

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



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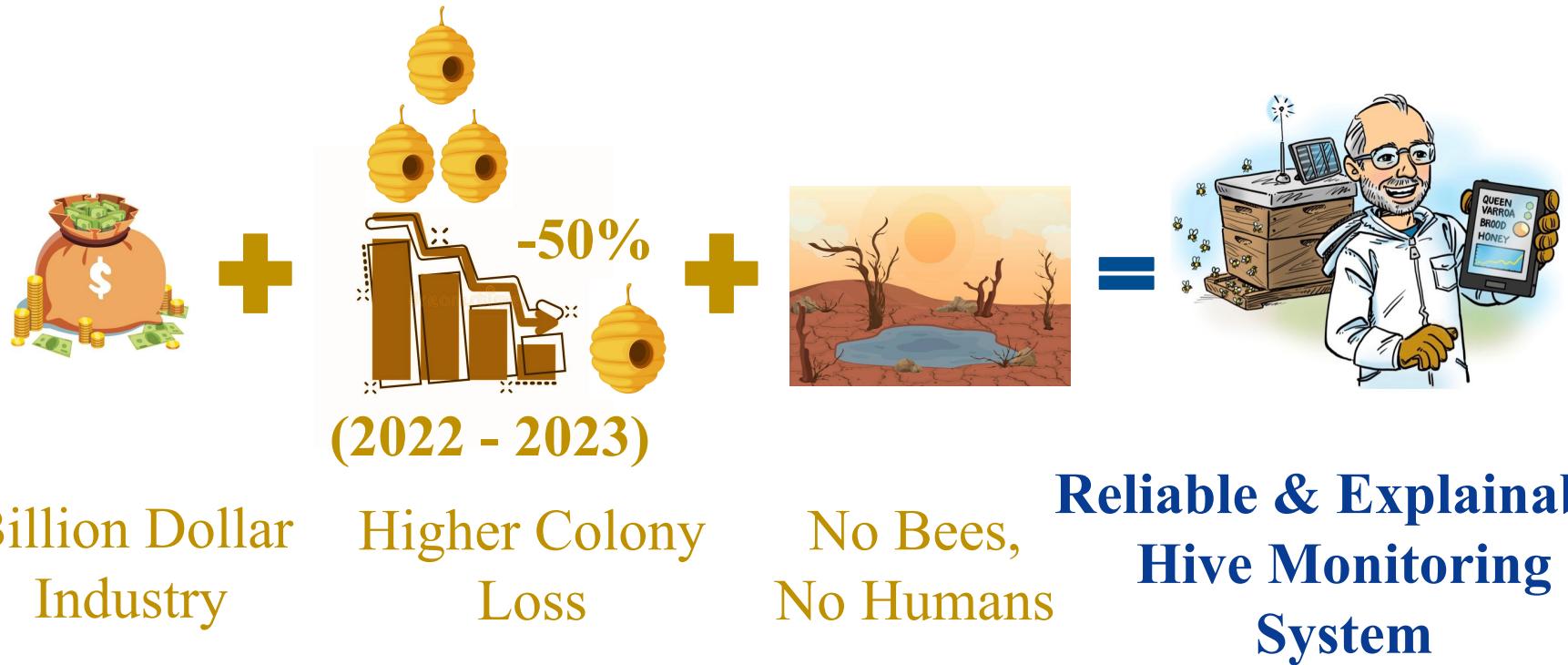
Outline

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

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- **Motivation & Background** ←
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Motivation



Background (1/3)

Hive temperature gives valuable information about hive health.

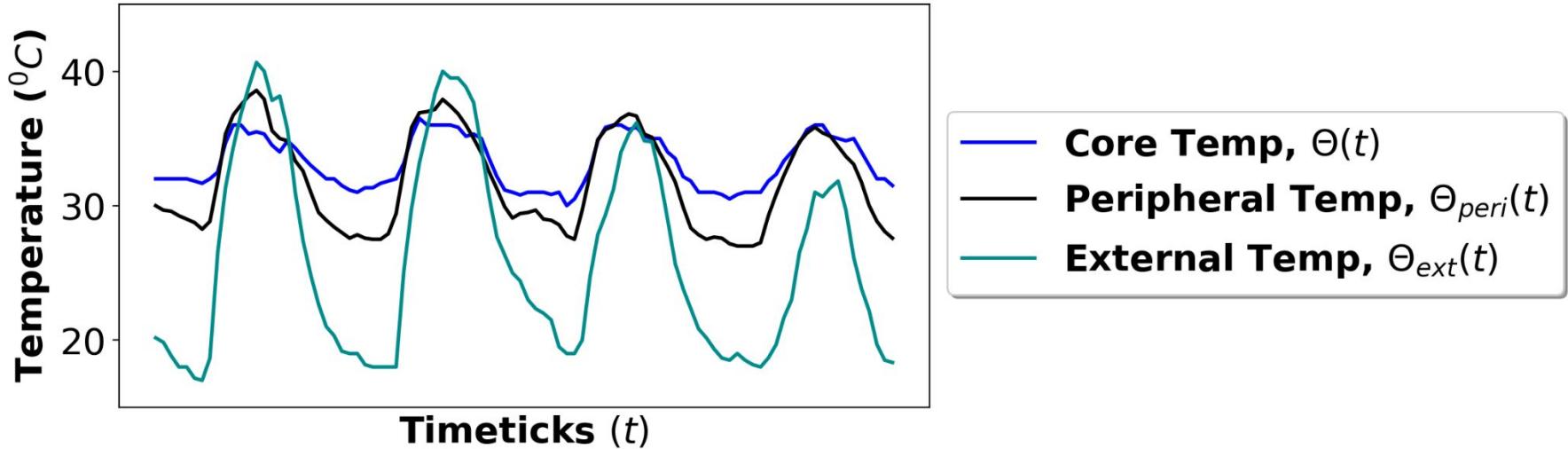


Core Area
(Near brood nest area)
Most Important!



Peripheral Area
(Near honey storage area)

Background (2/3)



$33^{\circ}\text{C} \leq \text{Core Temp, } \Theta(t) \leq 36^{\circ}\text{C} =$



$\Theta(t) \leq 33^{\circ}\text{C} \text{ or } \Theta(t) \geq 36^{\circ}\text{C} =$



Background (3/3)

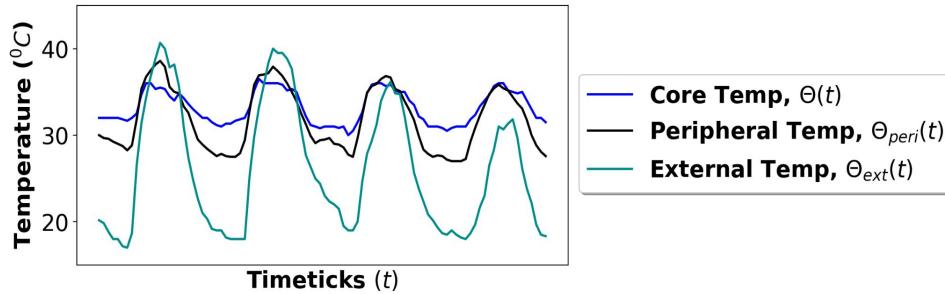
Think of hive core temperature as human body temperature....



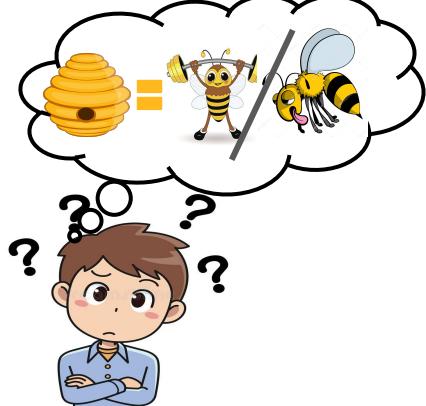
Change in thermoregulation ability = 1st order response to stressors

Problem Statement

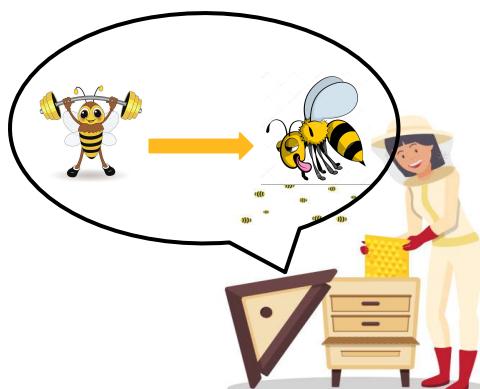
GIVEN:



DO:



G1: Quantify Bee Strength



G2: Detect & Explain Events



G3: Forecast

Related Work

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

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

Contributions : EBV

Addresses limitations of prior work

C1: Principled

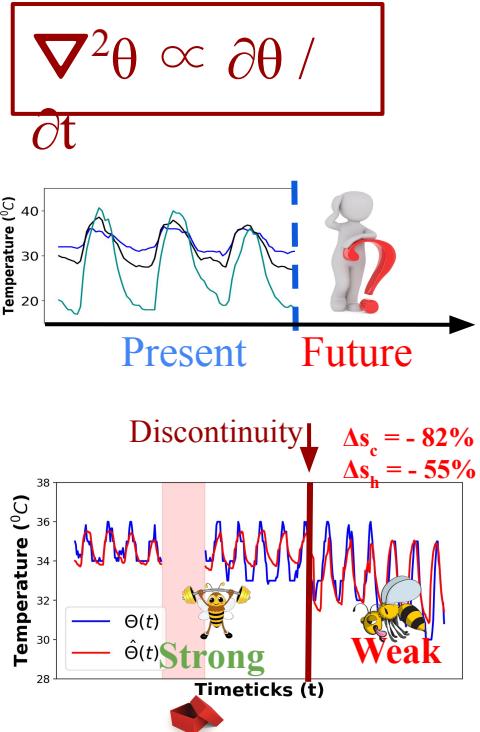
- Thermal diffusion
- Control Theory

C2: Effective

- Forecasting with high accuracy

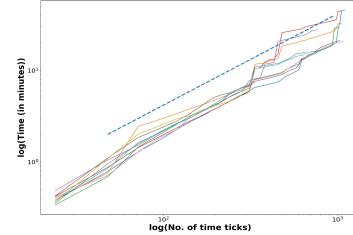
C3: Explainable

- Hive strength parameter
- State discontinuity detection



C4: Scalable

- Linear with input size



C5: Informative

- In line with domain experts



Outline

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



Peripheral Area
(Near honey storage area)



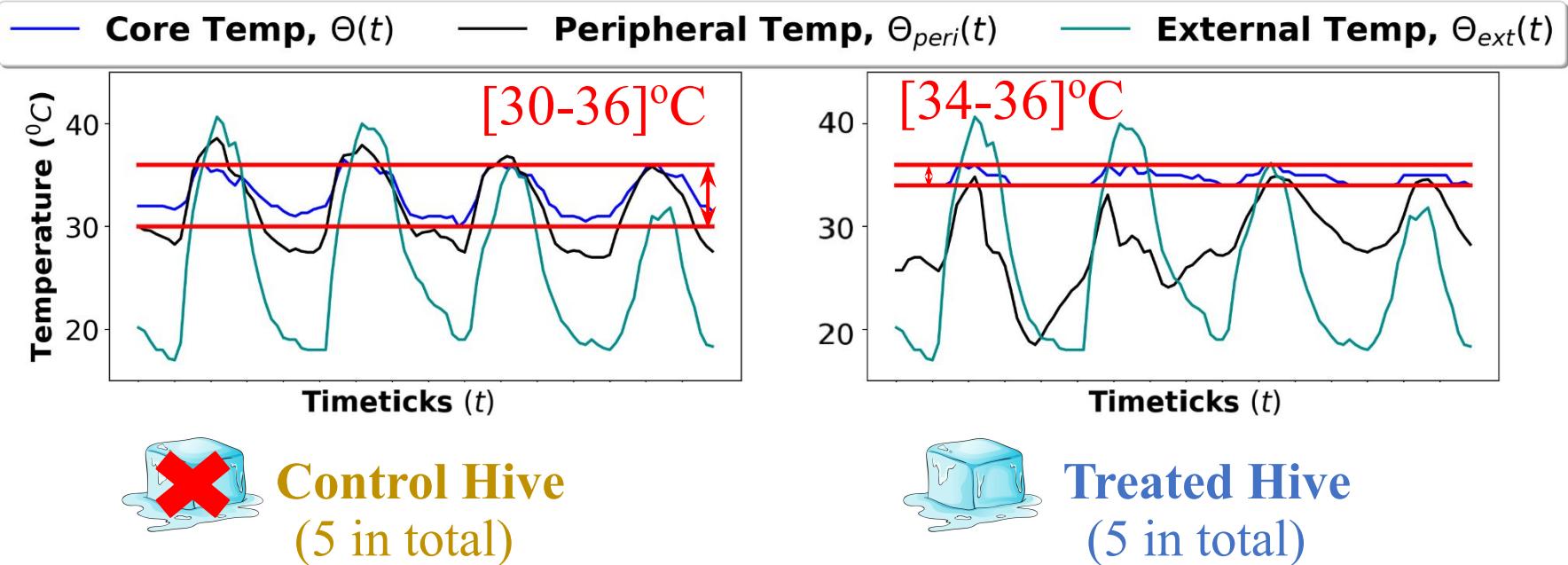
Core Area
(Near brood nest area)

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

Challenge: Very hot climate → Severely stressed hives

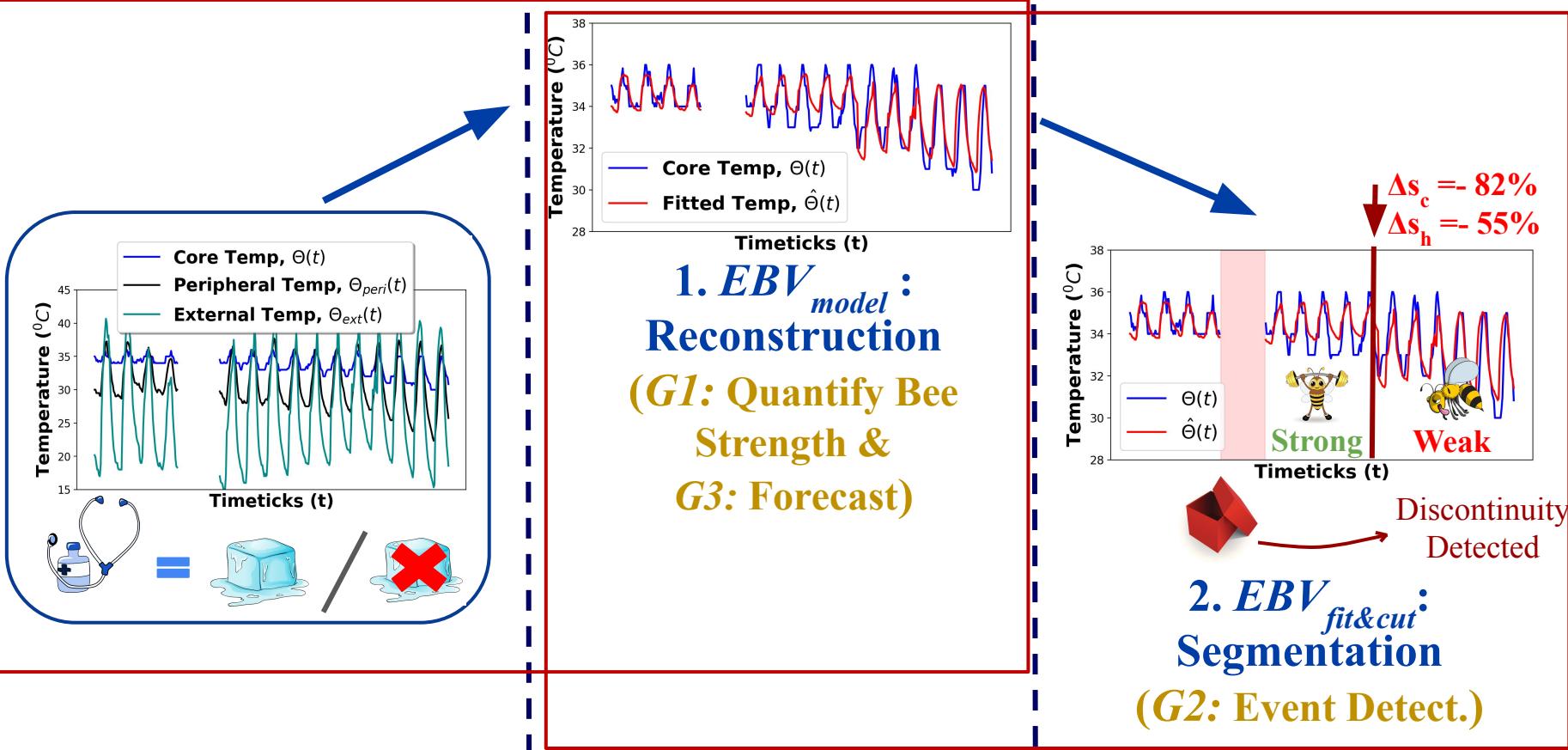
Probable Solution: Add ice cubes on top of hives

Recorded Temperature Data



Core Temperature Varies More in Control Hives !!

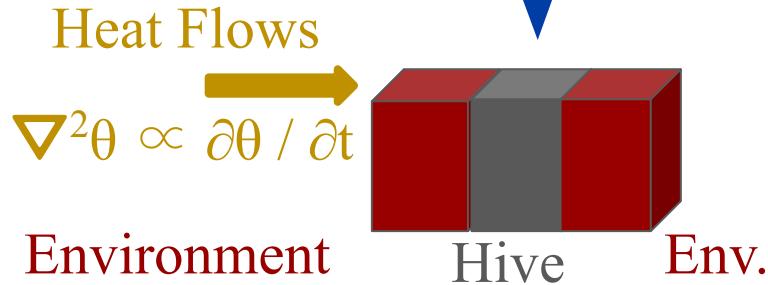
Overview of Proposed Method : EBV



EBV_{model} for Reconstruction & Forecasting

$$\frac{\partial \theta(t)}{\partial t} = \begin{cases} \theta_{ext}(t) + \theta_{adj}(t) - 2\theta(t) \\ \Theta_{ext}(t) + \theta_{adj}(t) - 2\theta(t) \end{cases}$$

- $s_c \theta(t)$ if $\theta_{ext}(t) \geq$
+ $s_h \theta(t)$ otherwise



Physics:
Thermal Diffusion

Env. Temp. \propto Hive Temp.



Control Theory:
'Split' P-Controller

Hive Temp. \propto Required bees' work

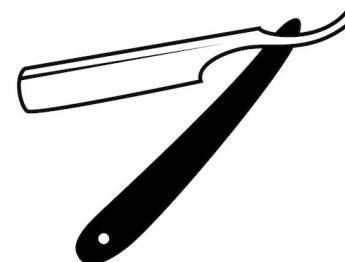
Details

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

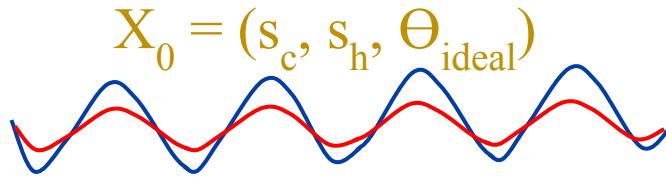
Hypothesis: Bees' strength will not change (*segment*) unless there are any stressors (*cut-point*).

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 ($p=3$)



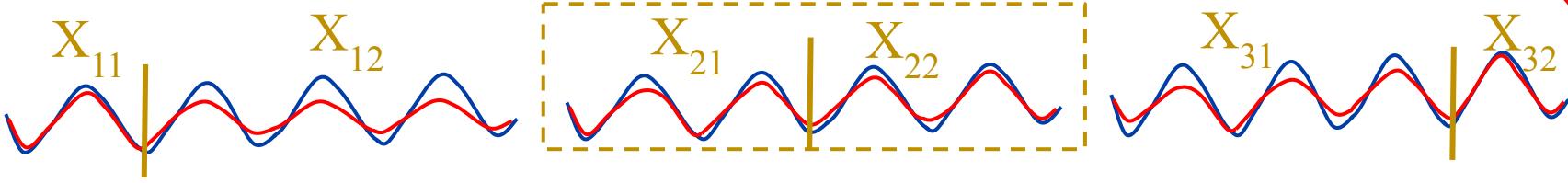
$$\text{AIC}_0 = -2\ln L_0 + 2(m + (m+1)p)$$

↑ ↑
Accuracy Model Complexity

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

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:

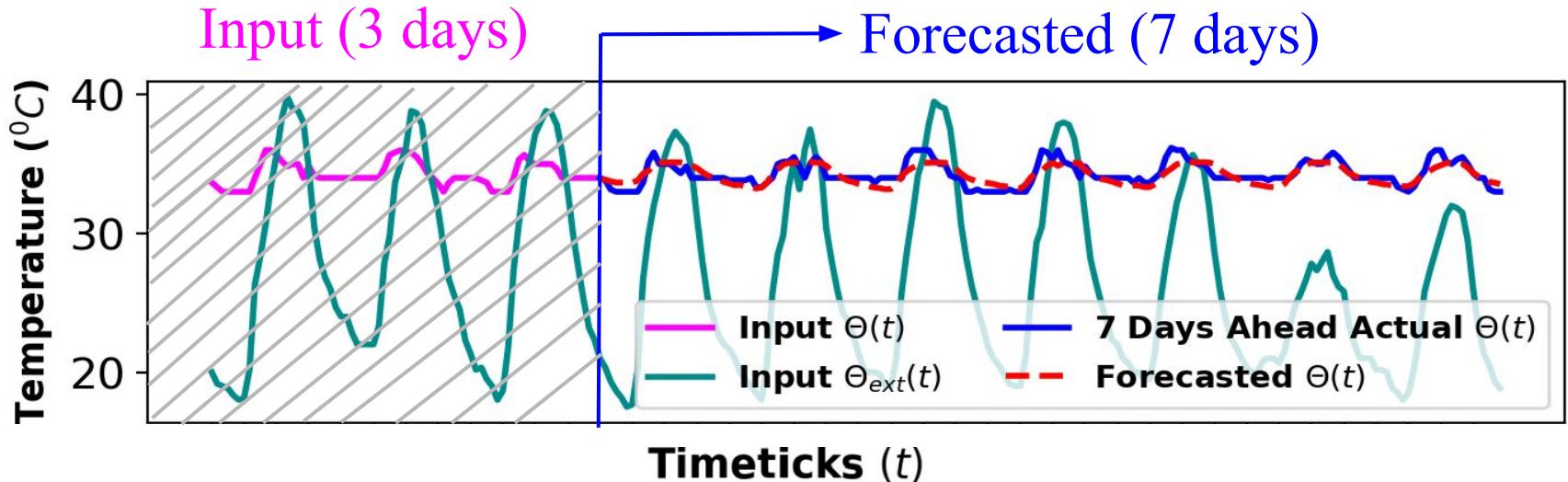
S3: Repeat Till Find Best Reconstruction with **Minimum AIC** !!

Details

Outline

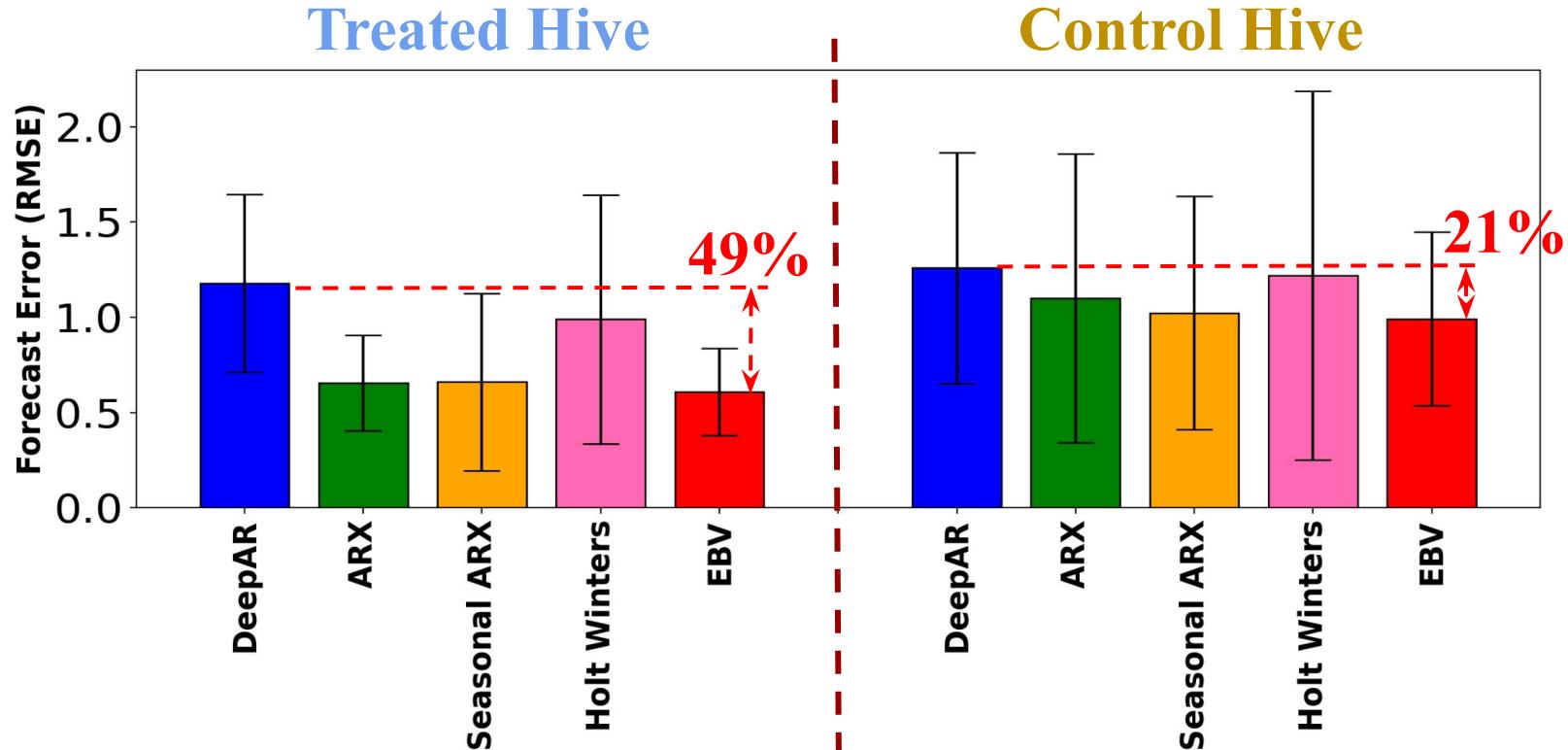
- Motivation & Background
- Method & Technical Solution
- Empirical Evaluation 
 - Q1 Effective: (a) Forecasting (*G3*) & (b) Event Detection (*G2*)
 - Q2 Explainable: (a) Event Detection (*G2*) & (b) Treatment Effect (*G2*)
 - Q3 Scalable: Linear on input size
 - Q4 Informative: Observation coincides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

Q1(a) Effective: Forecasting (G3)

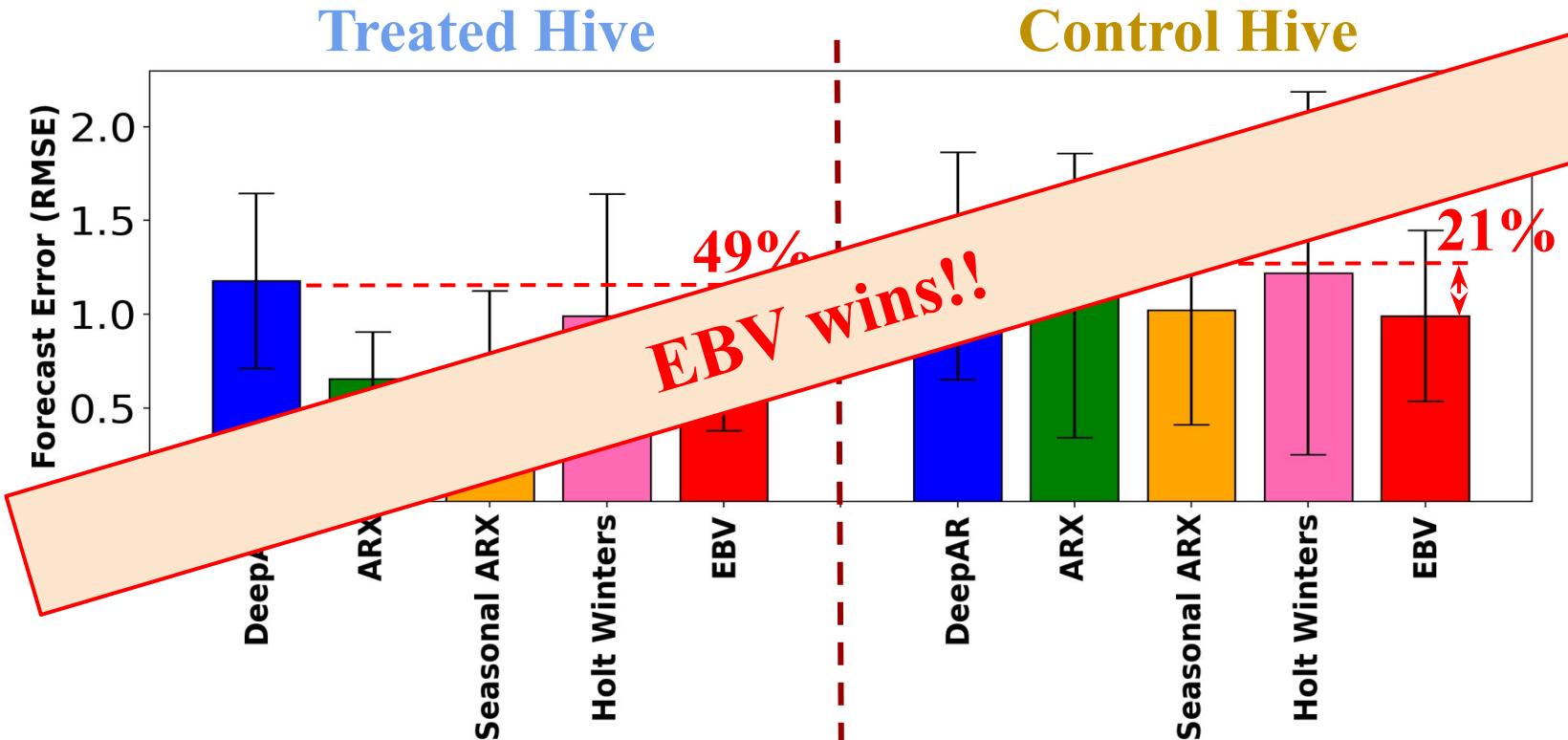


Control Hive

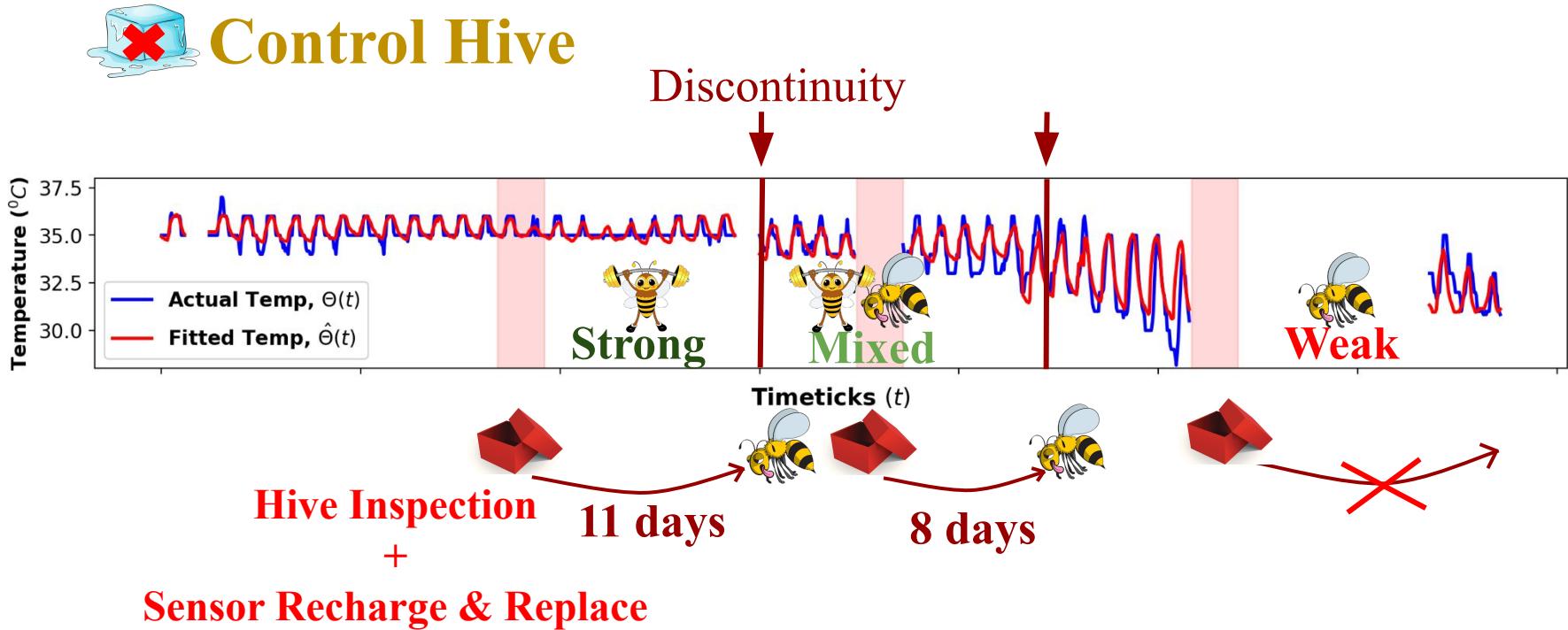
Q1(a) Effective: Improved Accuracy (G3)



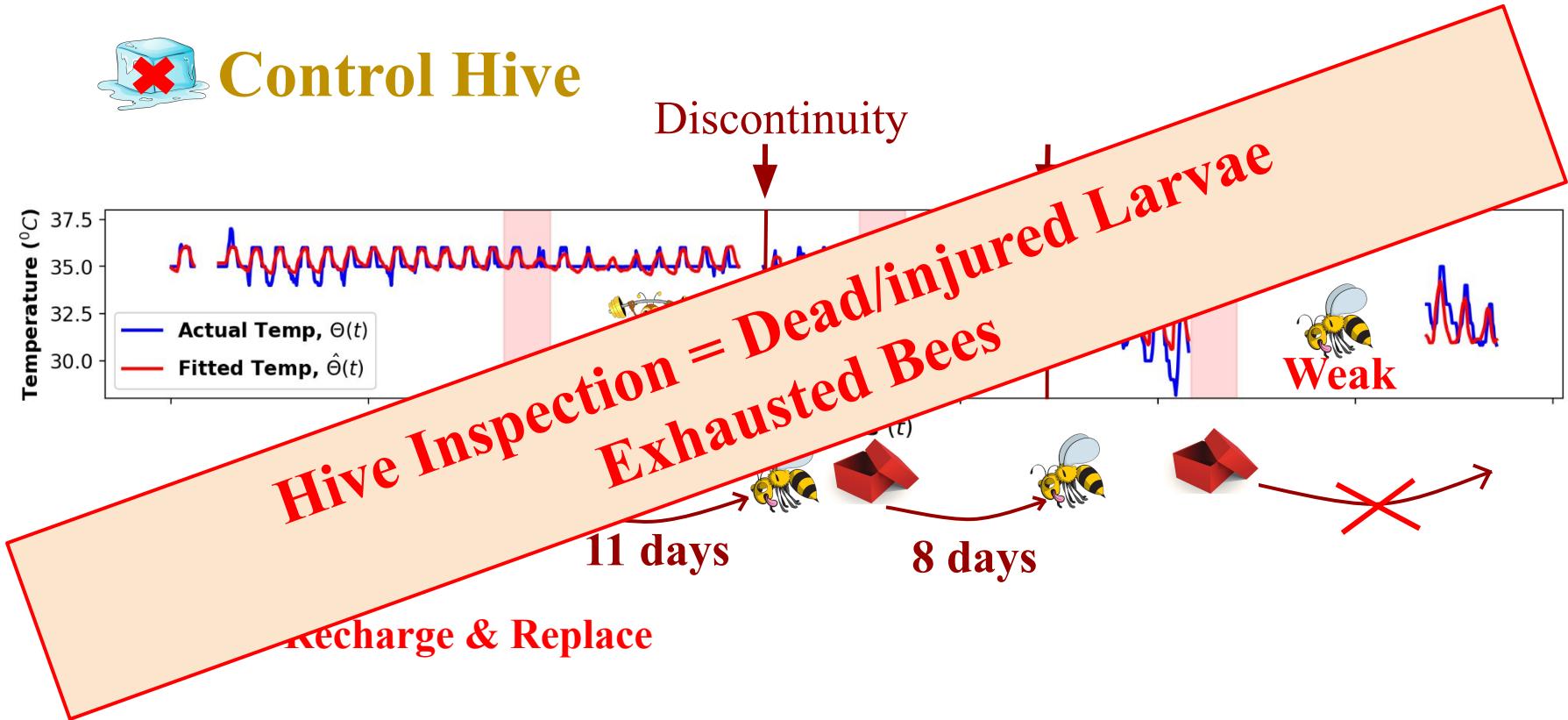
Q1(a) Effective: Improved Accuracy (G3)



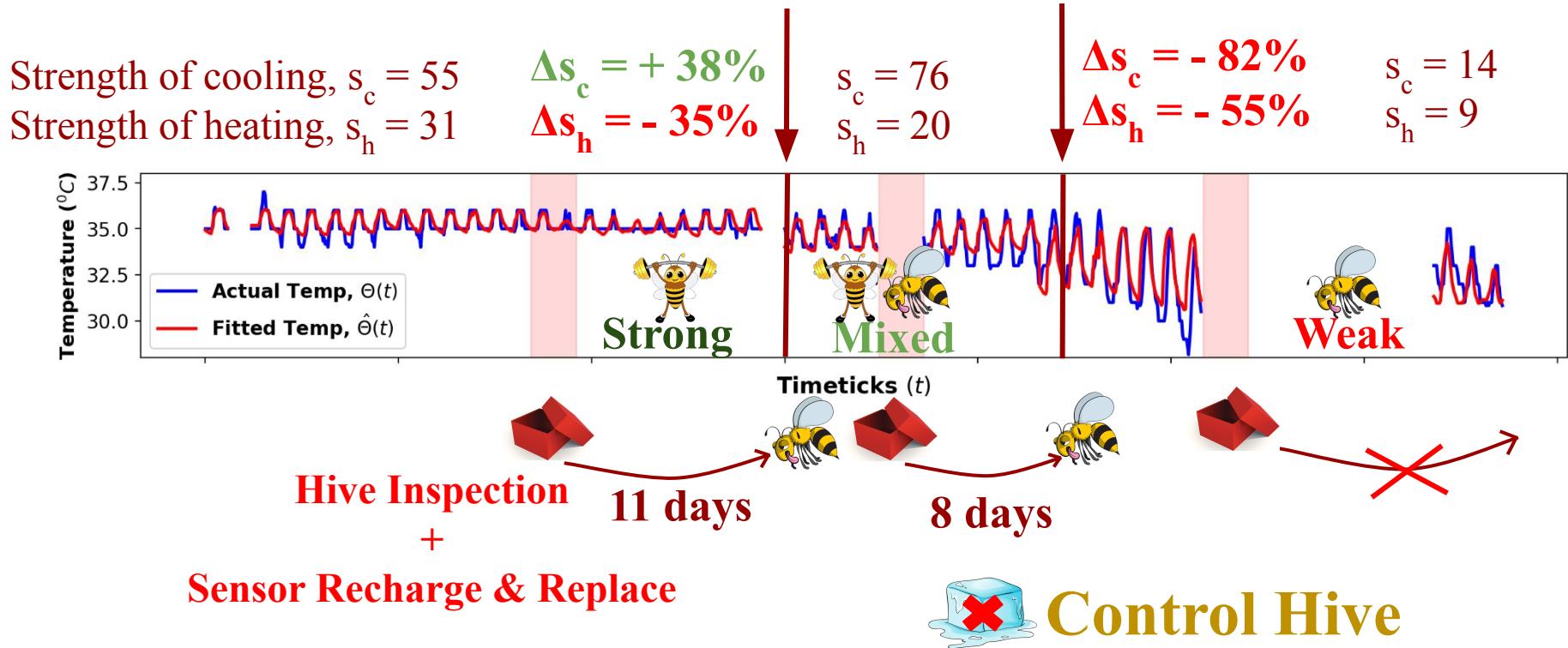
Q1(b) Effective: Event Detection (*G2*)



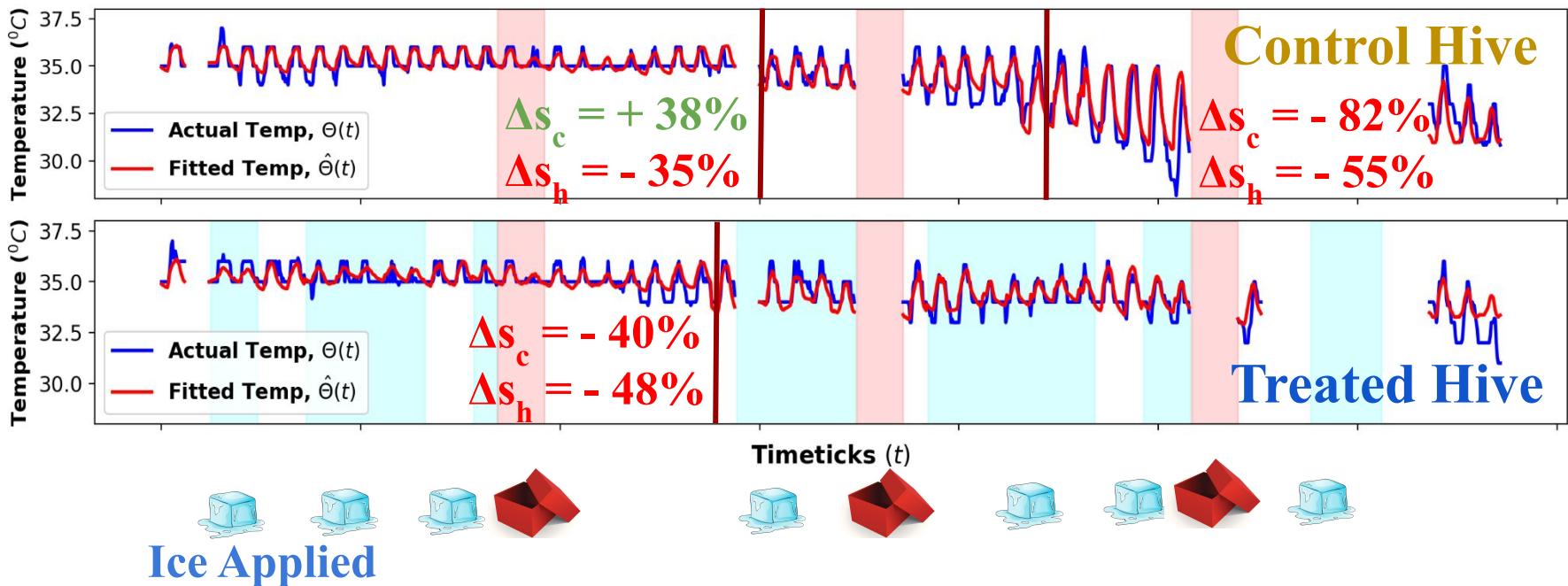
Q1(b) Effective: Event Detection (*G2*)



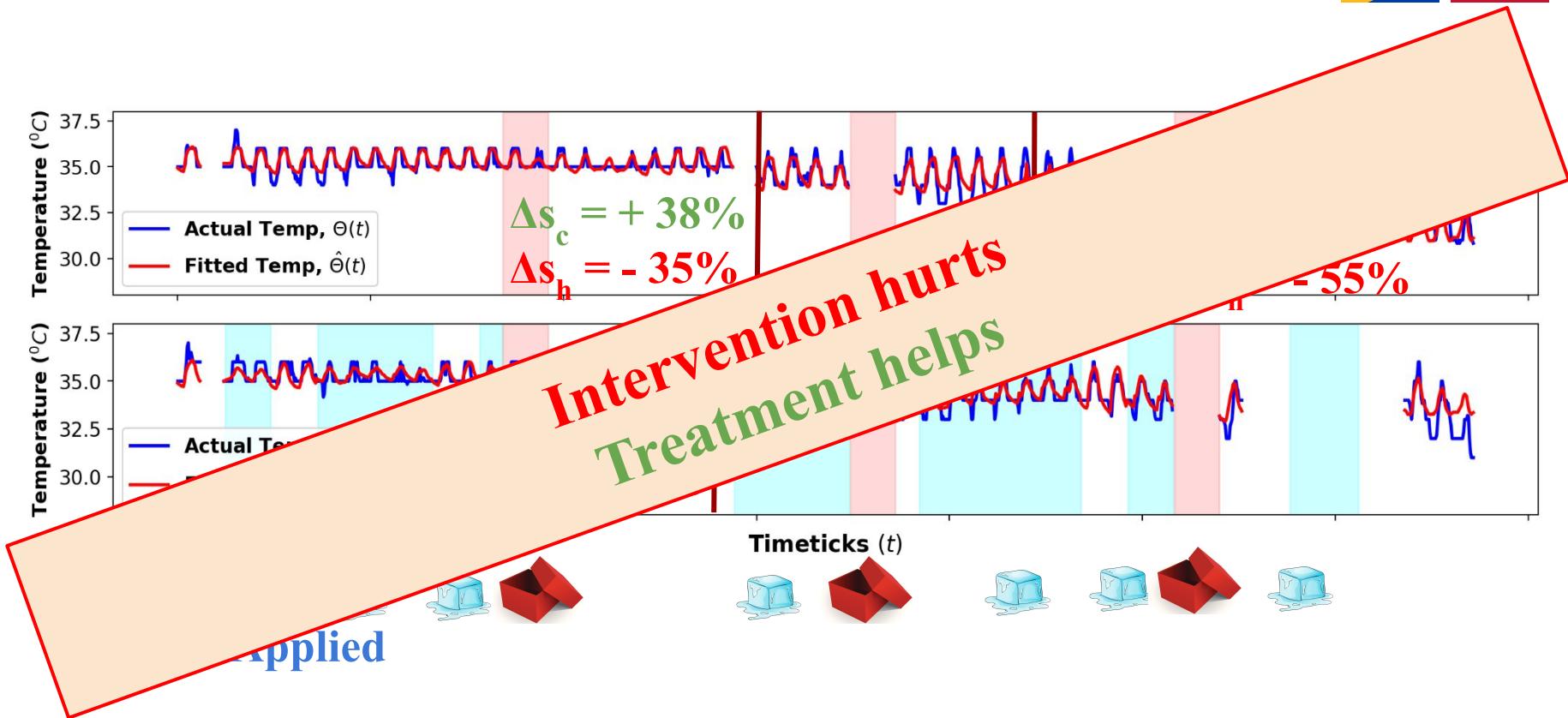
Q2(a) Explainable: Event Detection (*G2*)



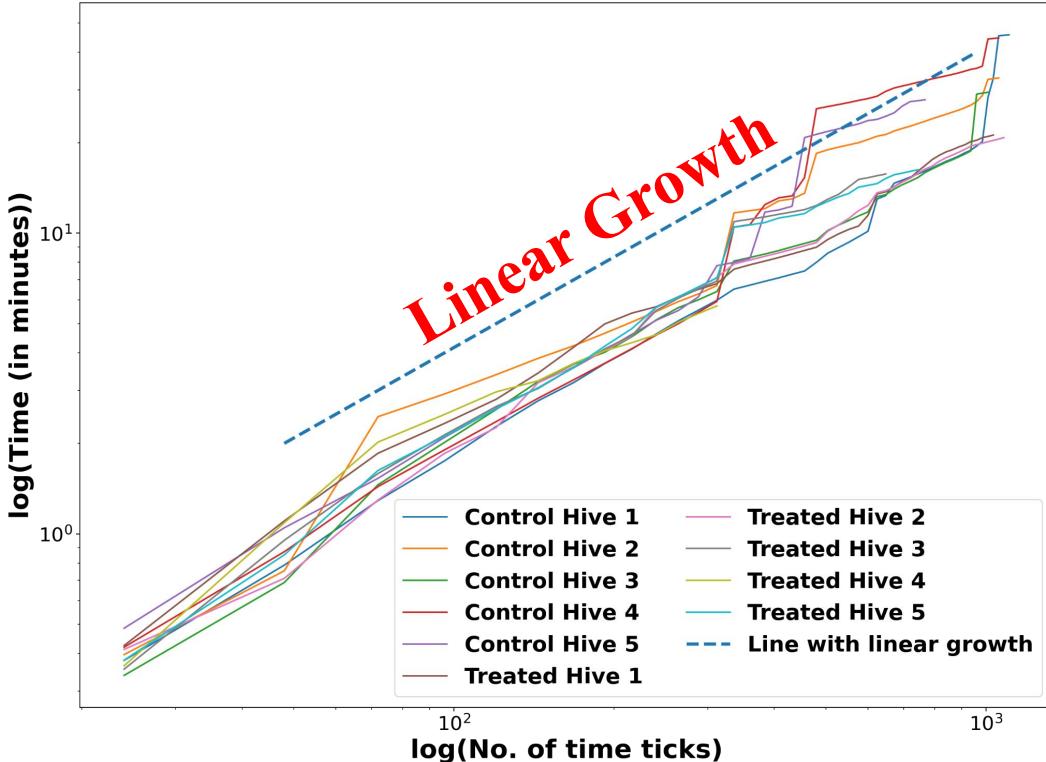
Q2(b) Explainable: Treatment Effect (*G2*)



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

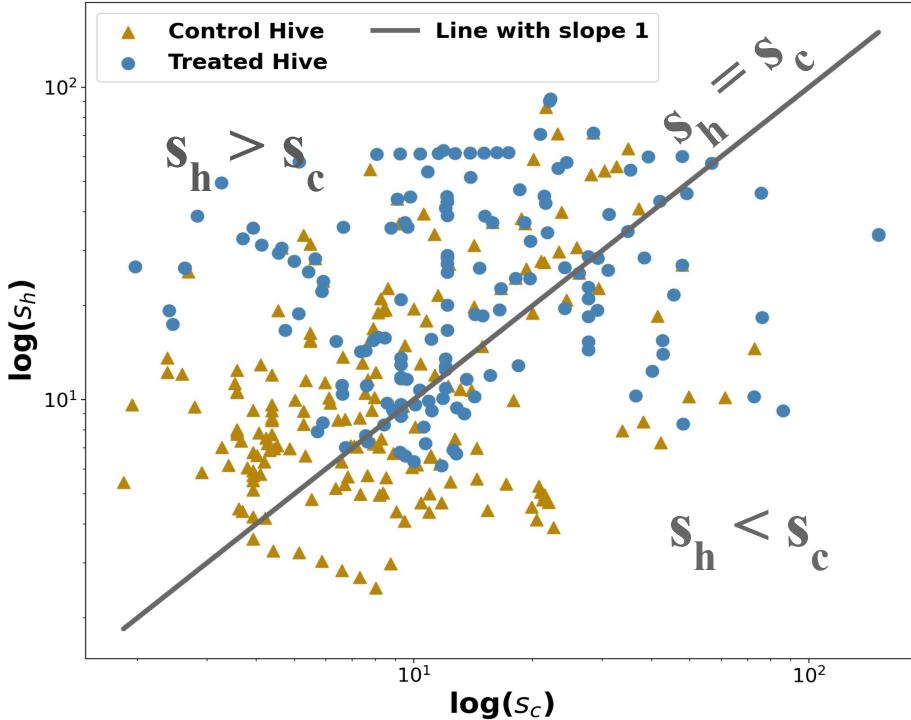


Q3 Scalable



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

Q4 Informative (G2: 1/3)

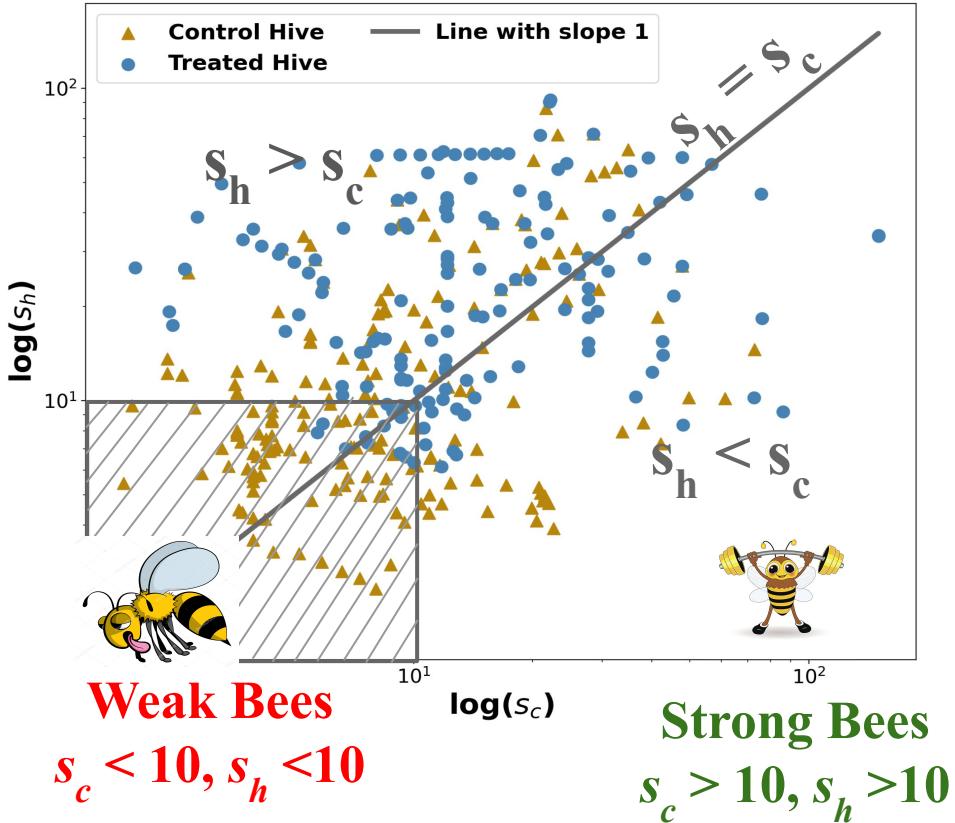


Observation (1):

Heating is easier than cooling

$$(s_h > s_c)$$

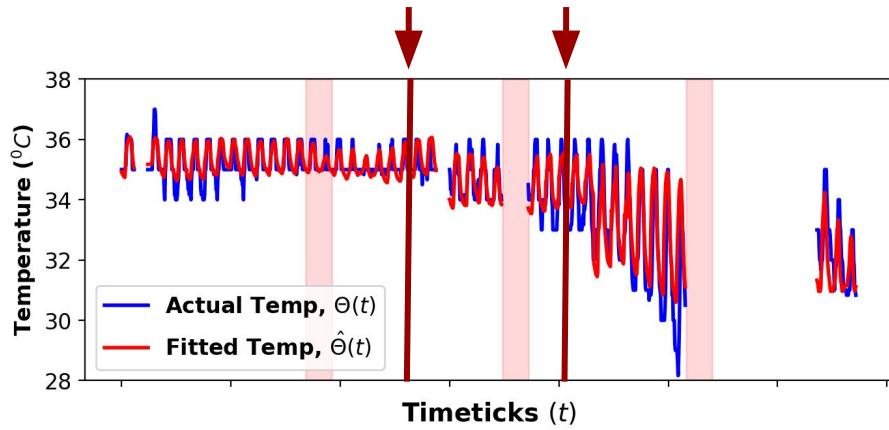
Q4 Informative (G2: 2/3)



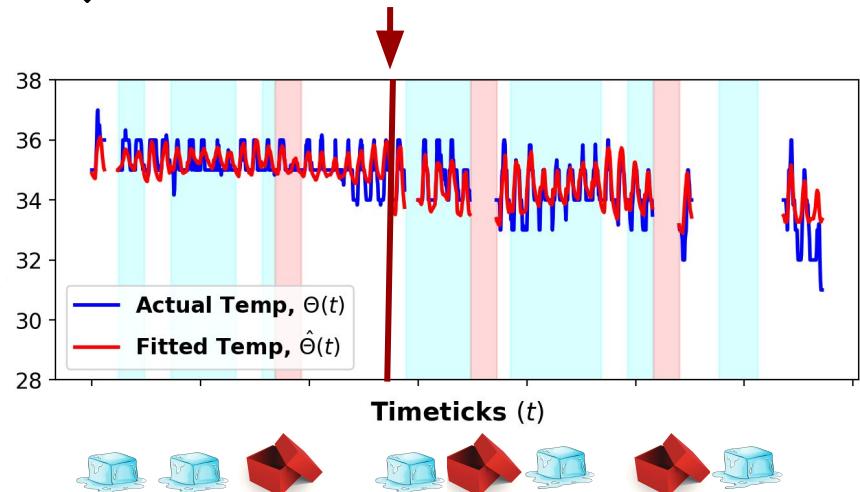
Observation (2):

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

Q4 Informative (G2: 3/3)



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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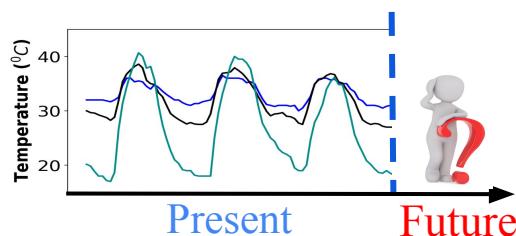
THANK YOU!!



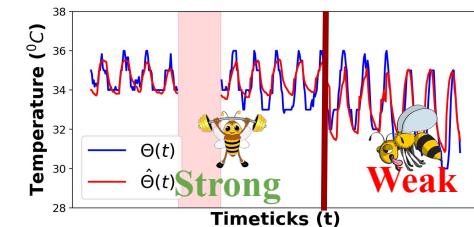
github.com/rtenlab/EBeeVet

✓ **C1: Principled**

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

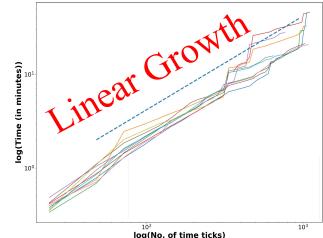


✓ **C2: Effective**



✓ **C3: Explainable**

✓ **C4: Scalable**



✓ **C5: Informative**



THANK YOU!!



github.com/rtenlab/EBeeVet

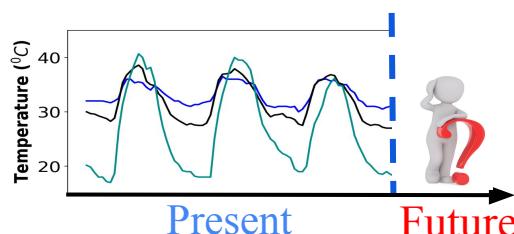
Contact:

mhoss037@ucr.edu

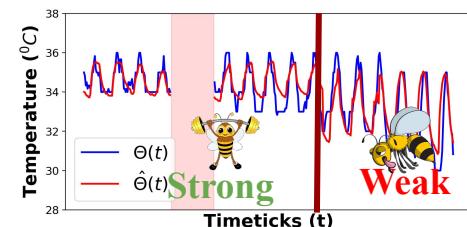


✓ **C1: Principled**

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

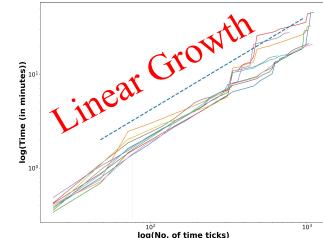


✓ **C2: Effective**

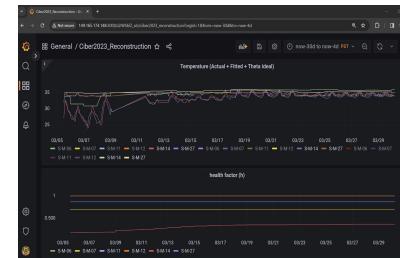


✓ **C3: Explainable**

✓ **C4: Scalable**



✓ **C5: Informative**



Ongoing Work:
Real-time
notification of
honey bee health

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