DNDS 6003: Urban networks and human mobility

Central European University, Fall Term 2018/2019

Class 9: Human mobility and: Epidemiology, community detection, urban mixing, polycentricity

Oct 18, 2018

http://michael.szell.net/teaching/dnds6003

Instructor: Prof. Michael Szell
@mszll

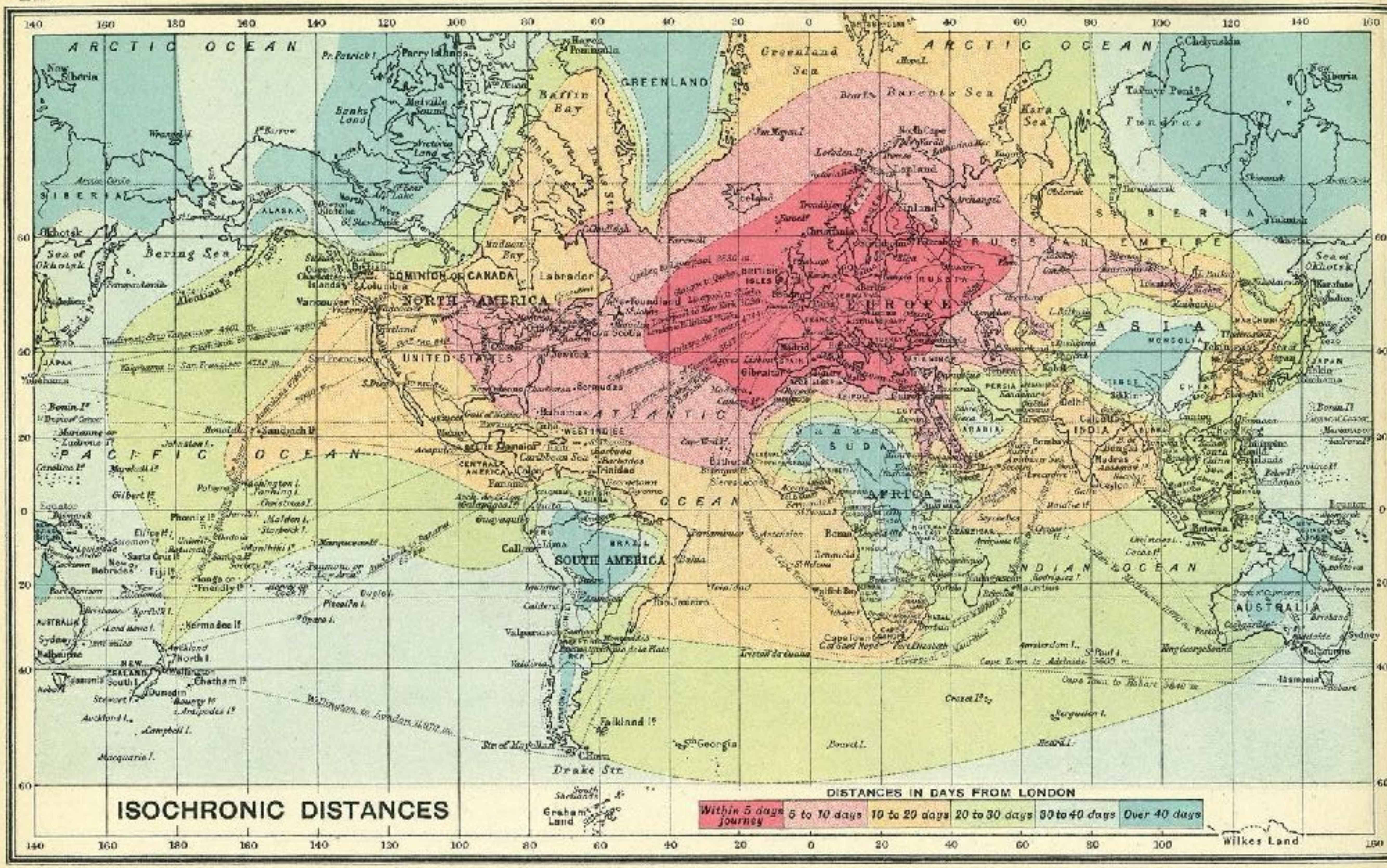
What will you learn today?

The importance of human mobility for epidemiology

Community detection of human mobility and interactions

Measuring polycentricity and its consequences

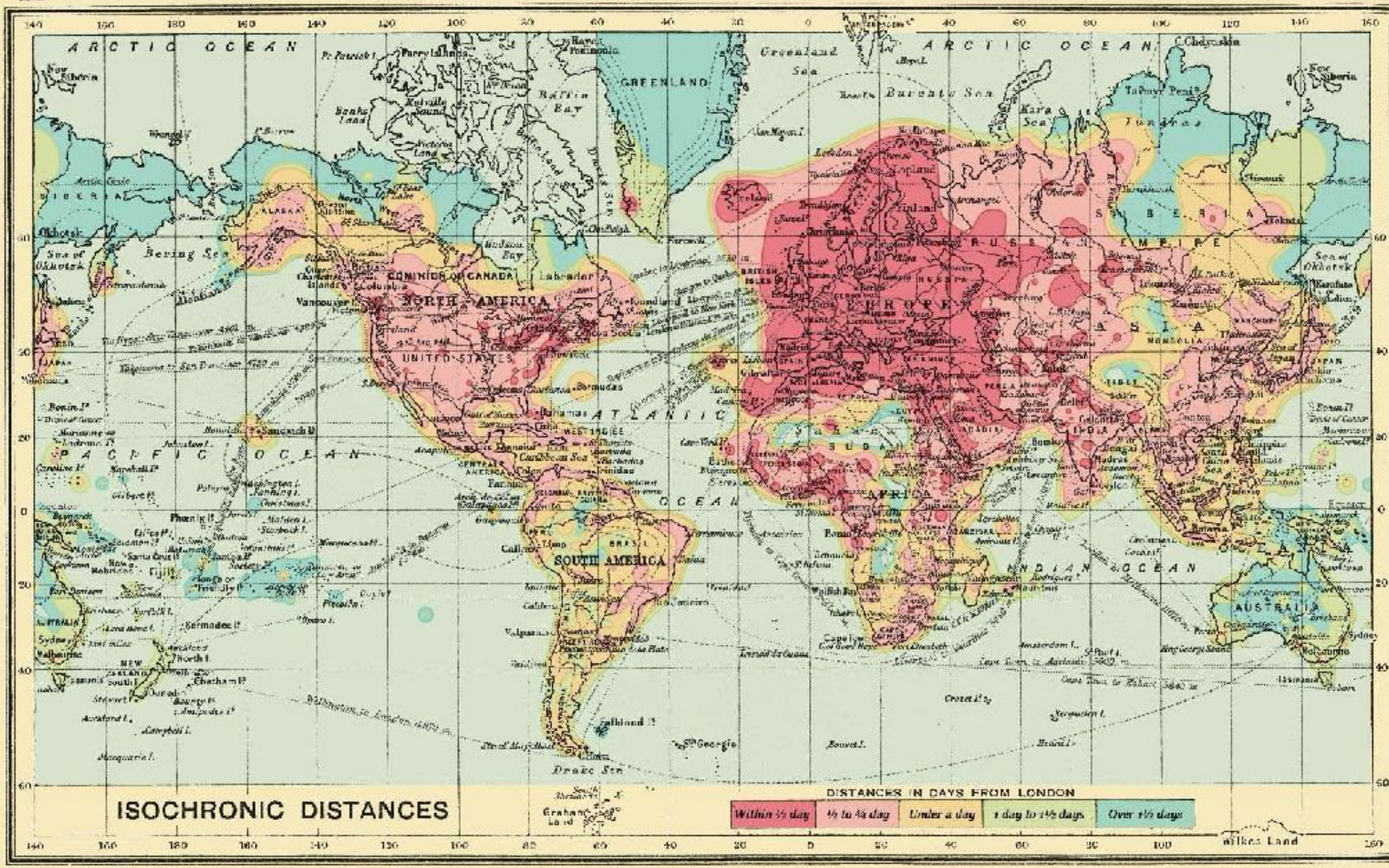
12B



1914

John George Bartholomew

12B



2016

Rome2rio

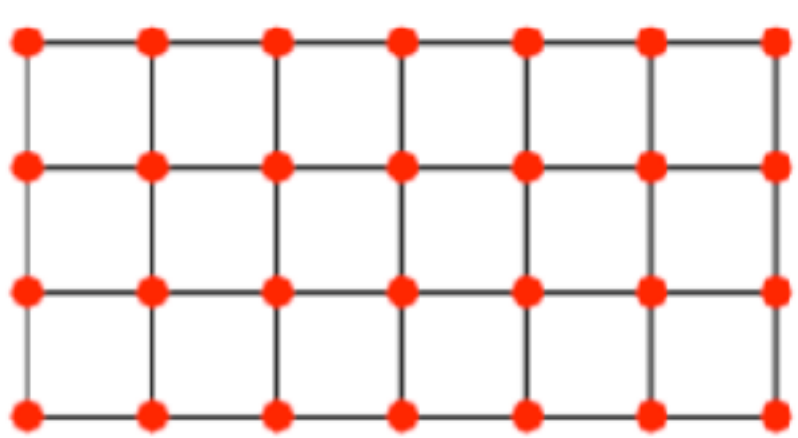
John George Bartholomew

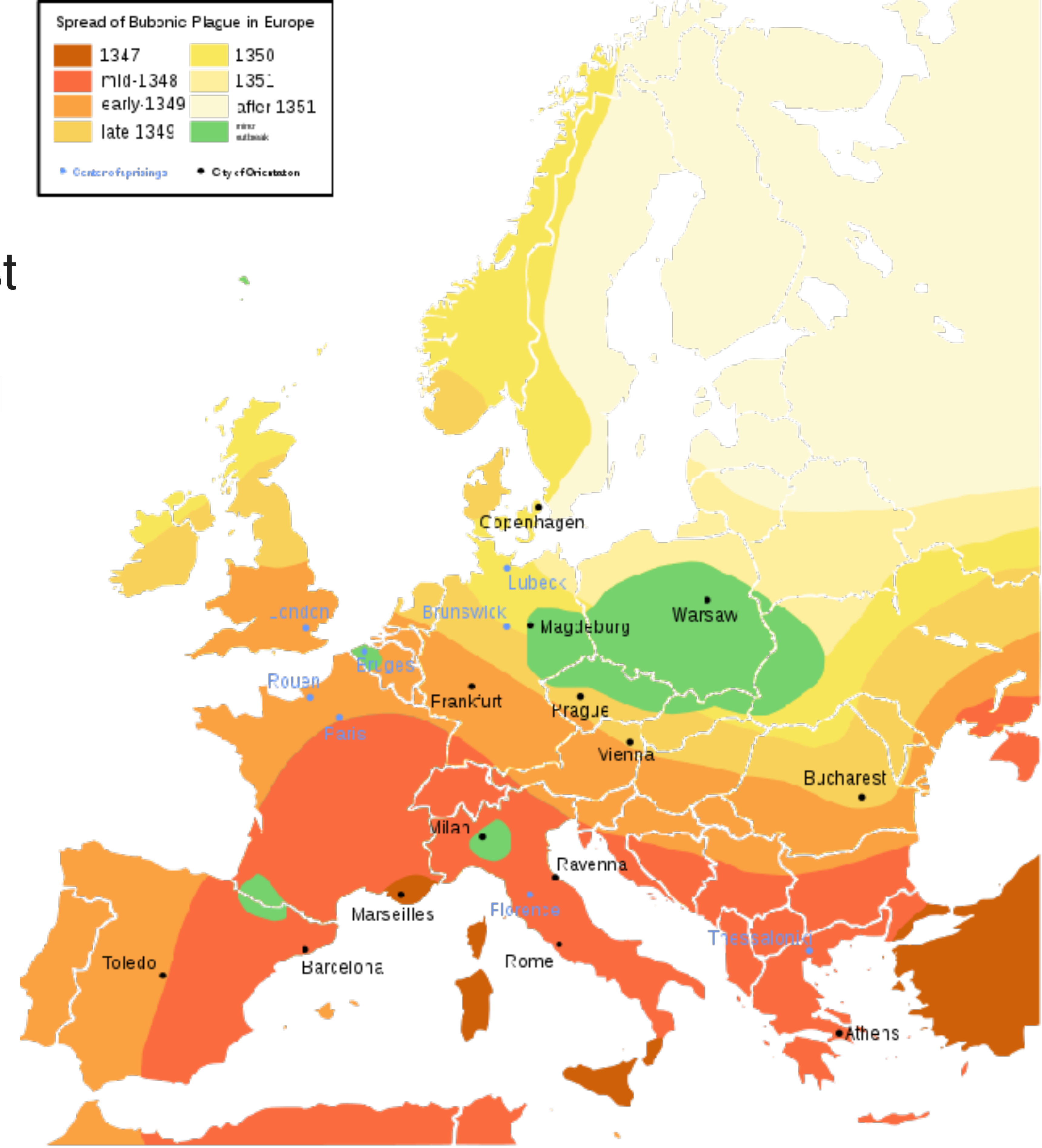
Isochronic distances became “patchy”: What happened?

Black death migration 1347-1353

Was one of the biggest pandemics in history: 75-200 Mio. from 1331 to 1353.

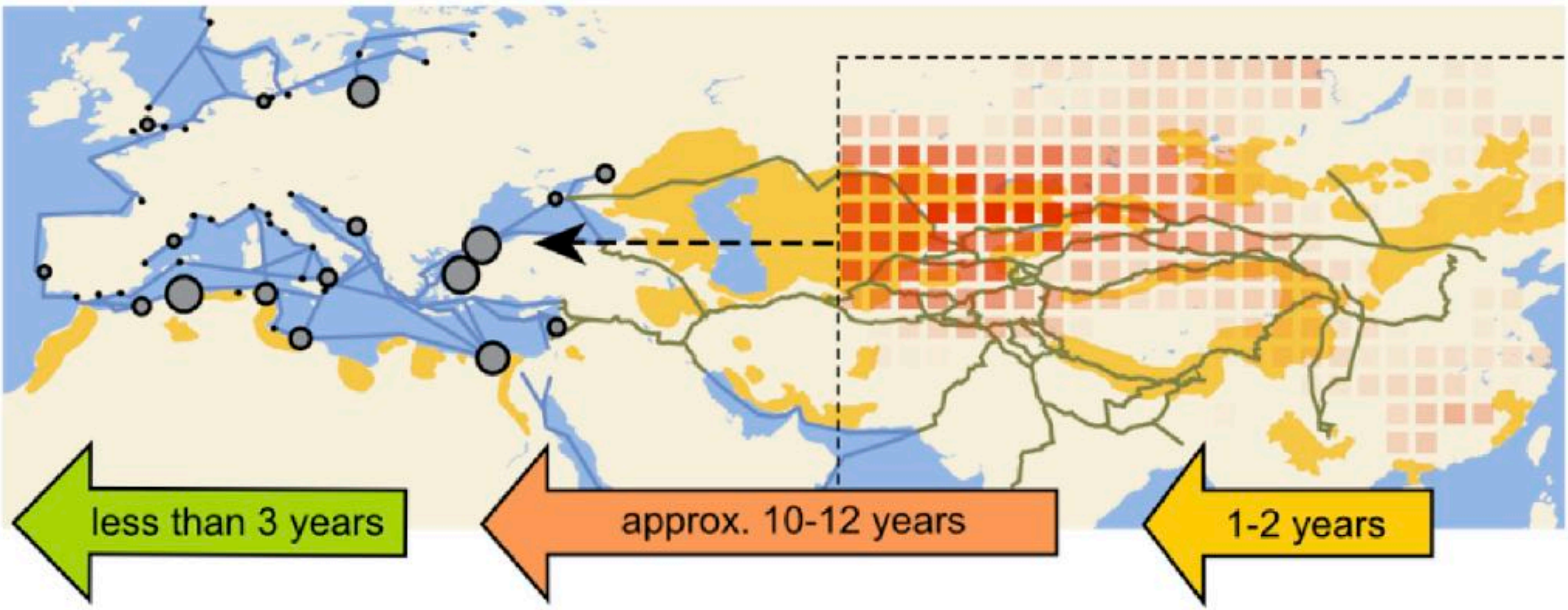
Its migration followed the sea and land trading routes of the medieval world.





https://en.wikipedia.org/wiki/Black_Death_migration

Black death migration

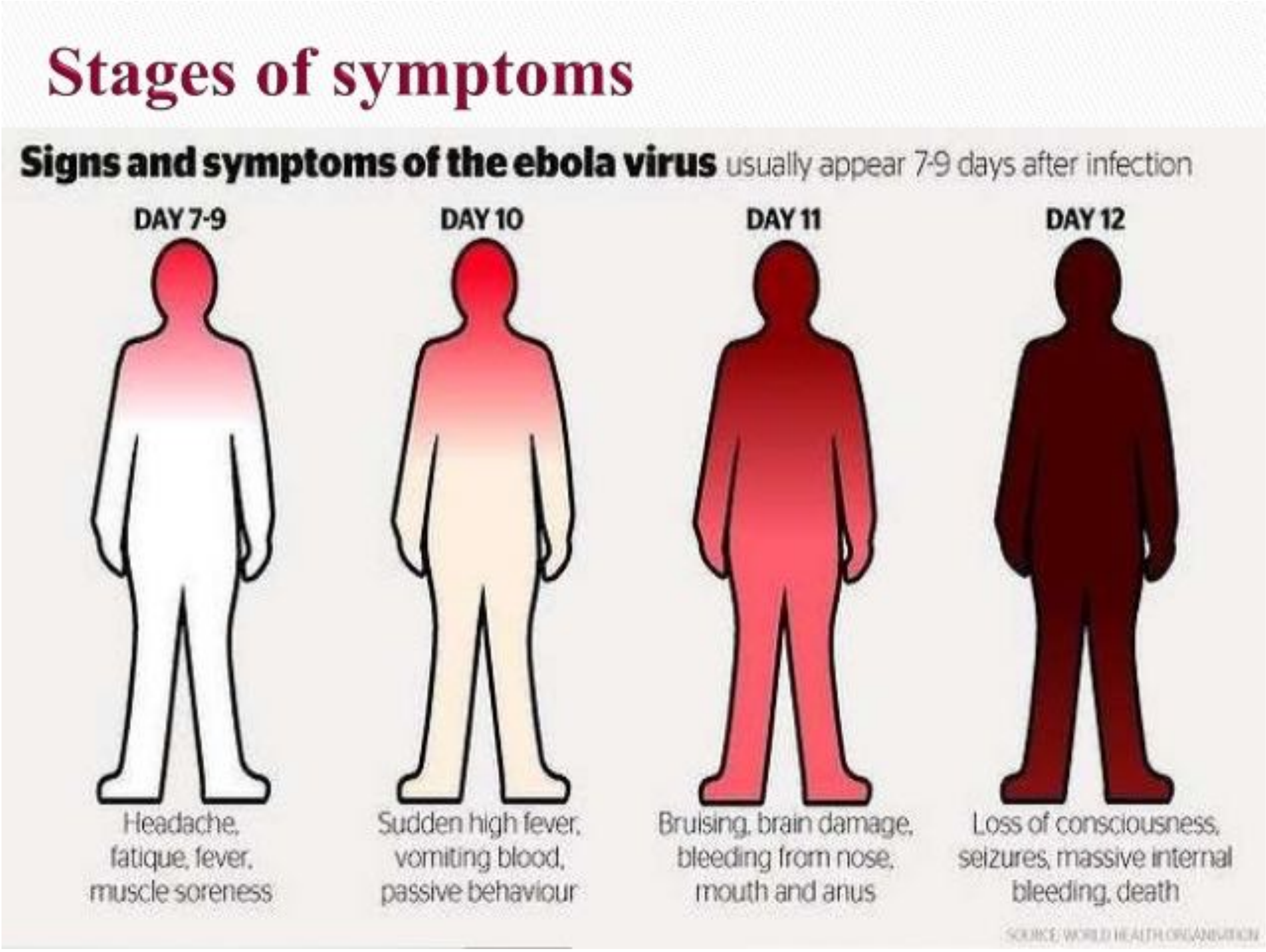


A new Asian plague pulse arrives in the harbors of Europe, and from there spreads into the mainland

Plague travels overland from western Central Asia to Europe, likely over the existing network of land traderoutes

Fleas find alternative hosts after a climate-induced rodent population boom and crash (red squares), and come into contact with humans.

Spread of Ebola 2014

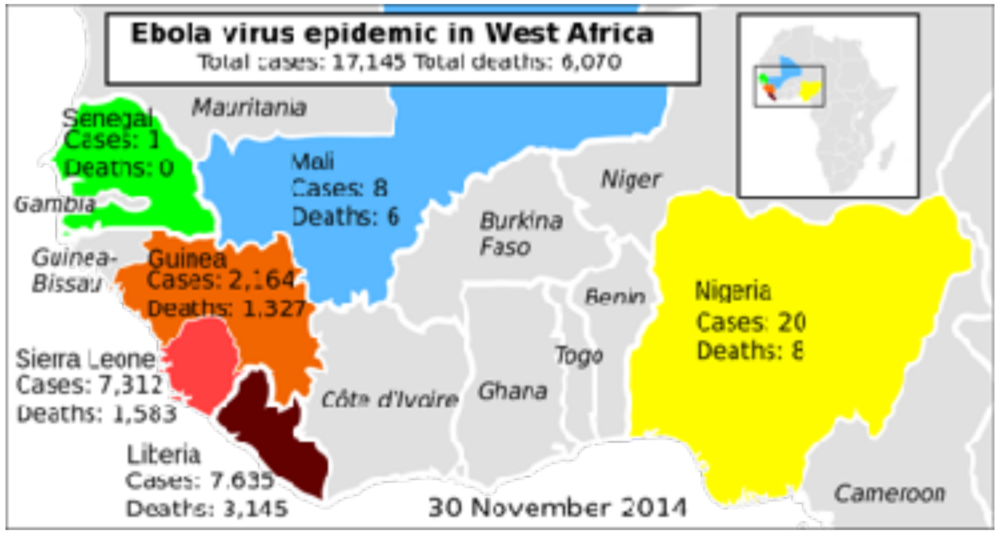


Over 50% fatality rate

No treatment

Spread of Ebola 2014

Largest outbreak of Ebola, by cases and geographic extent.

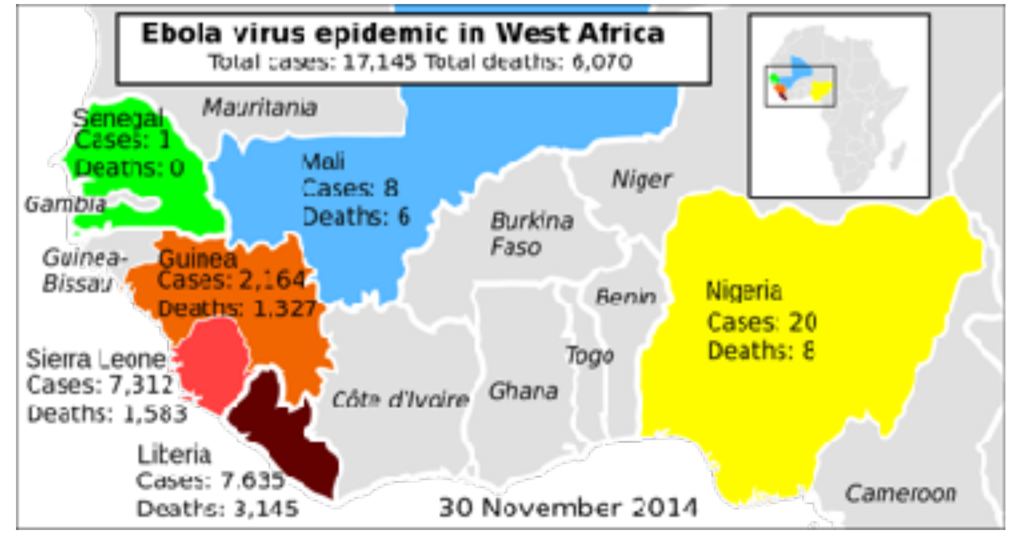


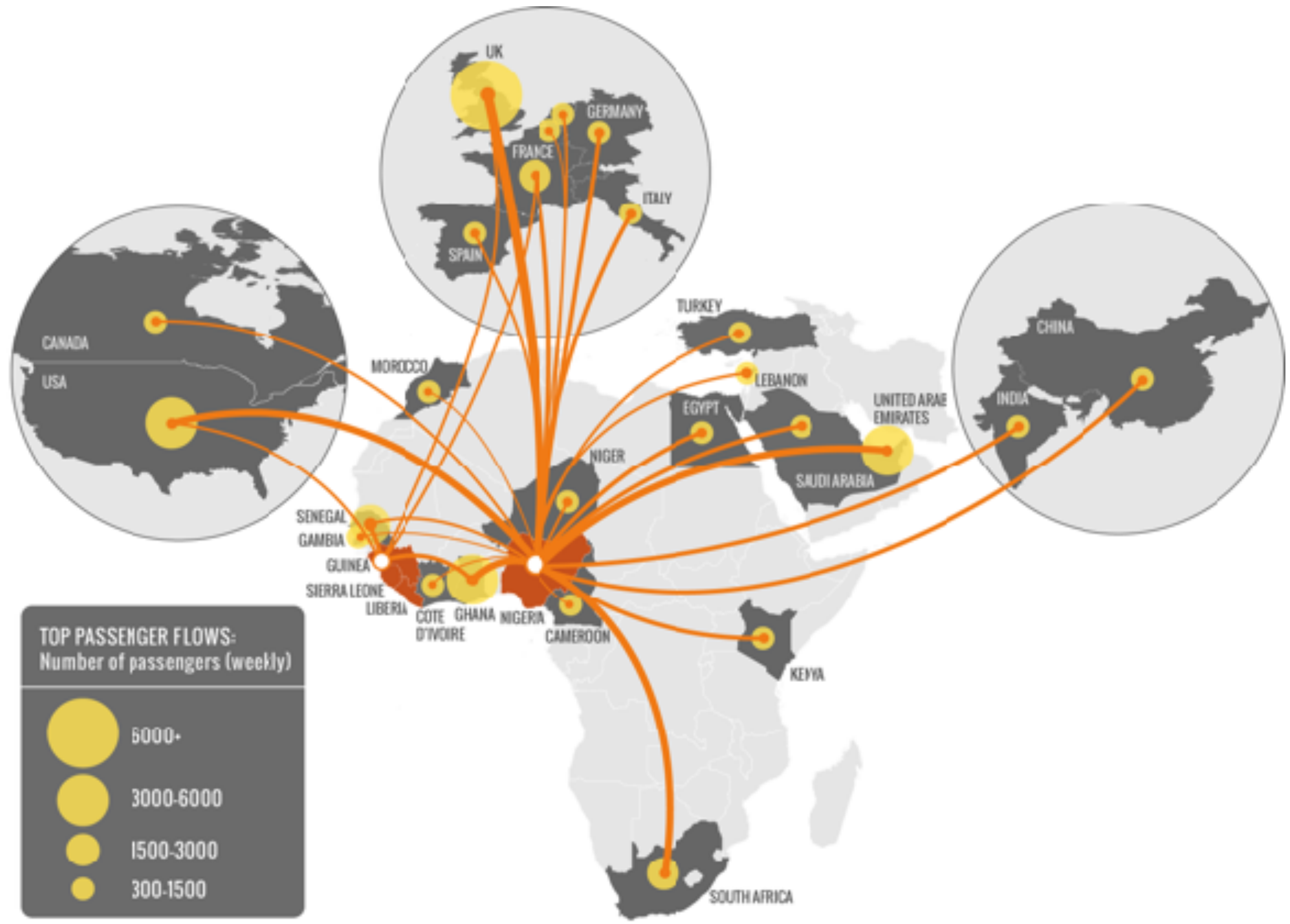
https://en.wikipedia.org/wiki/West_African_Ebola_virus_epidemic

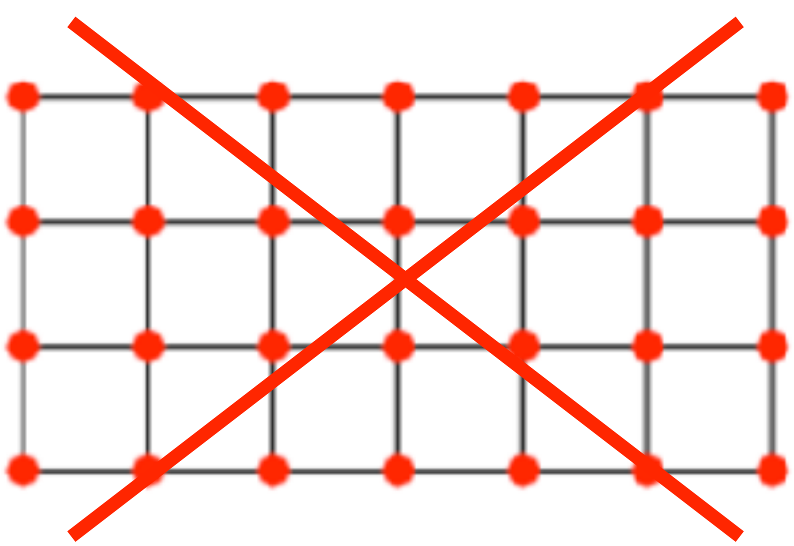
Spread of Ebola 2014

Largest outbreak of Ebola, by cases and geographic extent.

The virus was mostly “contained” in West Africa, but could have easily spread worldwide







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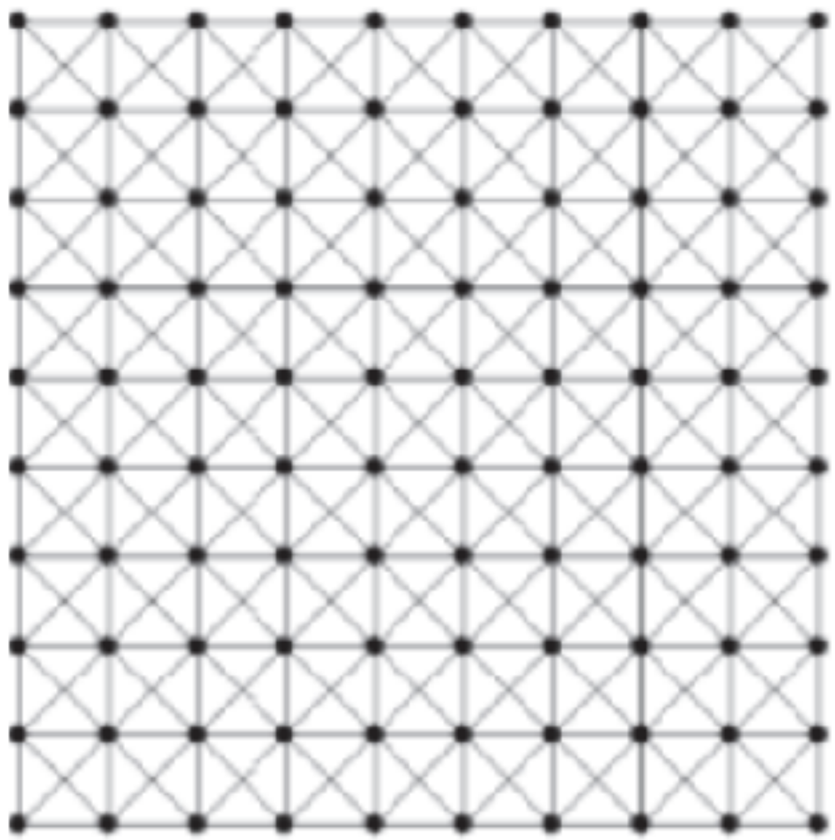
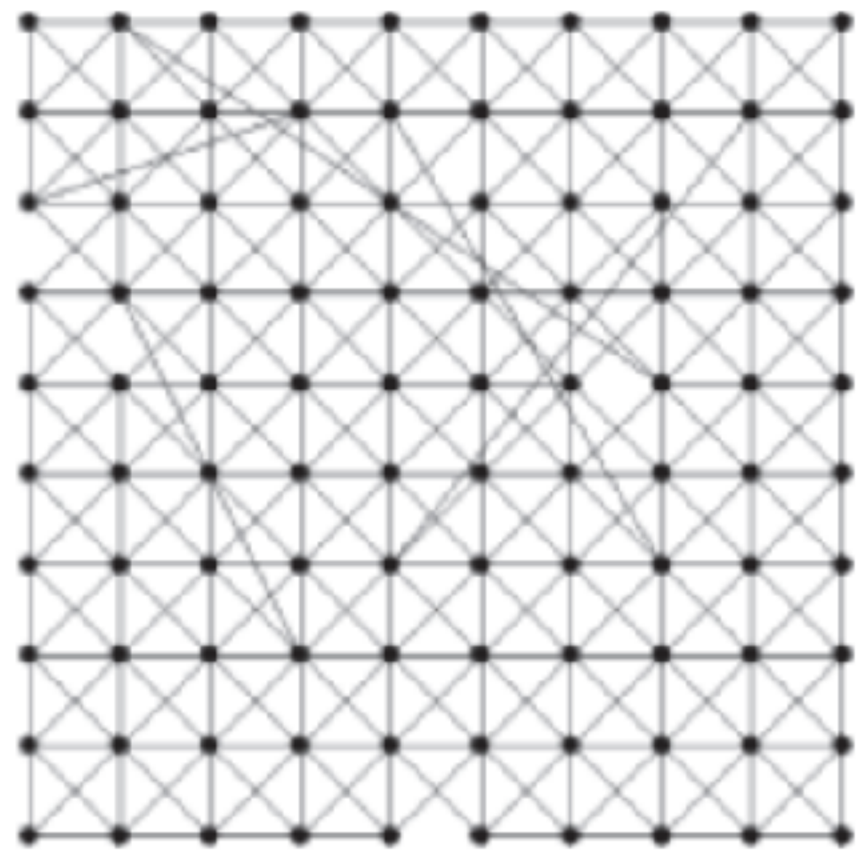
http://currents.plos.org/outbreaks/article/assessing-the-international-spreading-risk-associated-with-the-2014-west-african-ebola-outbreak/

The grid has turned into a small-world!



Regular network ϕ=0



Small-world network ϕ=0.01

Diseases now spread through the airline network

https://flightstorome.moovellab.com/#roadsinthesky

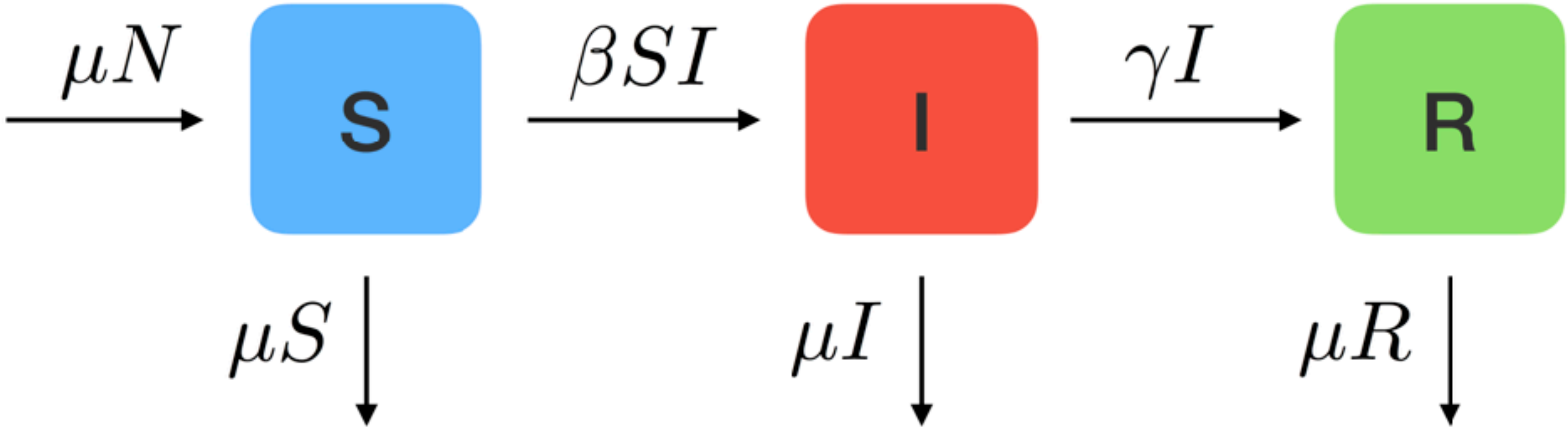
Change of technology and travel behavior

2013: **The Hidden Geometry of Complex, Network-Driven Contagion Phenomena**

Dirk Brockmann[1,2,3*] and Dirk Helbing[4,5]

https://www.youtube.com/watch?v=ECJ2DdPhMxI

Compartmental models

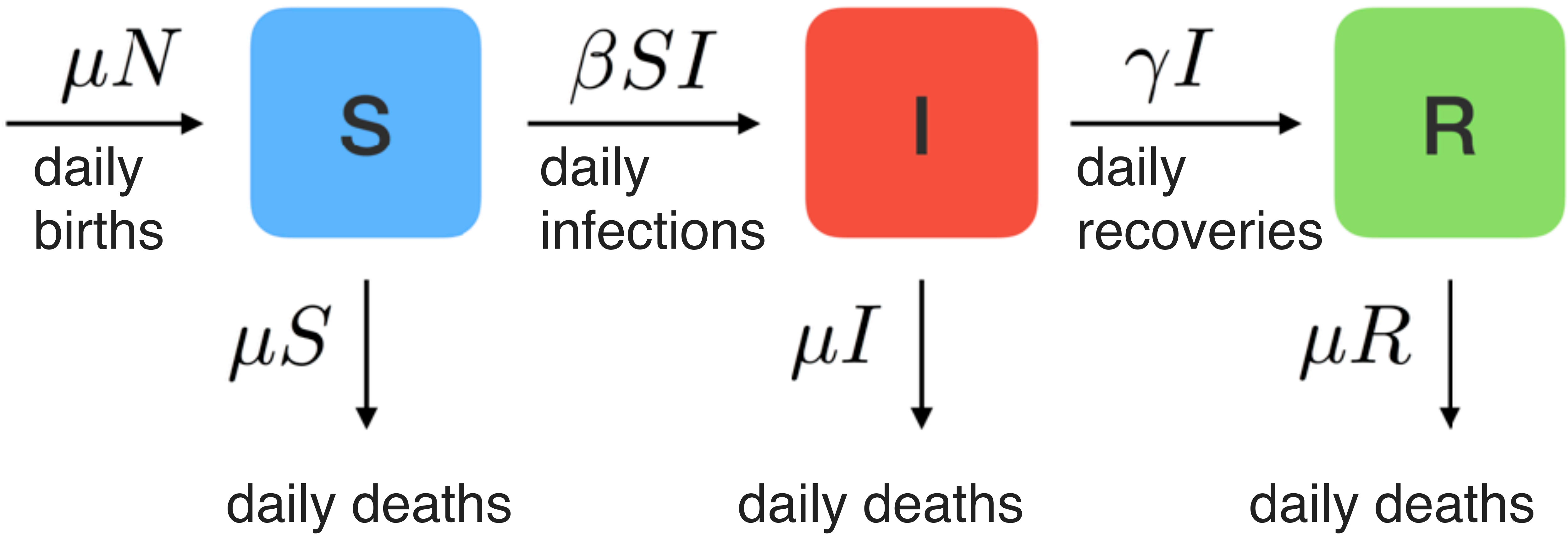


Compartment models are mathematical models of infectious diseases using differential equations. The population is divided into compartments, every individual in the same compartment has the same characteristics.

The simplest one is SIR (Susceptible, Infected, Recovered)

https://sineadmorris.github.io/project/the-sir-model/

Compartmental models



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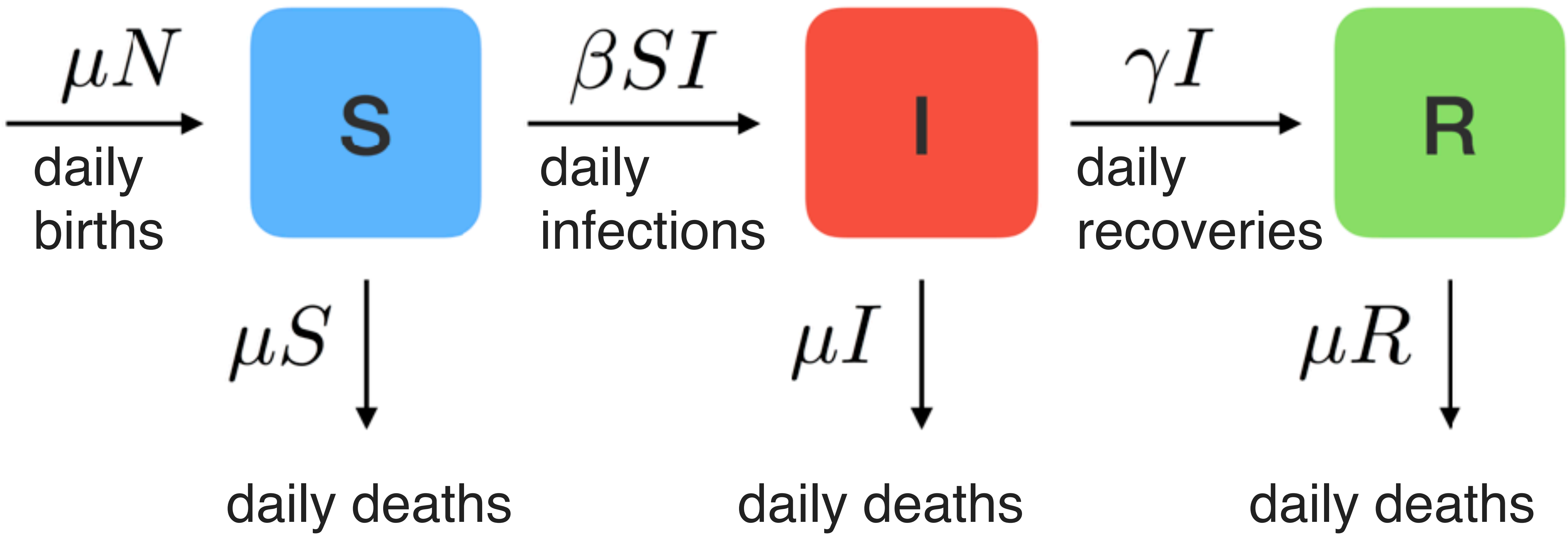
Compartmental models



$$\frac{dS}{dt} = \mu N - \beta SI - \mu S$$

$$\frac{dI}{dt} = \beta SI - \gamma I - \mu I$$

$$\frac{dR}{dt} = \gamma I - \mu R.$$

https://sineadmorris.github.io/project/the-sir-model/

Compartmental models without vital dynamics

Because dynamics of epidemics are much faster than the vital dynamics (birth and death), we can omit those.

$$\frac{dS}{dt} = -\frac{\beta IS}{N}$$

$$\frac{dI}{dt} = \frac{\beta IS}{N} - \gamma I$$

$$\frac{dR}{dt} = \gamma I.$$

Compartmental model of the air traffic network

$$\partial_t S_n = -\alpha I_n S_n / N_n,$$
$$\partial_t I_n = \alpha I_n S_n / N_n - \beta I_n \quad n = 1, \ldots, M$$

Exactly same set of equations, but for n nodes in the air traffic network.

Compartmental model of the air traffic network

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Exactly same set of equations, but for n nodes in the air traffic network.

Also, there are network flow dynamics:

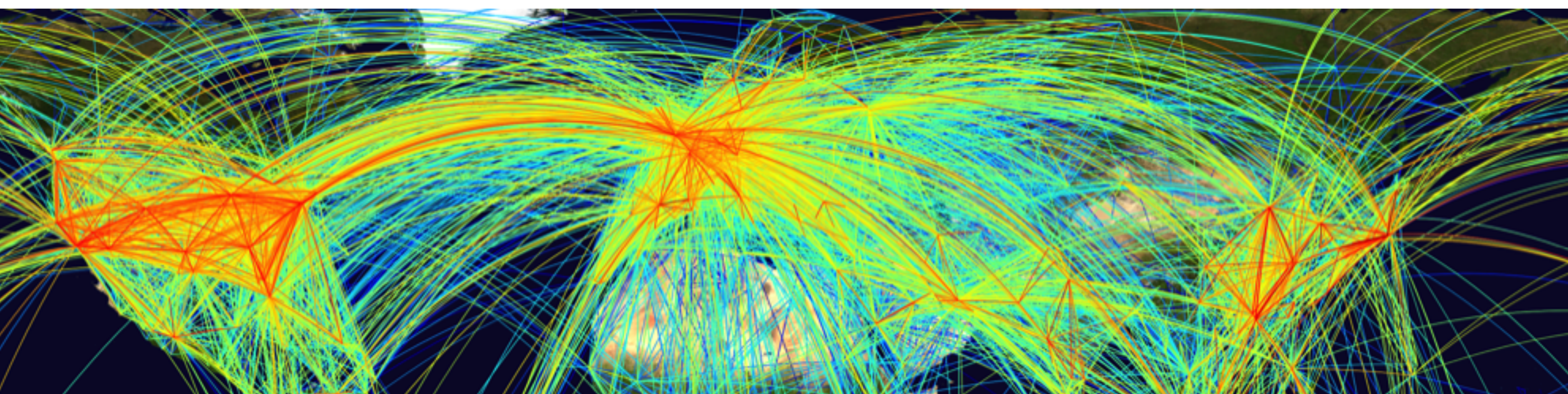
$$\partial_t U_n = \sum_{m \neq n} w_{nm} U_m - w_{mn} U_n$$

Where U stands for S,I, or R

Where w_{nm} is the flow from place n to m

4069 airports, 25,453 direct connections

Flow: 9,000,000 passengers per day



Compartmental model of the air traffic network

- Assume that the traffic in/out of a node is proportional to its population

- Define an effective distance (asymmetric)

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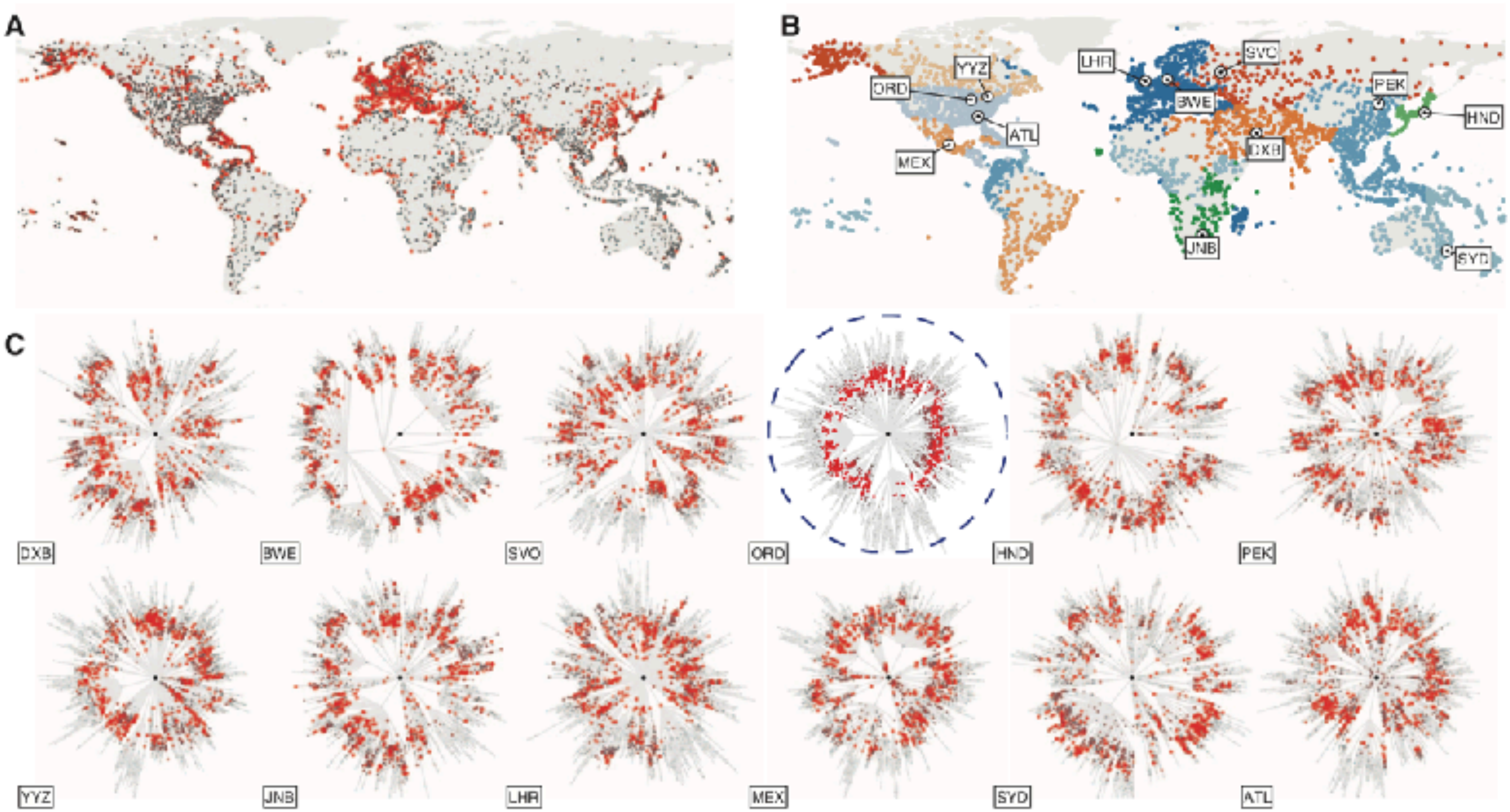
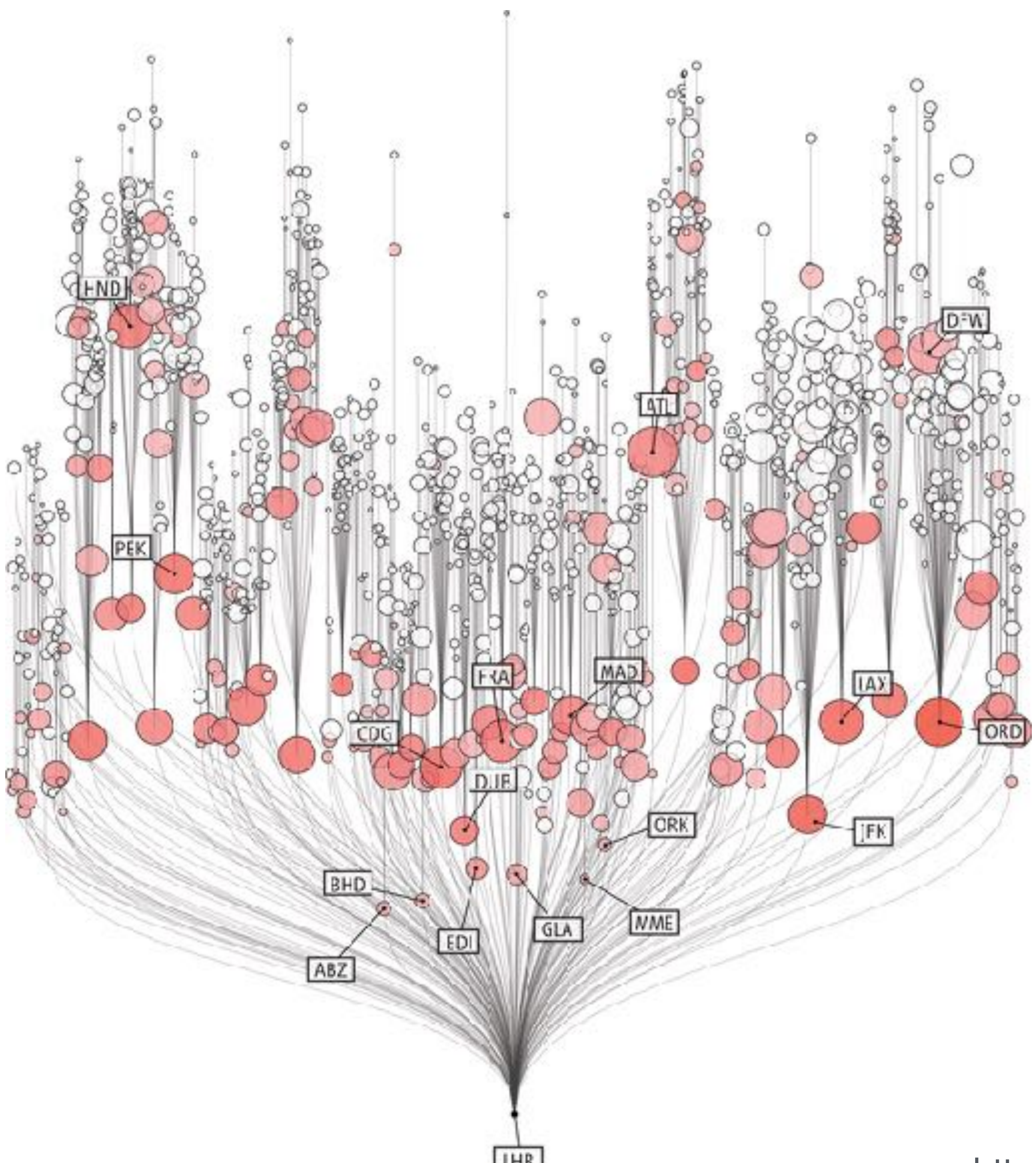
Each node has then a shortest path tree:



Compartmental model of the air traffic network

Alternative visualization:



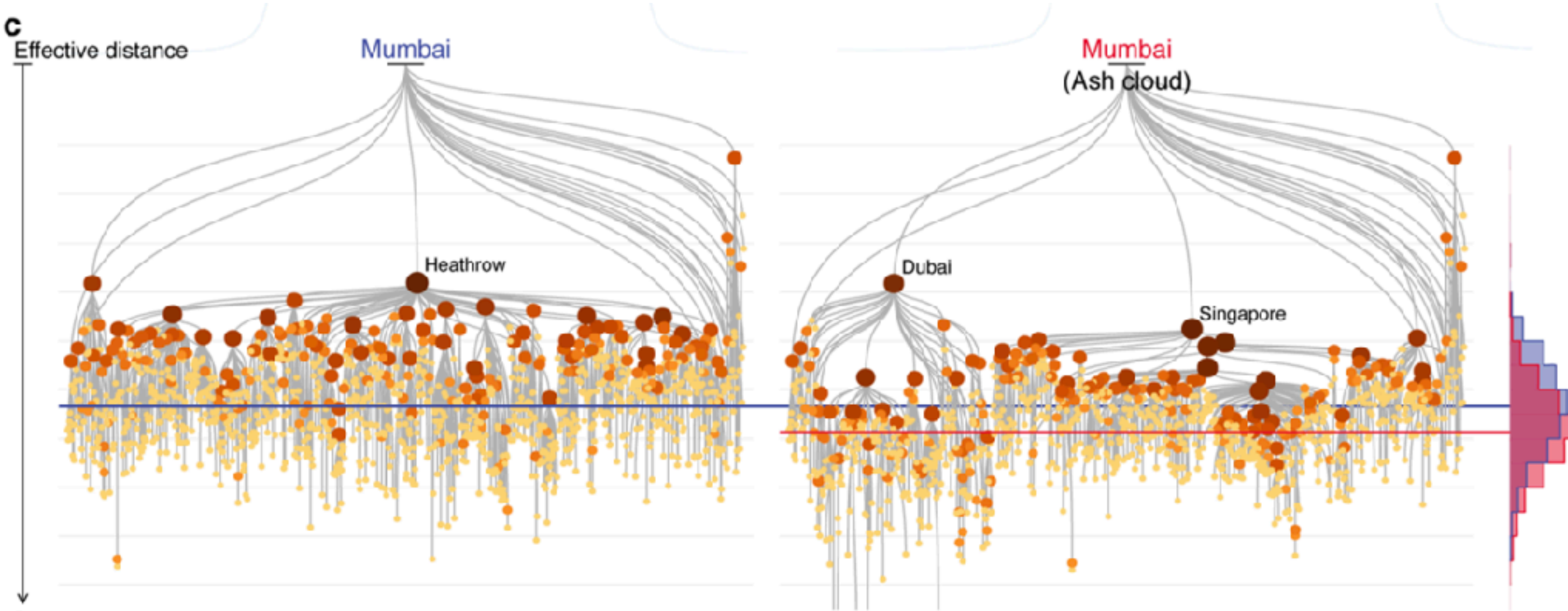
Node size: traffic
Node color: degree
Node y-position: distance

These shortest paths are not anymore about geographic distance!

http://science.sciencemag.org/content/342/6164/1330.full

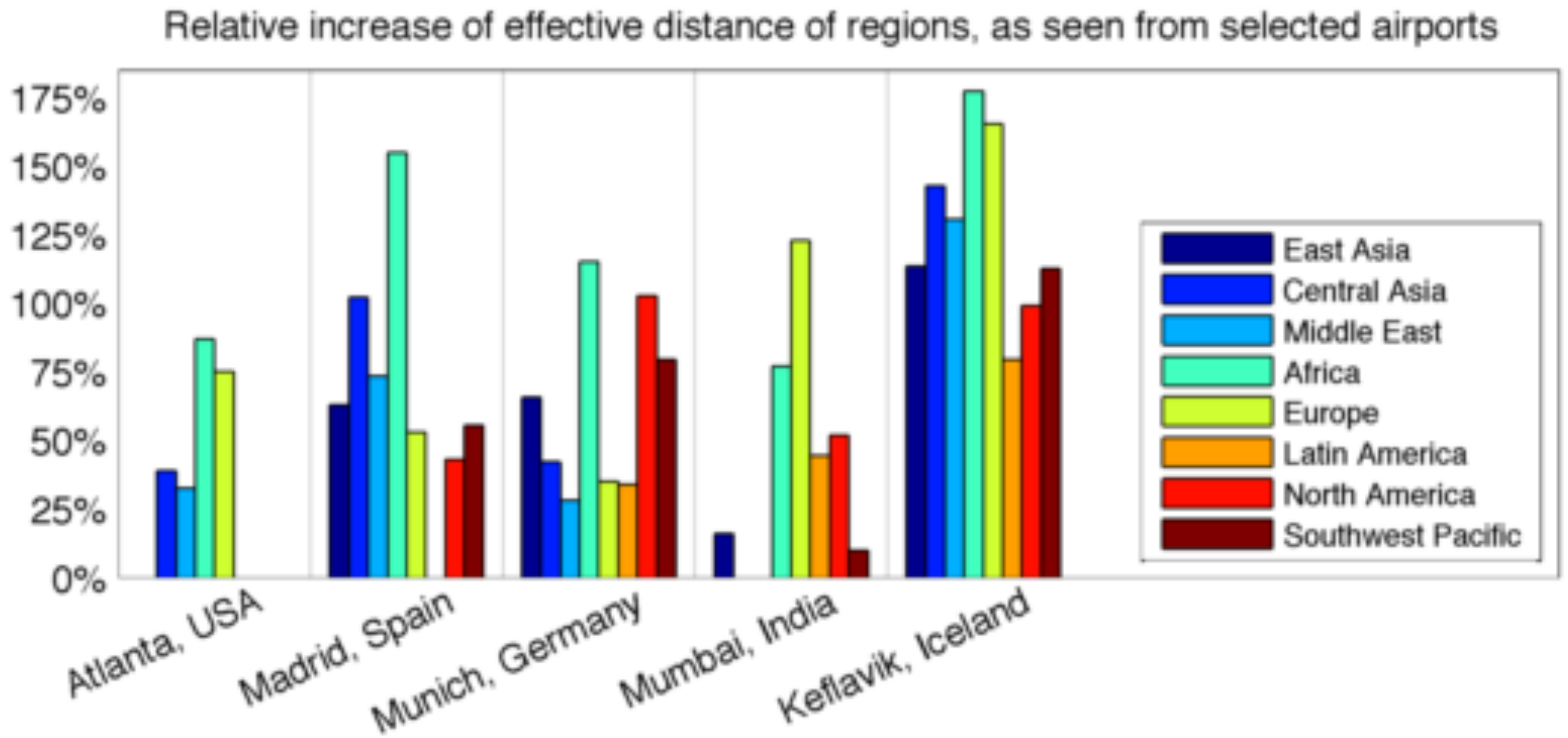
Application to Eyafjallajökull

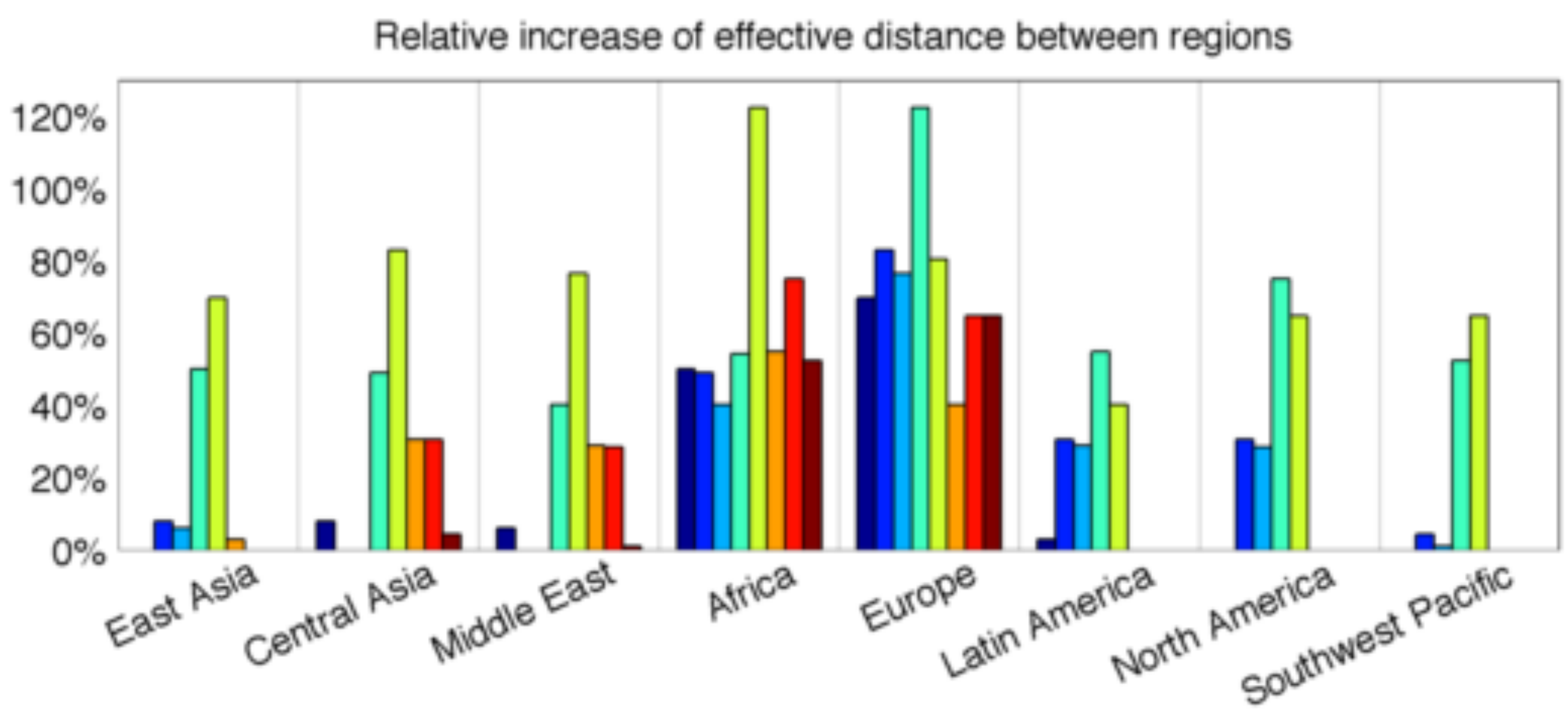
When the volcano broke out, 27 European airports closed (nodes removed), changing dramatically the shortest path trees worldwide



https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0069829

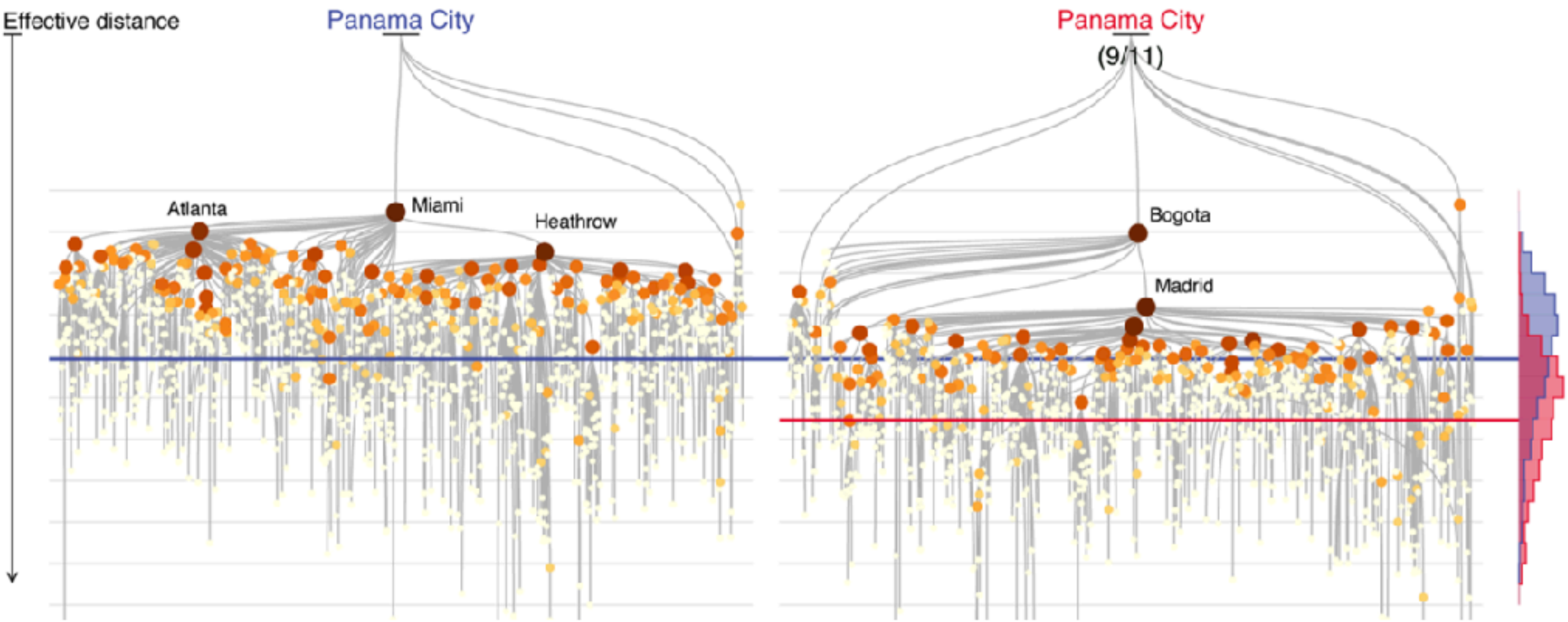
Application to Eyafjallajökull





https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0069829

Application to 9/11



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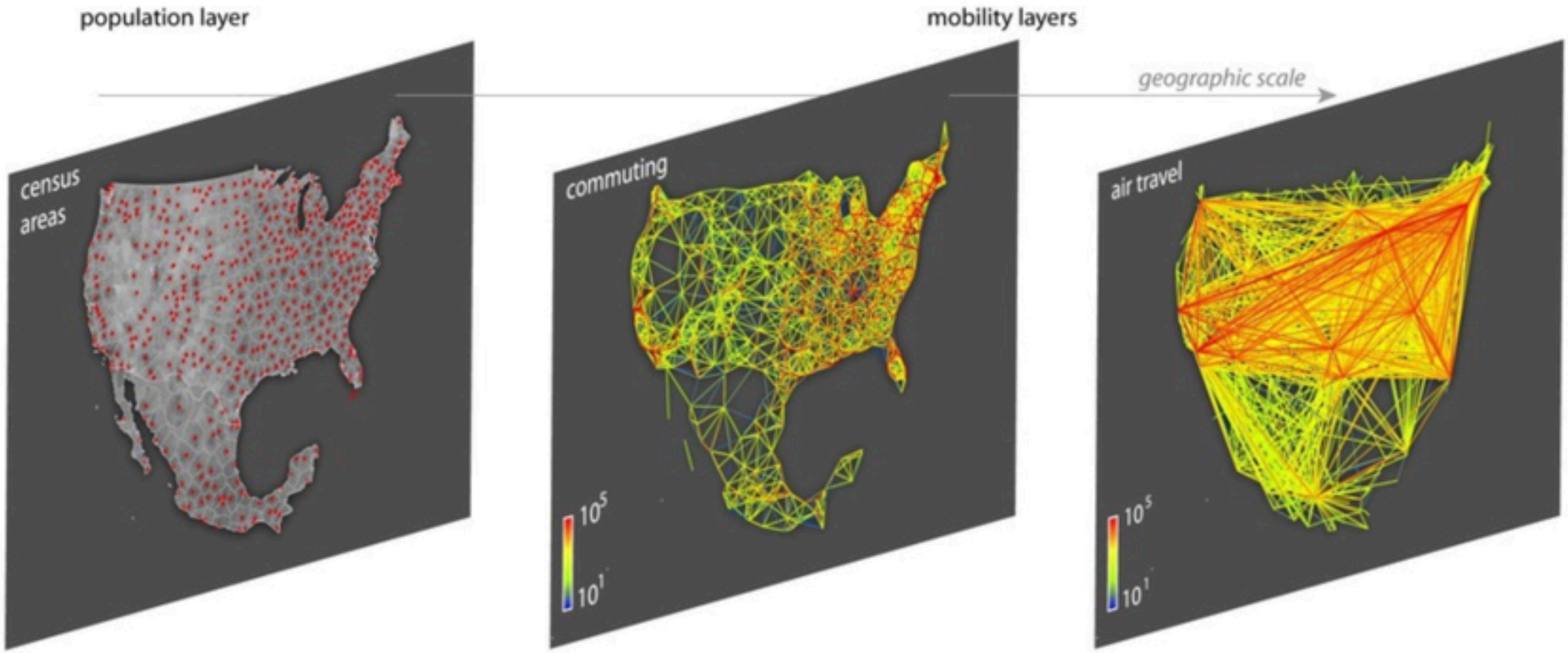
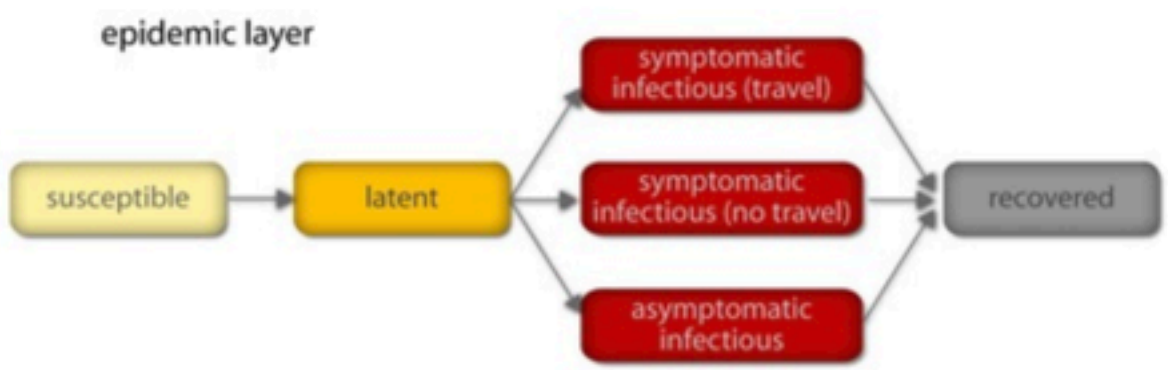
GLEAM (Global Epidemic and Mobility Model)





Parameter	Value	Description
β	from R_0	transmission probability
ε^{-1}	1.9 [1.1-2.5] d	average latency period
μ^{-1}	3 [3-5] d	average infectious period
p_t	50%	probability of traveling for infectious individuals
p_a	33%	probability of being asymptomatic
r_β	50%	relative infectiousness of asymptomatic infectious individuals

http://www.gleamviz.org