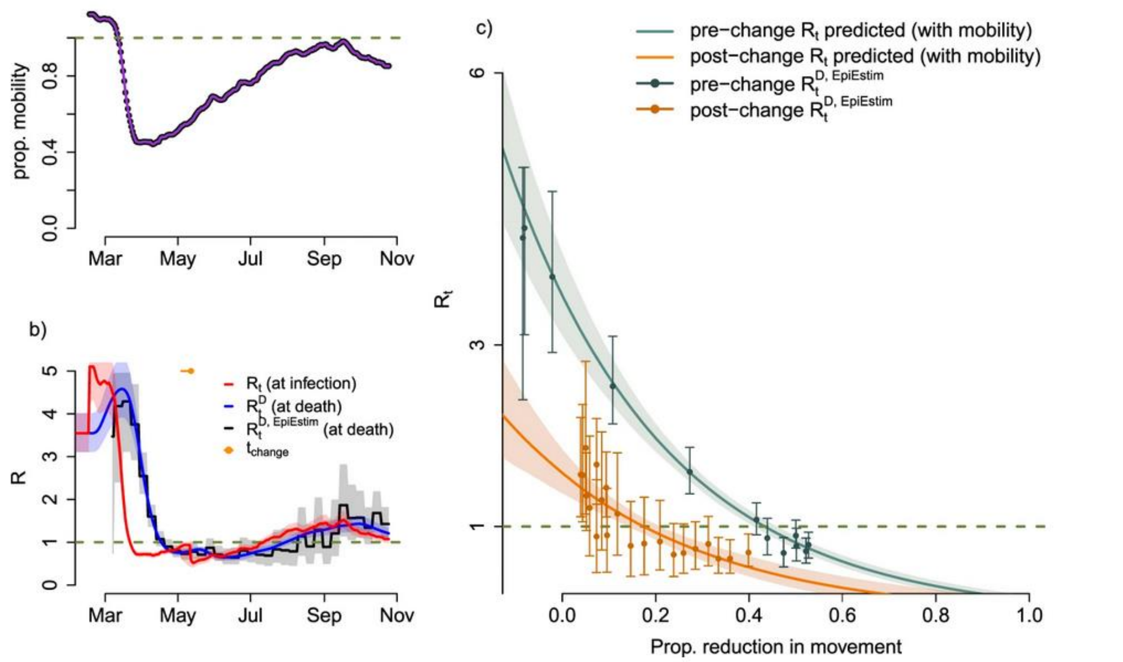
General human mobility models

Rory Gibb, PHID group meeting, November 2021

Mobility is a major driver of disease dynamics and spread in people…

Lockdown restrictions and COVID-19 in the UK



ARTICLE

Check for updates

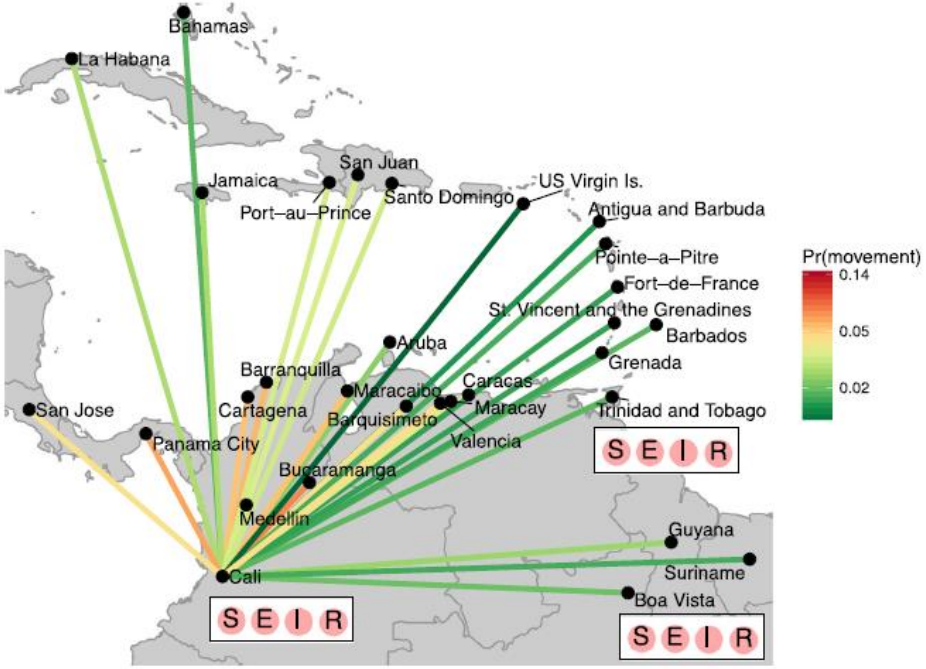
https://doi.org/10.1038/s41467-021-21358-2

OPEN

Reduction in mobility and COVID-19 transmission

Pierre Nouvellet[1,2✉], Sangeeta Bhatia[1], Anne Cori[1], Kylie E. C. Ainslie[1], Marc Baguelin[1], Samir Bhatt[1],

Spatial spread of Zika in the Americas



RESEARCH ARTICLE — Open Access

CrossMark

Projecting the end of the Zika virus epidemic in Latin America: a modelling analysis

Kathleen M. O'Reilly[1,2*], Rachel Lowe[2,3,4], W. John Edmunds[2,3], Philippe Mayaud[5], Adam Kucharski[2,3], Rosalind M. Eggo[2,3], Sebastian Funk[2,3], Deepit Bhatia[6,7], Kamran Khan[6,7], Moritz U. G. Kraemer[8,9,10],

… and in wildlife

ECOLOGY LETTERS

Ecology Letters, (2018) **21**: 588–604 doi: 10.1111/ele.12917

REVIEW AND SYNTHESIS

Going through the motions: incorporating movement analyses into disease research

Eric R. Dougherty[1*,†]
Dana P. Seidel[1,†] Colin J. Carlson[1]
Orr Spiegel[2] and
Wayne M. Getz[1, 3]

Abstract
Though epidemiology dates back to the 1700s, most mathematical representations of epidemics still use transmission rates averaged at the population scale, especially for wildlife diseases. In simplifying the contact process, we ignore the heterogeneities in host movements that complicate the real world, and overlook their impact on spatiotemporal patterns of disease burden. Movement ecology offers a set of tools that help unpack the transmission process, letting researchers more

Migrating Birds as Dispersal Vehicles for West Nile Virus

Jennifer Owen, Frank Moore, Nicholas Panella, Eric Edwards, Rachel Bru, Megan Hughes, and Nicholas Komar

Department of Biological Sciences, University of Southern Mississippi, Hattiesburg, MS 39406, USA

ARTICLE

Received 18 Feb 2013 | Accepted 15 Oct 2013 | Published 19 Nov 2013 DOI: 10.1038/ncomms3770

Continent-wide panmixia of an African fruit bat facilitates transmission of potentially zoonotic viruses

Alison J. Peel[1,2], David R. Sargan[1], Kate S. Baker[1,2,3], David T. S. Hayman[1,2,4,5,6], Jennifer A. Barr[7], Gary Crameri[7], Richard Suu-Ire[8,9], Christopher C. Broder[10], Tiziana Lembo[11], Lin-Fa Wang[7,12], Anthony R. Fooks[5,13], Stephen J. Rossiter[14], James L. N. Wood[1] & Andrew A. Cunningham[2]

Journal of Animal Ecology BRITISH ECOLOGICAL SOCIETY

Review

Unifying spatial and social network analysis in disease ecology

Gregory F. Albery, Lucinda Kirkpatrick, Josh A. Firth, Shweta Bansal

DOI: 10.1111/1365-2664.14031

Journal of Applied Ecology BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

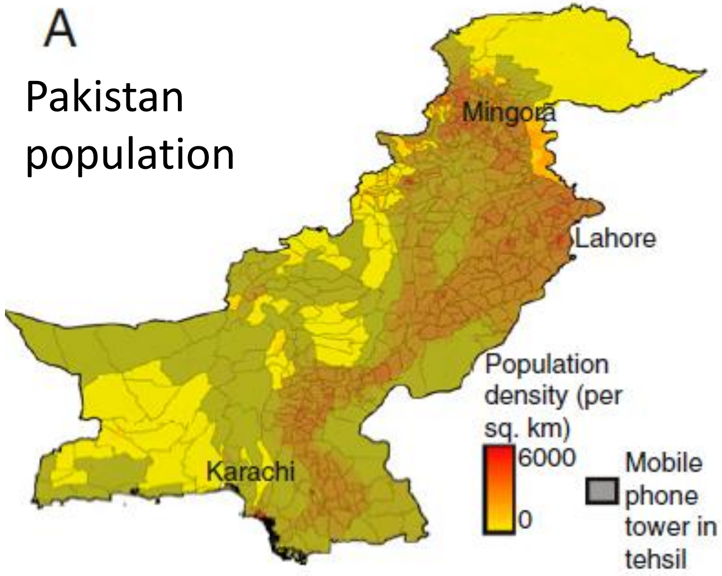
Roads and forest edges facilitate yellow fever virus dispersion

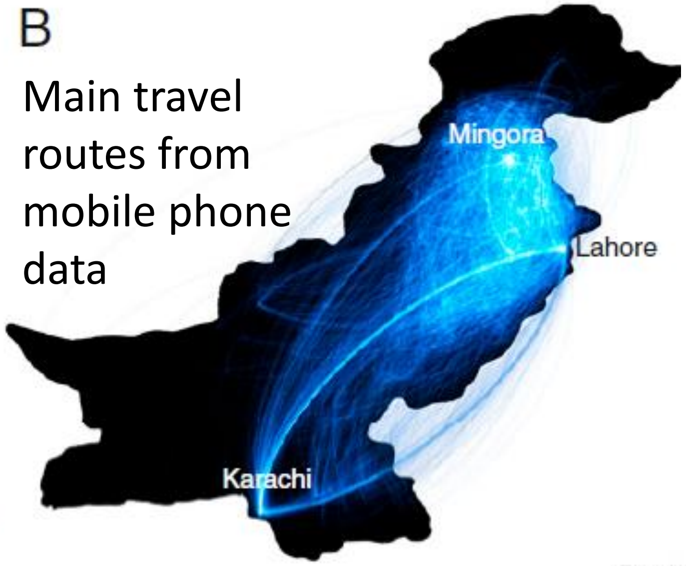
Paula Ribeiro Prist[1] | Leandro Reverberi Tambosi[1,2] | Luís Filipe Mucci[3] | Adriano Pinter[3] | Renato Pereira de Souza[4] | Renata de Lara Muylaert[5] |

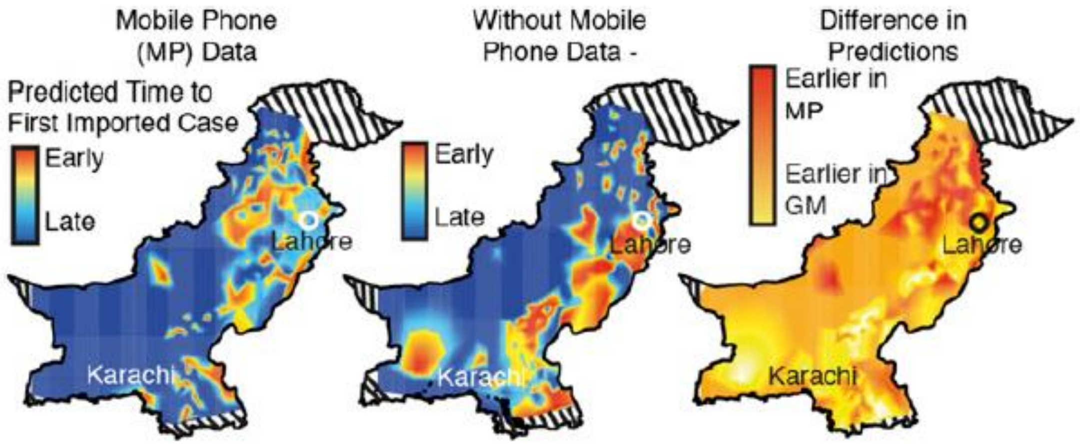
The problem

It is very challenging to measure (human) movement at the temporal and spatial scales required to incorporate into statistical or dynamical models of disease spread

One emerging solution: mobile data







Mobile phone data helps in predicting long-range introductions during 2013 dengue epidemic

PNAS

Impact of human mobility on the emergence of dengue epidemics in Pakistan

Amy Wesolowski[a,b], Taimur Qureshi[c], Maciej F. Boni[d,e], Pål Roe Sundsøy[c], Michael A. Johansson[b,f], Syed Basit Rasheed[g], Kenth Engø-Monsen[c], and Caroline O. Buckee[a,b,1]

[a]Department of Epidemiology, Harvard T. H. Chan School of Public Health, Boston, MA 02115; [b]Center for Communicable Disease Dynamics, Harvard T. H. Chan School of Public Health, Boston, MA 02115; [c]Telenor Research, Telenor Group, N-1360 Fornebu, Norway; [d]Oxford University Clinical Research Unit, Wellcome Trust Major Overseas Programme, Ho Chi Minh City, Vietnam; [e]Centre for Tropical Medicine, Nuffield Department of Clinical Medicine, University of Oxford, Oxford OX3 7FZ, United Kingdom; [f]Division of Vector-Borne Diseases, Centers for Disease Control, San Juan, Puerto Rico 00920; and [g]Department of Zoology, University of Peshawar, Peshawar 25120, Pakistan

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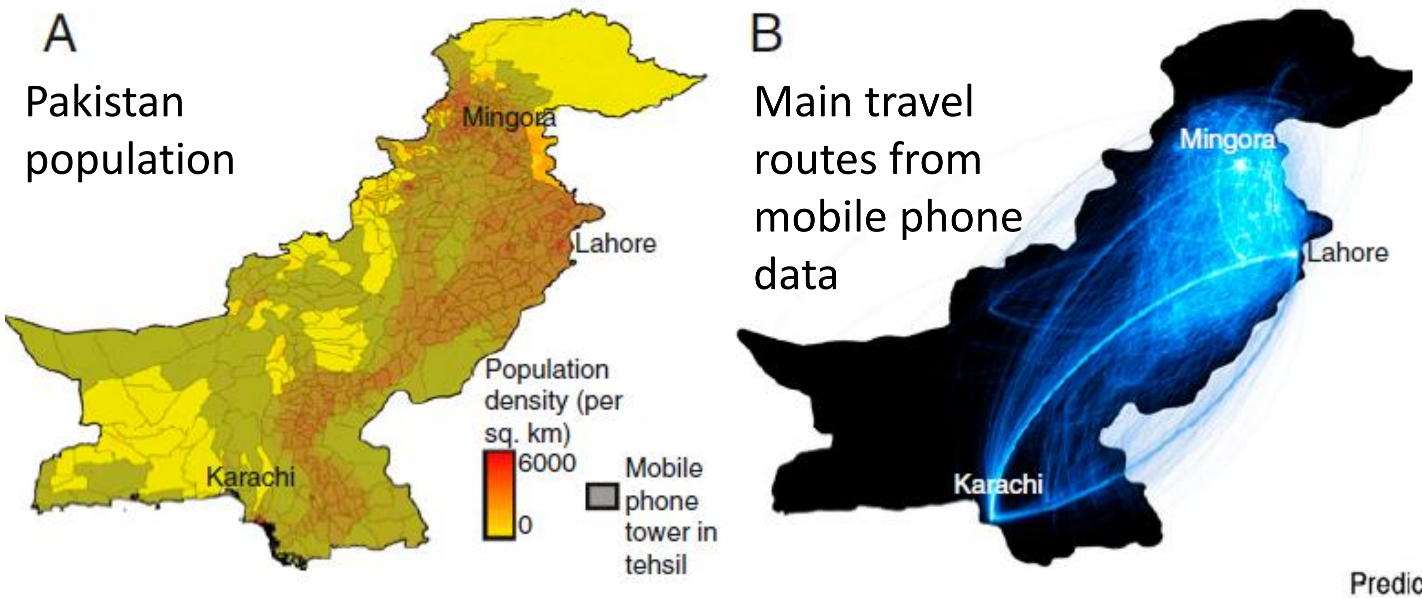
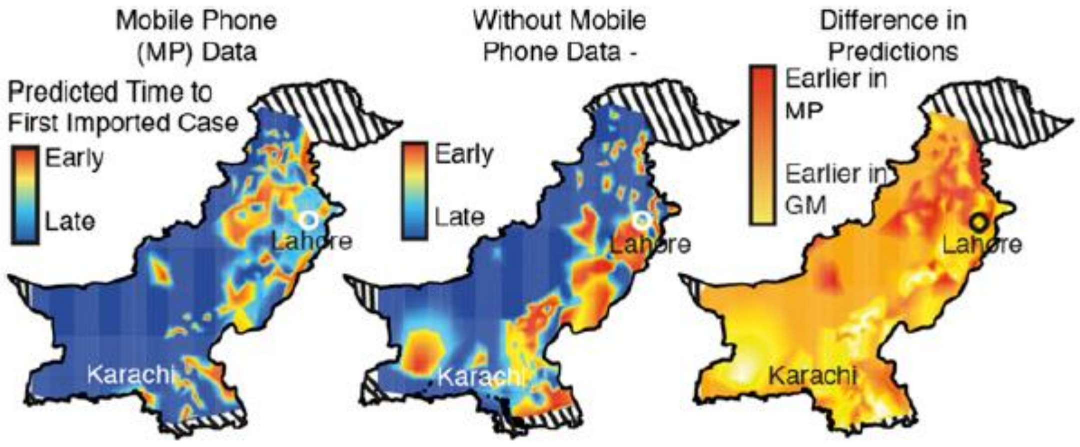


But…

- *Challenging and slow to access*
- *Spatially/temporally restricted (e.g. within country or few years)*
- *Privacy and consent concerns*



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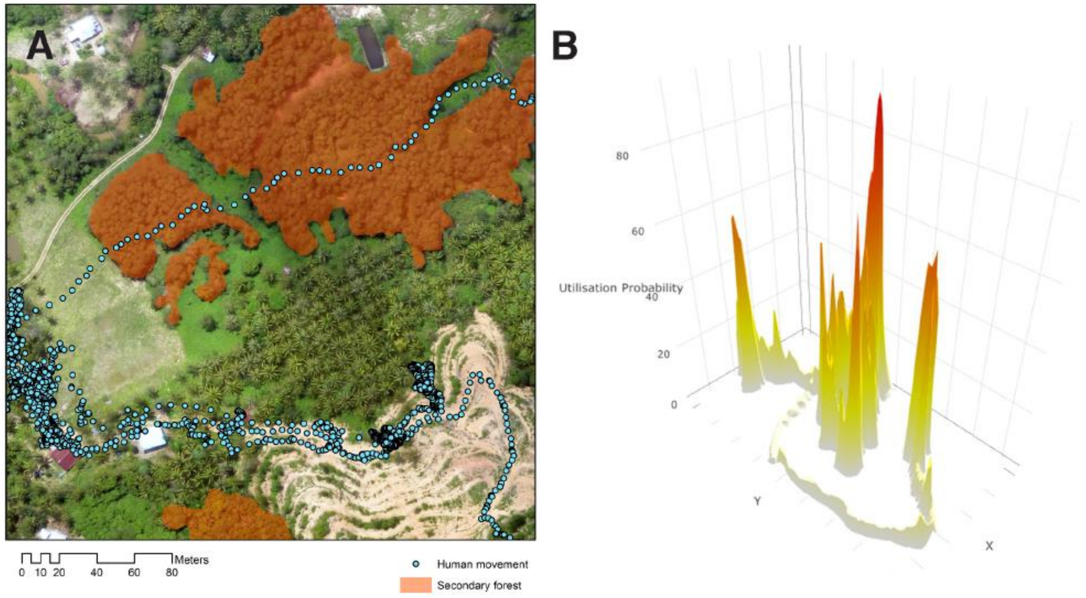
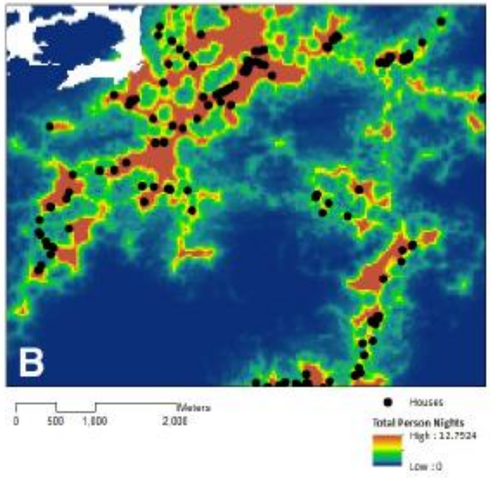
Another solution: GPS or other devices

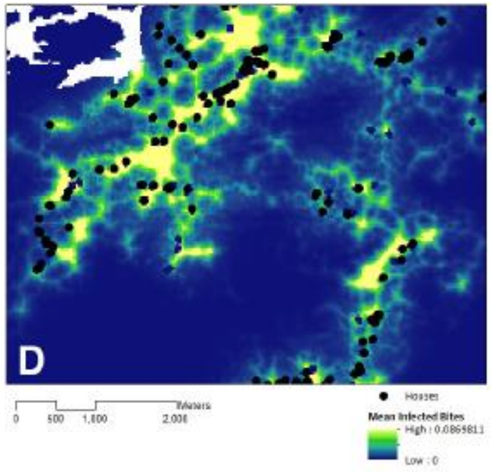
Individual activity spaces characterized using GPS…



Predicted overall distribution of human activity



Predicted distribution of infectious mosquito bites (*P. knowlsei*)



Fornace *et al.* 2019, eLife

Another solution: GPS or other devices

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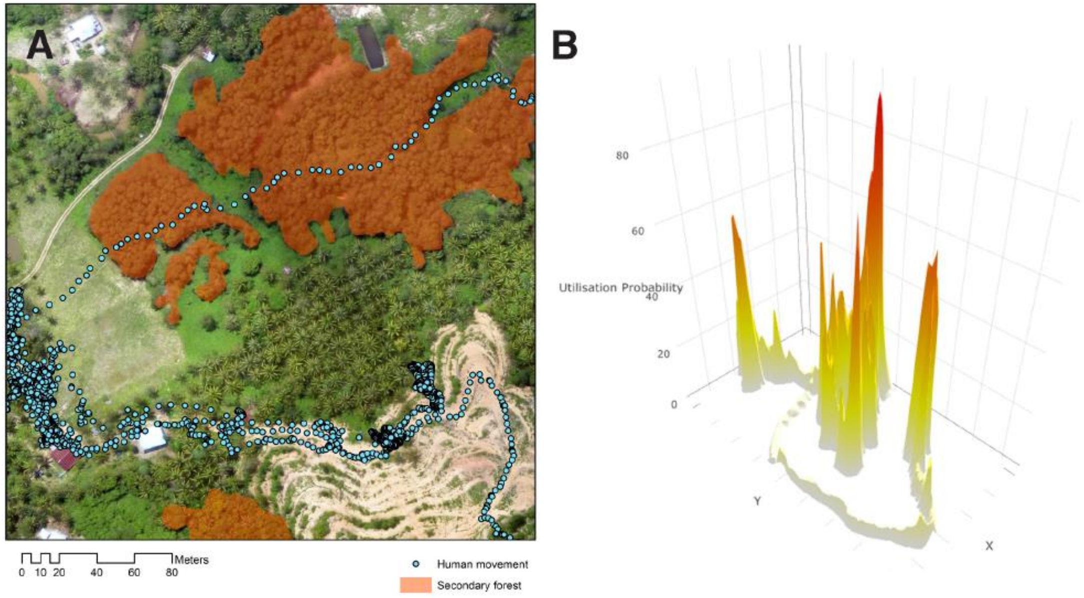

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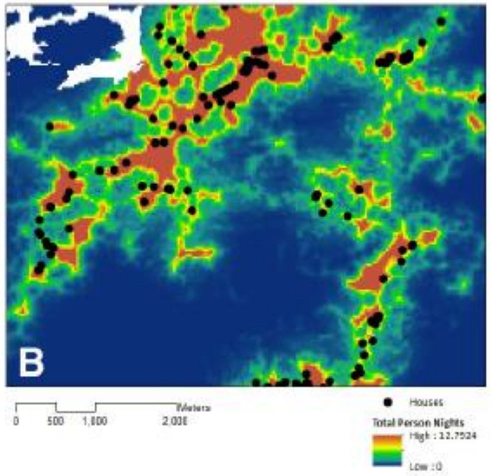

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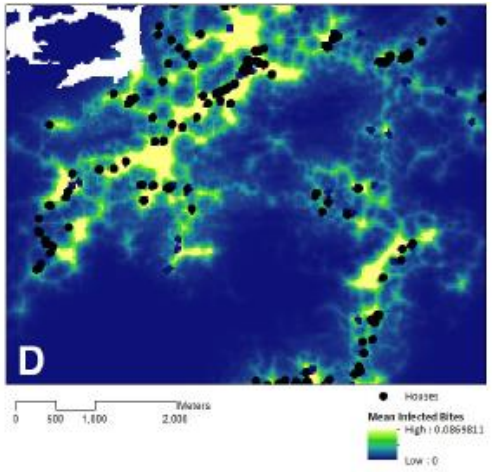


But…

- *Expensive and labour-intensive to collect*
- *So generally small-scale and short-term – appropriate for landscape studies but not necessarily large-scale epidemiological work*

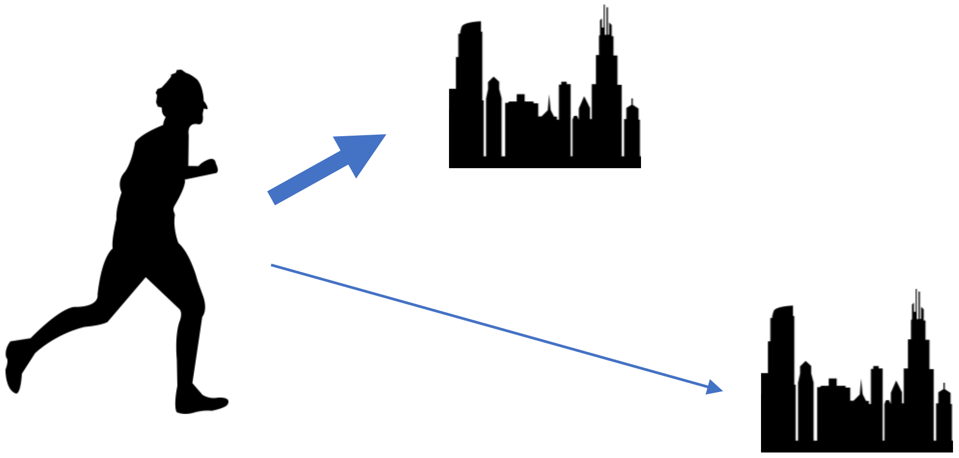
Fornace *et al.* 2019, eLife

Are there general “rules” of movement governing the likelihood of individuals moving from one location to another?

(Movement ecologists measure and predict these sorts of rules for wildlife, based on tracking or capture data – we tend to call them “resource selection functions”)

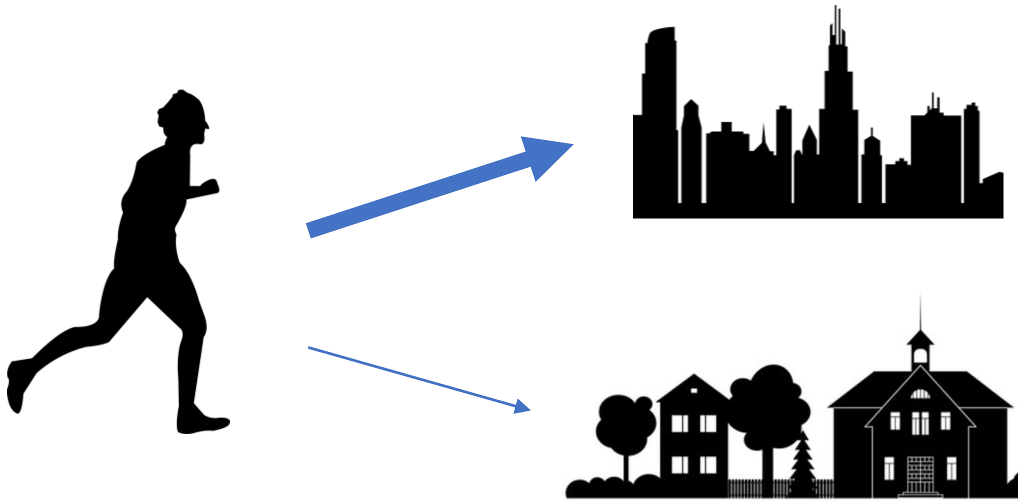
Some assumptions underpinning general human movement models

Proximity



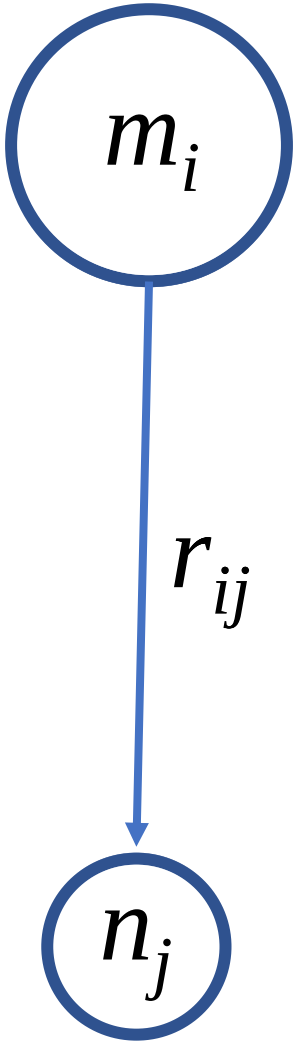
All else being equal, people are more likely to travel to more nearby locations

Attractiveness



People are more likely to travel to more populated locations, due to greater economic and social opportunities

The gravity model



$$T_{ij} = \frac{m_i^{\alpha} n_j^{\beta}}{f(r_{ij})} = \frac{\text{PopulationSource}^{\alpha} * \text{PopulationDest}^{\beta}}{\text{f(Distance)}}$$

Simplest formalization of the two assumptions: **the relative flux (or probability of movement) between two locations is proportional to some power of source and destination populations, penalized by a function of the distance between them**

Fast, flexible and widely used across economics, migration and epidemiology settings, *but* requires setting-specific mobility data to estimate attractiveness and distance-decay parameters (or some substantial assumptions)

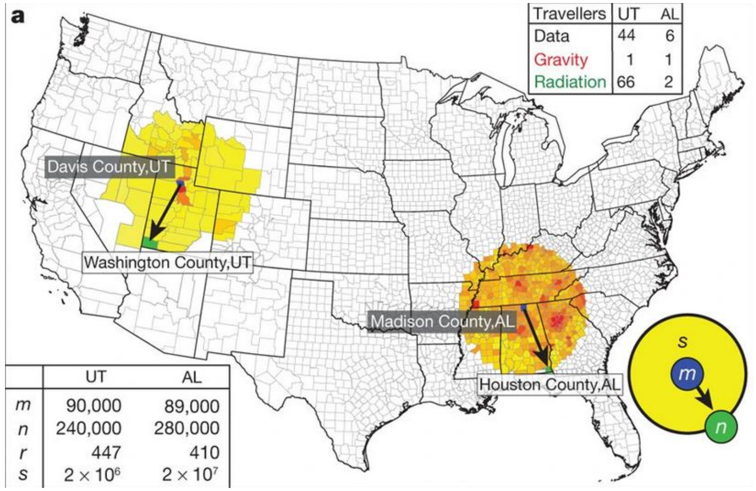
The radiation model

Total population within the radius r_{ij}

$$\langle T_{ij} \rangle = T_i \frac{m_i n_j}{(m_i + s_{ij})(m_i + n_j + s_{ij})}$$

A universal model for mobility and migration patterns

Filippo Simini[1,2,3], Marta C. González[4], Amos Maritan[2] & Albert-László Barabási[1,5,6]



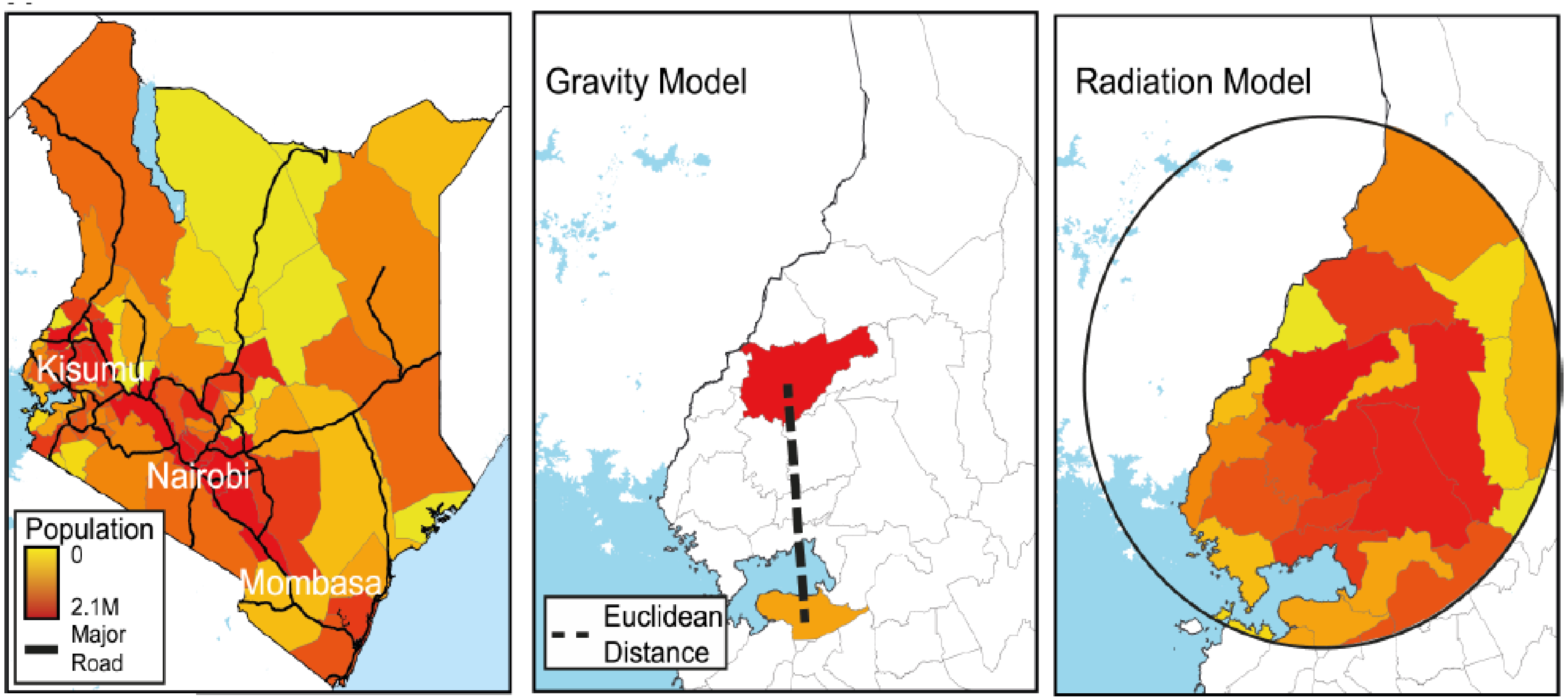
Simini *et al.* 2012, Nature

Based on the same principles as the gravity model, but **also accounts for the competitive pull of other densely populated areas more nearby than the destination.**

Relative fluxes between destinations are parameter-free – so can be applied without using context-specific data.

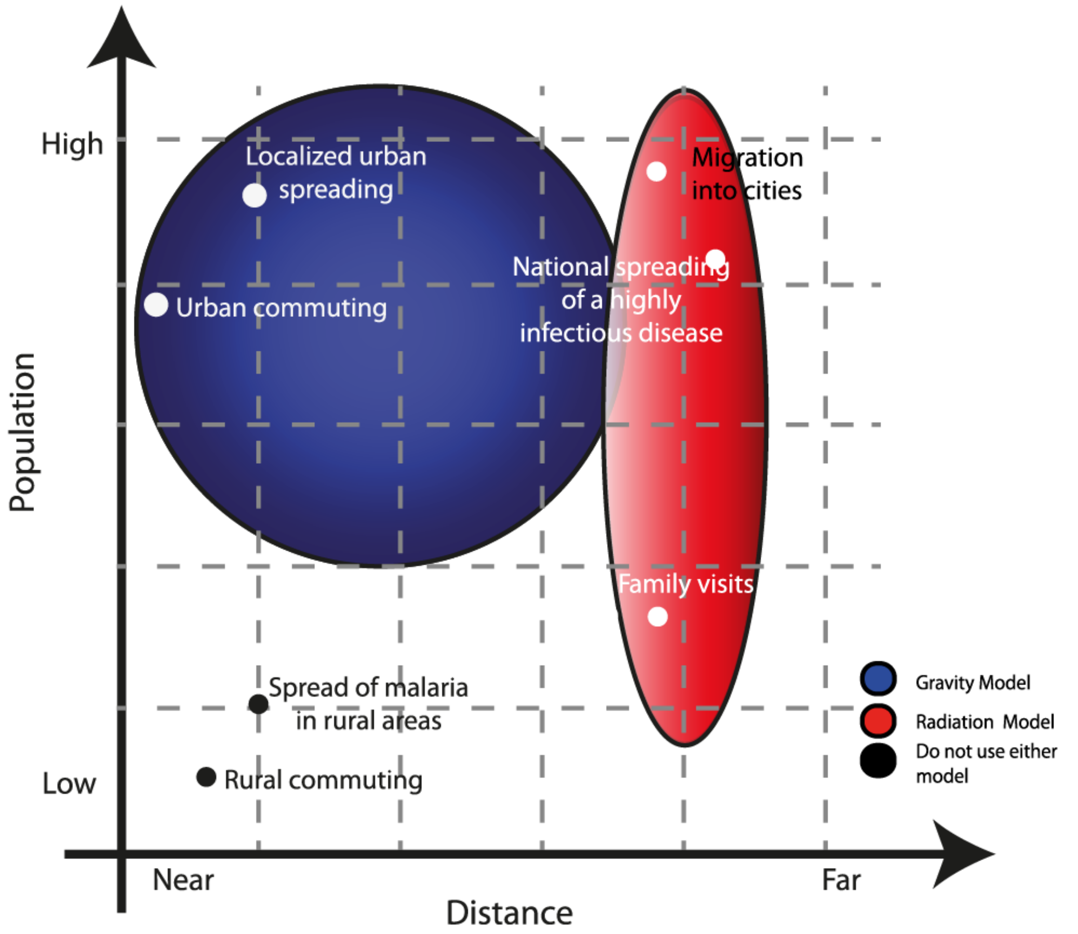
However, developed and validated against USA mobility information – how generalisable?

Comparative schematic of gravity and radiation models



Wesolowski *et al.* 2015, PLoS Comp Biol

A comparison of gravity and radiation model applications in LMIC settings



General guidance based on comparison of performance against mobile phone data in several African countries (but may be difficult to apply in practice)

Wesolowski *et al.* 2015, PLoS Comp Biol

More proposed “universal” laws of mobility..

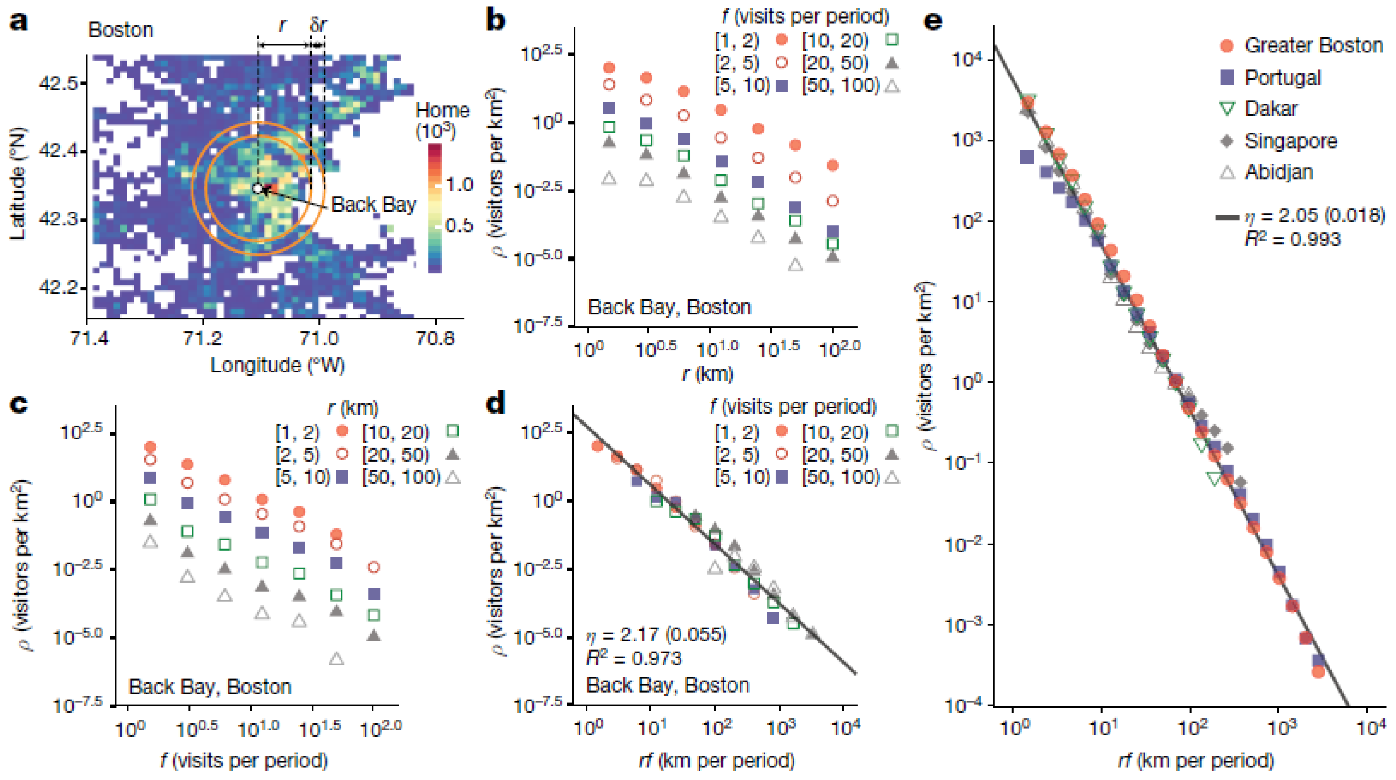
Article

The universal visitation law of human mobility

https://doi.org/10.1038/s41586-021-03480-9

Received: 30 May 2017

Accepted: 22 March 2021



There are likely to be many useful forms of human mobility models – in many cases incorporating *some* mobility proxies may be better than including *none*

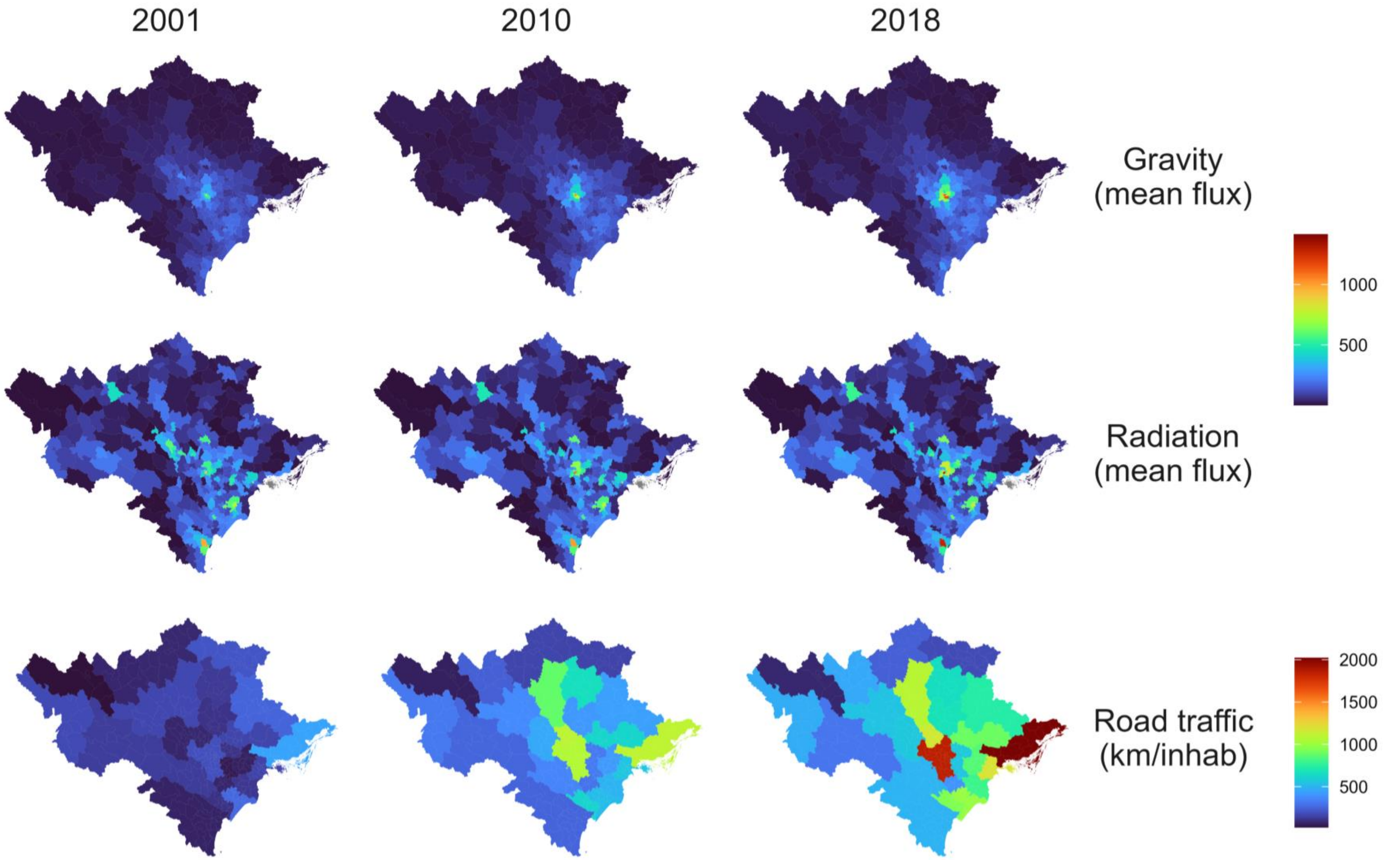
Schlapfer *et al.* 2021, Nature

Advantages and disadvantages of different mobility models

I ran out of time to do this.

If it is useful, I can do this and add it to the GitHub repo – let me know.

Example: long term mobility trends in north Vietnam



Some tutorial code in R