Thermodynamic Balance Control of Biosphere 2's Landscape Evolution Observatory

ARIZONA

MATHEMATICAL MODELING MATH 485-585

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Project Description

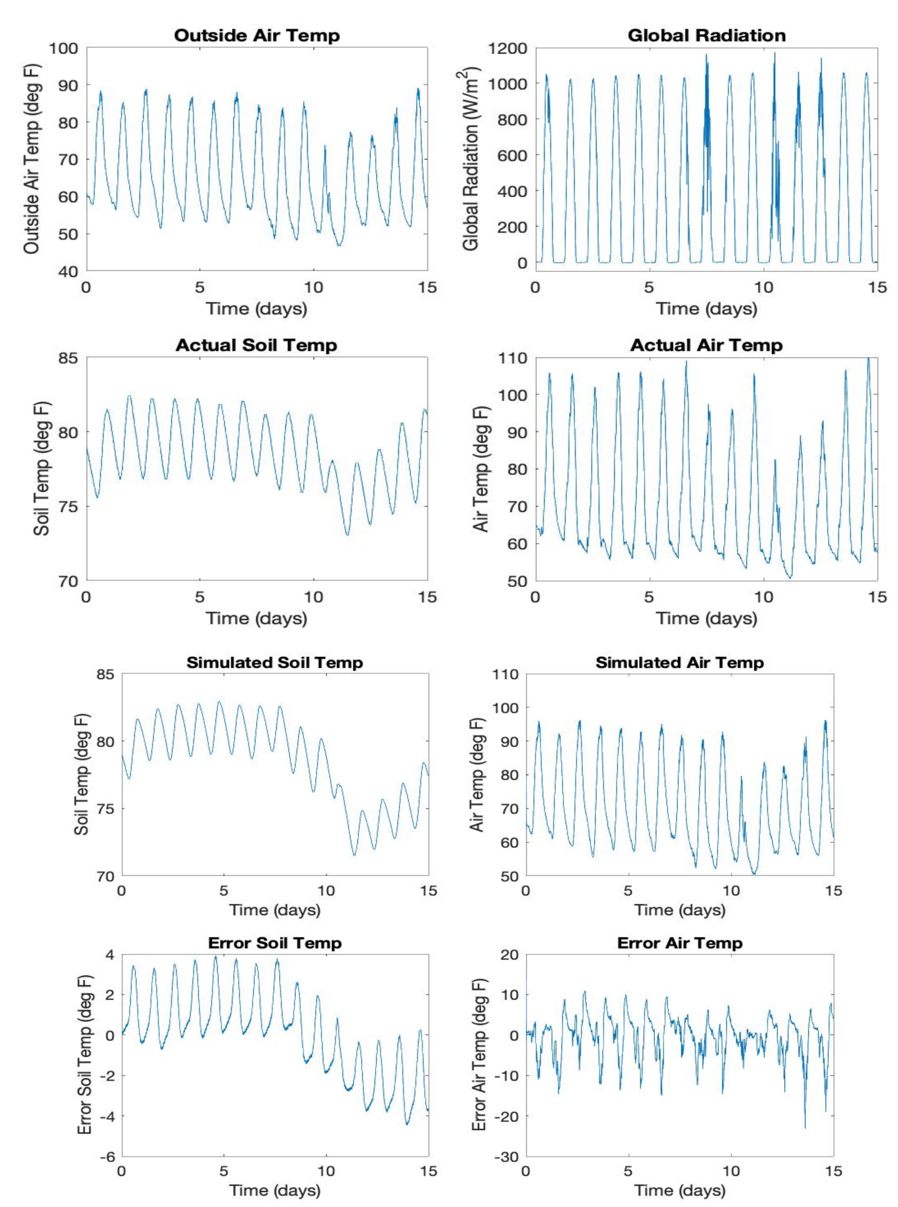
- Optimization of the thermodynamic balance control for Biosphere 2's Landscape Evolution Observatory.
- LEO consists of three adjacent greenhouse-like bays, each containing their own artificial landscape.
- LEO itself contains over 1800 individual sensors to monitor the water, carbon, physical, chemical and biological evolution of the landscapes.
- The biological communities in the LEO experiments are incredibly temperature sensitive, so accurate thermodynamic controls are vital.
- Biosphere 2 technicians manually adjust thermodynamic systems based on observed conditions without an underlying methodology.

Scientific Challenges

- Currently there is no model for the thermodynamic balance control of greenhouse-like structures similar to LEO.
- Data acquisition and integration from Biosphere 2 into a functioning model.

Application

- Providing a functioning model allows Biosphere 2 to optimize the temperature of the soil, which in turn improves the accuracy of LEO and all related current and future experiments.



Simulation results for 2 weeks in mid April in MATLAB, demonstrating correlation between live data and simulated results

Team Members:

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The Model

Our model is a system of differential equations relating dirt and air temperatures together based on Newton's Law of Cooling:

$$\frac{dT}{dt} = (a_1 \cdot G + k_1 \cdot (A - T))$$

$$\frac{dA}{dt} = (a_2 \cdot G + k_3 (H - A)) + k_2 \cdot (T - A) + k_4 ((B - A) + k_5 \cdot A)$$

T = Dirt Temperature | a_1 = Absorption factor of the soil
G = Global solar radiation | a_2 = Absorption factor of surrounding material
H = Air Handler | k_1 = Air to dirt | k_2 = Dirt to air
A = Air Temperature | k_3 = Water to air | k_4 = Ambient to inside air
B = Ambient Temperature | k_5 = Greenhouse effect

This system of differential equations was then recreated as a simulation with MATLAB and solved via the forward Euler method in 15-minute time steps to match live data from Biosphere 2.

Initial model parameters (a_1, a_2, k_1 k_2 k_3 k_4 k_5) were calibrated by hand to achieve average errors of approximately 2 °F for the soil temperature and 5 °F for air temperature.

Results

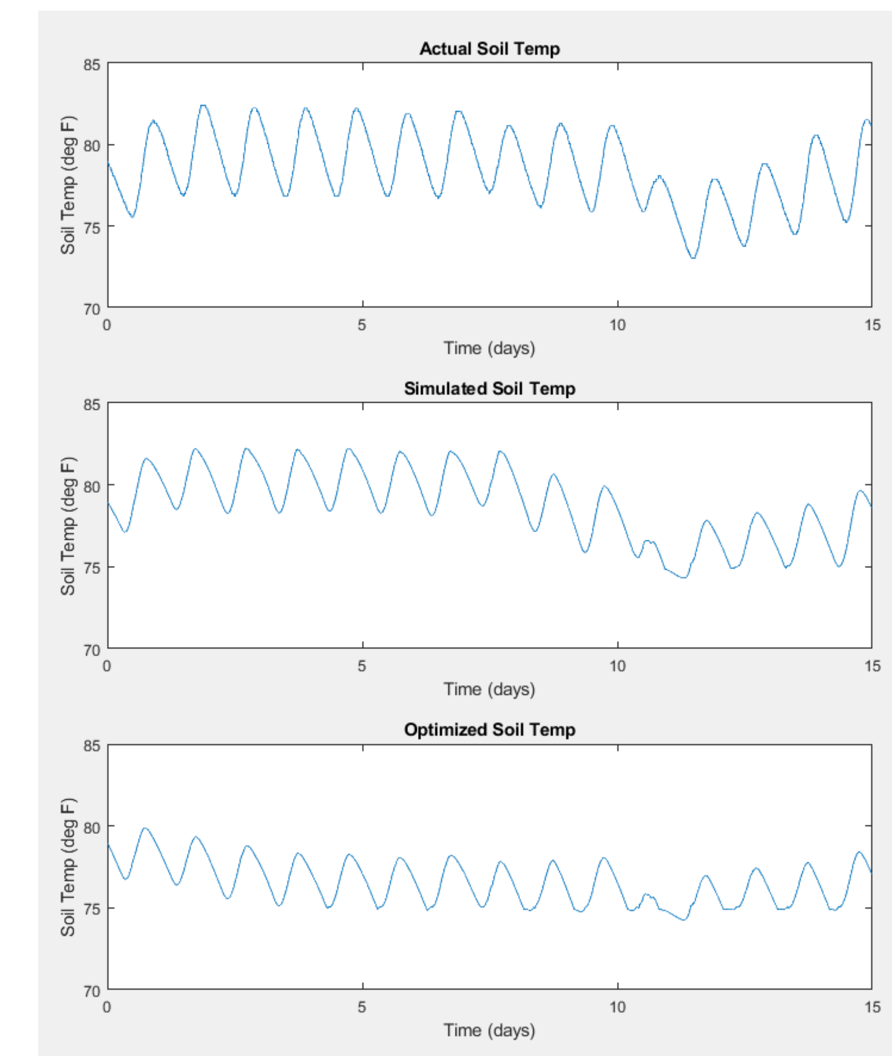
1. Created a system of differential equations to describe the thermodynamic balance of the greenhouse-like environment of the LEO experiment.
2. Created a simulation and solved the differential equation via forward Euler Method in MATLAB to mirror the behavior of live LEO data.
3. Optimized the parameters of the equations via nonlinear least squares optimization algorithm, which further refined the results to yield average errors of 1.3013 and 2.8539 °F respectively for air and soil.
4. Tested the optimized model on a variety of weather conditions and seasons to ensure generalized accuracy of the LEO simulation throughout the year.

Glossary of Technical Terms and Equations

Newton's Law of Cooling : $\frac{dT}{dt} = k(M - T)$.

Forward Euler Method: $y_{n+1} = y_n + hf(y_n t_n)$

Non-Linear Least Squares Optimization: $min_x f(x) = \sum_{i=1}^{m} f_i(x)^2$



Simulated Soil Temperature after optimization air handler usage in MATLAB

References

[1] Lawson, C. L. and R. J. Hanson. Solving Least-Squares Problems. Upper Saddle River, NJ: Prentice Hall. 1974. Chapter 23, p. 161.

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[3] Biosphere 2, the University of Arizona, "Landscape Evolution Observatory" Access Date: April 2020 https://biosphere2.org/research/projects/landscape-evolution-observatory

[4] Yahyaoui, Imene, "Chapter 2 – Modeling of the Photovoltaic Irrigation Plant Components" In "Specifications of Photovoltaic Pumping Systems in Agriculture" 2017, pp 15-57

[5] MATLAB. (2010). *version 9.7.0 (R2019b)*. Natick, Massachusetts: The MathWorks Inc.

Acknowledgments

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