Introduction to continuous-time movement modeling

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Overview

1. Home-range underestimation —a motivating problem

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2. Autocorrelation —problem or feature

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2. Autocorrelation —problem or feature
3. Continuous time versus discrete time

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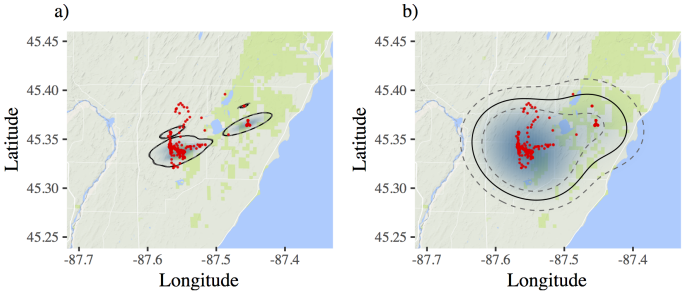
2. Autocorrelation —problem or feature
3. Continuous time versus discrete time
4. Continuous-time movement models

The underestimation of animal space use



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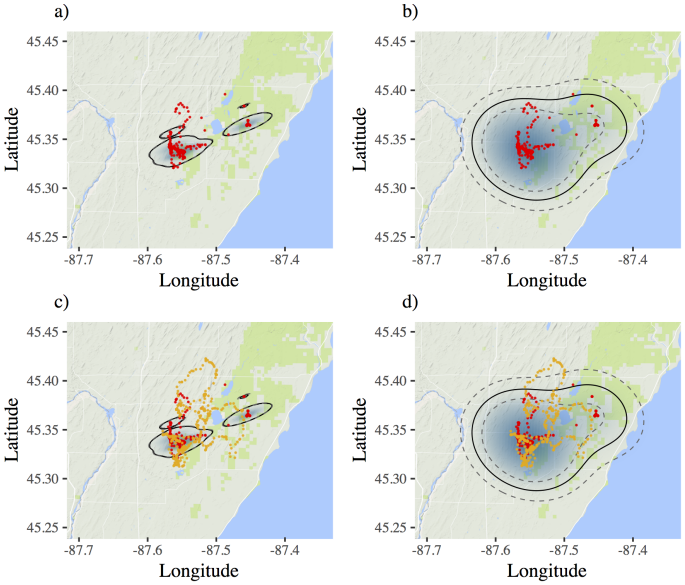

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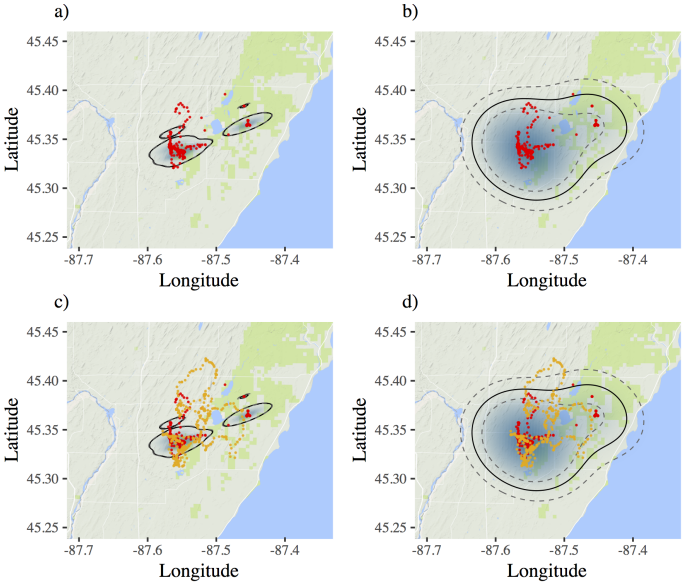

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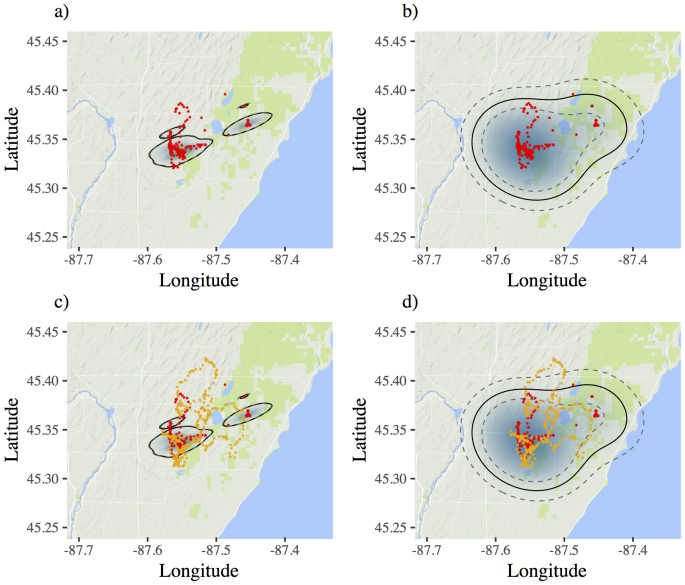

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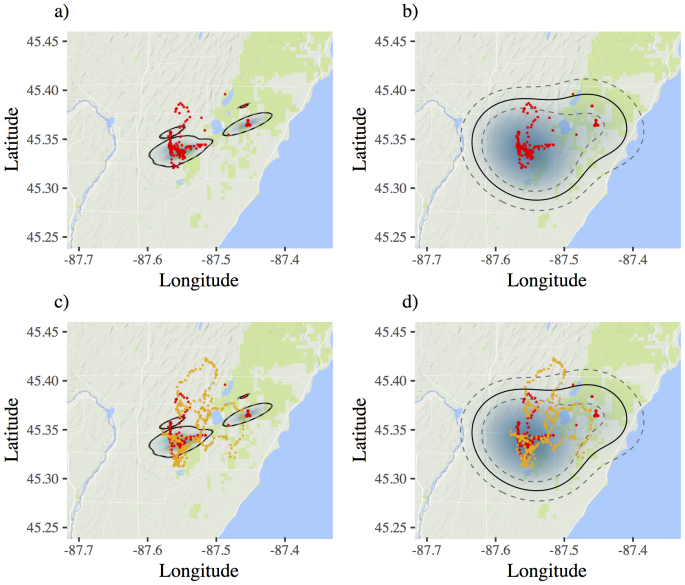

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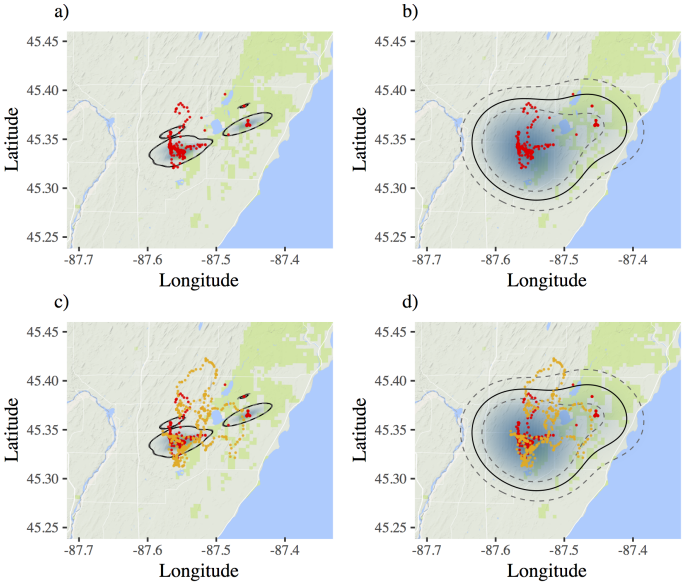

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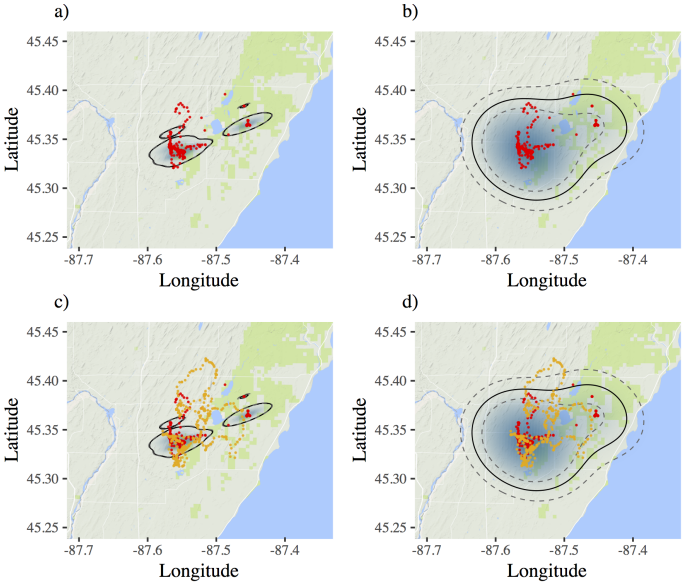

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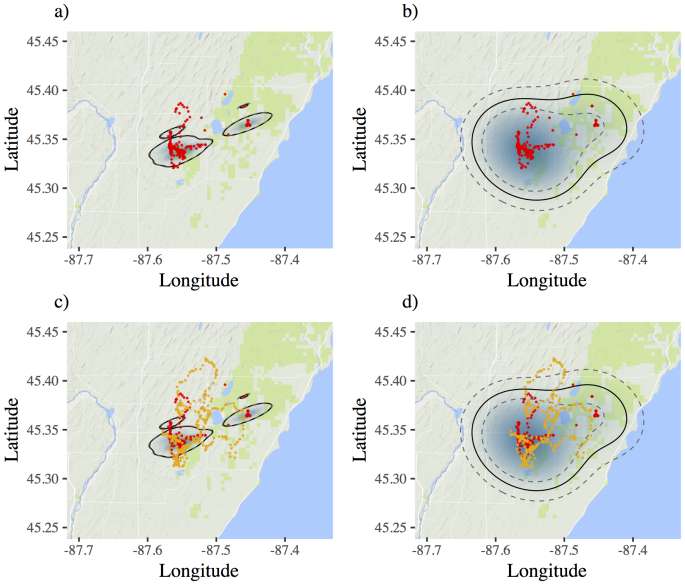

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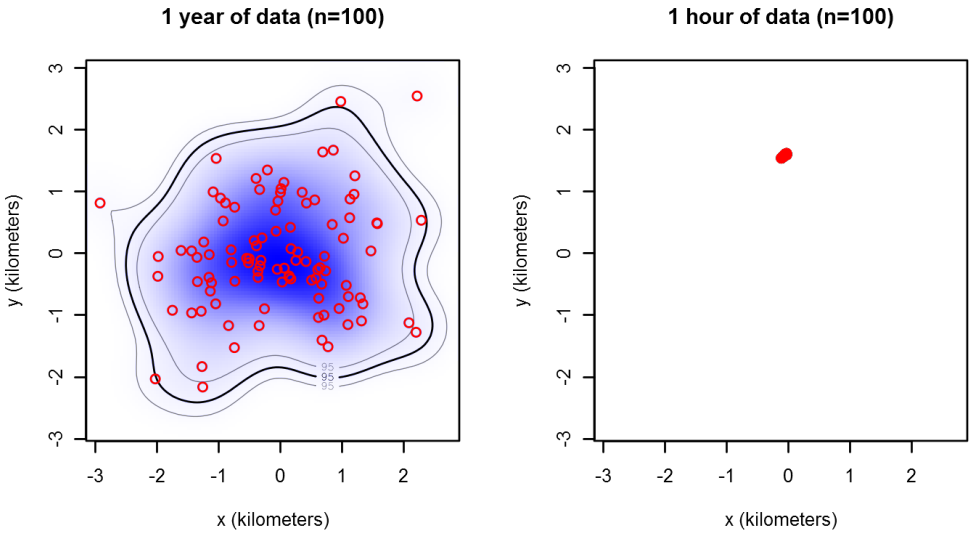


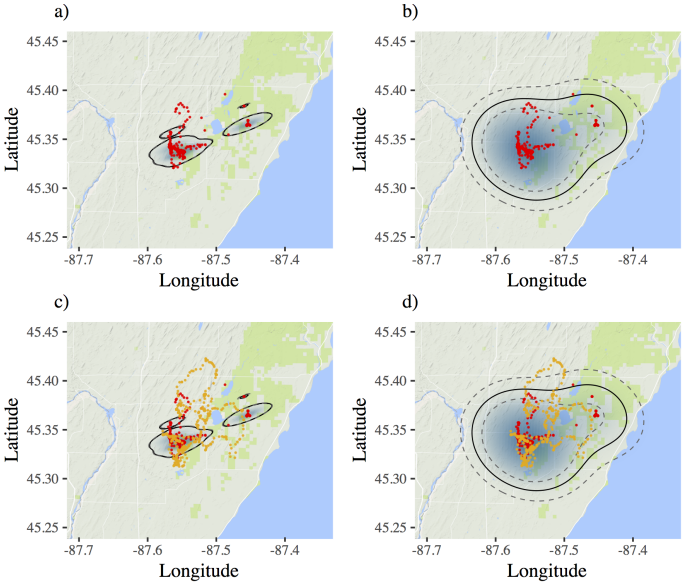
Q2: Does this happen in practice?

Ecological Monographs, 89(2), 2019, e01344

A comprehensive analysis of autocorrelation and bias in home range estimation

Michael J. Noonan [1,2] Marlee A. Tucker [3,4] Christen H. Fleming [1,2] Thomas S. Akre,[1] Susan C. Alberts,[5] Abdullahi H. Ali,[6] Jeanne Altmann,[7] Pamela Castro Antunes,[8] Jerrold L. Belant,[9] Dean Beyer,[10] Niels Blaum,[11] Katrin Böhning-Gaese,[3,4] Laury Cullen Jr.,[12] Rogerio Cunha de Paula,[13] Jasja Dekker,[14] Jonathan Drescher-Lehman,[1,15] Nina Farwig,[16] Claudia Fichtel,[17] Christina Fischer,[18] Adam T. Ford,[19] Jacob R. Goheen,[20] René Janssen,[21] Florian Jeltsch [11] Matthew Kauffman,[22] Peter M. Kappeler,[17] Flávia Koch,[17] Scott LaPoint [23,24] A. Catherine Markham,[25] Emilia Patricia Medici,[26] Ronaldo G. Morato [13,27] Ran Nathan,[28] Luiz Gustavo R. Oliveira-Santos,[8] Kirk A. Olson,[1,29] Bruce D. Patterson,[30] Agustin Paviolo [31] Emiliano Esterci Ramalho,[27,32] Sascha Rösner,[16] Dana G. Schabo,[16] Nuria Selva,[33] Agnieszka Sergiel,[33] Marina Xavier da Silva,[34] Orr Spiegel [35] Peter Thompson,[2] Wiebke Ullmann,[11] Filip Zięba,[36] Tomasz Zwijacz-Kozica,[36] William F. Fagan,[2] Thomas Mueller,[3,4] and Justin M. Calabrese [1,2,37]

The underestimation of animal space use, the solution



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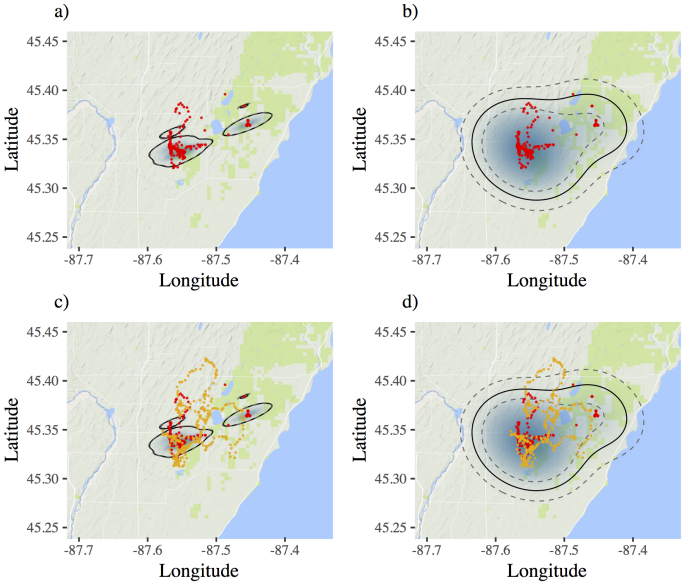

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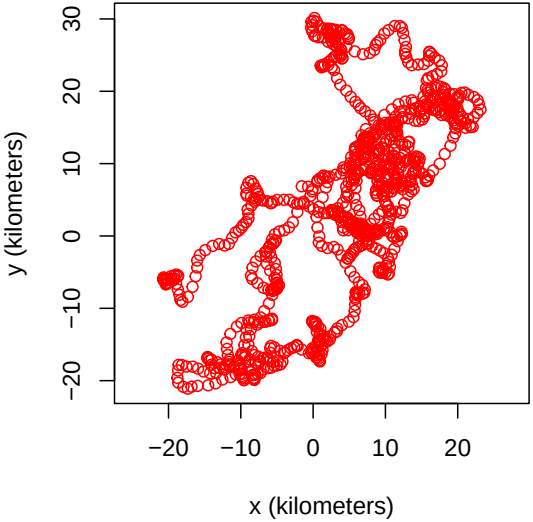

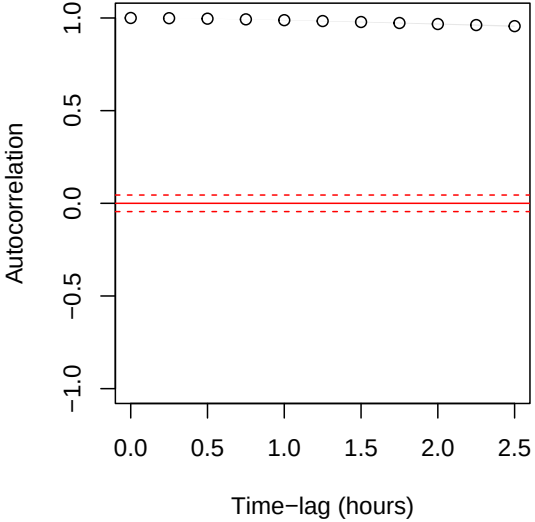

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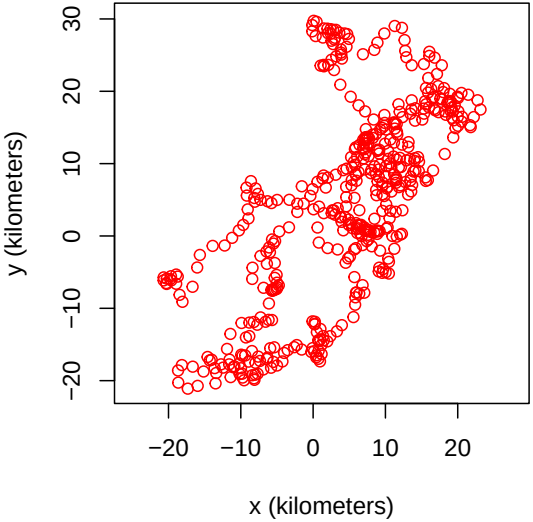

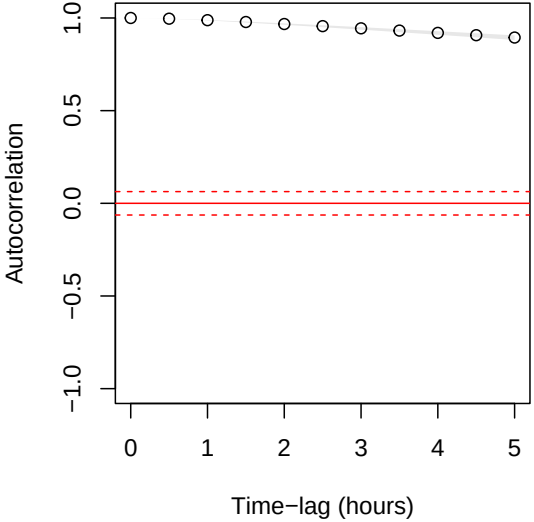

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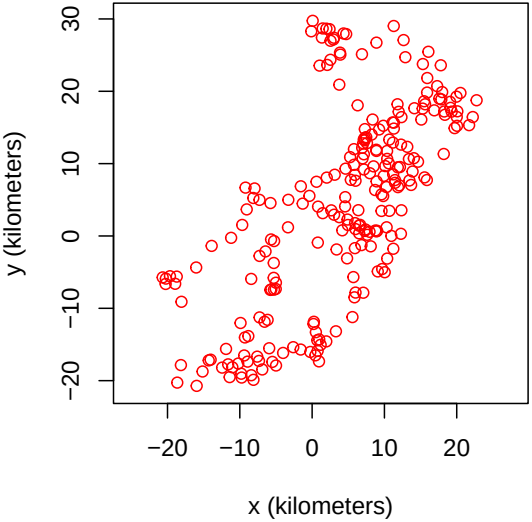

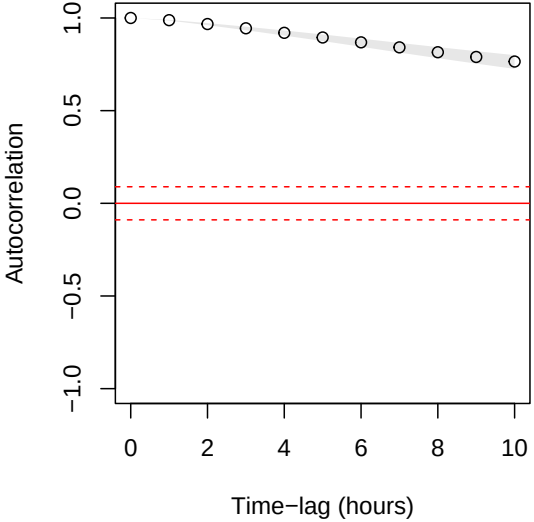

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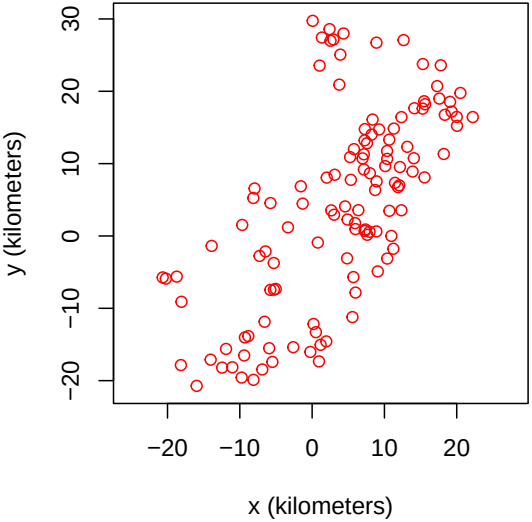

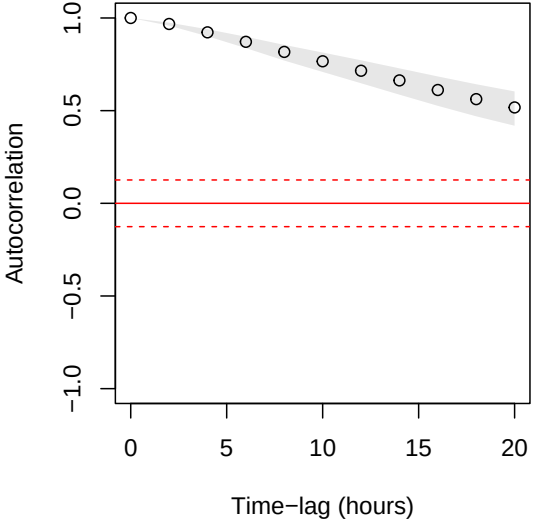

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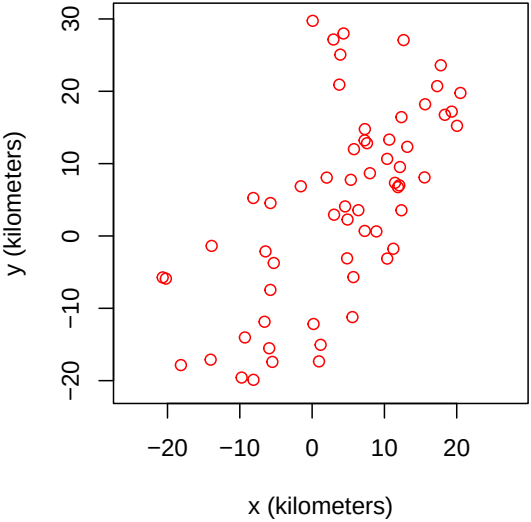

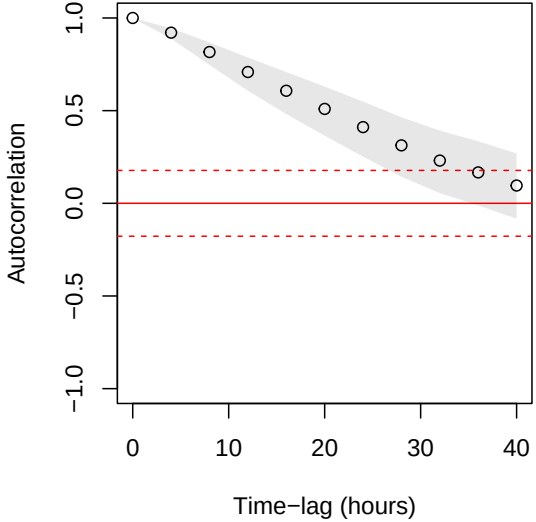

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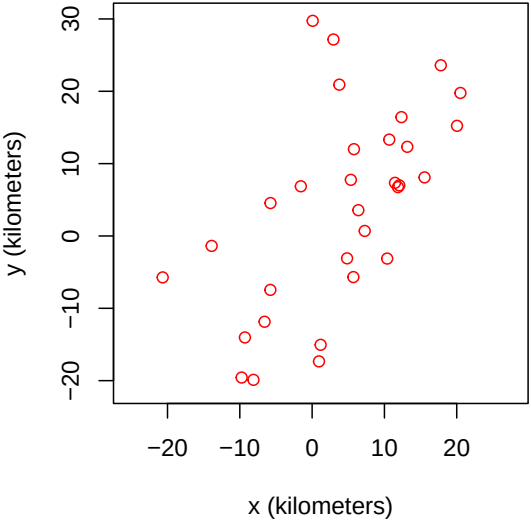

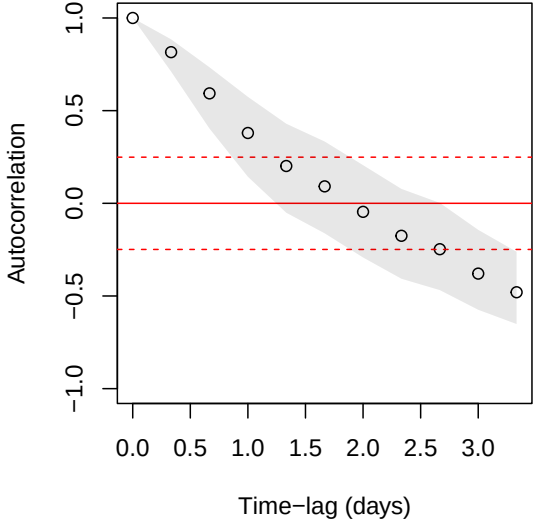

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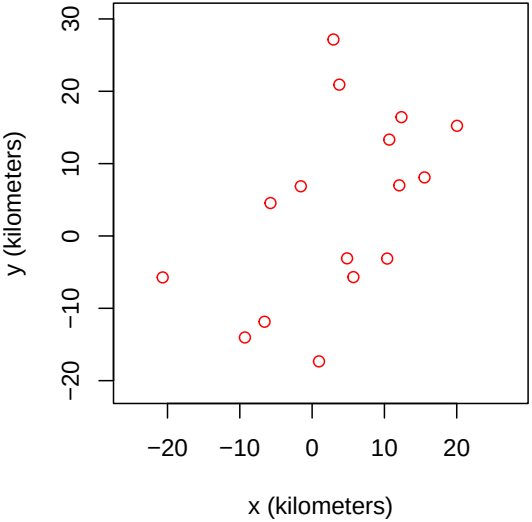
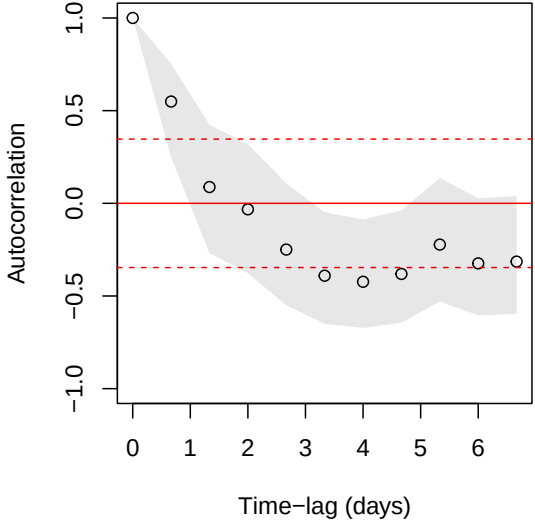
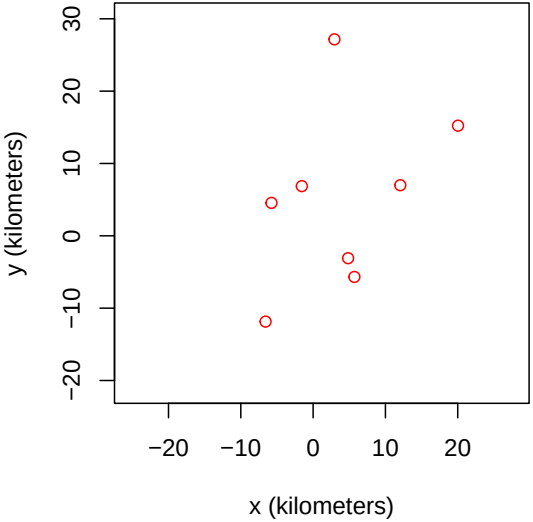
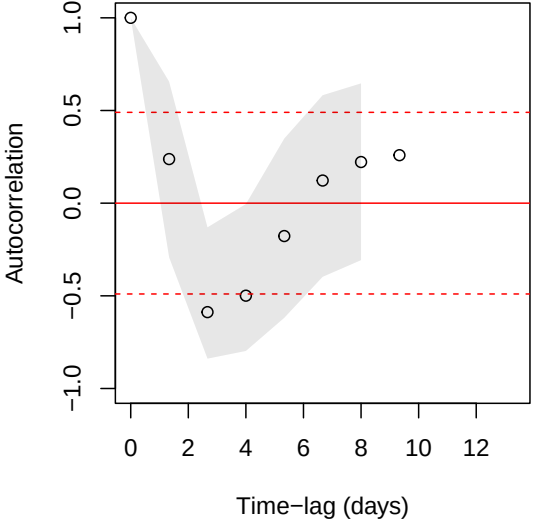
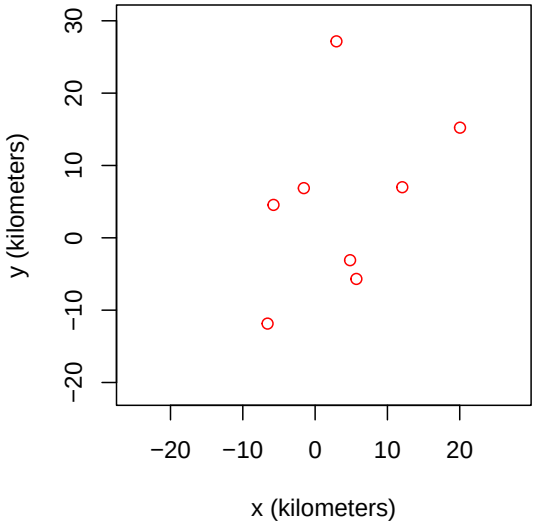


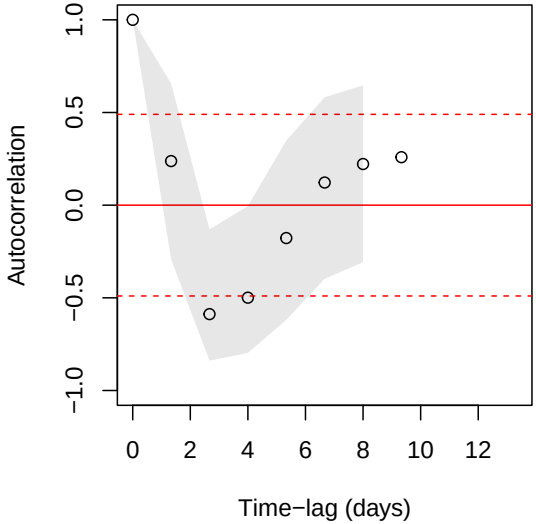


...you might have to thin a lot to reach IID



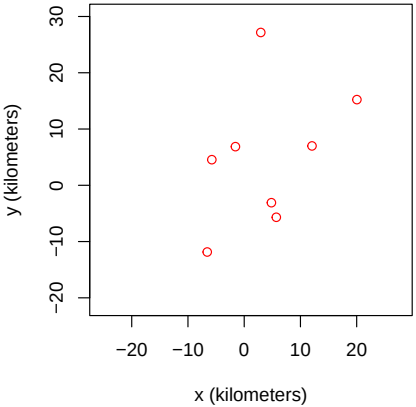


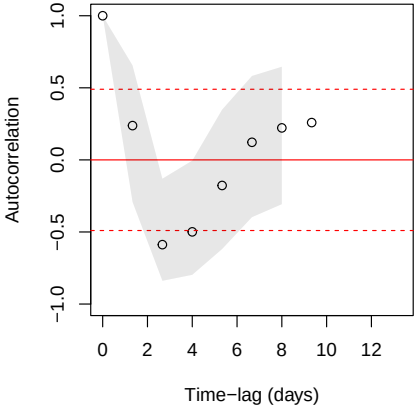




What about speed estimation with these data?

Autocorrelation is information





- Convenient for home-range analysis

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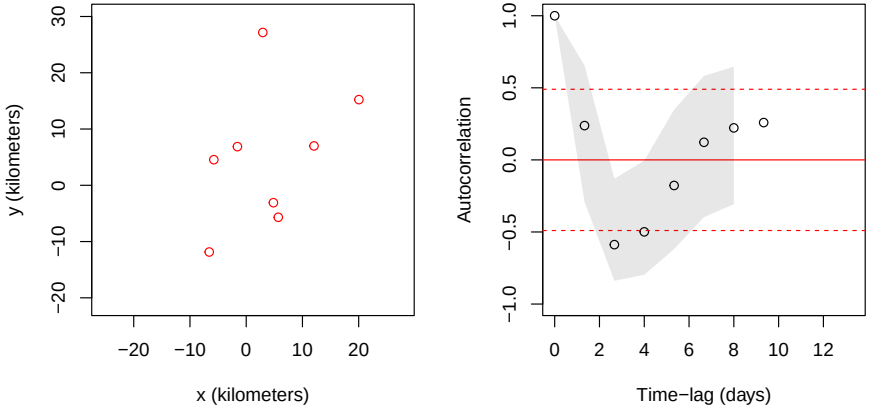

- Convenient for home-range analysis
- Worthless for speed/distance estimation

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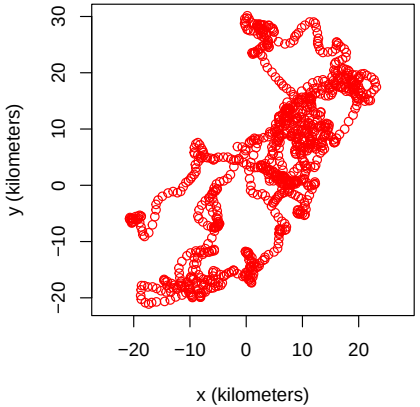

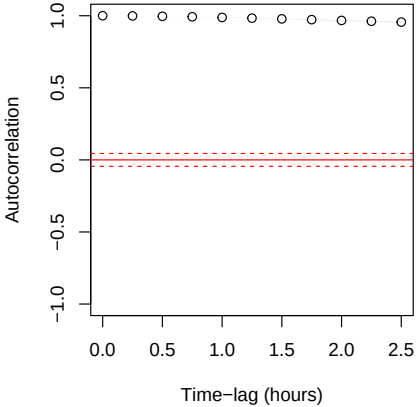

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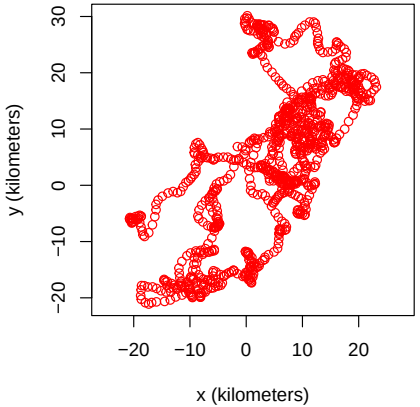

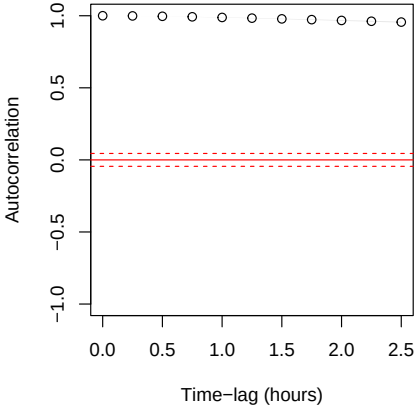

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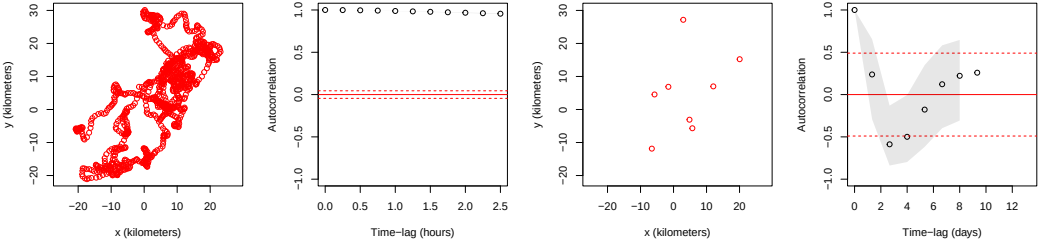
- Great for speed/distance estimation

Objective



We want methods that can handle whatever autocorrelation is present in the data

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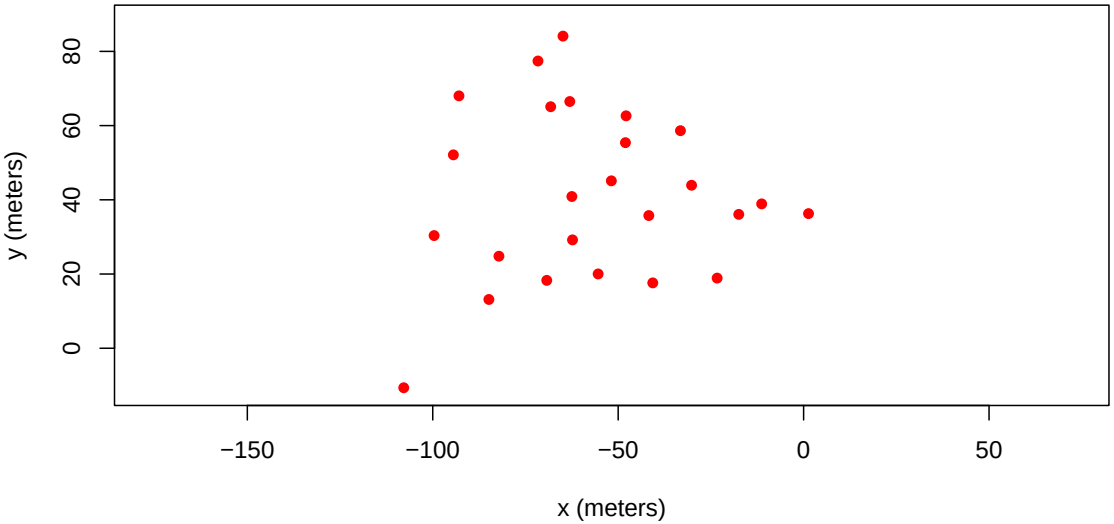

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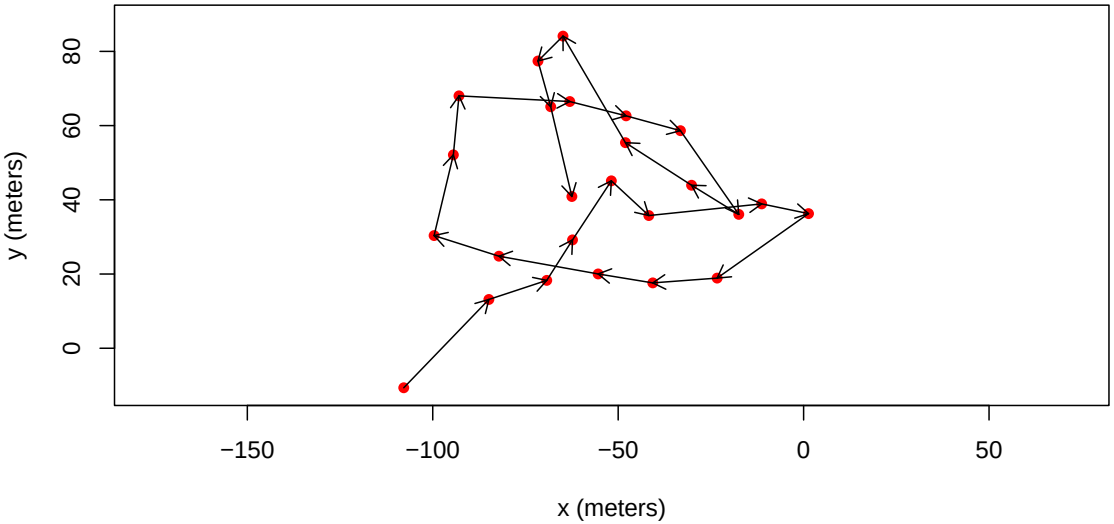

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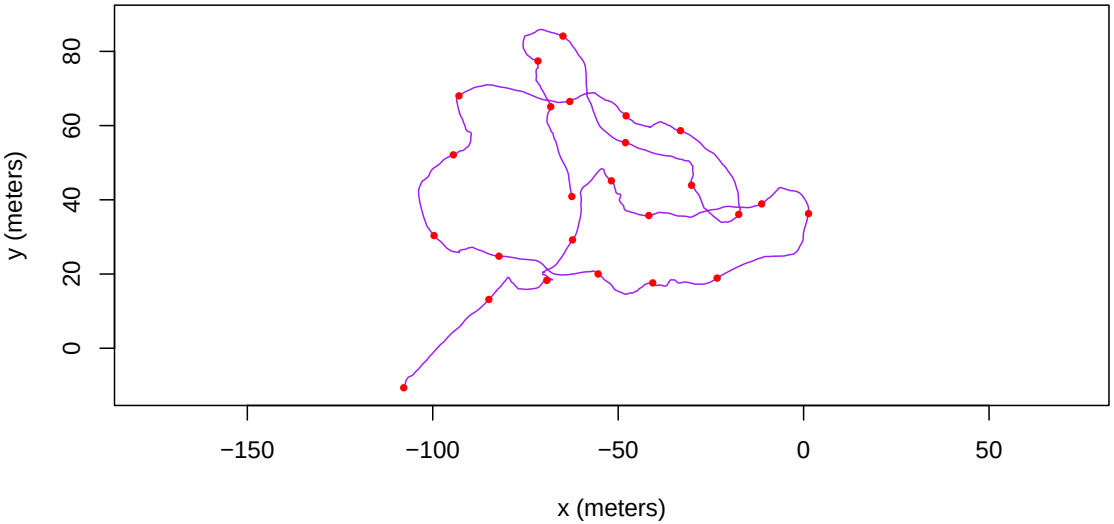

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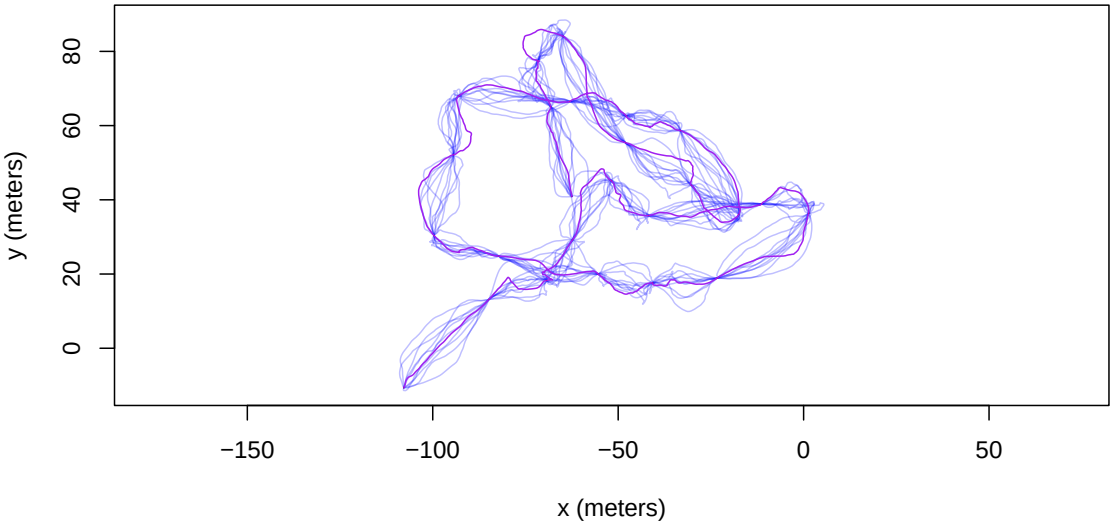

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    - Can easily model temporal and spatial scales that span orders of magnitude
    - Can accommodate speed, distance, acceleration, power and energy
  - Location error is easy to model (versus CRWs)

Building-block continuous-time stochastic process models

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- Independent locations

Accounting for non-independence: Stochastic process models

Building-block continuous-time stochastic process models

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Accounting for non-independence: Stochastic process models

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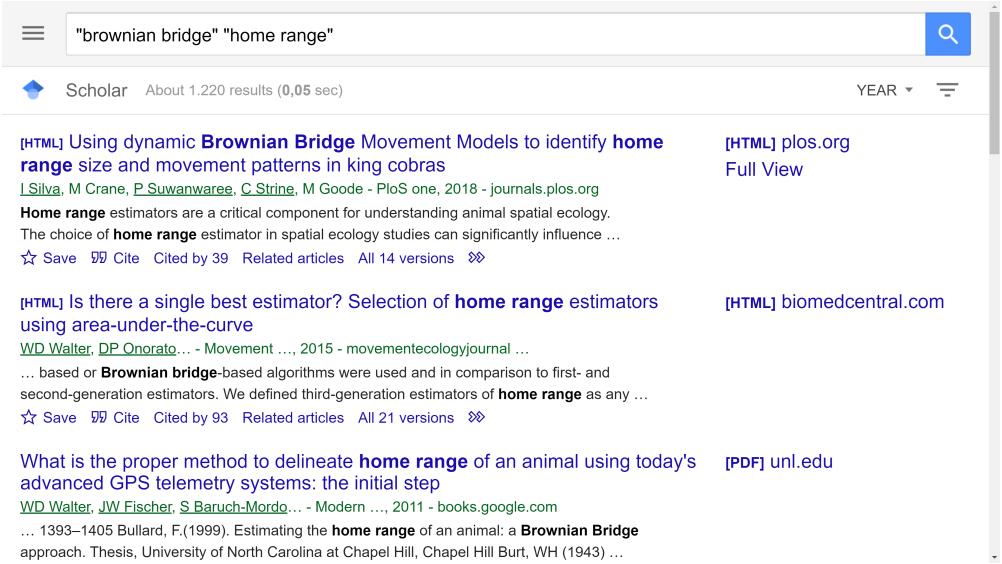
Accounting for non-independence: Brownian home range?



Accounting for non-independence: Brownian *home range*?

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Accounting for non-independence: Stochastic process model

PHYSICAL REVIEW E **91**, 032107 (2015)

Maximum-entropy description of animal movement

Chris H. Fleming,[1,2] Yiğit Subaşı,[3] and Justin M. Calabrese[1]

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[2]*Department of Biology, University of Maryland, College Park, College Park, Maryland 20742, USA*

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We introduce a class of maximum-entropy states that naturally includes within it all of the major continuous-time stochastic processes that have been applied to animal movement, including Brownian motion, Ornstein-Uhlenbeck motion, integrated Ornstein-Uhlenbeck motion, a recently discovered hybrid of the previous models, and a new model that describes central-place foraging. We are also able to predict a further hierarchy of new models that will emerge as data quality improves to better resolve the underlying continuity of animal movement. Finally, we also show that Langevin equations must obey a fluctuation-dissipation theorem to generate processes that fall from this class of maximum-entropy distributions when the constraints are purely kinematic.

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Accounting for non-independence: Stochastic process model

Building-block continuous-time stochastic process models

- Independent locations
- Brownian motion
- Ornstein-Uhlenbeck motion
- Integrated Ornstein-Uhlenbeck motion
- Missing maximum-entropy model

Accounting for non-independence: Stochastic process model

Building-block continuous-time stochastic process models

- Independent locations
- Brownian motion
- Ornstein-Uhlenbeck motion
- Integrated Ornstein-Uhlenbeck motion
- Missing maximum-entropy model

Don't assume a model, select a model

Accounting for non-independence: Stochastic process model

Building-block continuous-time stochastic process models

- Independent locations (KDE,MCP,RSF,...)
- Brownian motion (Brownian bridge)
- Ornstein-Uhlenbeck motion
- Integrated Ornstein-Uhlenbeck motion (`crawl`)
- Missing maximum-entropy model

Don't assume a model, select a model

Break for ctmm