Modelling airborne particle movement at national scale: consequences for long-term surveillance of plant epidemics

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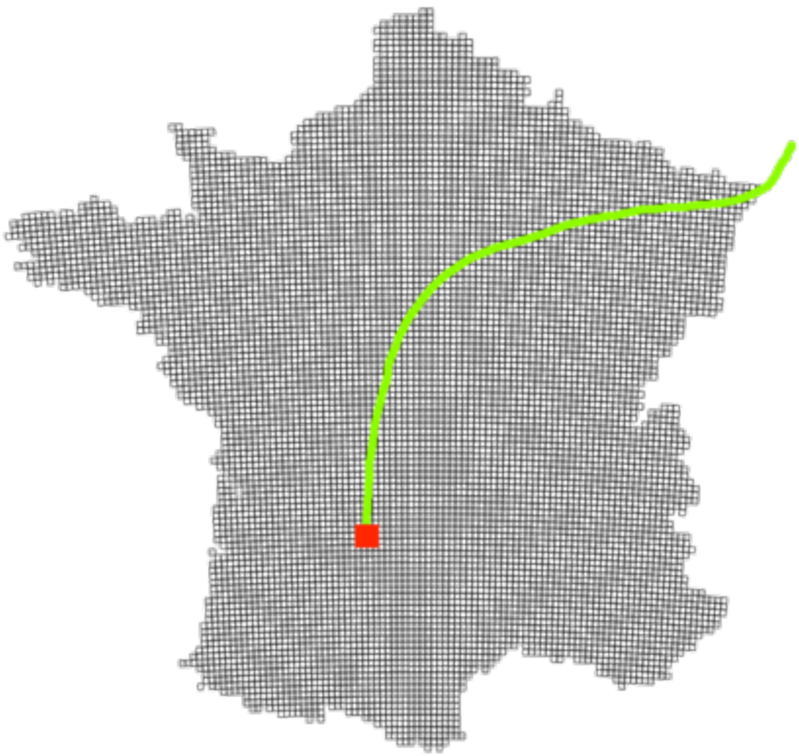
ModStatSAP 2020

November 24, 2020

Objectives

- Model air-mass connectivity over the entire country from past observations
- Discover spatial and temporal patterns of connectivity
- How connectivity change the *"geography"* of the region
- Inform epidemic-surveillance

Data



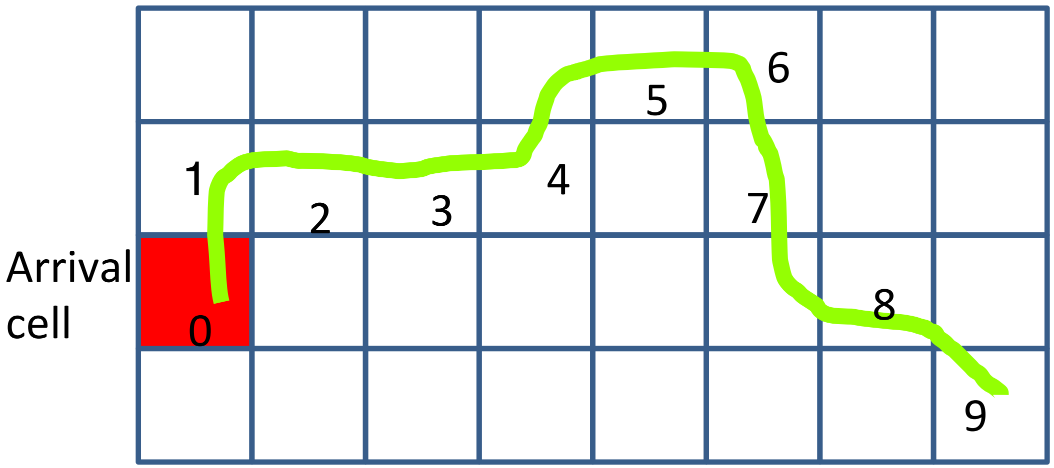
Airmass trajectories

- 48-hours backward
- 500m AMSL
- Computed daily at 00-06-12-18
- From 01/01/2013 to 31/12/2018
- 8401 arriving points (8X8 km grid)
- Generated with HYSPLIT[1]

TOTAL = 73.592.760 trajectories

[1] https://www.ready.noaa.gov/HYSPLIT.php

From raw data to networks



Connectivity matrix

$$M(i,0) = \begin{cases} 1 \ \forall\, i \ \in \{1, \ldots, 9\} \\ 0 \ else. \end{cases}$$

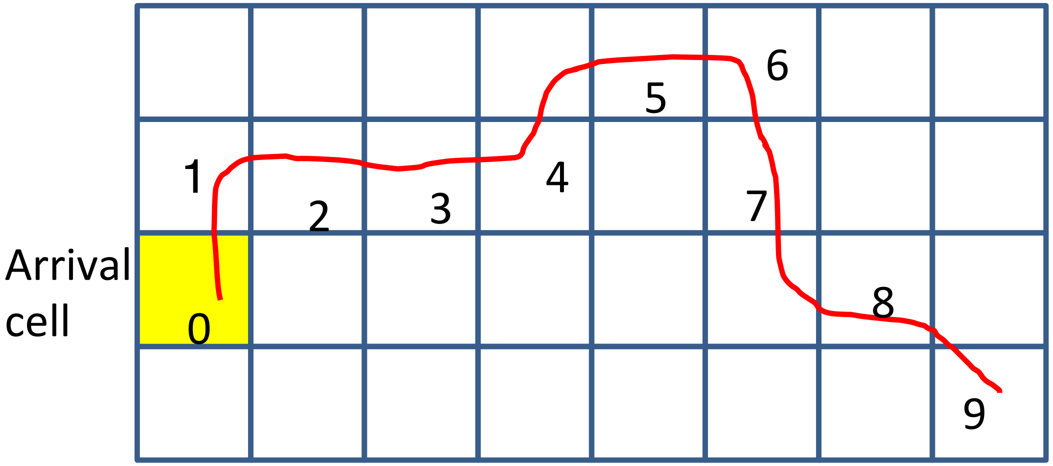
Averaging to grasp main signal

To reduce uncertainty, the connectivity matrices have been aggregated on yearly and hourly scales to obtain one matrix per day of the year: one day represents the average connectivity for the four moments of the days (00,06,12,18) across the 6 years of the study period (2013-2018)

Sinks & sources

Every day, every cell is the '**sink**' of the airmass that arrives at its center. Its **in-degree** is the number of cells that the airmass has crossed before arriving to the destination.

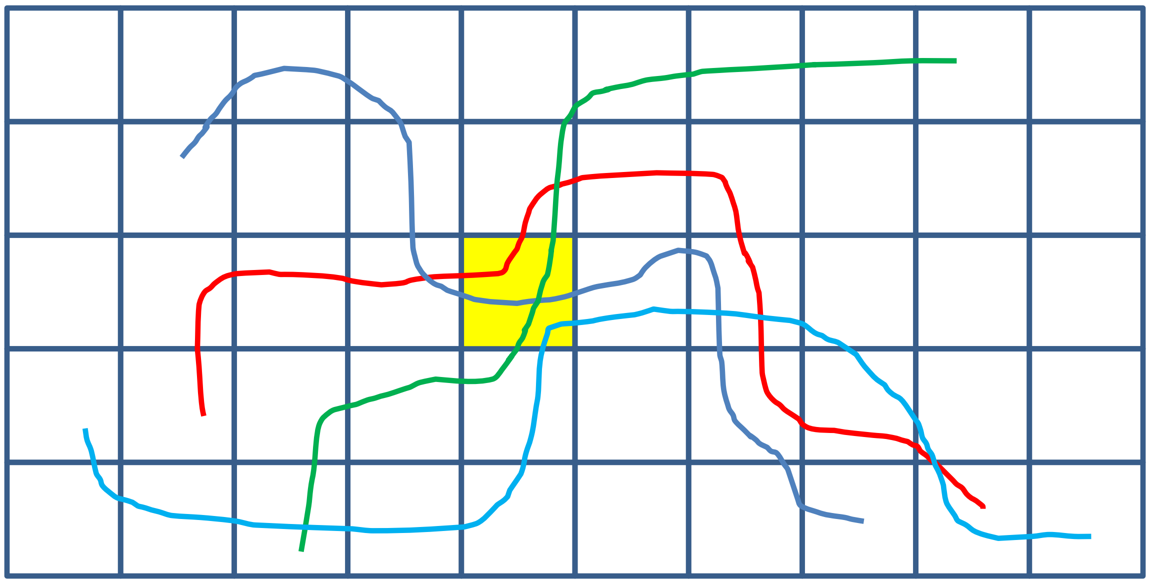
In the example, the arrival cell in yellow has received an airmass that hovered 9 other cells in the previous 48 hours.



Sinks & sources

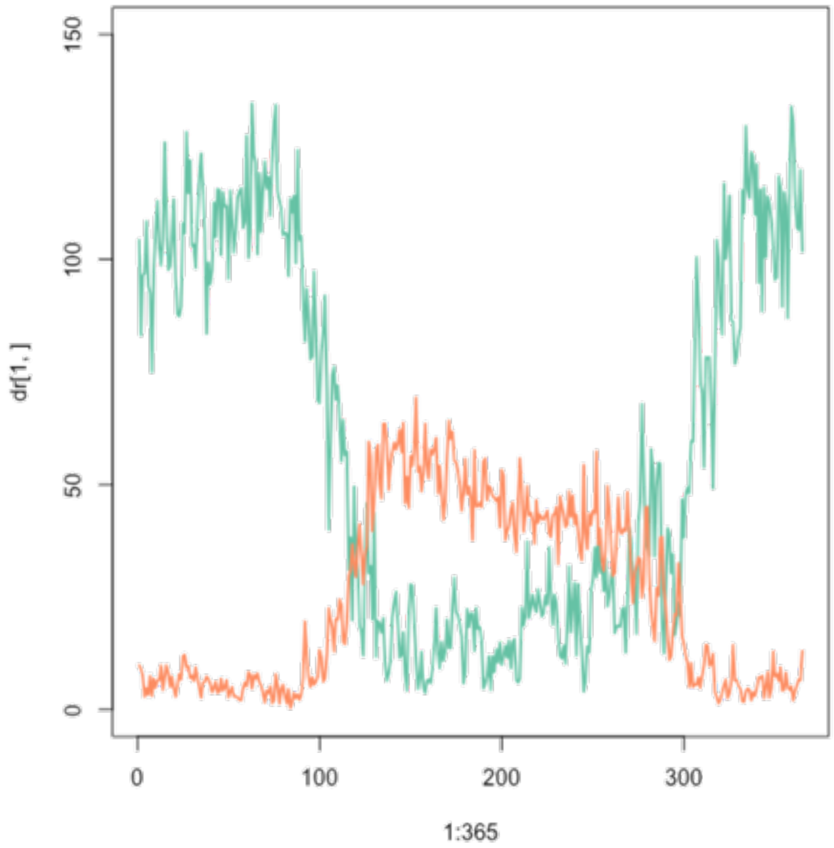
Every day, every cell is crossed by a certain number of airmasses that will end up in another cell. The number of airmasses hovering a cell is the **out-degree** and the cell is considered as a **source**.

In the example, the cell in yellow has been crossed by 4 trajectories going elsewhere in the space.



Observation

The behaviour in terms of sink and source of a watershed can vary across the year.



Green : in-degree of a cell
Orange: out-degree of the SAME cell.

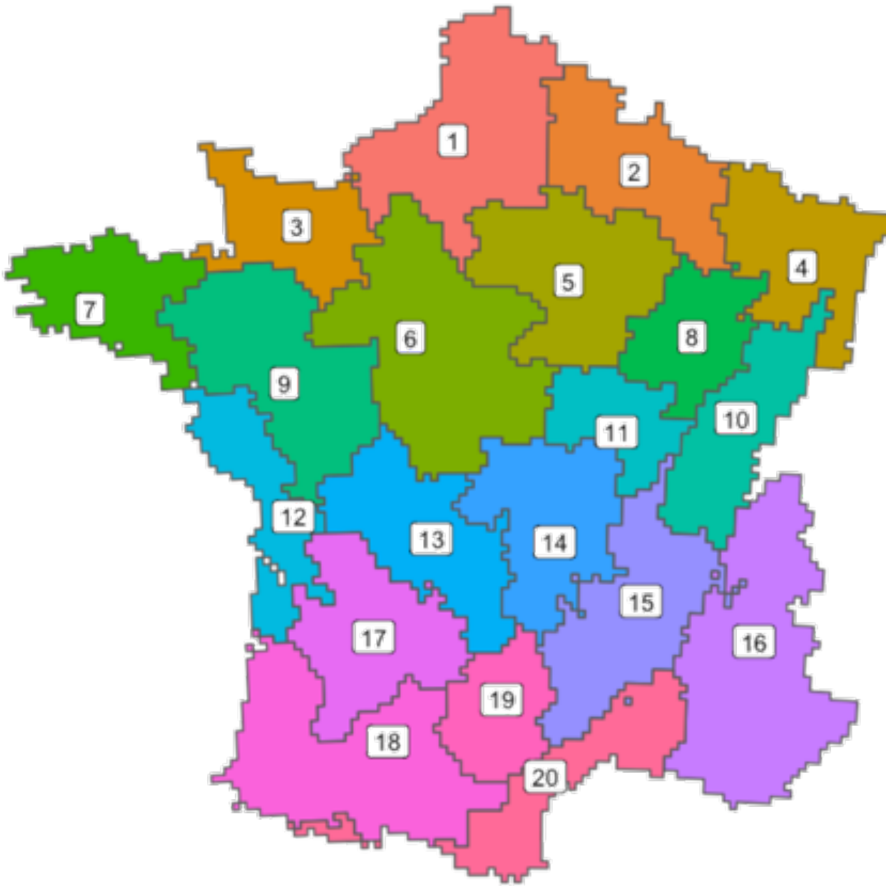
The horizontal axis represents the days of the year.

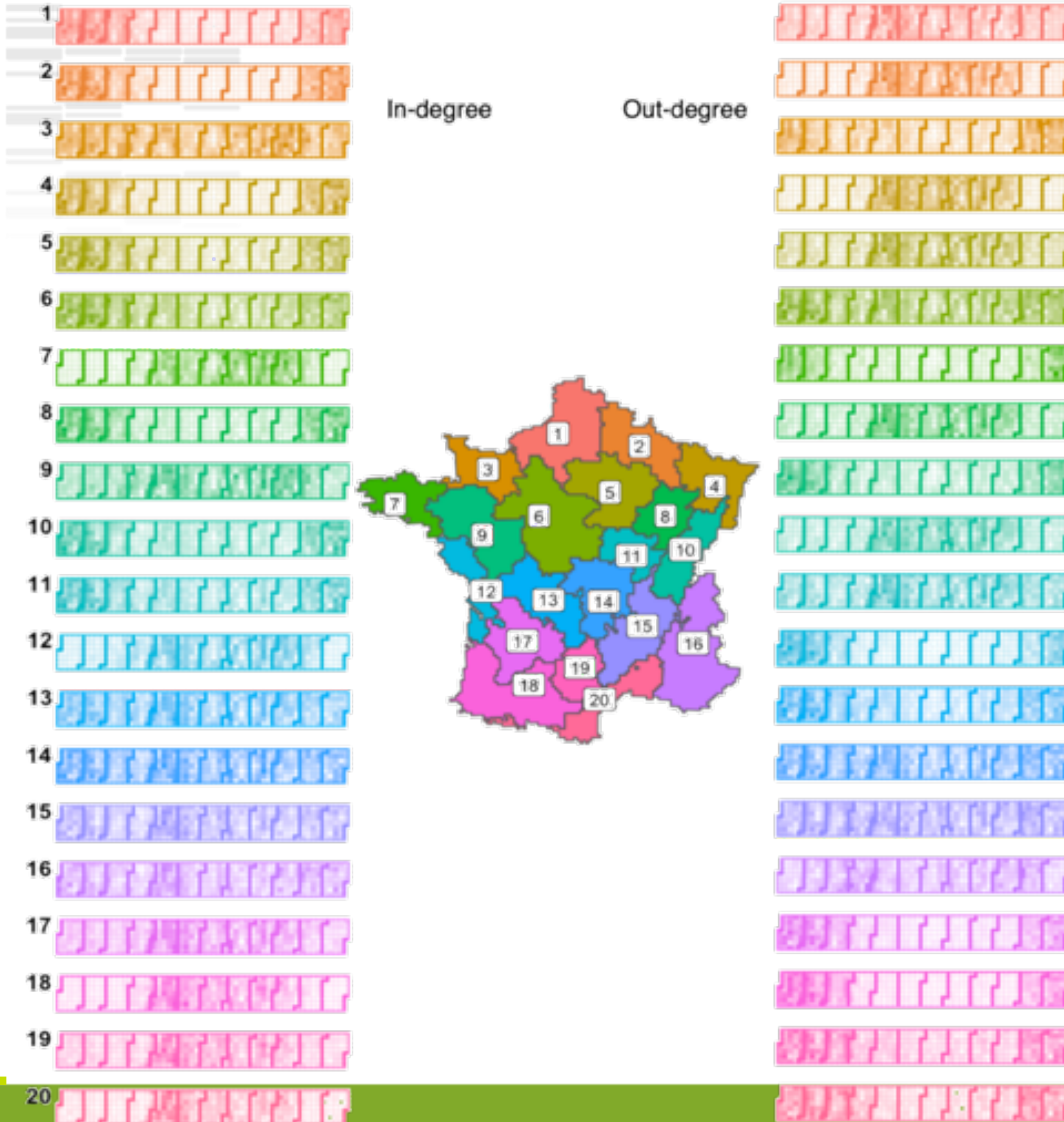
Notice how this cell behaves as:

- a strong sink in winter months
- as a moderate source during summer

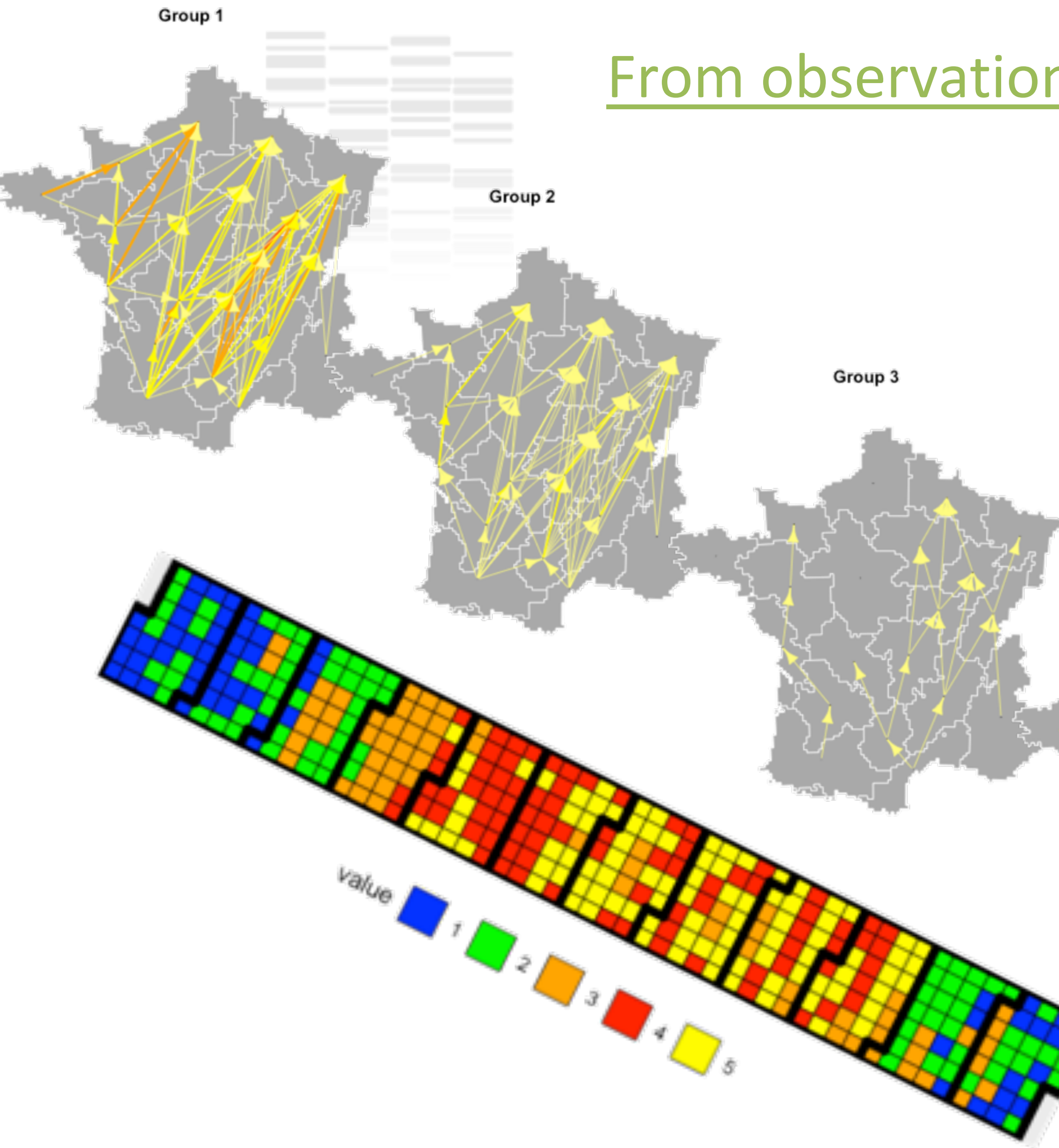
From observation to result

1. Consider the daily in- and out-degree of each cell as a time series
2. Compute Dynamic Time Warping (DTW) distance between in- and out-degree time series
3. Sum the obtained distance matrices and obtain dendrogram to perform hierarchical clustering

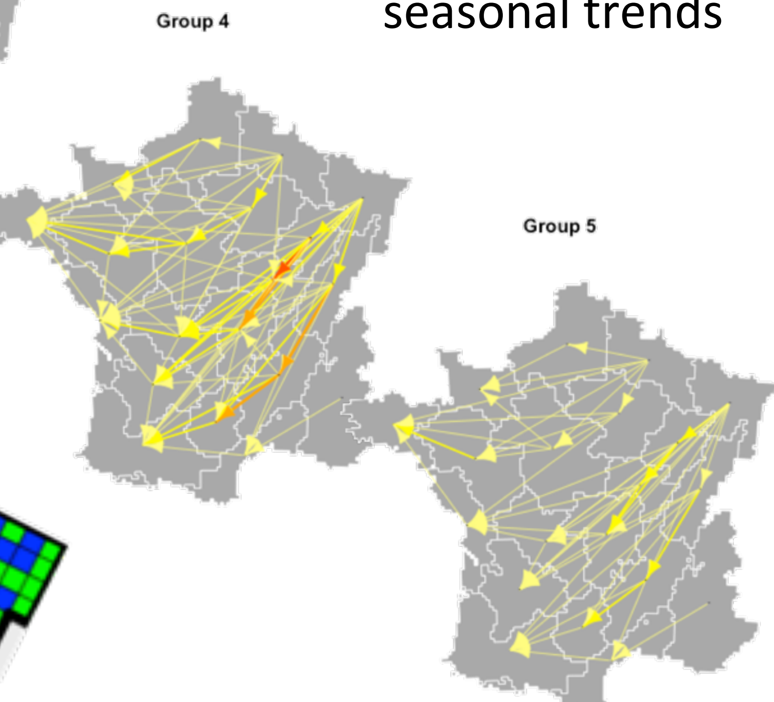



In-degree
Out-degree
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

From observation to result

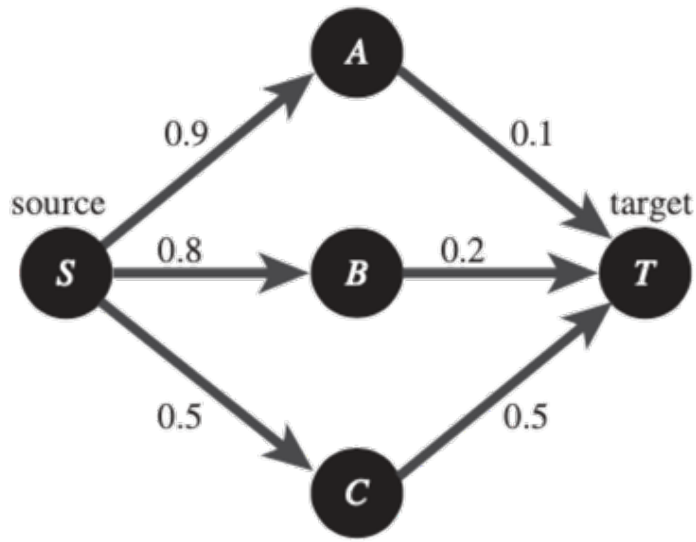


1. Compare daily connectivity matrices using CUT distance[1]
2. Perform hierarchical clustering to identify seasonal trends



[1]Liu et al. (2018). Cut based method for comparing complex networks. Scientific Report 8

Shortest path in a contact network



Additive search -> all paths are equal

P(S,A)+P(A,T) = P(S,B)+P(B,T) = P(S,C)+P(C,T)=1

Multiplicative search -> best path through node C

P(S,A)*P(A,T)=0.09 < P(S,B)*P(B,T)=0.16 < P(S,C)*P(C,T)=0.25

Effective distance

Simple transformation to transform contact probabilities into effective distances[1]:

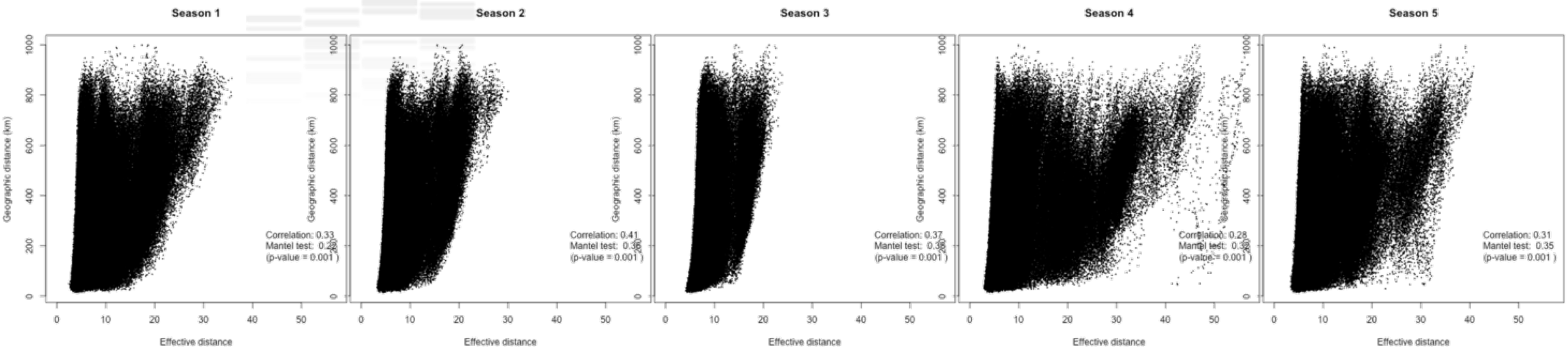
$$d_{ij} = 1 - \log(p_{ij})$$

Properties:

- $d_{ij} \geq 0$
- $d_{ij} = 1$ iff $p_{ij} = 1$
- $d_{ij} = \infty$ iff $p_{ij} = 0$
- $d_{ij} + d_{jk} \geq d_{ik}$
- Shortest-path network search: Dijkstra algorithm[2]

[1]Brockmann et al. (2013). The hidden geometry of complex, network-driven contagion phenomena. *Science*, *342*.
[2]Dijkstra (1959). "A note on two problems in connexion with graphs". *Num. Mat.* 1.

Geographic vs. effective distance

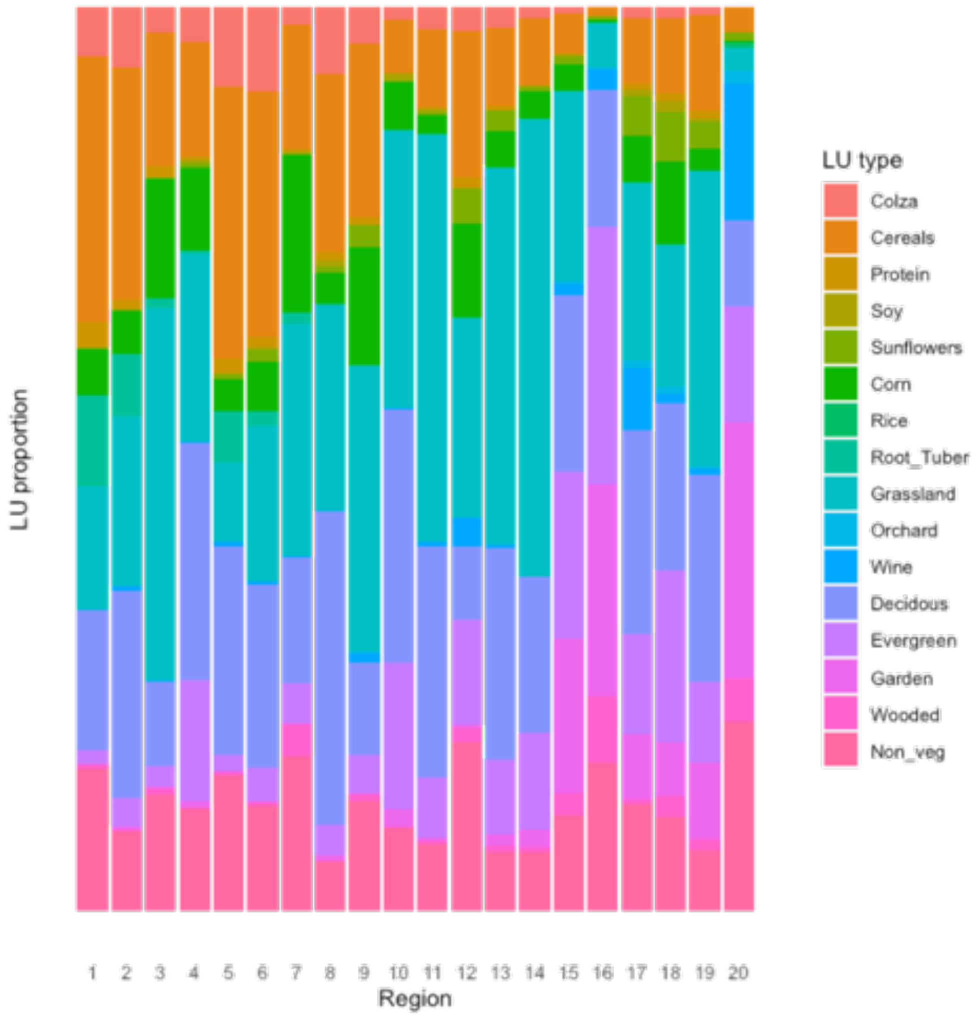


Season	Correlation	Mantel test
1	0.33	0.22***
2	0.41	0.36***
3	0.37	0.38***
4	0.28	0.32***
5	0.31	0.35***

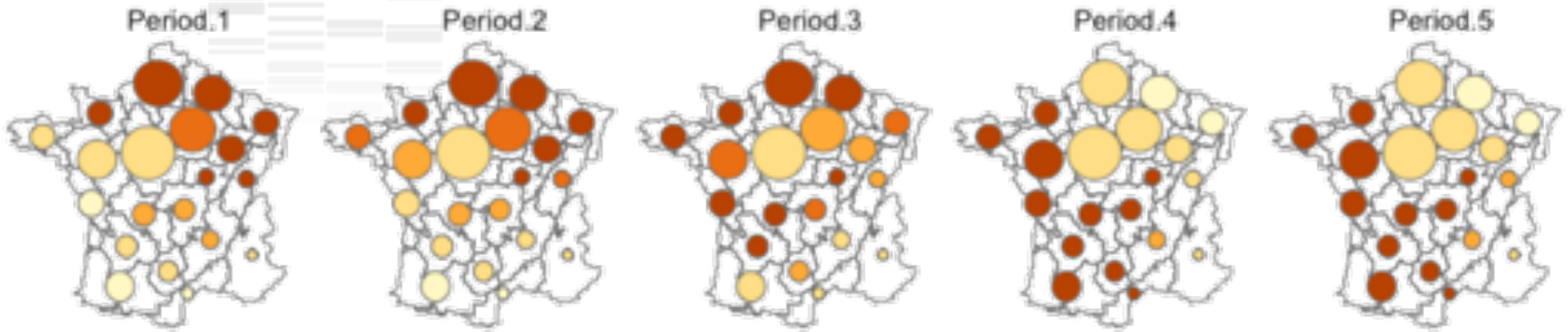
INRA SCIENCE & IMPACT

How airmass connectivity could inform epidemic surveillance

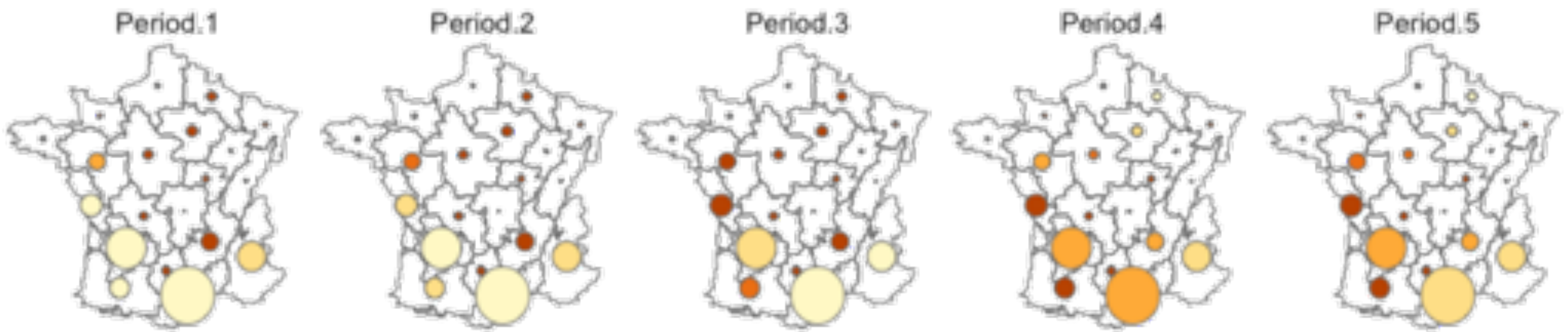
LU map 2019 OSO CESBIO



Cereals



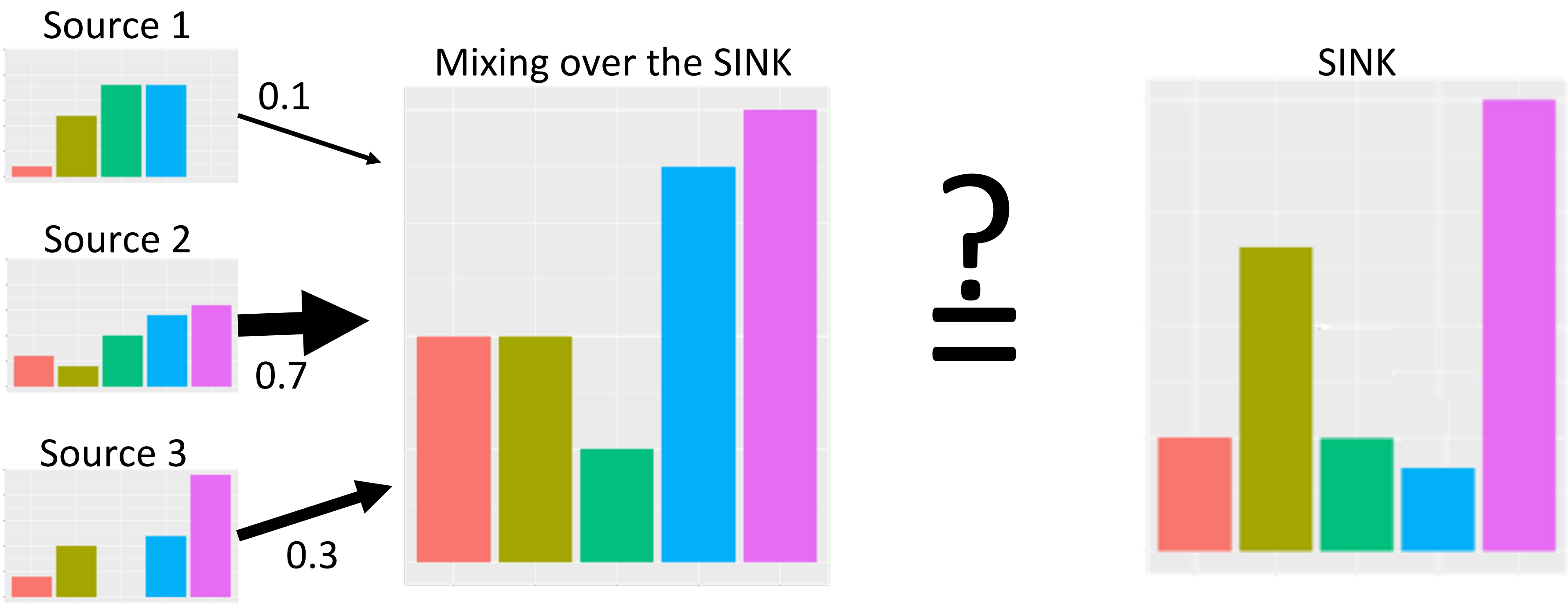
Wine



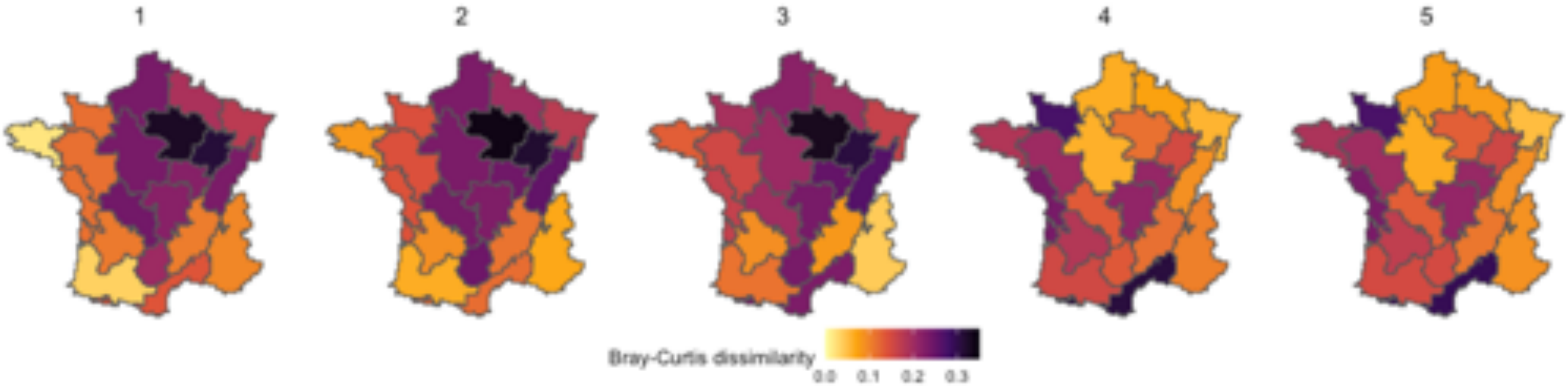
Circle size proportional to surface of LU type
Colour according to sink receptivity

An ecological approach

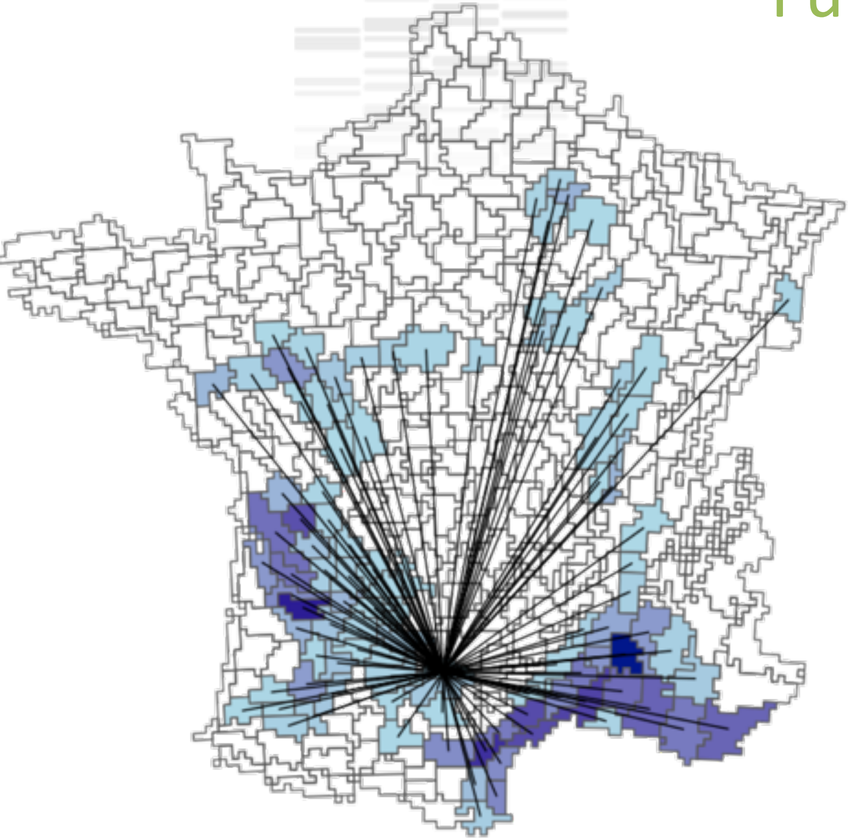
Bray-Curtis dissimilarity quantifies the compositional dissimilarity between two different populations



An ecological approach

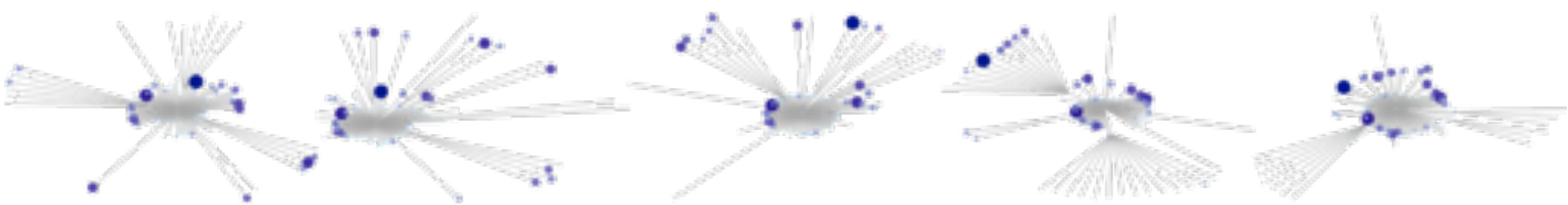


Future works



Network topology favours epidemic spread:

1. Surveillance: where & when to monitor?
2. Dangerous sites & seasons
3. Most probable paths of dissemination after outbreak



Thanks for your attention!