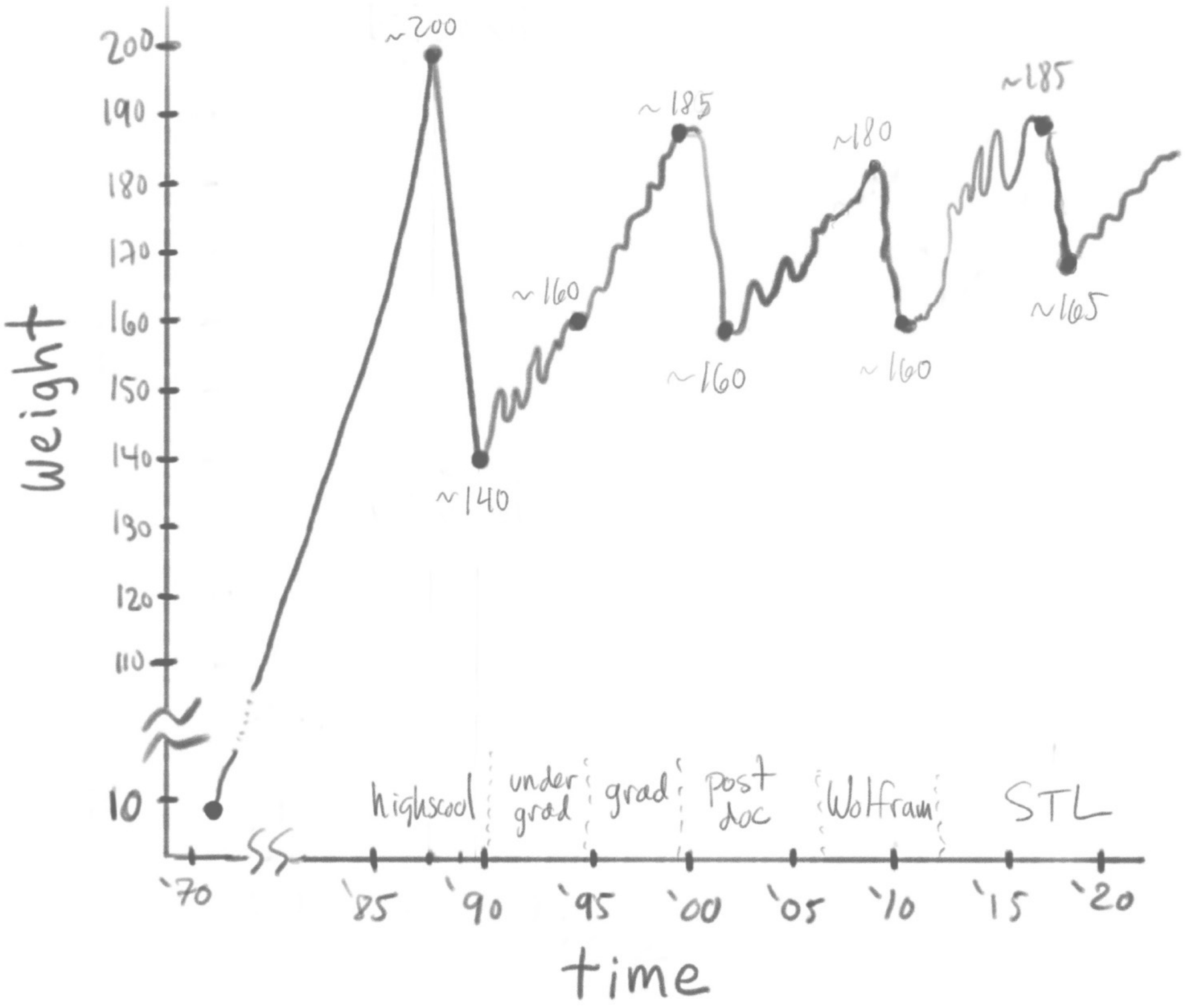
Building a Weight Forecaster

Jamie Williams

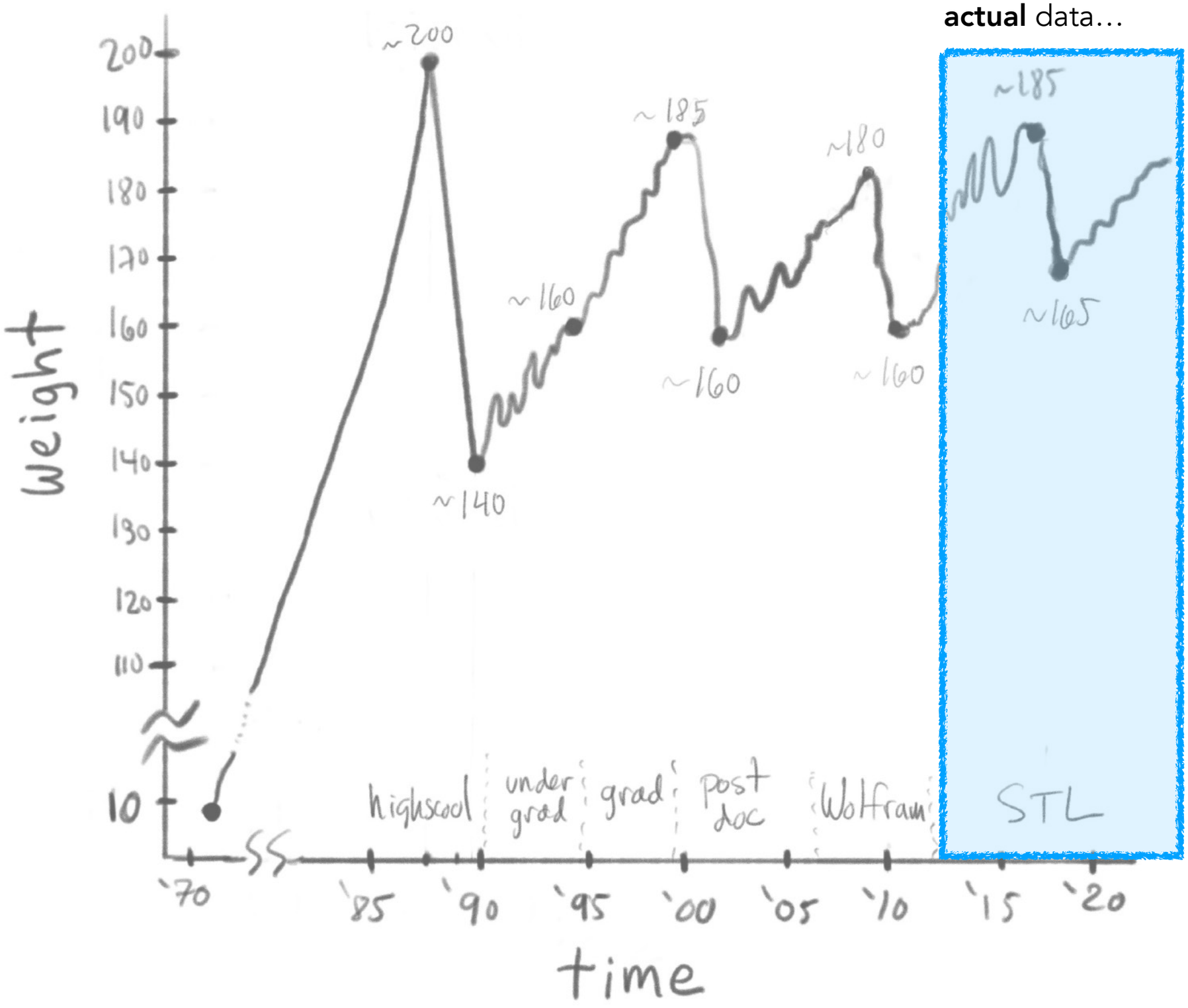
February 2021

A history of my weight



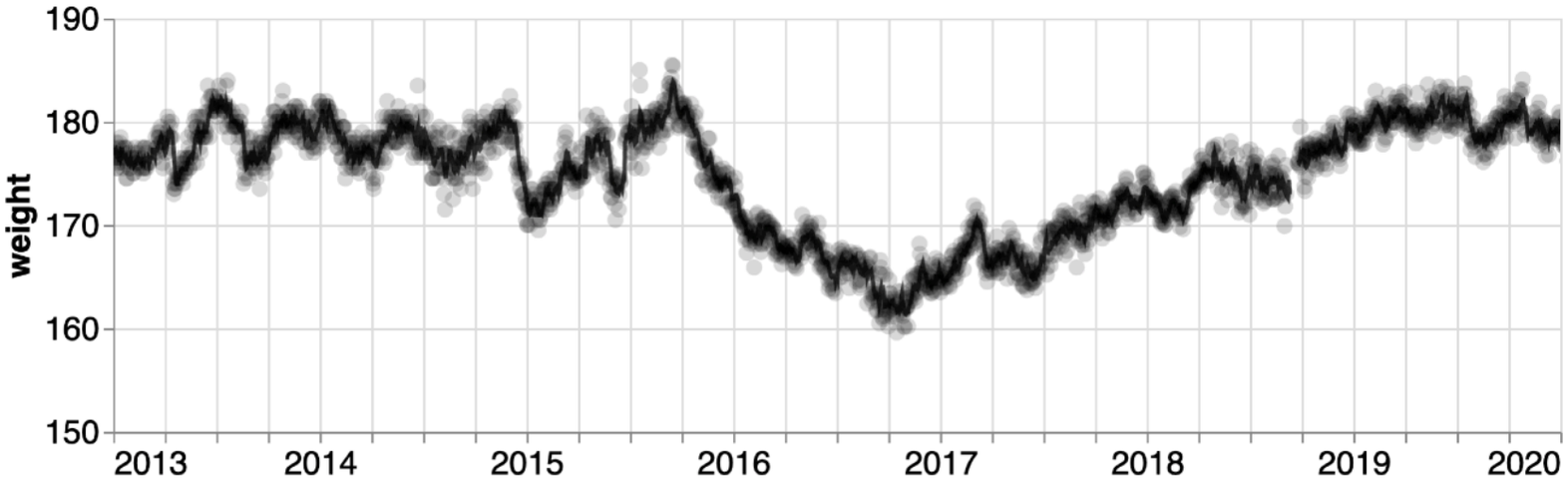
A history of my weight

let's zoom in with **actual** data…



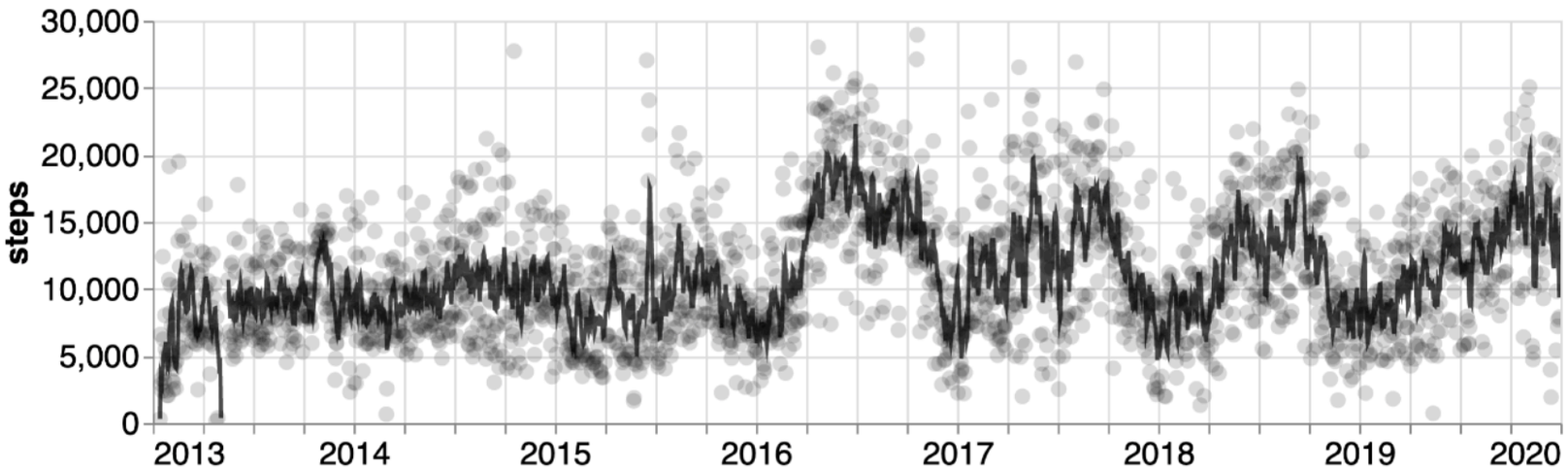
Weight, Steps, Calories

withings



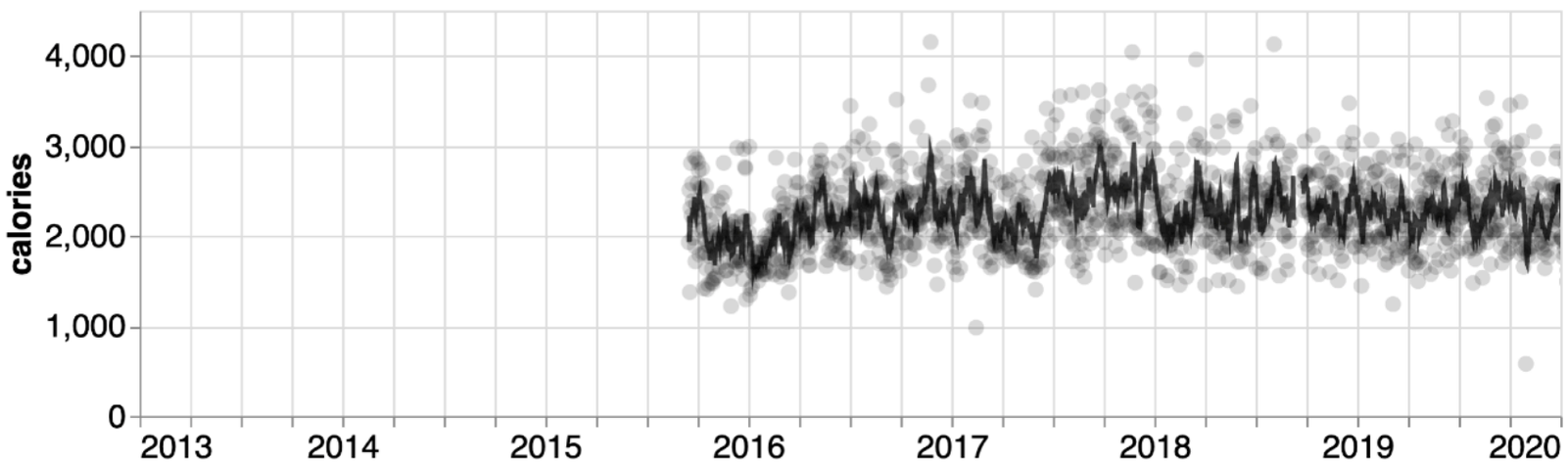
~95% coverage

fitbit



~99% coverage

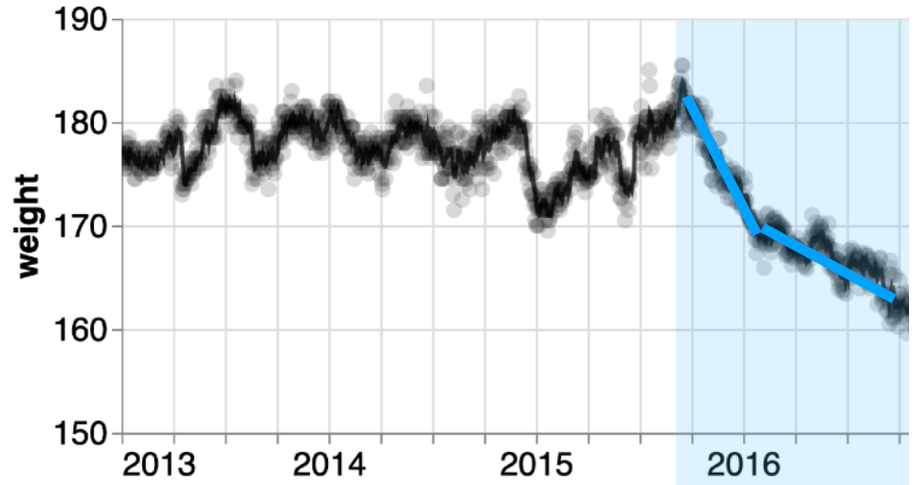
myfitnesspal



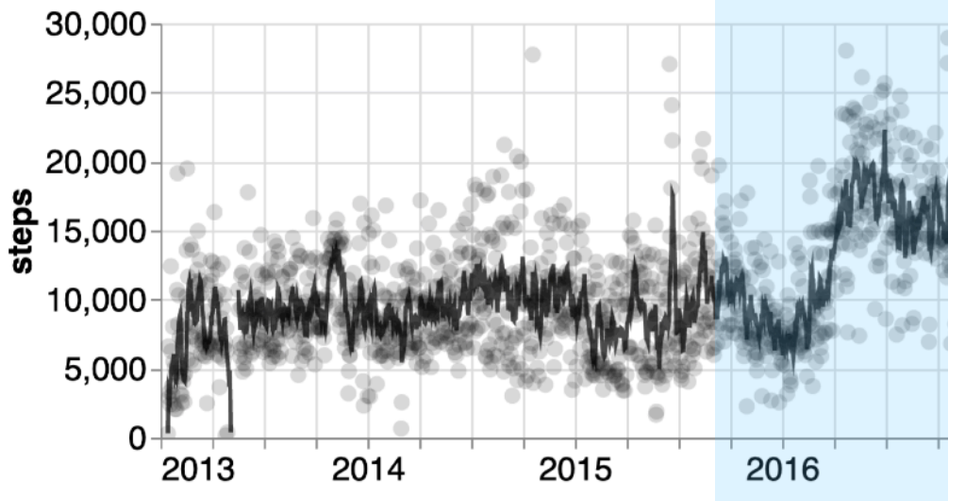
~99% coverage
(after 9 / `15)

Tracking calories helped me lose weight

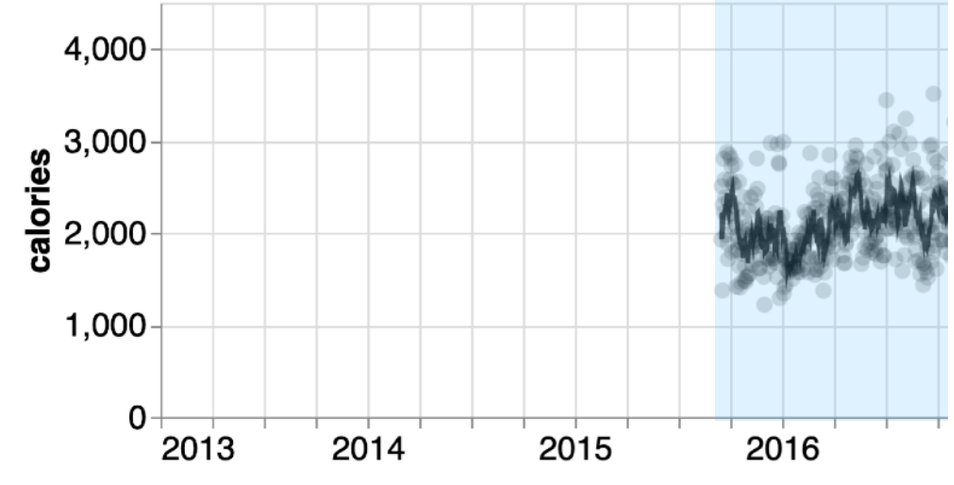
withings



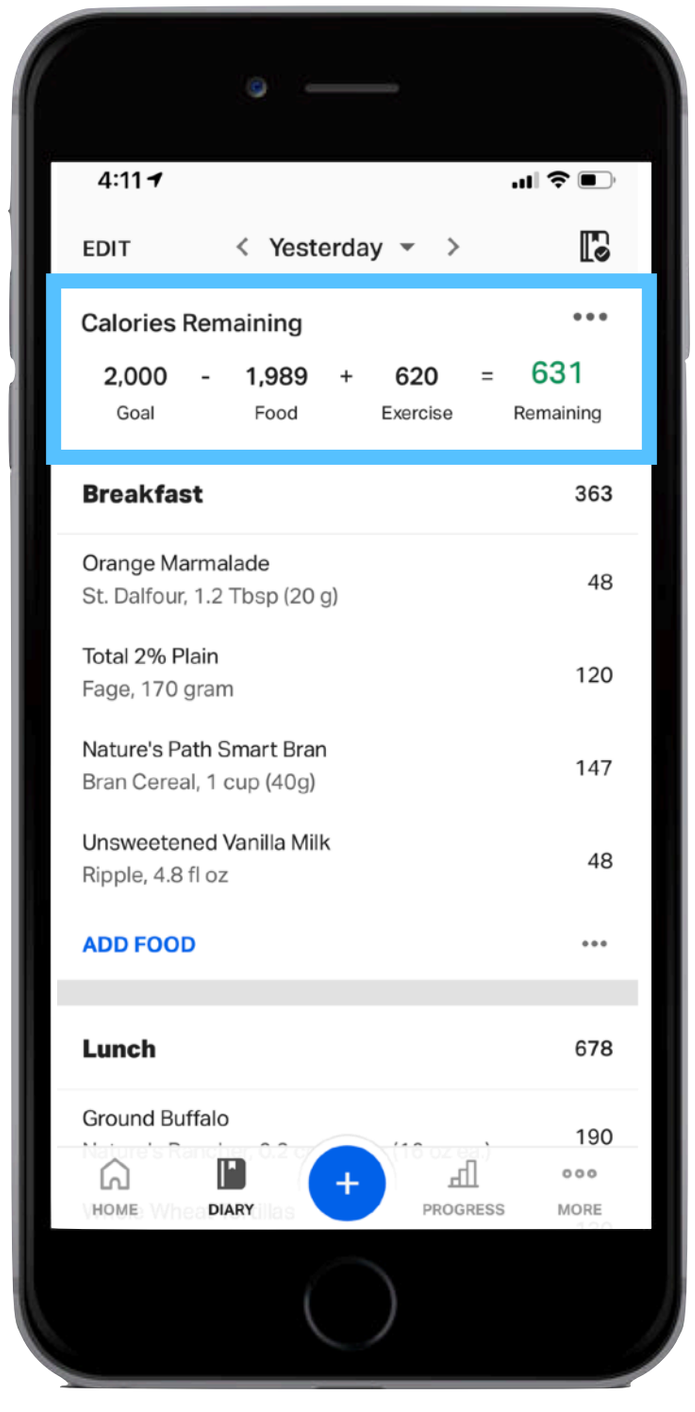
fitbit



myfitnesspal

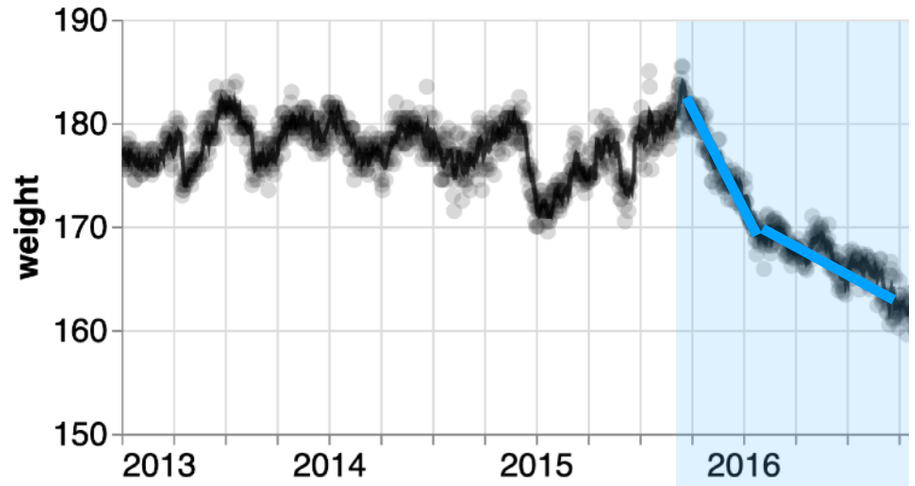


myfitnesspal

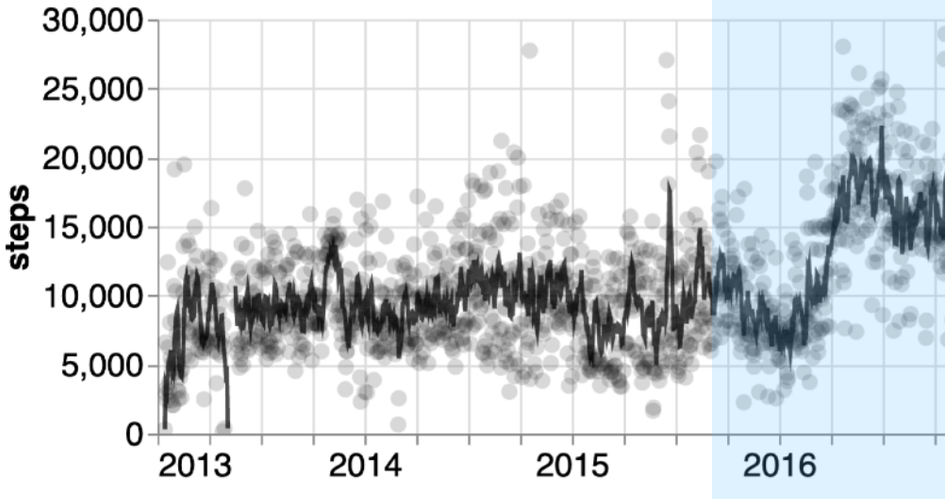


Tracking calories helped me lose weight

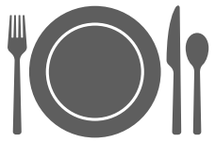
withings

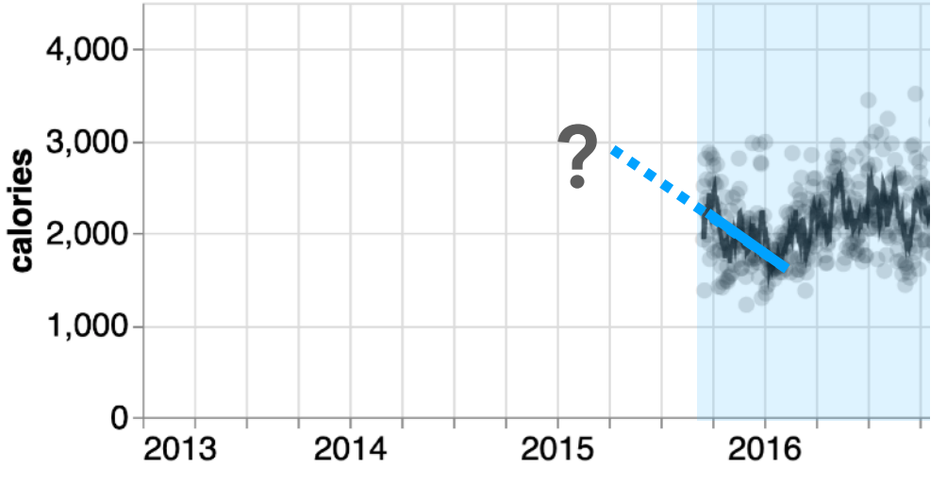


fitbit



myfitnesspal

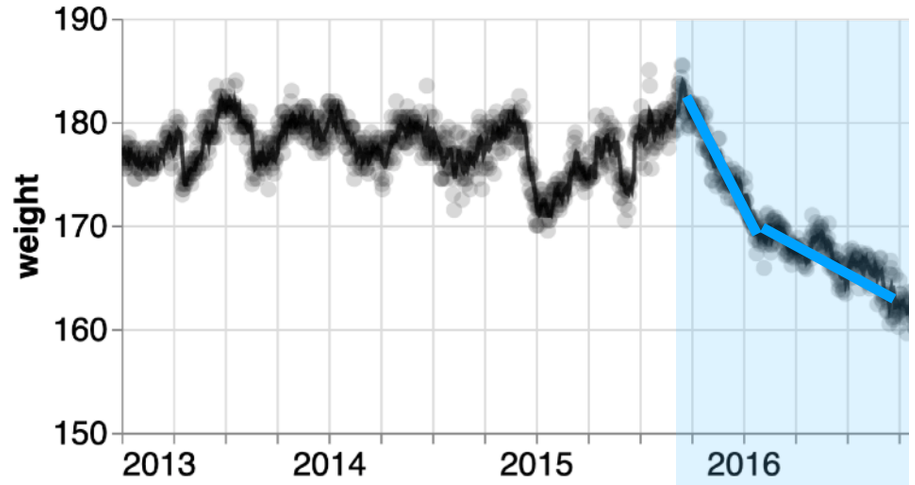




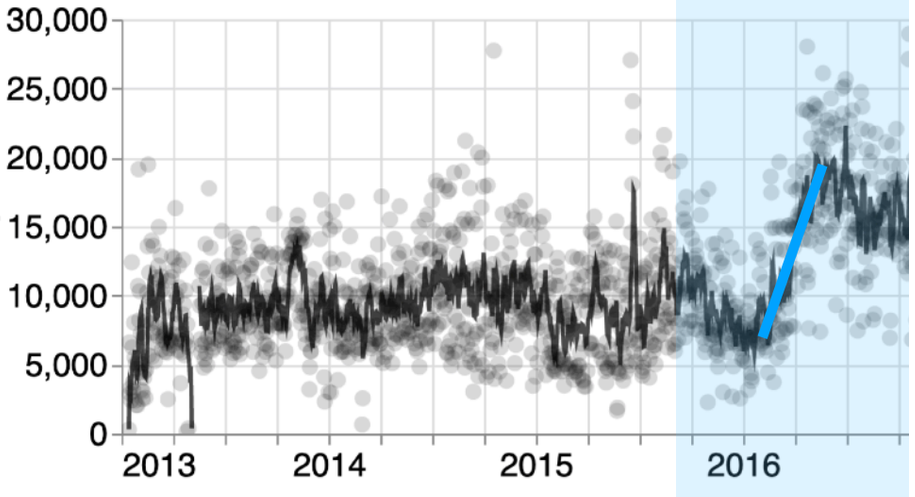
Calorie consumption decreased (initially).

Tracking calories helped me lose weight

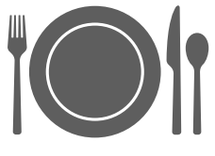
withings

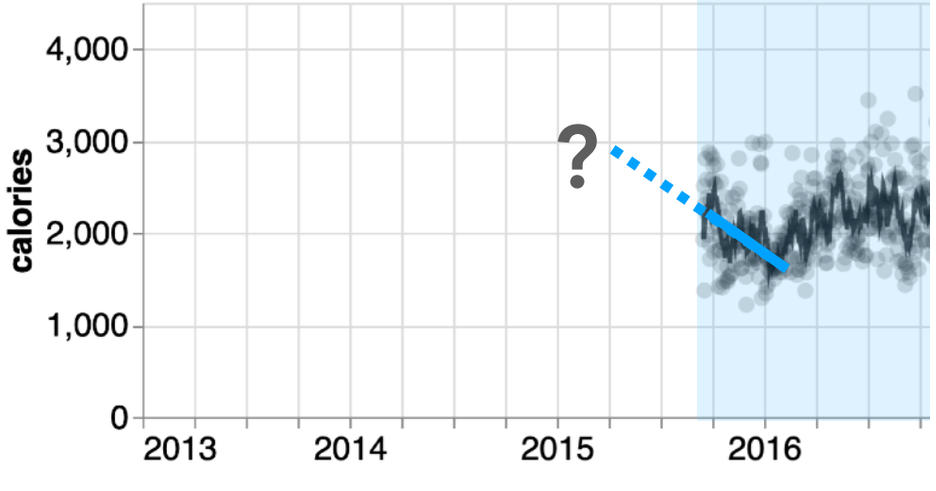


fitbit



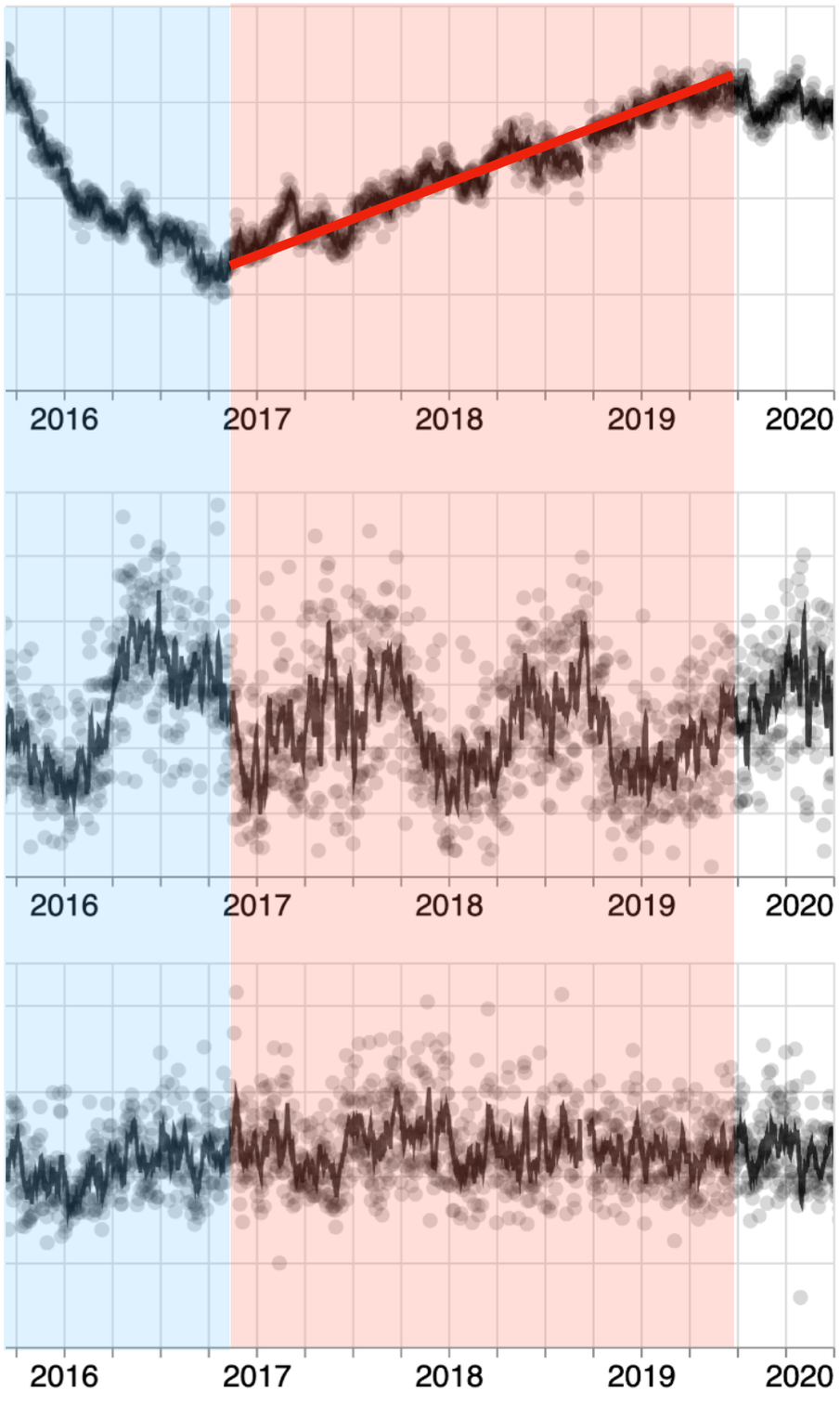
myfitnesspal





After the winter lull, I really stepped up my walking & jogging.

Bad habits returned, I regained weight ☹



What went wrong?

Lot's of factors:

- Overall increase in anxiety (**stress eating**):
  - Trump was elected
  - Twitter FOMO/doom scrolling
  - moved to a new apartment
  - switched teams at work
  - poor sleep
- Lacked **shopping discipline**: the only way I can avoid overeating is if I commit to **not <u>buying</u> snacks** in the first place.
- I eventually became **desensitized** to the data I was tracking (weight, steps, calories)

Descriptive ➡ Predictive ➡ **Prescriptive**

What happens when we become **desensitized** to the data?

Seeing how things are trending is powerful, but it provides **no causal insight** about the **consequences of my actions**.

It's **harder to ignore** the data if you have a model that can give you **specific advice** to achieve **specific outcomes:**

Eat **1800** cals, get **12K** steps, you'll lose about **1lb** each week and reach your goal in **6mo!**

A Compass

vs

GPS

Qualitative

Directional

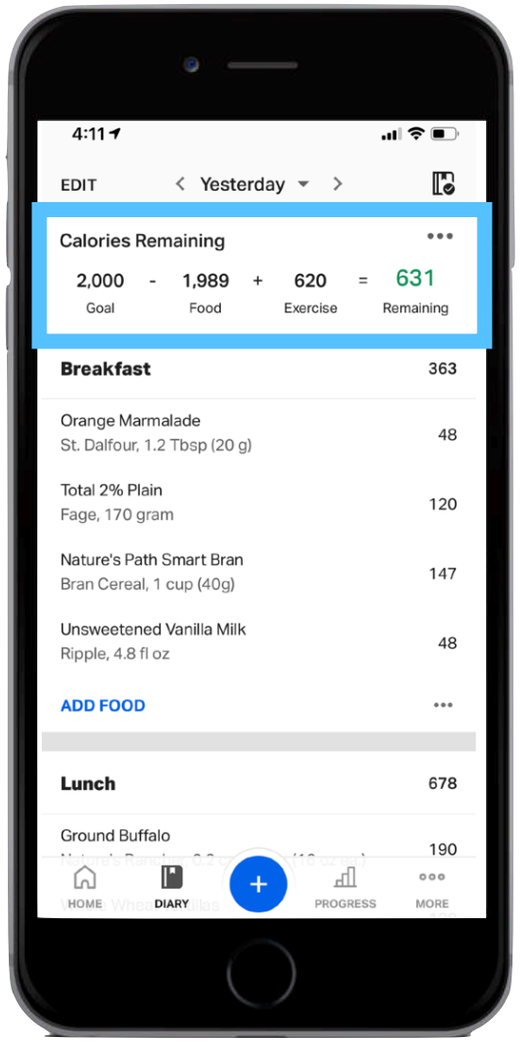
Rules of Thumb

Not Personalized

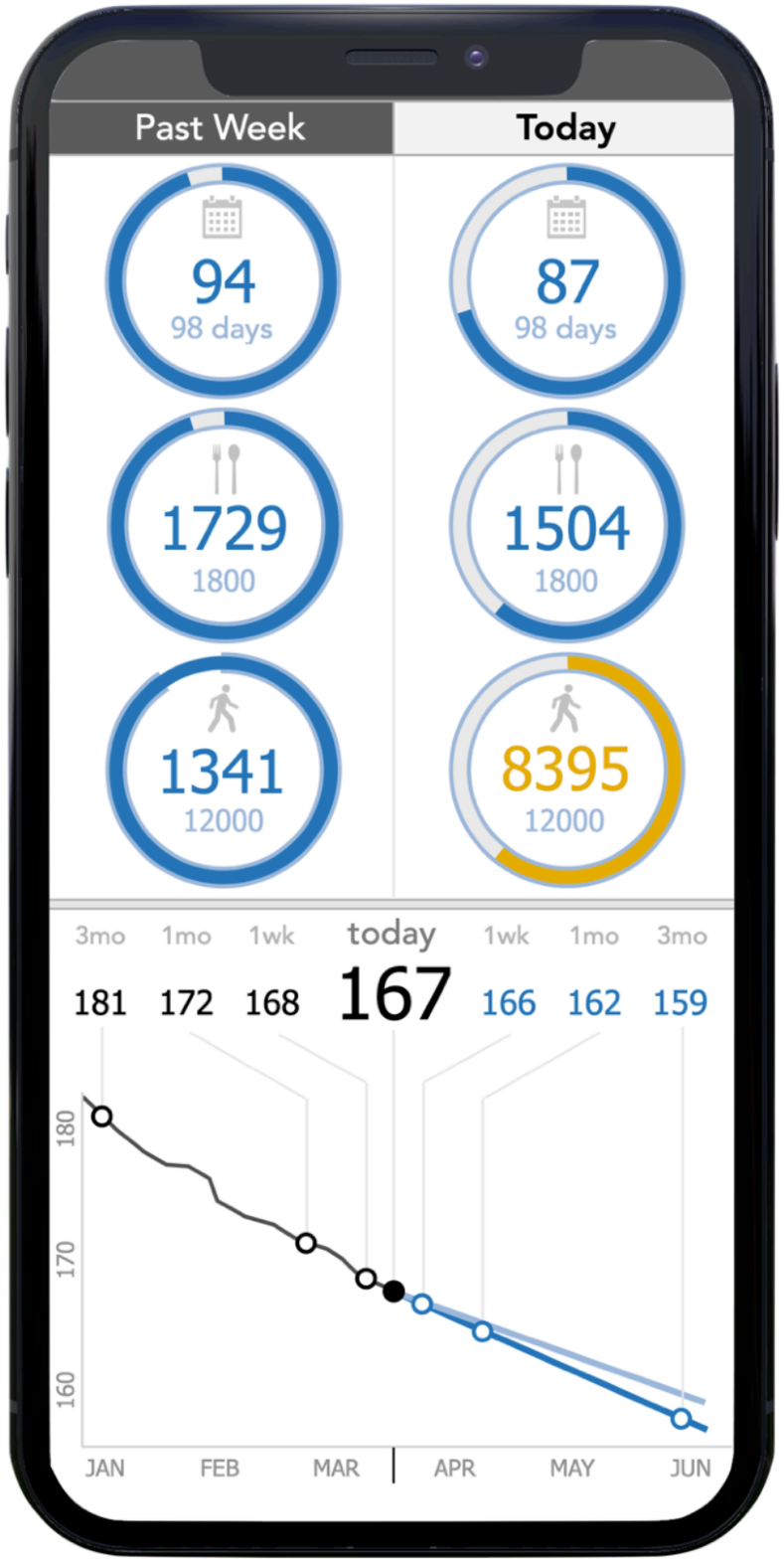
Quantitative

Predictive & **Prescriptive**

ML Model Trained
on Personal Data

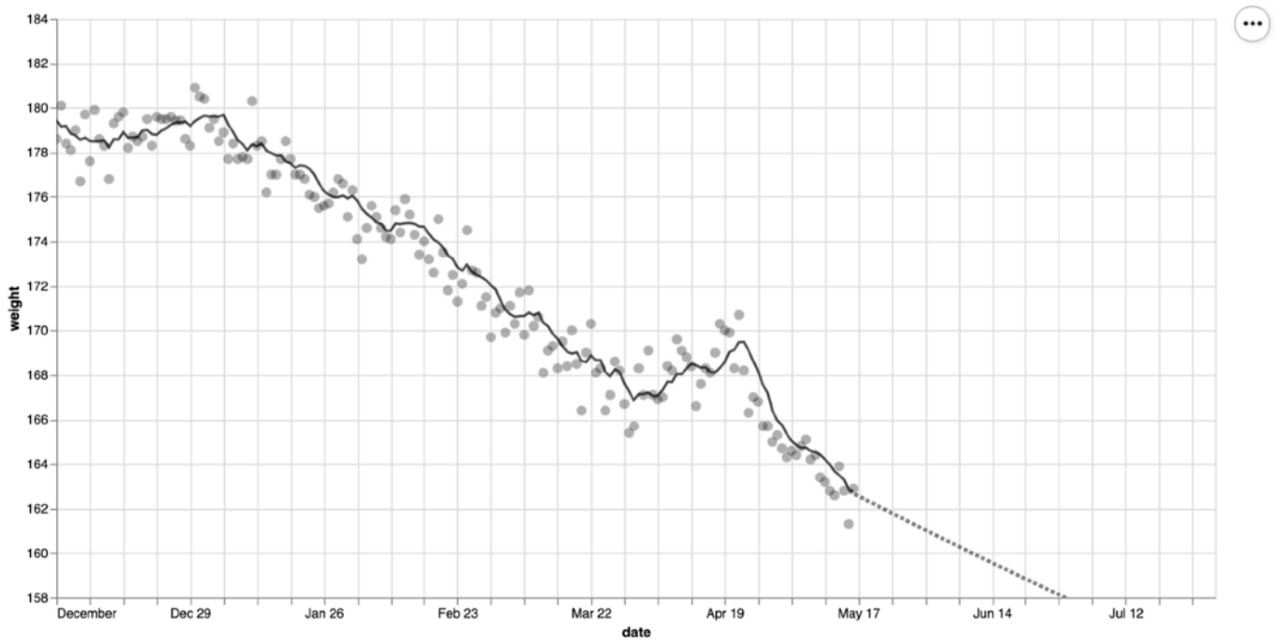


Mockup

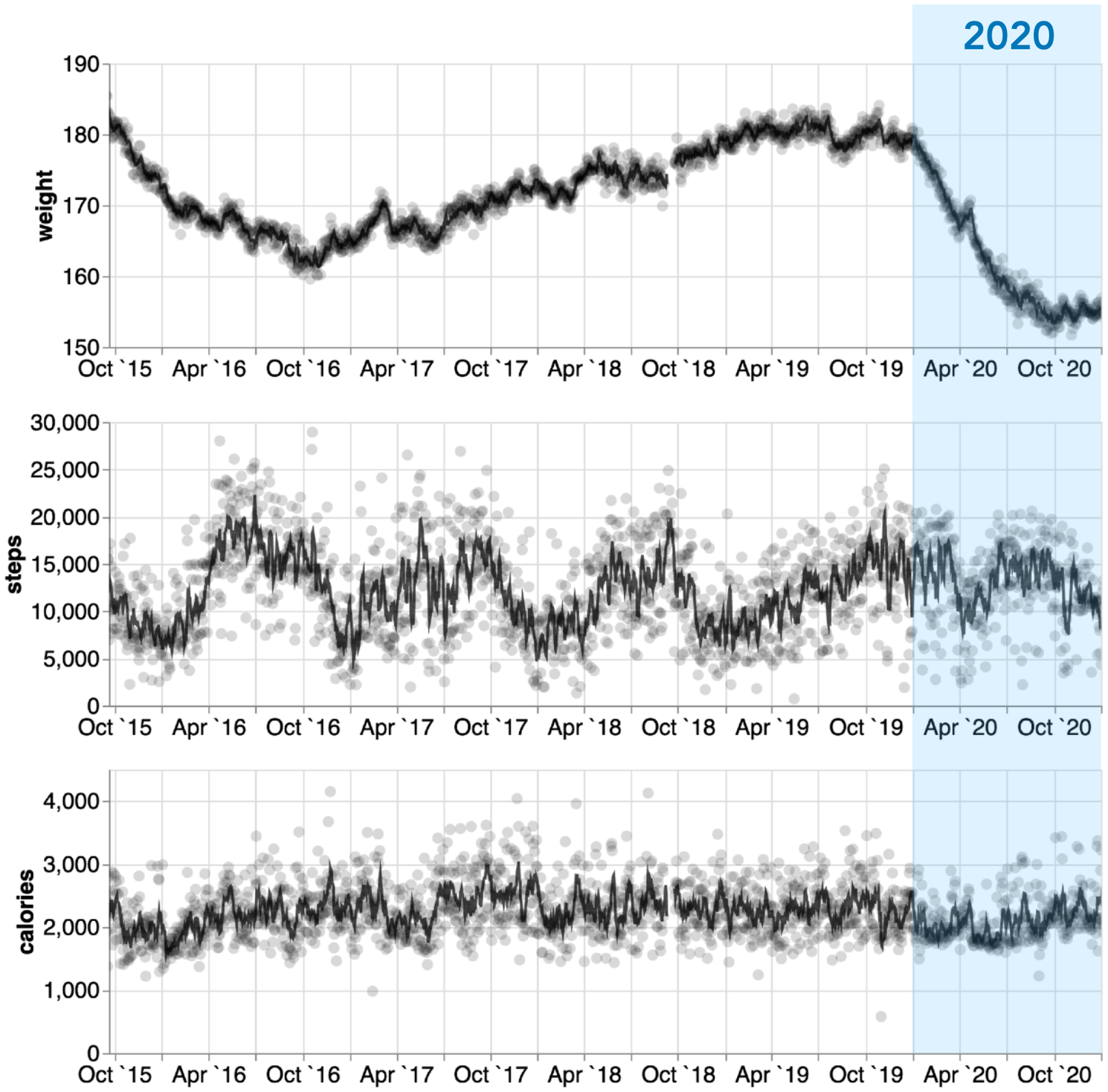


Jupyter-based MVP

	week	deviation	target	today	deviation	target
weight	162.8	2.8	160	162.9	2.9	160
date	Jun 11, 20	-19	Jun 30, 20	Jun 23, 20	-7	Jun 30, 20
weeks	3.71	-2.8	6.47	5.48	-1.0	6.49
rate	0.72	0.33	0.39	0.47	0.08	0.39
calories	1787	-163	1950	1861	-111	1972
steps	11082	0	11082	8989	-3011	12000



I lost over 25 lbs in 2020



Predicting weight change from energy balance

$$\frac{d}{dt}(\rho M) = E_{\text{in}} - E_{\text{out}}$$

ρ: energy density
M: body mass
E_{in}: energy intake
E_{out}: energy expended

$$\Delta M = \frac{\Delta E}{\rho} \qquad \rho \approx 3500\,\text{Cal/lb}$$

(energy content of pound of fat)

From this we get the often quoted rule of thumb:

Expend ~500 Cal per day to lose ~1 lb per week.

(more than you consume)

Estimating energy expended E_{out}

$$E_{\text{out}} = E_{\text{BMR}} + E_{\text{PA}}$$

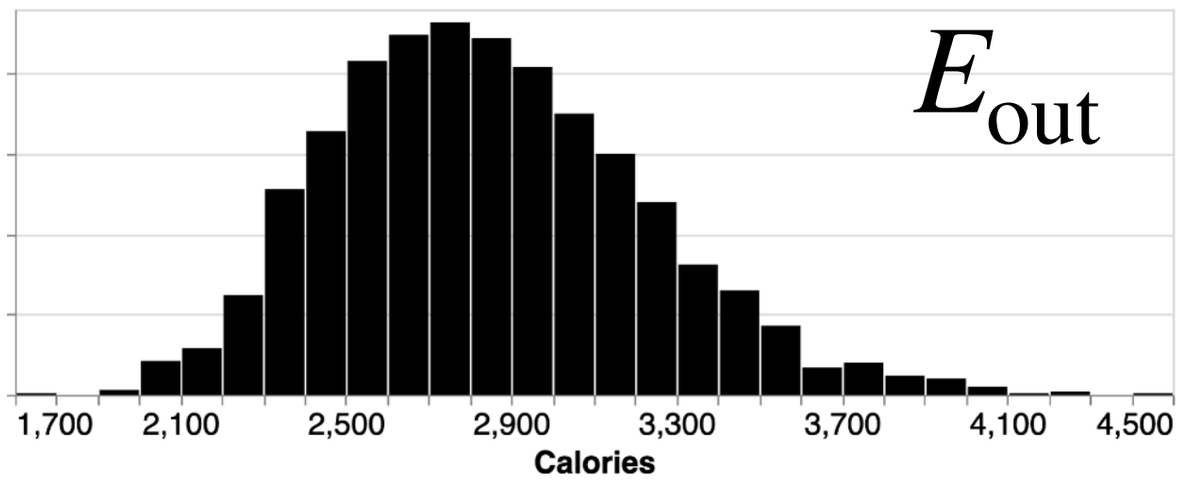
resting metabolism — physical activity

BMR varies widely by individual, can be estimated by standard formulae:

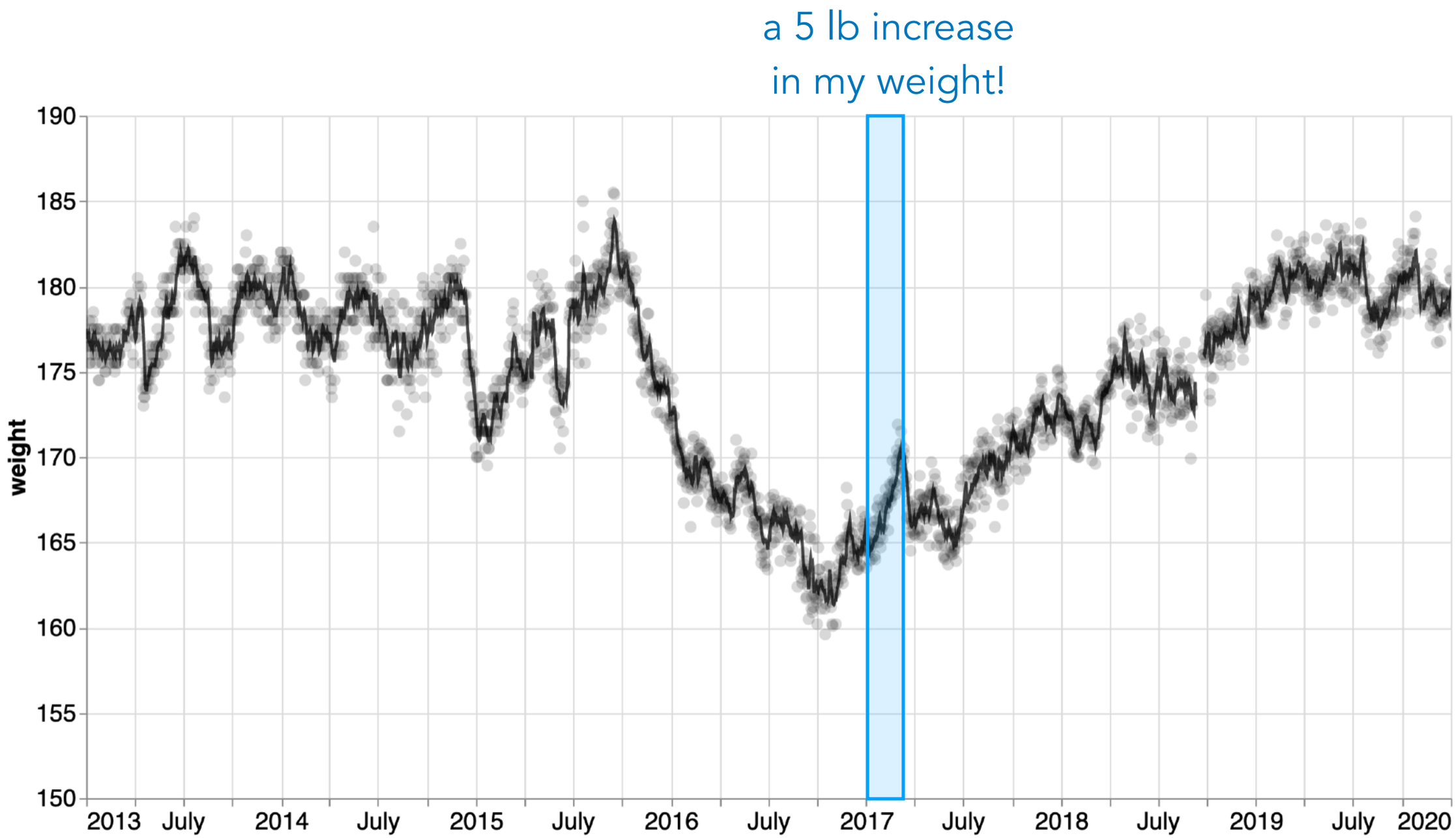
$$E_{\text{BMR}} \sim 1570\,\text{Cal}$$ (online BRM calculator)

Physical activity: Fitbit estimates it throughout the day based on steps, HR, etc.

$$E_{\text{PA}} \sim 500 \text{ to } 2500\,\text{Cal}$$



Apply the rule of thumb



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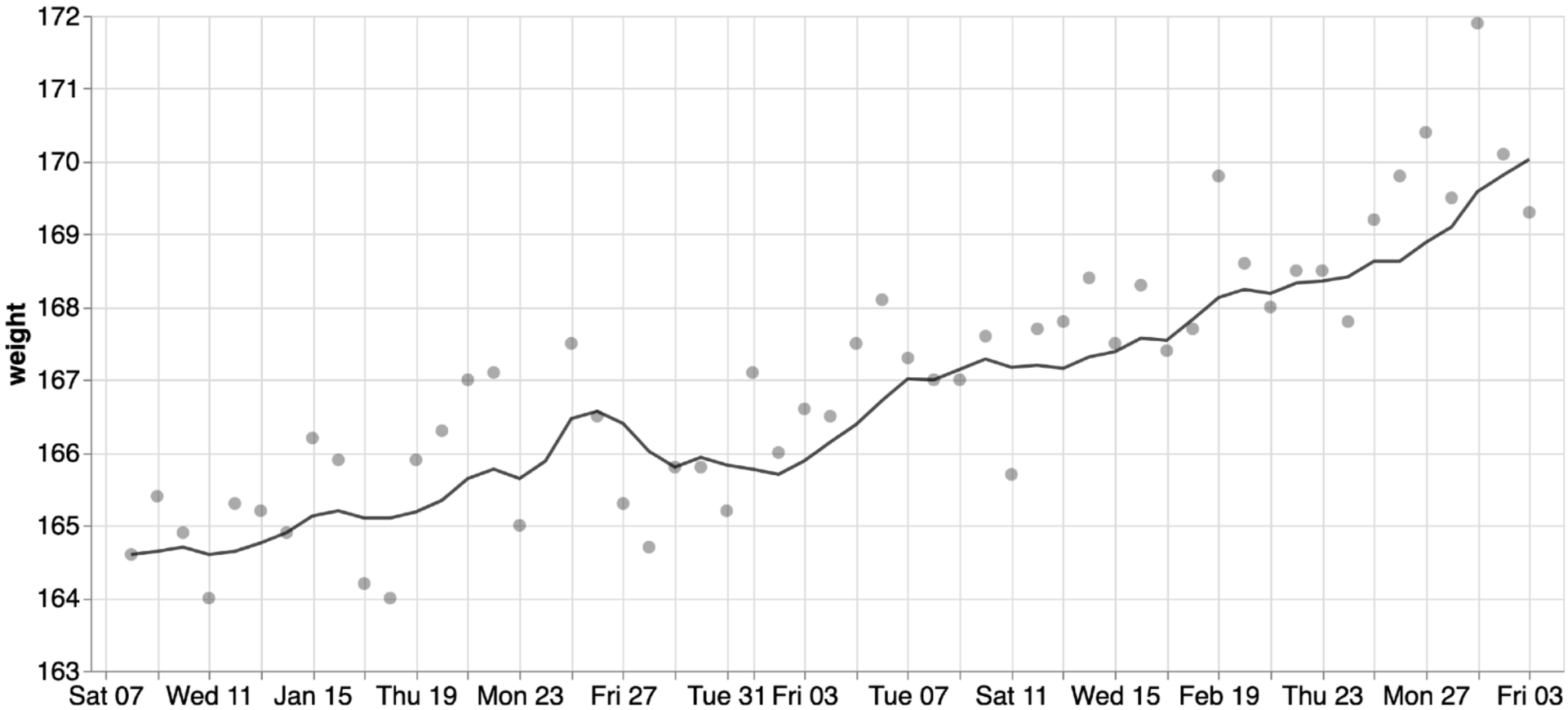
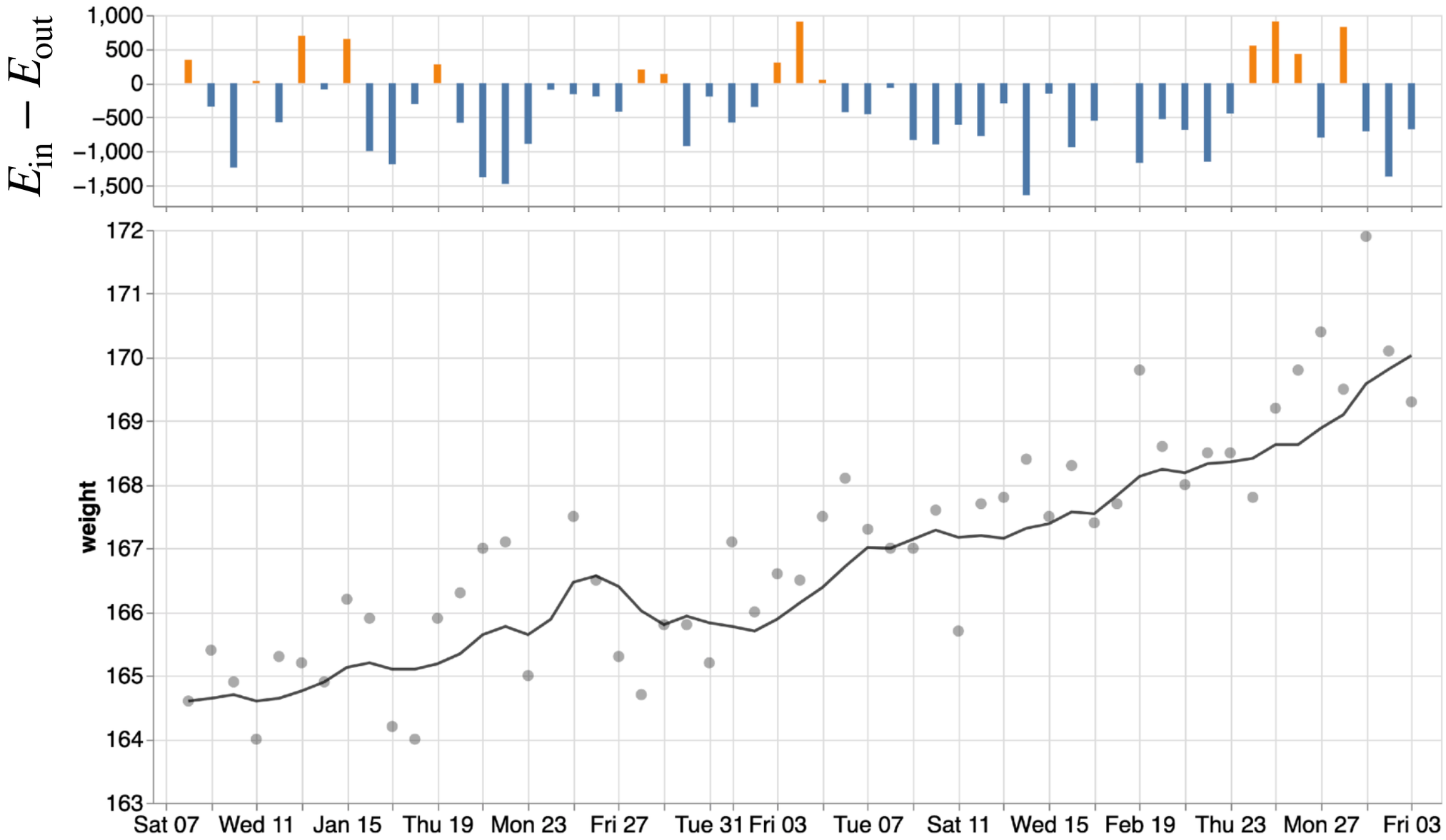


Apply the rule of thumb

E_{in} calories from myfitnesspal (recorded by me)

E_{out} calories from Fitbit (based on steps, HR, etc)



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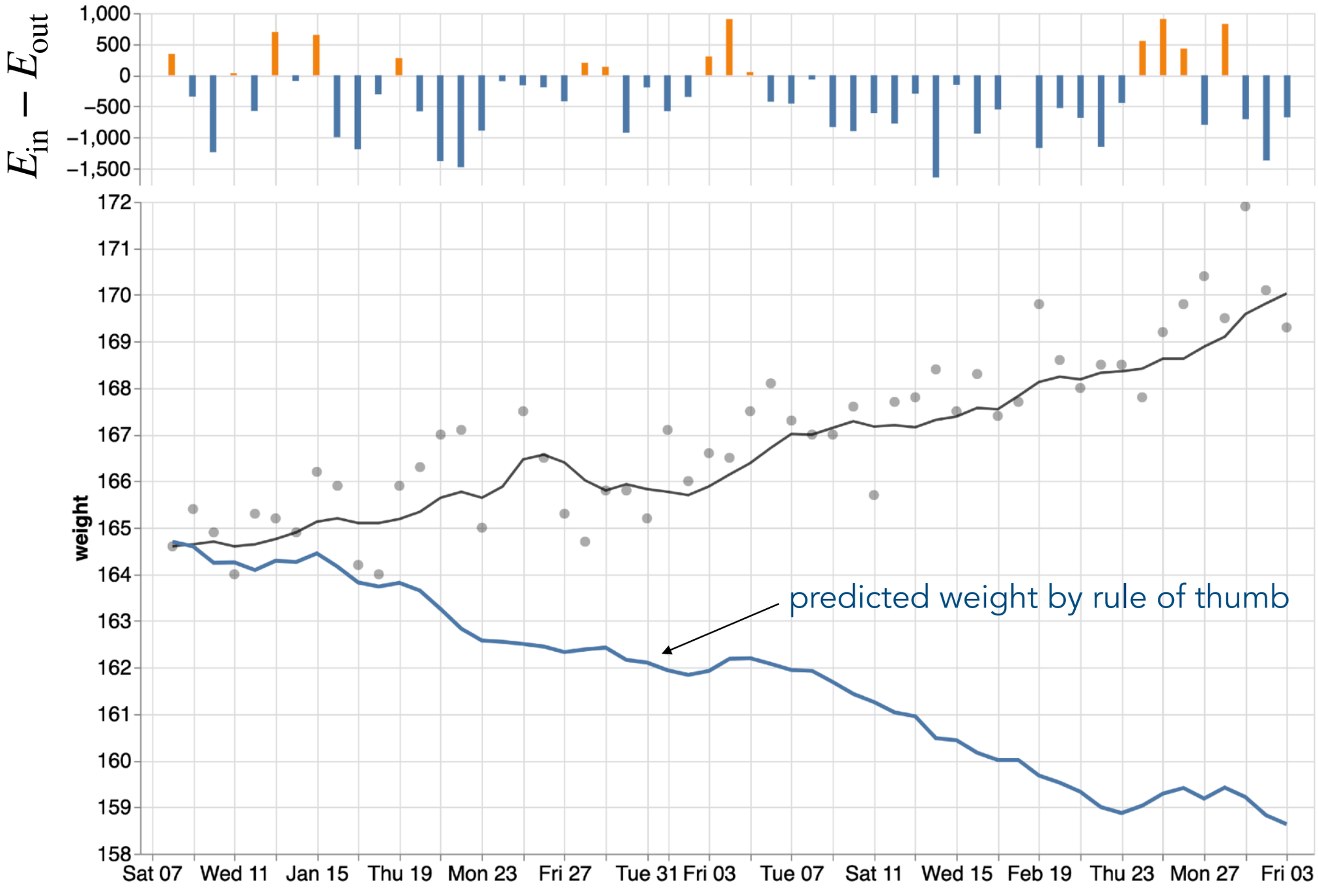
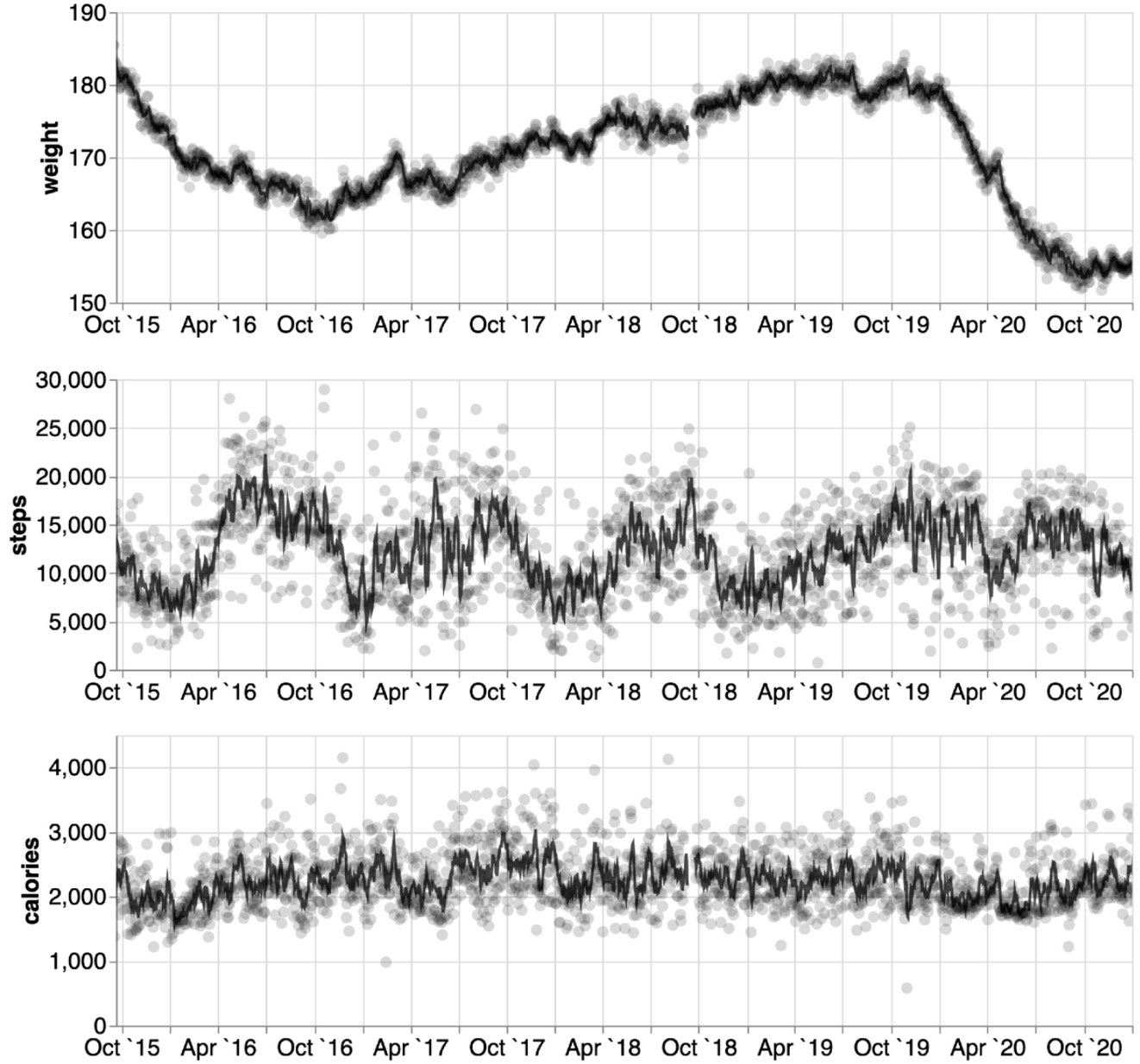
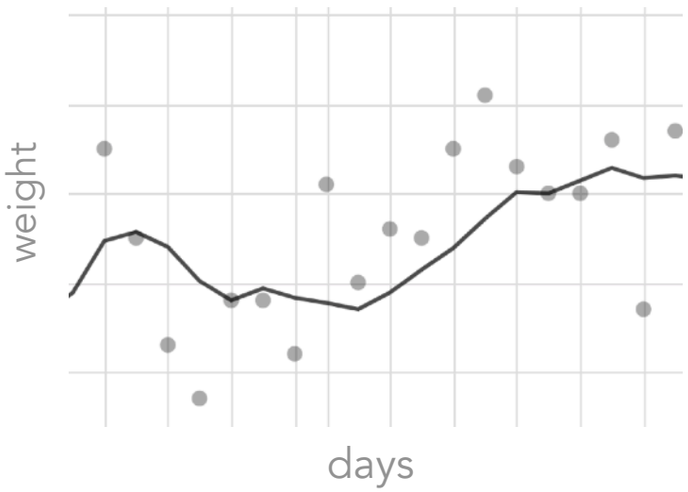


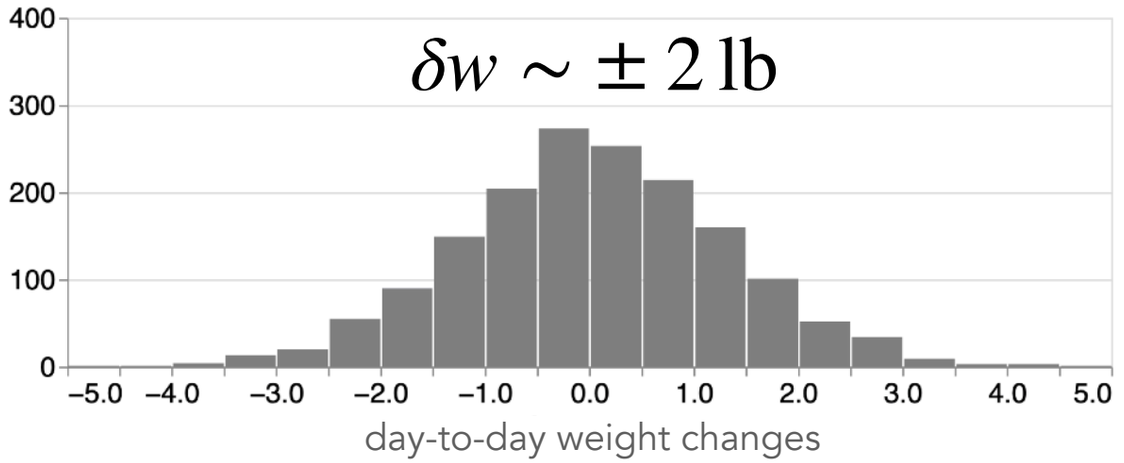
Train a simple regression model

I have over five years of daily measurements.



Day-to-day weight fluctuations

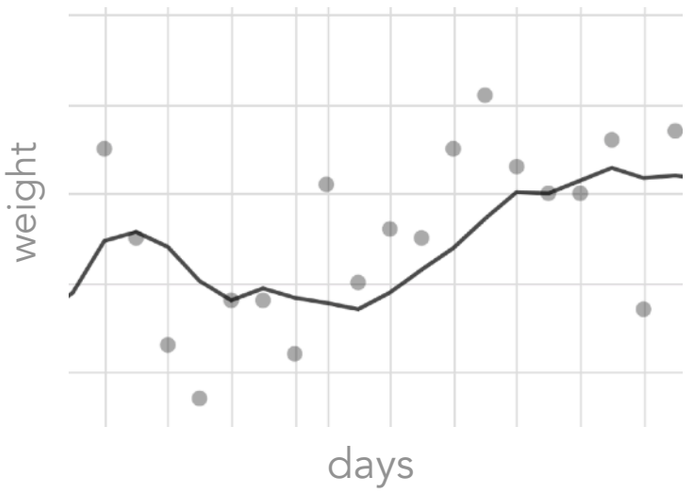


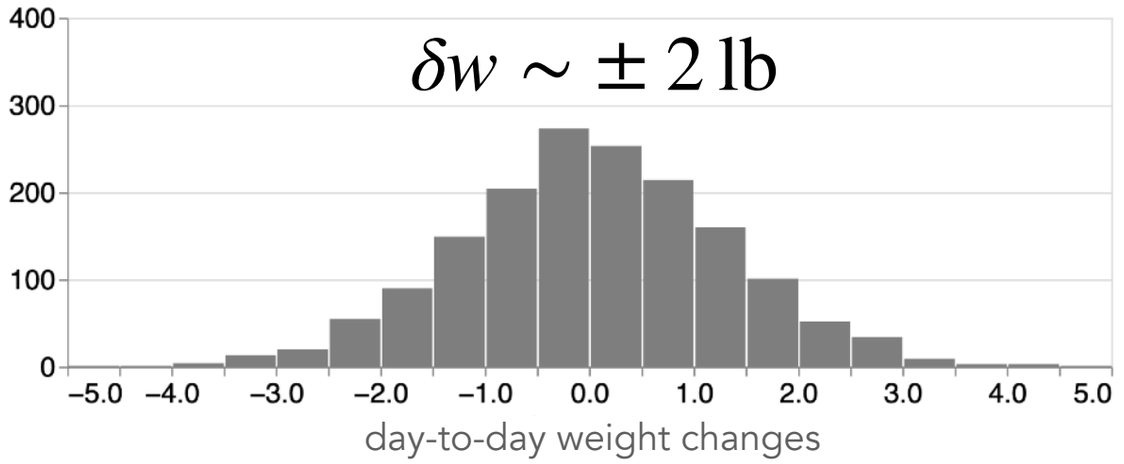


Throughout the day, my total weight can **vary** due to various processes:

- drinking
- eating
- exercising / sweating
- urinating & defecating
- breathing

Day-to-day weight fluctuations





Think of it as **two coupled systems** varying over **different time scales**:

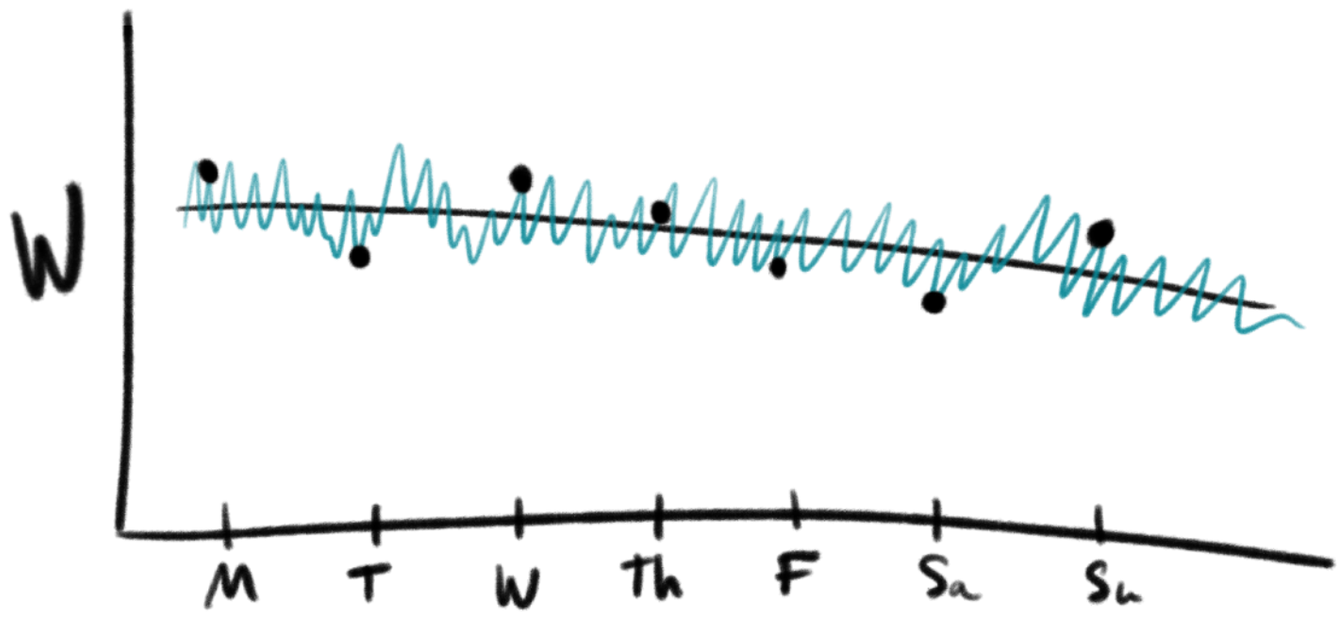
‘wet’ mass

fast / hourly

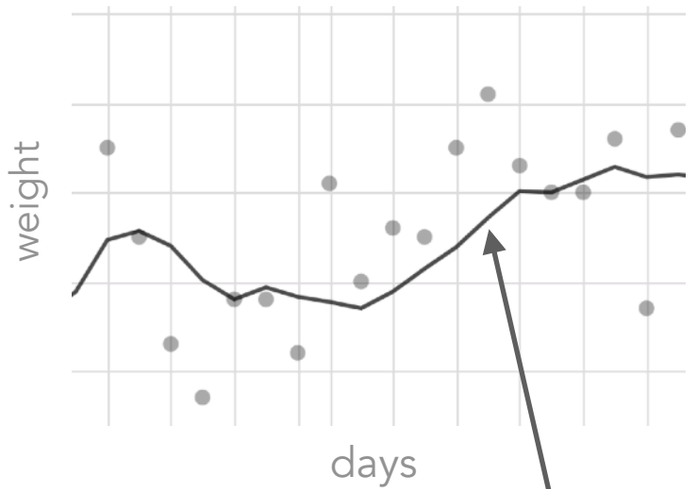
‘dry’ mass

slow / weekly

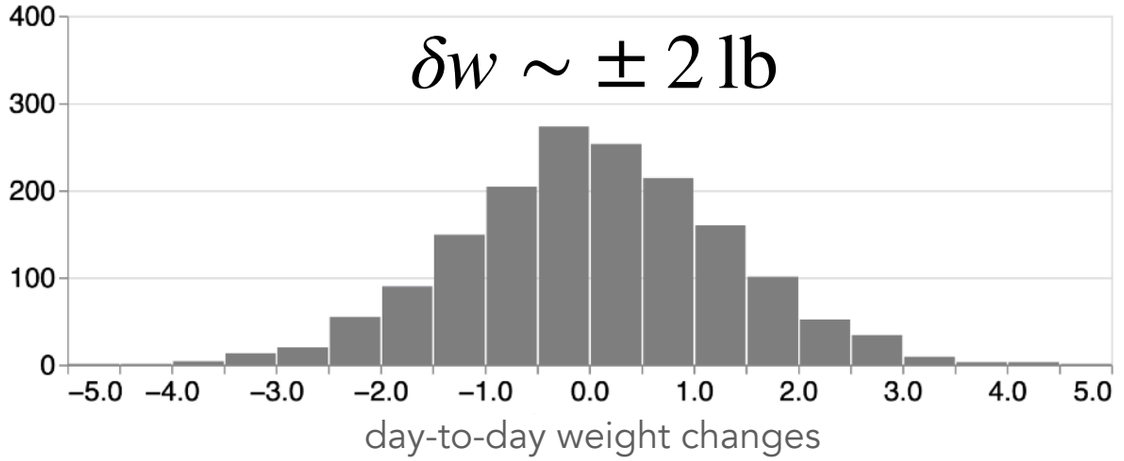
bone, muscle, fat, organs

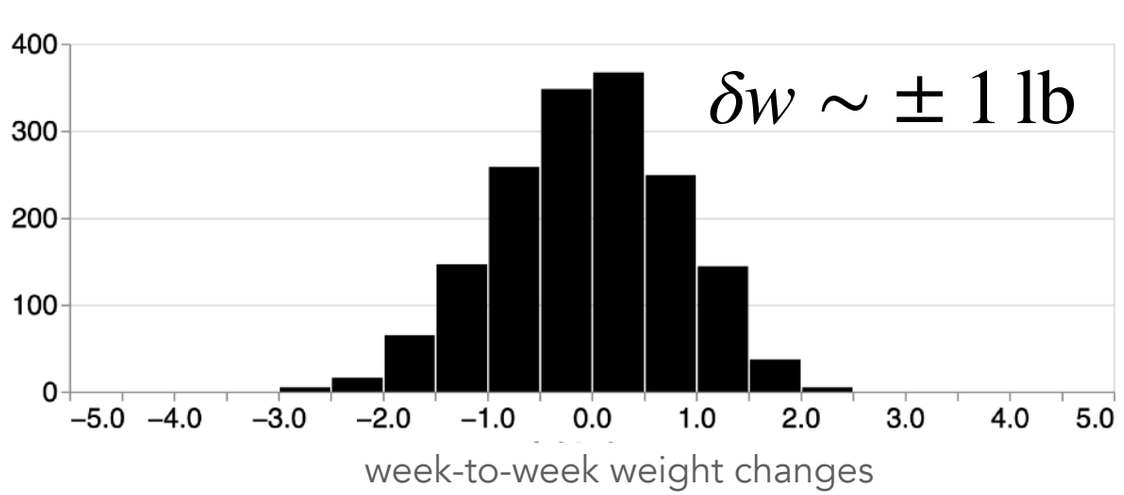


7day rolling avg, week-to-week changes



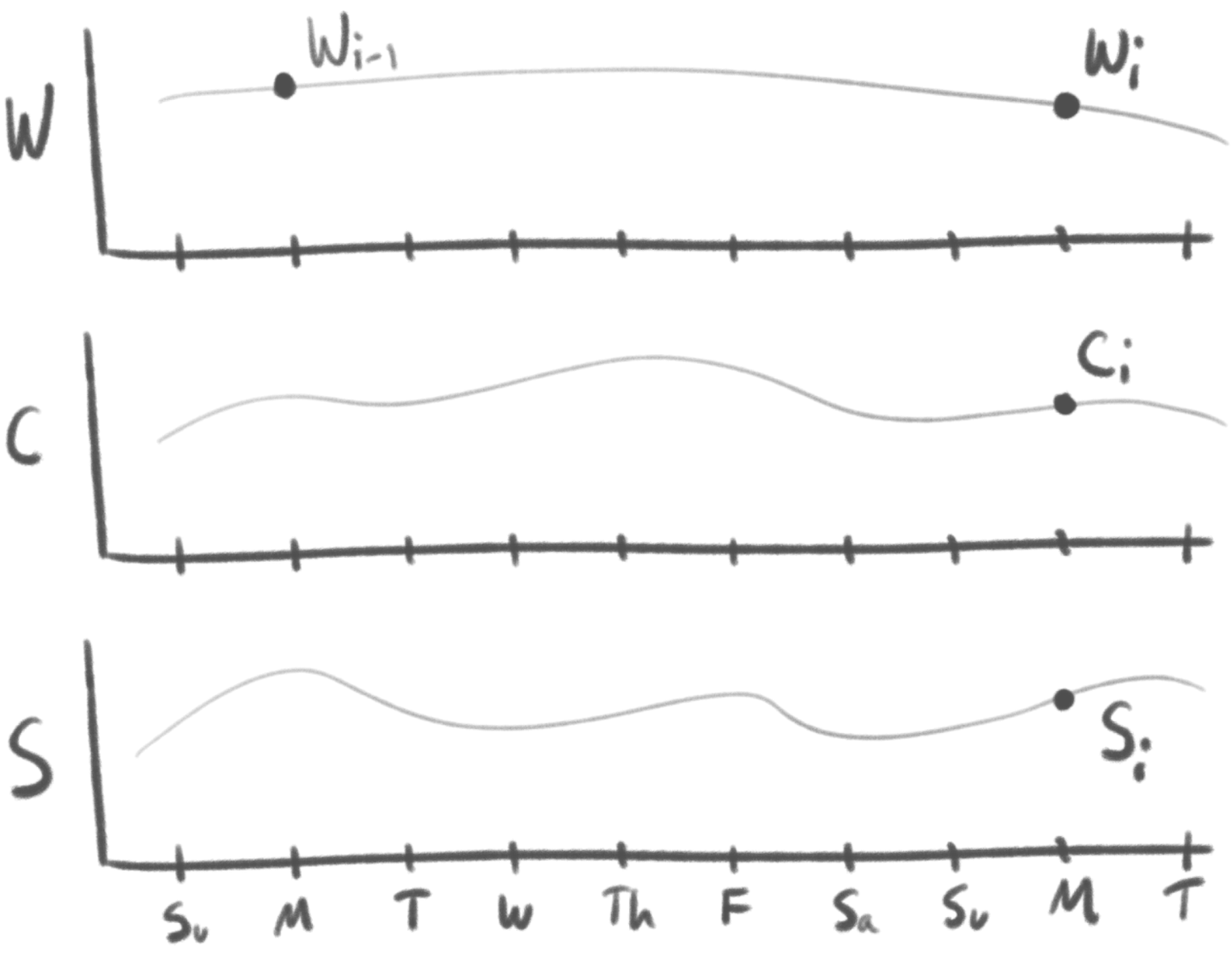
I decided to work with a **7 day rolling average** and consider week-to-week variations.





7day rolling avg, week-to-week changes

~first order Markov process



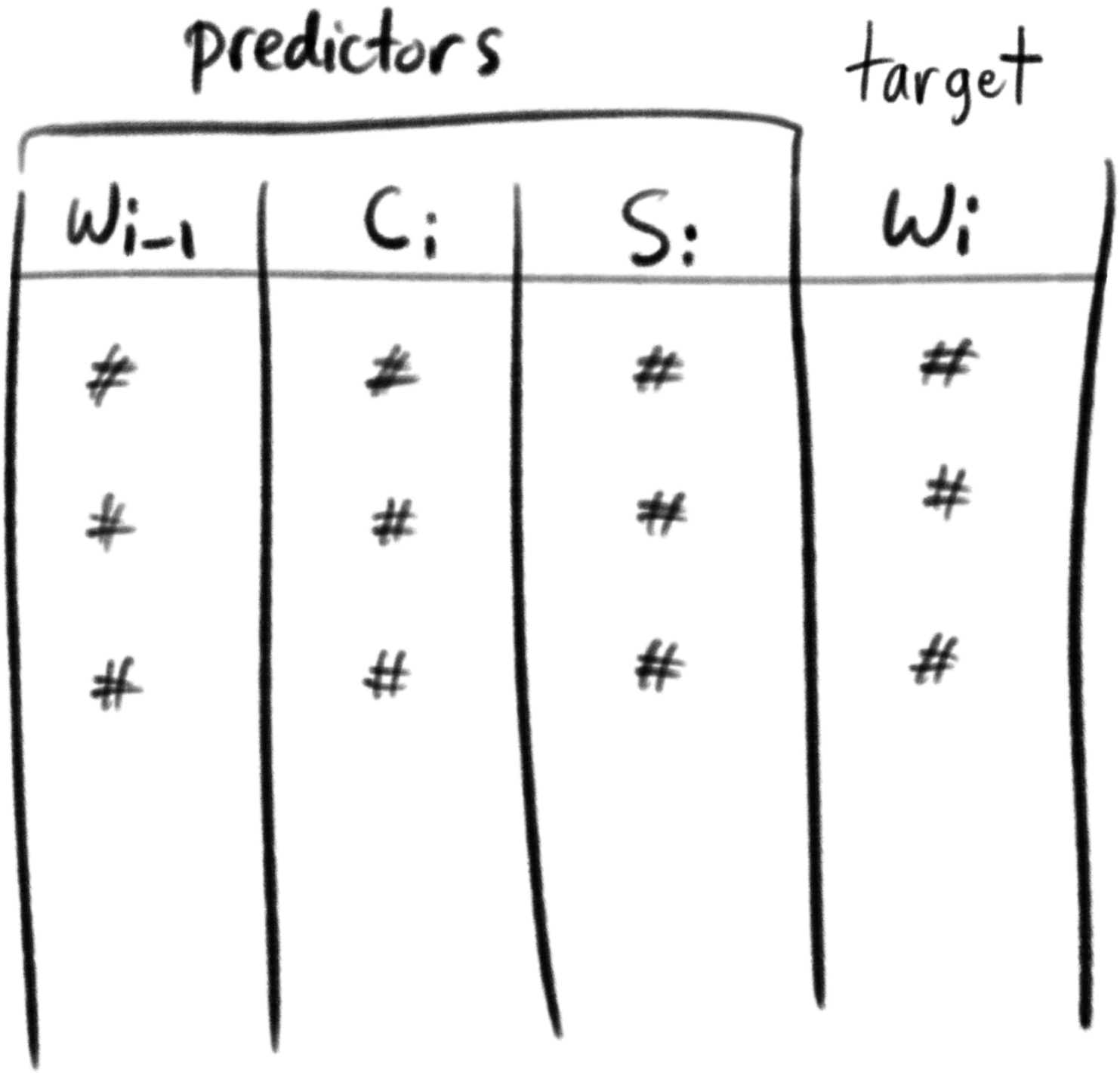
W_i 7d avg weight

W_{i-1} 7d avg weight 1 week ago

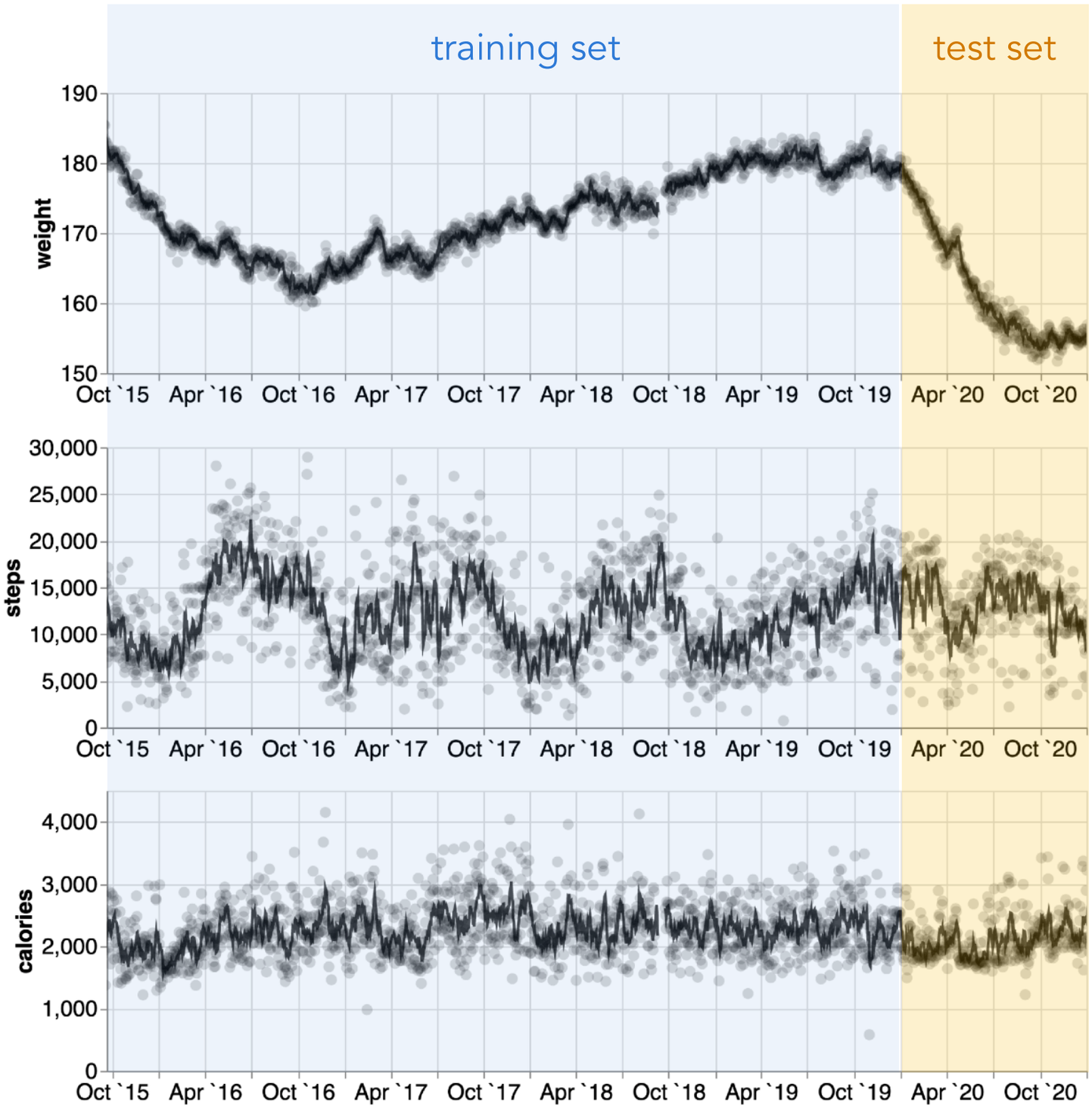
C_i 7d avg calories

S_i 7d avg steps

The Dataset



Train / test split



Regression fit to the data

$$W_i = a_0 + a_w W_{i-1} + a_c C_i + a_s S_i$$

Rearrange to get into the form of an energy balance equation:

$$W_i - W_{i-1} = \Delta W_i = a_c[C_i - \alpha_s S_i - (\alpha_0 + \alpha_w W_{i-1})]$$

weight change in a week

calories **in**

calories **out** due to steps

calories **out** due to BMR

$a_c \sim 0.002$ weekly pounds per calorie

⇨ **±500 calories** per day to gain/lose **1lb** per week

$\alpha_s \sim 0.024$ calories per step

⇨ **10K steps** burns about **240 calories**

$\alpha_0 \sim 616$ calories

$\alpha_w \sim 8$ calories per lb

⇨ at **160lbs**, burn about **1900 calories**

Solve for break-even calories

Setting the LHS to zero, we can solve for the **calories** to **maintain** a **constant weight**:

$$C_{\mathrm{BE}} = \alpha_s S + (\alpha_0 + \alpha_w W)$$

$$C_{\mathrm{BE}} \sim 2125 \text{ calories} \quad \text{(for S=10K, W=160lbs)}$$

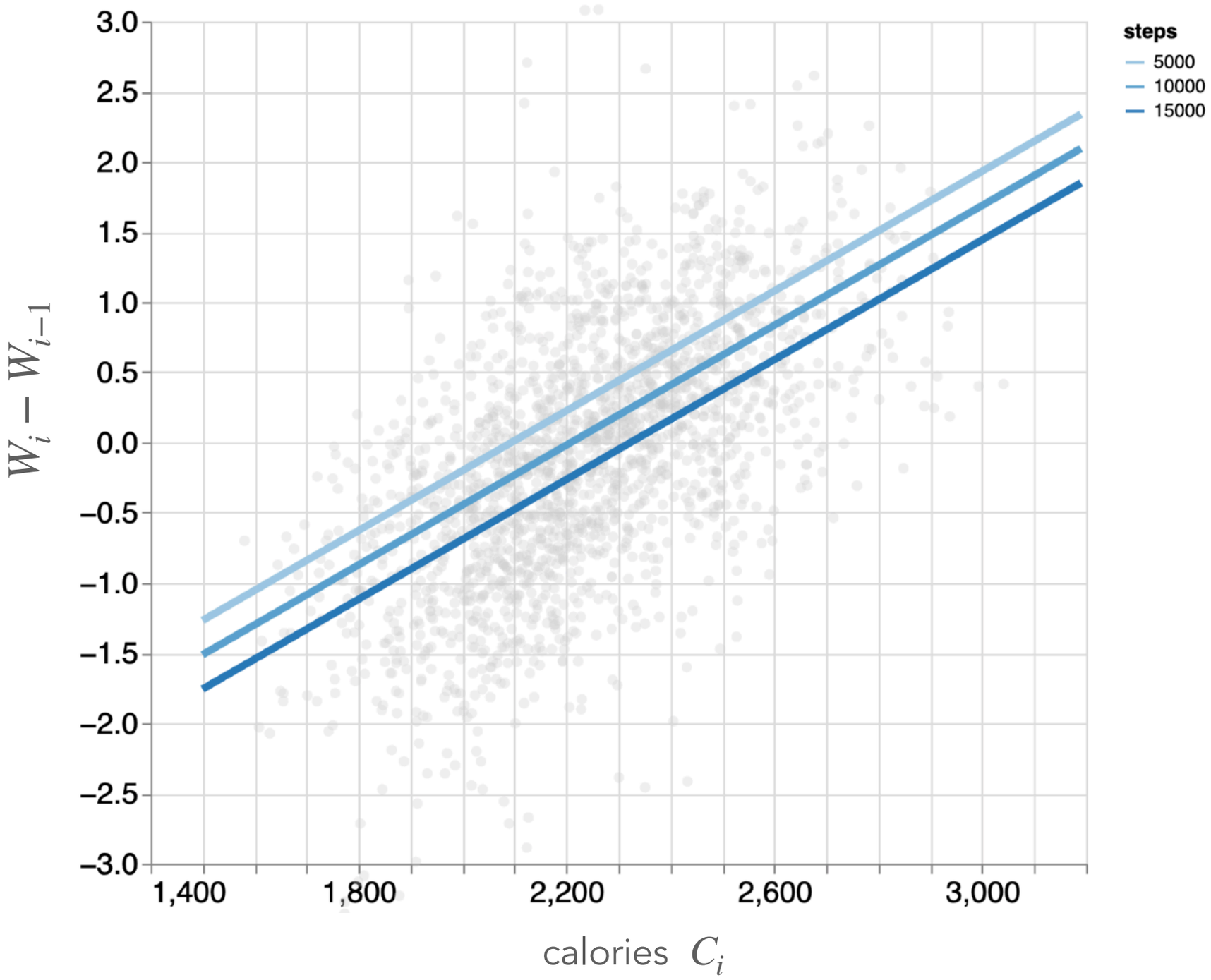
Alternatively, we can solve for the **steady-state weight**:

$$W_{\mathrm{ss}} = [C - \alpha_s S - \alpha_0]/\alpha_w$$

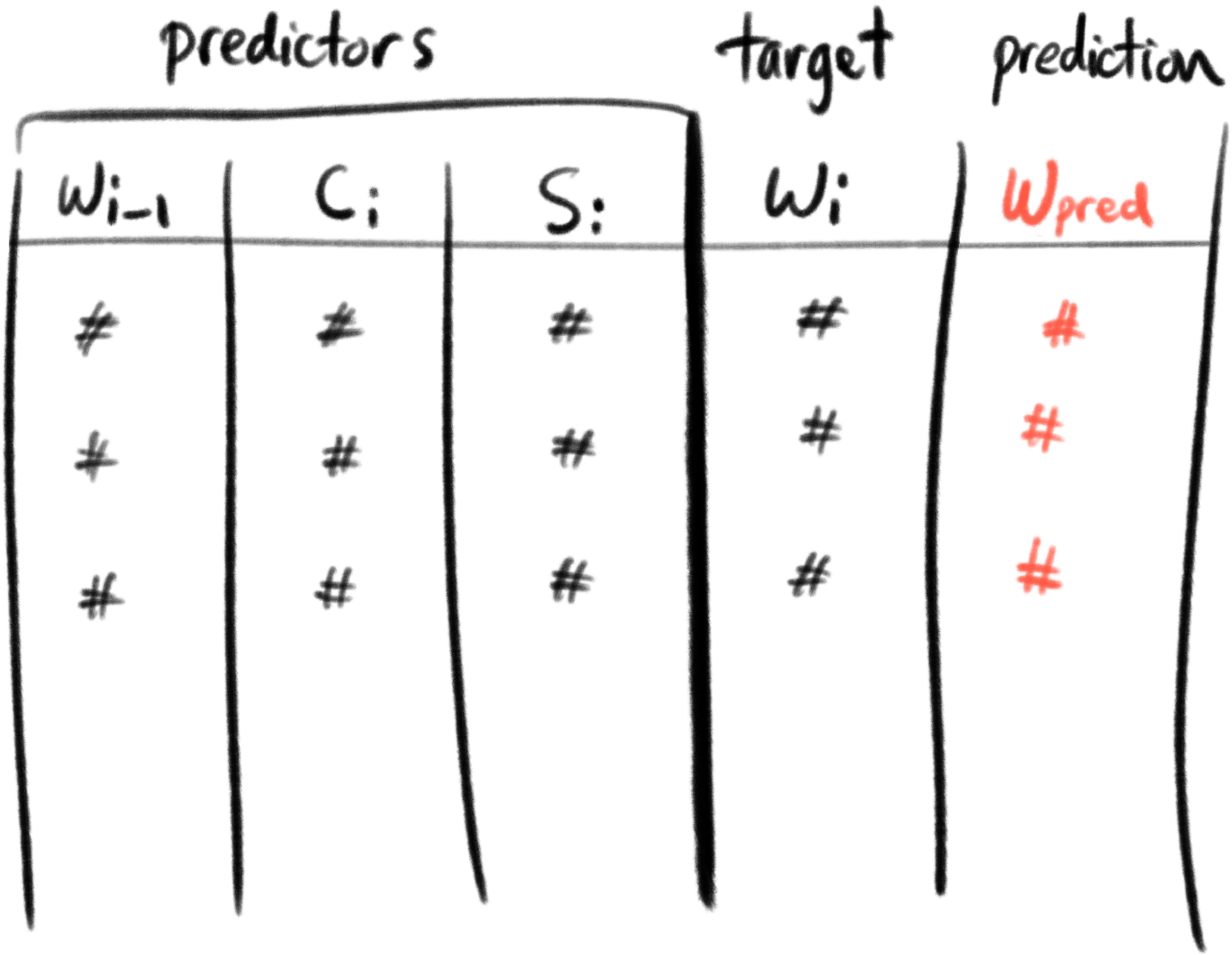
$$W_{\mathrm{ss}} \sim 160 \text{ lbs} \quad \text{(for S=10K, C=2125)}$$

Regression lines

Multiple regression is tricky to show in a single plot. Here I've assumed $W_{i-1} = 170\,\text{lb}$ and show three different values of steps S_i.



Predictions on training and test



Predictions on training and test

Forecasting by iterating discrete equations

initial weight

$$W_1 = a_0 + a_w W_0 + a_c C_1 + a_s S_1$$

$$W_2 = a_0 + a_w W_1 + a_c C_2 + a_s S_2$$

$$\vdots$$

n steps = n weeks

Forecasting by iterating discrete equations

i	W_{i-1}	C_i	S_i	W_{pred}
1	$\#_0$	$\#_1$	$\#_1$	$\#_1$
2	$\#_1$	$\#_2$	$\#_2$	$\#_2$
3	$\#_2$	$\#_3$	$\#_3$	$\#_3$
⋮	⋮	⋮	⋮	⋮

Steady state solution

If we assume constant calories C and steps S, then in the limit of $n \to \infty$, we recover the steady state solution we derived before:

$$W_1 = a_0 + a_w W_0 + a_c C + a_s S$$
$$= \beta + a_w W_0 \quad (\beta \equiv a_0 + a_c C + a_s S \Rightarrow \text{constant})$$

$$W_2 = \beta + a_w W_1 \rightarrow \beta + a_w W_0$$
$$= \beta(1 + a_w) + a_w^2 W_0$$

$$W_3 = \beta + a_w W_2$$
$$= \beta(1 + a_w + a_w^2) + a_w^3 W_0$$

$$\vdots$$

$$W_n = \beta \underbrace{(1 + a_w + a_w^2 + \cdots + a_w^n)}_{\frac{1}{1-a_w}} + a_w^n W_0$$

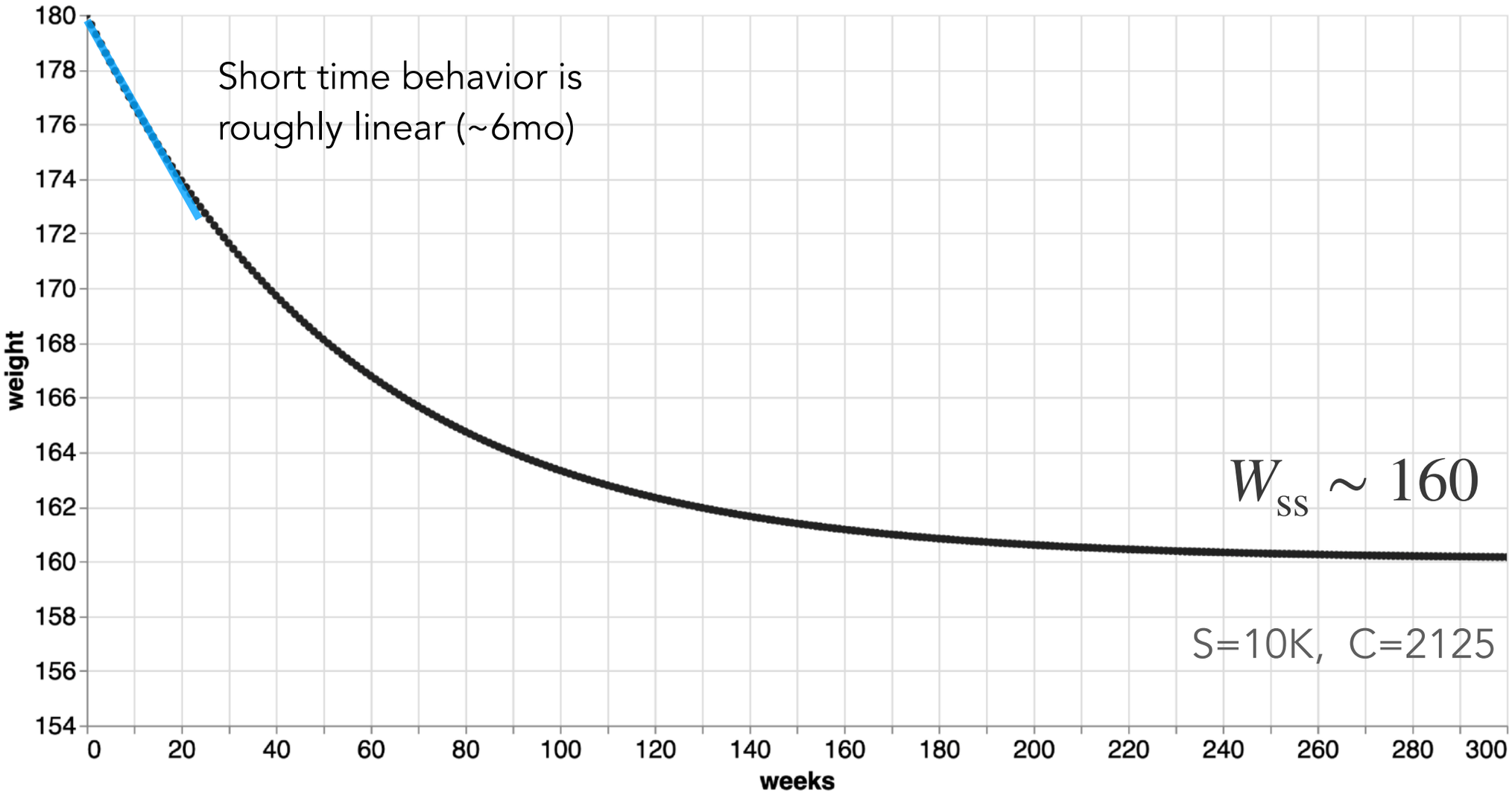
$a_w^n \to 0$ vanishes, $a_w < 1$

$$(1 - a_w) W_{ss} = a_0 + a_c C + a_s S$$

$$\boxed{W_{ss} = [C - \alpha_s S - \alpha_0]/\alpha_w}$$

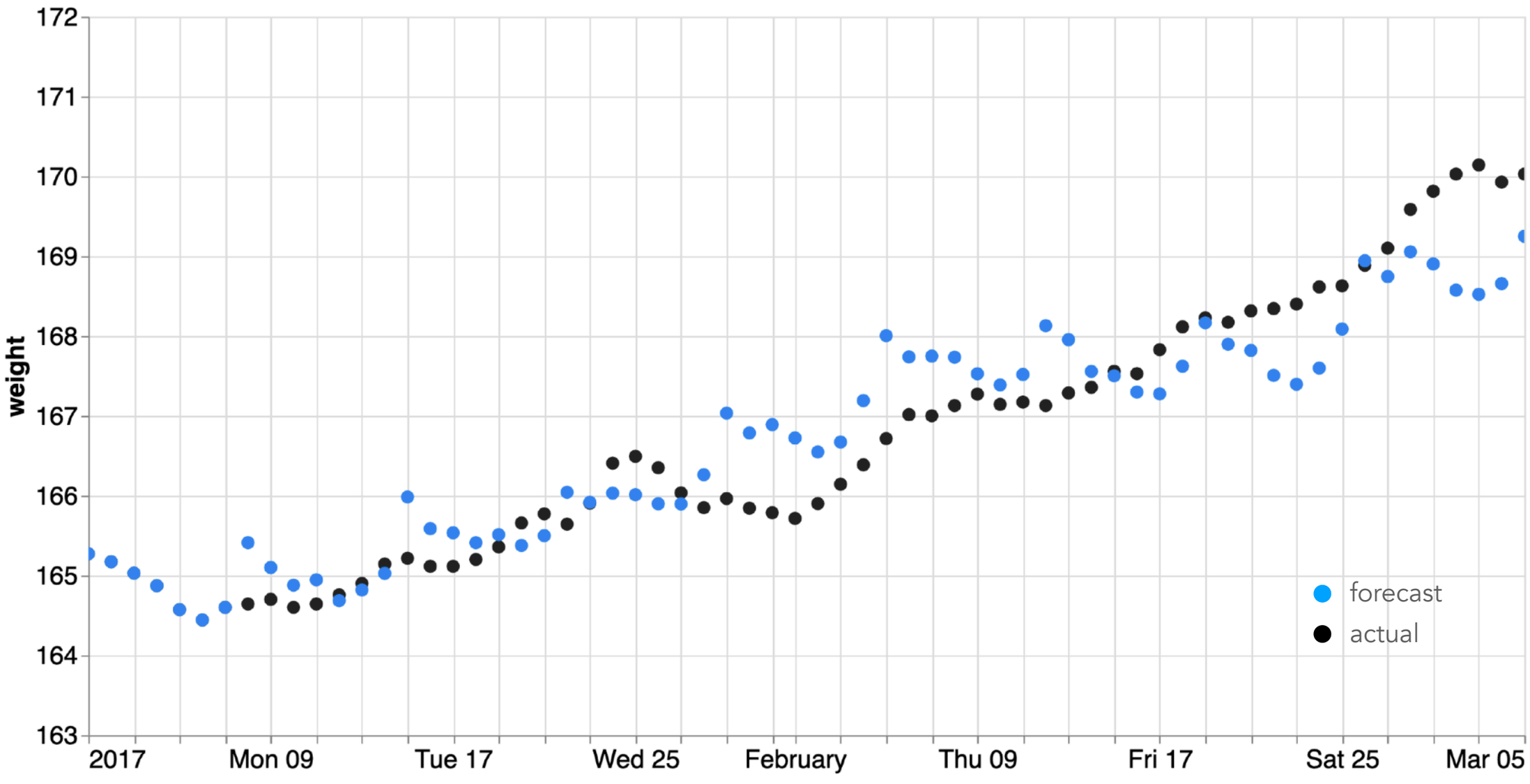
$$\begin{cases} \alpha_0 = -\frac{a_0}{a_c} \\ \alpha_s = -\frac{a_s}{a_c} \\ \alpha_w = \frac{(1-a_w)}{a_c} \end{cases}$$

Steady state solution

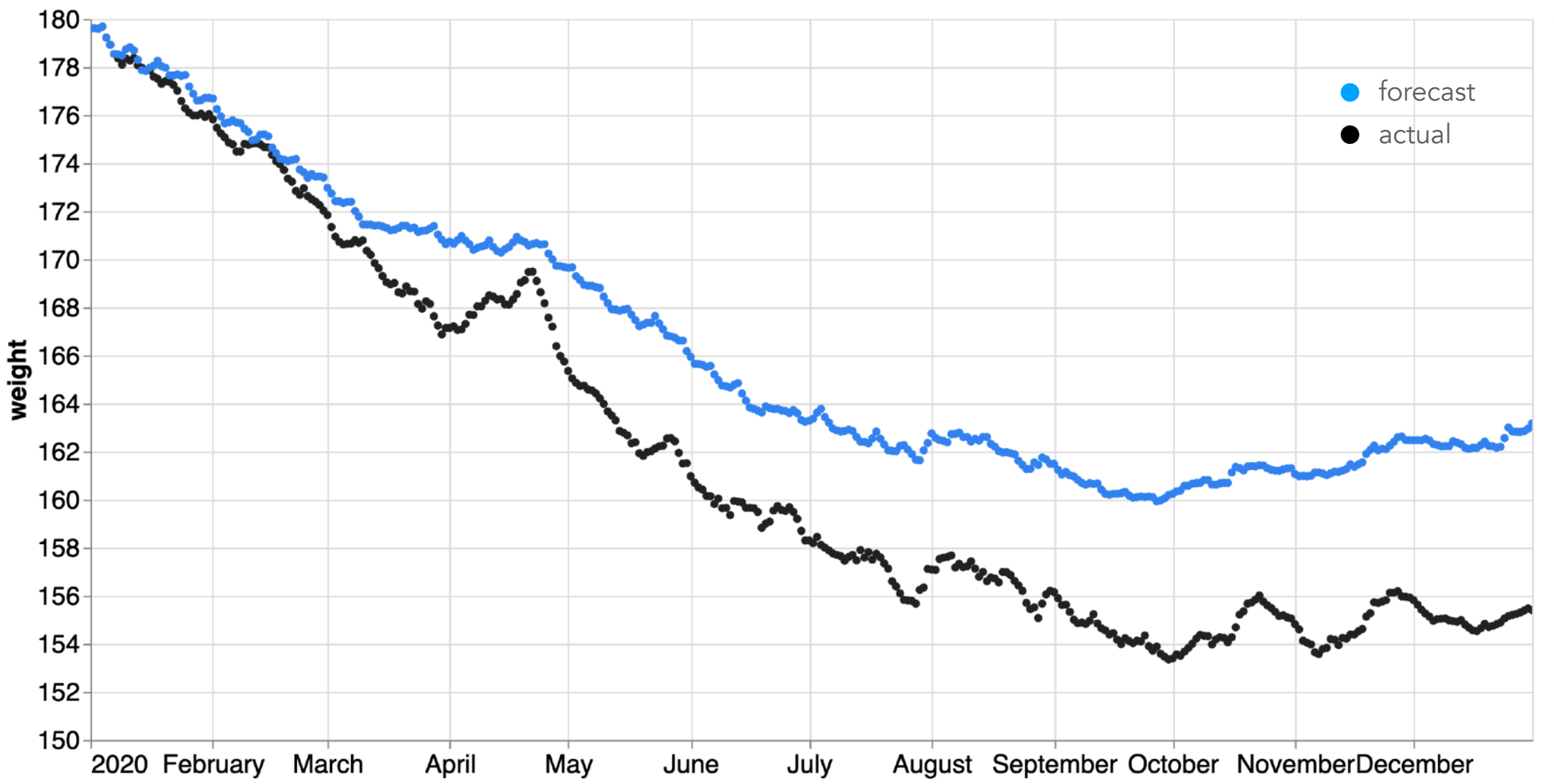


Forecast on short time frame

This is the same segment where the rule of thumb predicted weight loss.



Forecast deviates over longer periods

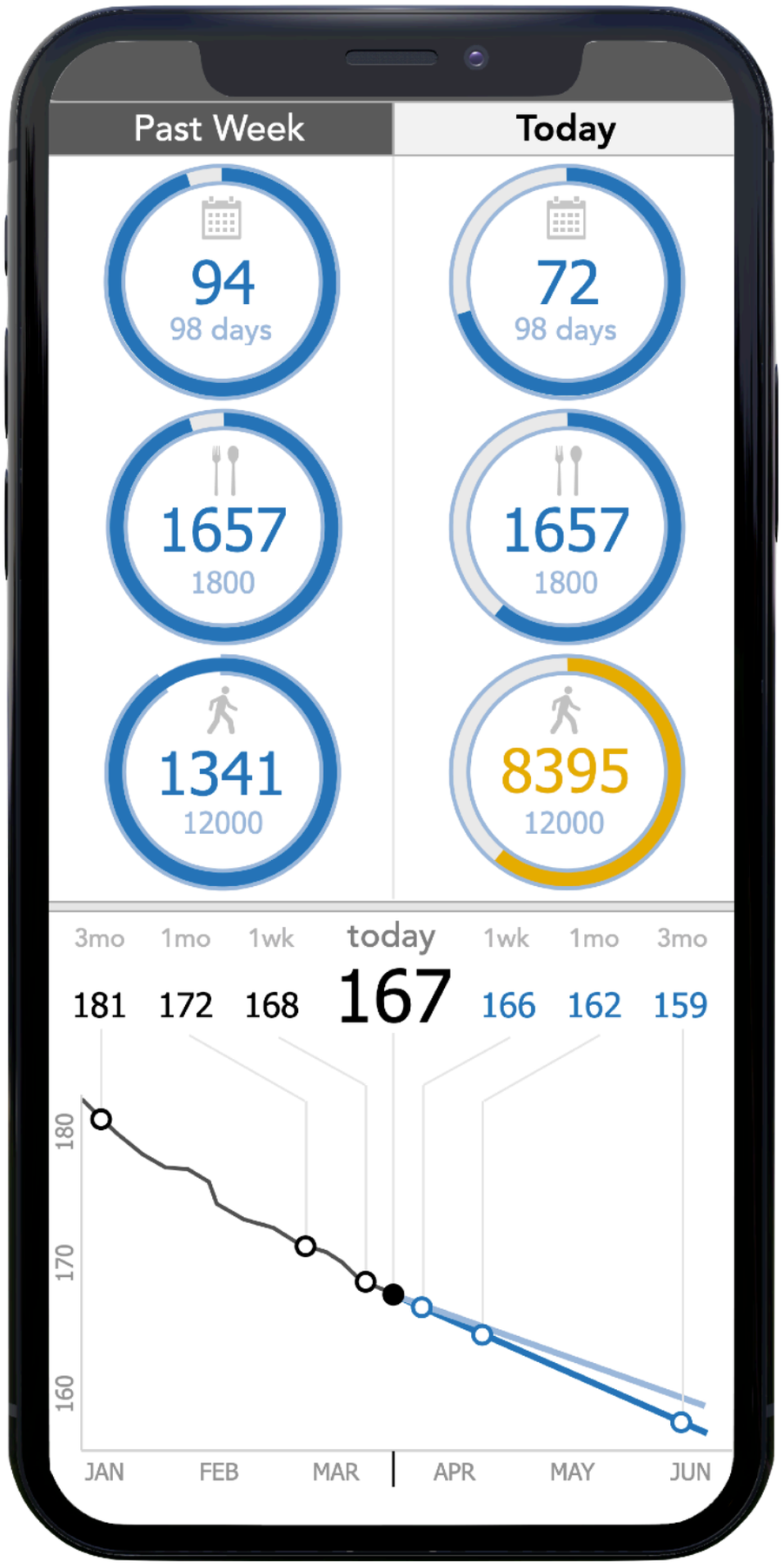


Use the **forecast** model as a prescriptive **guide**

- Let's say I currently weight 180 lbs.
- I'd like to weigh **160 lbs** in **six months**.
- Suppose I aim to get **12K steps** a day on average.
- What should my **target calories** be?

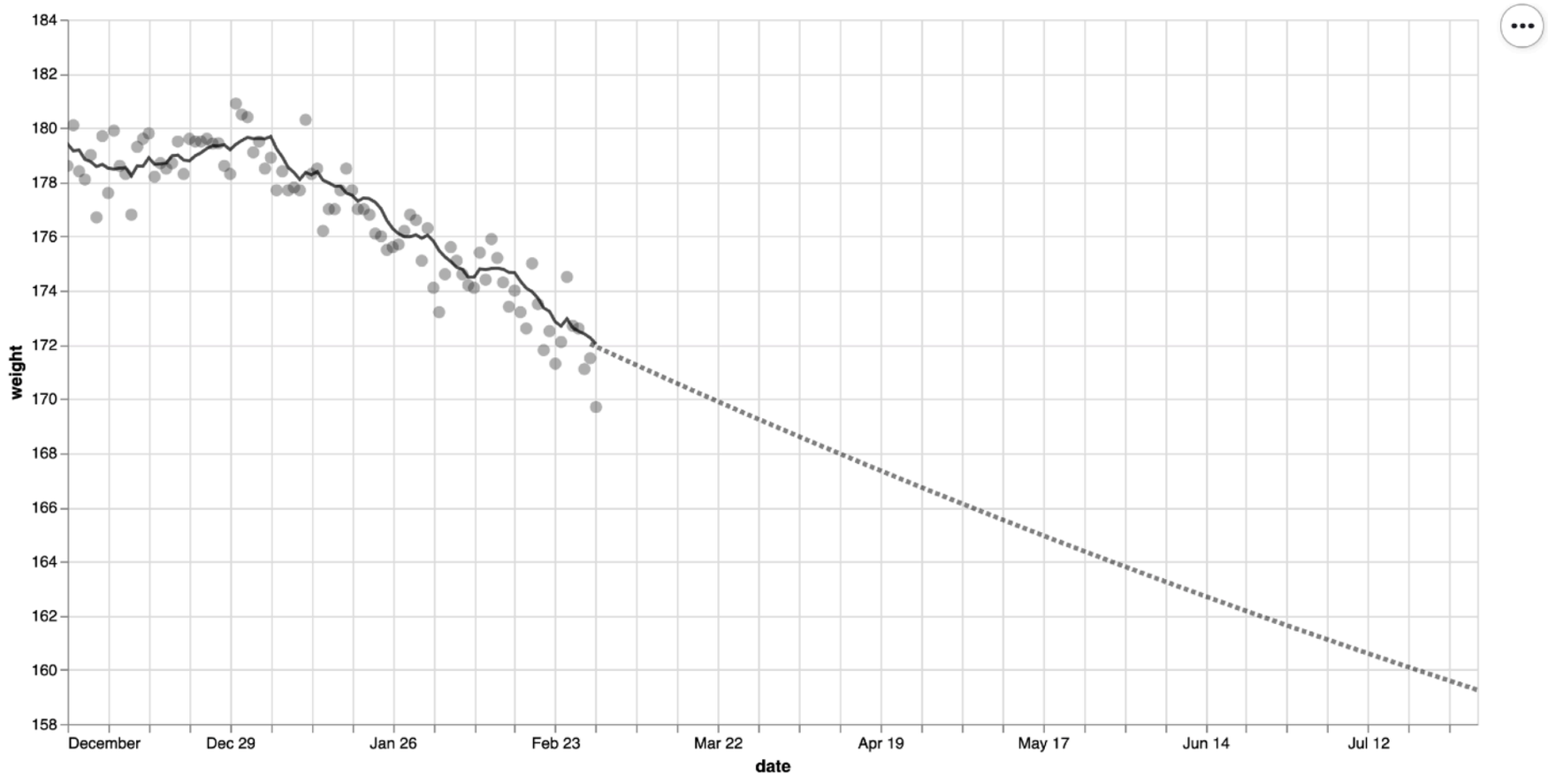
or

- Based on your **recent** behavior, you are currently:
  - eating ~**1,978** calories
  - getting ~ **10,389** steps
- Based on those trends, you will hit your target weight of **160 lbs** around **Aug. 12**.


Past Week
Today
94
98 days
72
98 days
1657
1800
1657
1800
1341
12000
8395
12000
3mo
1mo
1wk
today
1wk
1mo
3mo
181
172
168
167
166
162
159
180
170
160
JAN
FEB
MAR
APR
MAY
JUN

MVP Forecasting Dashboard

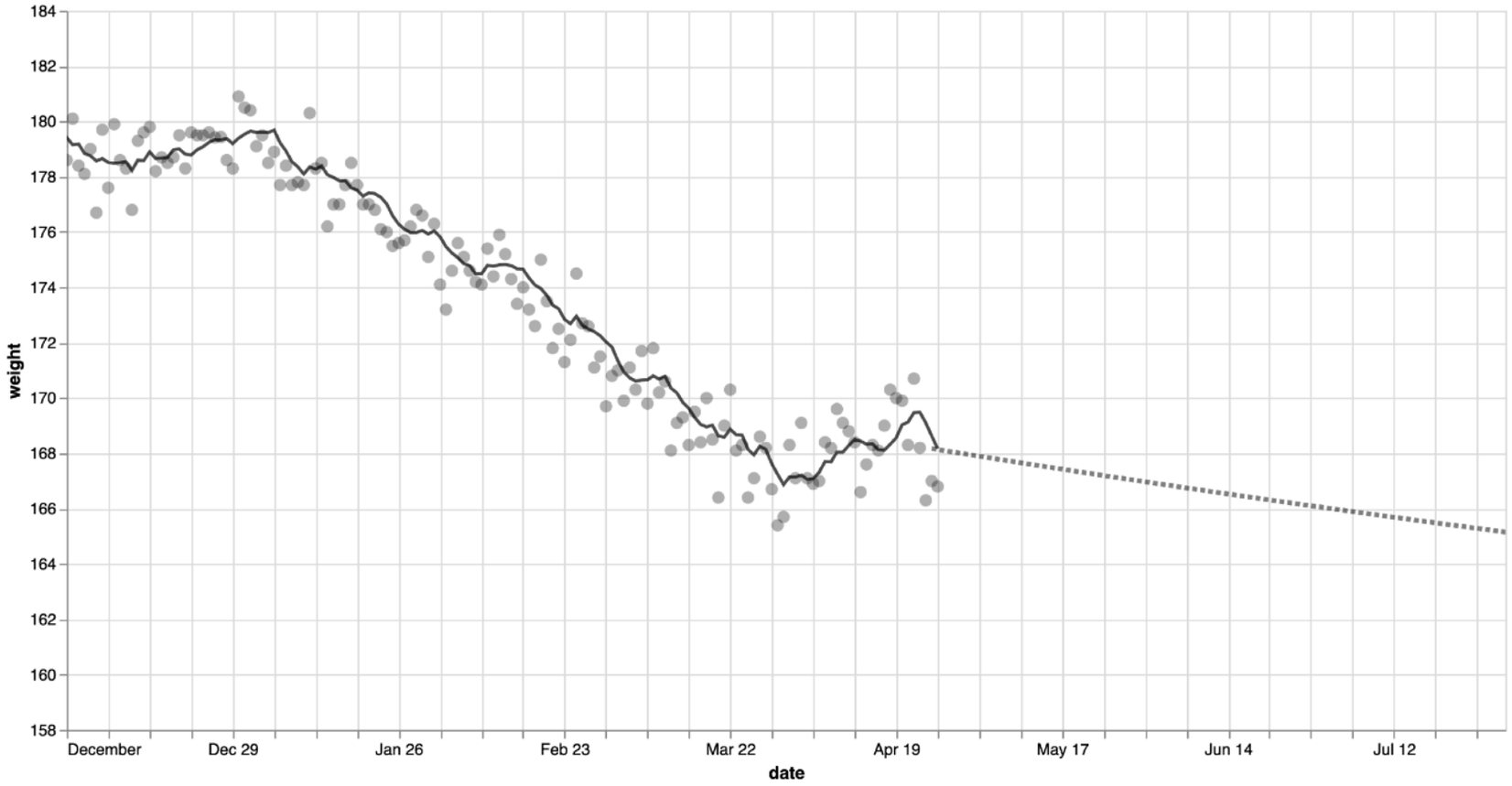
	week	deviation	target	today	deviation	target
weight	172.0	12.0	160	169.7	9.7	160
date	Jul 21, 20	21	Jun 30, 20	May 25, 20	-36	Jun 30, 20
weeks	20.3	3.0	17.32	12.16	-5.2	17.32
rate	0.55	-0.1	0.65	0.94	0.29	0.65
calories	1965	51	1914	1853	-22	1875
steps	13658	0	13658	17339	5339	12000



MVP Forecasting Dashboard

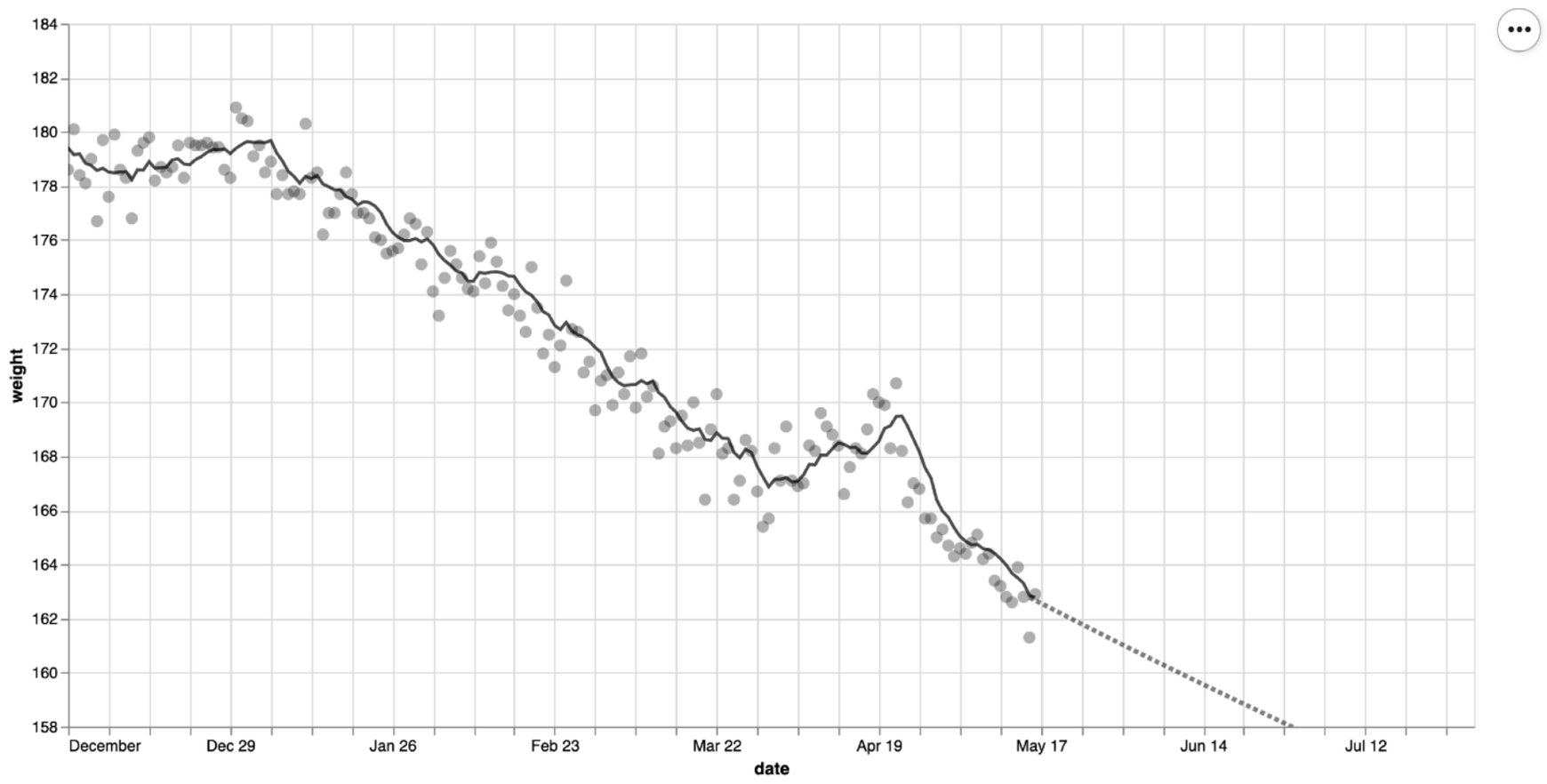
	week	deviation	target	today	deviation	target
weight	168.2	8.2	160	166.8	6.8	160
date	Mar 29, 21	272	Jun 30, 20	Jun 25, 20	-5	Jun 30, 20
weeks	48.19	38.8	9.34	8.63	-0.7	9.34
rate	0.17	-0.67	0.84	0.91	0.07	0.84
calories	2051	354	1697	1779	11	1768
steps	8991	0	8991	14038	2038	12000

...



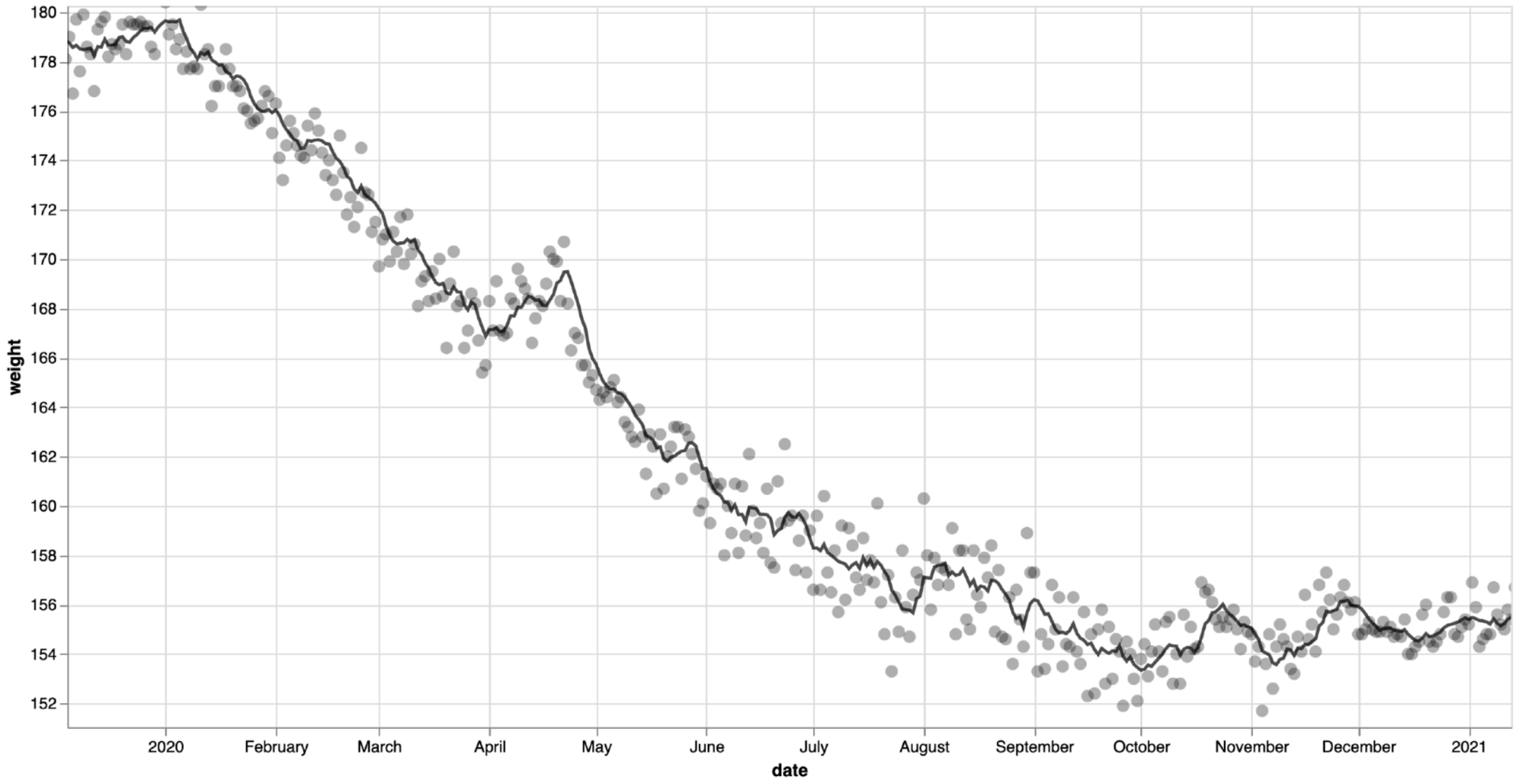
MVP Forecasting Dashboard

	week	deviation	target	today	deviation	target
weight	162.8	2.8	160	162.9	2.9	160
date	Jun 11, 20	-19	Jun 30, 20	Jun 23, 20	-7	Jun 30, 20
weeks	3.71	-2.8	6.47	5.48	-1.0	6.49
rate	0.72	0.33	0.39	0.47	0.08	0.39
calories	1787	-163	1950	1861	-111	1972
steps	11082	0	11082	8989	-3011	12000



Goal accomplished!

In the summer I shifted my target to 155 lbs, and eventually got there…



Future Directions

- Use more **granular** Fitbit **activity** data instead of generic steps, e.g. **minutes** of ‘very active’, ‘fairly active’, ‘lightly active’, ‘sedentary’.
- Use a **Bayesian probabilistic** approach to get a better handle on **predictive uncertainty**.
- explore model parameters:
    - different **predictive windows**: 3d, 4d, … , 7d
    - different **averaging** / **smoothing** methods
- Build v2: a web or **mobile app**.

Nov 4, 3:45PM	Walk	3,956	N/A	39:15	263 cals	View Details
Nov 4, 8:26AM	Walk	3,003	N/A	29:52	221 cals	View Details
Nov 4, 7:44AM	Run	6,417	N/A	41:48	502 cals	View Details