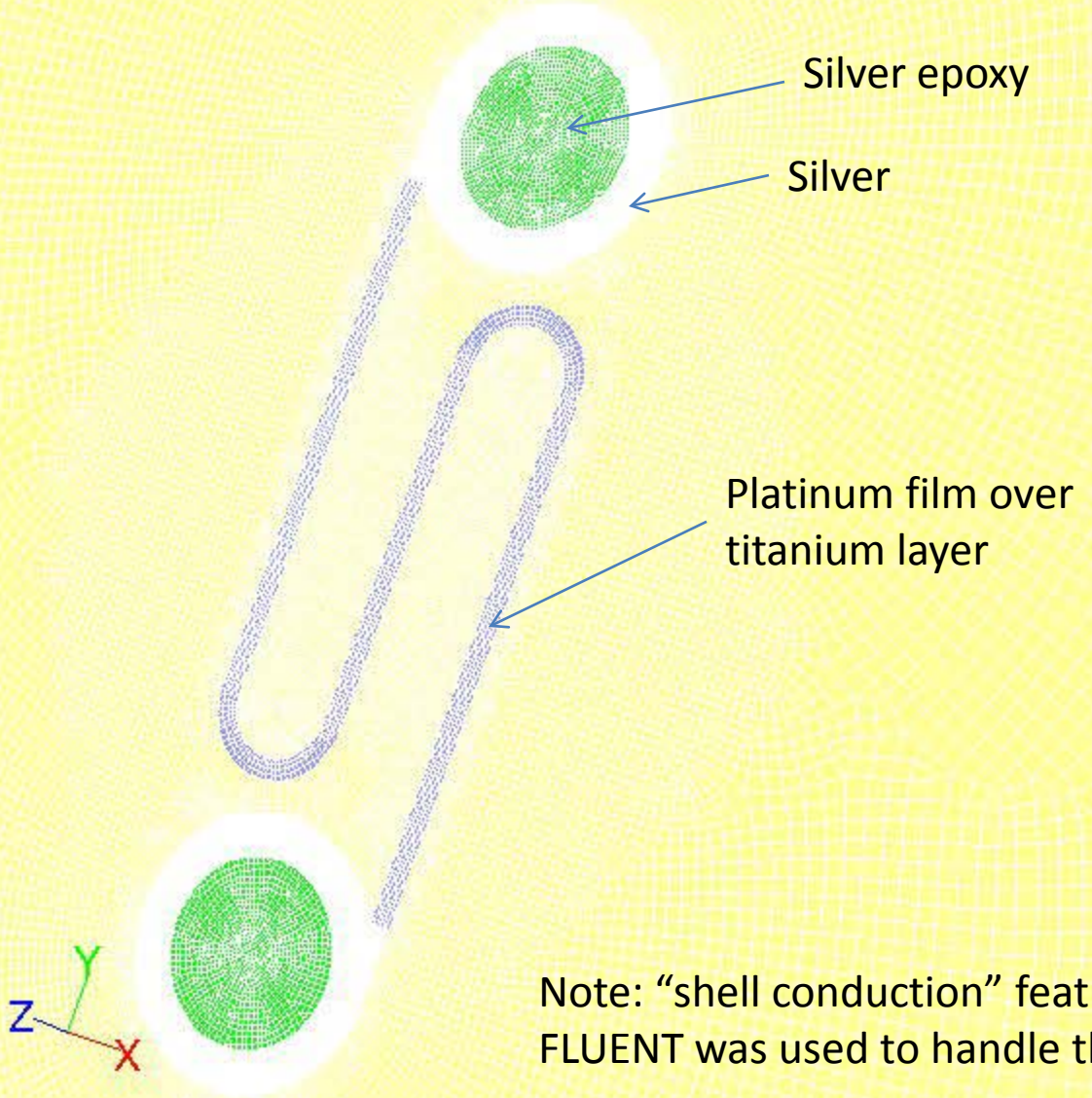
- Sensor measurements differ from undisturbed temperature
- Computational Fluent model created to demonstrate and investigate existence of an error



“Undisturbed” temperature

Sensor Grid





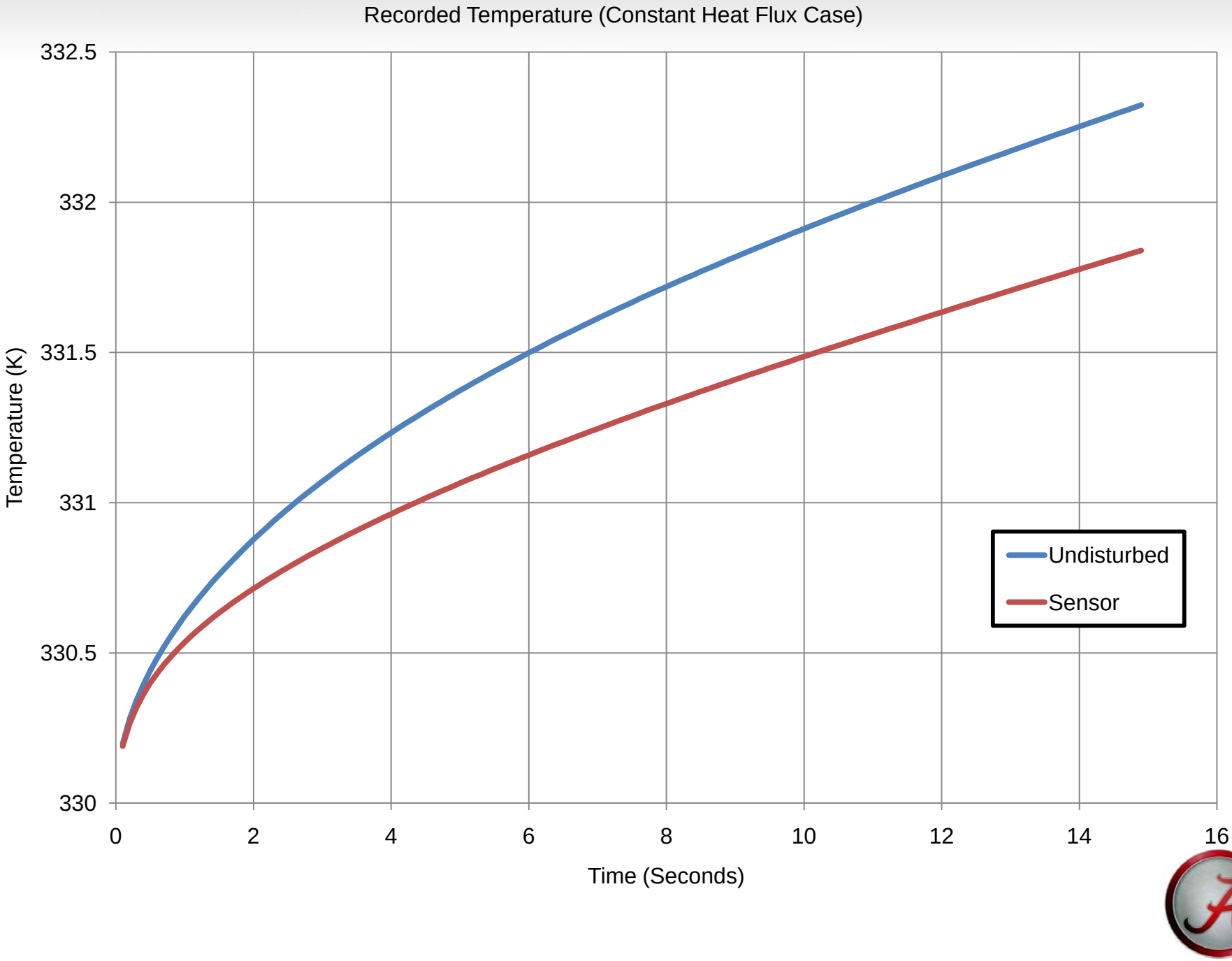
Note: “shell conduction” feature of FLUENT was used to handle thin layers

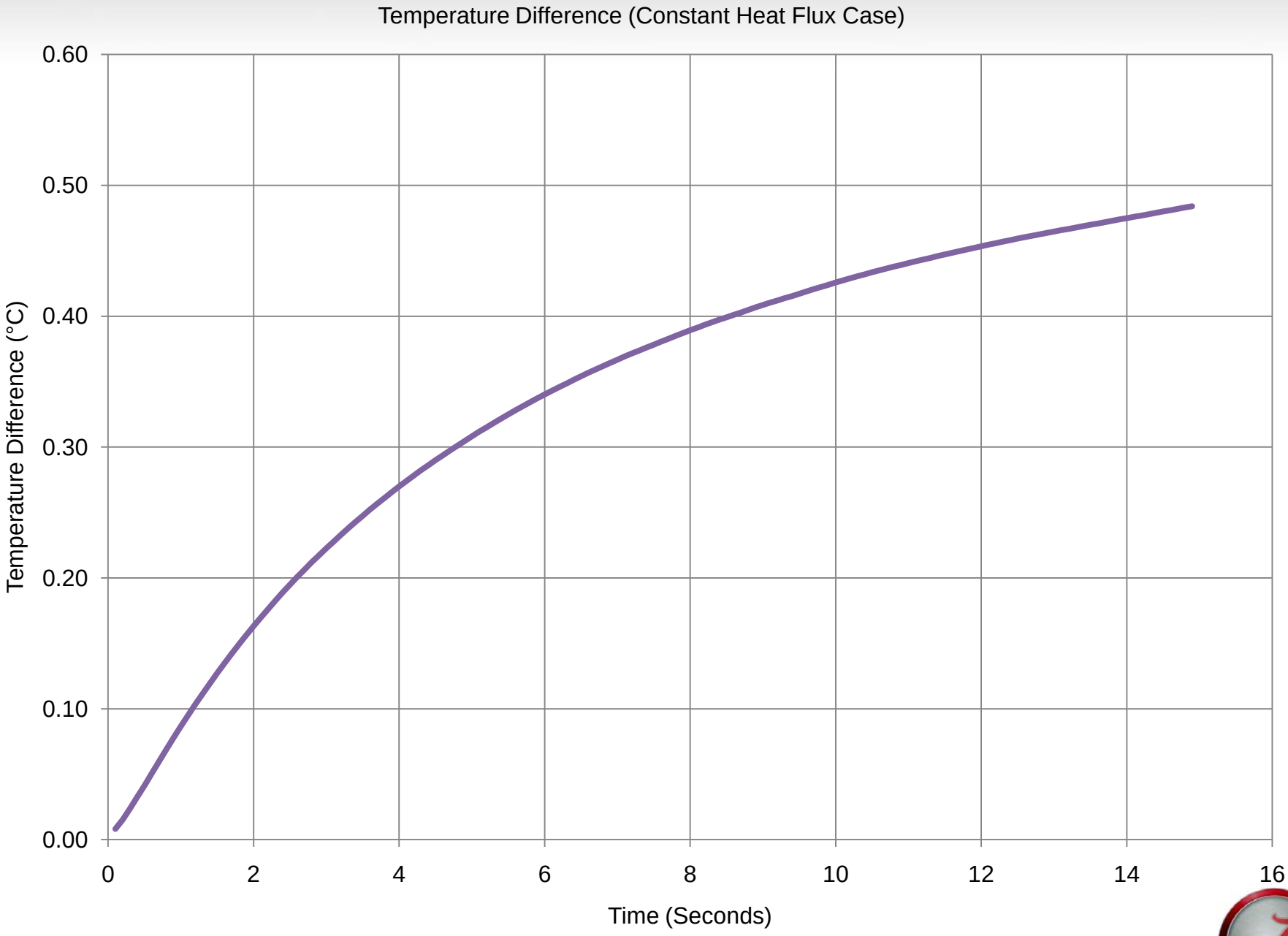
Mesh (Time=0.0000e+00)

May 16, 2010
ANSYS FLUENT 12.0 (3d, pbns, lam, transient)

Demonstration of Temperature Error

- Apply constant heat flux q_m =1000 W/m^2
- Compare sensor response to undisturbed response


Recorded Temperature (Constant Heat Flux Case)
332.5
332
331.5
331
330.5
330
Temperature (K)
0
2
4
6
8
10
12
14
16
Time (Seconds)
Undisturbed
Sensor


Temperature Difference (Constant Heat Flux Case)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Temperature Difference (°C)
0
2
4
6
8
10
12
14
16
Time (Seconds)

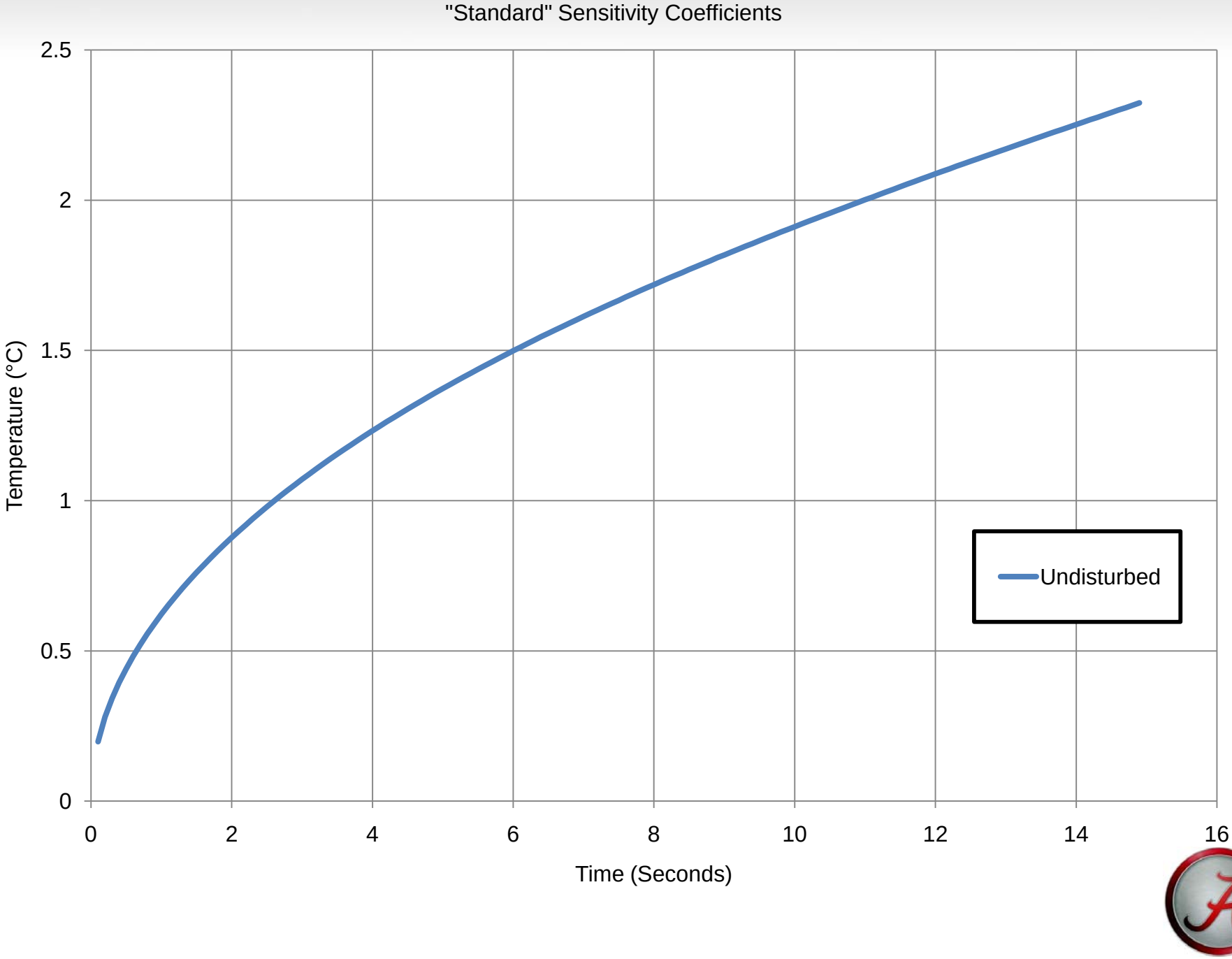
Corresponding Heat Flux Error

- Calculating heat flux at gage location
  - Cook Feldman Algorithm
    - Common method to compute heat flux from surface temperature measurement
  - Beck's Method
    - Also can be applied and has some advantage to address the sensor error

Sensitivity Coefficients

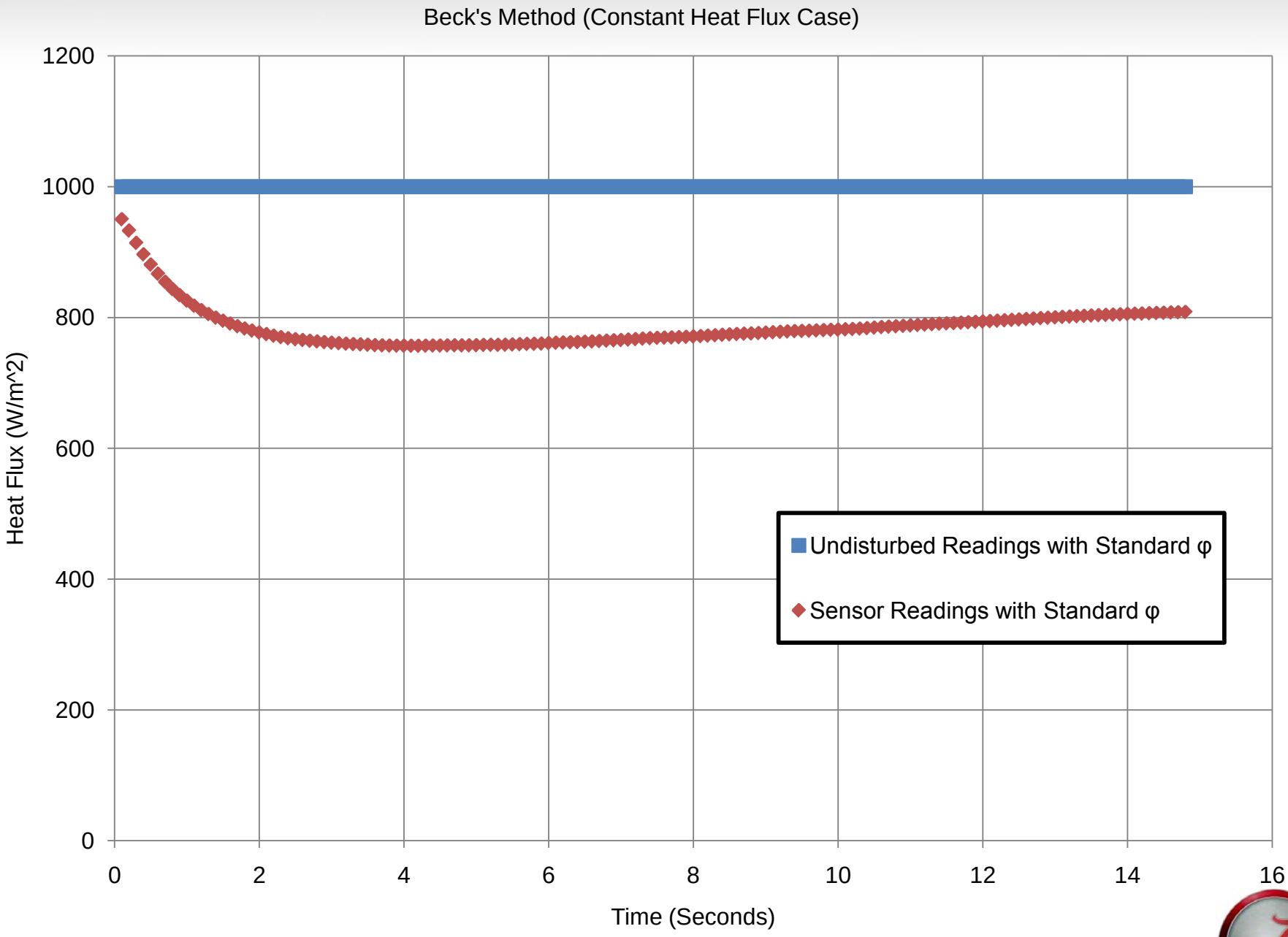
- Constant Heat Flux Case
  - Use results from Fluent simulation with constant heat flux
  - Determined “standard” sensitivity coefficients, ϕ, for the undisturbed location

$$\phi = \left.\frac{\partial T_m}{\partial q_m}\right|_{q_m = const}$$


"Standard" Sensitivity Coefficients
2.5
2
1.5
1
0.5
0
Temperature (°C)
0
2
4
6
8
10
12
14
16
Time (Seconds)
Undisturbed

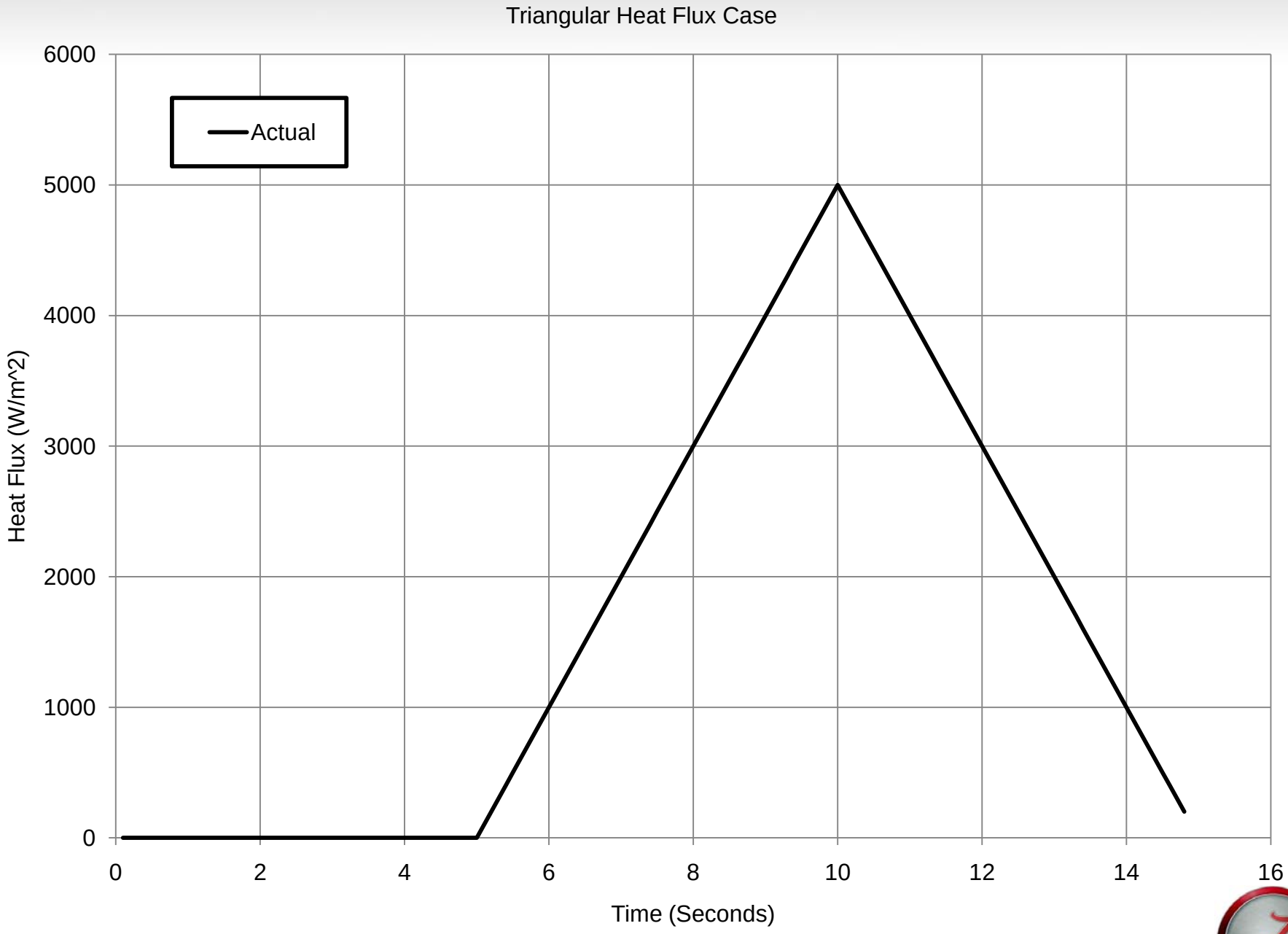
Surface Heat Flux

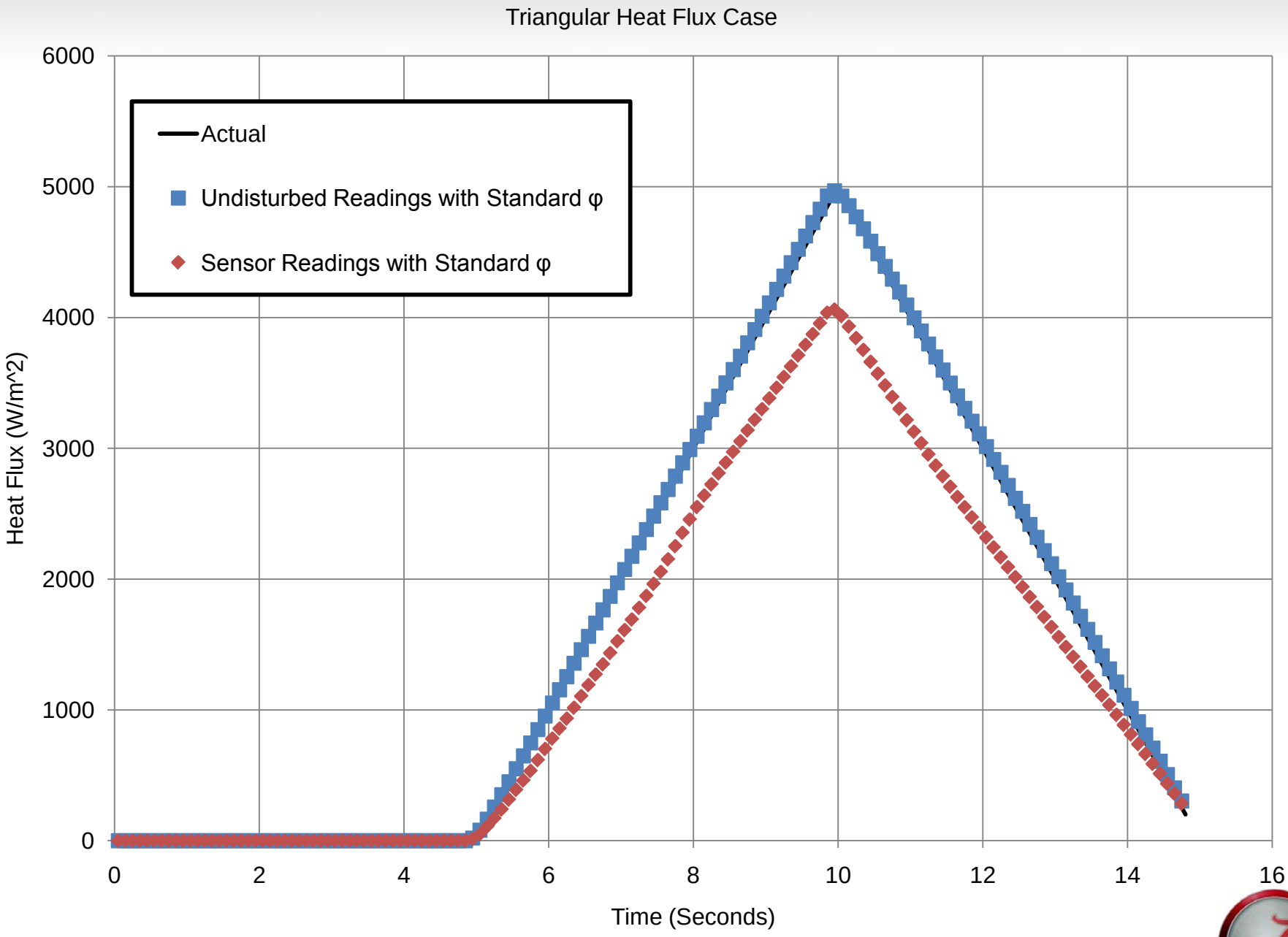
- Use the “standard” sensitivity coefficients and superposition/convolution to compute surface heat flux using:
  - “undisturbed” temperature measurements
  - Sensor temperature measurements


Beck's Method (Constant Heat Flux Case)
Heat Flux (W/m^2)
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
16
Time (Seconds)
Undisturbed Readings with Standard φ
Sensor Readings with Standard φ

Test Case: Triangular Heat Flux

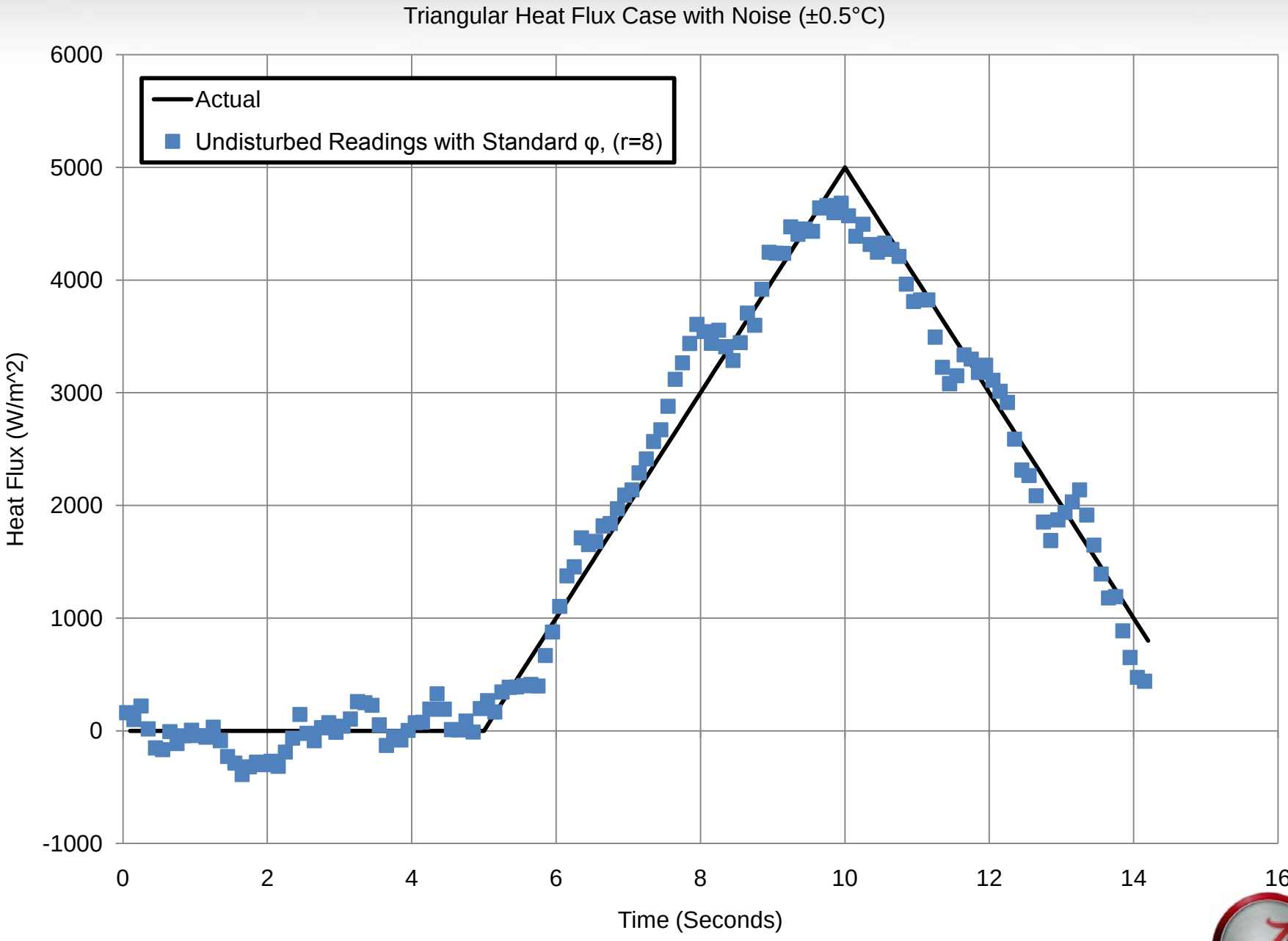
- Applied a triangular heat flux
- Ran case through forward solver (Fluent)
- Applied Beck's Method
  - Using "standard" sensitivity coefficients from constant heat flux case
  - Superposition/convolution

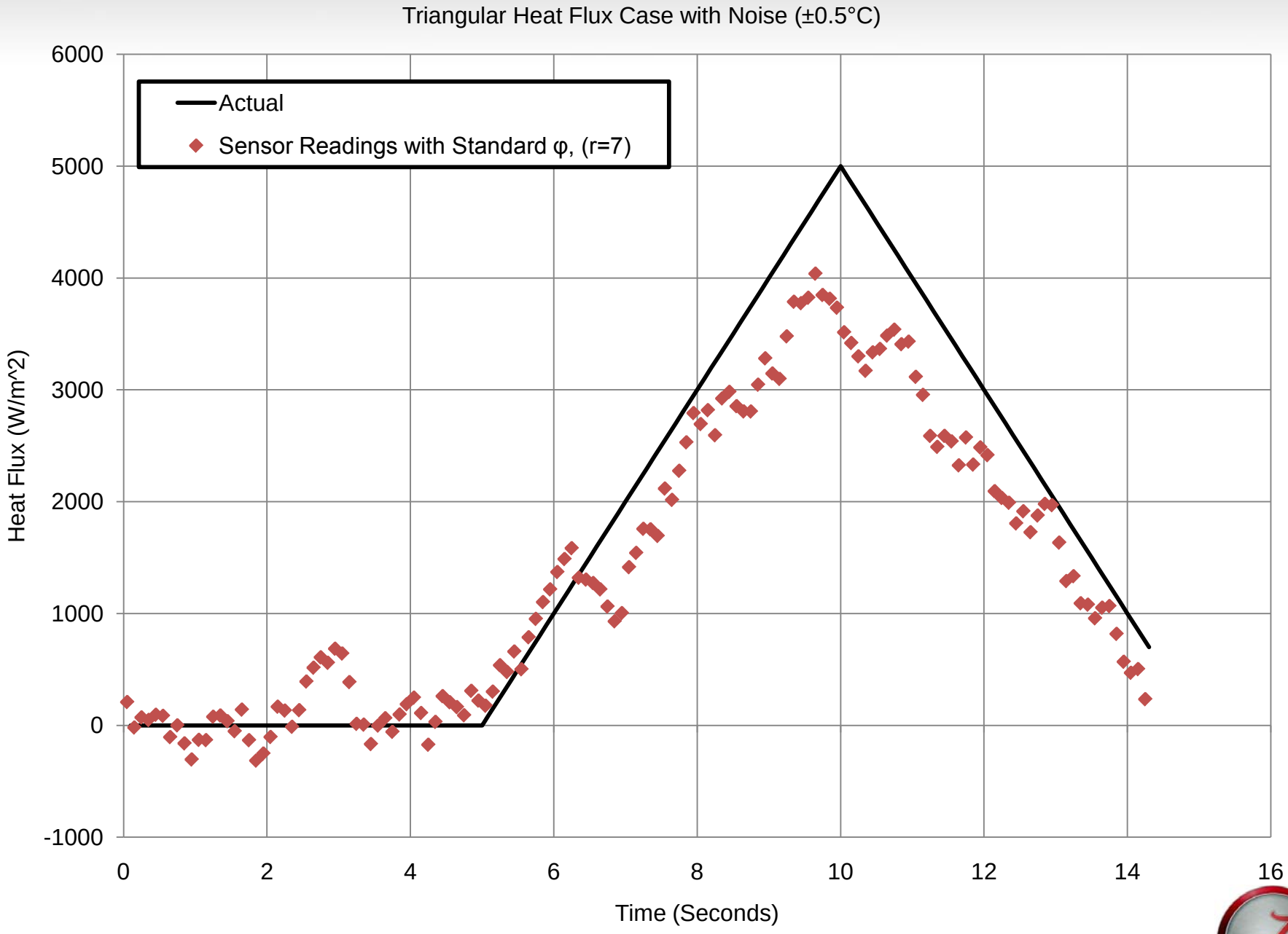

Triangular Heat Flux Case
Actual
Heat Flux (W/m^2)
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
16
Time (Seconds)


Triangular Heat Flux Case
Actual
Undisturbed Readings with Standard φ
Sensor Readings with Standard φ
Heat Flux (W/m^2)
Time (Seconds)
0
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12
14
16

Triangular Heat Flux Case – Noise Considerations

- What if there was noise due to measurement sensitivity?
  - Add ±0.5°C of random noise

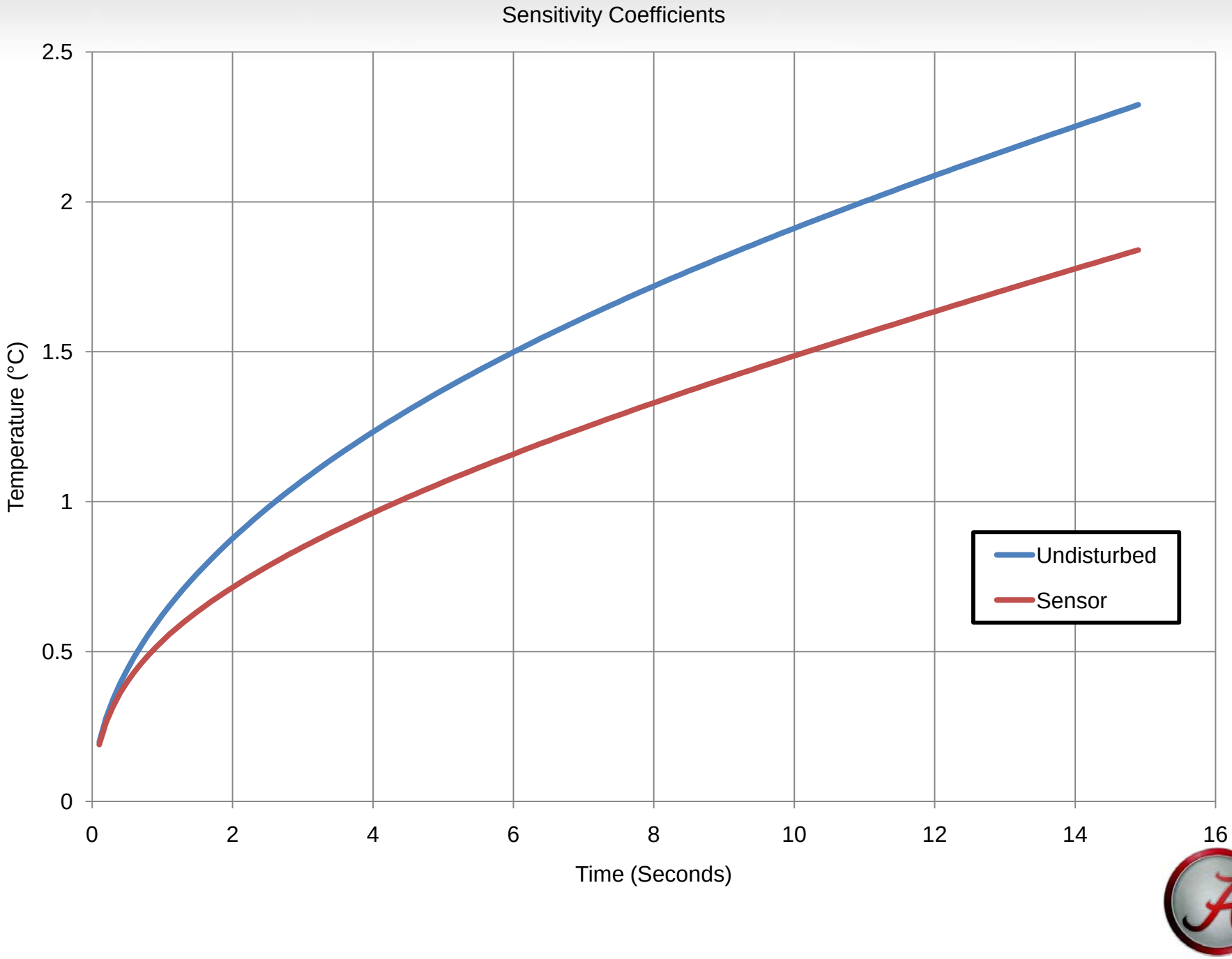

Triangular Heat Flux Case with Noise (±0.5°C)
Actual
Undisturbed Readings with Standard φ, (r=8)
Heat Flux (W/m^2)
6000
5000
4000
3000
2000
1000
0
-1000
0
2
4
6
8
10
12
14
16
Time (Seconds)

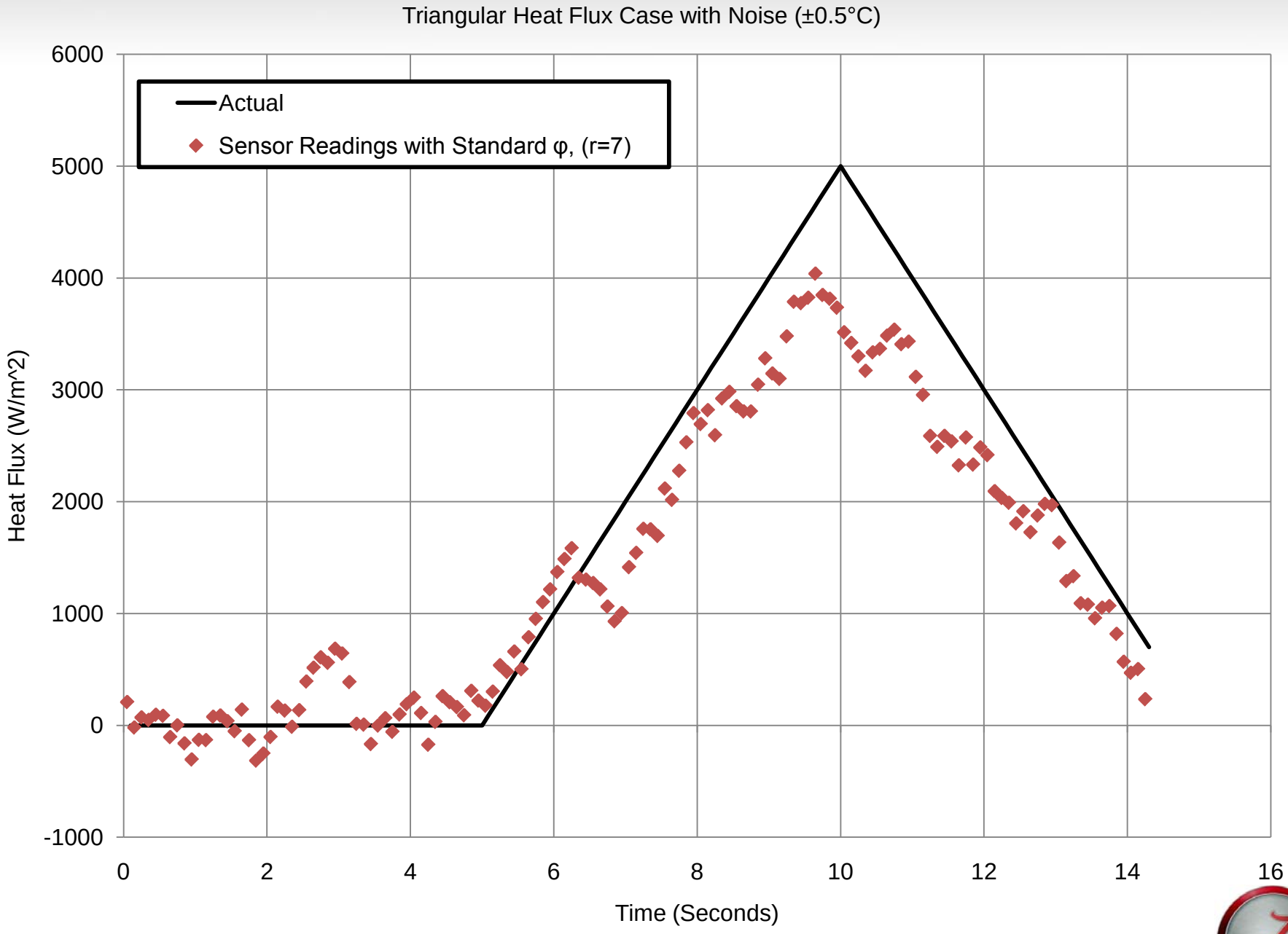

Triangular Heat Flux Case with Noise (±0.5°C)
Actual
Sensor Readings with Standard φ, (r=7)
Heat Flux (W/m^2)
6000
5000
4000
3000
2000
1000
0
-1000
0
2
4
6
8
10
12
14
16
Time (Seconds)

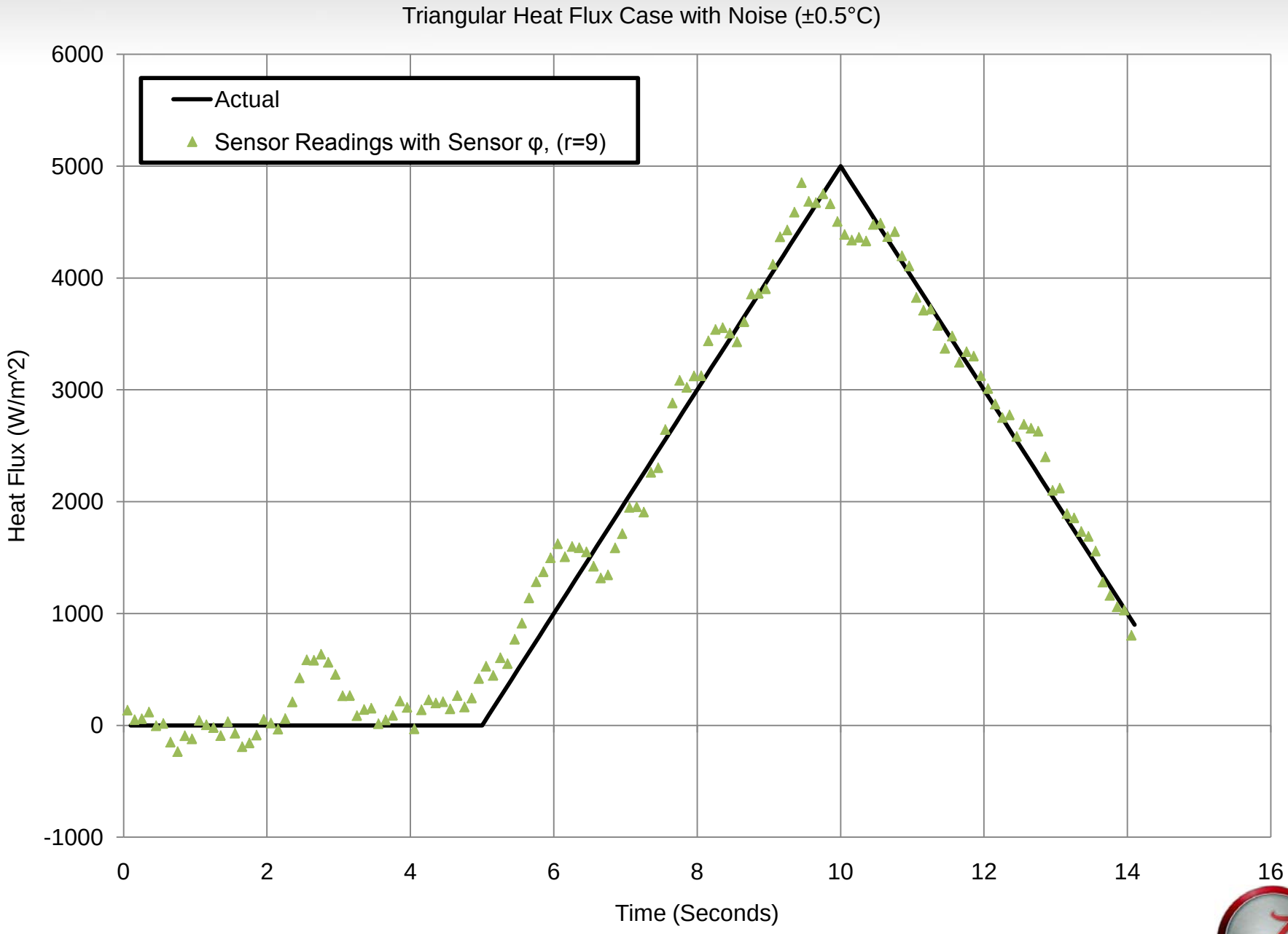
Use Sensor "ϕ" to get Improvement

- With Beck's method, we can use sensitivity coefficients that incorporate the *sensor dynamics* to get a corrected heat flux directly

- Use results from q_m = constant to compute the sensitivity coefficients <u>for the sensor</u>


Sensitivity Coefficients
2.5
2
1.5
1
0.5
0
Temperature (°C)
0
2
4
6
8
10
12
14
16
Time (Seconds)
Undisturbed
Sensor

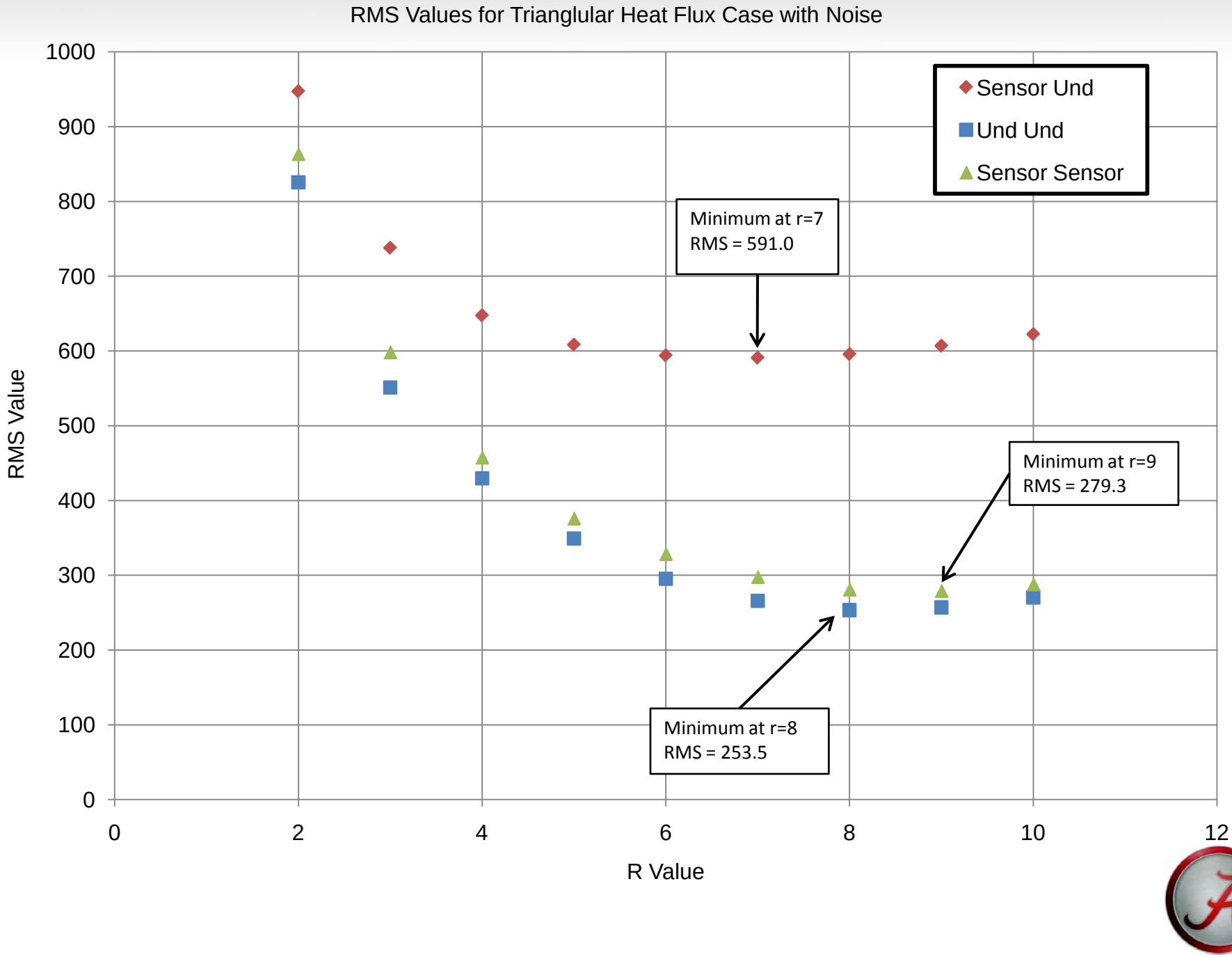

Triangular Heat Flux Case with Noise (±0.5°C)
Actual
Sensor Readings with Standard φ, (r=7)
Heat Flux (W/m^2)
6000
5000
4000
3000
2000
1000
0
-1000
0
2
4
6
8
10
12
14
16
Time (Seconds)

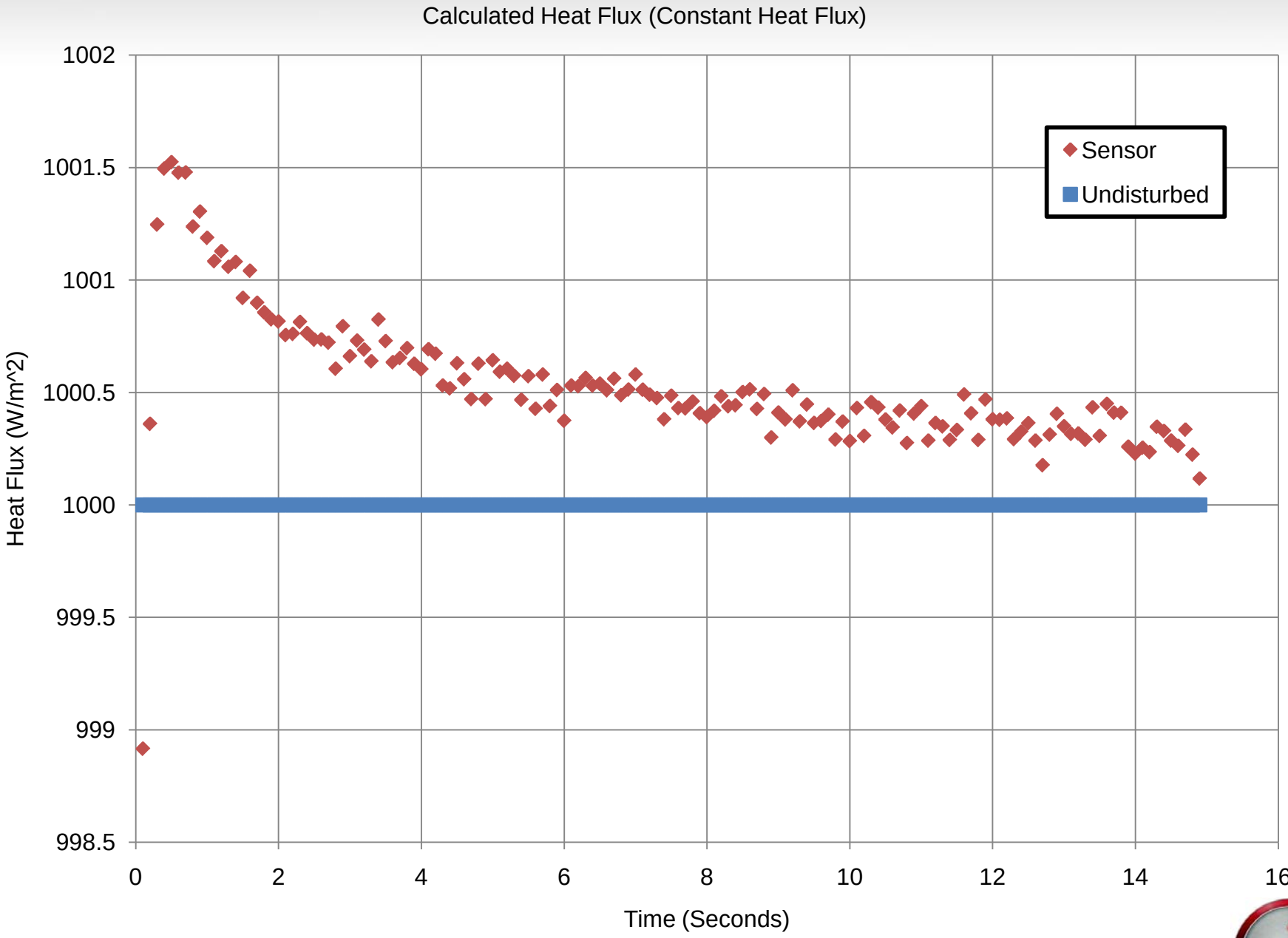

Triangular Heat Flux Case with Noise (±0.5°C)
Actual
Sensor Readings with Sensor φ, (r=9)
Heat Flux (W/m^2)
6000
5000
4000
3000
2000
1000
0
-1000
0
2
4
6
8
10
12
14
16
Time (Seconds)

Conclusions

- Presence of temperature sensors disturb the temperature field
  - Results in temperature measurement bias
- Measured (biased) temperature data in the IHCP result in large (~20%) errors in heat flux
- Sensitivity coefficients that incorporate sensor dynamics directly yield “corrected” values of heat flux

Questions


RMS Values for Trianglular Heat Flux Case with Noise
RMS Value
R Value
Sensor Und
Und Und
Sensor Sensor
Minimum at r=7
RMS = 591.0
Minimum at r=9
RMS = 279.3
Minimum at r=8
RMS = 253.5
0
100
200
300
400
500
600
700
800
900
1000
0
2
4
6
8
10
12


Calculated Heat Flux (Constant Heat Flux)
Heat Flux (W/m^2)
1002
1001.5
1001
1000.5
1000
999.5
999
998.5
0
2
4
6
8
10
12
14
16
Time (Seconds)
Sensor
Undisturbed