Are global epidemics predictable? The SARS case study

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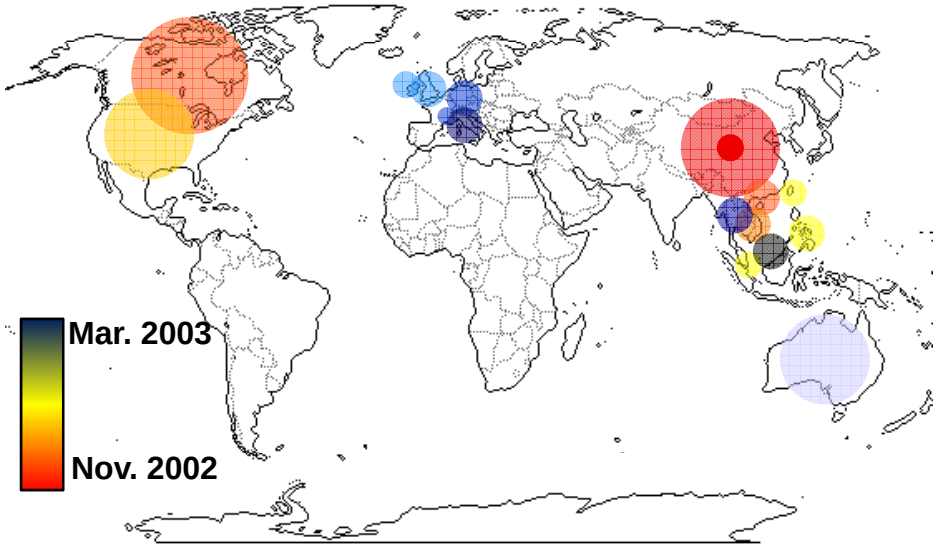
weather forecasts

- sophisticated simulations
- super-computers
- huge datasets
- historical weather patterns
- non-linear equations for fluid and gas masses

mathematical models of the atmosphere

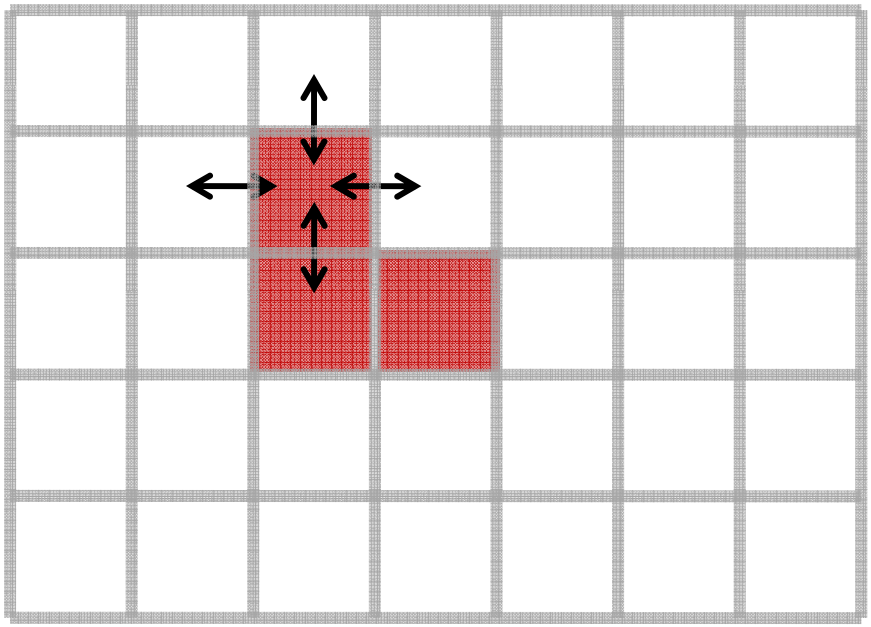
weather forecasts *vs.* epidemic forecasts

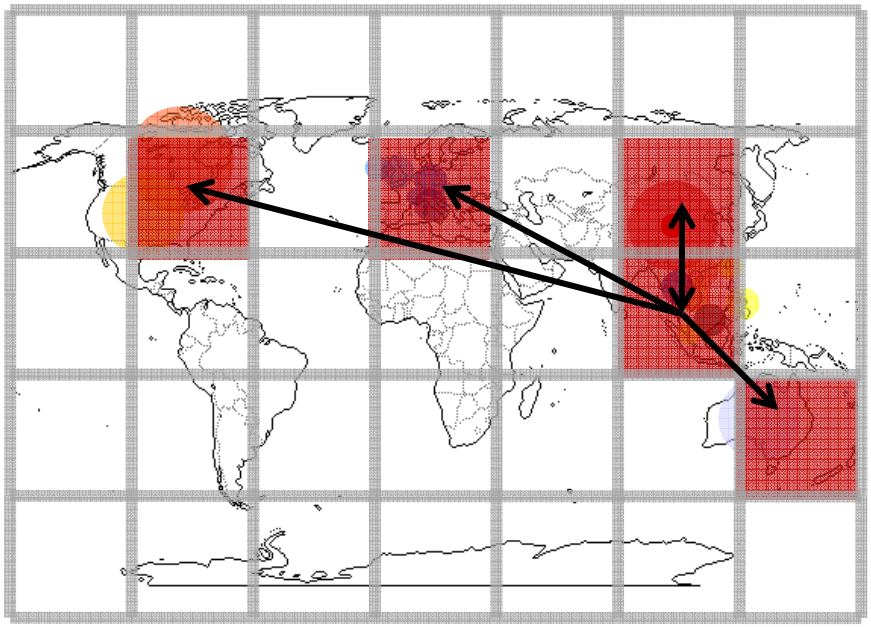


fluid and gas masses subject to physical laws

heterogeneous individuals, social behavior, infection dynamics

discrete computational approach

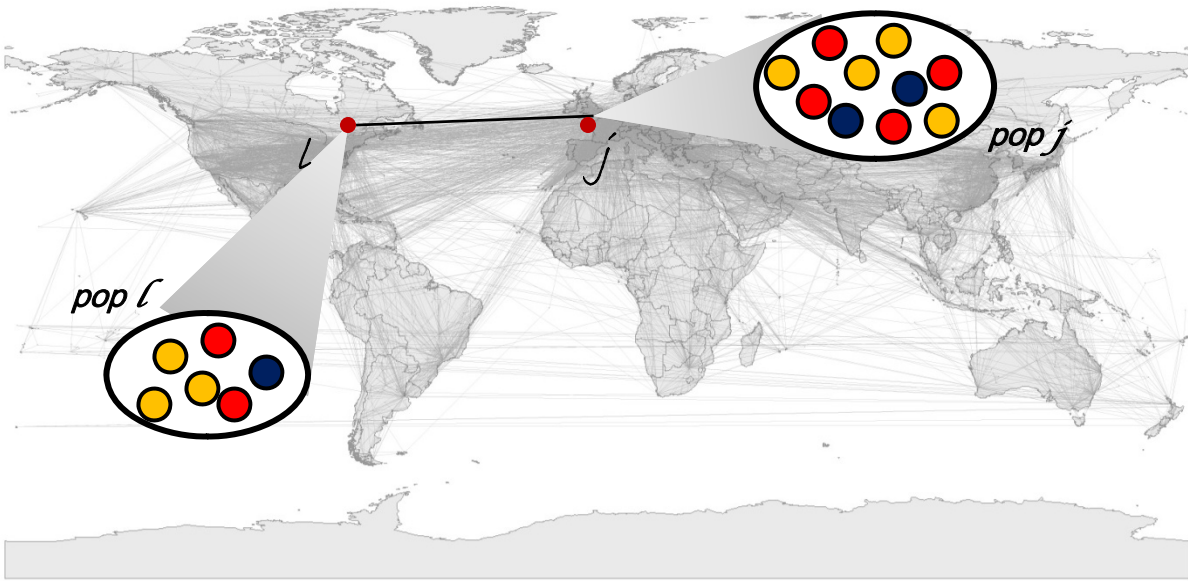




non local interactions
connectivity fluctuations

extension to complex networks

global spread of epidemics via air travel



Baroyan et al, 1969:
≈40 russian cities

Rvachev & Longini, 1985:
50 airports worldwide

Grais et al, 1988:
150 airports in the US

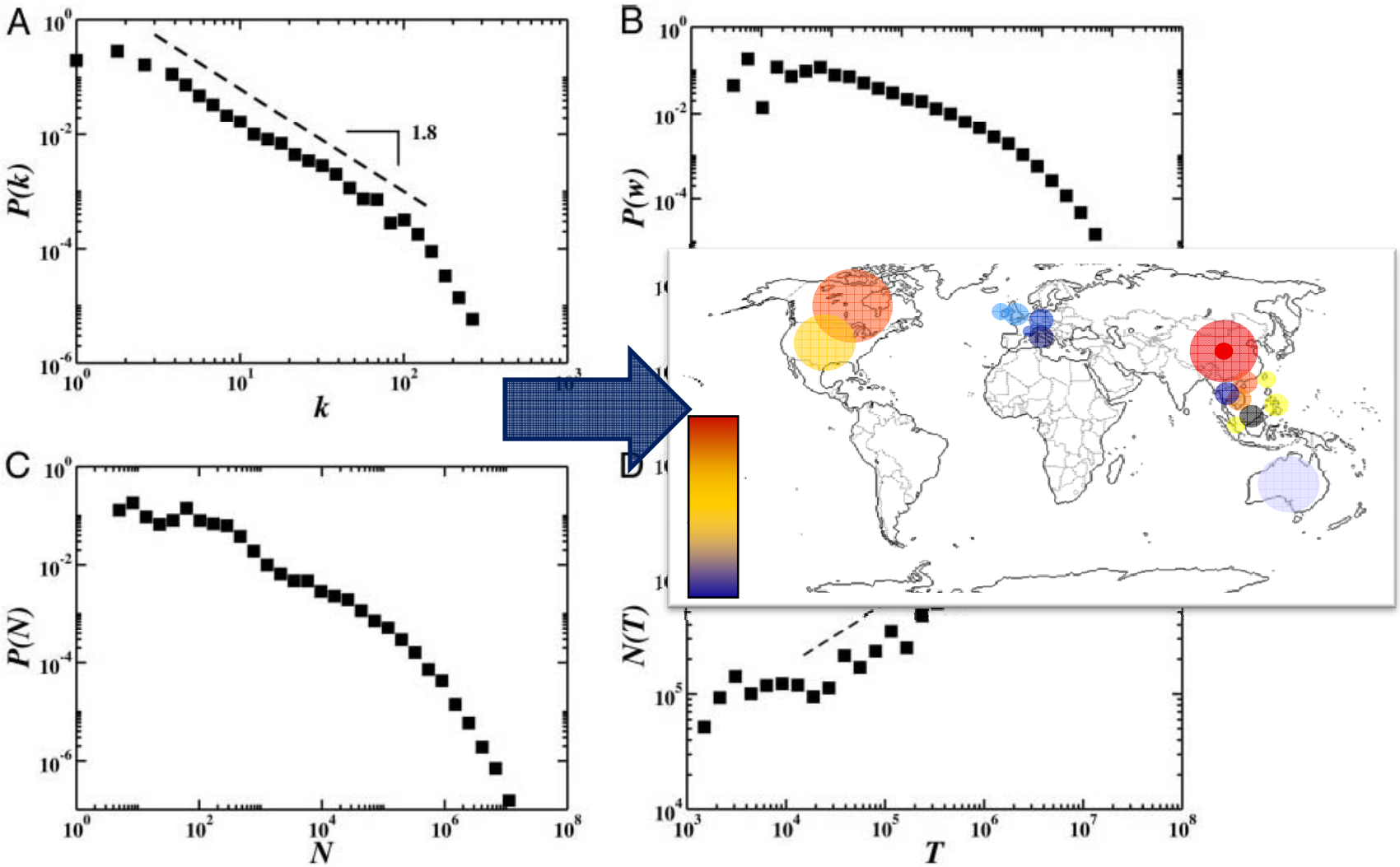
Hufnagel et al, 2004:
500 top airports worldwide

Complete IATA database:

3100 airports worldwide
220 countries
≈ 20,000 connections
w_{ij} #passengers on connection i-j
>99% total traffic

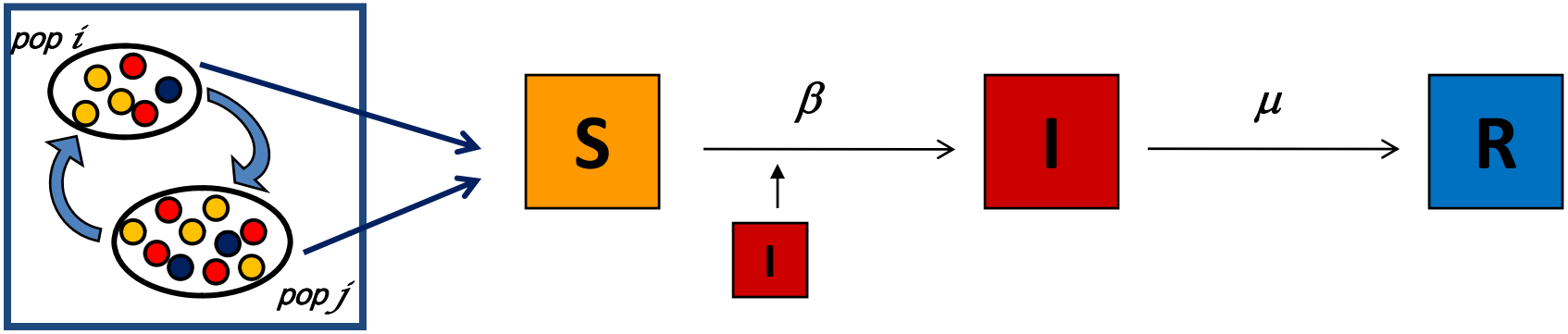
Colizza, Barrat, Barthelemy & Vespignani, PNAS (2006)

world-wide airport network: properties



Colizza, Barrat, Barthelemy & Vespignani, PNAS (2006)

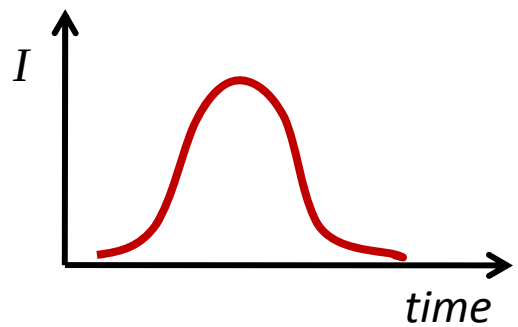
intra-city: *discrete stochastic* infection dynamics



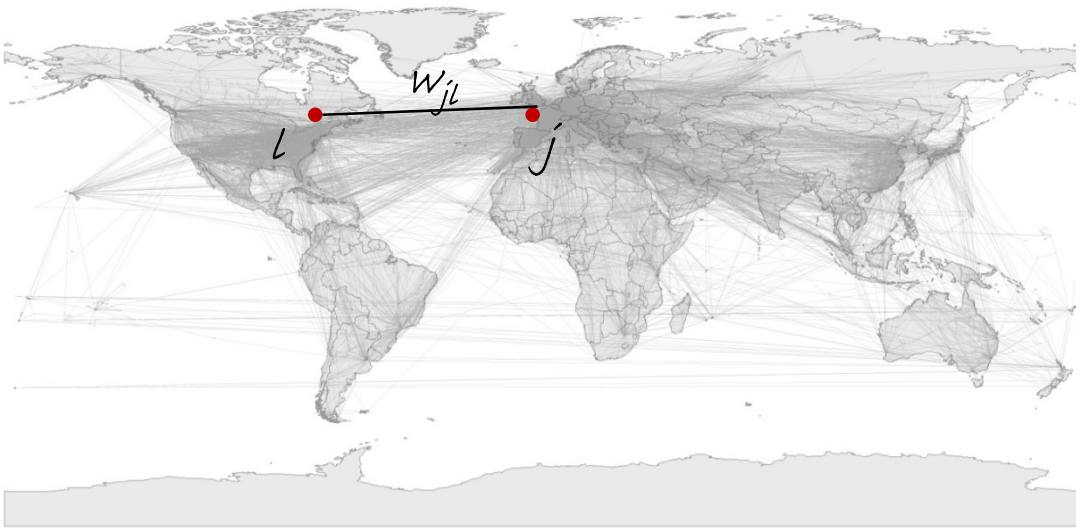
$$S_{t+1} = S_t - \Delta S$$
$$I_{t+1} = I_t + \Delta S - \Delta R$$
$$R_{t+1} = R_t - \Delta R$$

$$\Delta S = \text{Binom}(S_t, \beta I_t / N)$$

$$\Delta R = \text{Binom}(I_t, \mu)$$



inter-cities: *discrete stochastic* air travel



probability that any individual in compartment *X* travels from j to l:

- proportional to the traffic flow
- inversely proportional to the population

$$p_{jl} = \frac{w_{jl}}{N_j}$$

multinomial extraction of travelers ξ_{jl} in class *X*:

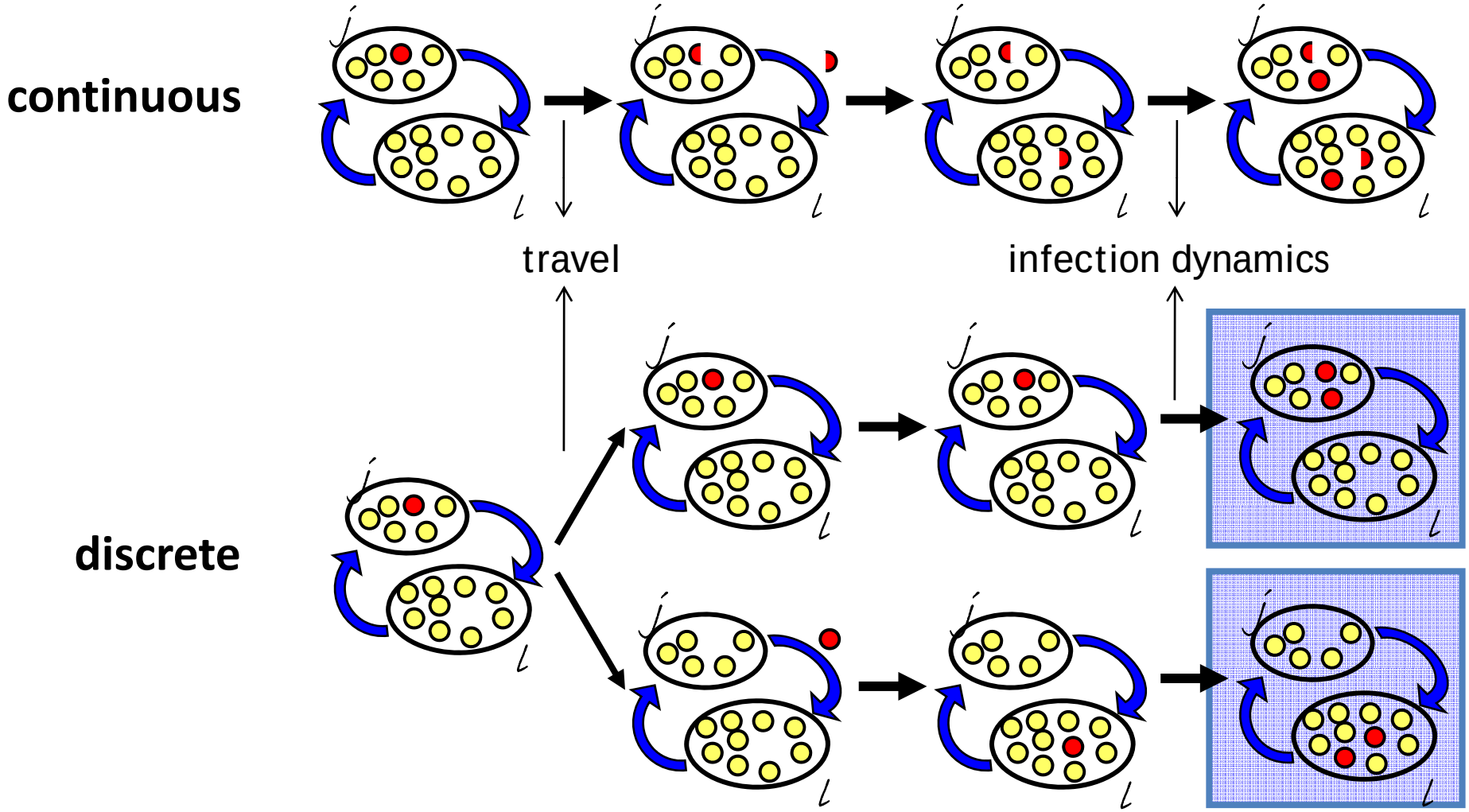
$$P(\{\xi_l\}) = \frac{X_j!}{(X_j - \sum_l \xi_{jl})! \prod_l \xi_{jl}!} \prod_l p_{jl}^{\xi_{jl}} \left(1 - \sum_l p_{jl}\right)^{(X_j - \sum_l \xi_{jl})}$$

stochastic travel operator: net balance influx – outflux

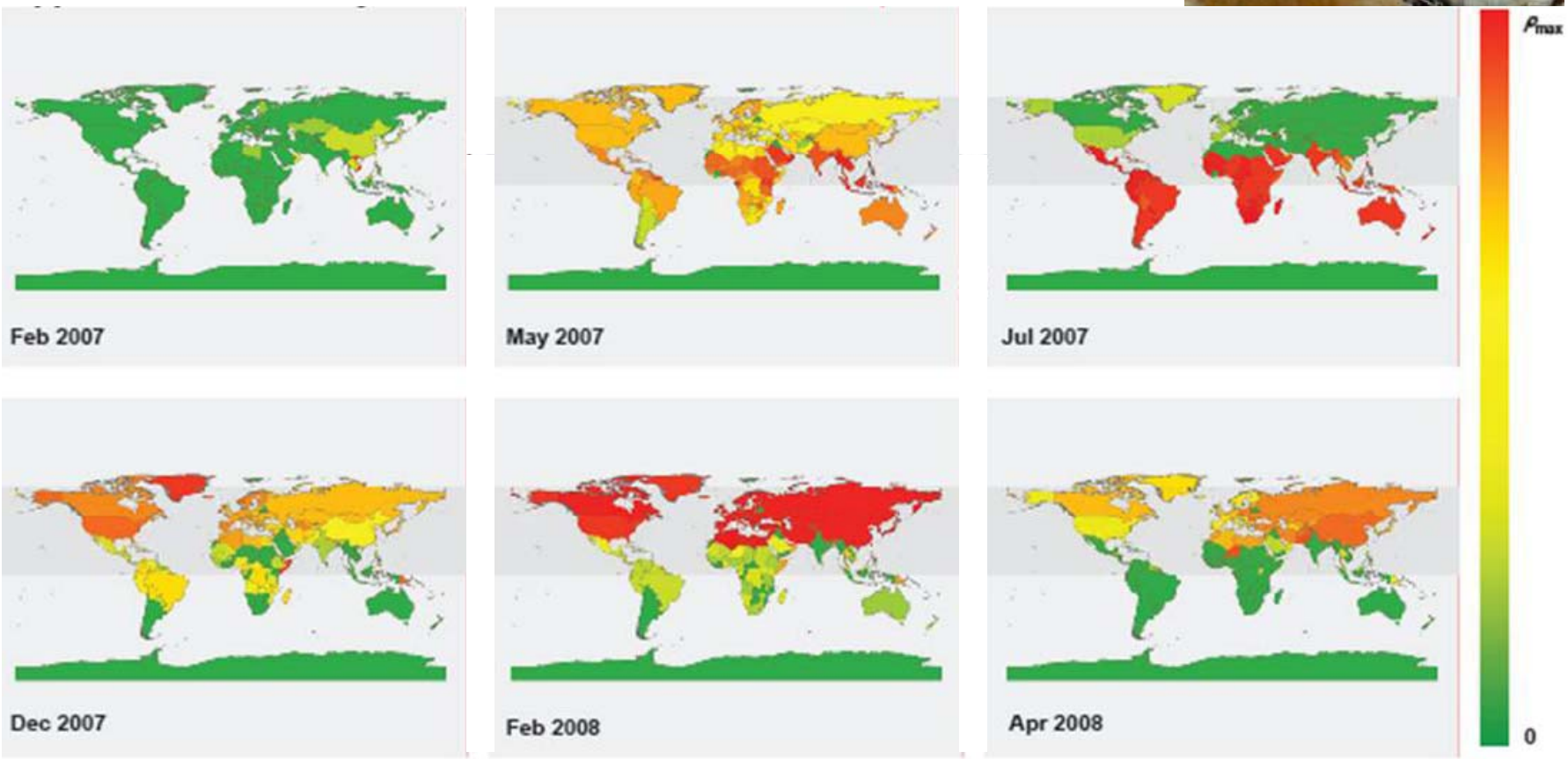
$$\Omega_j(\{X\}) = \sum_l \left(\xi_{jl}(X_j) - \xi_{lj}(X_l)\right)$$

discrete vs. *continuous* air travel

$$\boxed{\left\langle \xi_{jl}(I_j) \right\rangle = p_{jl} I_j < 1 \text{ !!!}}$$



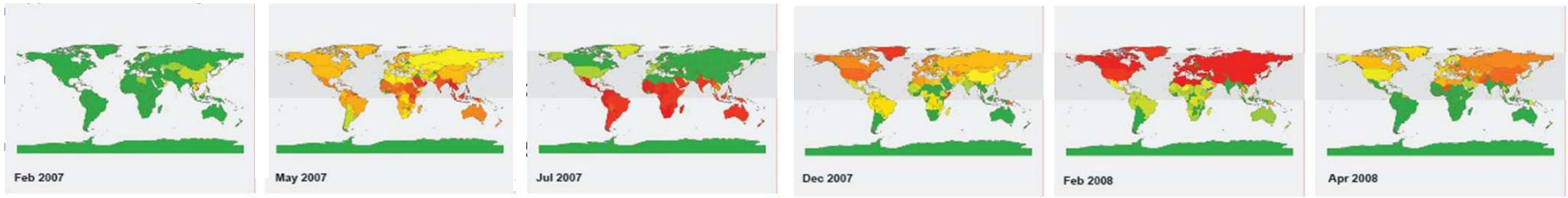
predictions: e.g. pandemic flu



Colizza, Barrat, Barthelemy , Valleron & Vespignani, PLoS Medicine (2007)

reliability of predictions?

one outbreak realization:



another outbreak realization ?

overlap measure

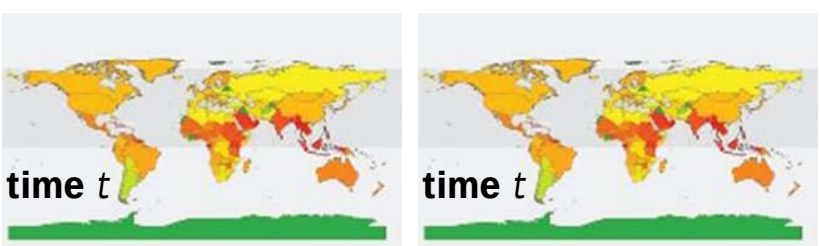
$$\vec{\pi}(t), \quad \pi_j(t) = \frac{I_j(t)}{\sum_l I_l(t)}$$

normalized probability that an infectious is in city j

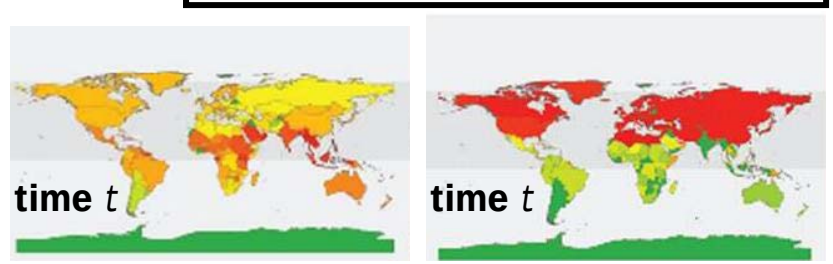
Similarity between **2 outbreak realizations**:

Overlap function

$$\Theta(t) = \sum_j \sqrt{\pi_j^I \pi_j^{II}}$$



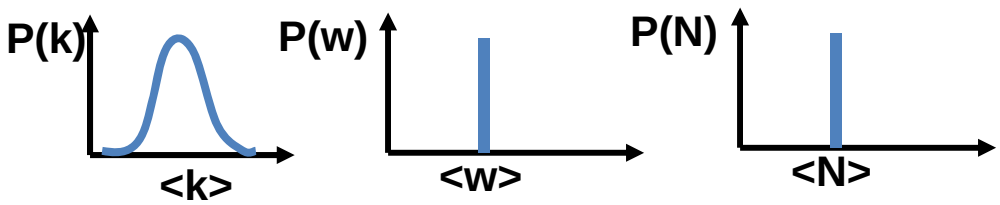
$$\Theta(t) = 1$$



$$\Theta(t) < 1$$

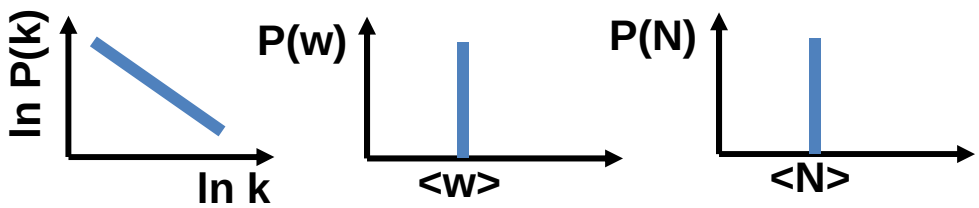
impact of complexity

- ***HOMN***



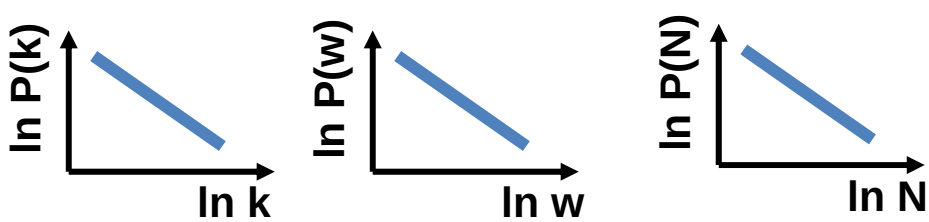
no complexity

- ***HETN***



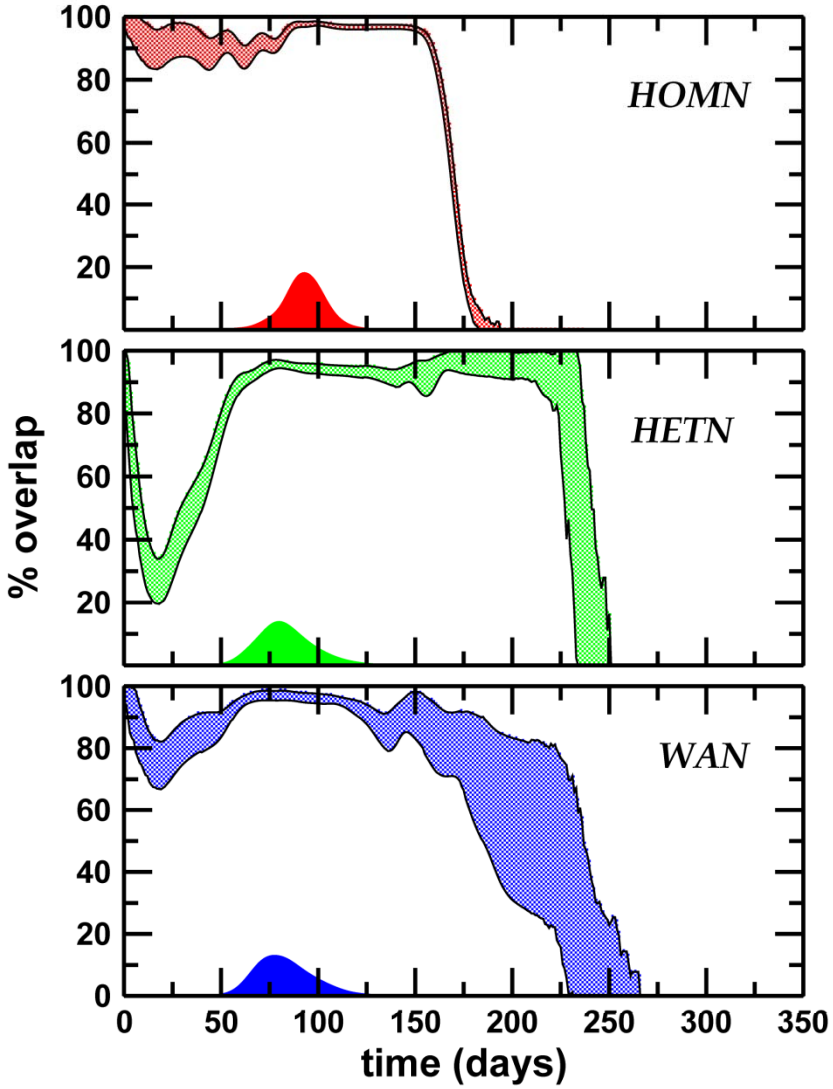
complexity in the topology

- ***WAN***

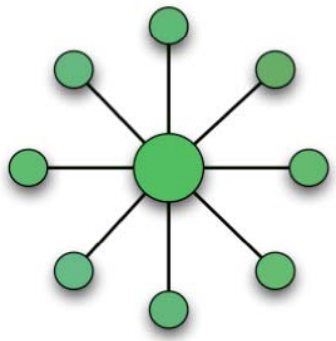


complexity in the topology and traffic

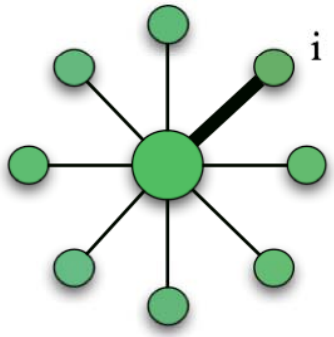
predictability



no degree fluctuations
no weight fluctuations



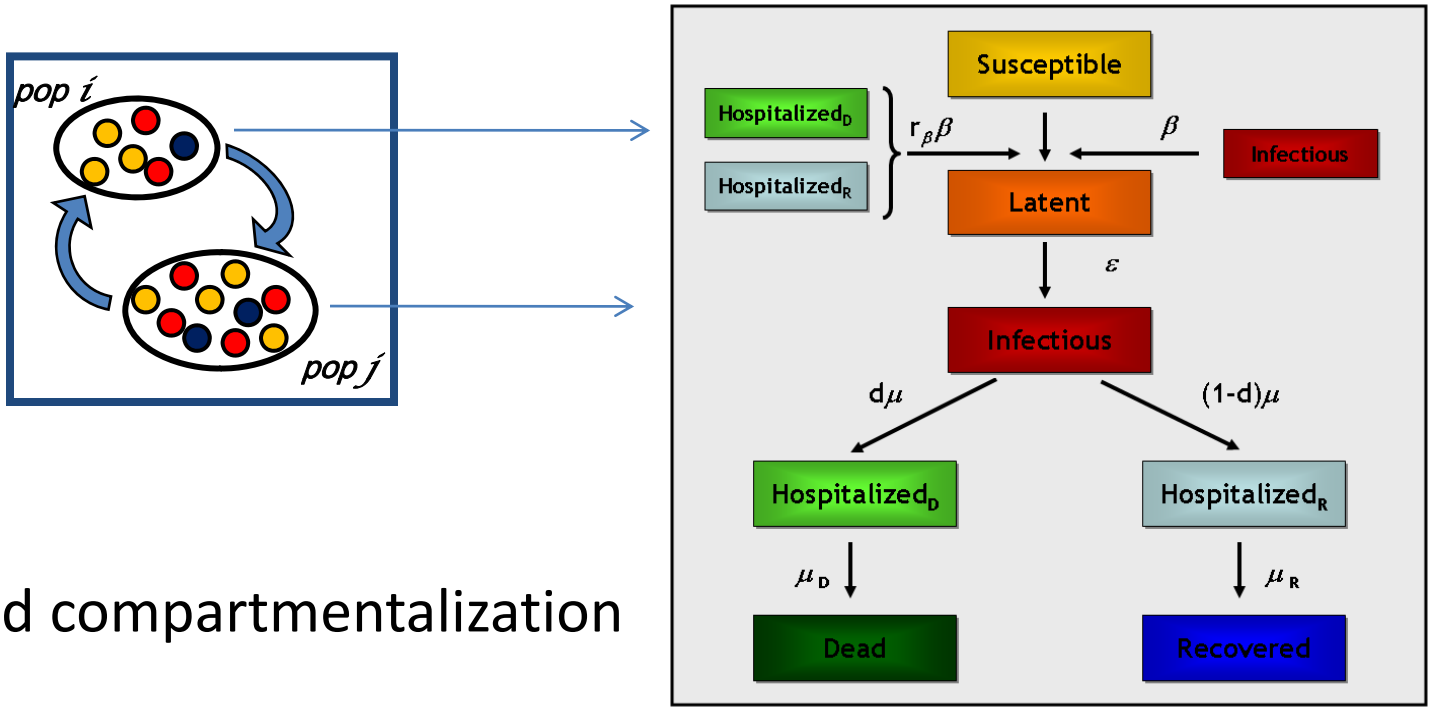
+ degree heterogeneity



+ weight heterogeneity

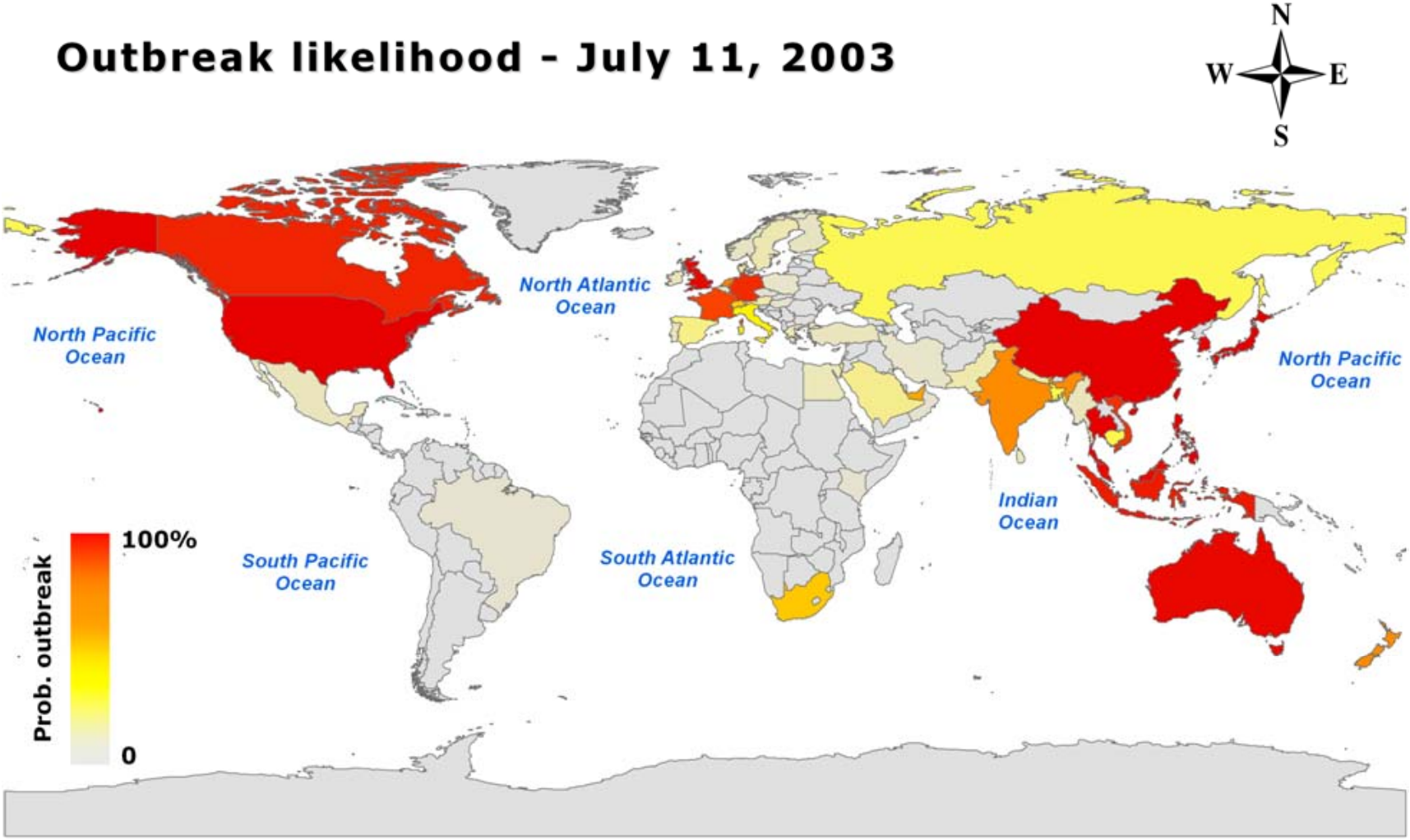
Colizza, Barrat, Barthelemy & Vespignani, PNAS (2006)

case study: SARS

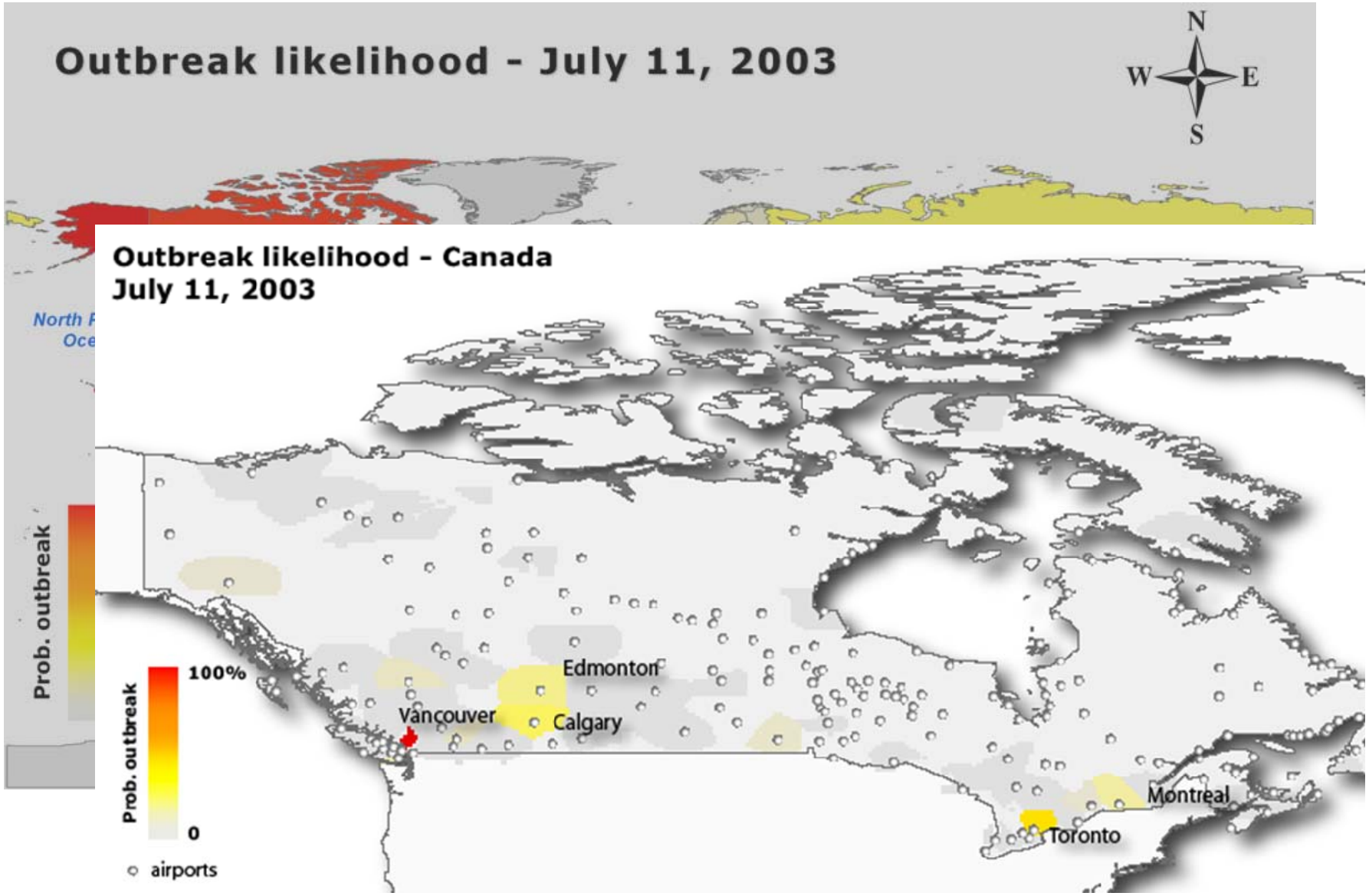


- refined compartmentalization
- parameter estimation: clinical data + local fit
- geotemporal initial conditions: available empirical data
- modeling intervention measures: standard effective modeling

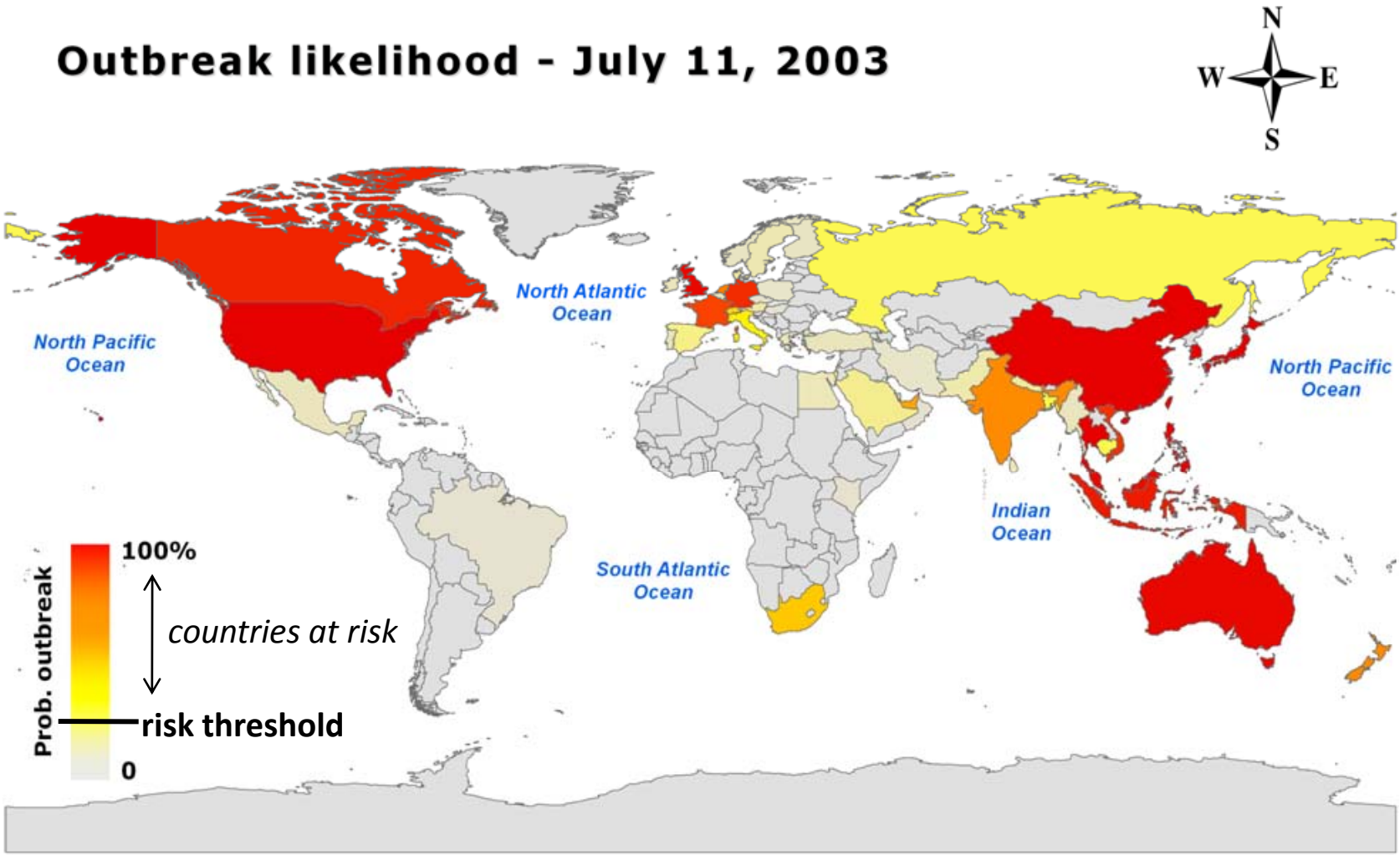
SARS: outbreak likelihood



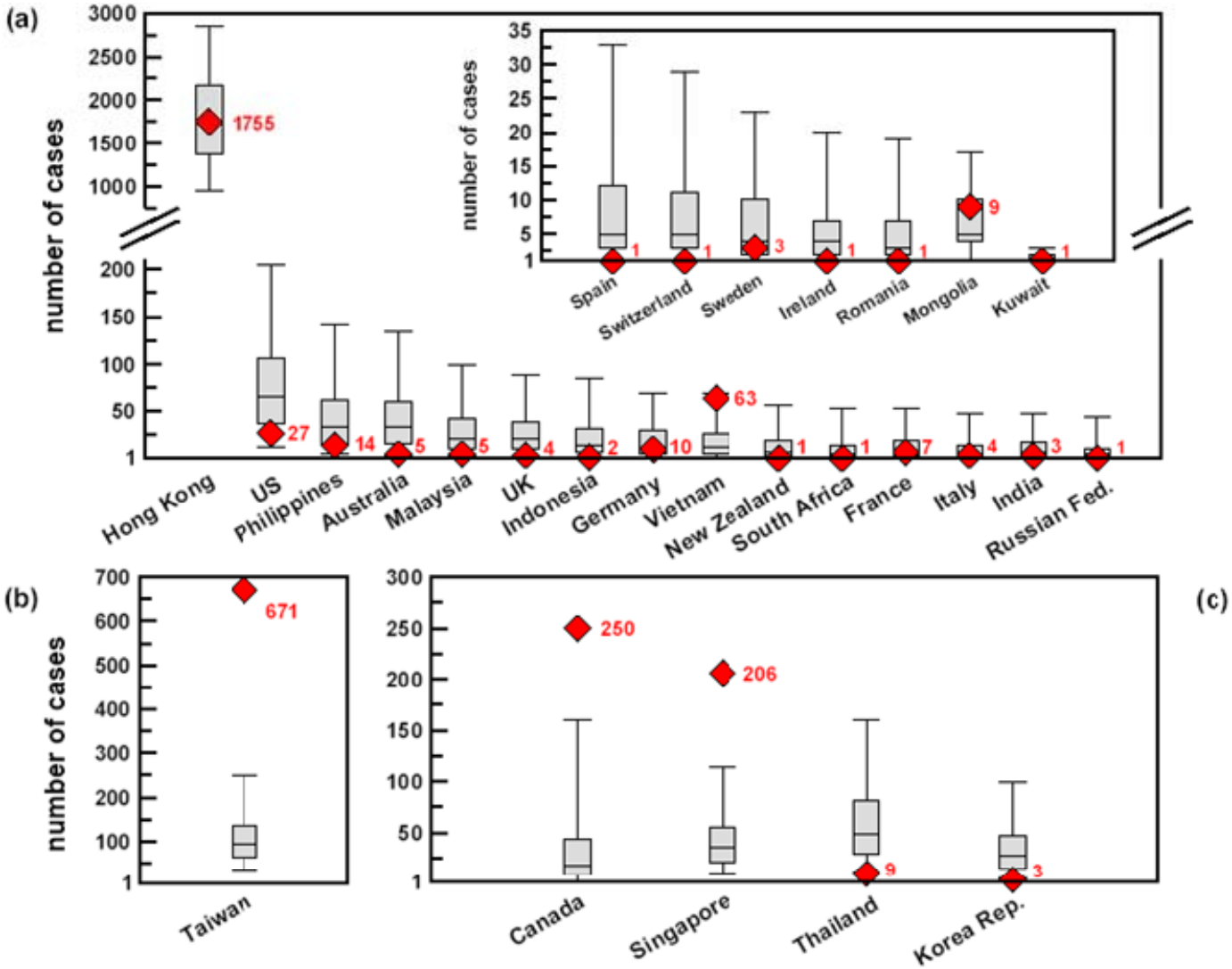
SARS: outbreak likelihood



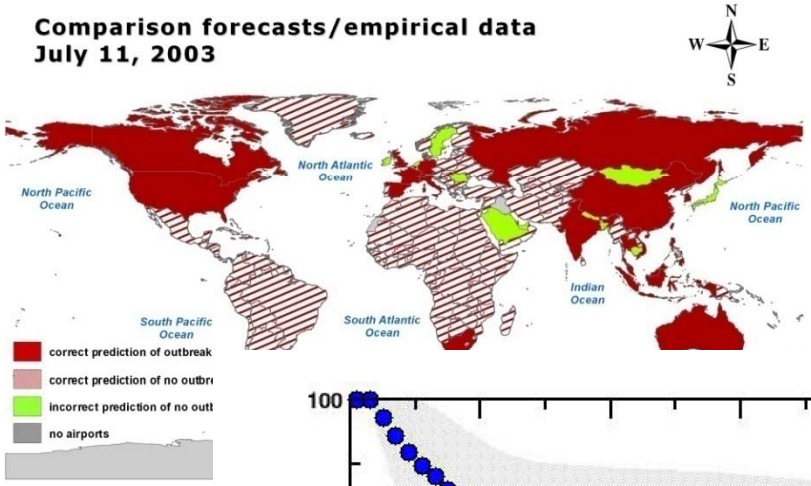
SARS: predictions

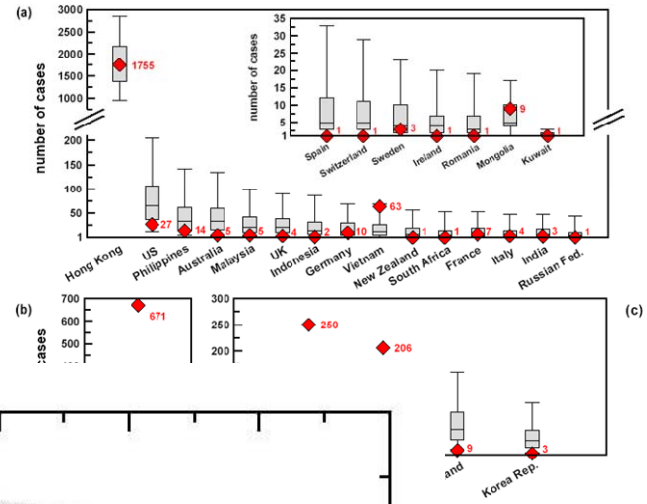


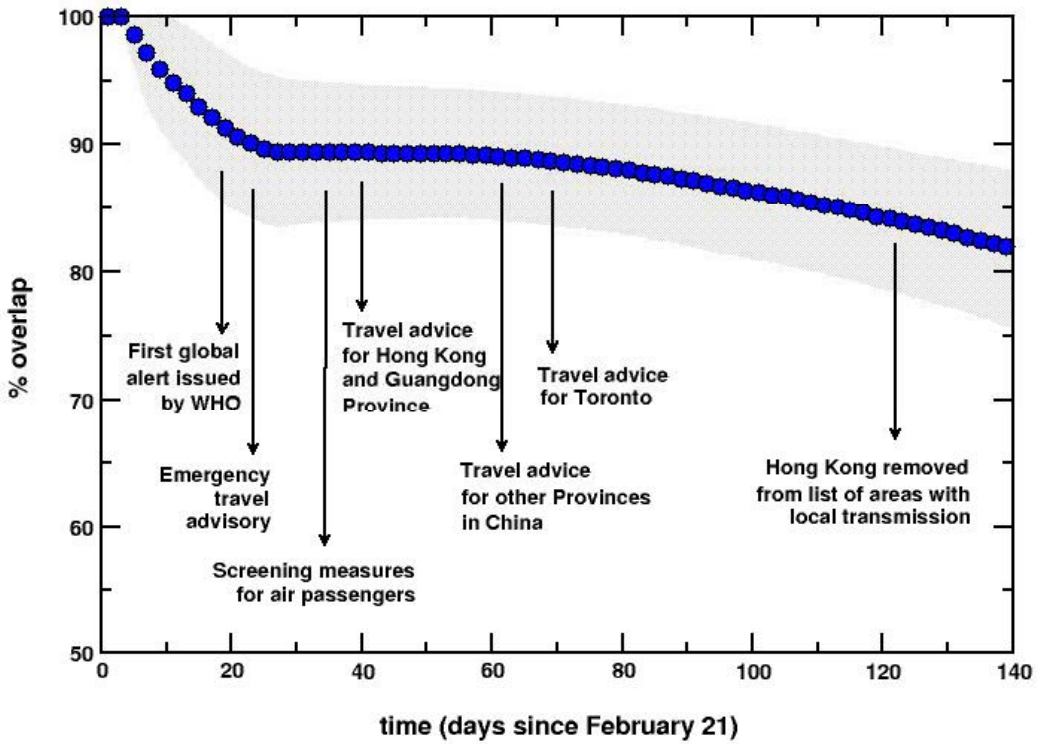
SARS: predictions (2)



SARS: predictions & predictability







SARS - Epidemic Pathways

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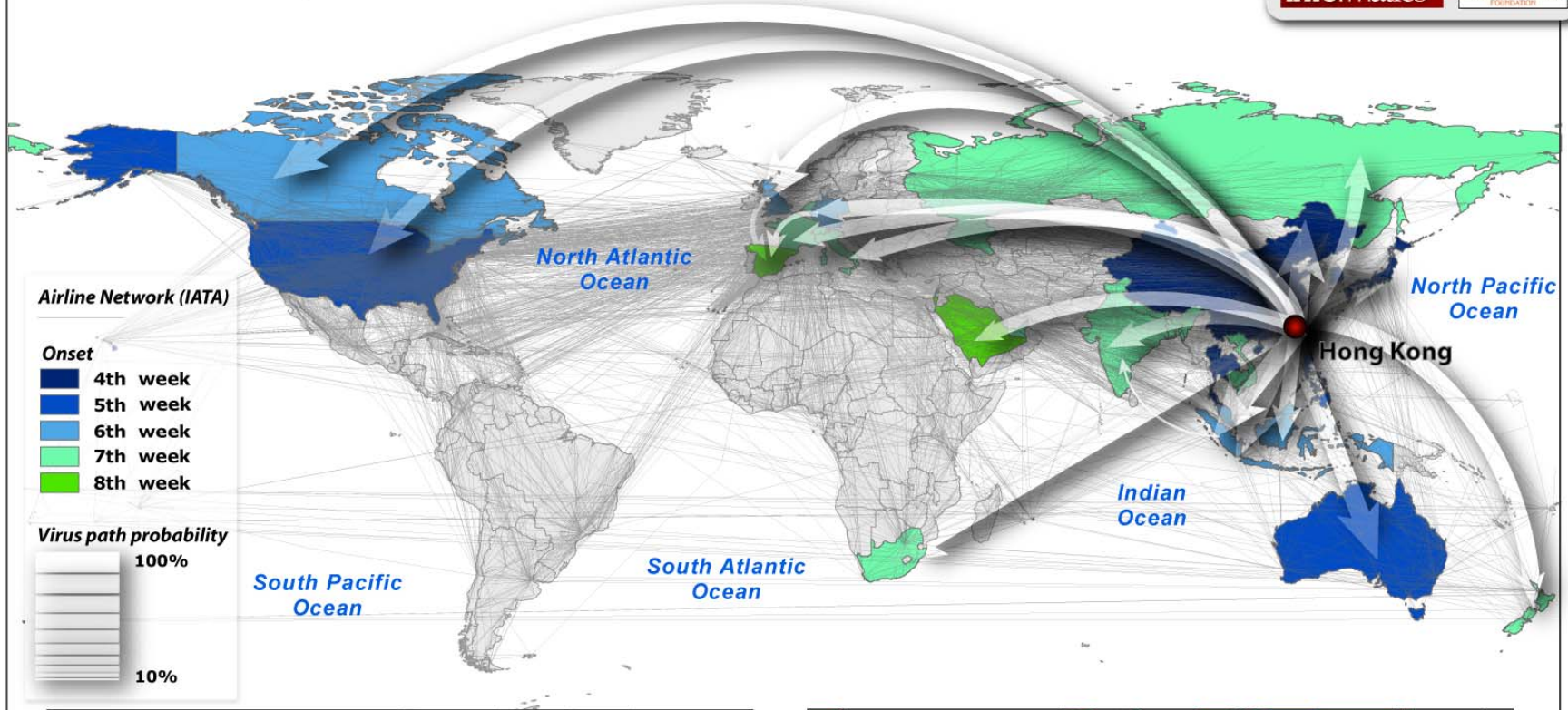

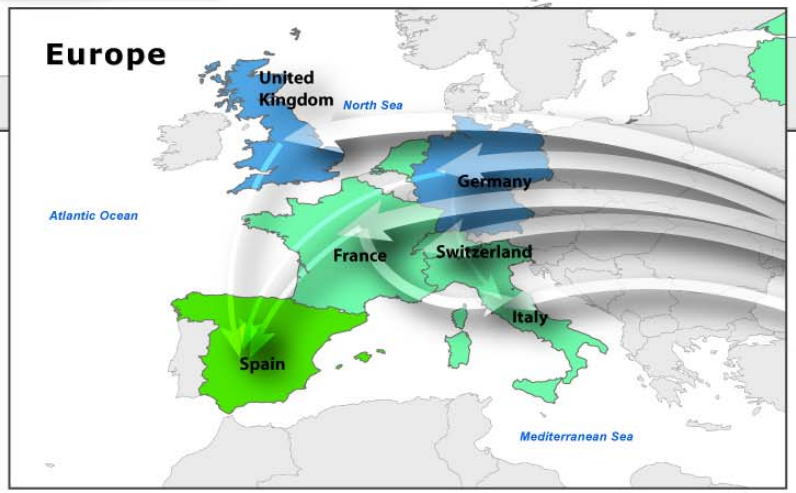

acknowledgments & refs

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