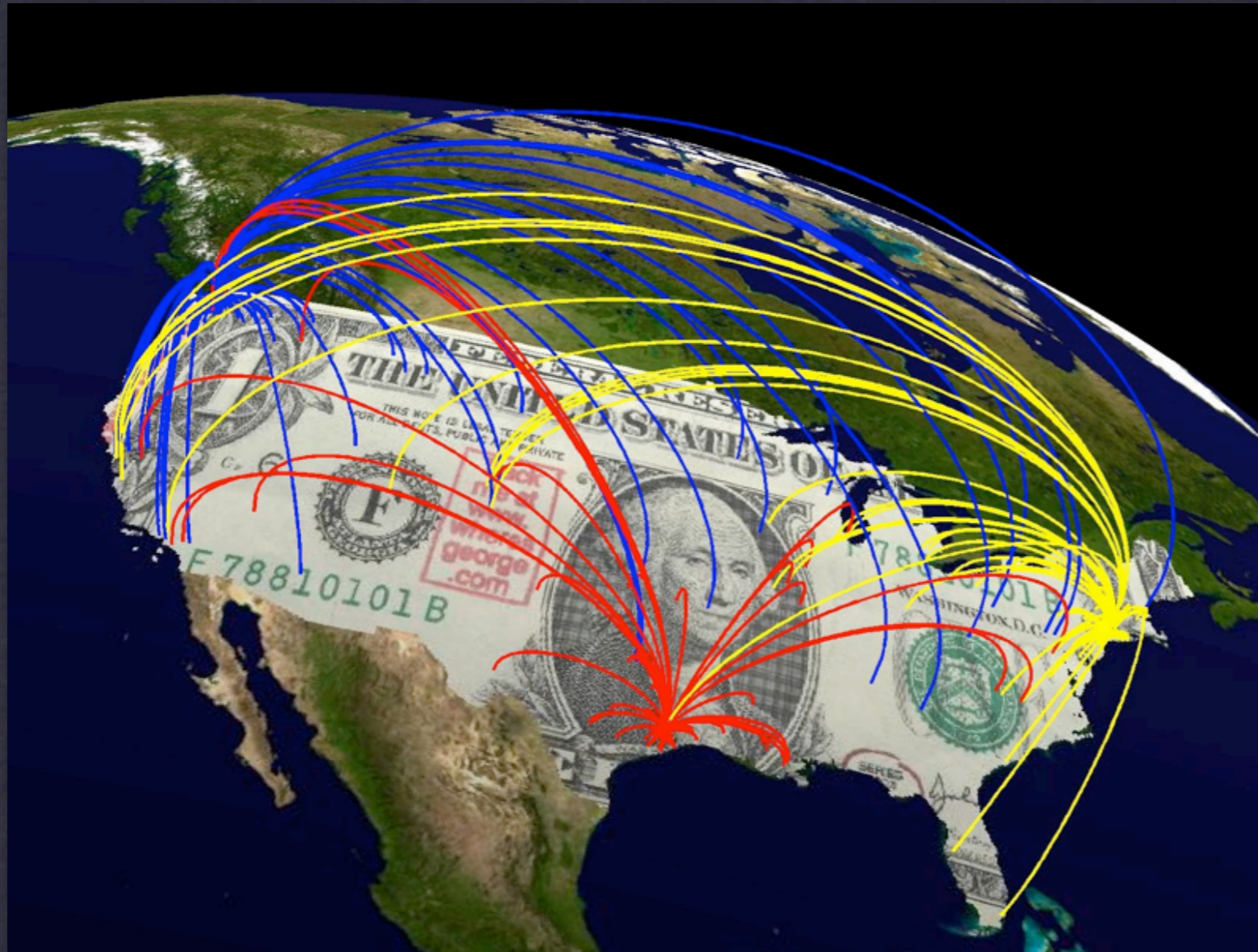


“Feel sick? Follow the money!”

Scaling Laws and Network Perspectives on Human Mobility



Dirk Brockmann

ESAM

Northwestern University,
Evanston, IL &

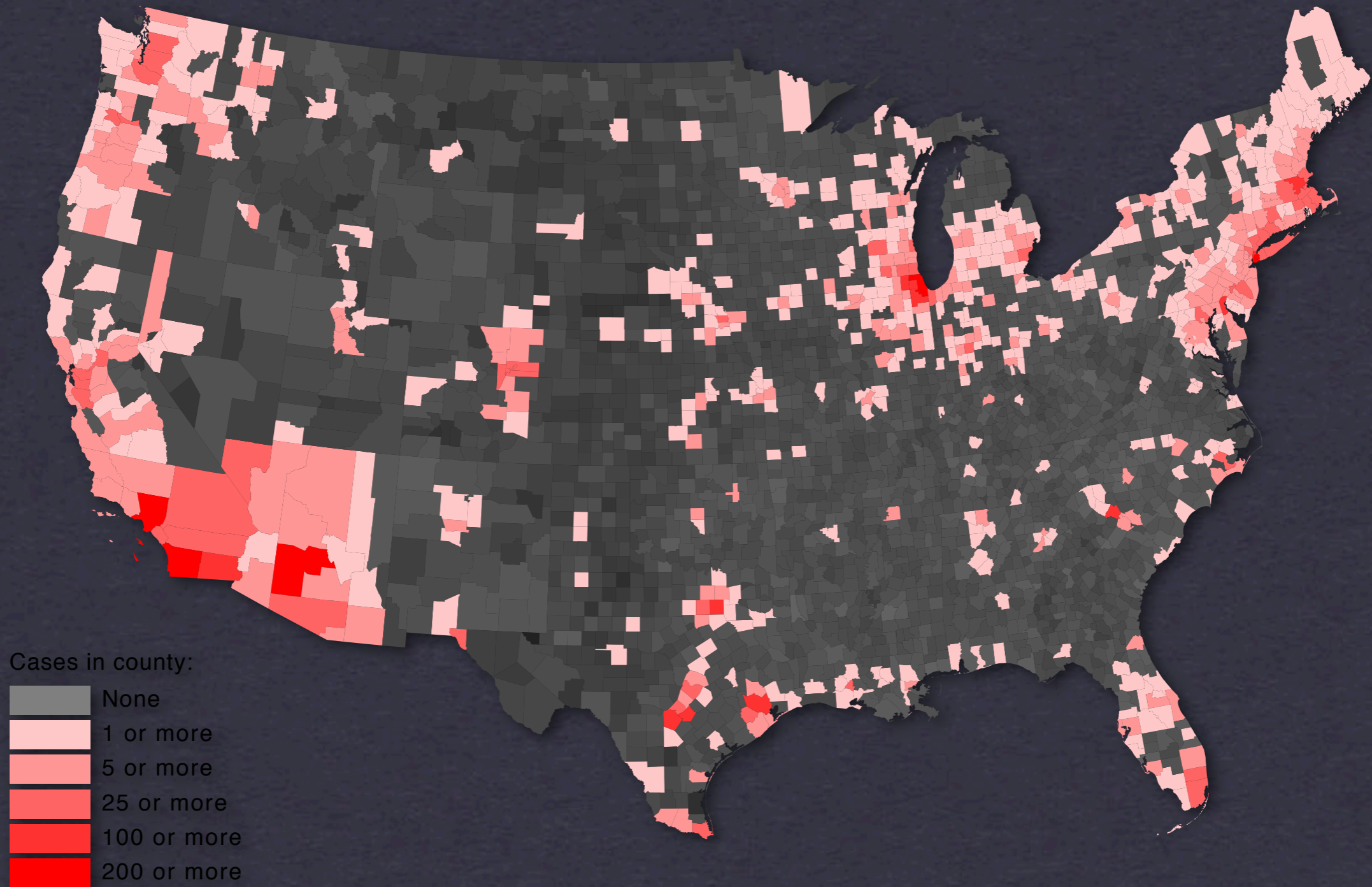
Northwestern Institute on
Complex Systems



Brockmann, D., Hufnagel, L., Geisel, T., *Nature*, 2006

Hufnagel, L., Brockmann, D. & Geisel, T., *Proc. Natl. Acad. Sci.*, 2004

the questions



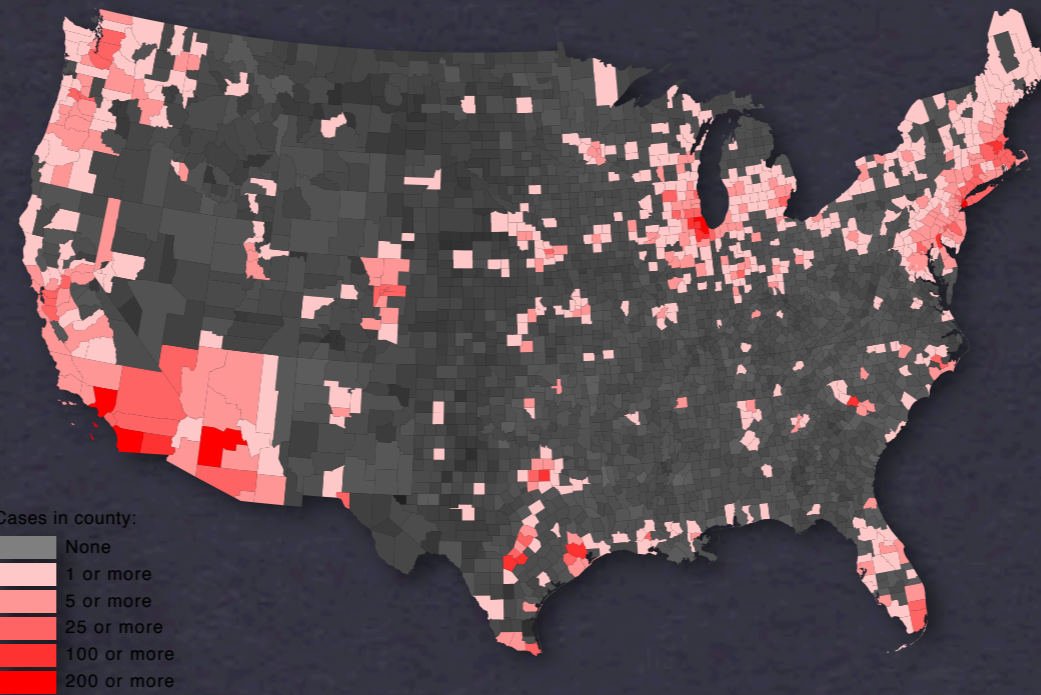
Dirk Brockmann

ESAM & NICO

Northwestern University

<http://rocs.northwestern.edu>

the questions



Where?

When?

How many?



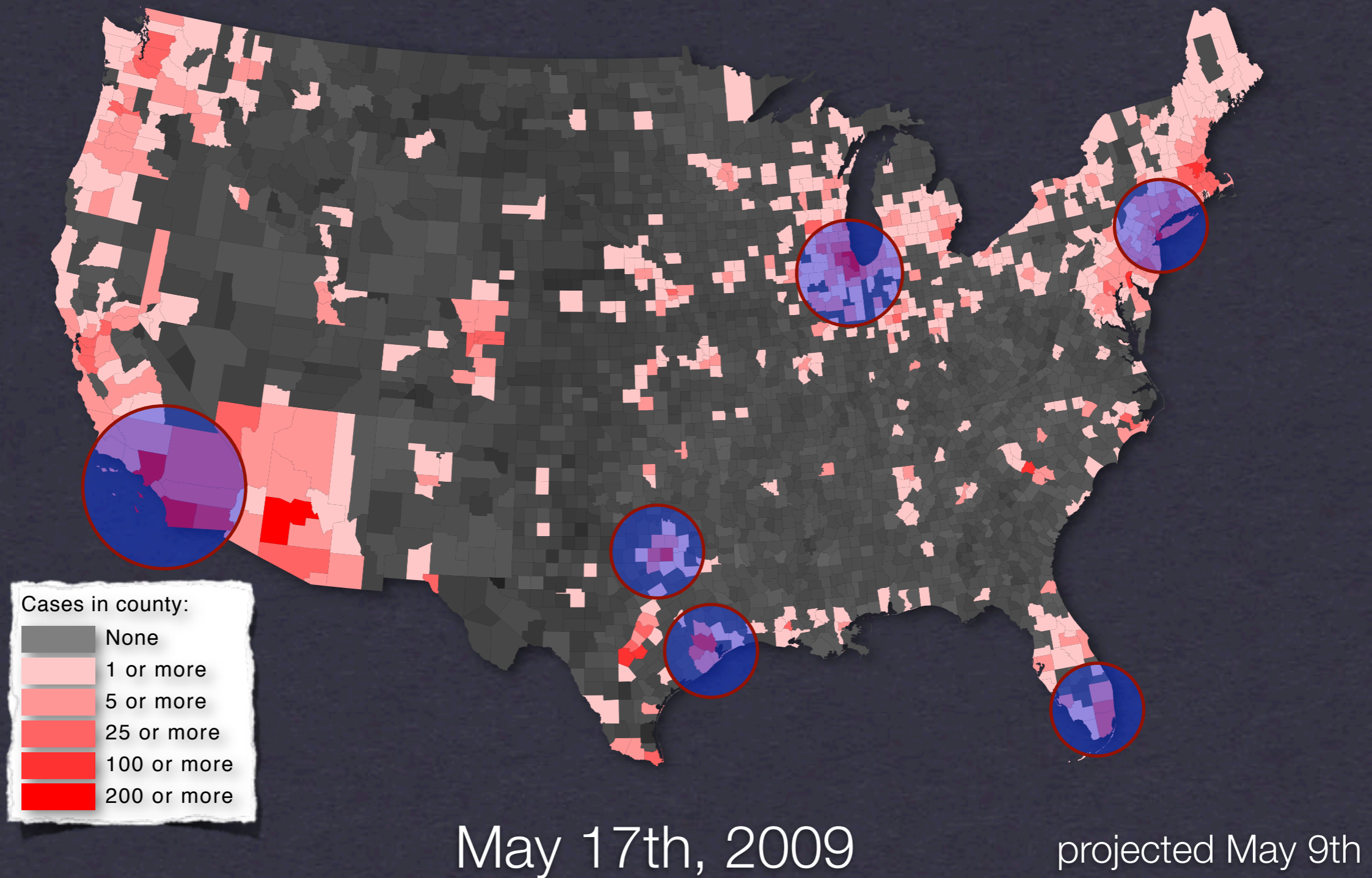
Dirk Brockmann

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<http://rocs.northwestern.edu>

where?



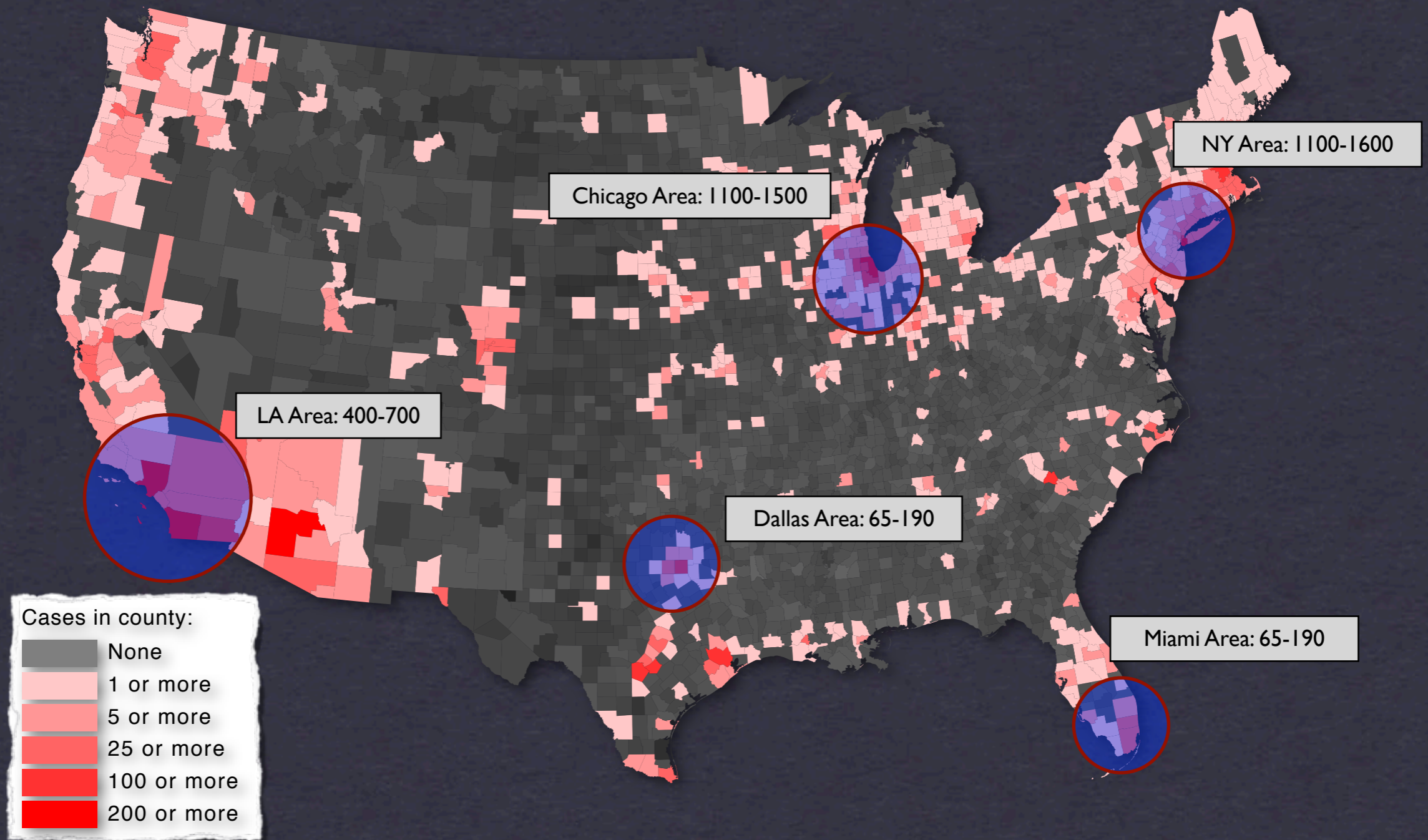
Dirk Brockmann

ESAM & NICO

Northwestern University

<http://rocs.northwestern.edu>

how many?



May 17th, 2009

projected May 9th



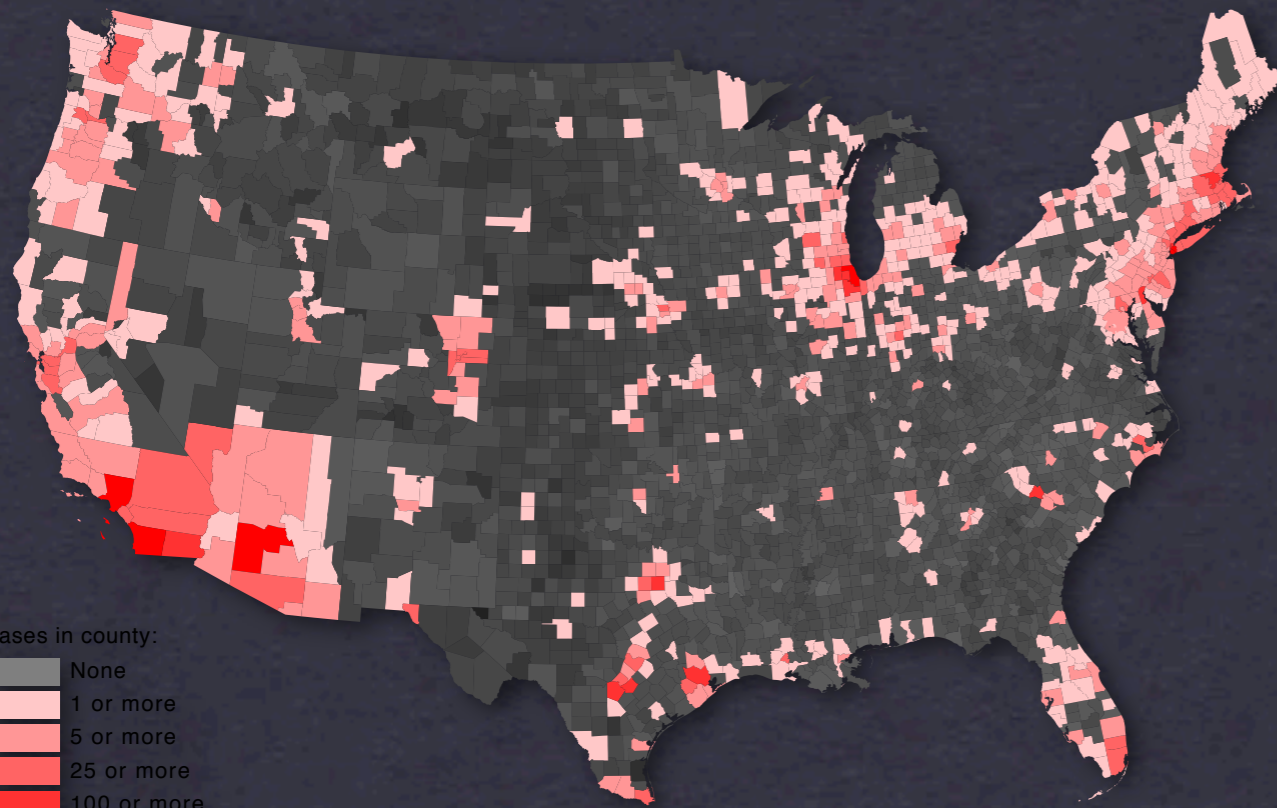
Dirk Brockmann

ESAM & NICO

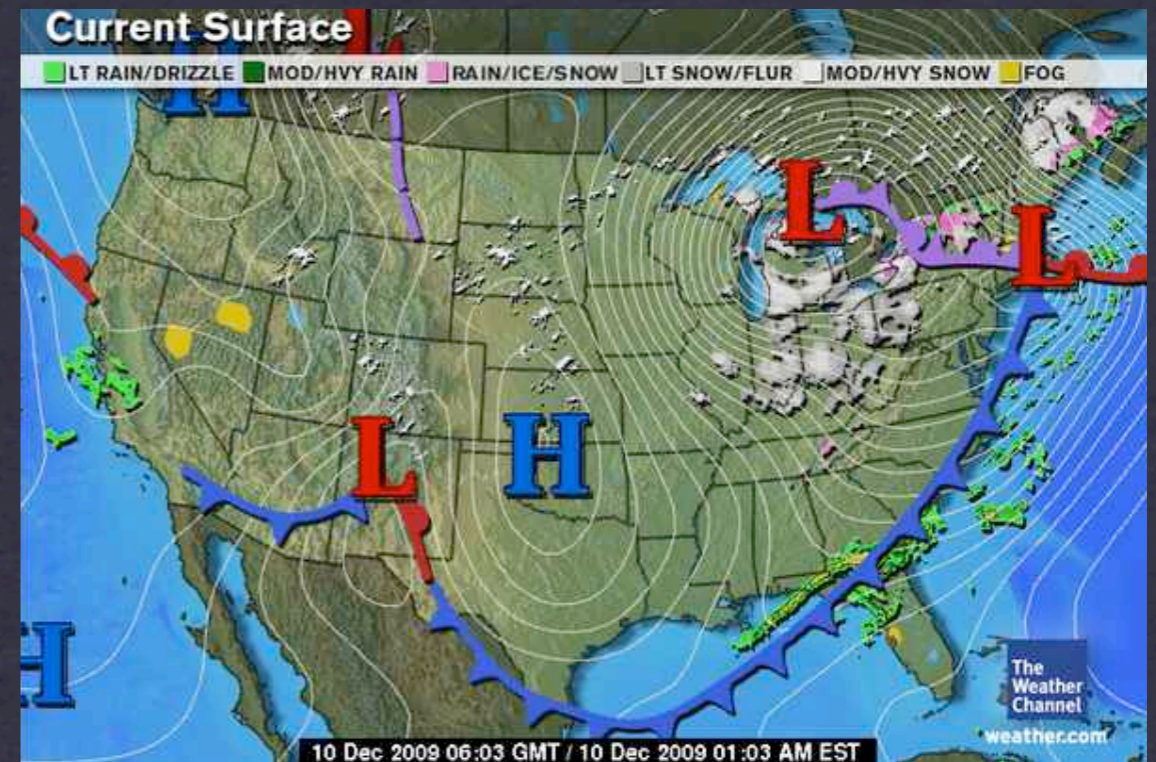
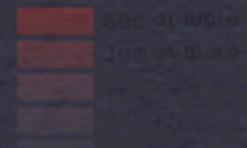
Northwestern University

<http://rocs.northwestern.edu>

complex phenomena



Cases in county:



Dirk Brockmann

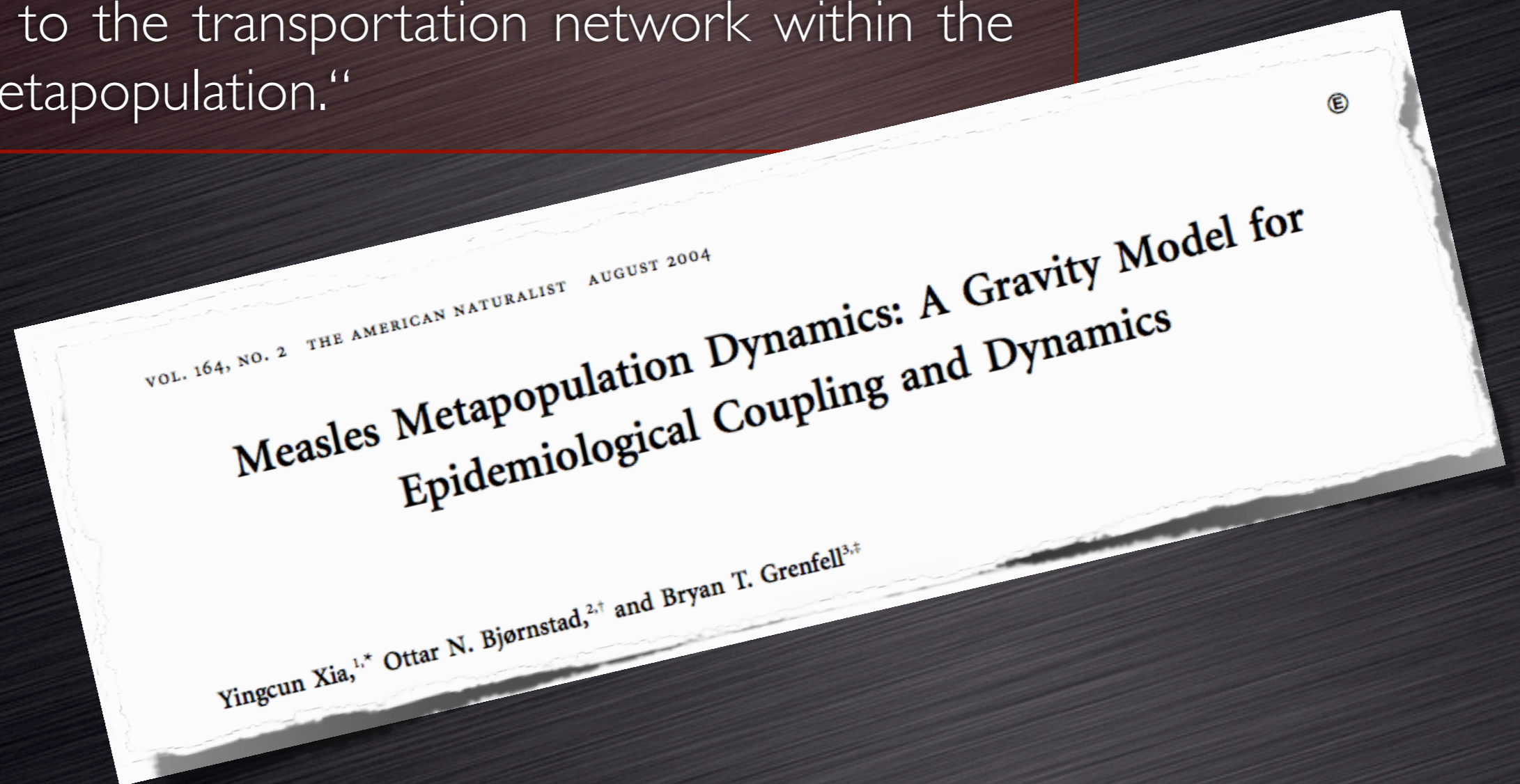
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why?

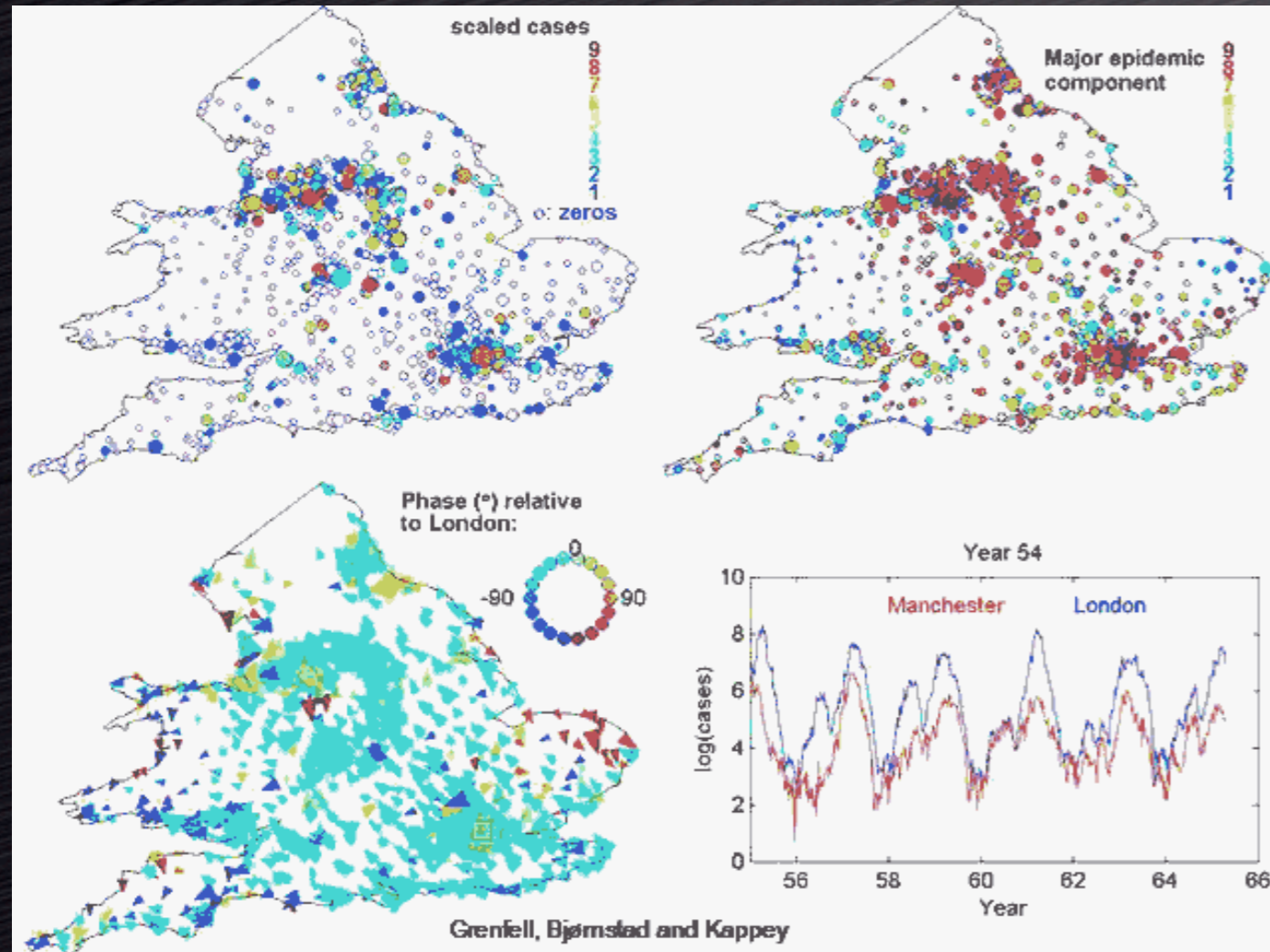
„Spatial transmission of directly transmitted infectious diseases is ultimately tied to movement by the hosts. [...] spatial spread (the disease's spatial coupling) may therefore be expected to be related to the transportation network within the host metapopulation.“



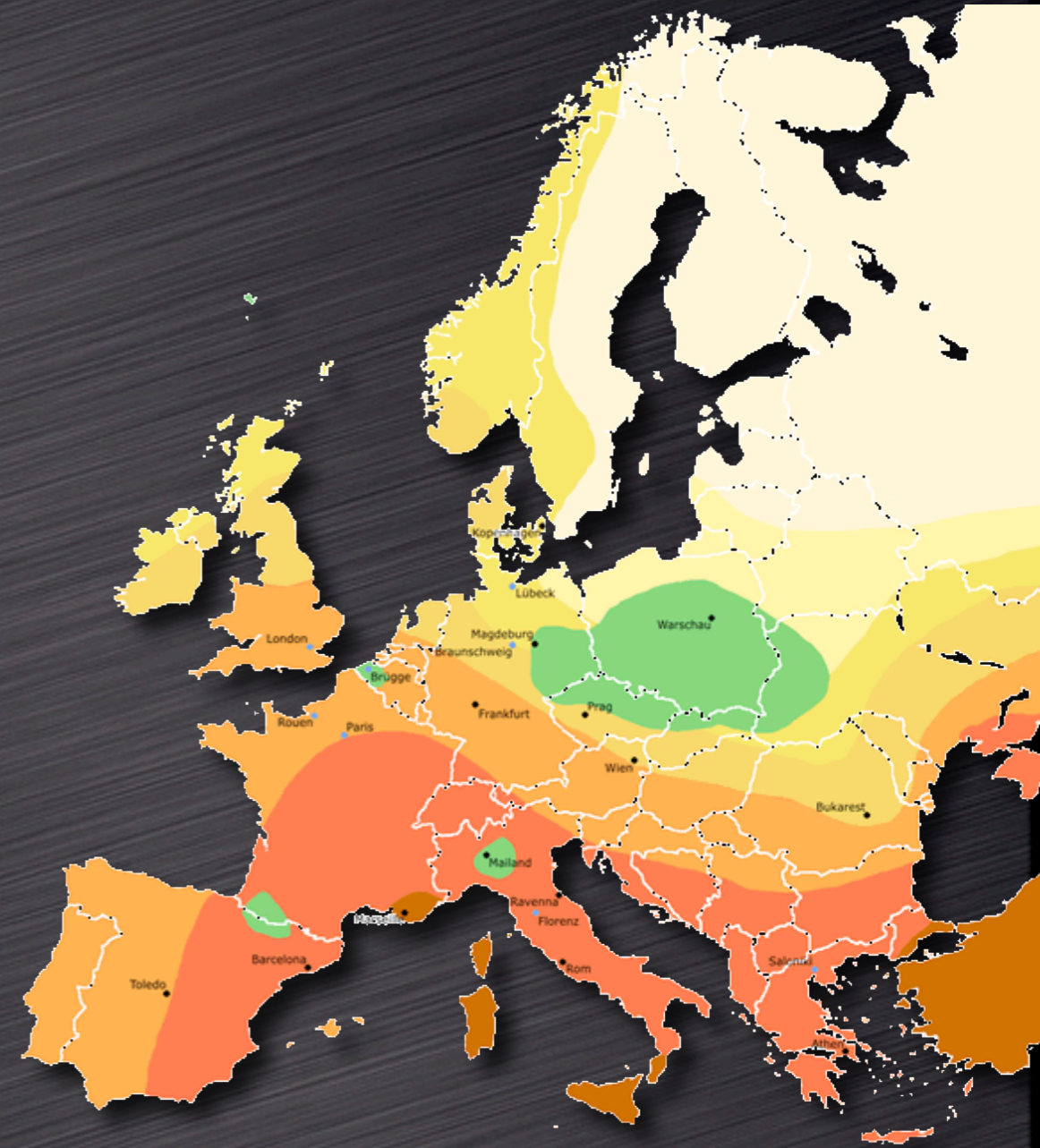
geography and spatial dynamics of disease

“black death” (1347-1350)

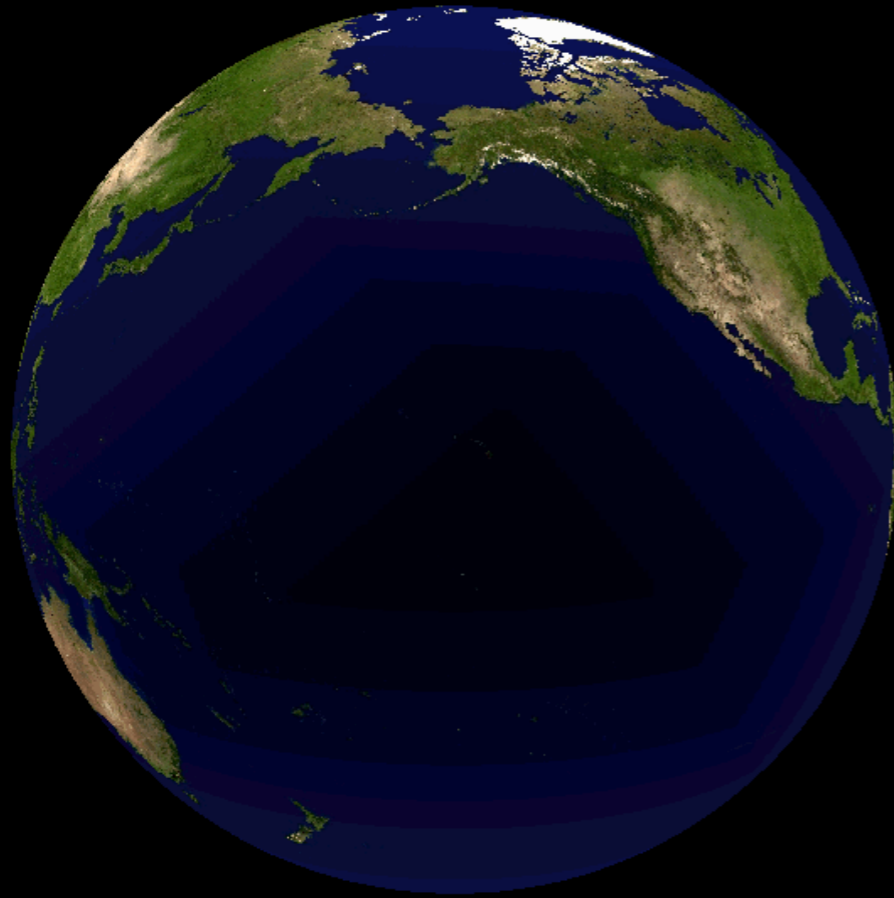
measles GB (1956-1965)



Grenfell, B. T., Bjørnstad, O. N. & Kappey, J. Nature 414, 716 (2001).

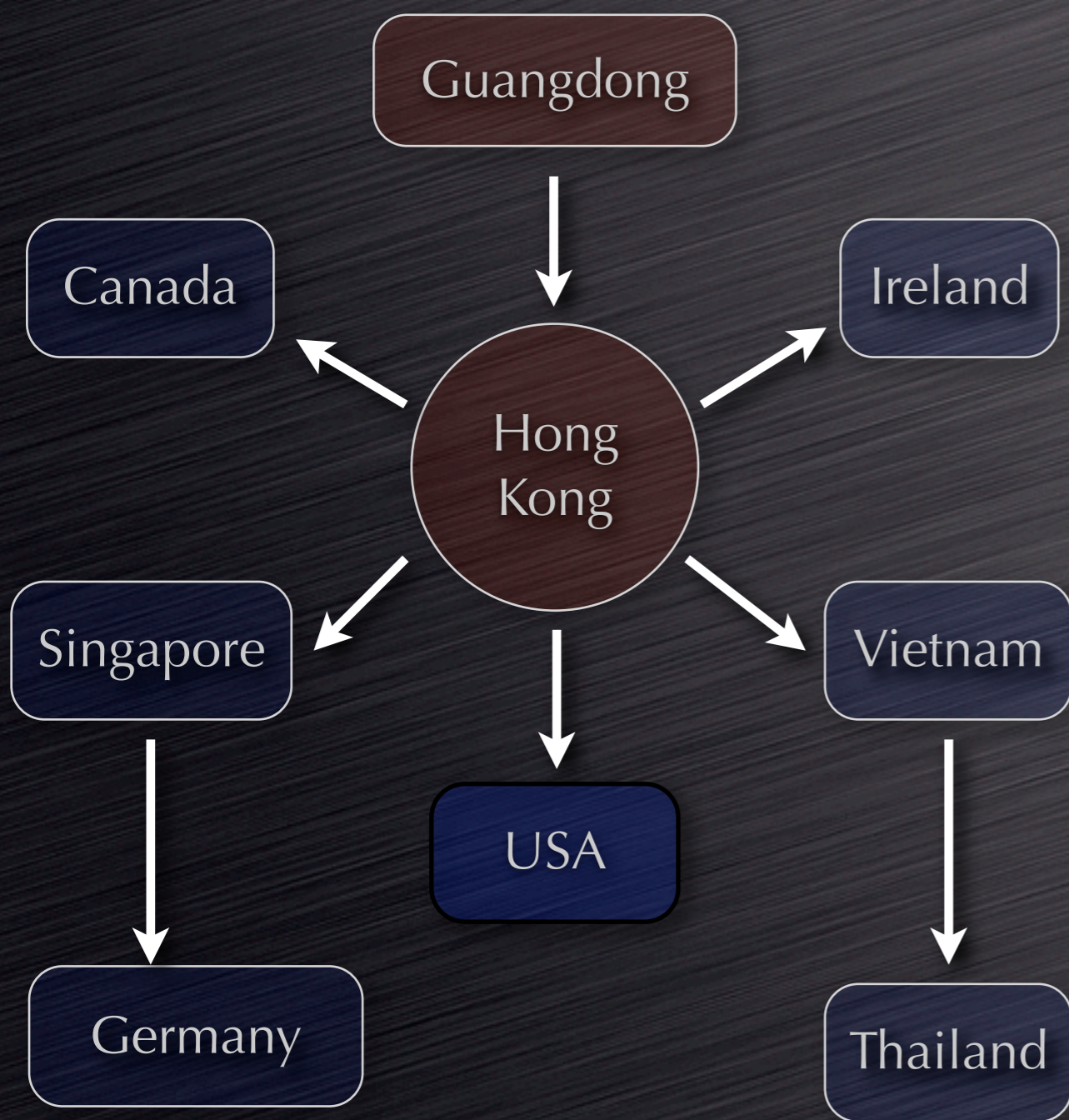


travel in the 21st century

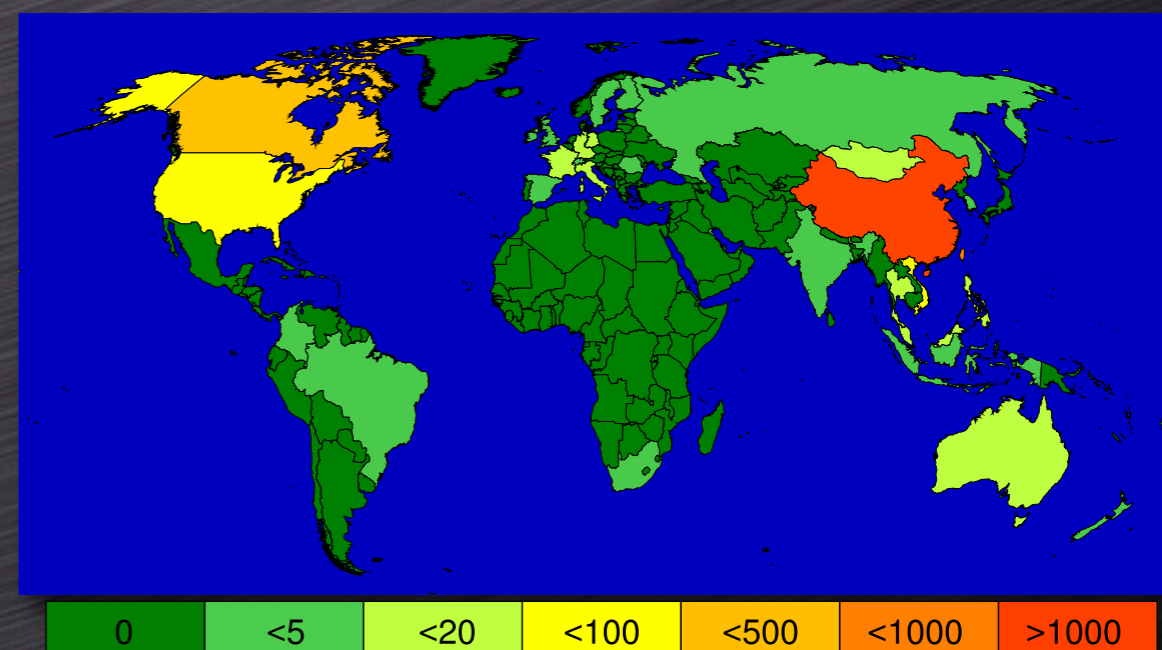


- 3 billion passengers/yr.
- 4095 airports
- 2 Mio. flights/week

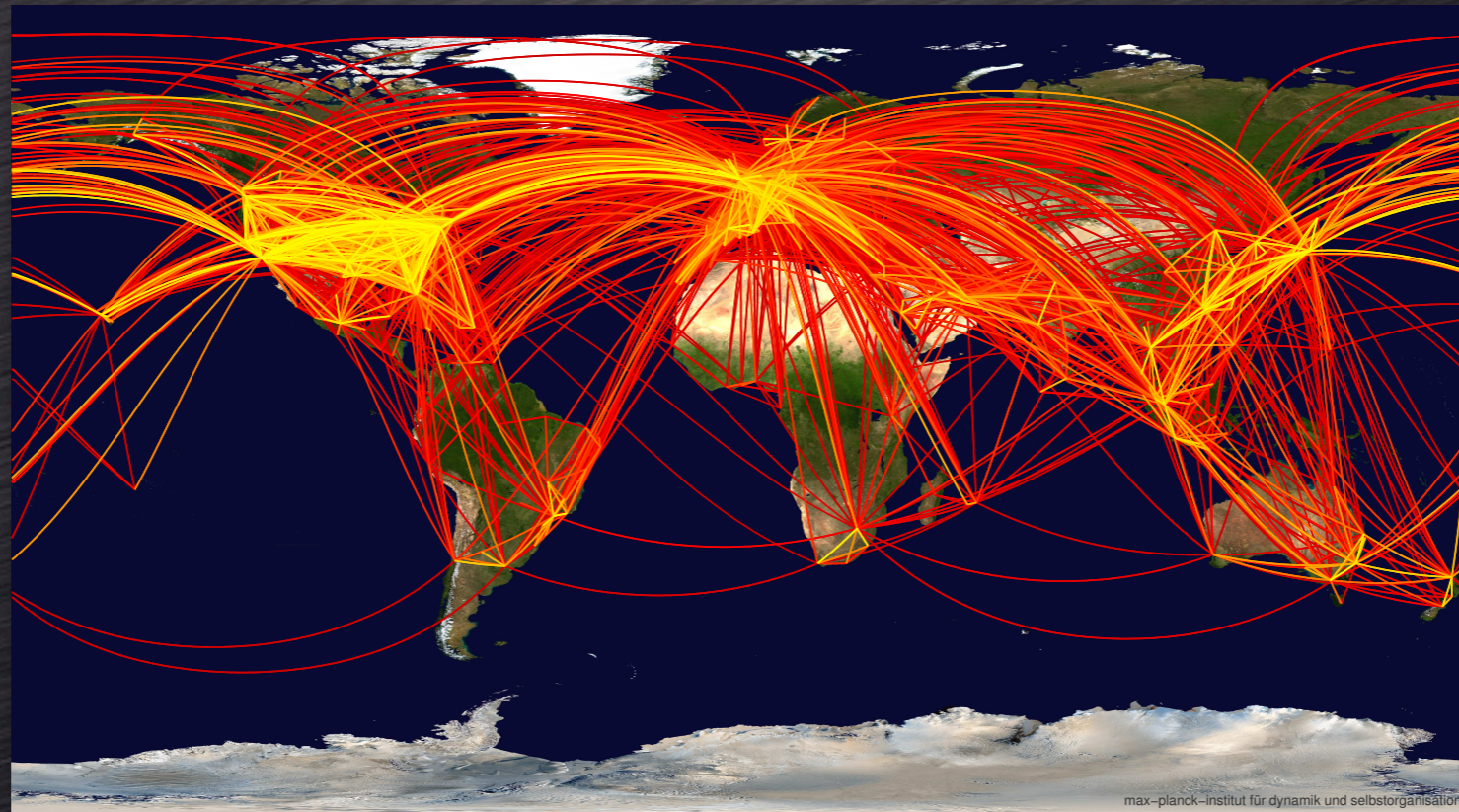
the „severe acute respiratory syndrome” (SARS)



- caused by coronavirus
- first outbreak: China
- February 2003 in Hong Kong
- worldwide spread in over 30 countries
- approx 8000 infections



the first model for the worldwide spread of an epidemic



- Is it possible to **describe & predict** the spread of human infectious diseases based on human air transportation?

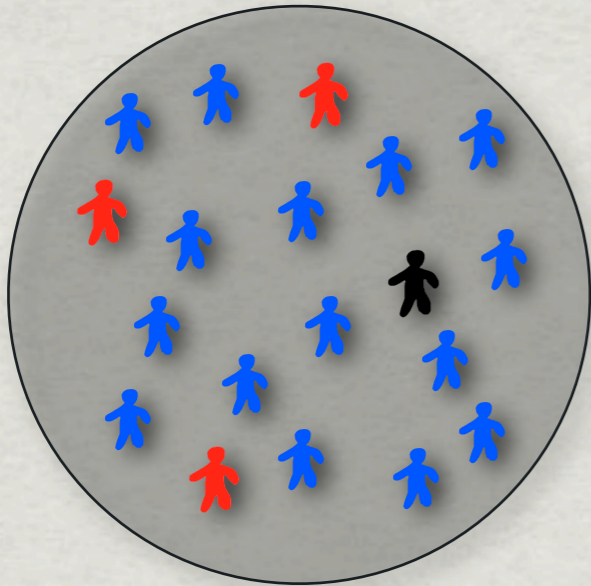
Hufnagel, L., Brockmann, D. & Geisel, T., *Proc. Natl. Acad. Sci.*, 2004



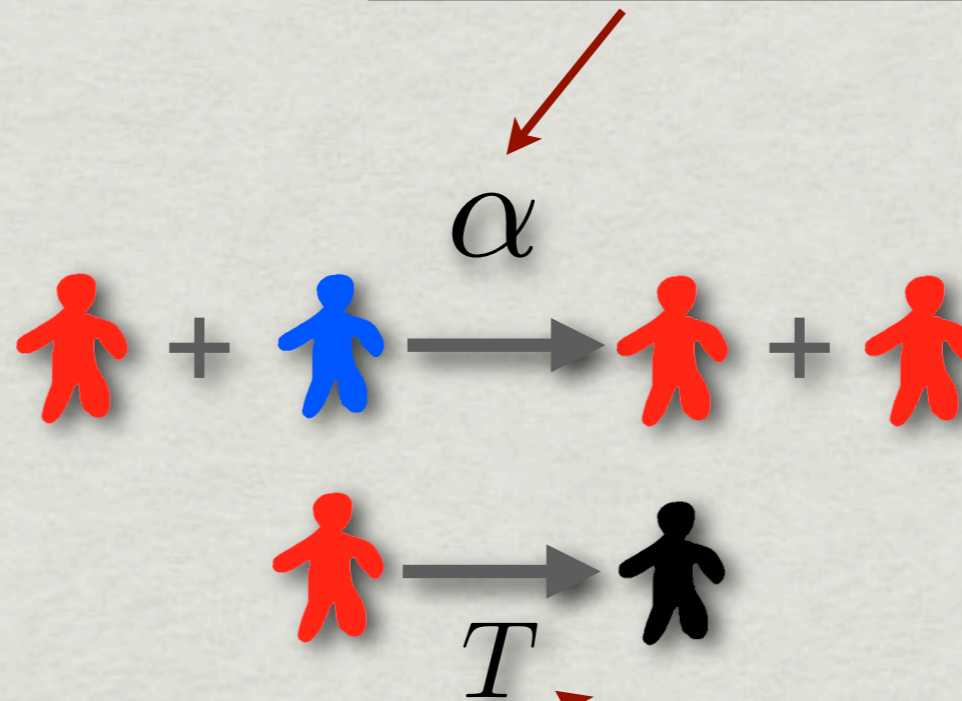
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the SIR model

N ← Population Size



infection rate:
e.g. 2 effective contacts/week

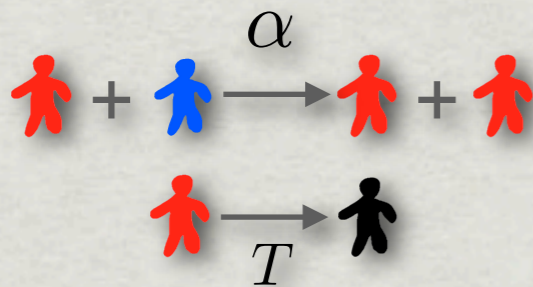
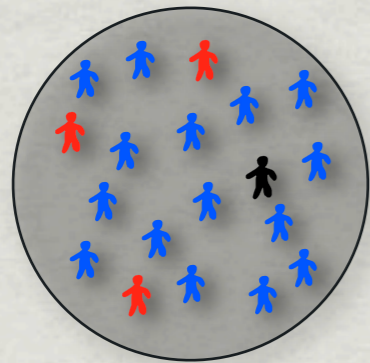


infectious period
e.g. 4 days.

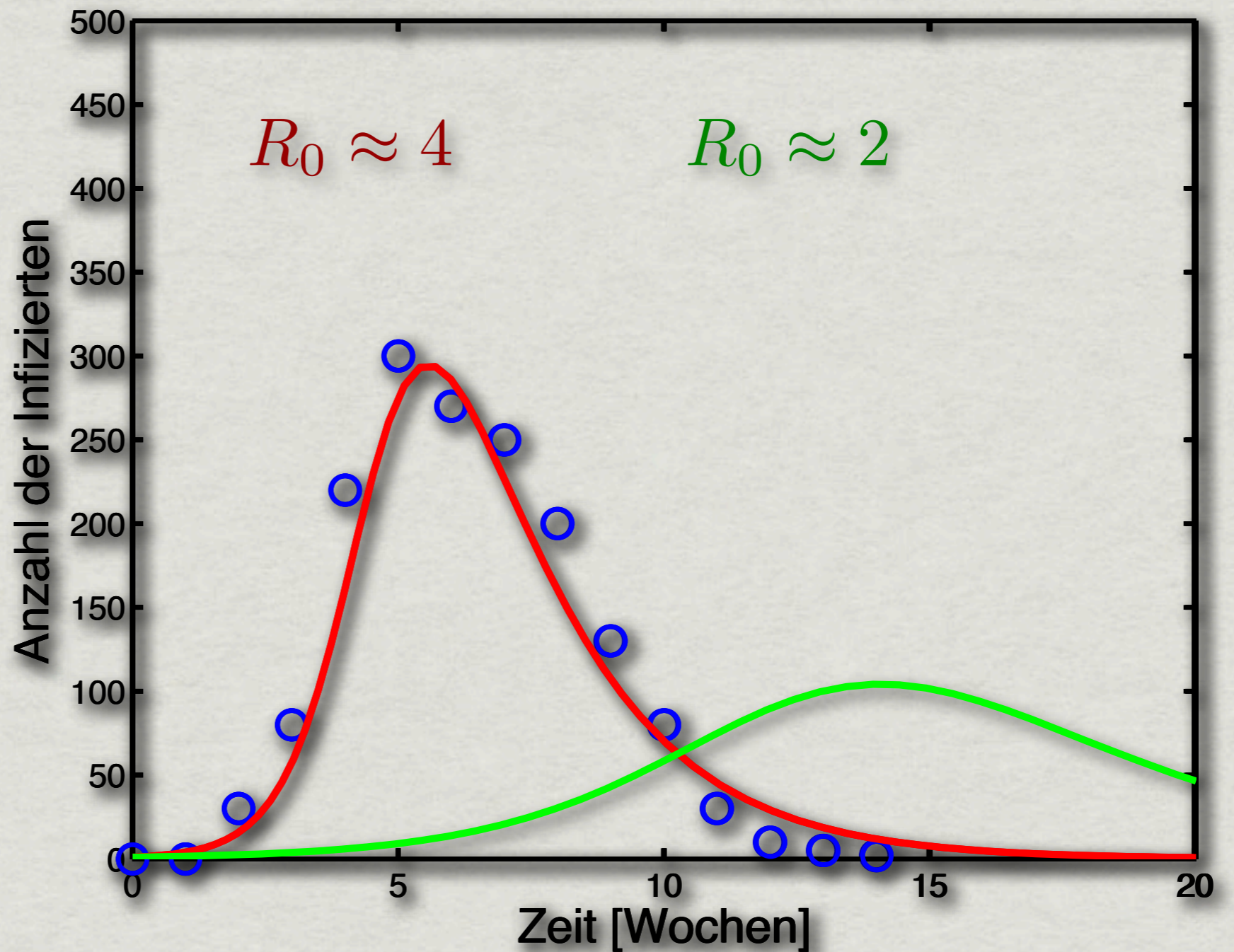
The basic reproduction number

$$\alpha \times T = R_0 > 1$$

example: measles in boarding school UK



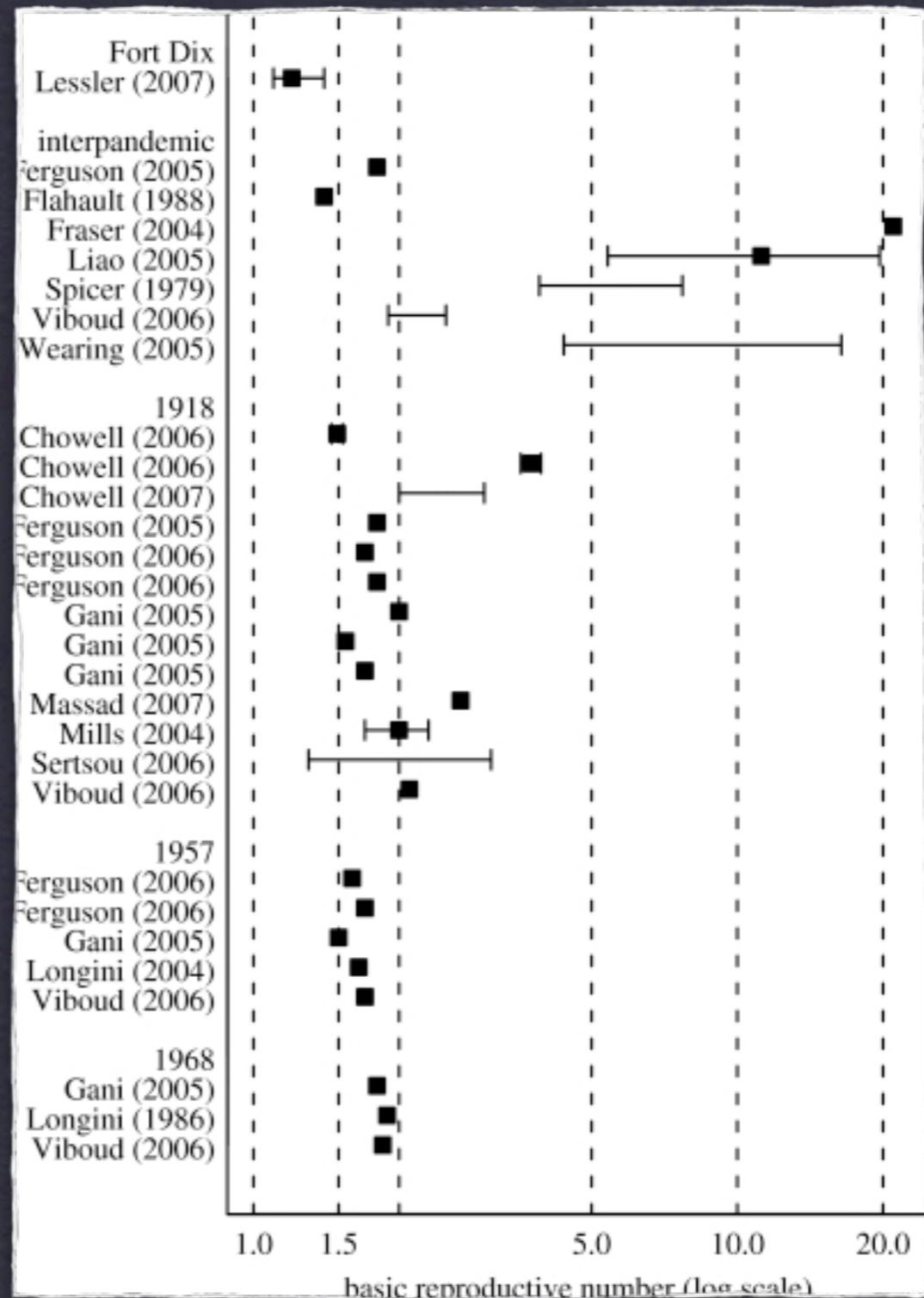
- $N = 763$
- $T = 2$ weeks



The basic reproduction number

R_0

The **average** number of secondary infection caused by one infected individual in an **entirely susceptible** population



model for the worldwide spread of an epidemic



Is it possible to describe (& and at some point predict) the global spread of human infectious diseases based on human air transportation?

Hufnagel, L., Brockmann, D. & Geisel, T., *PNAS*, 2004



Dirk Brockmann

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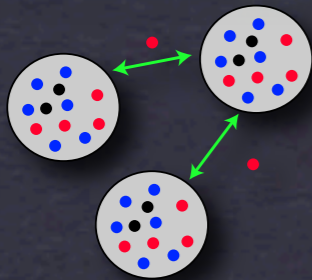
Northwestern University

<http://rocs.northwestern.edu>

a model for the global spread of SARS

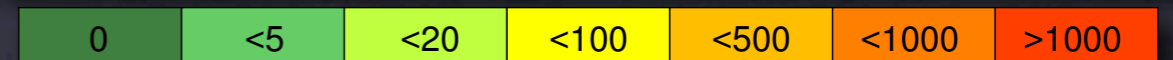
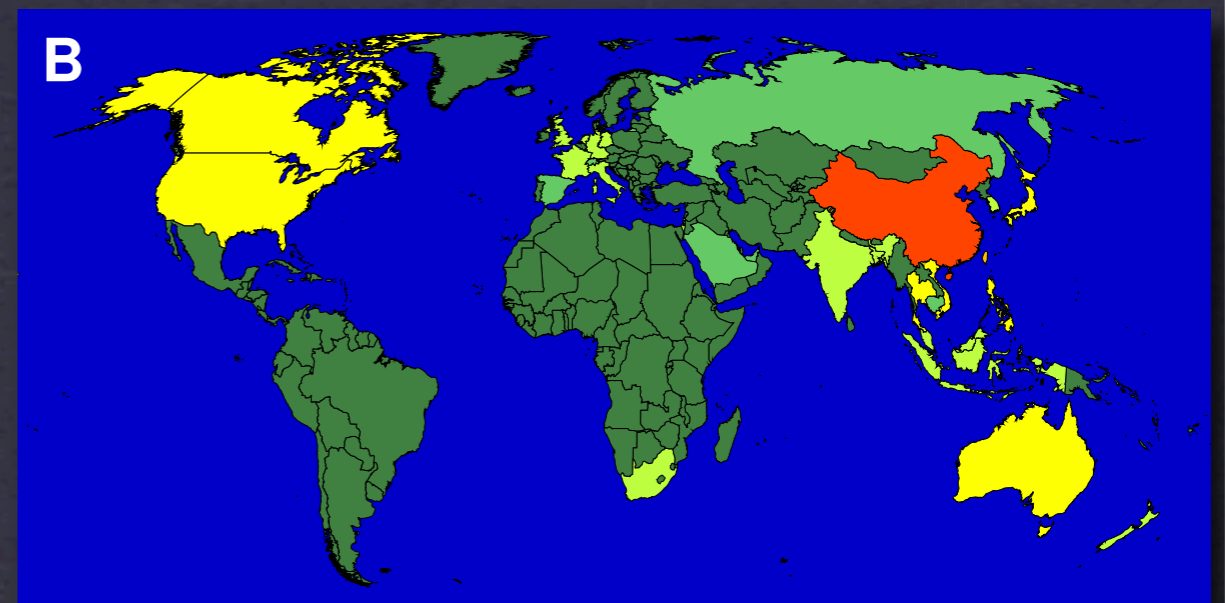
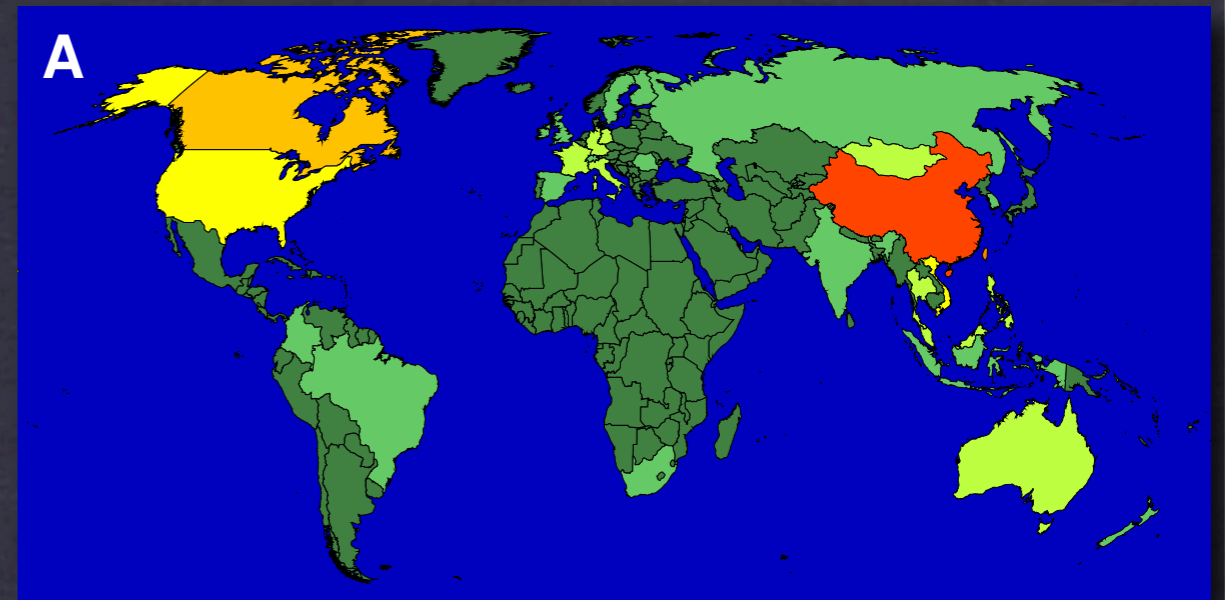
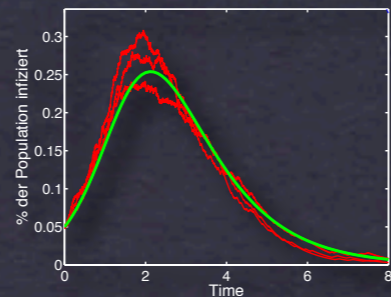


LOCAL SIR DYNAMICS



+

↓



A: WHO B: MODEL

Hufnagel, L., Brockmann, D. & Geisel, T., *PNAS*, 2004



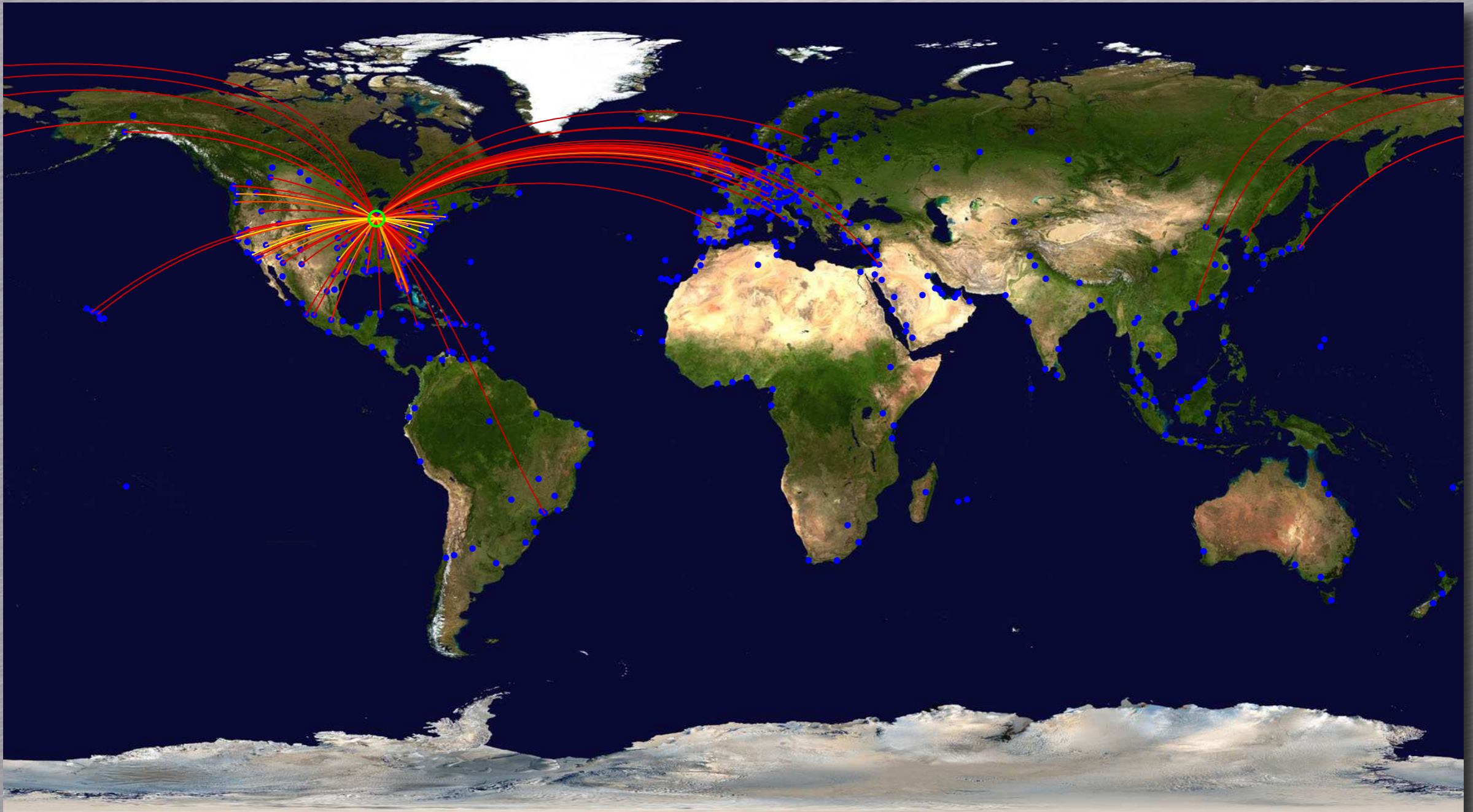
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Chicago vs. Frankfurt



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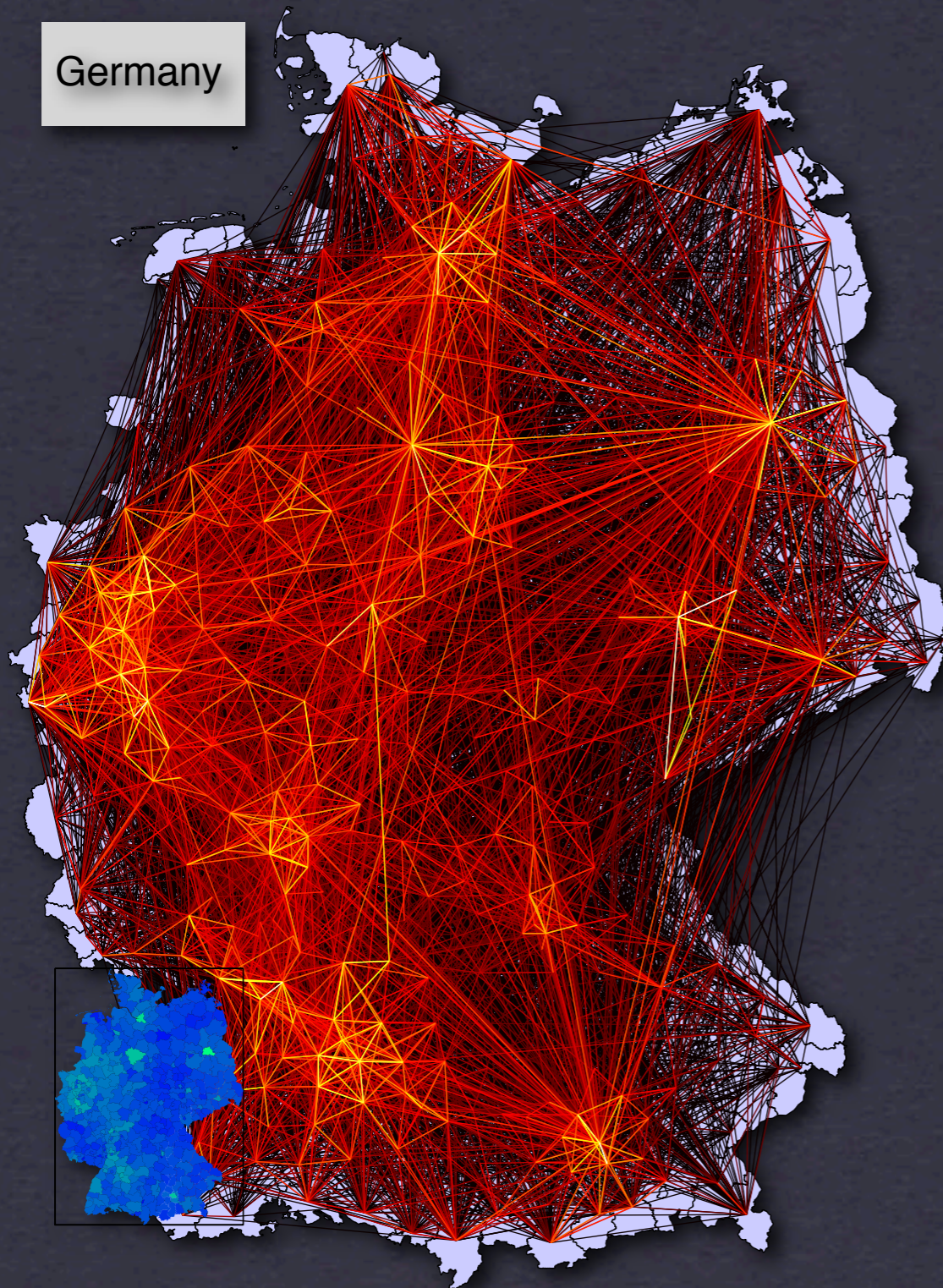
Take home message

With the exact knowledge of human traffic networks the development of quantitative models for the geographic spread of emergent infectious diseases on large scales is possible.

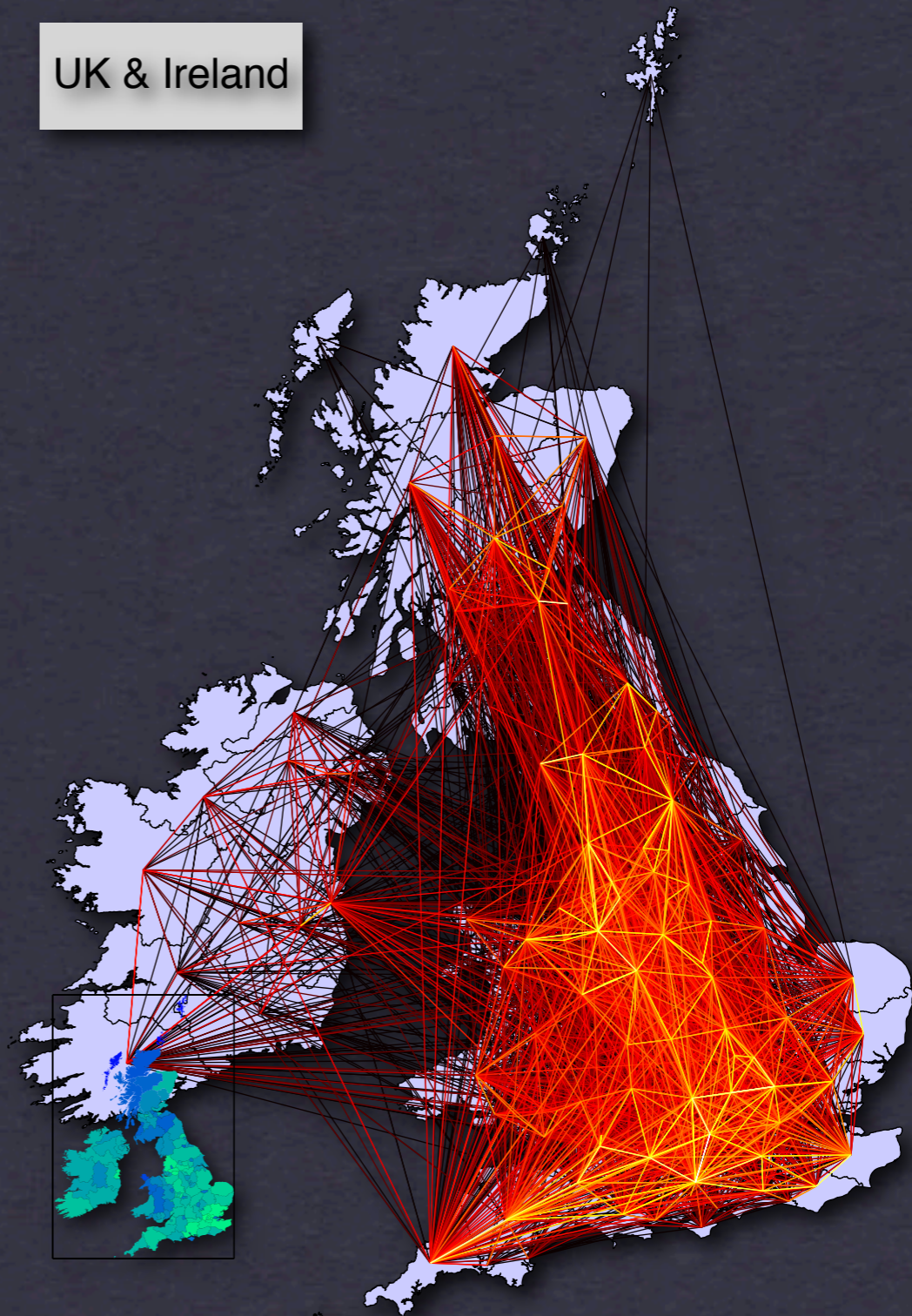


multi-scale mobility networks

Germany



UK & Ireland



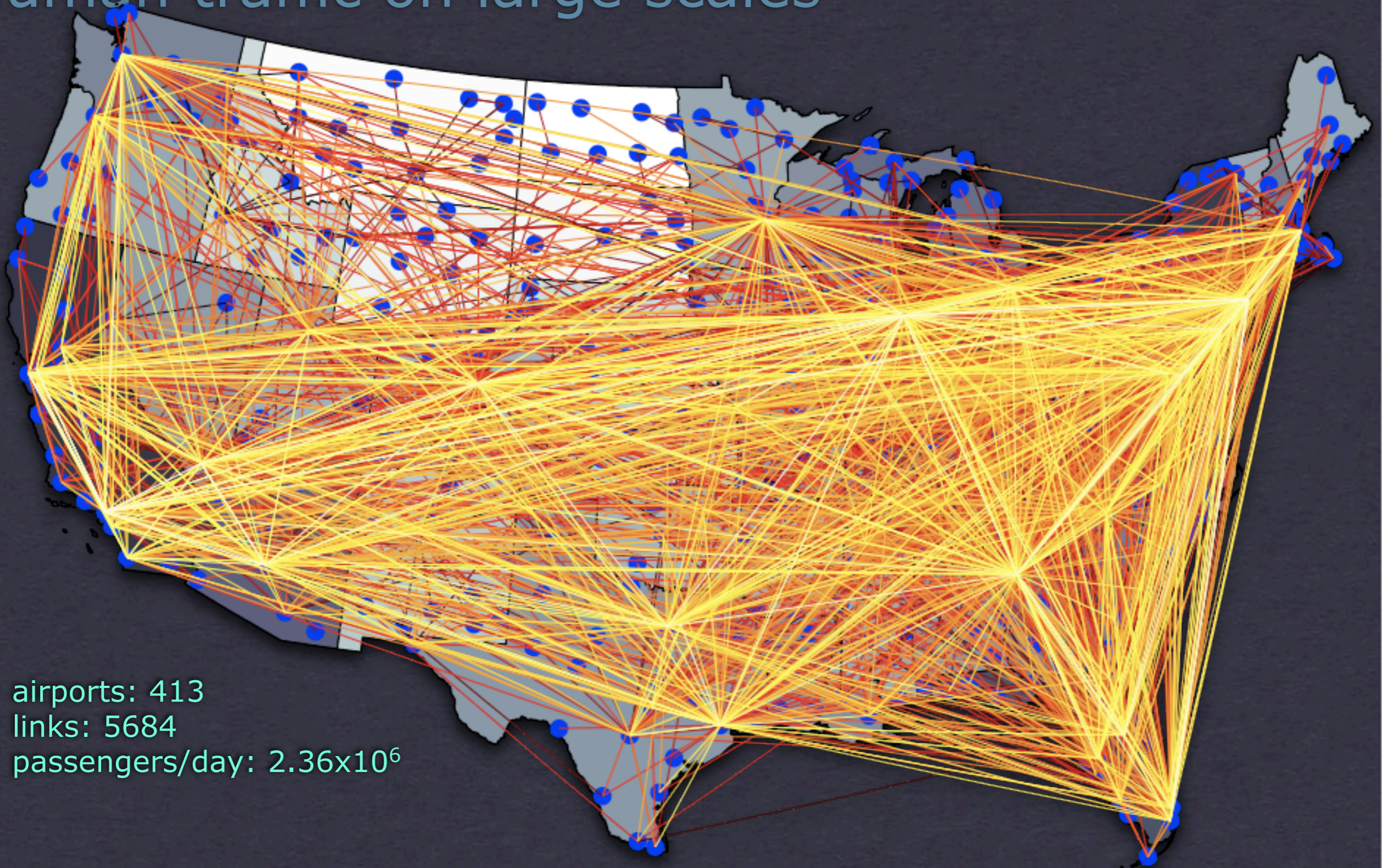
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human traffic on large scales



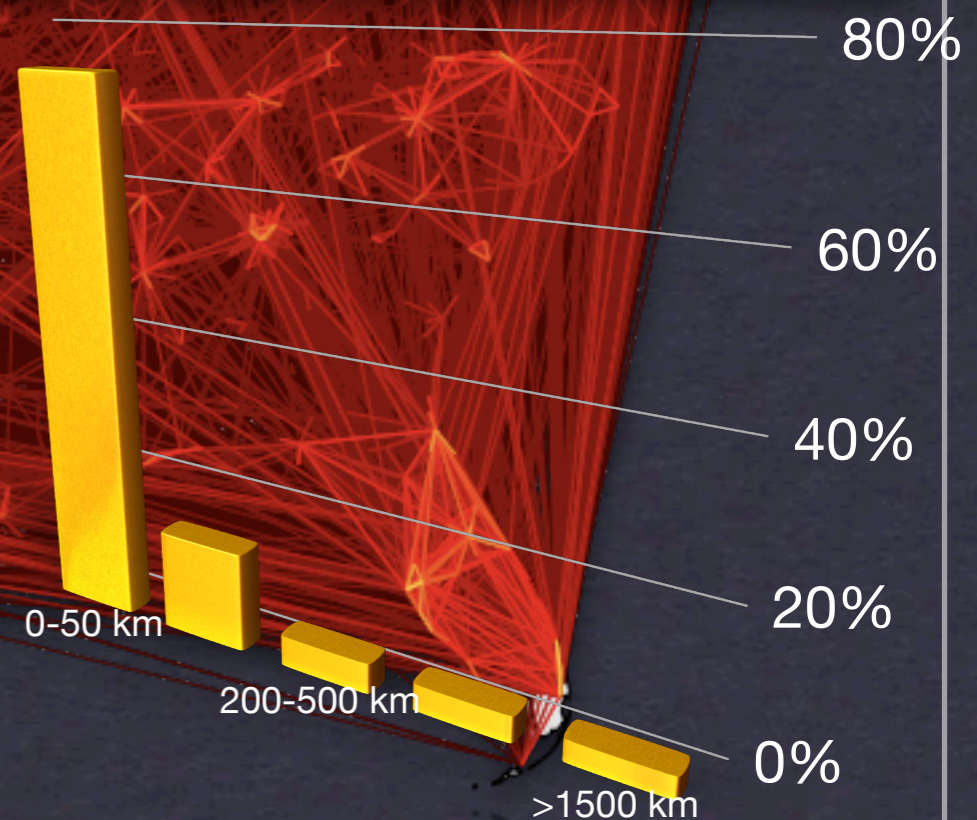
airports: 413
links: 5684
passengers/day: 2.36×10^6

R. Guimera, et al., PNAS (2005), A. Barrat, et al., JStat (2005), L. Dall'Asta et al. JStat (2006).

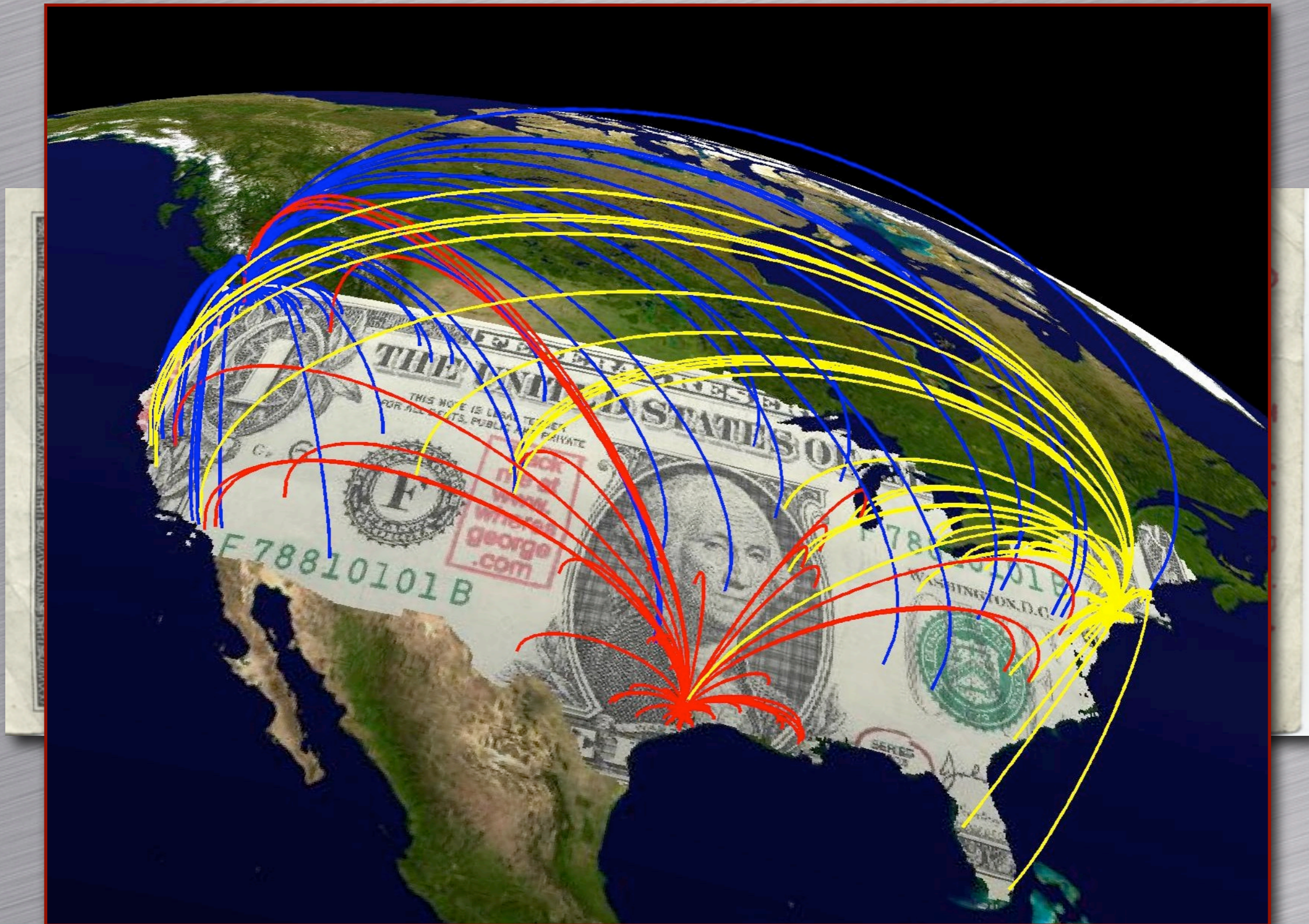
multiscale traffic network

- long distance connections exist
- short distance connections are strong
- all counties connected

nodes: 3108 US counties

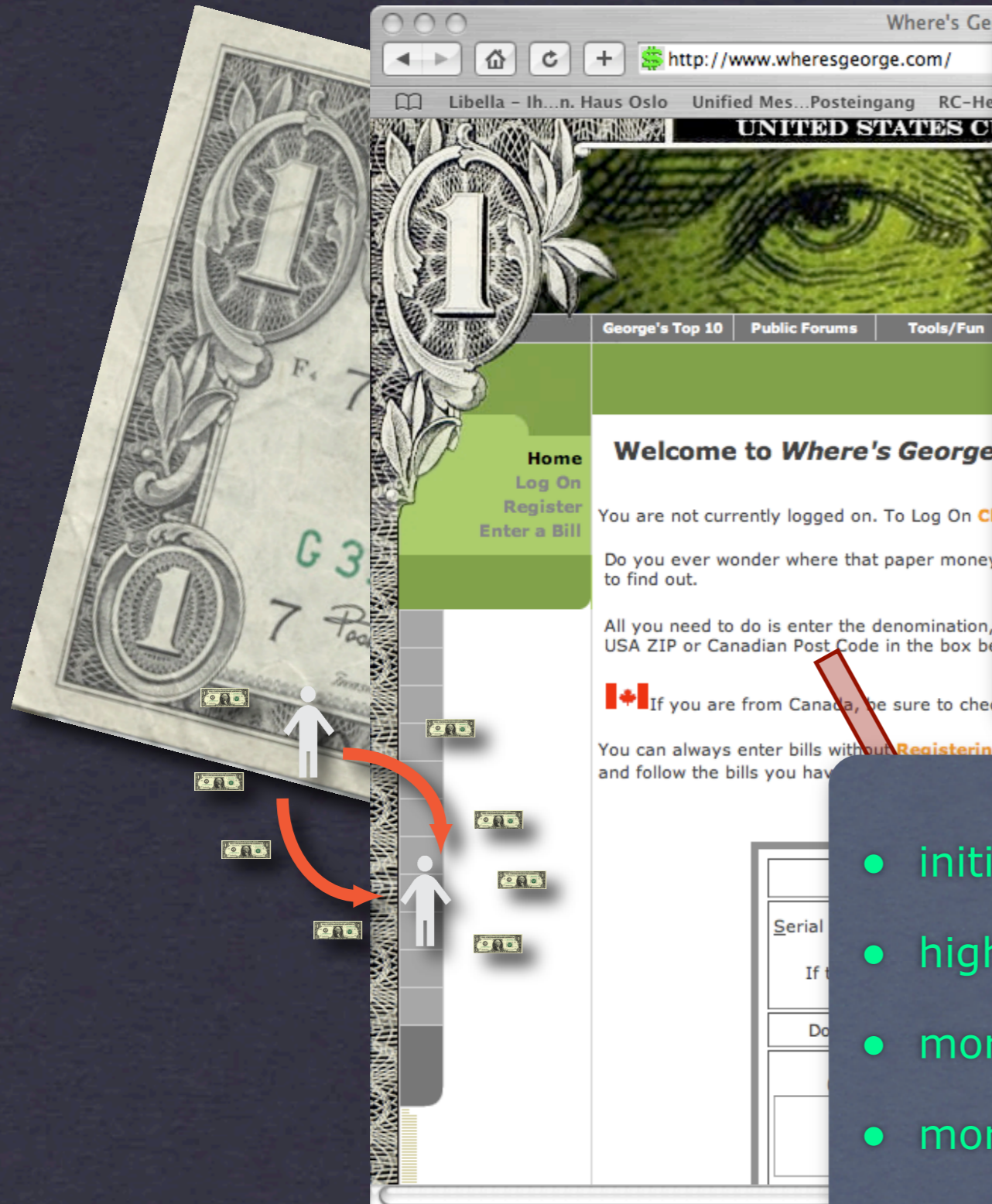


Idea: „Follow the money!“



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wheresgeorge.com - global money circulation



1. bills are registered
2. bills enter circulation
3. bills travel
4. bills are reported
5. bills reenter circulation
- 6....

- initiated in 1998 by Hank Eskin
- high spatial and temporal resolution
- more than 100 million bills are registered
- more than 10 million bills with hits

human mobility and money dispersal

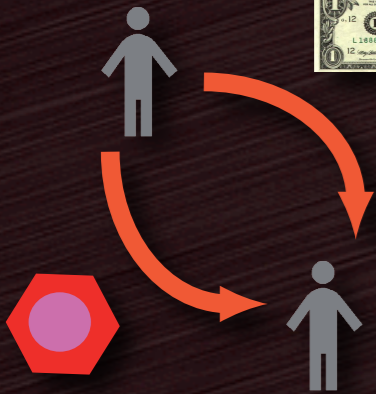


the idea



indirect measurement
of human travel
behavior

the immense size of the
dataset permits reliable
estimates of the
geostatistical properties
of human travel.



www.wheresgeorge.com

www.eurobilltracker.com

Where's George? @ 2.2
http://www.wheresgeorge.com/

UNITED STATES CURRENCY TRACKING PROJECT

where's george?

George's Top 10 Public Forums Tools/Fun Store FAQs/Help About Us Contact Us

HELP with this page

Home
Log On
Register
Enter a Bill

Welcome to *Where's George?*!

You are not currently logged on. To Log On [Click Here](#)

Do you ever wonder where that paper money in your pocket has been, or where it will go next? This is the place to find out.

All you need to do is enter the denomination, series, and serial number of any US dollar bill, and your current USA ZIP or Canadian Post Code in the box below.

Canada If you are from Canada, be sure to check out [Where's Willy?](#) to track your Canadian Currency!

You can always enter bills without **Registering**, but you will need to have an account to be able to come back later and follow the bills you have entered. You can enter your bill now, and register later, too.

ENTER A BILL

Denomination: \$1 Select: Bill Series

Serial Number: (10 or 11 chars) (USA or Canada ONLY)
If the serial number has a 'star' use the * key (shift-8) International Users-[Click Here](#)
Don't know your Zip code? [Click Here](#)

Current Zip/Postal Code

Do you have this bill right now? Yes No

Please enter a short note about this bill if you like:
(Where did you get it, its condition, etc...Five lines maximum).

Begleiten Sie die Euro-Scheine auf ihrer Reise

http://www.eurobilltracker.com/

EuroBillTracker

Begleiten Sie die Euro-Scheine auf ihrer Reise seit 1. Januar 2002

MENU ::
Home
Über diese Seite
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Neu anmelden

Durchmischung
Statistiken
News
Fragen & Antworten (FAQ)
Forum

E-mail
Passwort
 Auto-Login
OK

Language :
(en) (fr)
(nl) (de)
(it) (gr)
(es) (fi)
(pt) (se)
(eo) (sk)
(ca) (pl)

Der Zweck des Ganzen

EuroBillTracker ist ein internationales und nichtkommerzielles Team aus Freiwilligen. Der Sinn dieses Projekts ist es zu verfolgen, wie die Eurobanknoten durch Europa und die ganze Welt wandern. Jeder Benutzer gibt die Seriennummern seiner Geldscheine und den Ort ein, wo er sie erhalten hat. Aus diesen Informationen macht die Site folgendes:

- Durchmischung: Wie vermischen sich die Scheine und in welcher Zeit? Sehen Sie sich dazu den Menüpunkt "Durchmischung" an.
- Tracking (Verfolgen der Banknoten): Wenn ein bereits registrierter Geldschein erneut eingegeben wird, werden alle Nutzer, die ihn zuvor eingegeben hatten, per e-mail benachrichtigt und alle anderen können den Notenreport sehen.
- Statistiken und Rangfolgen: Wer sind die besten Benutzer, welches das aktivste Land? Wo sind die Scheine jetzt?

Eurobanknoten und -münzen wurden am 01. Januar 2002 in Umlauf gebracht und seit diesem Tag verfolgen wir die Scheine. Philippe Girolami (Giro) hat diese Site ursprünglich geschaffen. Anssi Johansson (Avij) betreibt sie seit Mitte 2003 als zweiter Webmaster. Übersetzungen und zahlreiche andere Aufgaben werden durch eine Gruppe aktiver EBT-User erledigt - ohne sie wären wir nicht da, wo wir heute sind :) Danke!

EuroBillTracker ist in keiner Weise mit der Europäischen Union, der Europäischen Zentralbank, nationalen Zentralbanken oder irgendeinem Finanzdienstleister verbunden. Die Benutzung von EBT ist vollkommen kostenlos. Bitte besuchen Sie die Rubriken FAQ, Statistiken und Durchmischung, um mehr Informationen zu erhalten.

Treffer nach Datum

2006-03-28 21:31:50	5 Pxxxx4106xxx	SCHPOL - Juud
2006-03-28 21:11:47	5 Xxxxx8695xxx	Elmo - Josephus
2006-03-28 21:05:50	20 Pxxxx3794xxx	Sport-Mass - emppu 112
2006-03-28 20:25:23	5 Pxxxx1468xxx	aron - the taxman
2006-03-28 20:04:31	5 Uxxxx9758xxx	DioDreD - Sonik
2006-03-28 19:57:00	10 Xxxxx1071xxx	Dutchfan - Gosina
2006-03-28 19:46:55	5 Zxxxx3010xxx	bhoeyb - sergeantmajor

Gesamt ::

Wert	:: 327411975 C
Benutzer	:: 82664
Scheine	:: 15191511
Interessante Treffer	:: 49102

Top Benutzer (# der Banknoten) ::

1.	ans	274321
2.	hoppa	181220
3.	bhoeyb	172152
4.	Westinghouse	155680
5.	J.R.K.	143675
6.	de-jo	140454
7.	joergb30	138718
8.	Spanier_20	138443
9.	LeuBs~	120000
10.	Sport-Mass	116501

Beste User bei der Werbung neuer User ::

1.	FVS	1151
2.	Fundamental	1011
3.	avij	951
4.	HNL	562
5.	bocky	555
6.	Rufes	552
7.	Ralf_ebt	549
8.	Lucia	489
9.	rosalbissima	394
10.	Eurot jakoon	376



dirk brockmann - northwestern university - <http://rocs.northwestern.edu>

we didn't show that

....infectious diseases
spread by
contaminated dollar
bills....

----- Original Message -----
Subject: Where is George
Date: Fri, 3 Feb 2006 18:38:50 +0200
From: klafter@post.tau.ac.il
To: geisel@jupiter.chaos.gwdg.de
CC: klafter@post.tau.ac.il

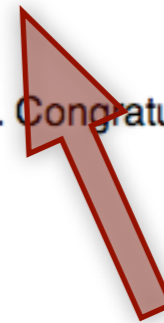
Dear Theo,

How are you? Congratulation for the nice Nature paper. It has already caught the attention of readers. Moreover, I must tell you that driving home a short while ago listening to a radio program which is on every Friday I heard that scientists at the Max-Planck (yes, this is how it was pronounced) Institute found an interesting pattern of how dollar bills spread. The guy mentioned that this is how epidemics might spread; namely by contaminated dollar bills.....The conclusion was: use credit cards.....

Not a bad exposure for a paper that just appeared. Congratulations. Long live Levy flight (walks, etc...).

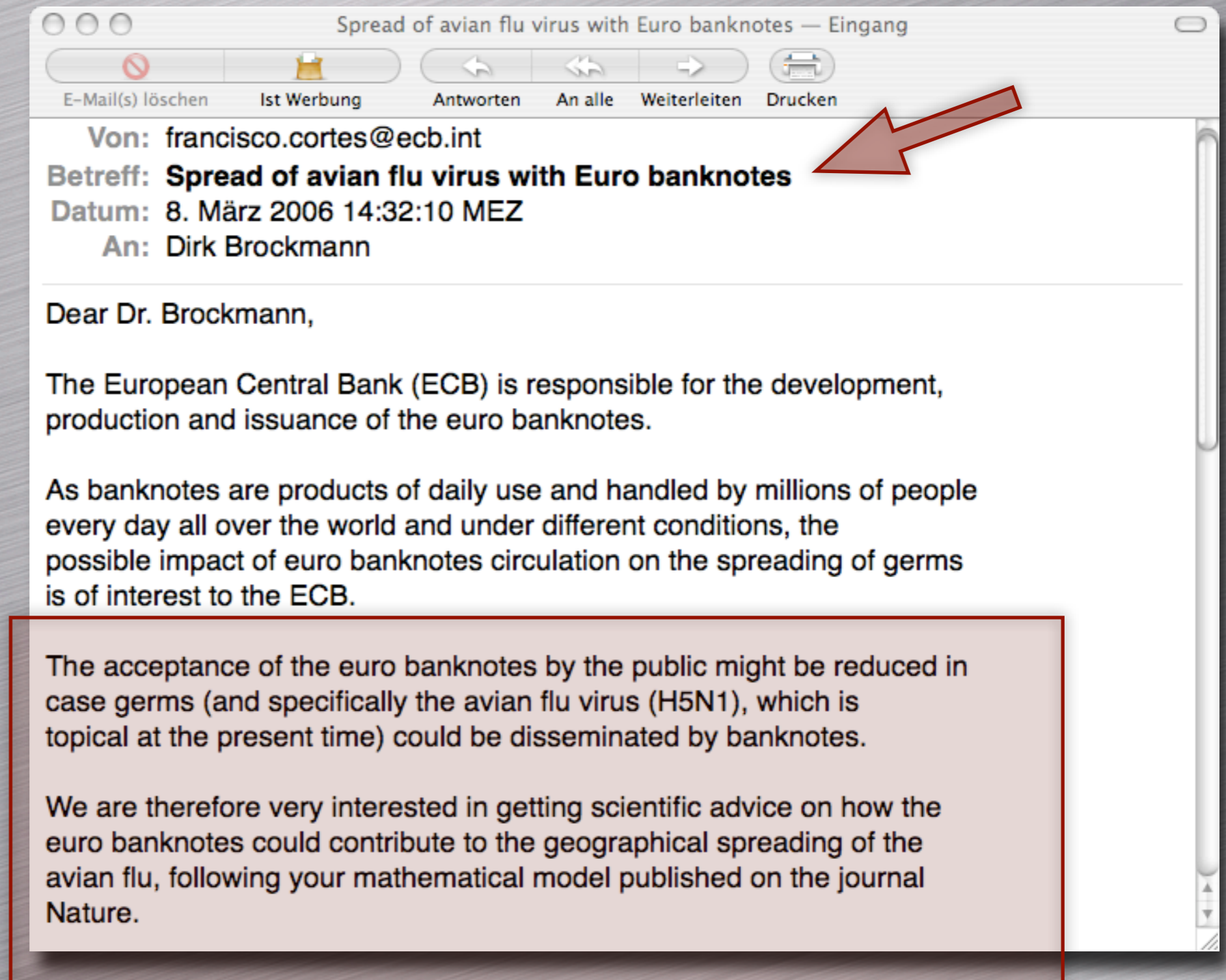
Yossi.

J. Klafter
Heinemann Chair of Physical Chemistry
Tel Aviv University
Tel Aviv 69978
Israel
<http://www.tau.ac.il/~klafter1>

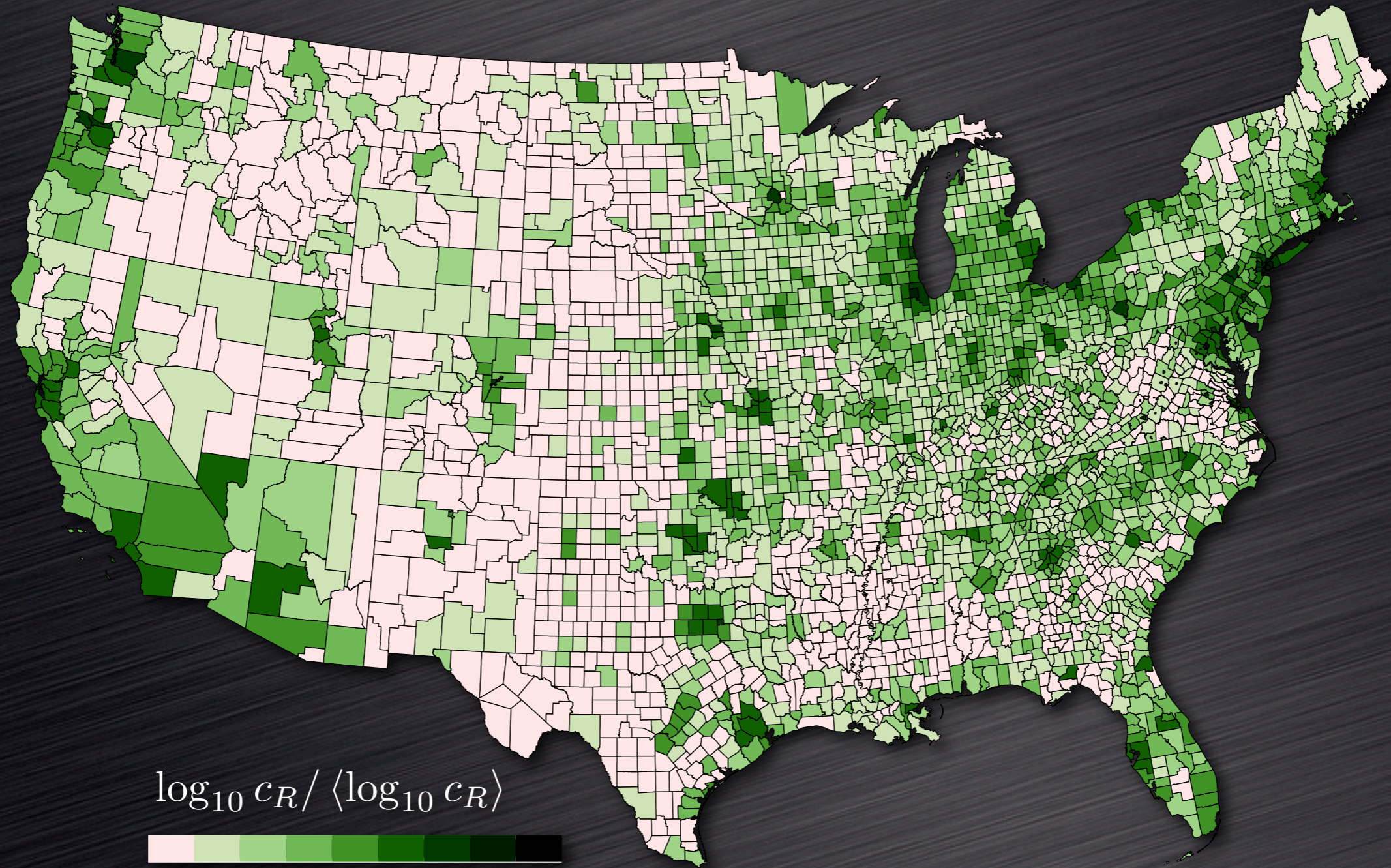


we didn't show that

....infectious diseases spread by contaminated Euros.



report density

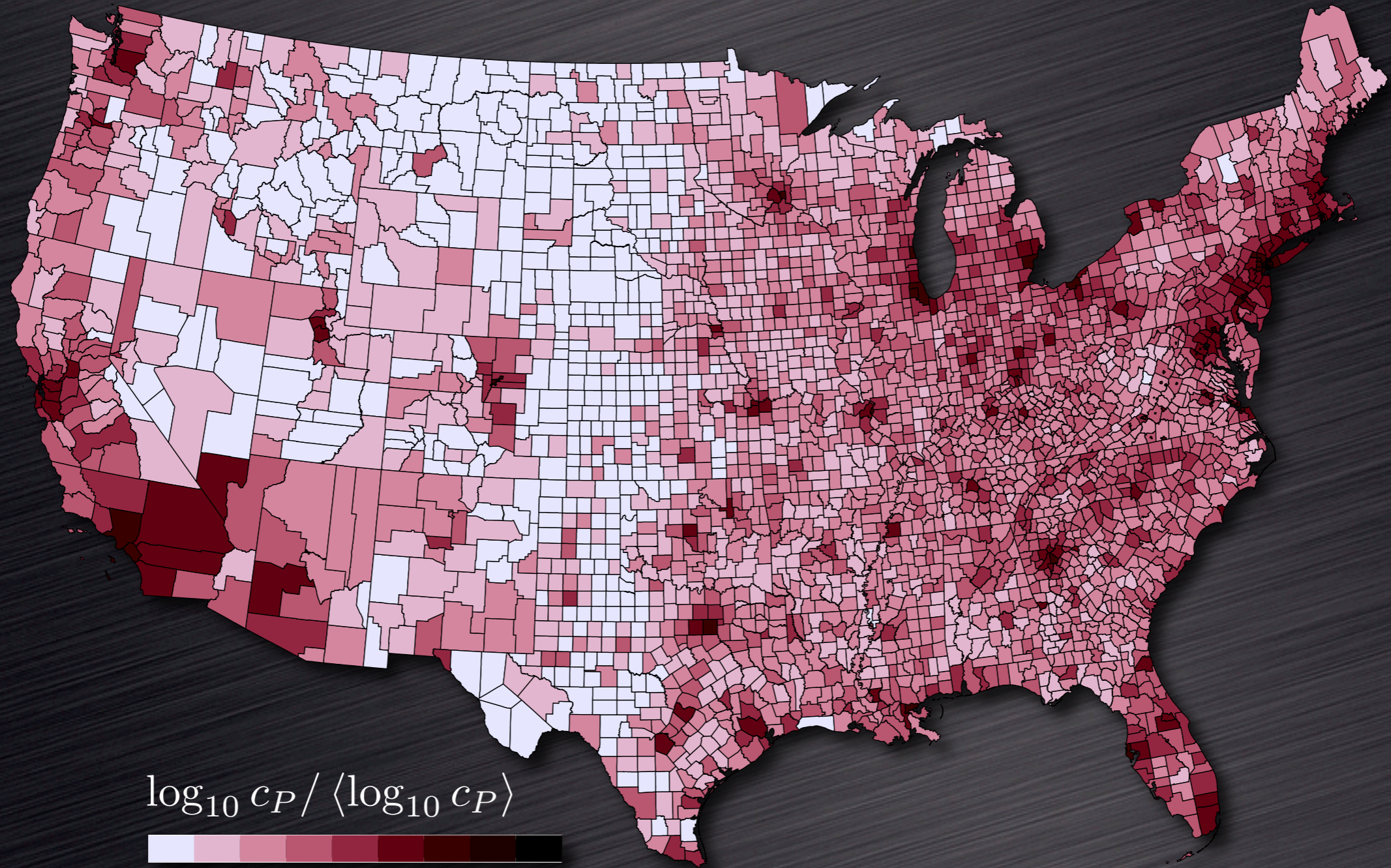


total number of reports: 1,033,095



dirk brockmann - max planck institute for dynamics and self-organization - www.ds.mpg.de

population density

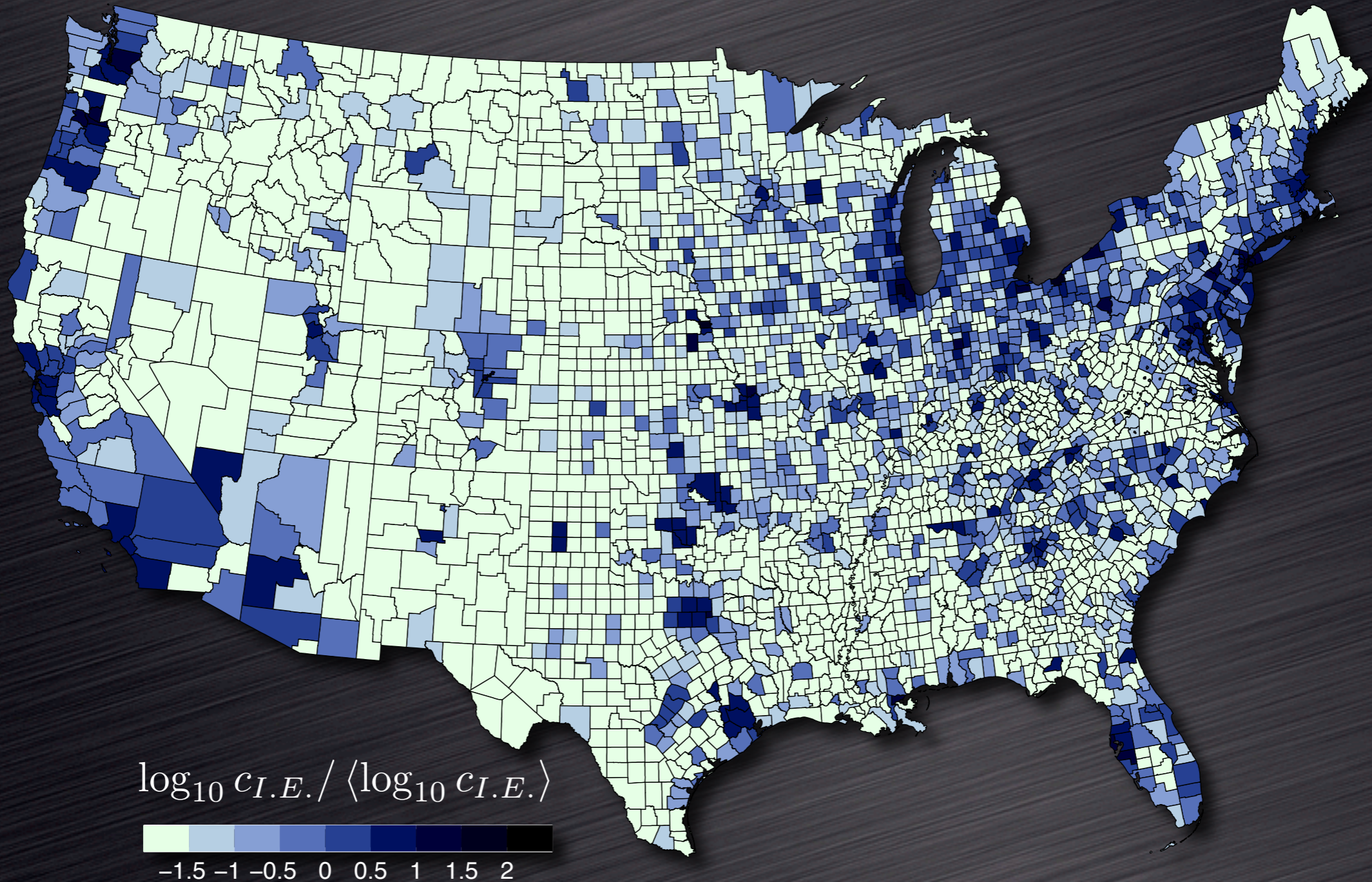


total population: 280 Mio.

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initial entry density

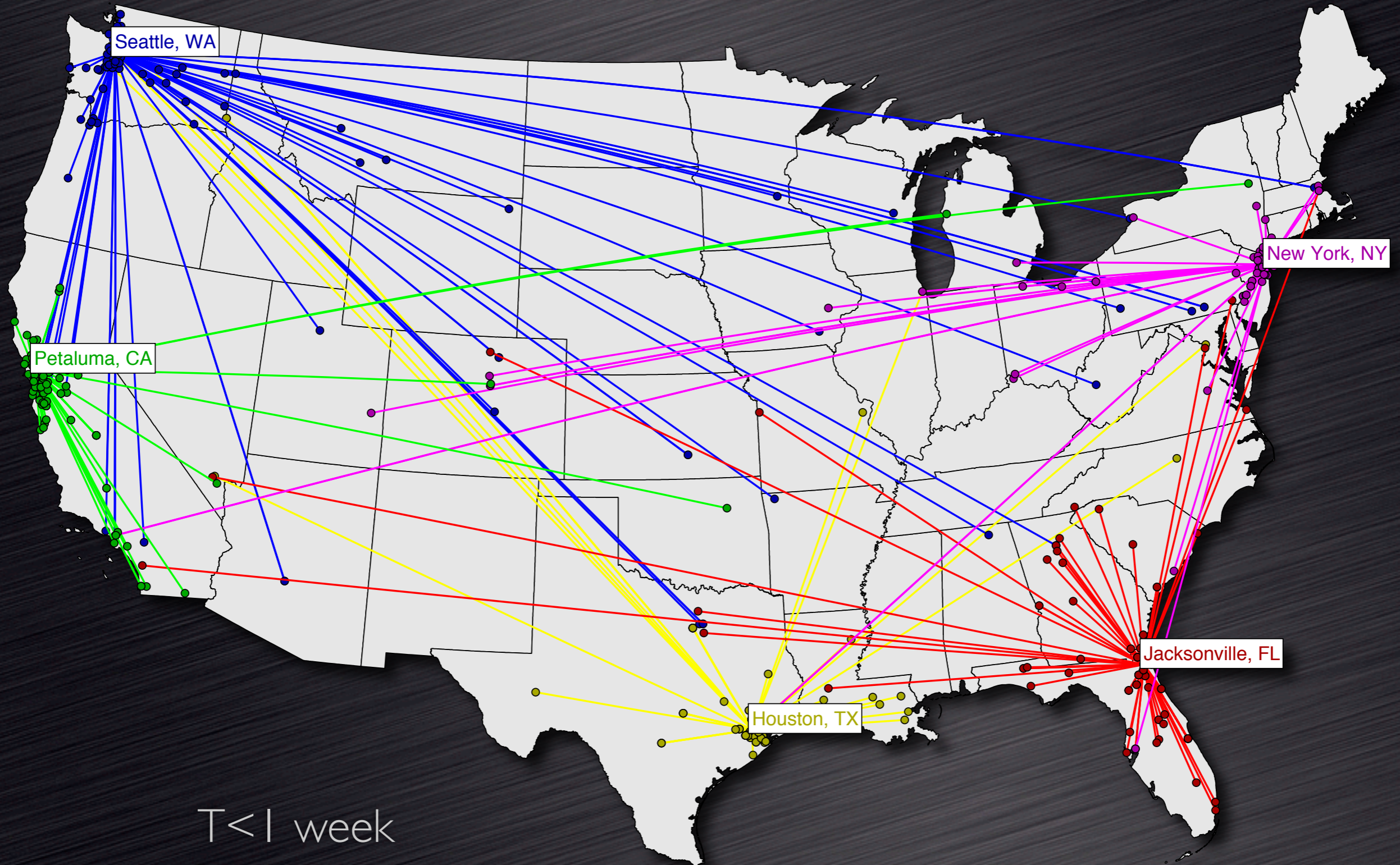


total number of initial entries: 408,321



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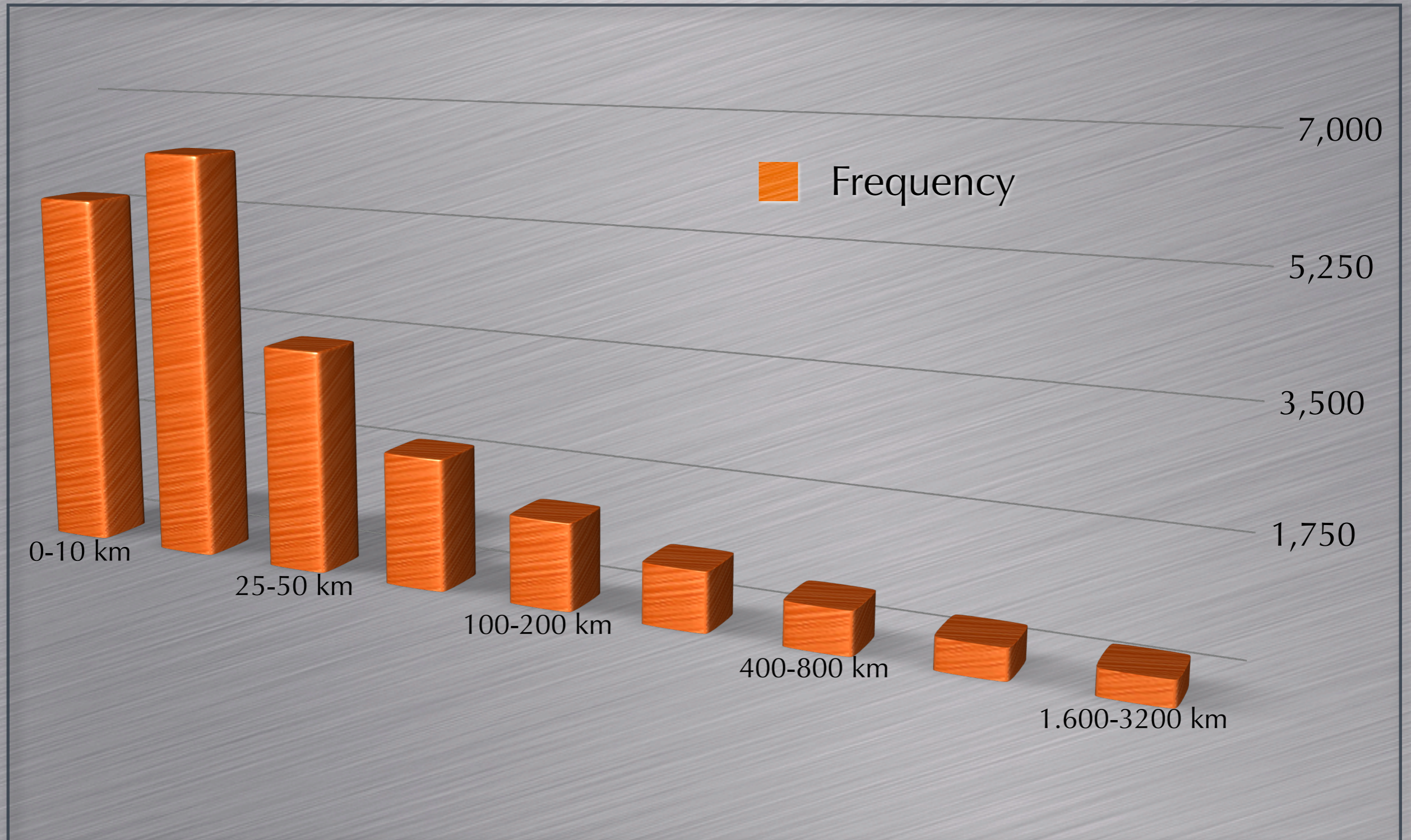
dynamics and short time trajectories



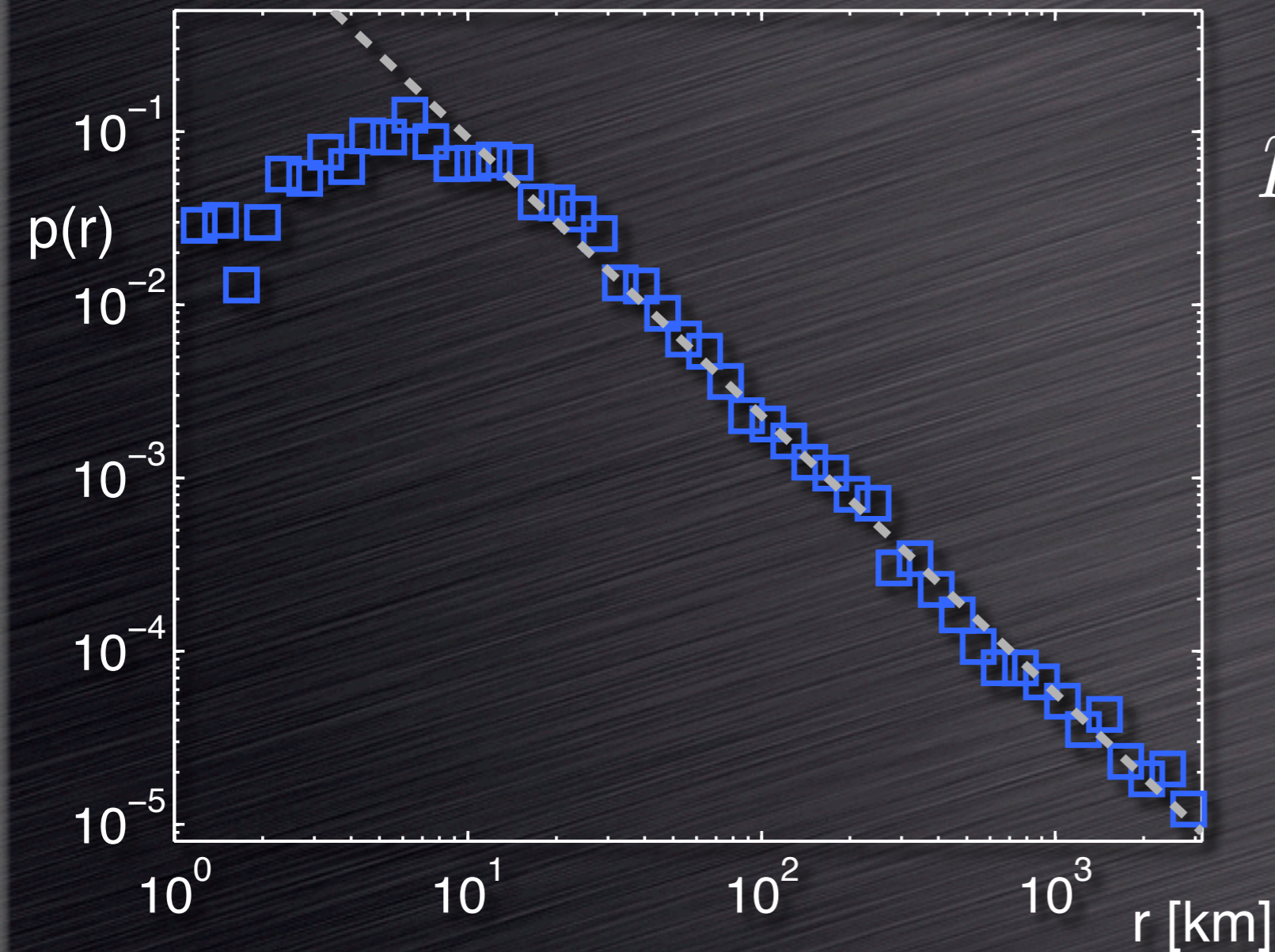
$T < 1$ week



Distance Histogram



more mathematically



$$p(r) \sim \frac{1}{r^{1+\beta}} \quad \beta \approx 0.6$$

inverse power law
(20-3500 km)

- there's no typical travel distance
- distances are **scale free**

Brockmann, D., Hufnagel, L. & Geisel, T., *Nature* 2006



What does **scale free** mean?

How **tall** is an adult human being on average?

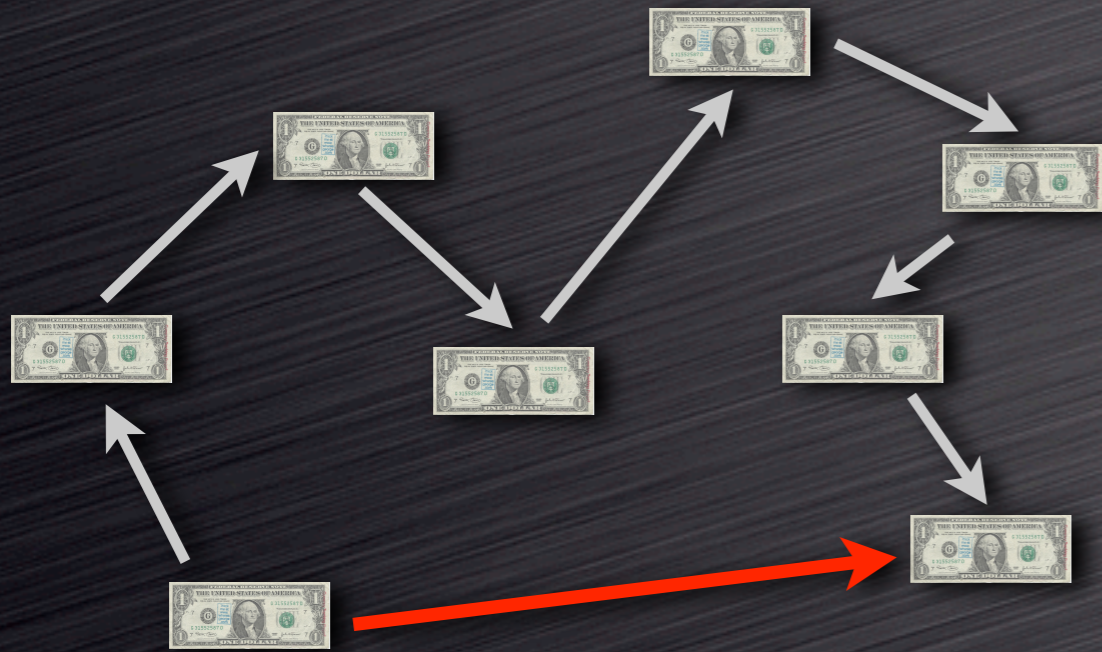
How **high** is the average income of an adult human being?



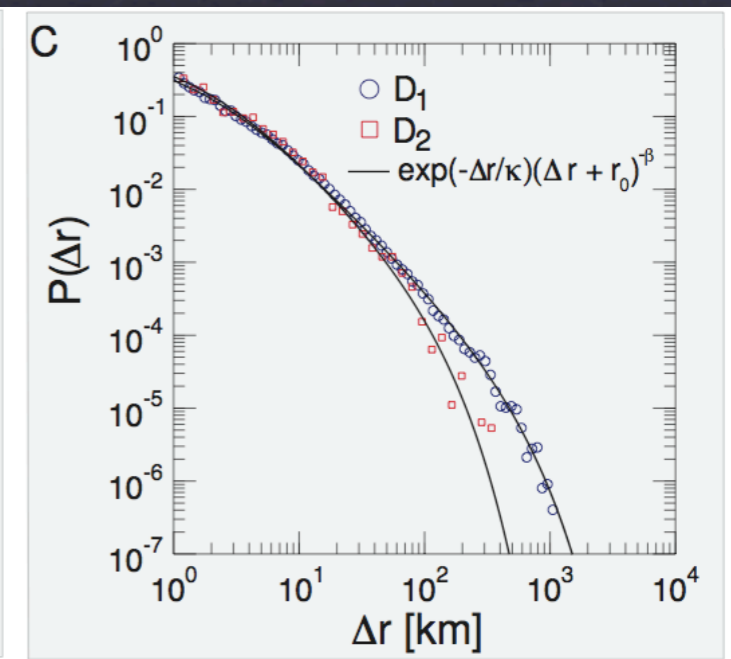
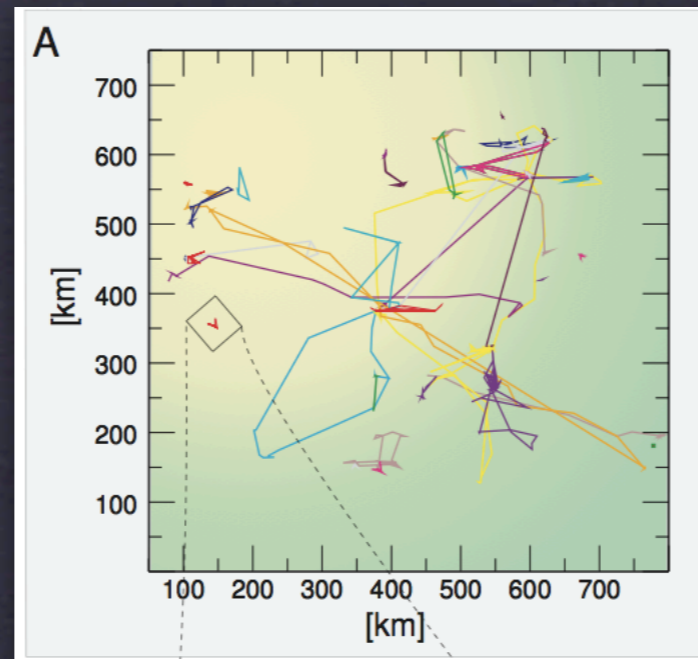
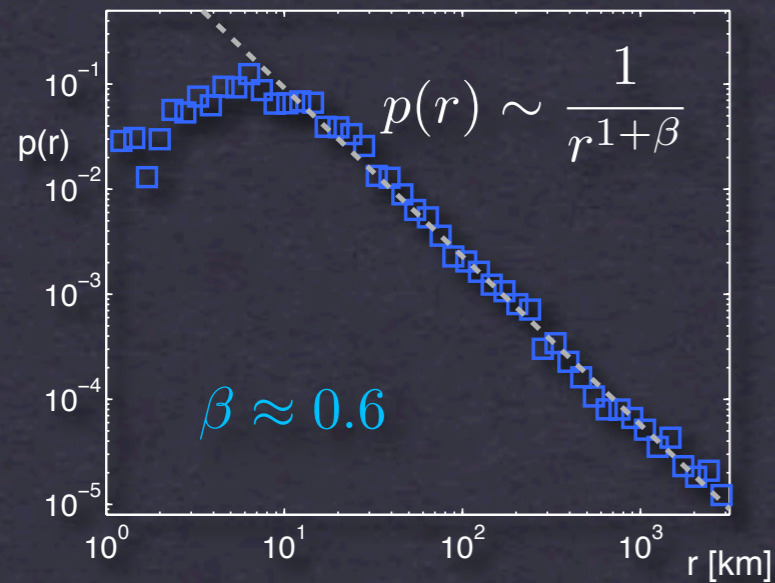
what is scale free? - Example: Geology



Implications for the geometry of money circulation



individual mobility patterns



from Gonzalez et al. Nature (2008)



H1N1 Outbreak



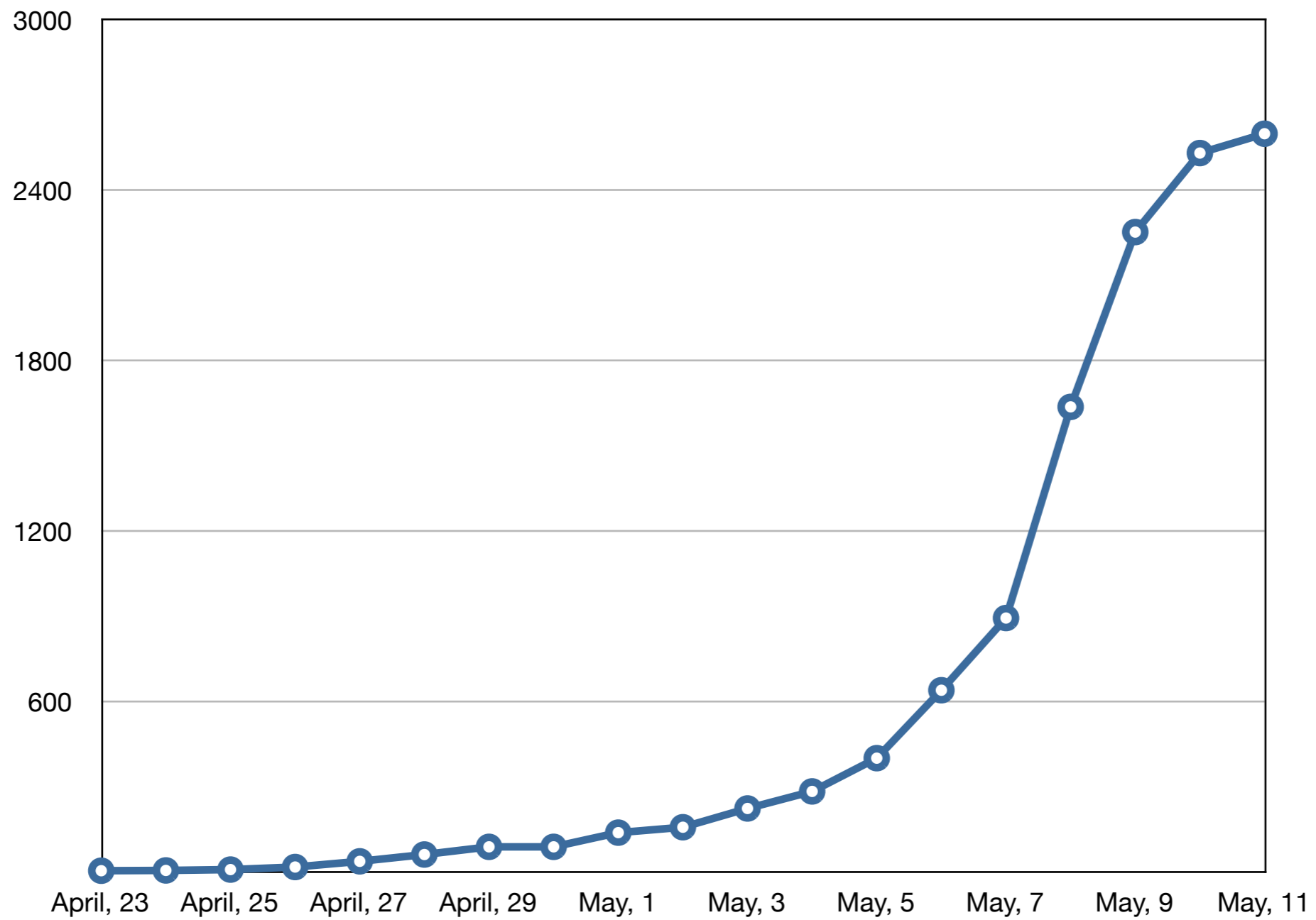
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cases in US



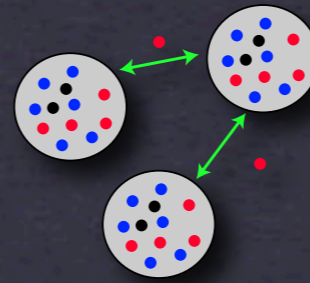
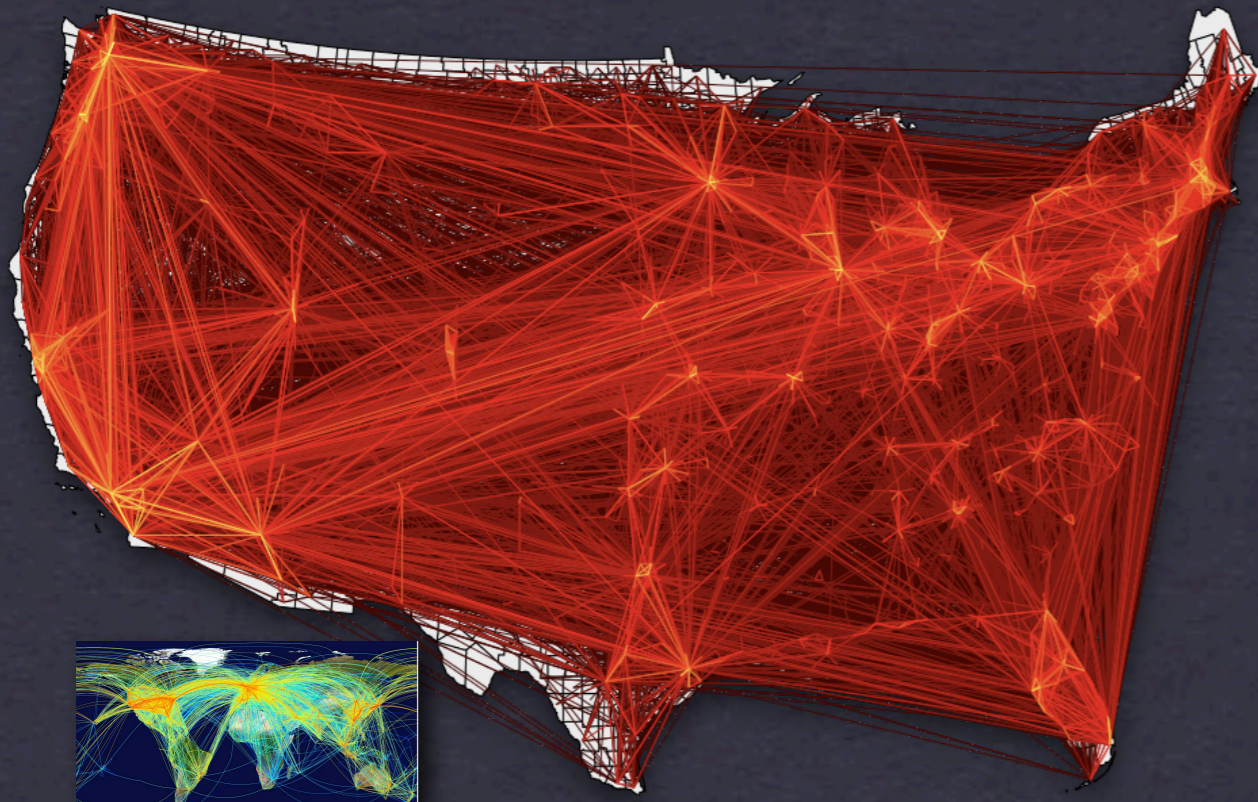
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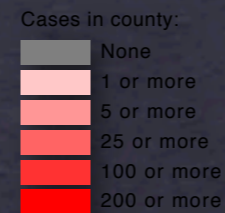
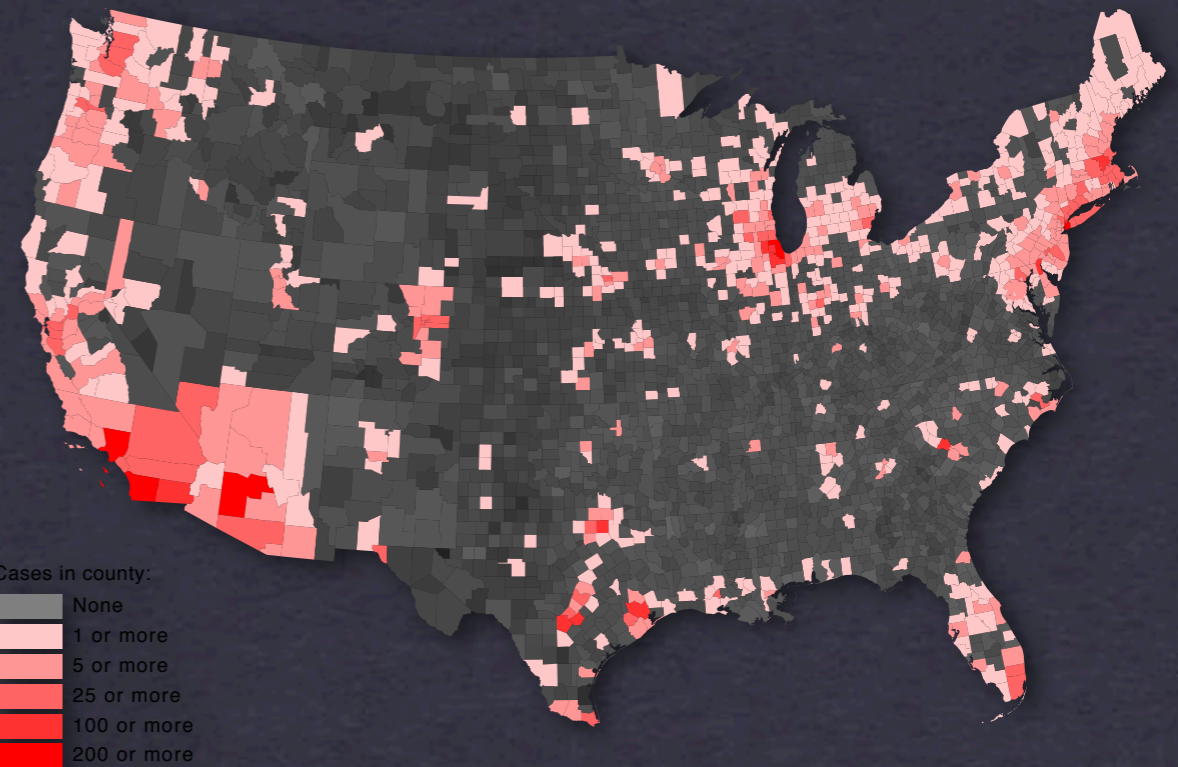
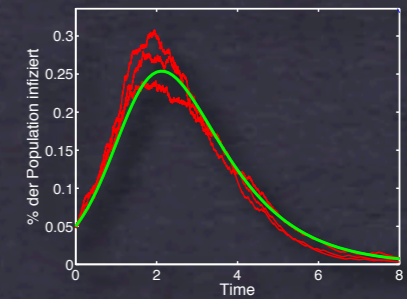
<http://rocs.northwestern.edu>

a model for the spread of H1N1 in the US



+

LOCAL SIR DYNAMICS



Dirk Brockmann

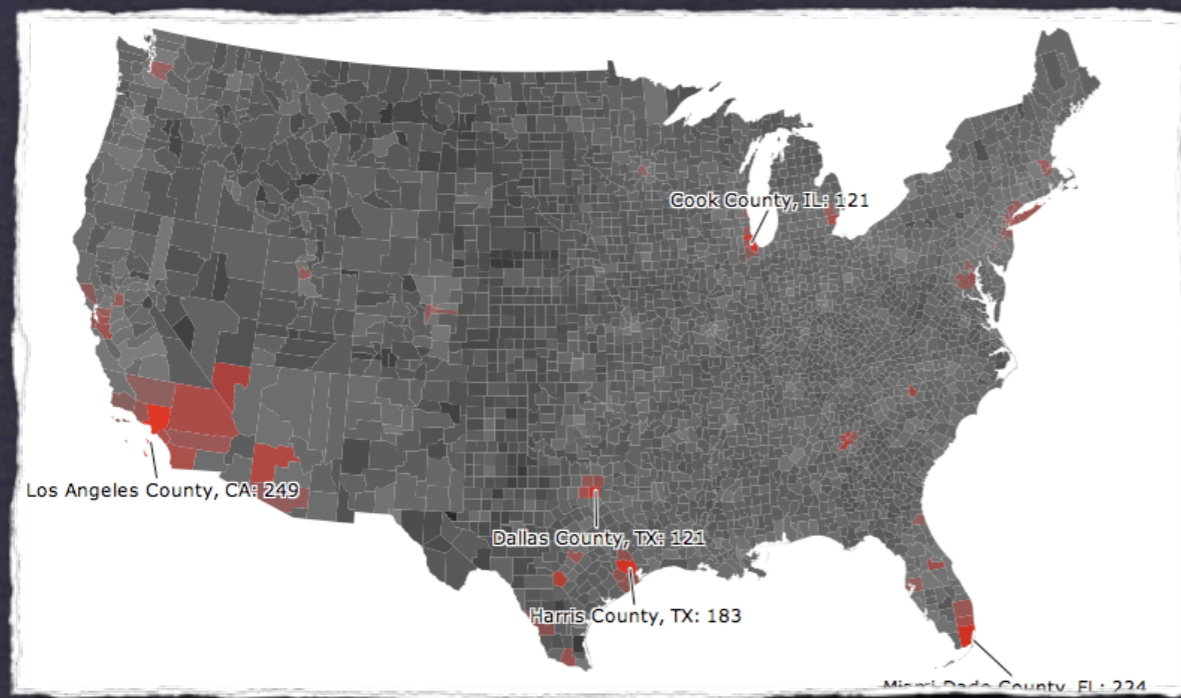
ESAM & NICO

Northwestern University

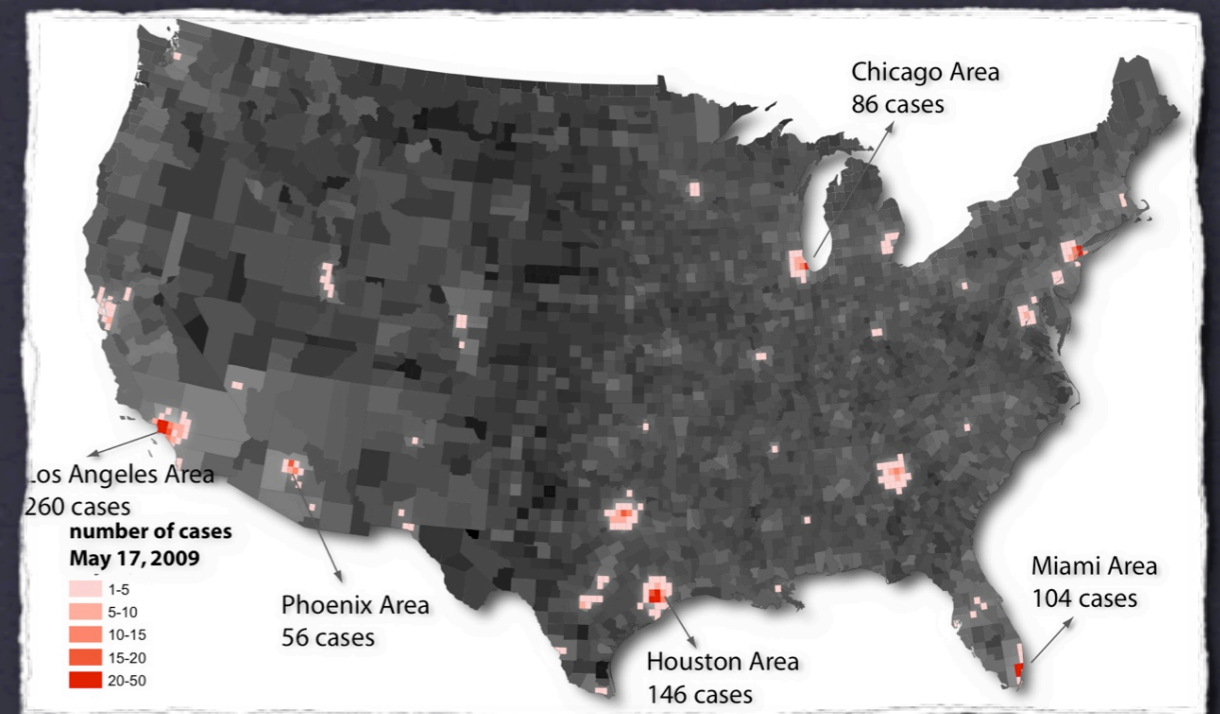
<http://rocs.northwestern.edu>

comparison to other approaches

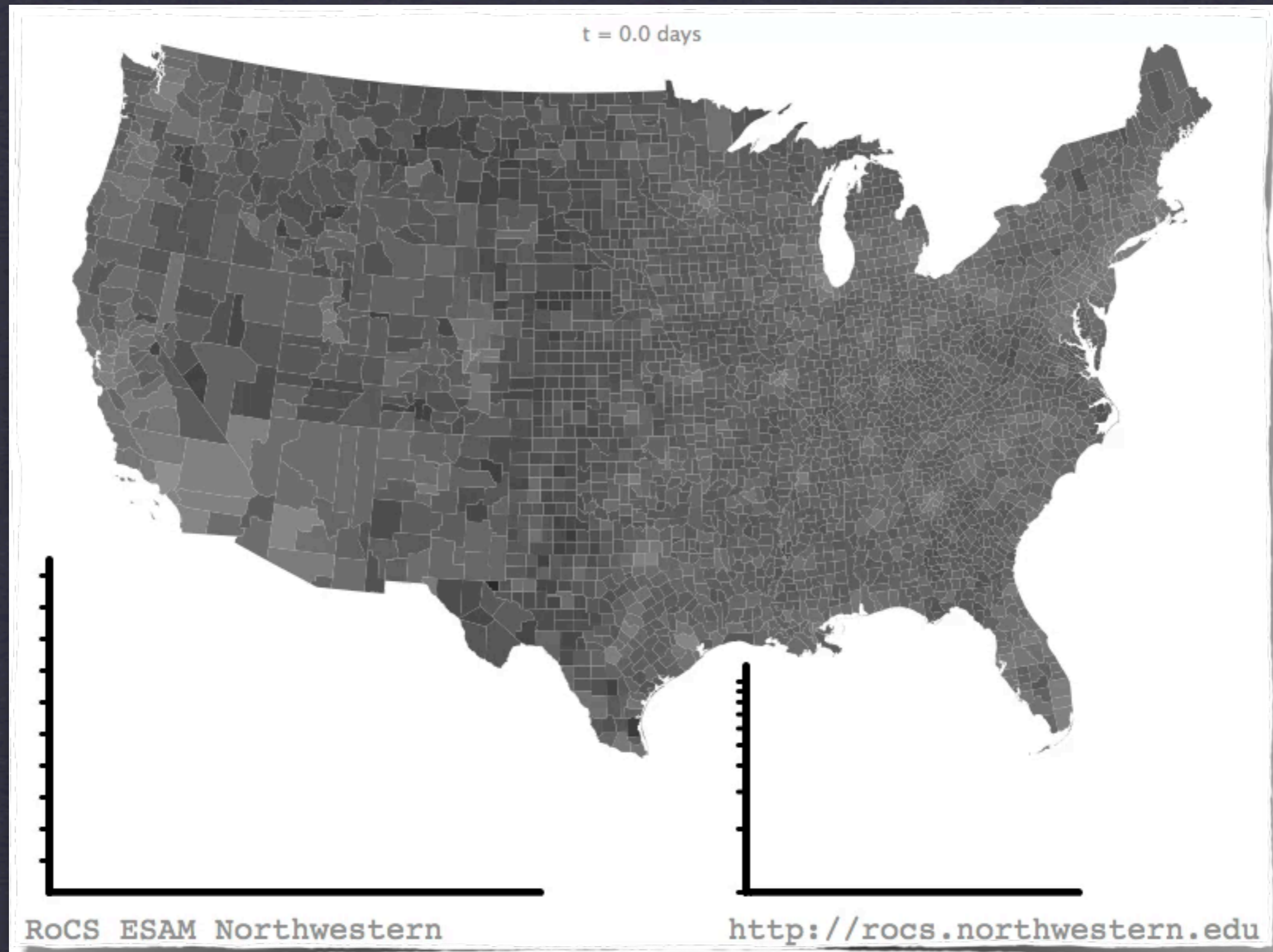
Northwestern Group



Indiana Group



pandemic scenario



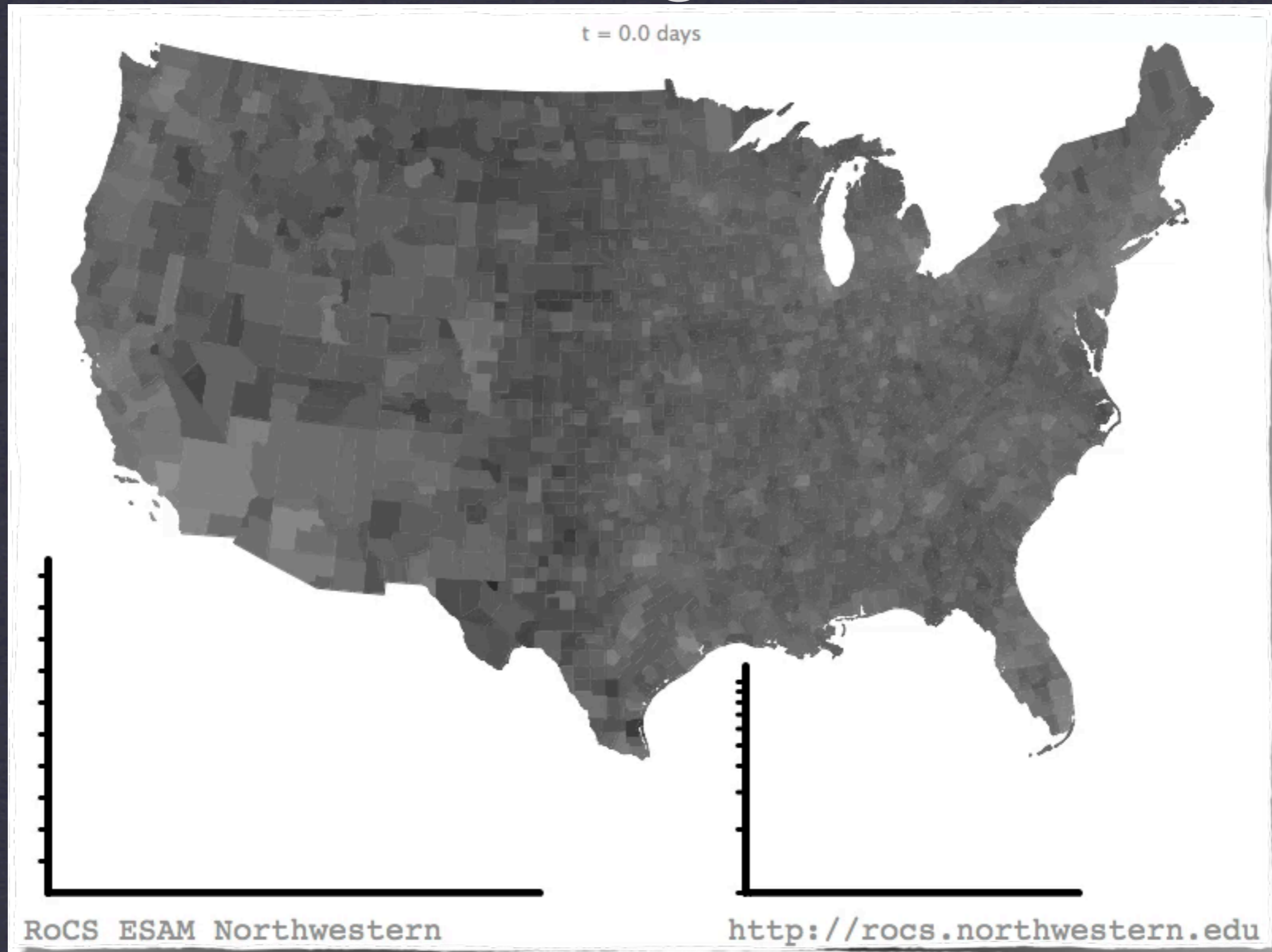
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without long distance



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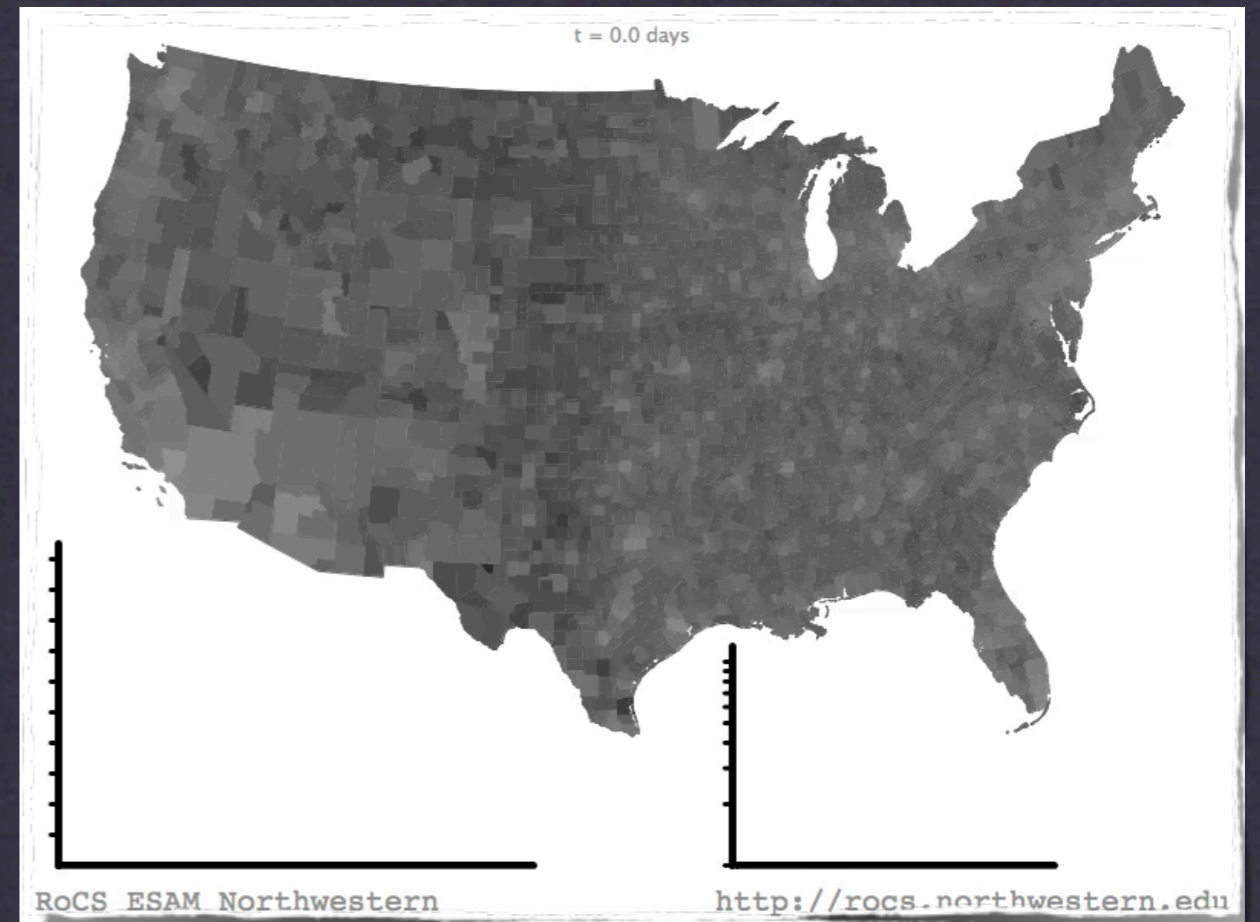
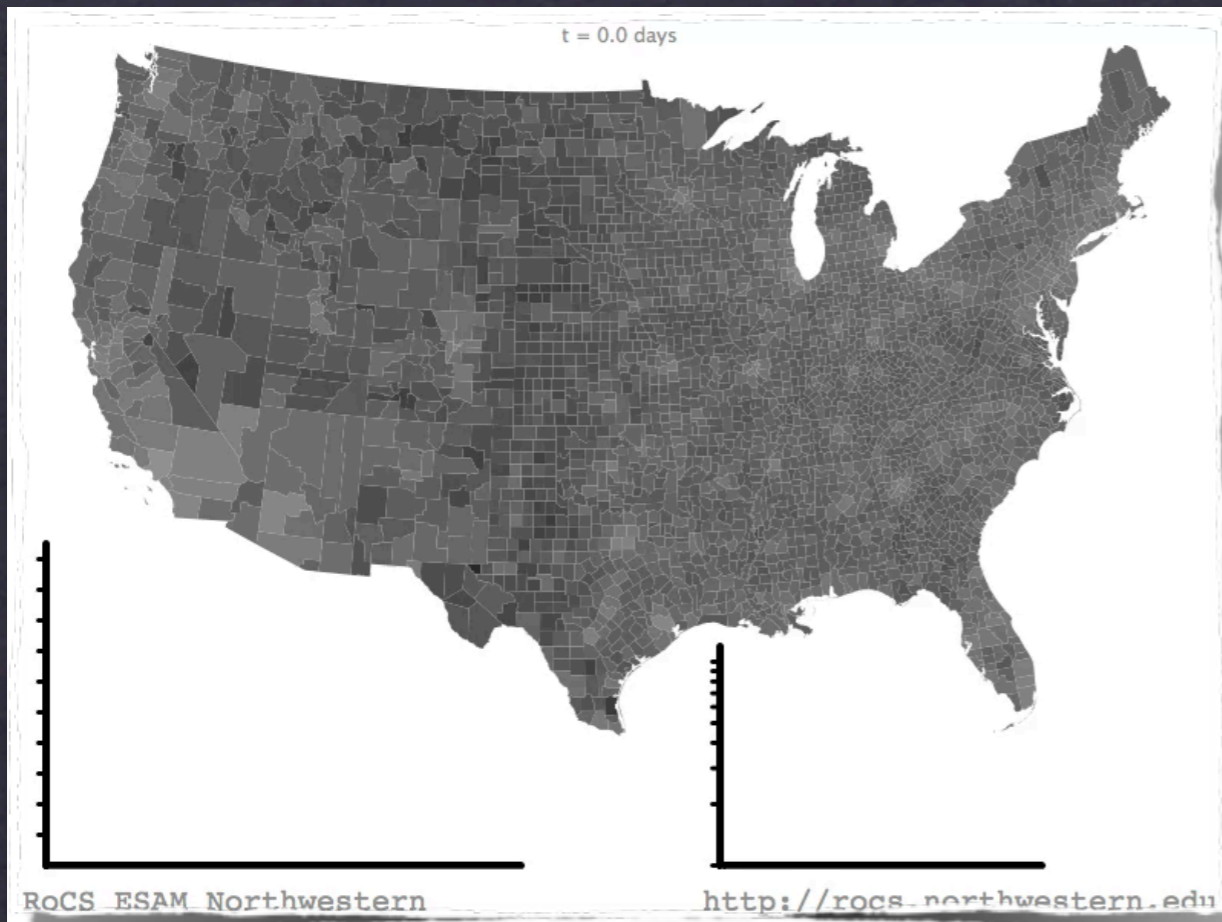
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time

multiscale mobility

local mobility



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acknowledgements

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- first asked question “Where is George?”
- invented wheresgeorge.com



The Georgers:

Wattsburg Gary, ChuckB, CARL, Crazy Georger, E=Mc², ÅÐÂM, KAT, TopCat, SFN1.0, Larry, Moe &, Curly, Sew GTO Crazy Guy #1, BIAGIO, Bloody John Rackham, Ish Kabibble, MsK, StayFloopy, Skrae, Friends of Pine Ridge Reservation, Ms Money, \$teve, Thirsty Gator, Dave - Fremont NE, The Old Sailor, Ø E.carinata Ø, brian 001, Sew GTO Crazy Guy #2, Rick From Cleveland, RITCHIE, Colleen S, L L T - J L T - J W T, H2UMMER, Lea, Team Movieguy, Ðřãñã, Jack, Gene (the Sailor), PIERCED COWBOY, Paul, Chris of Calvert, Mooster, Phil from Williamsville, ^=ROY=^=, Charles aka Beer Man, Howard from Moon!, John, Bank of Frank, Henry, ScrabbleScott, PitBo\$\$, WheatPenny, Hikini, 2TravelingFools, @h@€±€, Mike-Gorn, PrisonMac, * * *Daddy Eagle* * *, g w, Bill Stamper, dirt poor, bifyu, XineGirl, The Jazzman, Smerdlock, Doomer °, ^Blizz^, Carl, Poor Old Harold, Kauai Boy, Zinger, Joe Hank@, \$upes Fan (Formerly known as Daryn), Jiffy, DANIEL, Thatll do Pig, Hank,, Ordinary Avg Guy, Norman, KidsDads, Dave From Central MAss, Jimmy, Frank in Omaha NE., jim l8wheeler, The Harmony Crew (Career Soldier), choo-chooman, Sir Eldren, Hockey Ref, TÊD, TWIGMAN, Christopher, NapaMac, RaymondCT, Kirby, Ed, SPA DAN, Eugene, Don & Sandy, Orion Slayer, Chuckycheeselnk, Terry, Larry from Merritt Island, David, Thomas, Ru\$\$, Kail, AZ Richard, Larry, jane, Say Goodnight Gracie, Don in Lake City, Susan in Nassau Bay, Evan, Man In The Wild, WE STAND UNITED, Triac, tnvarealtors.com, Chuck, BEVERLY, Tribefan, LSU Fan in, New Mexico, Turtle Woman 2.2 & baby on the way!!!!, Bigdipper, BIG SKY BOB, SteVe7_01, Mister Softee, Ügo, Timberwolf, criptid, ST214, Beth Peluso, Terry, Cathy from Katy, SykoByte, Patty from Oz, Dave, R.J., Sam The Sham, Dubya, dm, Regis, Dr.Bob, ron, Mike, Weasel, Skibibbles, Thomas, psychprof, Jesse in SD, IceTiger, YardBoy, P3 in Michigan, Night Hawk, amorgan, kevin klan, Webfoot, Violet, Hoppy, Team Bugg!, Adam B., M*BOMB, Ian, PepperMike, Ralphie-Boy, Janis, Jim in St. Joe, Cathleen, Jollie Mollie, Velo Ale, Schwinn Rider, Buddy D, Bob, JimF, HbG & Handy Randy, Steve, Ku@+, SLICKARELLI, Lisa, Pete, Michael, Dan the Man, Kelly, Gerald, Greg the Doughboy™, paul, Lesa at the beach, Cha~Ching, Kevan (aka NativeMainer), George, Celia, TeqSutlJeBelWij, zanardi, Jane, Dwight, Tim, YYZ, SpeedRacer@™[Ø], PotatoHead, Mab * IguanaGirl, Carolyn W., DrASK, Kevin the Bill Tracker, Rebecca from Mars, DEAN

Dennis Derryberry:



- cabinet maker in Waitsfield, VT
- drew our attention to WG

