HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF

CASUS CENTER FOR ADVANCED SYSTEMS UNDERSTANDING

MARE-Madeira 2025

Movement speed estimation

Using the 'ctmm' R package

Inês Silva

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CBG Max Planck Institute of Molecular Cell Biology and Genetics

UFZ HELMHOLTZ Centre for Environmental Research

Uniwersytet Wrocławski

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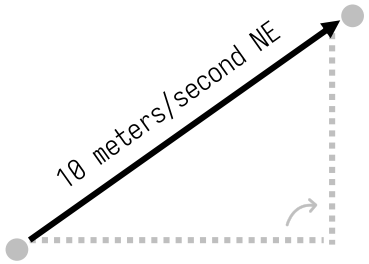
Vectors

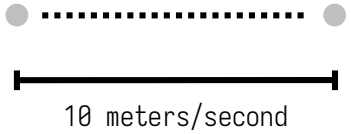
Specified by both ***magnitude*** (value + unit) and ***direction***

Scalars

Specified by only ***magnitude*** (value + unit)

Displacement	magnitude of **velocity** vector	Distance
Velocity		**Speed**
Acceleration		Acceleration/deceleration
N/A		Time





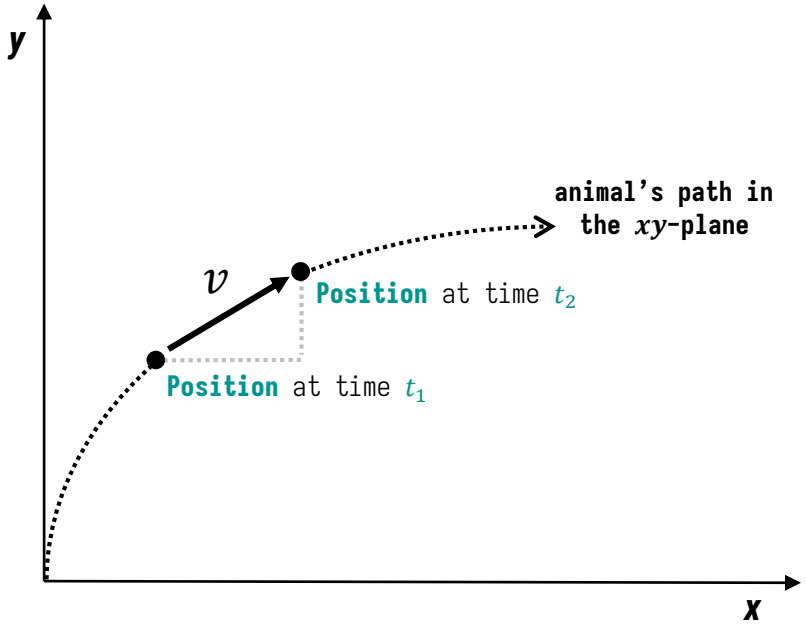
Average **velocity**

Displacement divided by ***time***

Instantaneous **velocity**

The instantaneous rate of change of the ***position vector*** with respect to ***time***
(*i.e.*, examined for a ***very small time interval***)

$$\boldsymbol{v_t} = \lim_{\Delta t \to 0} \frac{\Delta \mathbf{r}}{\Delta t}$$



↳ For ***speed***, take the magnitude only.

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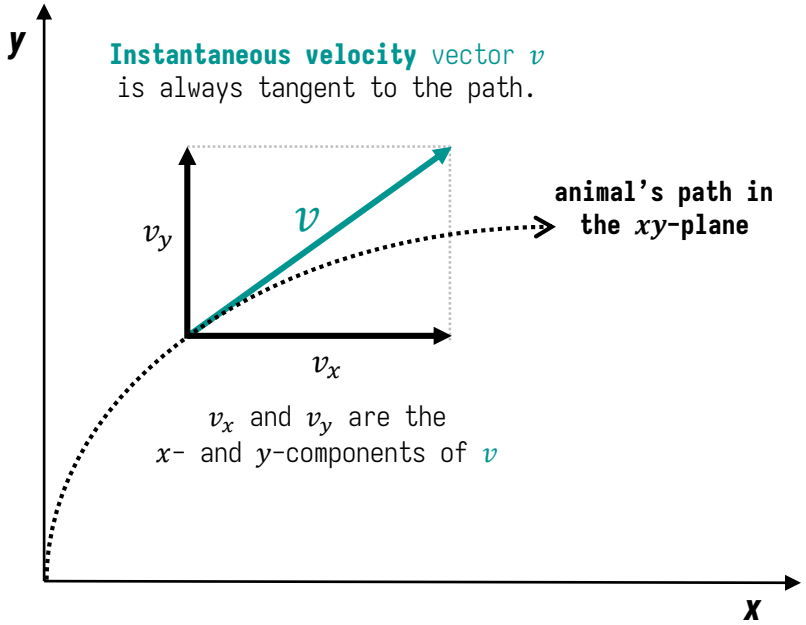

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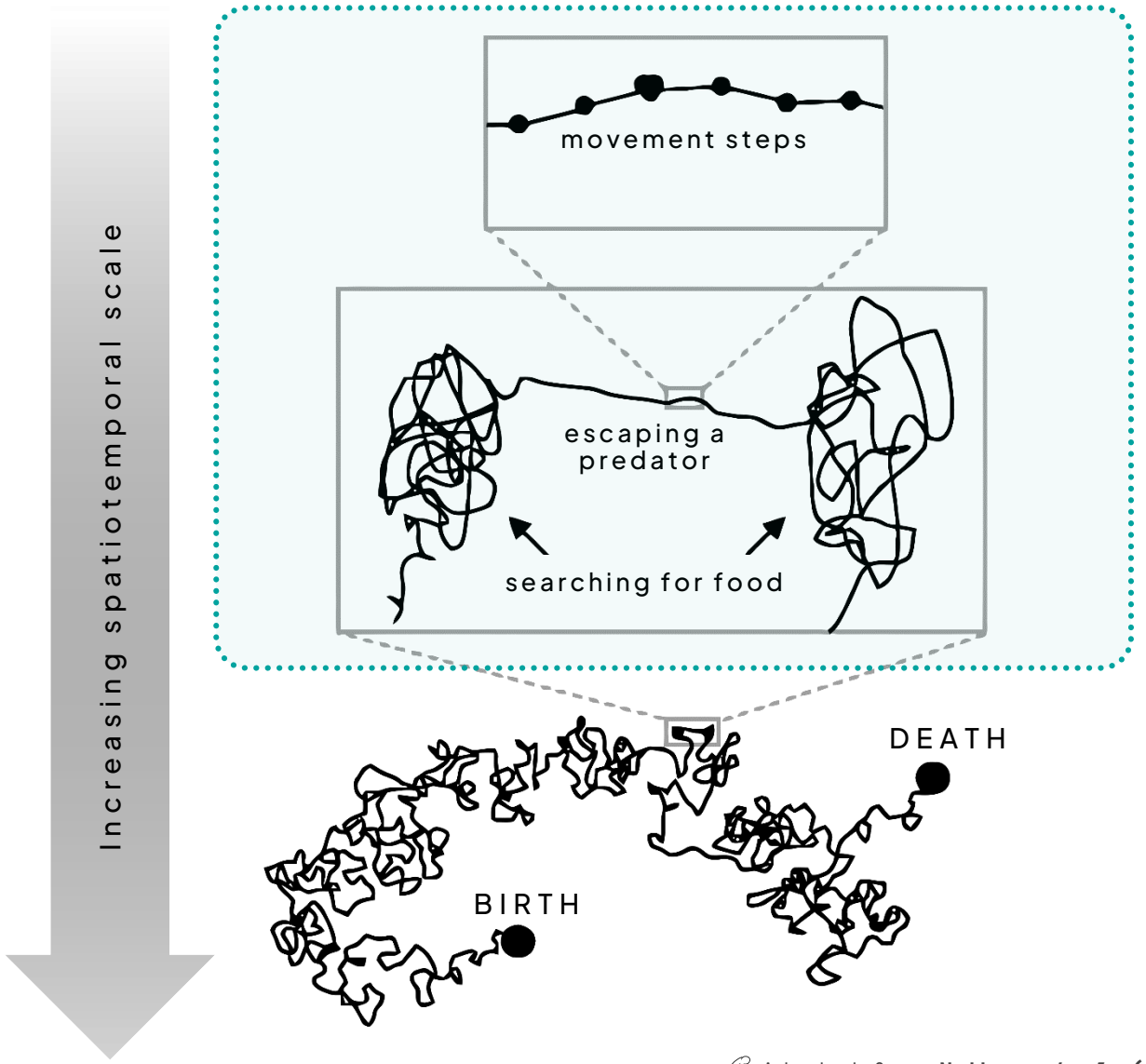
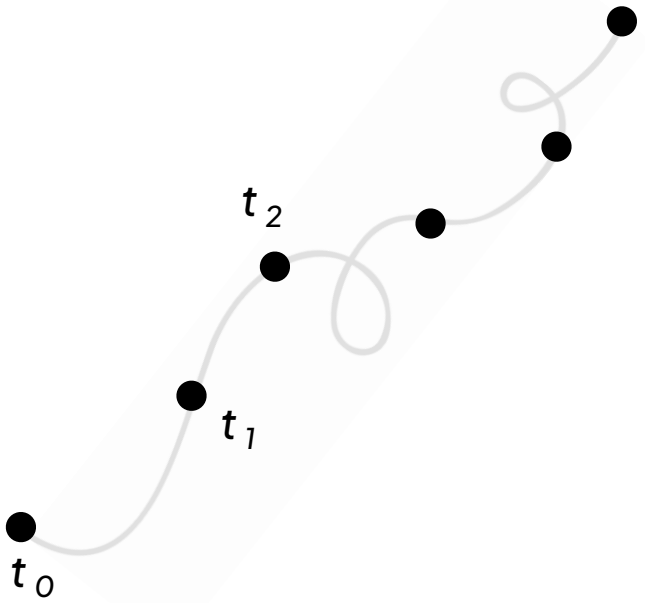
Speed- and distance-related metrics provide quantifiable links between ***behavior and energetics***, can inform on risk/reward tradeoffs or as signals of ***anthropogenic disturbance***.



Adapted from **Nathan *et al.* (2008)**



Speed and distance traveled are among the most routinely estimated metrics from animal tracking data.

Usually estimated by summing the ***straight-line distance (SLD)*** between location estimates…

$$\hat{d} = |\Delta \mathbf{r}| = \sqrt{\Delta x^2 + \Delta y^2}$$

… and divide that by Δt if speed if the desired metric.

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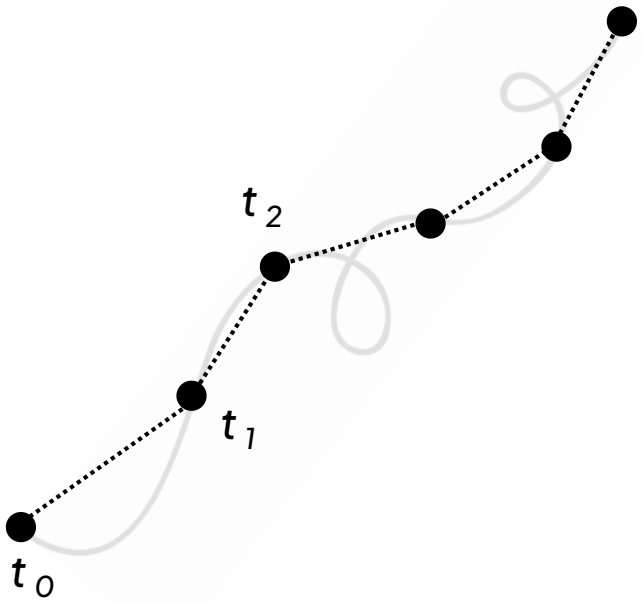

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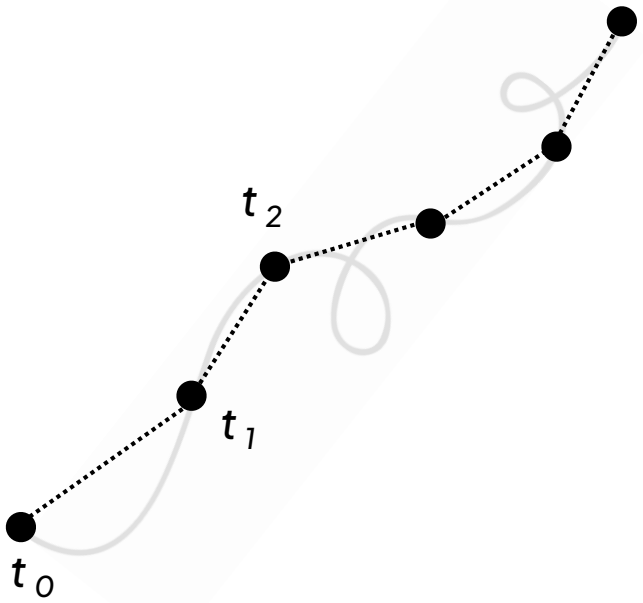

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… and divide that by Δt if speed if the desired metric.

Although SLD is easy to quantify, it is also ***heavily biased***.

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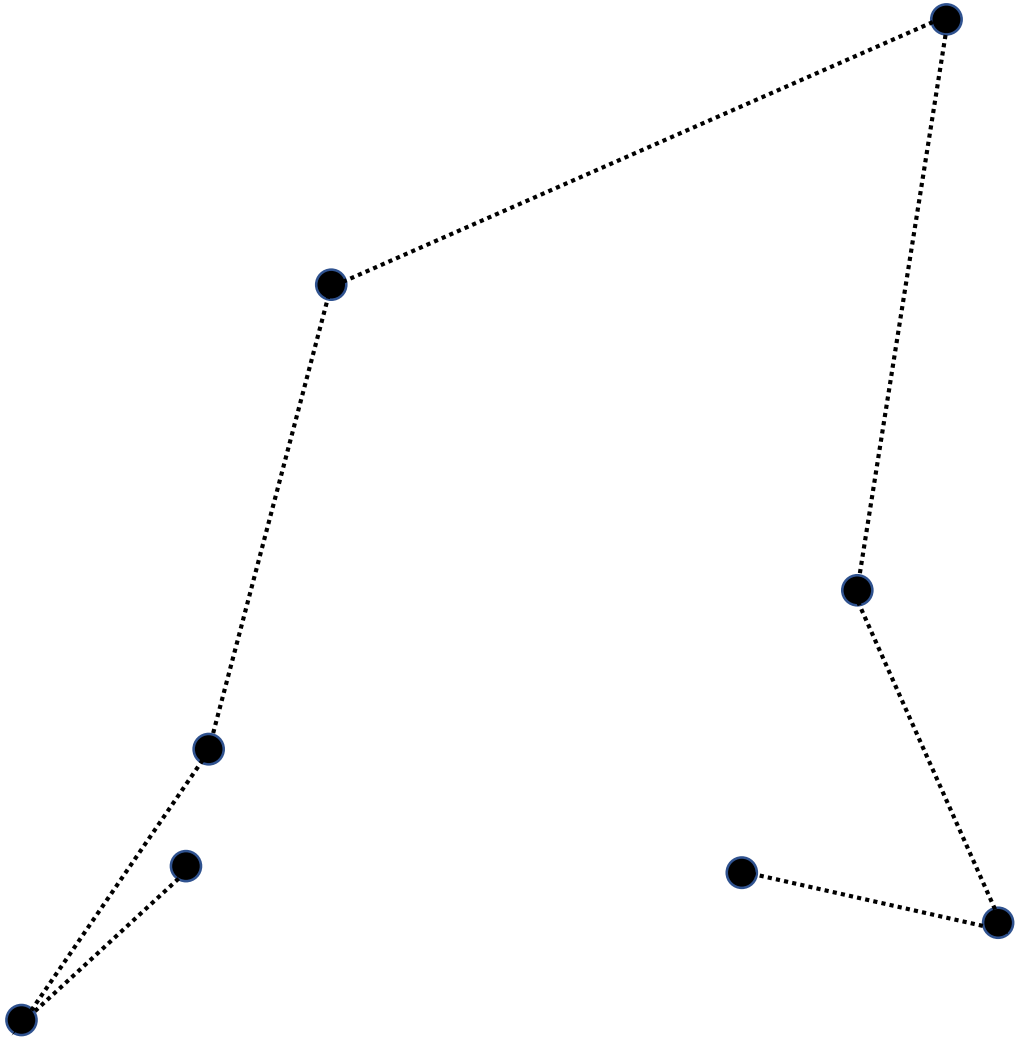
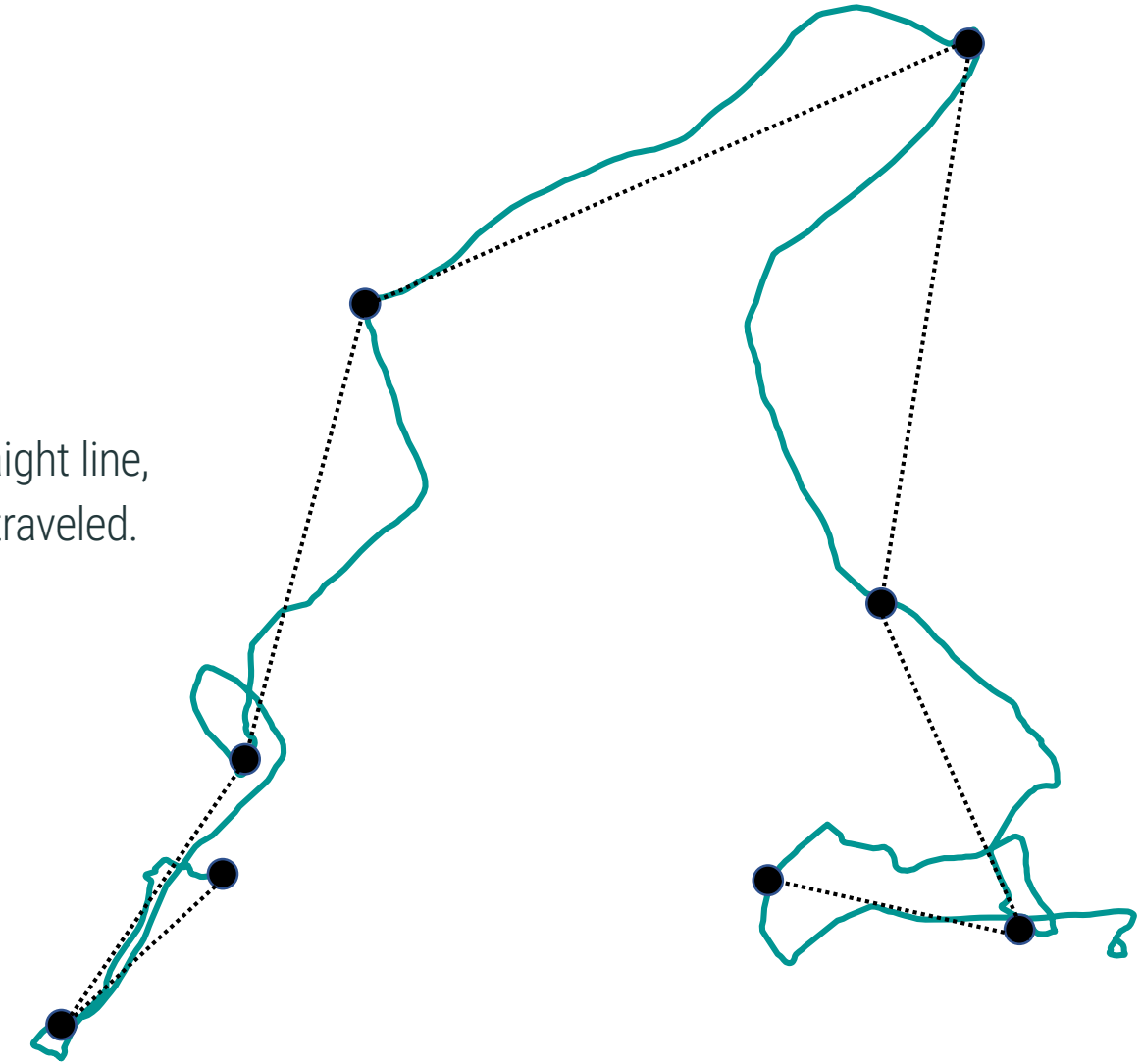


Unless the animal moved in a perfectly straight line, this will always ***underestimate*** distance traveled.



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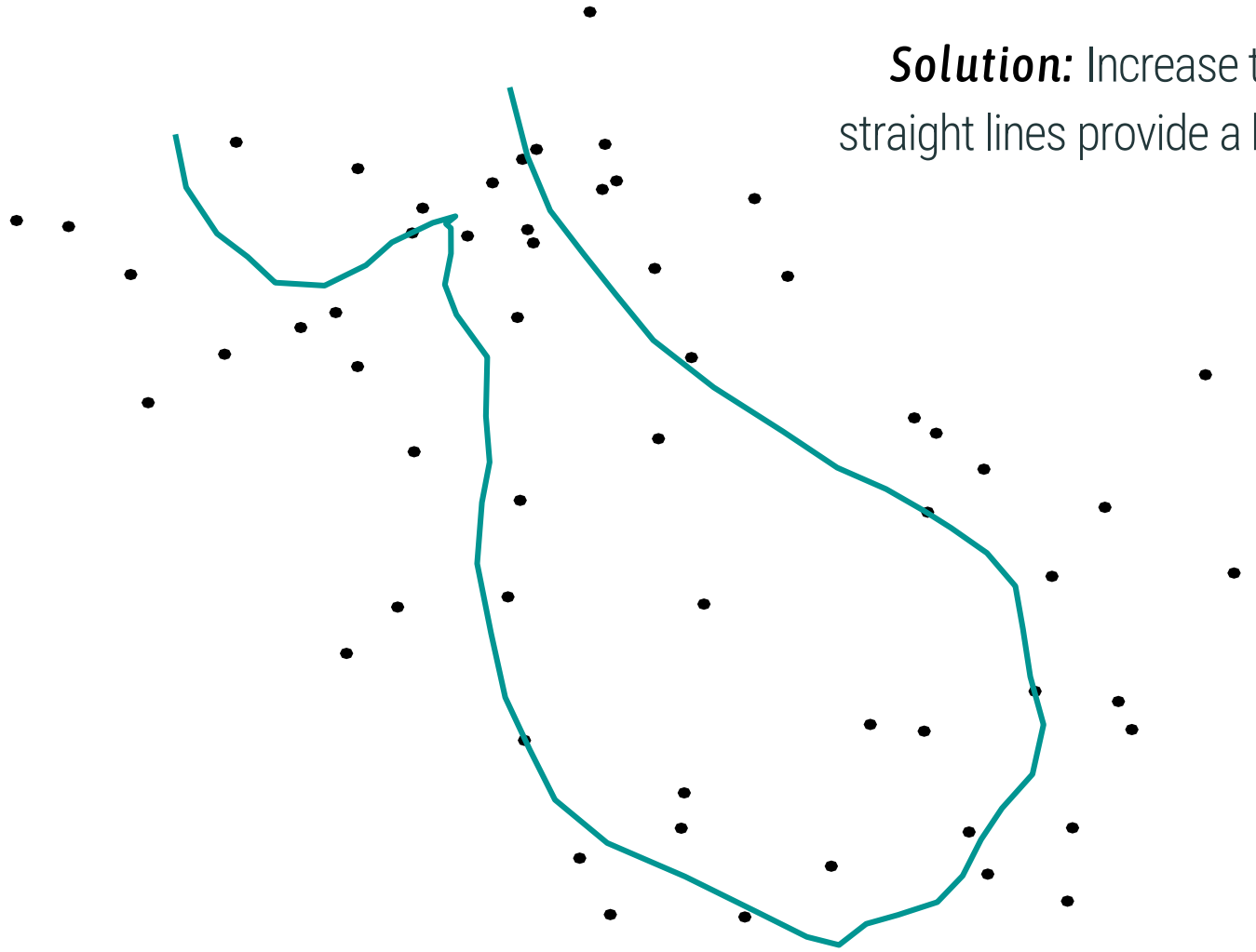
Solution: Increase the sampling frequency until the straight lines provide a better ***approximation*** of a curve?



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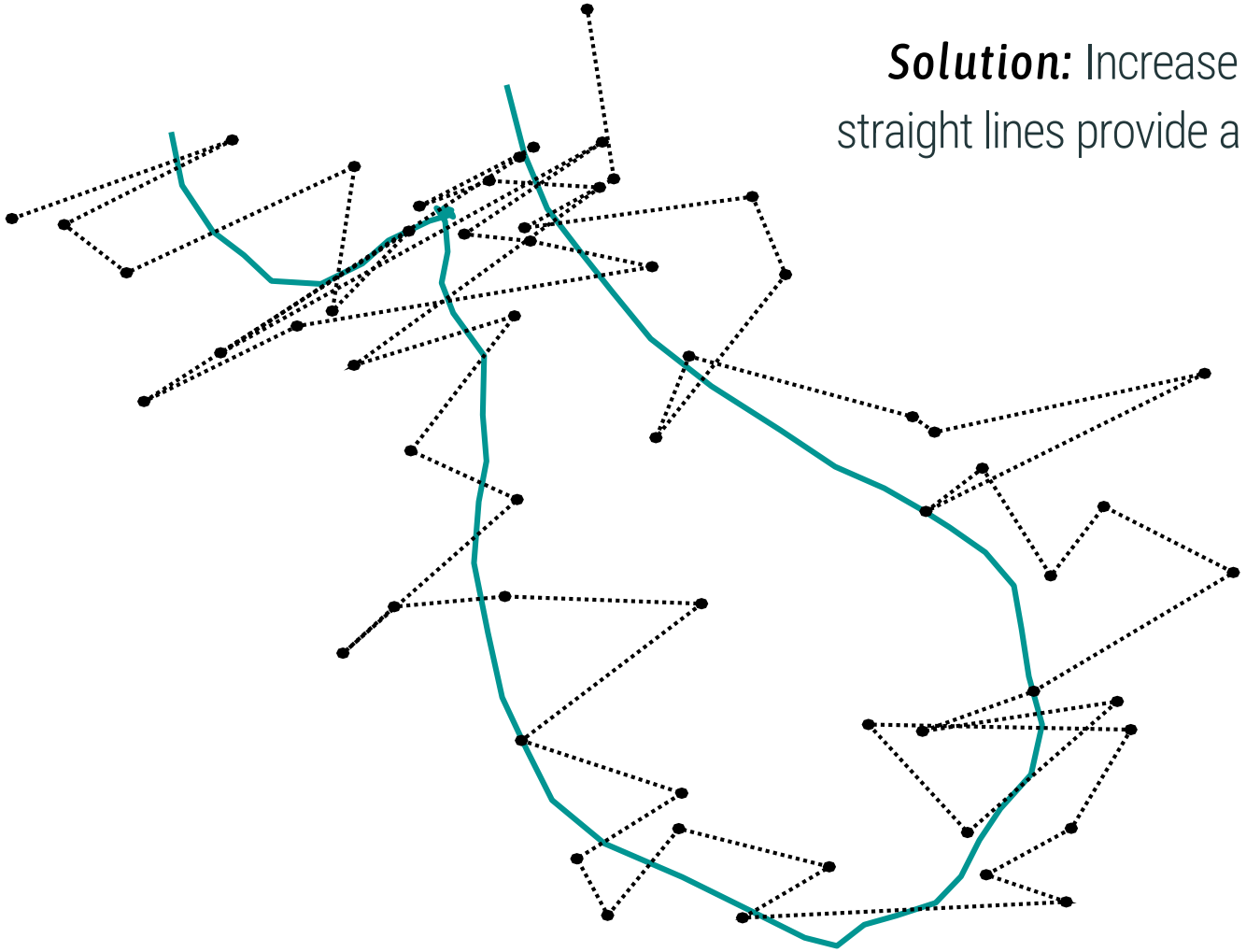

Solution: Increase the sampling frequency until the straight lines provide a better ***approximation*** of a curve?

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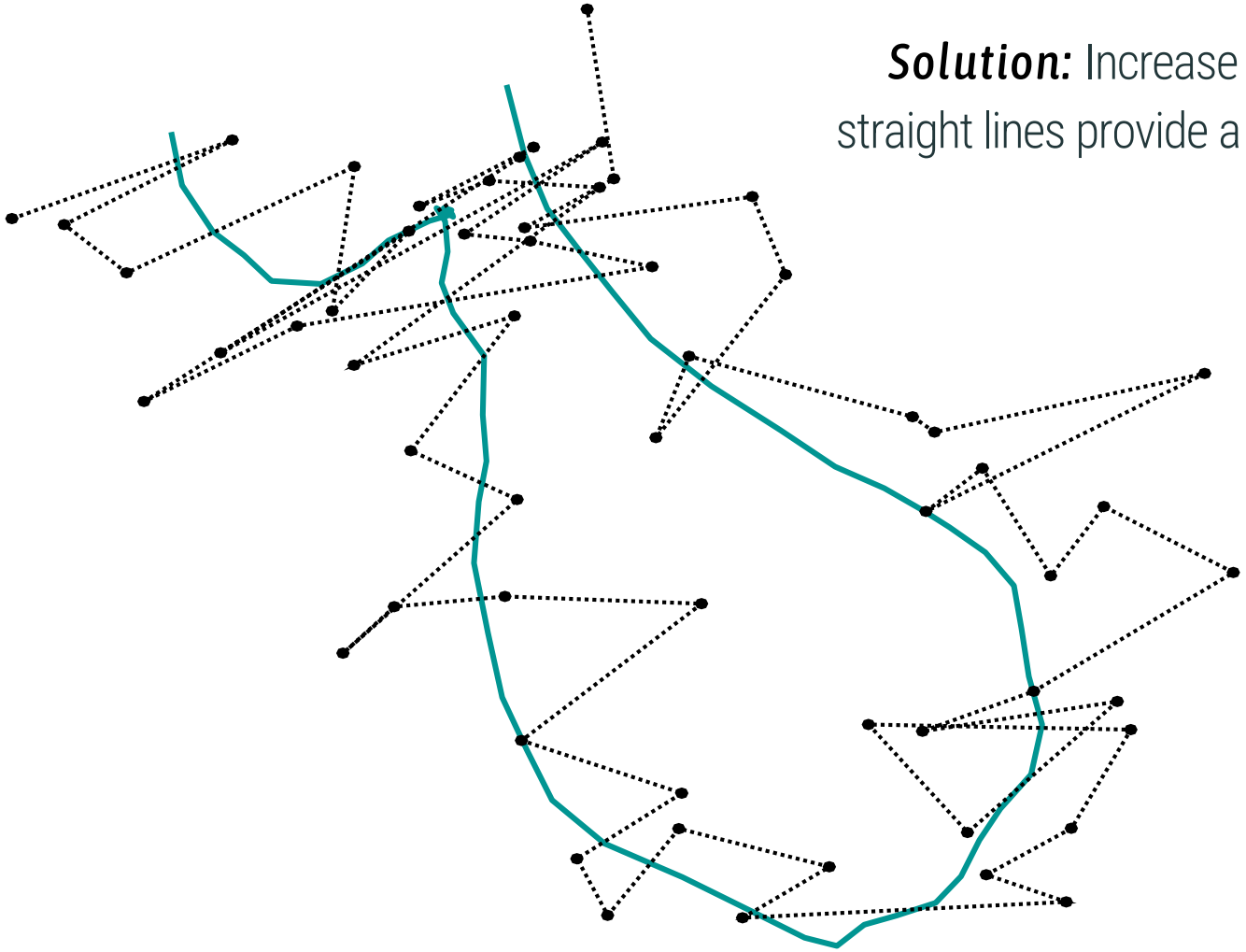

Solution: Increase the sampling frequency until the straight lines provide a better ***approximation*** of a curve?

However,
If error is uncorrelated in time, estimates converge to ***infinity*** with infinite sampling frequency $(\Delta t \rightarrow 0)$.

Why? The actual distance traveled by the animal goes to ***0*** in the limit where $\Delta t \rightarrow 0$, but the magnitude of uncorrelated measurement error is ***independent of t***.

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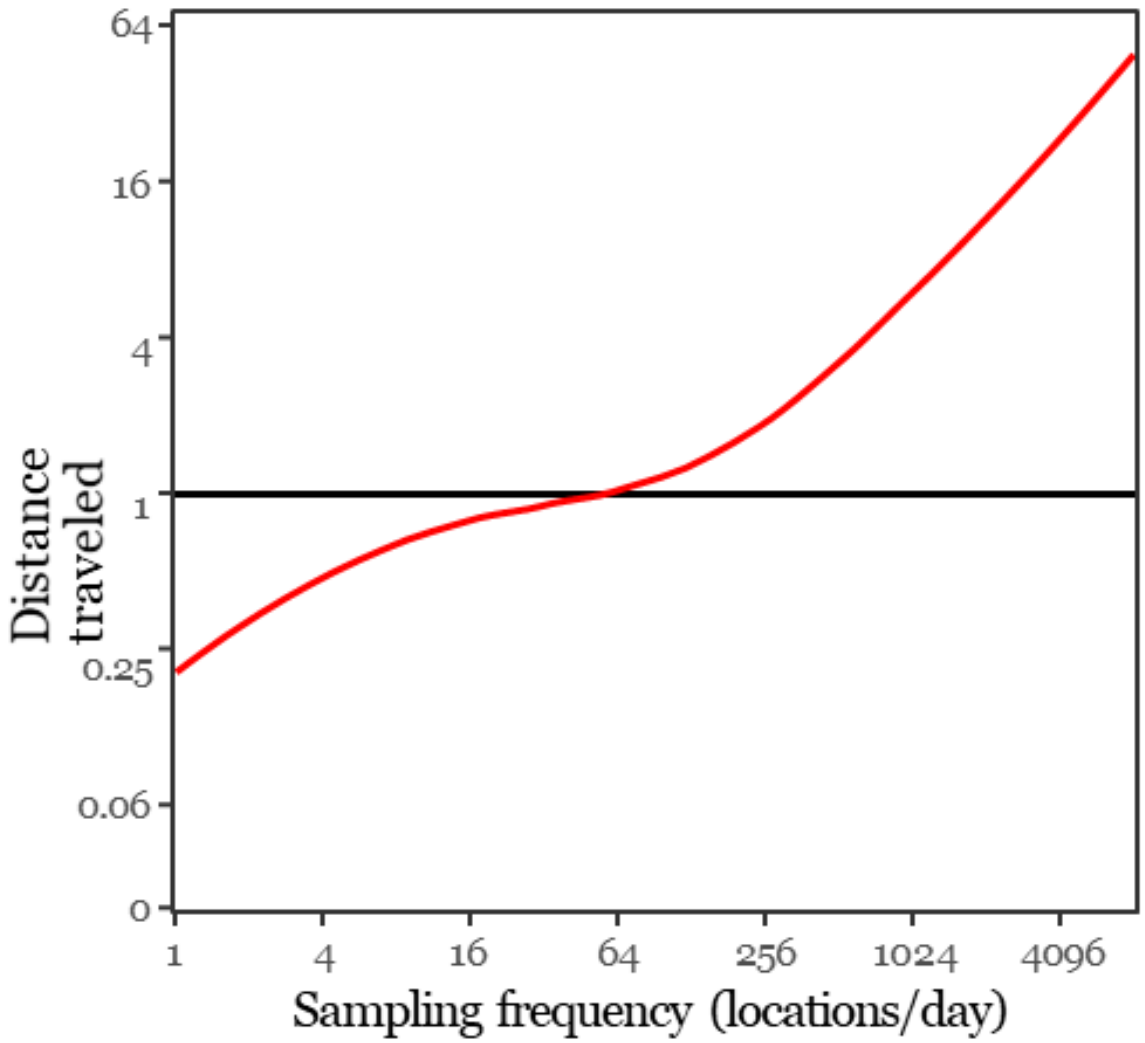

64
16
4
1
0.25
0.06
0
Distance traveled
1
4
16
64
256
1024
4096
Sampling frequency (locations/day)

Continuous-time speed and distance (CTSD)

Noonan *et al.* (2020)

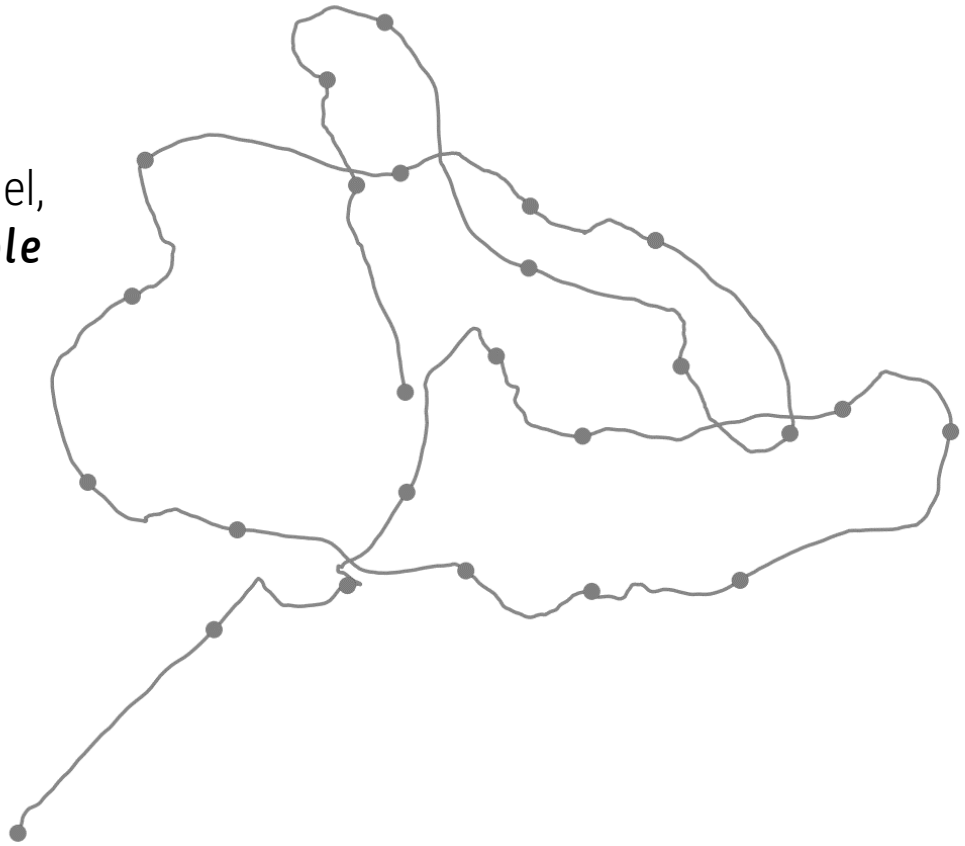
	Autocorrelation			
Model	Position	Velocity	Restricted	Parameters:
IID	No	No	Yes	τ = NULL
BM	Yes	No	No	$\tau = \infty$
OU	Yes	No	Yes	$\tau = \tau_p$
IOU	Yes	Yes	No	$\tau = \{\infty, \tau_v\}$
OUF	Yes	Yes	Yes	$\tau = \{\tau_p, \tau_v\}$

Requires a *correlated velocity model*.

Continuous-time speed and distance (CTSD)

Noonan *et al.* (2020)

Select best-fit movement model, so we can repeat over ***multiple rounds of simulations***.



Continuous-time speed and distance (CTSD)

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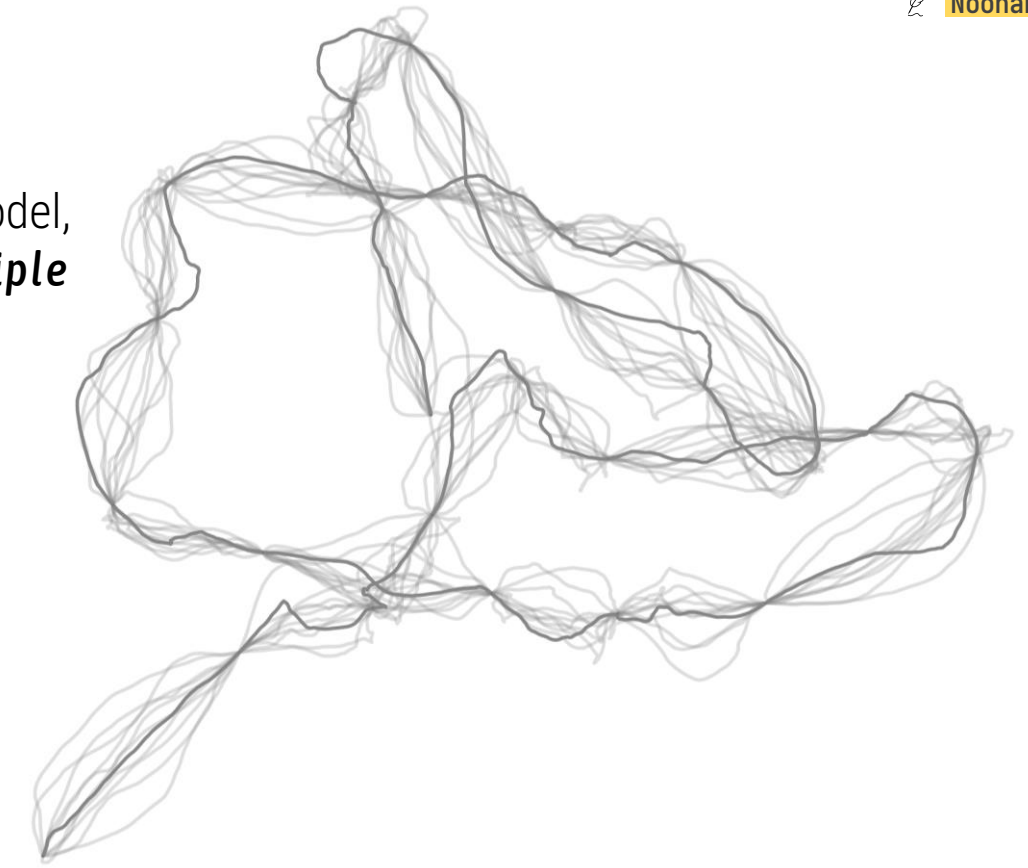
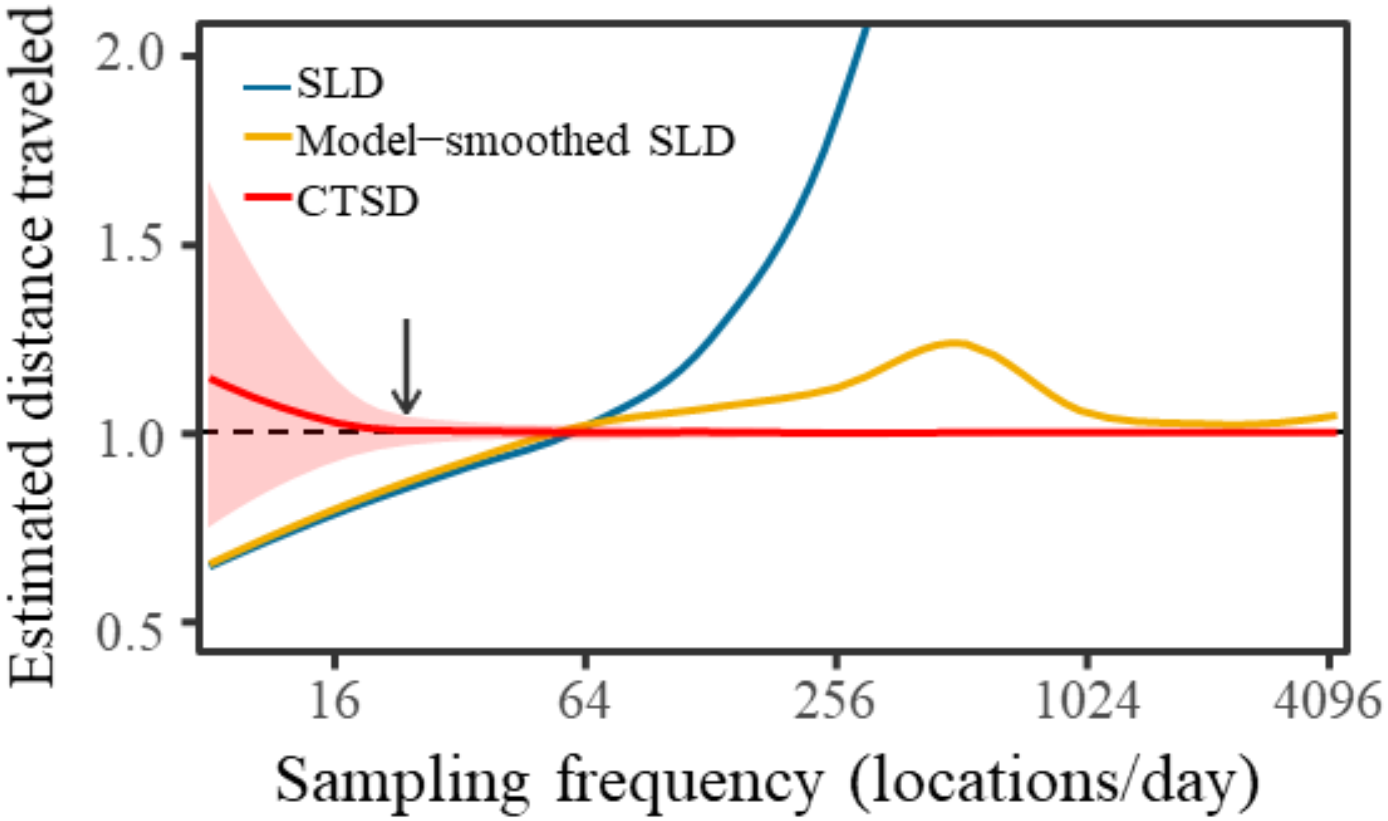


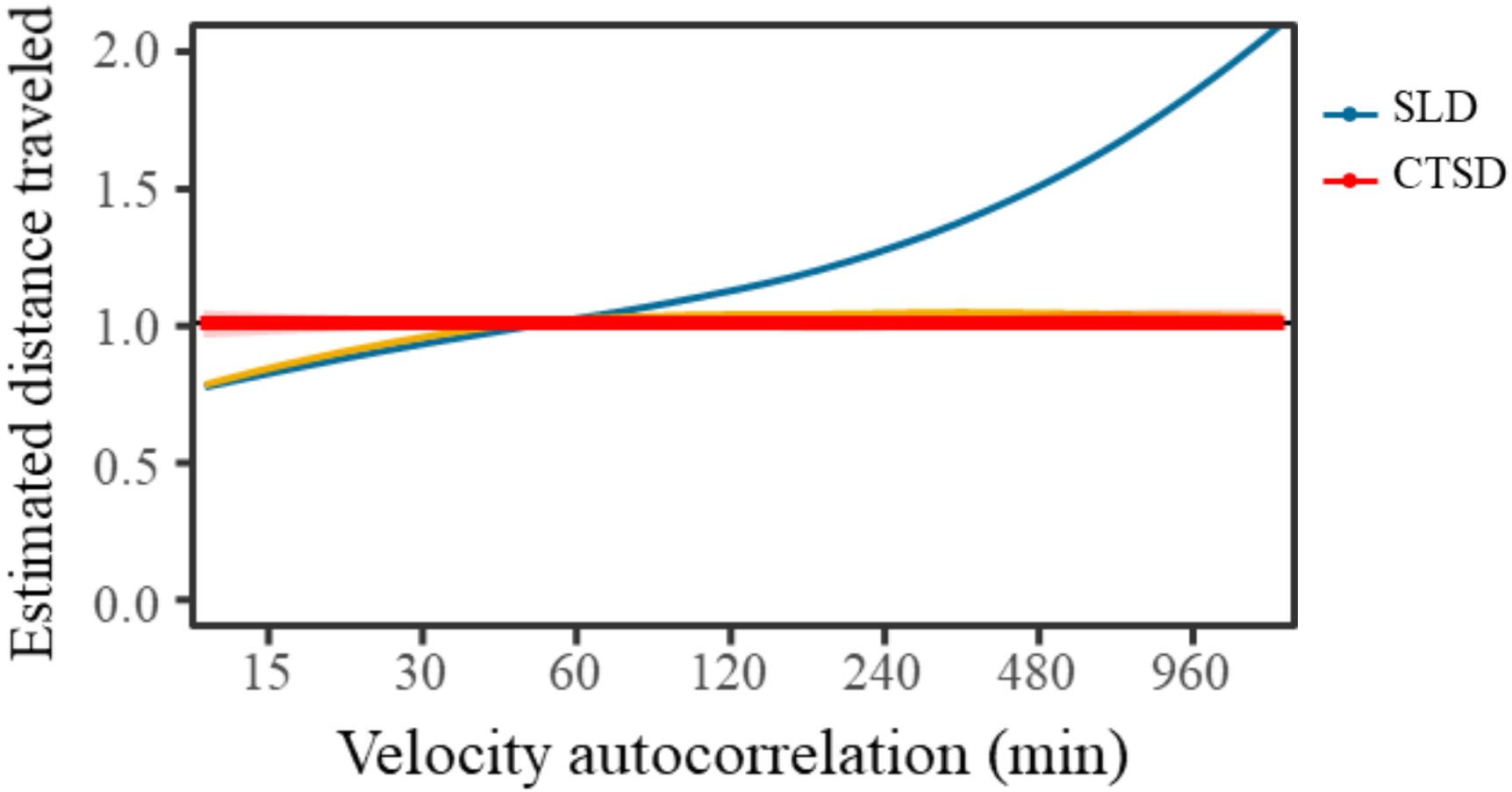
Continuous-time speed and distance (CTSD)

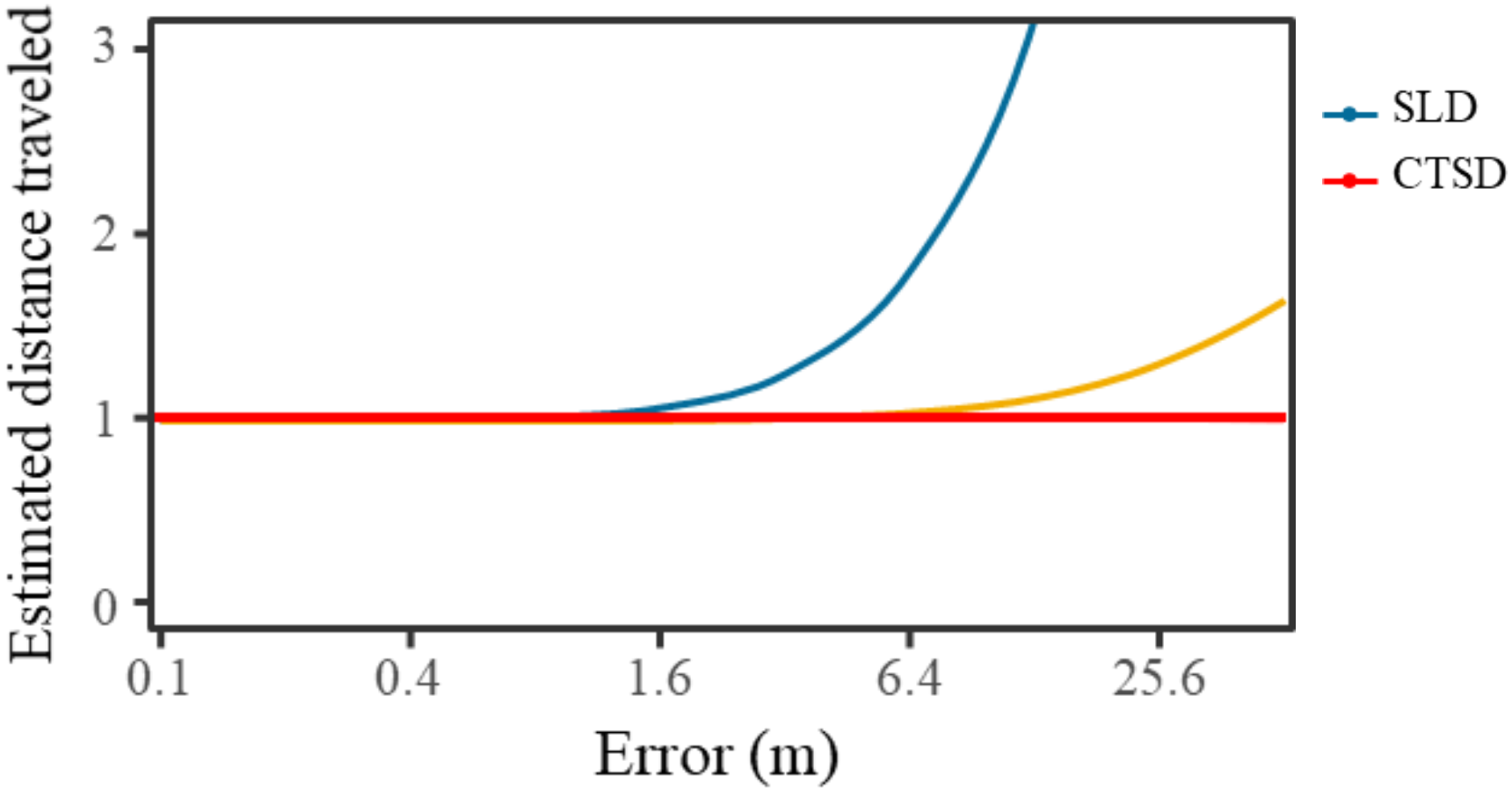
Noonan *et al.* (2020)

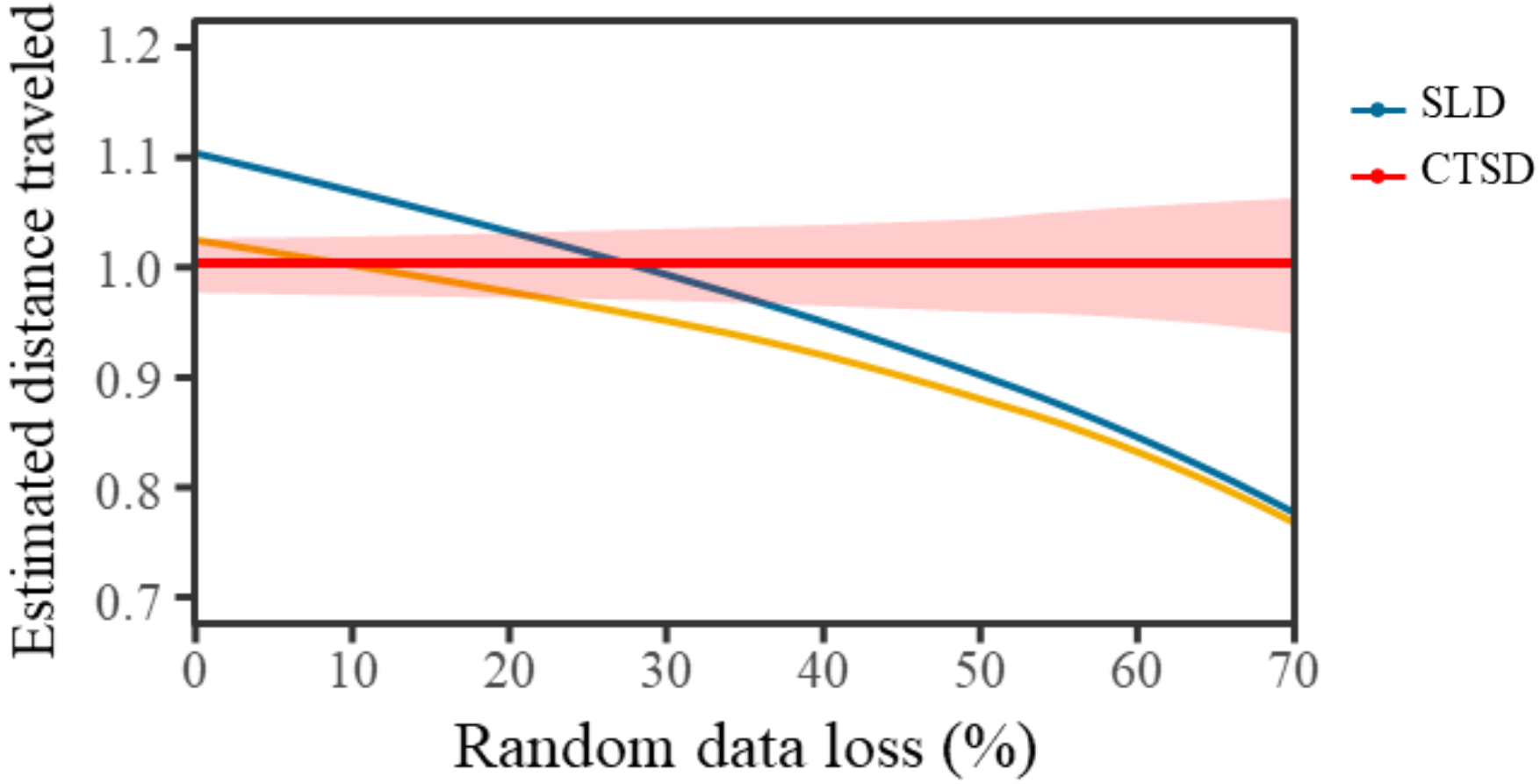
Select best-fit movement model, so we can repeat over ***multiple rounds of simulations***…

…Until we get a ***point estimate***, and variance around the estimate (for the ***confidence intervals***).

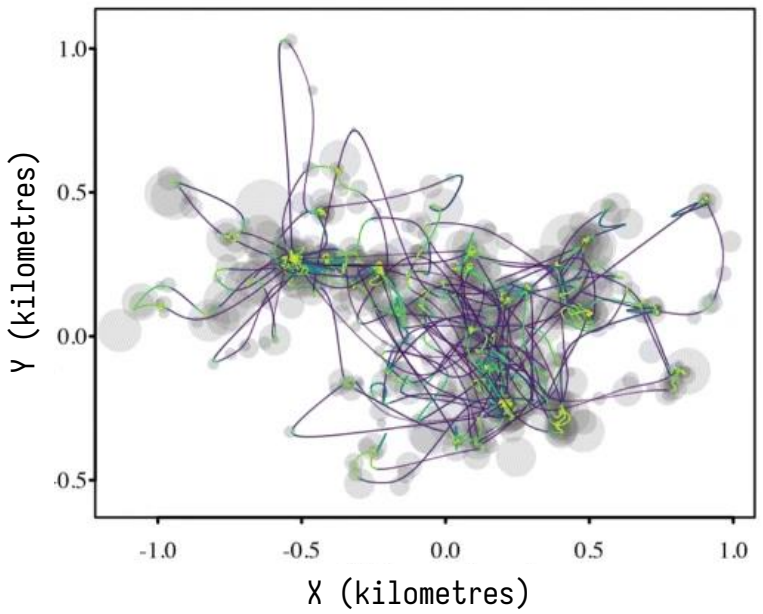

Estimated distance traveled
2.0
1.5
1.0
0.5
SLD
Model−smoothed SLD
CTSD
16
64
256
1024
4096
Sampling frequency (locations/day)

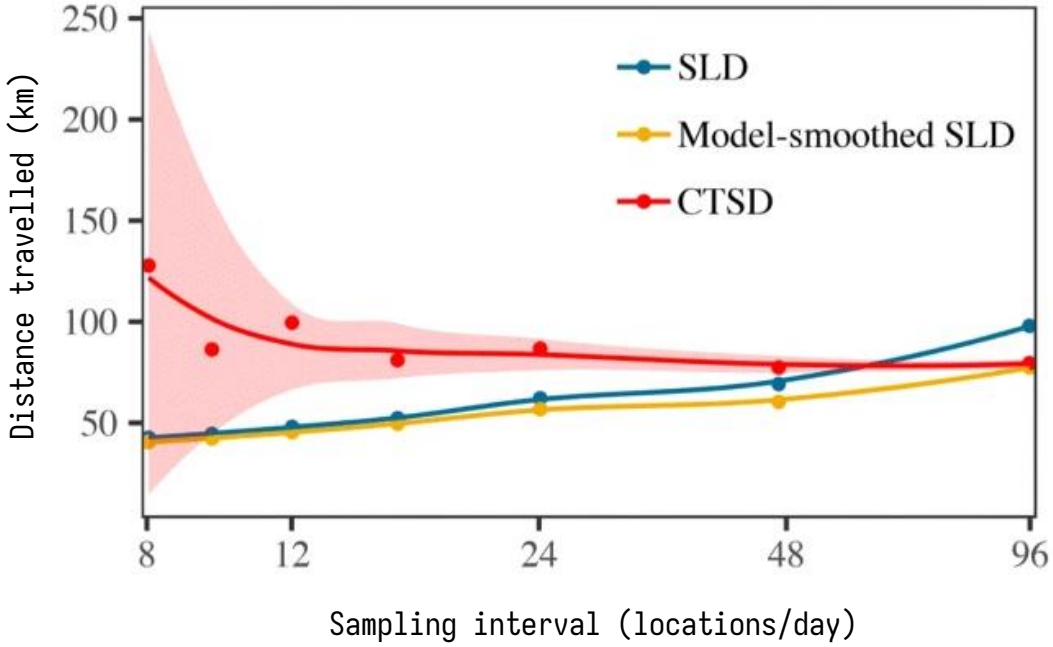

Estimated distance traveled
2.0
1.5
1.0
0.5
0.0
15
30
60
120
240
480
960
Velocity autocorrelation (min)
SLD
CTSD


Estimated distance traveled
3
2
1
0
0.1
0.4
1.6
6.4
25.6
Error (m)
SLD
CTSD


Estimated distance traveled
1.2
1.1
1.0
0.9
0.8
0.7
0
10
20
30
40
50
60
70
Random data loss (%)
SLD
CTSD

Sampling *frequency (max)*
1 fix every 15 minutes



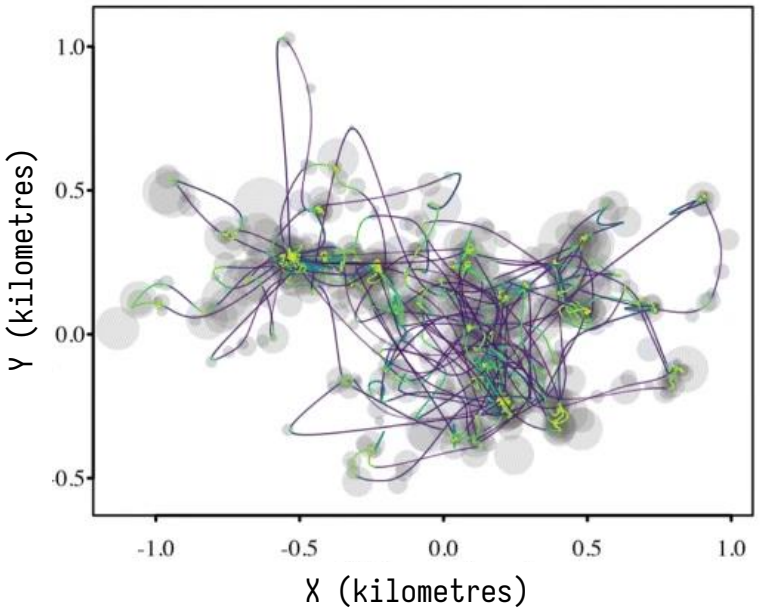


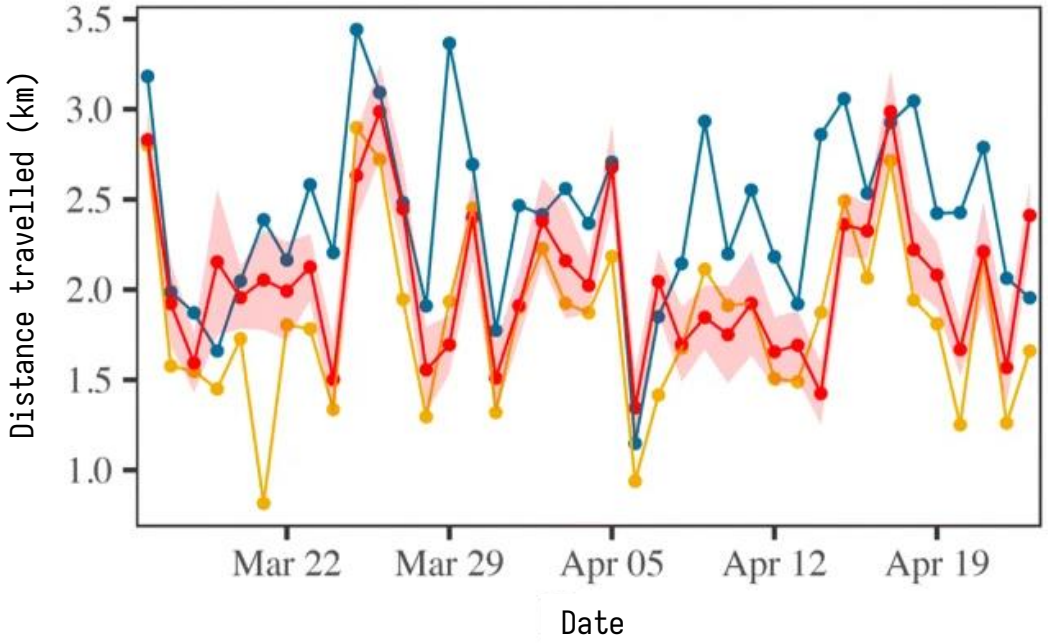
Chuck Homler

LC

White-nosed coati
(Nasua narica)

Sampling *frequency (max)*
1 fix every 15 minutes





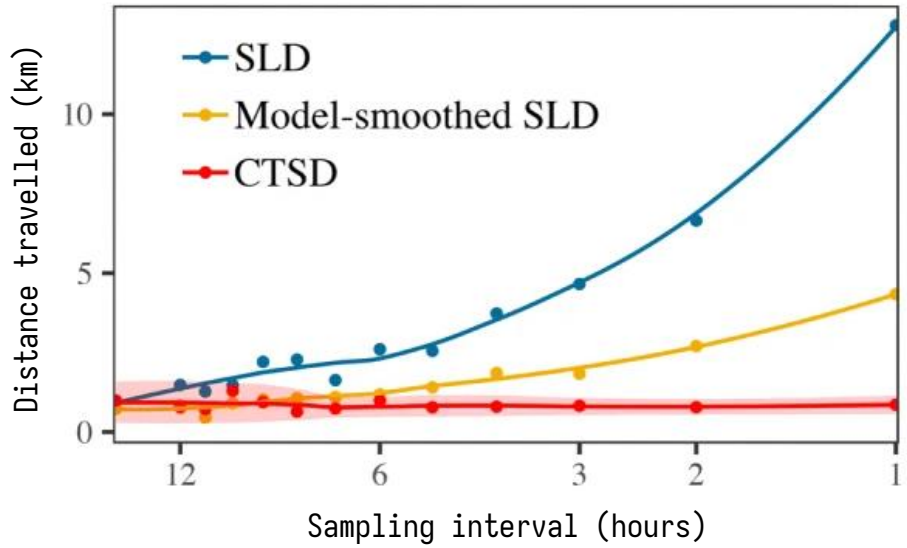
Chuck Homler

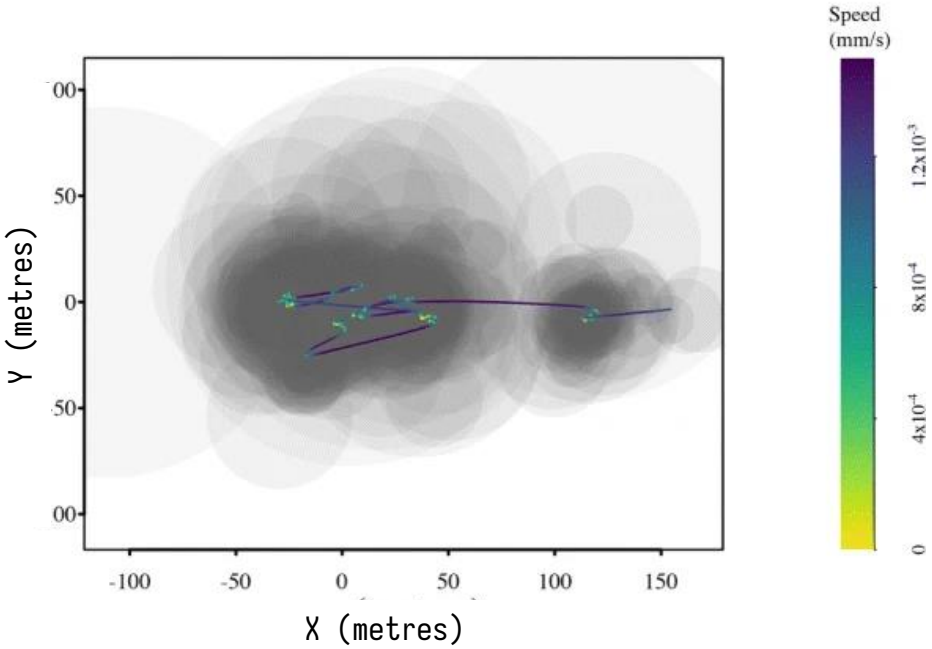
LC

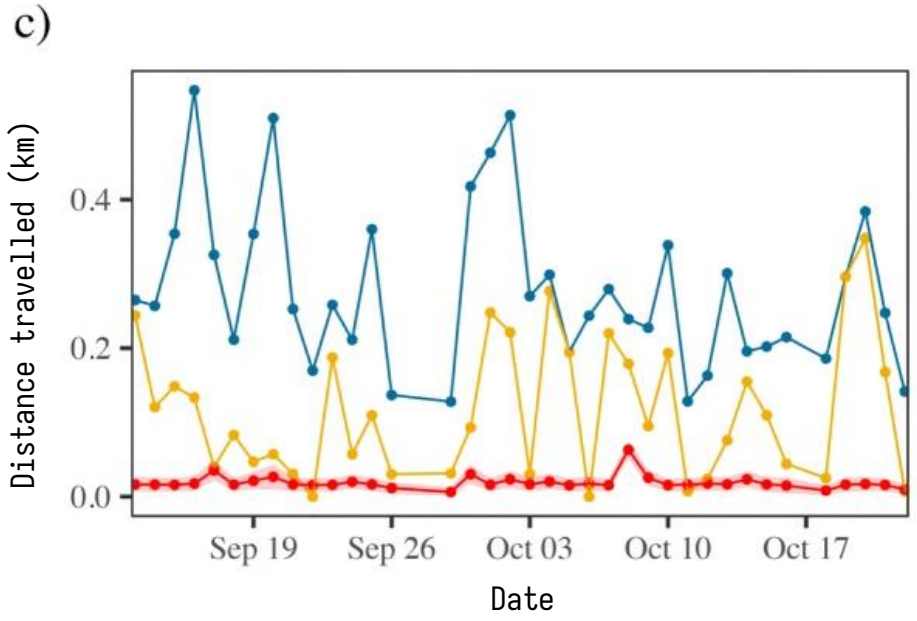
White-nosed coati
(Nasua narica)

Wood turble

(Glyptemys insculpta)







To keep in mind…