Industry Session 5: Energy Harvesting

Chip Scale Thermoelectric Generator for Smart Agriculture

Presented By

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OVERVIEW

- **Introduction**
- **ADI chip-scale TEG development**
- **TEG-powered CbM sensor node**
- **TEG-powered ground spike for smart agriculture**
- **Conclusions**

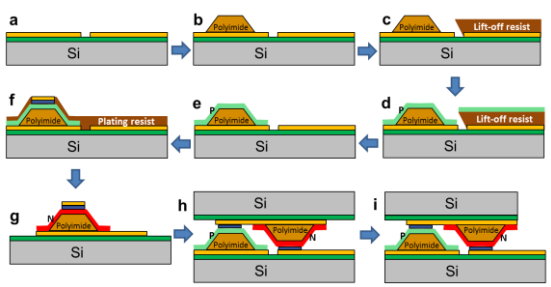
ADI Chip-Scale Thermoelectric Generator (TEG)

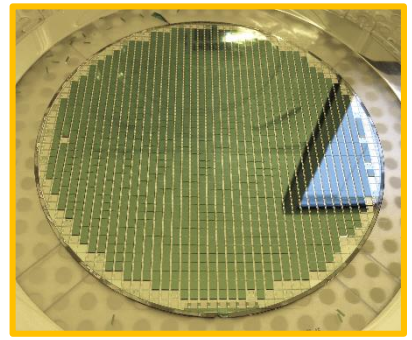
- **Leveraging ADI manufacturing and processing know-how to build *high-performance*, *low-cost* devices**
- **Compared with typical bulk solutions:**

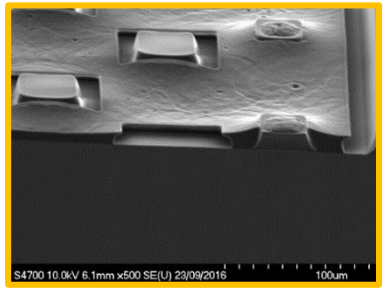
vs

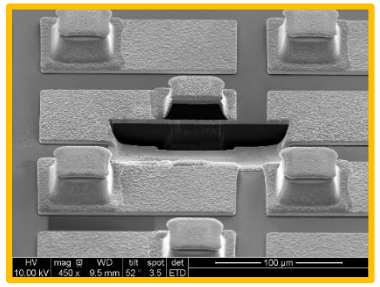
  - **Small device area (*10mm²*)**
  - **Higher output voltage: *Maximize efficiency* of power management**
  - **Higher thermal impedance: *Maximize ΔT captured***

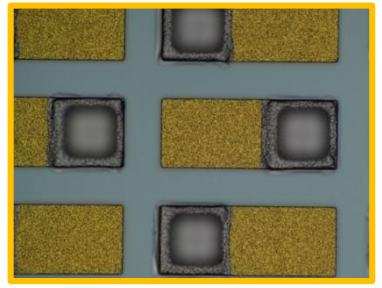
In-house 8" wafer processing











ADI Chip-Scale Thermoelectric Generator (TEG)

- Leveraging ADI manufacturing and processing know-how to build *high-performance*, *low-cost* devices
- Compared with typical bulk solutions:

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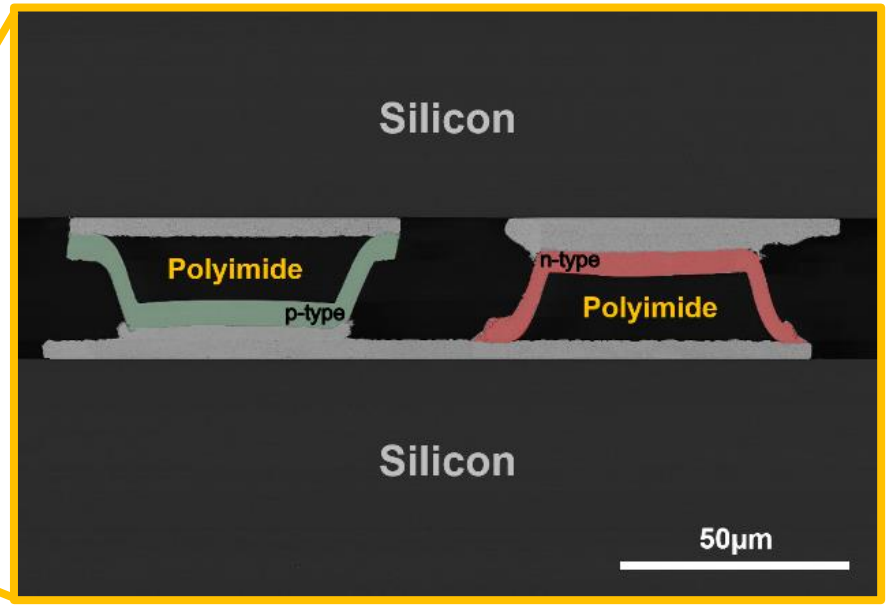


ANALOG DEVICES TEG

- *Based on novel device architecture*
- *TE materials deposited along polyimide slope*
- *Long leg length, large thermal resistance*

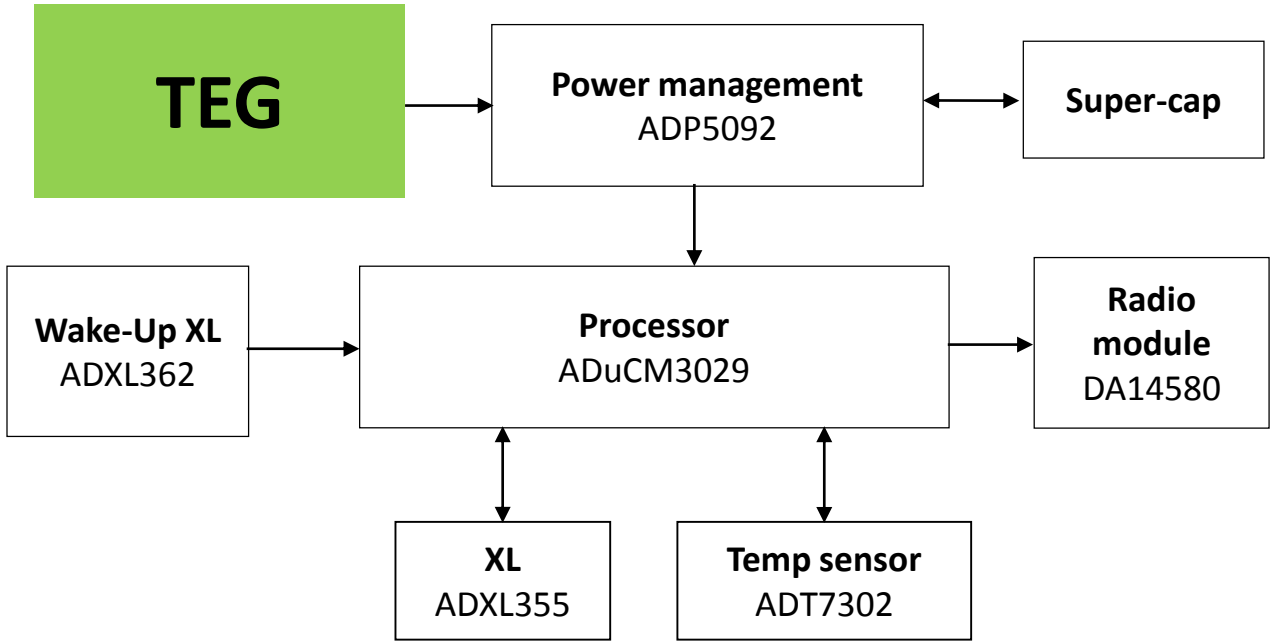
- Small device area (*10mm²*)
- Higher output voltage: *Maximize efficiency* of power management
- Higher thermal impedance: *Maximize ΔT captured*

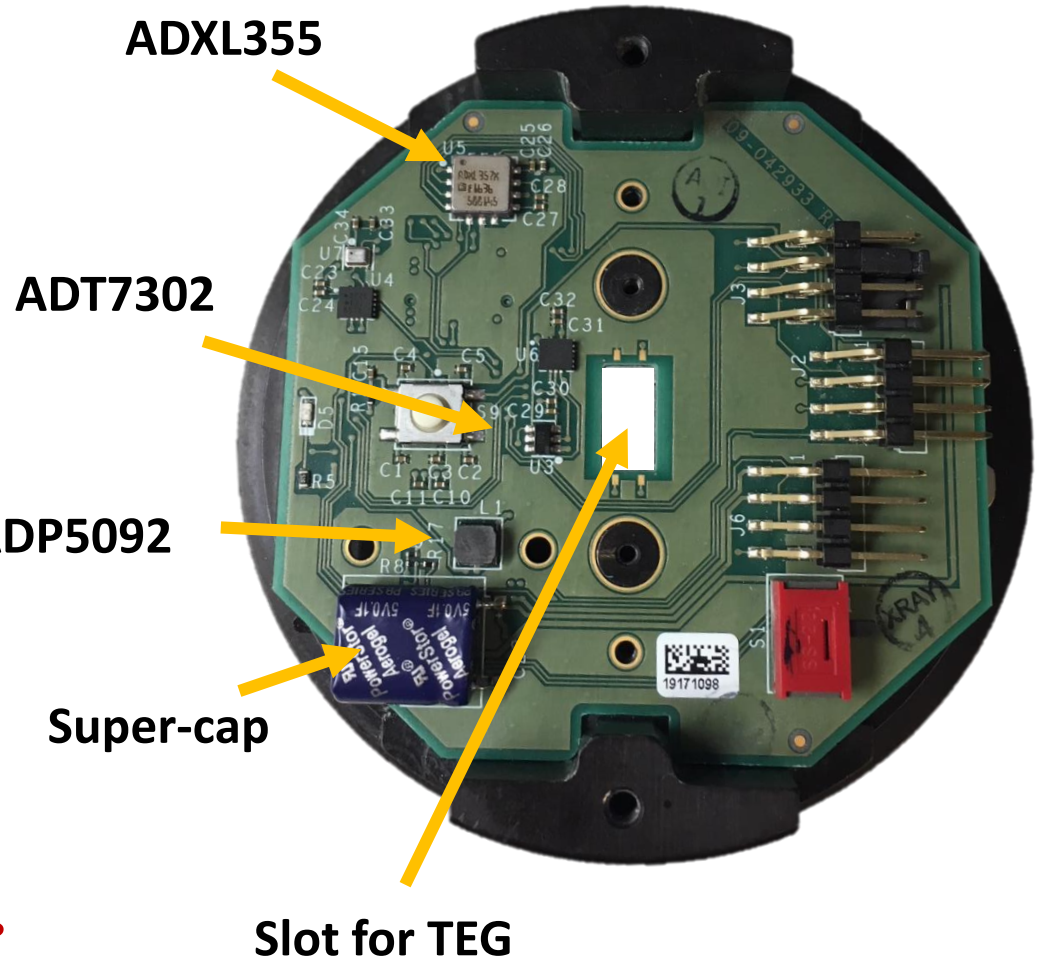
Optimized for harvesting low levels of heat close to room temperature

Generate energy to power wireless sensor nodes and other small devices

Condition-based Monitoring (CbM) Sensor Node

Block diagram





- ***ADuCM3029 microcontroller***
  - **4 programmable active and sleep modes**
  - **SPI, I²C and UART interfaces**
- **Several ultra-low-power ANALOG DEVICES *vibration and temperature sensors***

Condition-based Monitoring Sensor Node

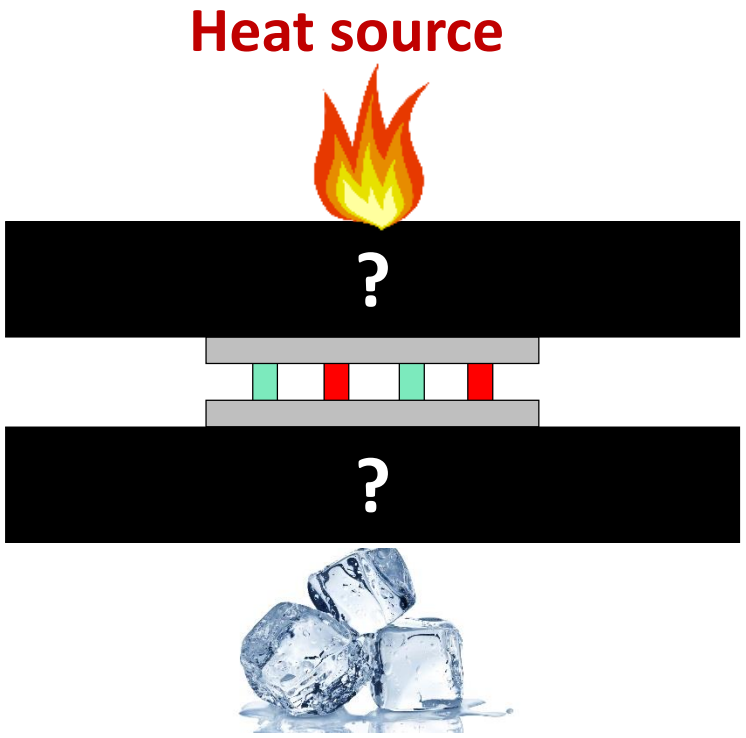
Power consumption

Update rate	DA14580 *BLE*	ADuCM3029 *uC*	ADXL355 *XL*	ADXL362 *Wake-up*	ADT7302 *Temp*	Total
30 sec	172	16.1	5.56	4.89	0.24	199
30 min	5.82	0.433	0.093	5.39	0.004	11.7

Average power in µW

- **Data updates every 30 sec:** Power consumption dominated by transmission → ΔT ~ ***10°C***
- **Data updates every 30 min:** Wake-up XL power consumption comparable to BLE → ΔT ~ ***2°C***

Designing the TEG Thermal System



System-level Considerations

Geometry

- Shape and available area of heat source
- Shape and available area of cold source
- Available volume for heat sink

Interfaces

- Surface material of heat source (metal, magnetic, ceramic, etc.)
- Surface material of cold source
- Requirements for adhesion

Thermal

- Typical temperatures of heat source, cold source
- Temperature of ambient
- Typical airflow conditions

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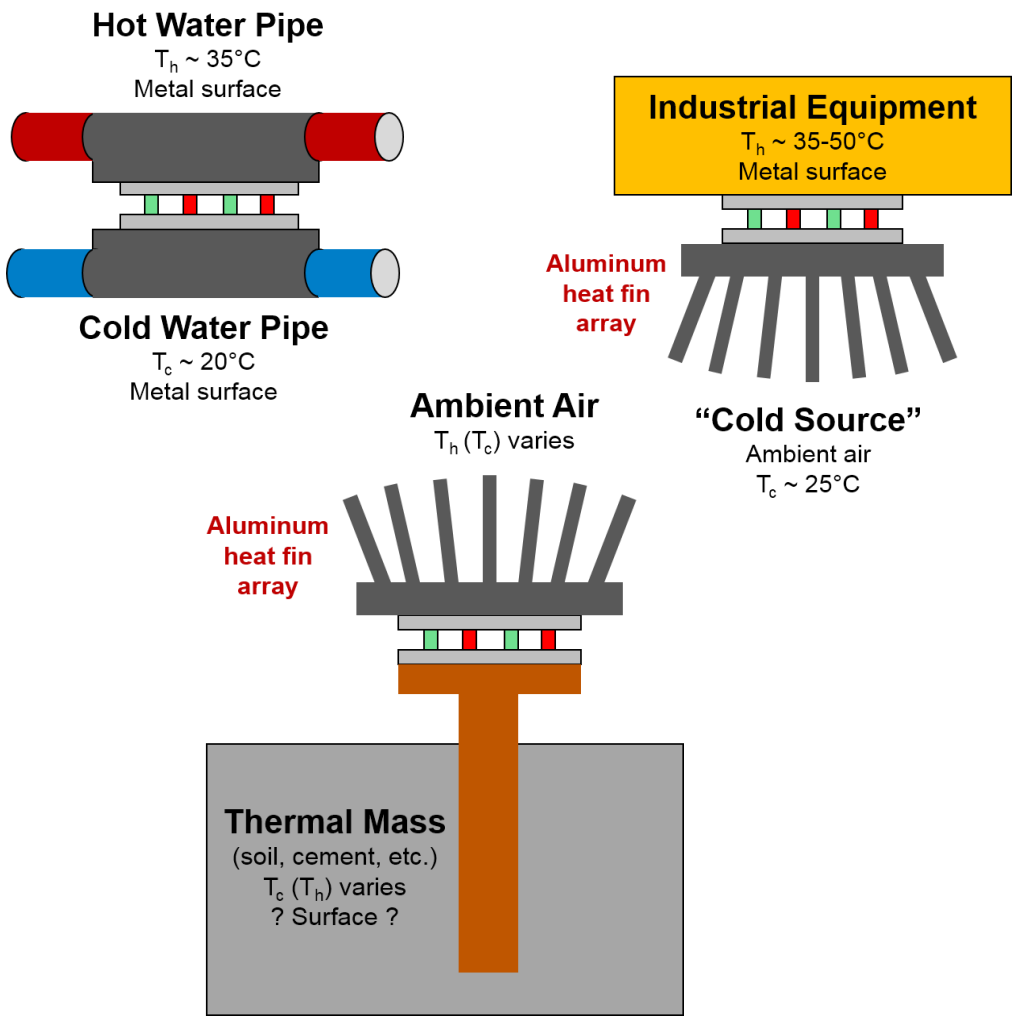

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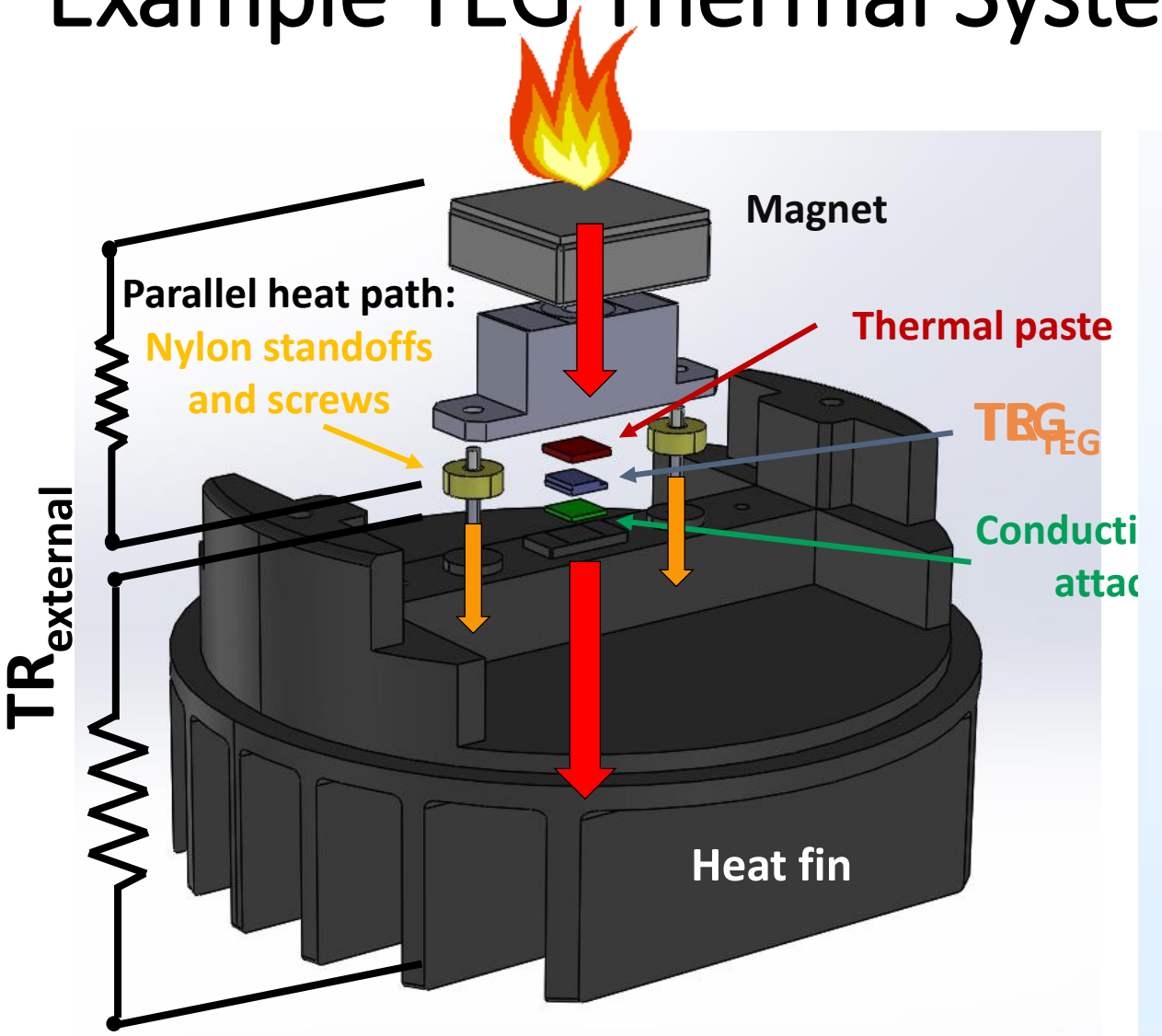
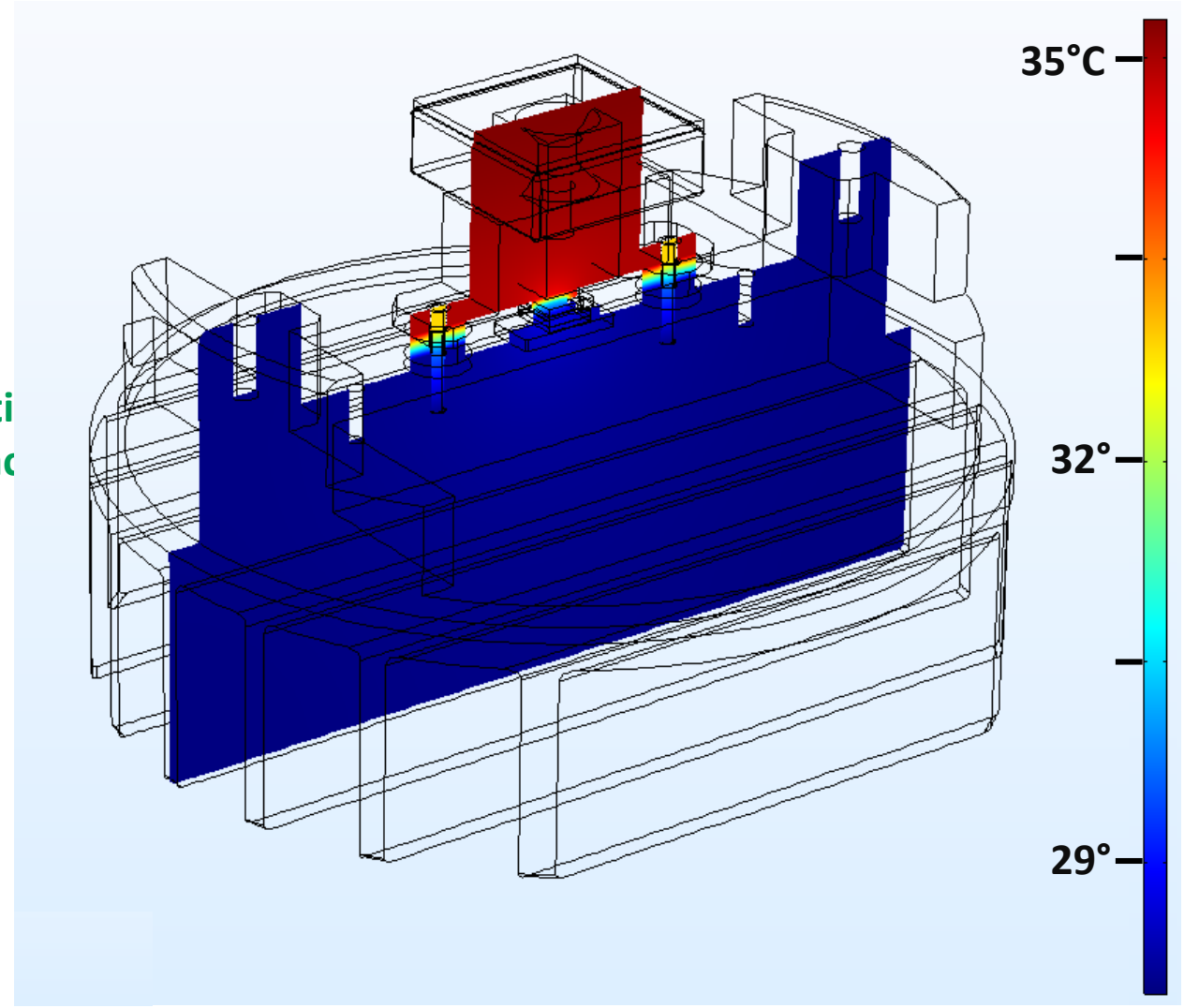
Example TEG Thermal System: CbM Node



PCB and plastic housing not shown

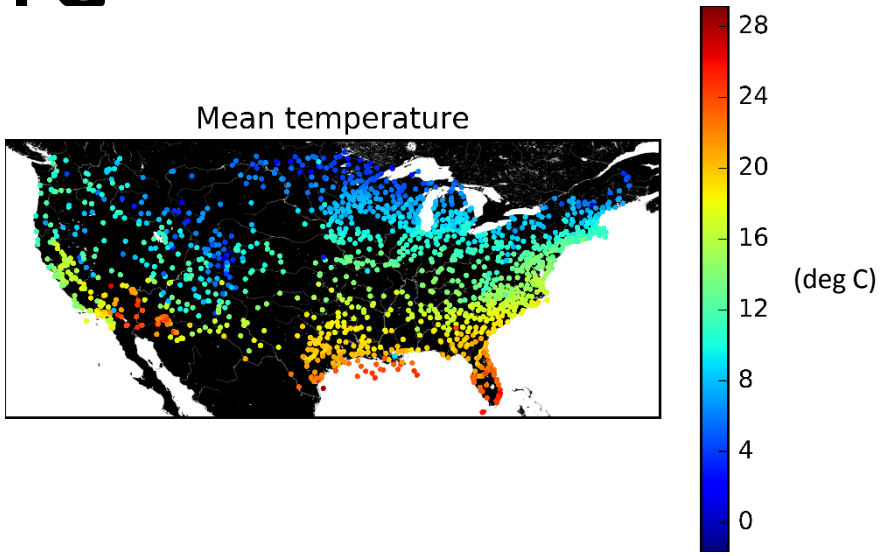
Modeled Temperature Profile

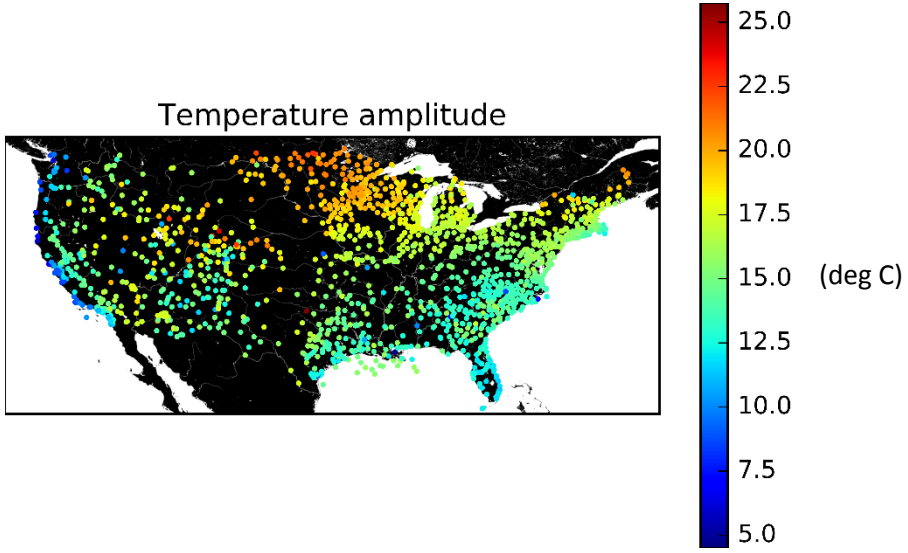


Application to Smart Agriculture

- Temperature varies significantly both by location and throughout the year in the United States

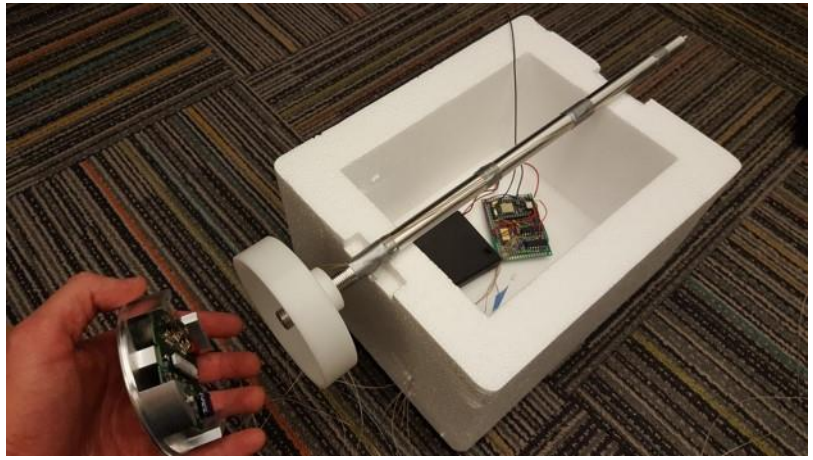
- With Analog Garage developments in thermoelectric energy harvesters, how might we utilize these natural thermal resources as a technology enabler in industries like smart agriculture, construction, or environmental monitoring more broadly?



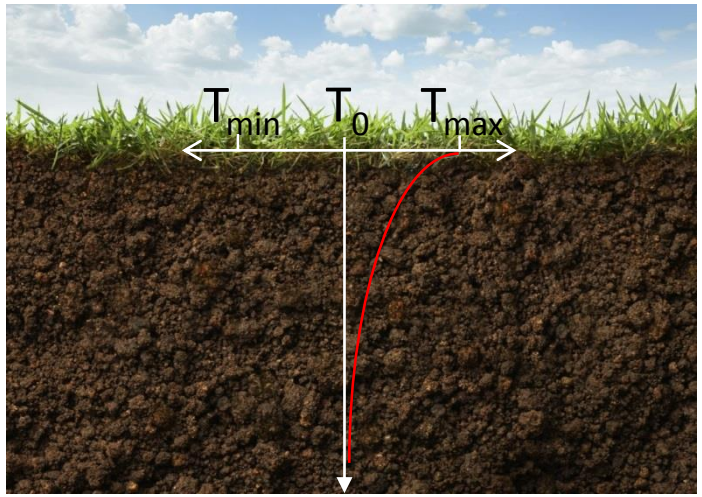


Thermal Ground Spike

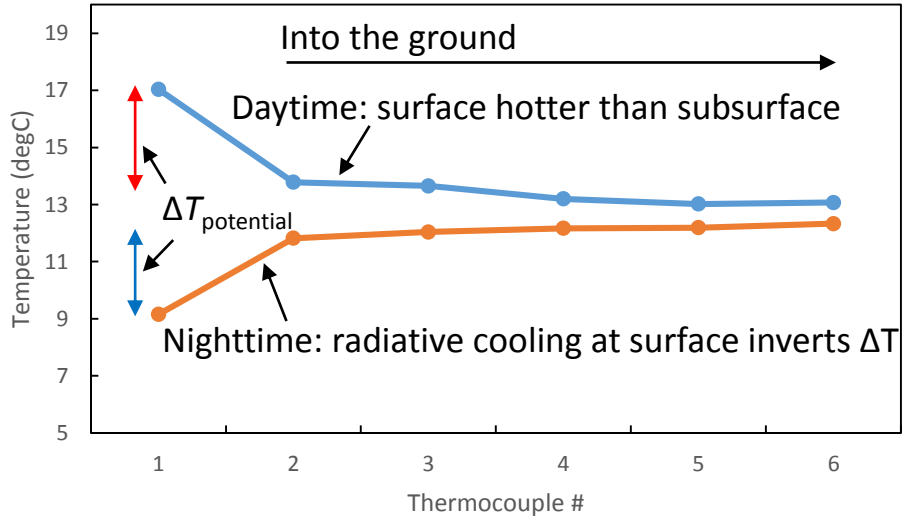
- Tested WiFi-enabled prototype to measure temperature differences available for TEG harvesting and send data to the cloud



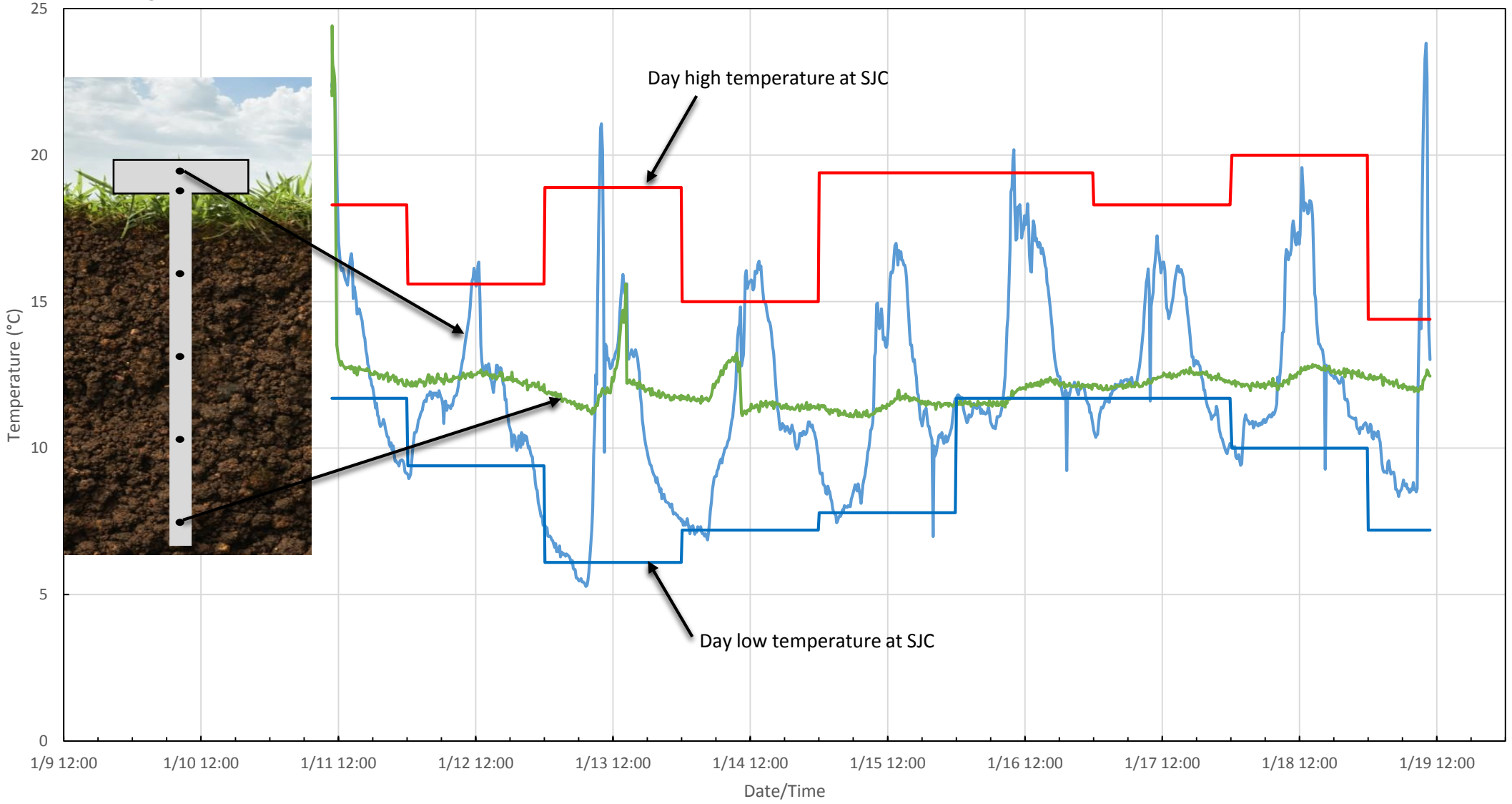
Embedded in ground for testing



Periodic temperature cycling vs. depth due to diffusion from surface



Multi-Day Field Test



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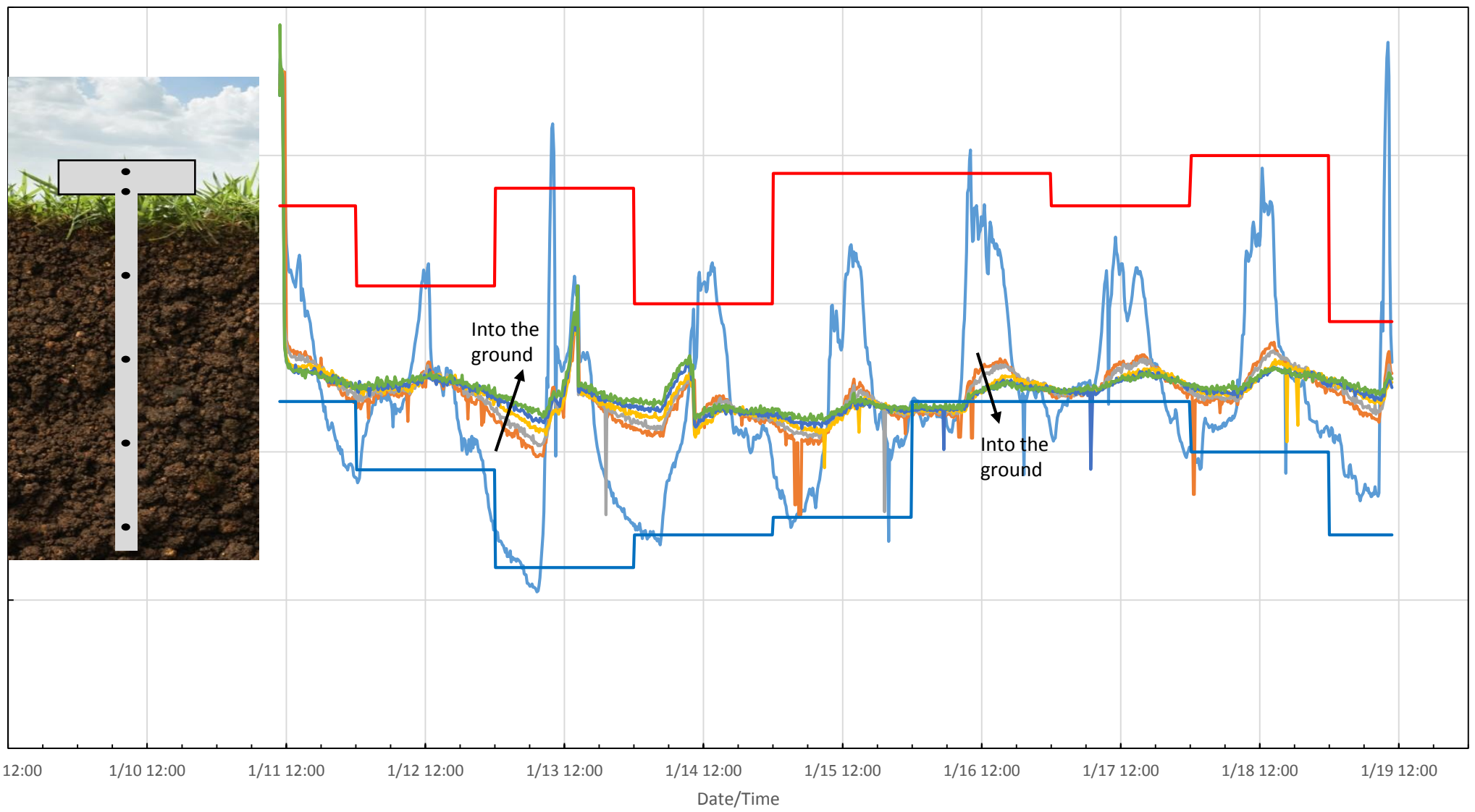

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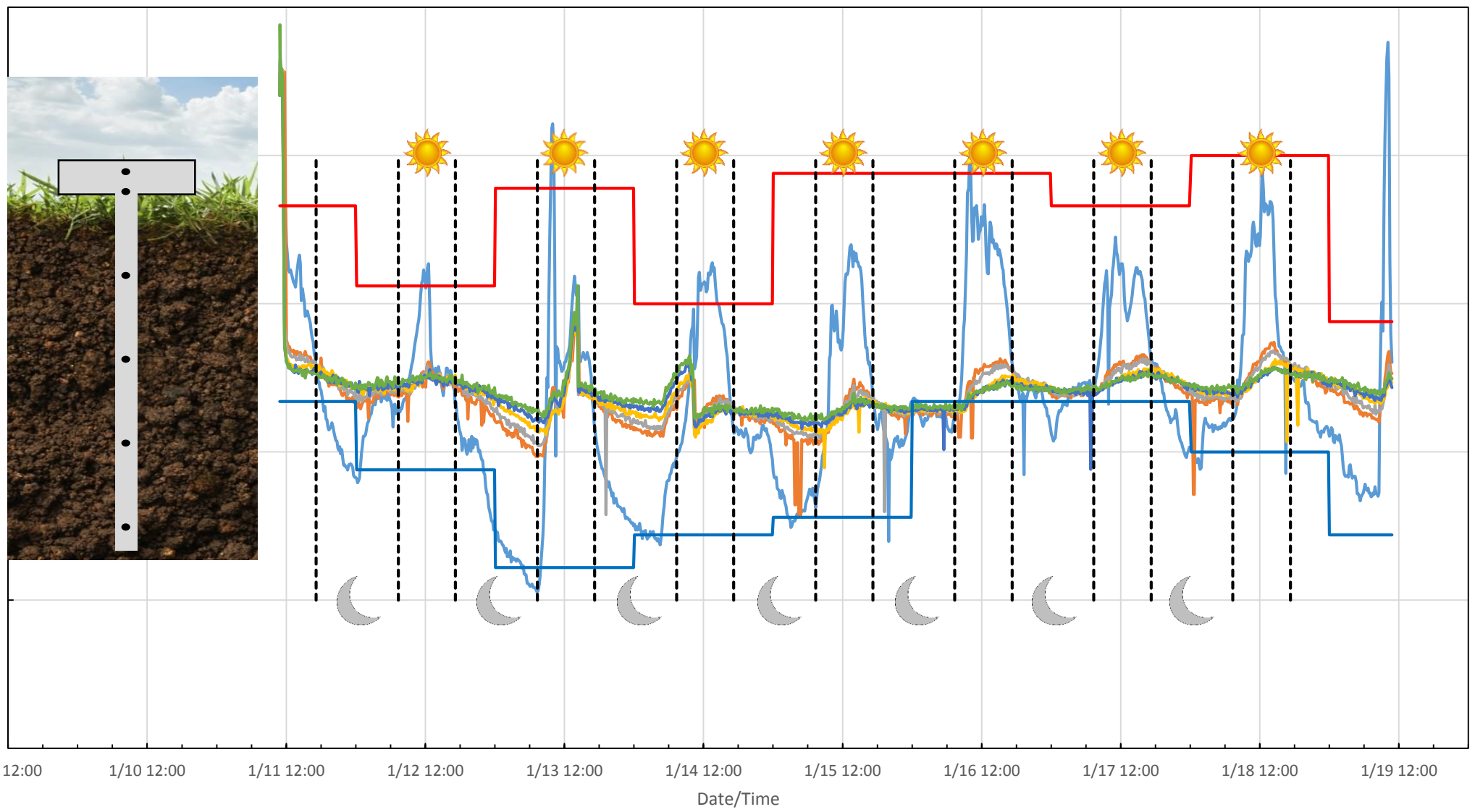

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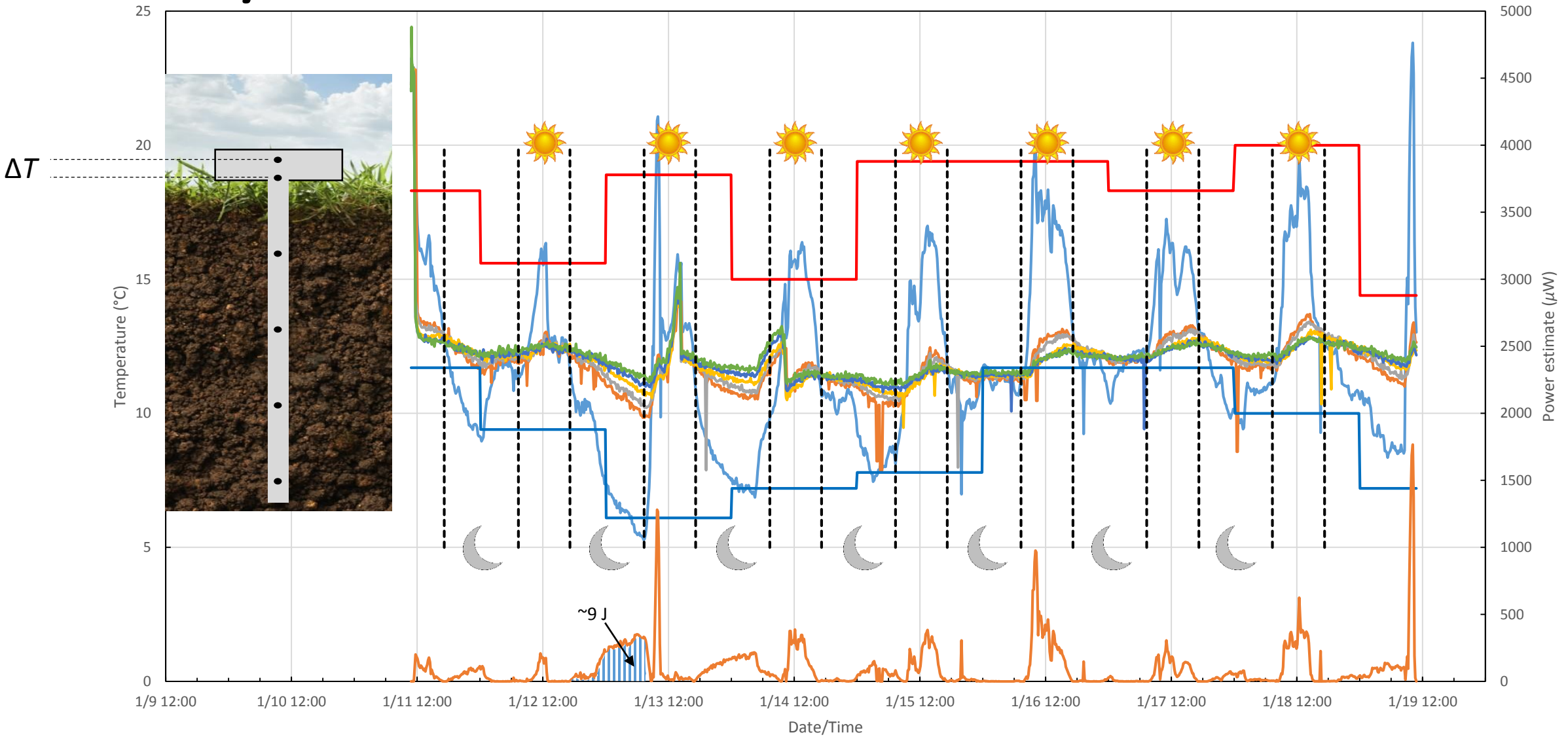

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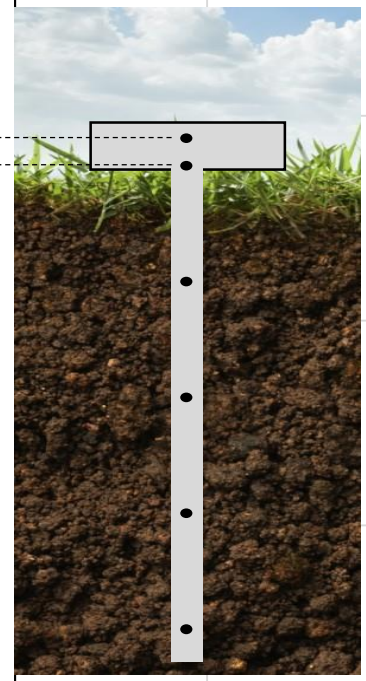
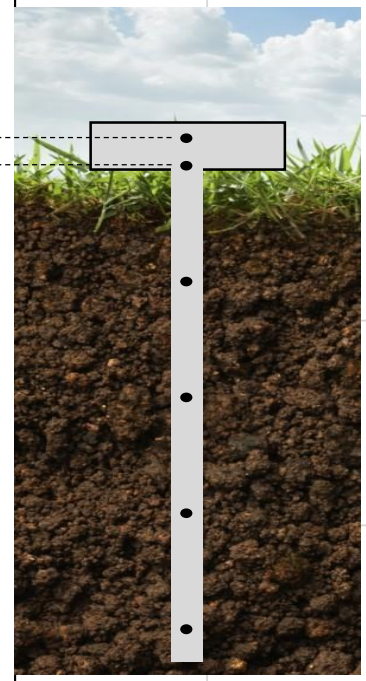


7-Day Totals

Daytime: 34 J → 57 μW

Nighttime: 21 J → 35 μW Day+Night → 92 μW

Multi-Day Field Test



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CbM design points

~200 μW → 30 second update intervals

~12 μW → 30 minute update intervals

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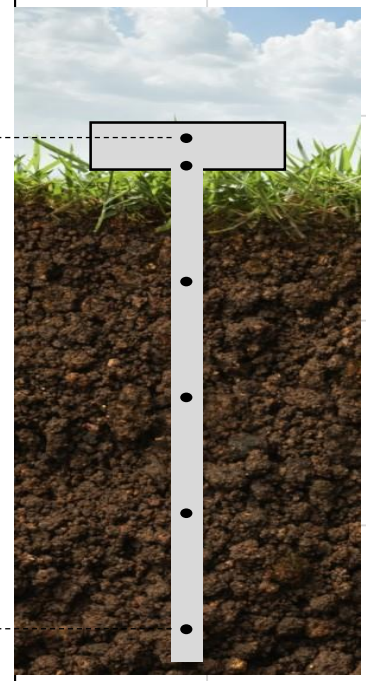

ΔT

Temperature (°C)

Power estimate (μW)

~14 J

1/9 12

7-Day Totals

Daytime: 41 J → 68 μW (20% increase)

Nighttime: 34 J → 57 μW (60% increase) Day+Night → 125 μW

CbM design points

~200 μW → 30 second update intervals

~12 μW → 30 minute update intervals

Q & A

Thanks a lot for your time and attention!

Any questions and/or comments?

References

- (To be added)