EBV: Electronic Bee-Veterinarian for Principled Mining and Forecasting of Honeybee Time Series

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Registration and travel support for this presentation was provided by the Society for Industrial and Applied Mathematics

Outline

- Motivation & Background
- Method & Technical Solution
- Empirical Evaluation
- Conclusion

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- **Motivation & Background**
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Motivation

+

(2022 - 2023)

+

=

Billion Dollar Industry

Higher Colony Loss

No Bees, No Humans

Reliable & Explainable Hive Monitoring System

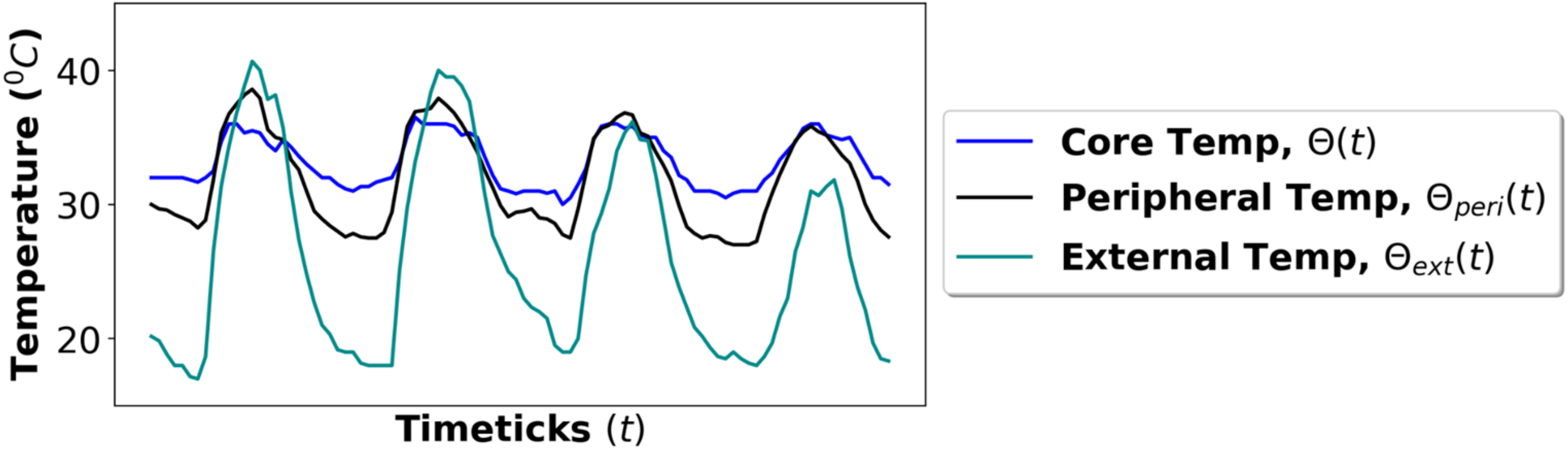
Background (1/3)

Hive temperature gives valuable information about hive health.

Core Area
(Near brood nest area)
Most Important!

Peripheral Area
(Near honey storage area)

Background (2/3)



$33^0C \leq$ Core Temp, $\Theta(t) \leq 36^0C$ = 

$\Theta(t) \leq 33^0C$ or $\Theta(t) \geq 36^0C$ = 

Background (3/3)

Think of hive core temperature as human body temperature….

Cooling during Heat

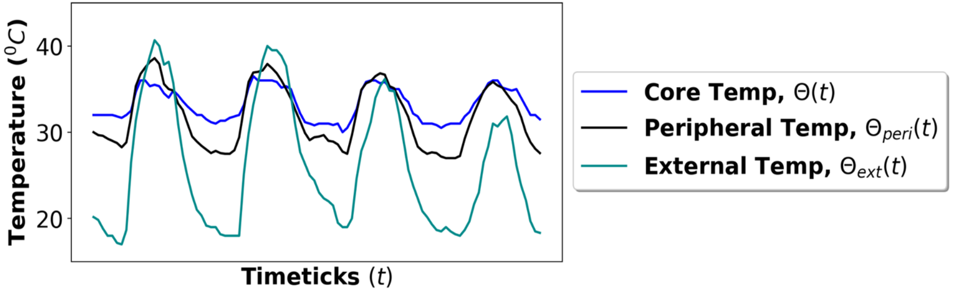
Heating during Cold

= Thermoregulation

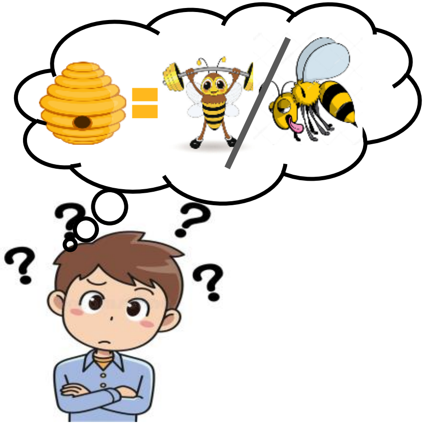
Change in thermoregulation ability = 1st order response to stressors

Problem Statement

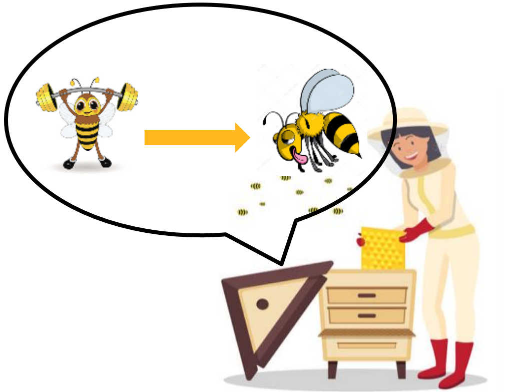
GIVEN:



DO:



G1: Quantify Bee Strength



G2: Detect & Explain Events

G3: Forecast

Related Work

Property \ Method	Hive monitoring and analysis	Traditional time series	Deep Learning	EBV (Ours)
	Poor Performance (rule based: arbitrary threshold)	Blackbox & Domain agnostic	Blackbox & Domain agnostic	Unsupervised
C1: domain-specific	✓			✓
C2: effective		?	?	✓
C3: explainable	?			✓
C4: scalable		✓	?	✓

Joe-Air Jiang et al., Compt. Elect. Agri. 2016; Stefania Cecchi et at., Sensors 2020; many more.

Contributions : EBV

Addresses limitations of prior work

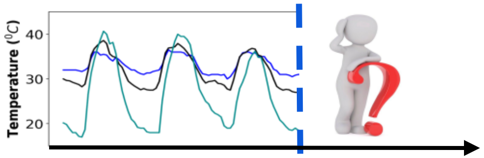
C1: Principled

- Thermal diffusion
- Control Theory

$$\nabla^2\theta \propto \partial\theta / \partial t$$

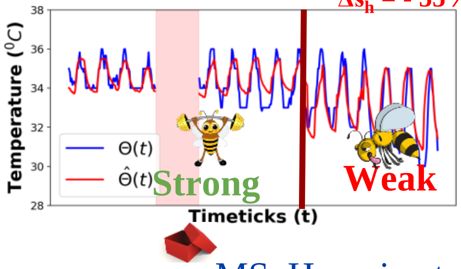
C2: Effective

- Forecasting with high accuracy



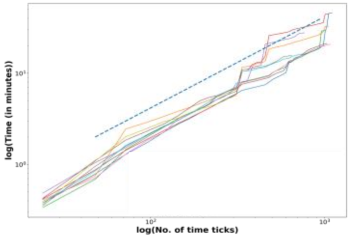
C3: Explainable

- Hive strength parameter
- State discontinuity detection



C4: Scalable

- Linear with input size



C5: Informative

- In line with domain experts

MS. Hossain et al.

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- **Method & Technical Solution**
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Dataset & Experimental Setup

Sensors

Peripheral Area
(Near honey storage area)

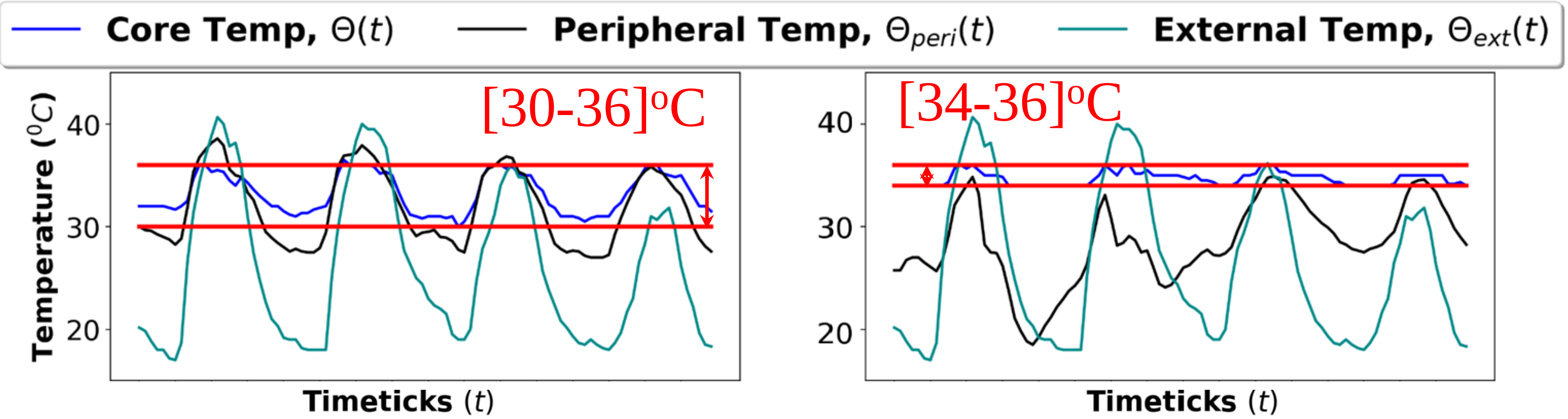
Core Area
(Near brood nest area)

Riverside, California, USA (Aug’21 - Sep’21)

Challenge: Very hot climate → Severely stressed hives

Probable Solution: Add ice cubes on top of hives

Recorded Temperature Data

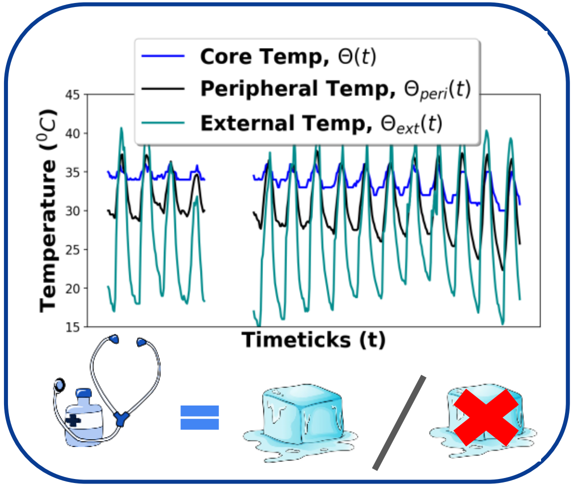


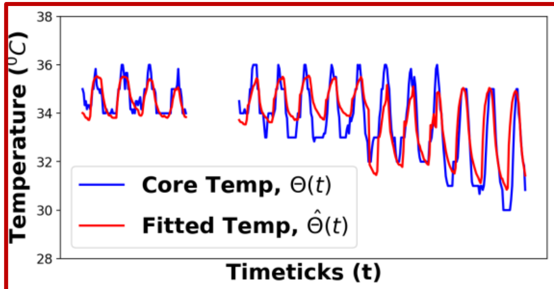
Control Hive
(5 in total)

Treated Hive
(5 in total)

Core Temperature Varies More in Control Hives !!

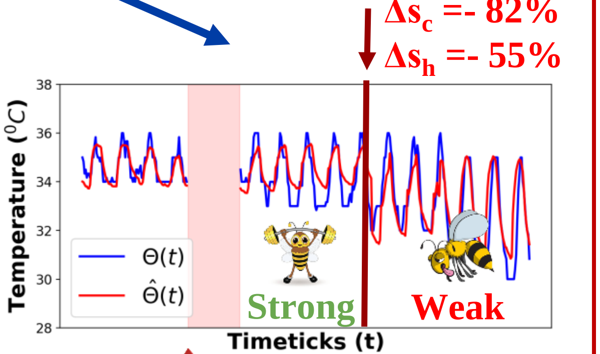
Overview of Proposed Method : EBV





1. EBV_{model} : Reconstruction

(*G1:* Quantify Bee Strength & *G3:* Forecast)



Discontinuity Detected

2. $EBV_{fit\&cut}$: Segmentation

(*G2:* Event Detect.)

EBV_{model} for Reconstruction & Forecasting

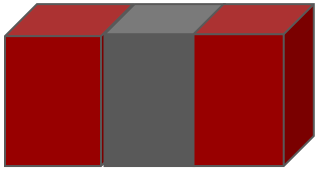
UCR | Carnegie Mellon University

Details

$$\frac{\partial\theta(t)}{\partial t} = \begin{cases} \theta_{ext}(t) + \theta_{adj}(t) - 2\theta(t) - s_c\theta(t) & \text{if } \theta_{ext}(t) \geq 0 \\ \theta_{ext}(t) + \theta_{adj}(t) - 2\theta(t) + s_h\theta(t) & \text{otherwise} \end{cases}$$

Heat Flows

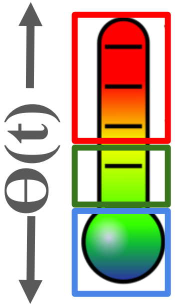
$\nabla^2\theta \propto \partial\theta / \partial t$



Environment Hive Env.

Physics:
Thermal Diffusion

Env. Temp. ∝ Hive Temp.



Cooling : Strength, s_c

Set Point : Θ_{ideal}

Heating : Strength, s_h

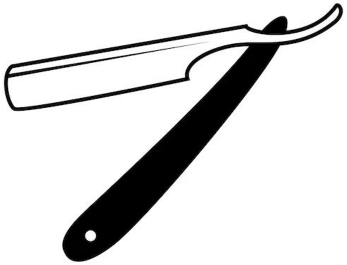
Control Theory:
***'Split'* P-Controller**

Hive Temp. ∝ Required bees' work

Segmentation Algorithm : $EBV_{fit\&cut}$ (1/2)

Hypothesis: Bees' strength will not change *(segment)* unless there are any stressors *(cut-point)*.

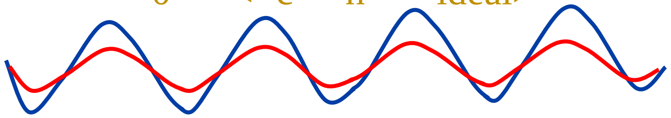
Q: How to find segments and cut-points?



A: (a) *Occam's Razor:* Simple & Accurate
(b) *Greedy Algorithm:* Fast Execution

S1: Represent the sequence with no cuts (m=0) & one set of params (p=3)

$X_0 = (s_c, s_h, \Theta_{ideal})$



$$AIC_0 = -2\ln L_0 + 2(m + (m+1)p)$$

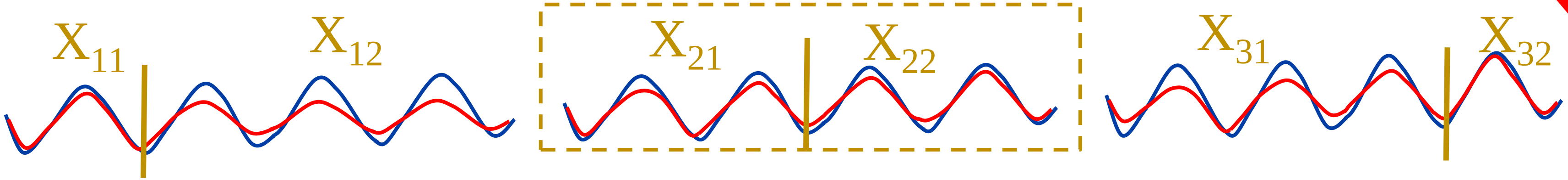
Accuracy — Model Complexity

Segmentation Algorithm : $EBV_{fit\&cut}$ (2/2)

Details

Q: How to find segments and cut-points? (cntd…)

S2: Now try with a single cut and two segments



$AIC_1 = -2\ln L_1 + 2(m + (m+1)p)$; m = 1, p = 2*3 =6

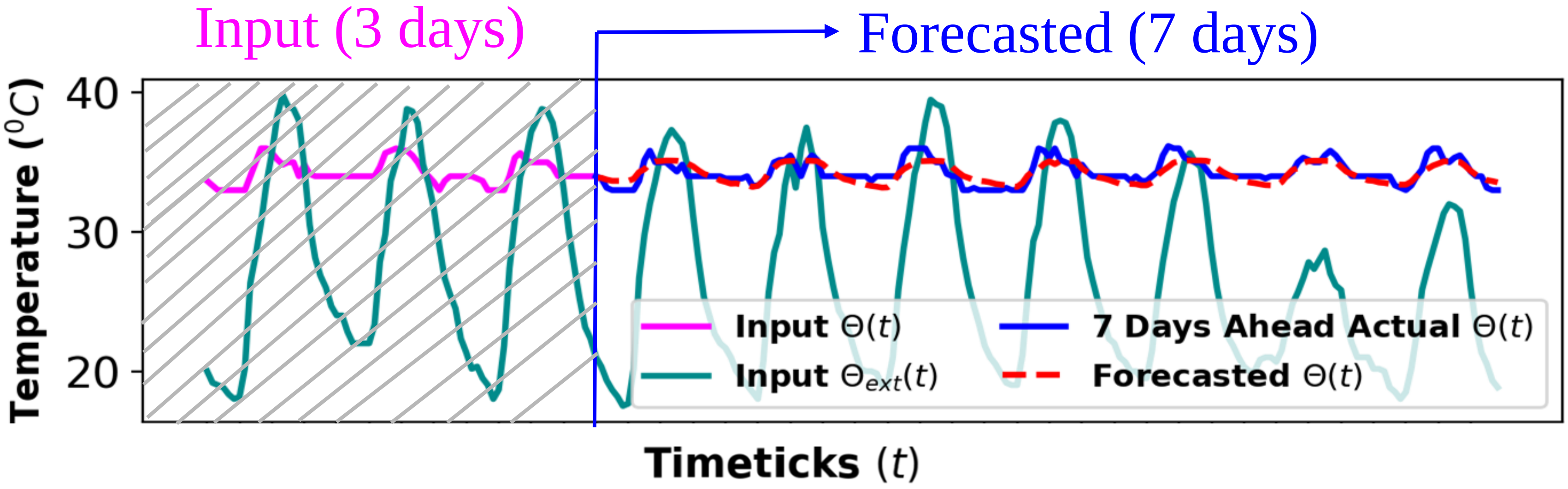
Compare: ($AIC_1 < AIC_0$) ? If **TRUE:**

S3: Repeat Till Find Best Reconstruction with *Minimum AIC* !!

Outline

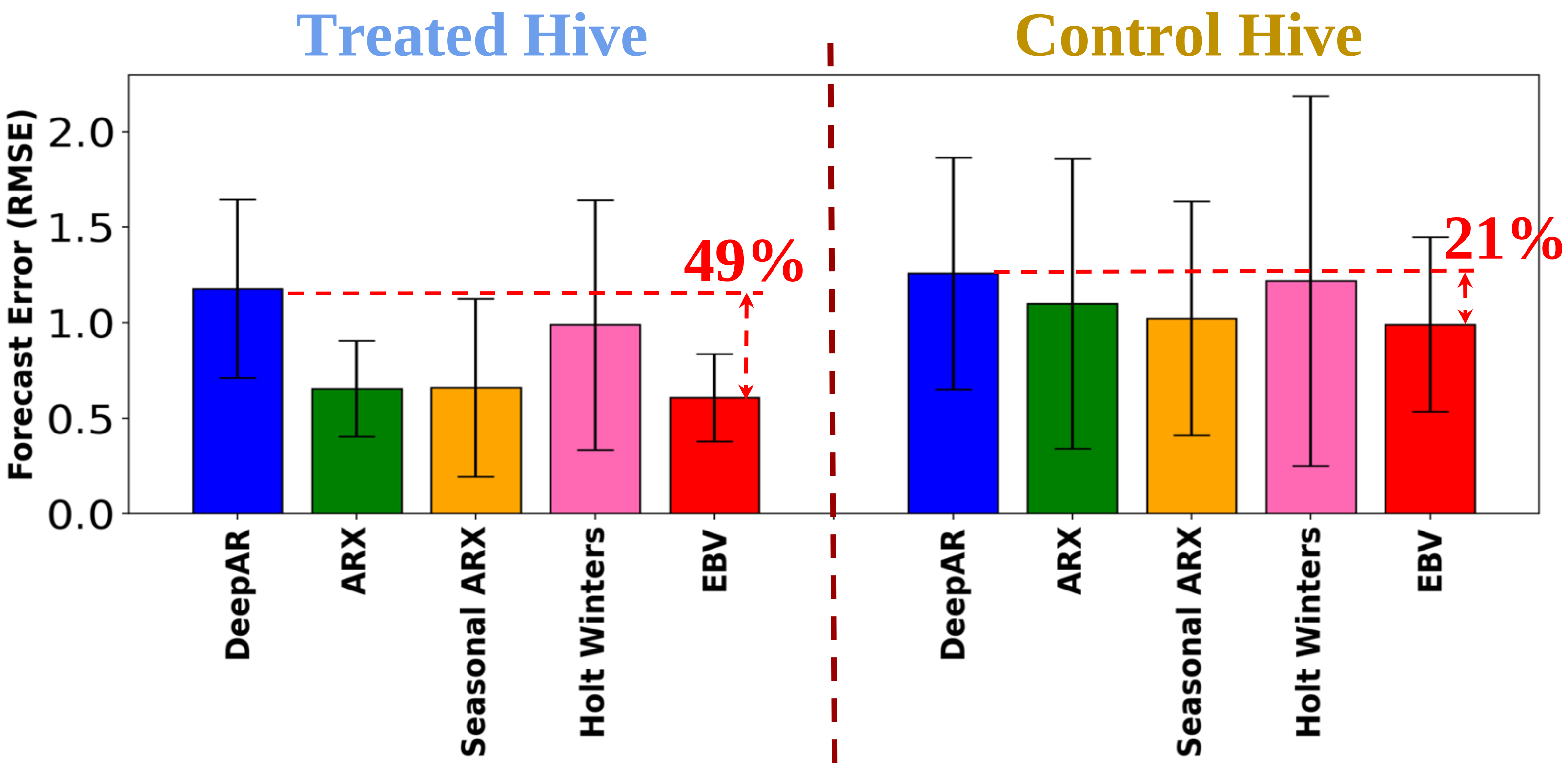
- Motivation & Background
- Method & Technical Solution
- **Empirical Evaluation**
  - **Q1 Effective: (a) Forecasting (*G3*) & (b) Event Detection (*G2*)**
  - **Q2 Explainable: (a) Event Detection (*G2*) & (b) Treatment Effect (*G2*)**
  - **Q3 Scalable: Linear on input size**
  - **Q4 Informative: Observation coincides with experts (*G2*)**
- Conclusion

Q1(a) Effective: Forecasting (*G3*)

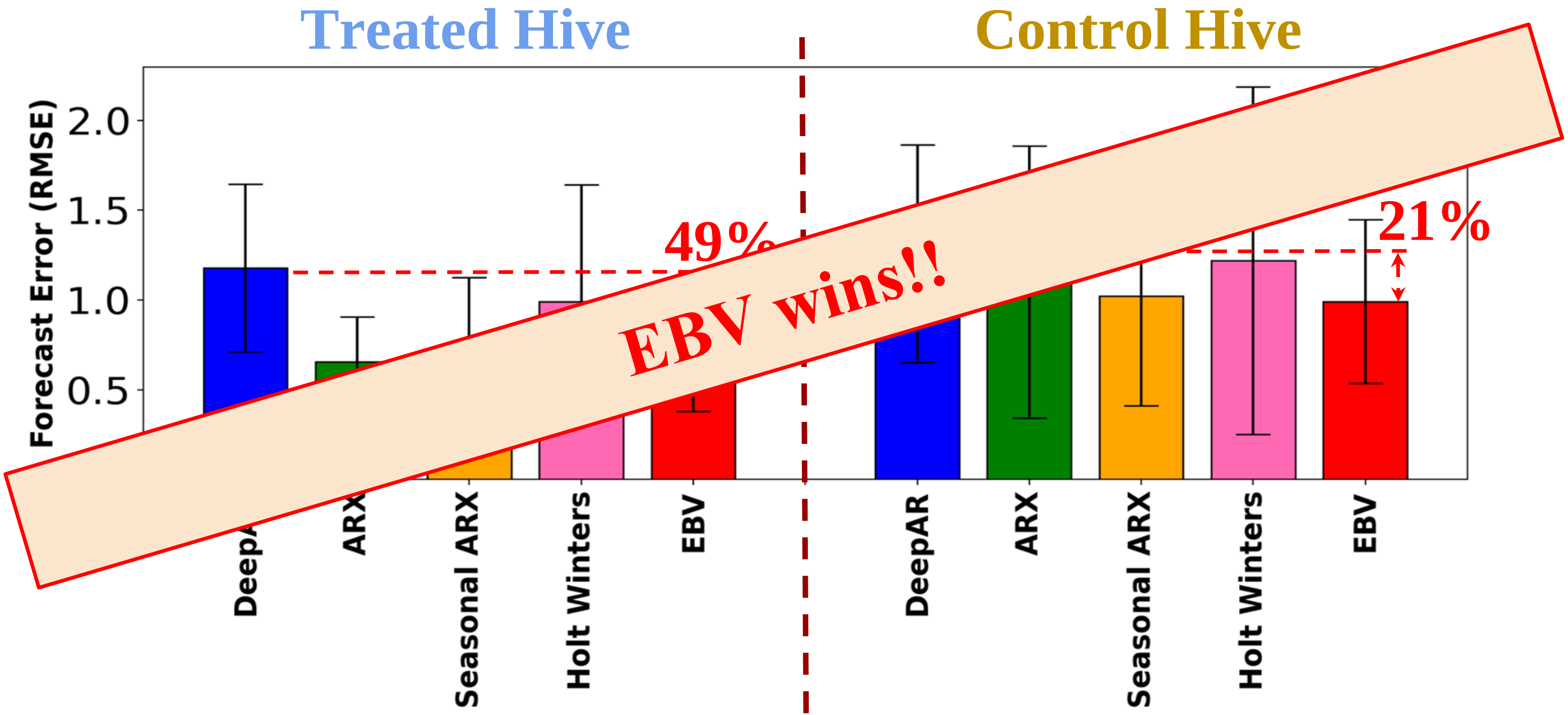


Control Hive

Q1(a) Effective: Improved Accuracy (*G3*)

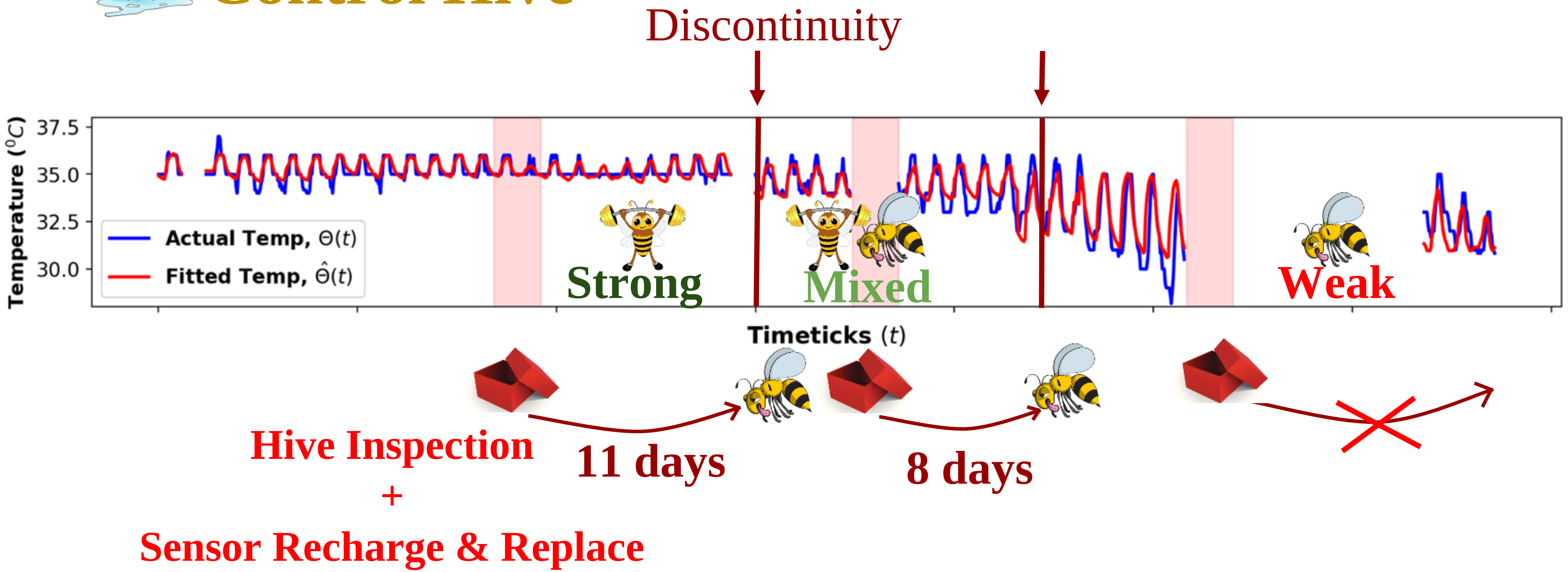


Q1(a) Effective: Improved Accuracy (*G3*)



Q1(b) Effective: Event Detection (*G*2)

Control Hive



Q1(b) Effective: Event Detection (G2)

Control Hive

Q2(a) Explainable: Event Detection ($G2$)

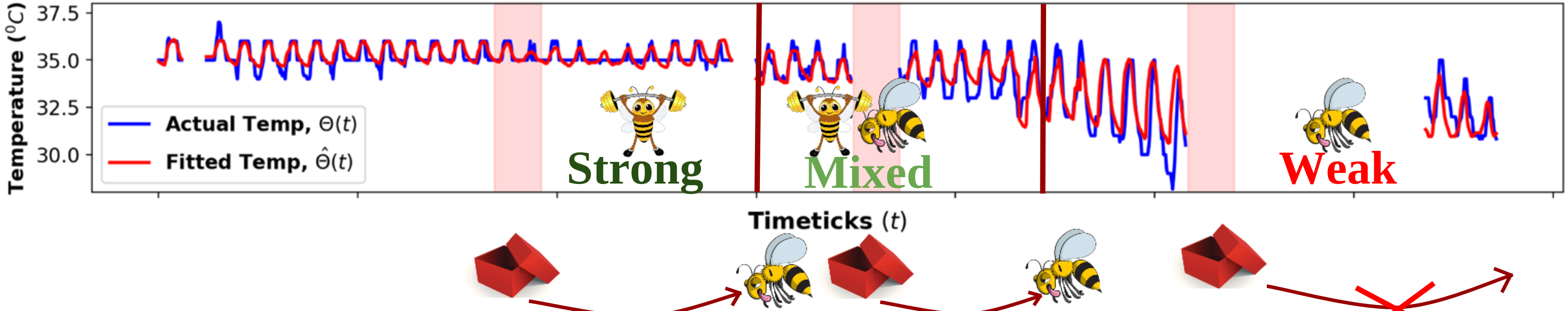
Strength of cooling, $s_c = 55$
Strength of heating, $s_h = 31$

$\Delta s_c = +38\%$
$\Delta s_h = -35\%$

$s_c = 76$
$s_h = 20$

$\Delta s_c = -82\%$
$\Delta s_h = -55\%$

$s_c = 14$
$s_h = 9$



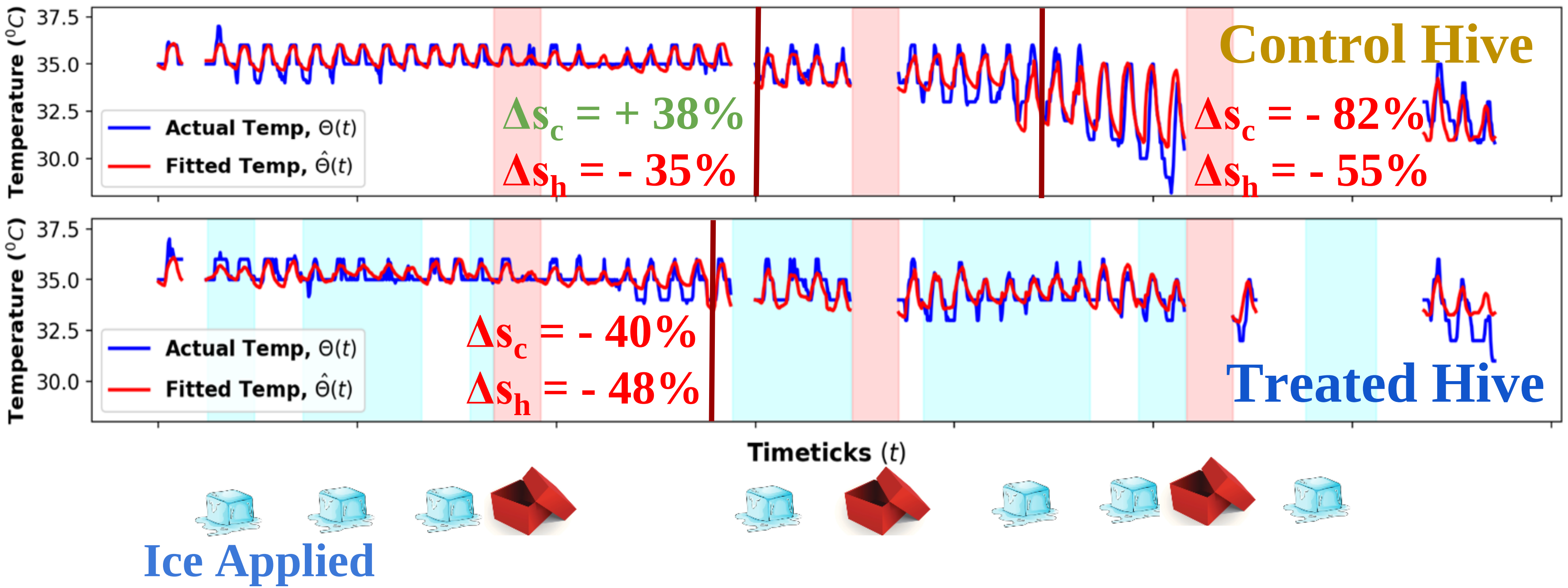
Hive Inspection
+
Sensor Recharge & Replace

11 days

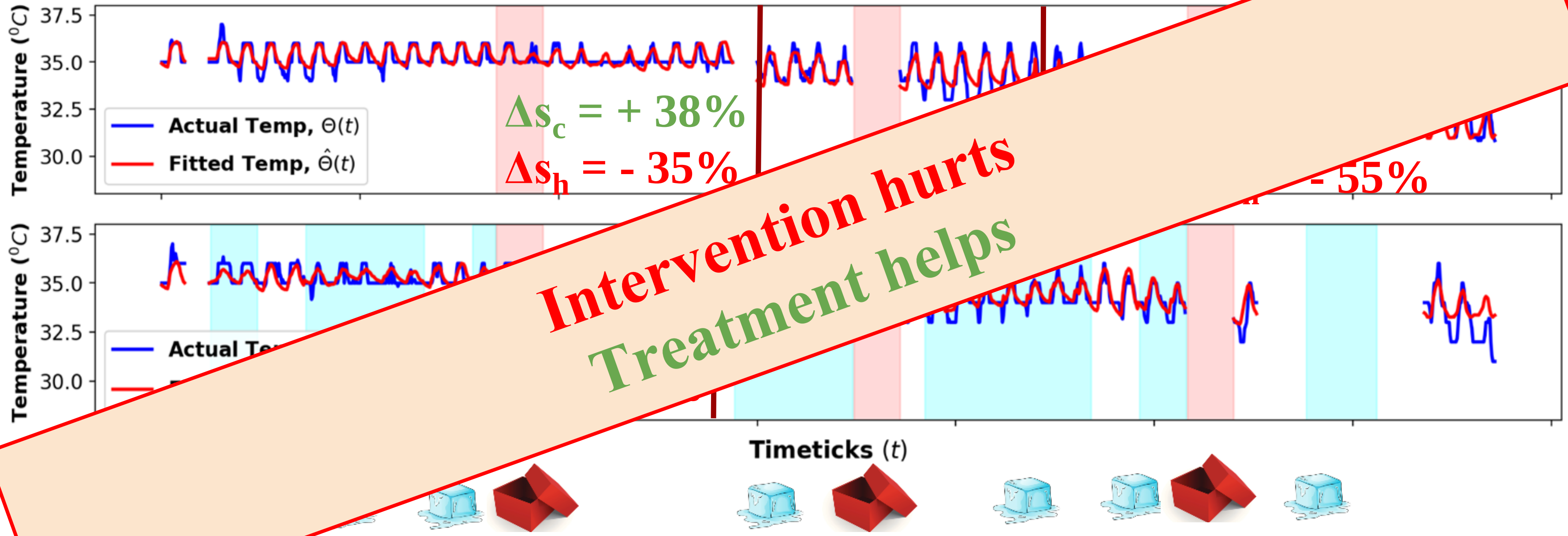
8 days

Control Hive

Q2(b) Explainable: Treatment Effect (*G*2)



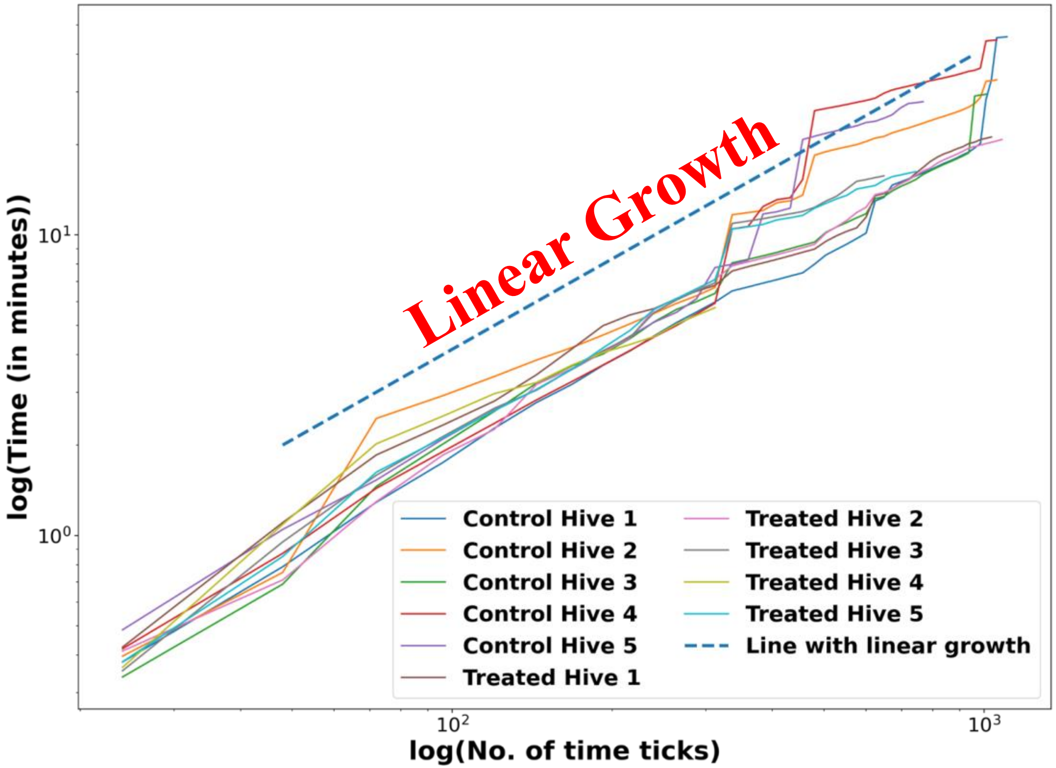
Q2(b) Explainable: Treatment Effect ($G2$)



Intervention hurts
Treatment helps

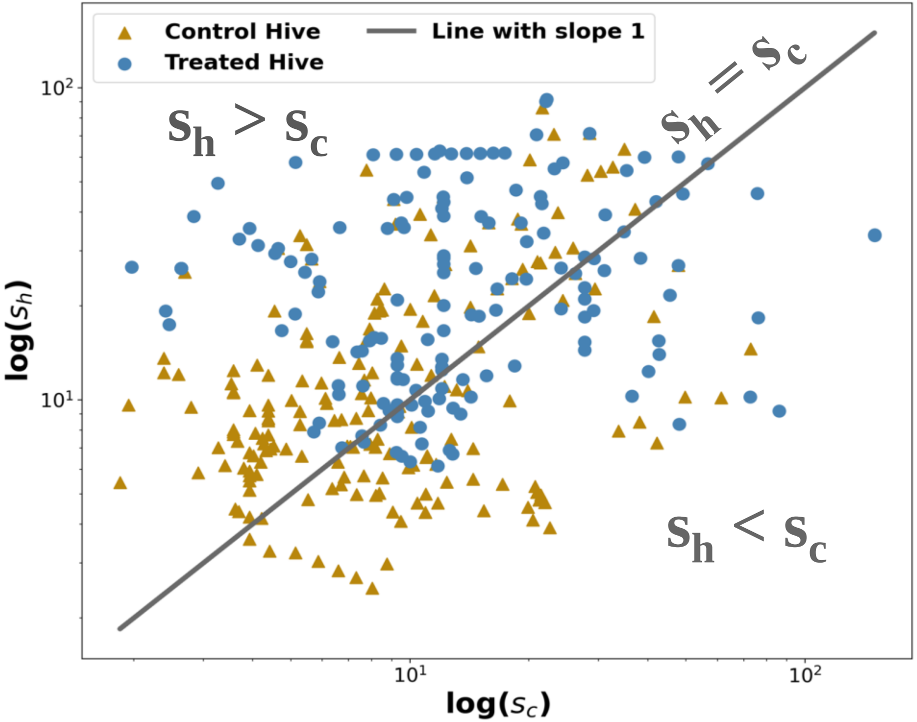
Applied

Q3 Scalable



- ***Linear & Fast:*** 20 min for 2 months of data
- ***"Embarrassingly Parallel"***

Q4 Informative (*G*2: 1/3)

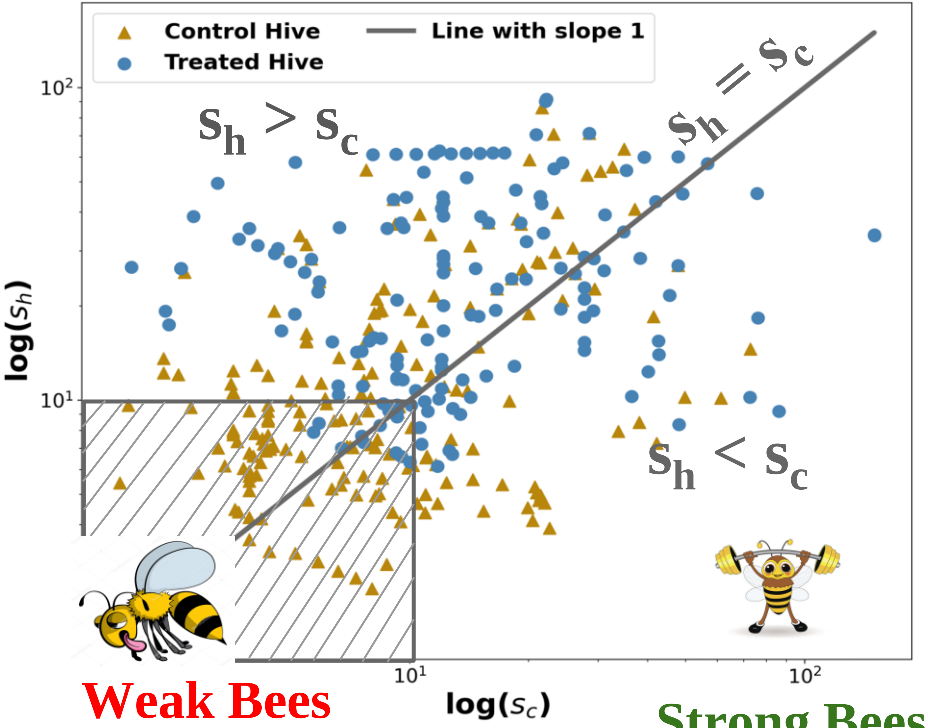


Observation (1):

Heating is easier than cooling

$(s_h > s_c)$

Q4 Informative (*G*2: 2/3)



Weak Bees

$s_c < 10, s_h < 10$

Strong Bees

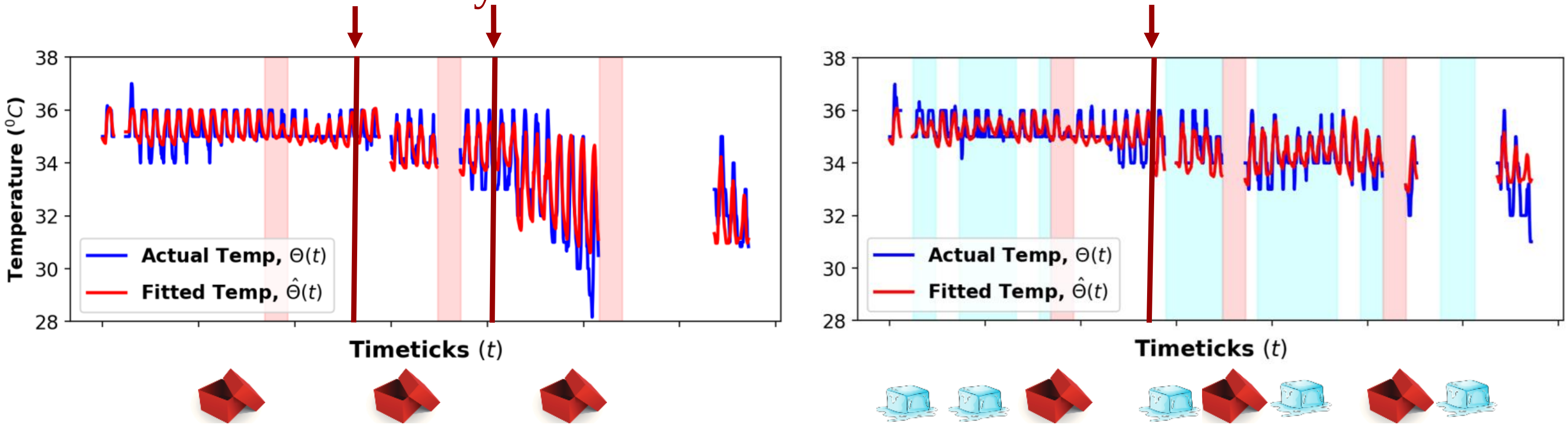
$s_c > 10, s_h > 10$

Observation (2):

Bees in treated hives are stronger, i.e. better thermoregulation

Q4 Informative (*G*2: 3/3)

Discontinuity



Control Hive

Treated Hive

Observation (3):

Positive Cumulative Effect of Ice Treatment

Control (= un-treated) hives suffer more from hive-openings.

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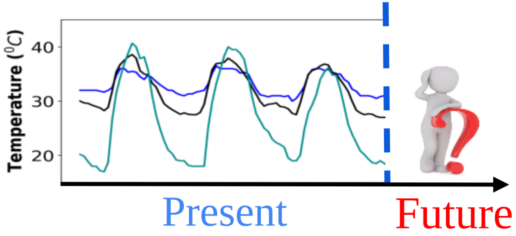
THANK YOU!!

github.com/rtenlab/EBeeVet

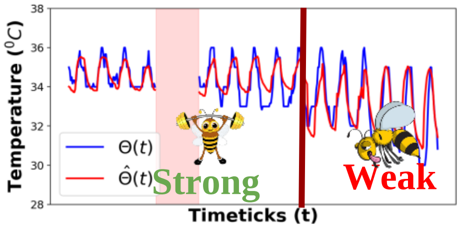
***C1:* Principled**

$$\nabla^2\theta \propto \partial\theta / \partial t$$

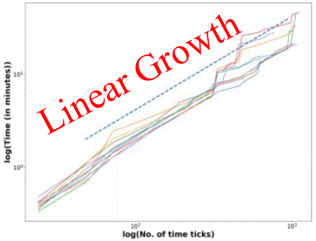
***C2:* Effective**



***C3:* Explainable**



***C4:* Scalable**



***C5:* Informative**

THANK YOU!!

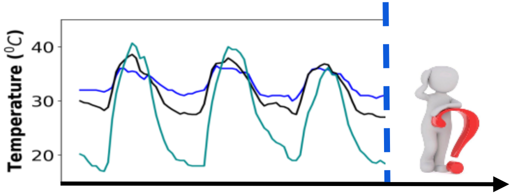
github.com/rtenlab/EBeeVet

Contact:
mhoss037@ucr.edu

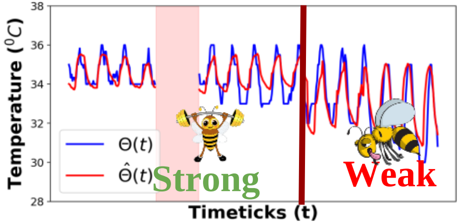
***C1:* Principled**

$\nabla^2\theta \propto \partial\theta / \partial t$

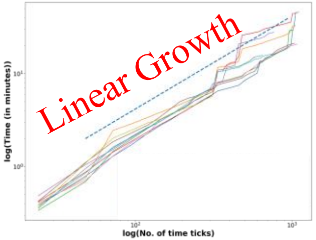
***C2:* Effective**



***C3:* Explainable**



***C4:* Scalable**



***C5:* Informative**

Ongoing Work:
Real-time notification of honey bee health

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