Geographic information systems and pandemic control: Modeling spatial spread of influenza

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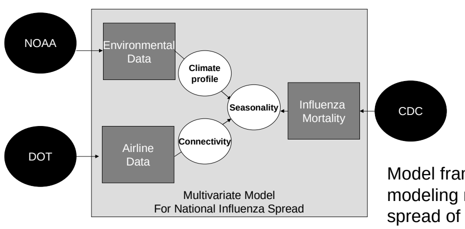
BACKGROUND

Influenza spread

- There is surprisingly little empirical evidence on how influenza spreads through cities, regions, nations and across the globe.
  - Transportation networks are thought to drive the rapid global diffusion of new strains
  - Pronounced seasonal patterns and simultaneous cases across large areas indicate the possible effect of climatic drivers
  - Other factors: Circulating subtype, age distribution, home-work commuting, vaccination coverage…
- However, unexplained spatial-temporal variation exists in onset, duration and magnitude of each transmission period
- Systematic examination of influenza spatiotemporal patterns at multiple spatial scales could enhance our understanding of influenza transmission
- Defining the factors that drive spatial-temporal patterns in seasonality can help build capacity for epidemic and pandemic control

OBJECTIVE

- Here, we assess the role of airline volume on empirical spatiotemporal patterns of influenza mortality
- We characterize the spatial variability in the timing of influenza mortality across the United States and assess its relationship to airline volume.
- Specifically, we examine how airline activity may influence both the introduction of new viral strains and their spread.

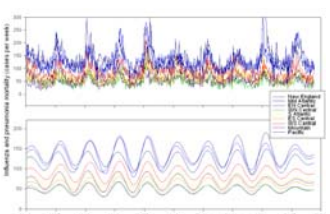


Model framework for modeling national spread of influenza

NATIONAL INFLUENZA MORTALITY

Data source

- Weekly mortality from pneumonia and influenza (P&I)
- 122 cities
- Nine seasons: 1996-1997 to 2004-200
- Total 396,506 deaths aggregated by nine geographic regions



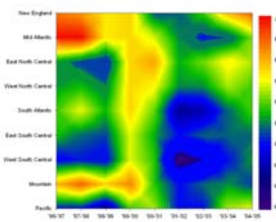
Modeling seasonality

- To isolate the seasonal (annual) cycles of influenza mortality we band-pass filtered each of the regional time series using a two-pole, two-pass (zero phase) Butterworth filter
- The seasonal time series plus mean can explains 99.8% of the national P&I mortality

MODEL OF DOMESTIC SPREAD

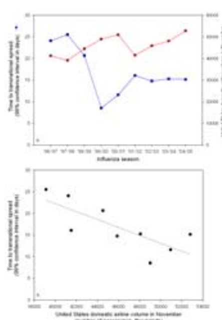
Estimating spread

- We subset the filtered data by influenza year (week 40 to week 39 of the following year) and performed cross-correlation with the national time series for each possible comparison (9 regions* 9 years to estimate phase shifts (lag or lead times).
- The phase shift with the maximum cross-correlation served as an estimate of the relative timing in a given region and a given year.
- 99% Confidence Interval in the phase shifts around the national curve provided an estimation of yearly spread



Airline Travel

- Monthly estimates of passengers on domestic flights were obtained from October to December of
- Monthly estimates of passengers on international flights were obtained from September to November of each influenza season each influenza season
- Confounding by winter severity and dominant viral subtype were included

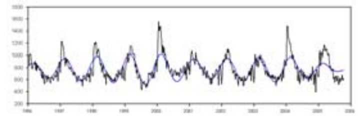


Domestic travel and spread

- November travel predicts spread with a slope of -0.94 days/ million passengers [r2=0.60; P=0.014]
- Reduction in the number of passengers by one million (2% reduction from current volume) slows spread by one day
- Travel during the Thanksgiving holiday may be central to the yearly national spread of influenza.

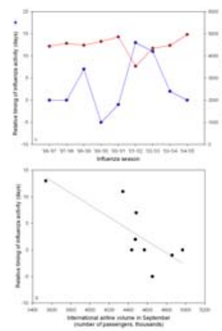
50% reduction in domestic airline travel in November would double the time to transnational spread of the epidemic to over 5 weeks.

THE 9/11 EFFECT



Estimating peak

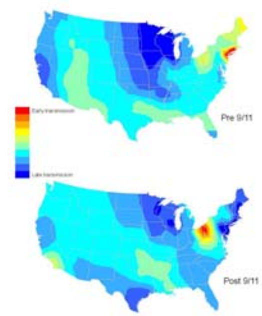
- For each season, peak date of influenza activity was calculated from the filtered seasonal curve



International travel and peak

- September predicts seasonal peak with a delay of 11 days for every million passengers not flying [r2=0.59; P=0.016].
- During 2001-2002, international flight volume decreased by 27%, and peak influenza mortality was delayed by two weeks.
- September may be the critical month for entry of new influenza strains into the U.S. from foreign countries.

The importance of airline activity was highlighted by the impact of the September 11th flight ban and depression of air travel market (Natural experiment)



Shifted pattern of spread

- Early influenza transmission normally occurs in the New York City area
- During the 2001-2002 season, early transmission was shifted to the Midwest

50% reduction in international airline travel in September may offset peak mortality by about a month, possibly delaying the introduction of a new pandemic strain and provide critical lead time for vaccine manufacturing and distribution.

CONCLUSIONS

- Our findings enable quantification of the potential impact that a mandated reduction in airline flights might have on virus spread.
- Population-wide contact reduction measures may be critical in reducing the rate of spread.
- When combined with early detection, reducing airline activity through travel advisories, flight restrictions or even a complete flight ban may provide critical lead time for vaccine manufacturing and distribution.
- Policy makers would need to balance the social, constitutional, legal, economic, and logistic consequences of travel restriction