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Zhijie Zhang

Dongmei Chen

Wenbao Liu

Lei Wang

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Zhijie Zhang[a,b], Dongmei Chen[a*], Wenbao Liu[a], Lei Wang[a]

[a] Laboratory of Geographic Information and Spatial Analysis, Department of Geography, Queen's University, Kingston K7L 3N6, Ontario, Canada (chendm@queensu.ca)

[b] Department of Epidemiology, School of Public Health, Fudan University, Shanghai 200032, China (epistat@gmail.com)

*Corresponding author and presenter

Abstract: Highly pathogenic avian influenza viruses H5N1 have spread throughout Asia, Europe, and Africa in the past decade, raising serious worldwide concerns about a potential new pandemic. Many studies have investigated the spread of the HPAI H5N1 virus and discussed its possible risk factors. However, the climate factor, which can affect the whole process of H5N1 outbreaks, has been greatly ignored. The objective of this preliminary study is to use a GIS-based approach to explore the potential impacts of temperature change on H5N1 outbreaks. We have divided the outbreaks into five epidemic waves. Although the temperature ranges of different epidemic waves are overlapped, the season period of different waves are varied, indicating that temperature may play an important role in the timing of outbreaks. Current measures might successfully control the epidemic strength of H5N1 outbreaks, but they did not change its epidemic cycles. The risk of H5N1 outbreaks reflected from the spatial viewpoint is still very high, and long-term efficient control strategies on H5N1 outbreaks should be explored for sustainable effects.

Keywords: Avian influenza; climate change; temperature; poultry; disease control; geographic information system

1. INTRODUCTION

Avian influenza (AI) caused by the highly pathogenic avian influenza (HPAI) virus subtype H5N1 was first reported on a geese farm in southern China in 1996; human cases were then reported in Hong Kong in 1997 (Claas et al., 1998; Shortridge et al., 1998; Subbarao et al., 1998), which demonstrated the direct transmission of H5N1 virus from birds to humans for the first time. This virus reemerged in late 2003. Since then it has spread from Southeast Asia to Central Asia, the Middle East, Africa and Europe, and over 60 countries have experienced HPAI H5N1 outbreaks by now (Alexander, 2007; OIE, 2009).

During this time, many wild birds were culled and millions of poultry were killed to control the disease, resulting in huge economic losses in the poultry industries of the affected regions (FAO, 2007; OIE, 2008). Before February 10, 2010, 474 human infections were reported, of which 282 were fatal (WHO, 2010). Avian influenza posed a significant pandemic threat and emphasized the need for worldwide pandemic preparedness (Doherty et al., 2006; Webster& Govorkova, 2006).

For an efficient control strategy, the risk factors of this disease must be first identified. Previous studies have suggested that the migration of wild birds, movements of domestic birds, poultry

transportation, illegal trade, highway networks, vegetation zones and human activities all contribute partly to the occurrence and spread of the disease (Farnsworth et al., 2009; Gilbert et al., 2006; Jourdain et al., 2007), but it is still debatable which ones are key factors. Many experimental studies have revealed that temperature can affect the survival time of the H5N1 virus, and lower temperature seems to support survival of the virus (Songserm et al., 2005; Tiensin et al., 2007). Unfortunately, no studies have been conducted to explore the impacts of air temperature on H5N1 outbreaks except a review paper (Gilbert et al., 2008) which only discussed the matter in broad and general ideas. This preliminary study was designed to shed light on whether and how climate change will affect H5N1 outbreaks at a global scale. We explored the relationship between air temperature and H5N1 outbreaks using the H5N1 outbreak database from 2004-2009.

2. DATA AND METHODS

2.1 Data source and data preprocessing

Avian Influenza data: HPAI H5N1outbreak data on domestic poultry from 1 January 2004 to 31 December 2009 were obtained from the database of the Global Animal Health Information System of the Food and Agricultural Organization (FAO) Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases programme (EMPRES-i) (FAO, 2010). Each confirmed outbreak contained 19 variables, but only the most related variables of outbreak location (latitude and longitude), continent, country and date of observation were used in this study. These data were geocoded based on their latitude and longitude.

Climate Data: Terrestrial air temperature data recorded in gridded monthly time series from January 2004 to December 2008 were downloaded from the Center for Climatic Research of the Department of Geography, University of Delaware (http://climate.geog.udel.edu/~climate/html_pages/download.html). Ordinary kriging was applied to interpolate the monthly gridded data to generate sixty continuous temperature surfaces (12months/yr x 5 yrs =60). Then, the monthly air temperatures for all the outbreaks were extracted based on their locations and observation dates.

Base Data: The country-based global map was obtained from the internal data of ARCGIS software (Environmental Systems Research Institute, Inc., Redlands, CA). It was used to overlay with analysis results and facilitate the visualization.

2.2 Analysis

Continent-based global H5N1 outbreaks from 2004 to 2009 were summarized in a table to show the epidemic situation on a coarse scale. To display the overall dynamics of H5N1 outbreaks over time, a histogram was constructed to display its temporal distribution by counting the number of reported outbreaks per month from 2004 to 2009 in the world; then, different epidemic waves which indicate the beginning and ending periods of outbreaks were divided for following analysis. The epidemic waves were used to choose the air temperature range of H5N1 outbreaks. Mean temperatures and standard deviations were used to visually compare the temperature changes between different epidemic waves and to determine the possible temperature range for H5N1 outbreaks. Then H5N1 outbreaks were divided into corresponding subsets according to the above epidemic phases and depicted in the country-based global map for visual comparison. All these manipulations were done in ARCGIS 9.3 software (Environmental Systems Research Institute, Inc., Redlands, CA) and R software (R Development Core Team).

3. RESULTS

There were 6135 outbreaks in all from 1 January 2004 to 31 December 2009, according to the FAO-collected database. Only three continents — Asia, Africa and Europe — reported outbreaks during that period. Asia had the most cases and was the earliest to report H5N1 outbreaks. Europe had the fewest outbreaks, although its H5N1 outbreaks were reported earlier than those in Africa (Table 1).

Table 1 Continent-based summaries of global H5N1 outbreaks from 2004-2009

Continent	Year						
	2004	2005	2006	2007	2008	2009	Total
Africa	0	0	157	279	121	45	602
Asia	4136	228	338	228	352	86	5368
Europe	0	33	84	45	3	0	165
Total	4136	261	579	552	476	131	6135

Six epidemic waves may be divided through visual inspection of the global epidemic curve, including Epidemic Wave 1 to Epidemic Wave 6 (abbr. EW1 to EW6). Their periods are from 01/Jan/2004 to 30/June/2004 (EW1), 01/July/2004 to 30/June/2005 (EW2), 01/July/2005 to 31/Oct/2006 (EW3), 01/Nov/2006 to 31/Oct/2007 (EW4), 01/Nov/2007 to 31/Oct/2008 (EW5), and 01/Nov/2008 to 31/Dec/2009 (EW6), respectively (Figure 1). EW1 and EW3-EW6 reveal a high occurrence of H5N1 outbreaks from January to March, while EW2 shows a different peak from October to December. In addition, we found that EW2 and EW3 started in or around July, while the later waves, EW4-EW6, seem to have been postponed to November.
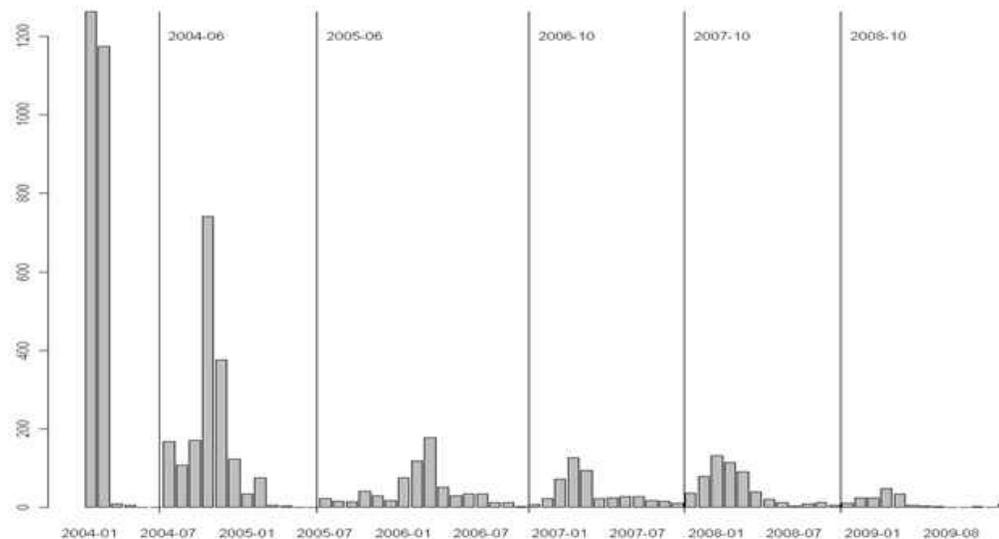

Figure 1 Epidemic wave of monthly counted global H5N1 outbreaks from 1 January 2004 to 31 December 2009.

The sample sizes, mean temperatures and standard deviations were displayed for EW1-EW5 and total EW1-EW5 (Figure 2). The temperatures were not very consistent in different epidemic waves, but their ranges largely overlapped. The highest mean temperature appeared in EW2 and the temperature began to gradually drop from EW3. Comparing Figure 2 and Figure 3,

we see that the wider the H5N1 outbreaks were distributed, the larger the temperature variation, which may prompt the suitable range of air temperature for H5N1 outbreaks to be possibly broad, so the combined 95% confidence interval (CI) of EW1-EW5 was chosen as the feasible temperature range for H5N1 outbreaks (1.16, 29.59 in this study).
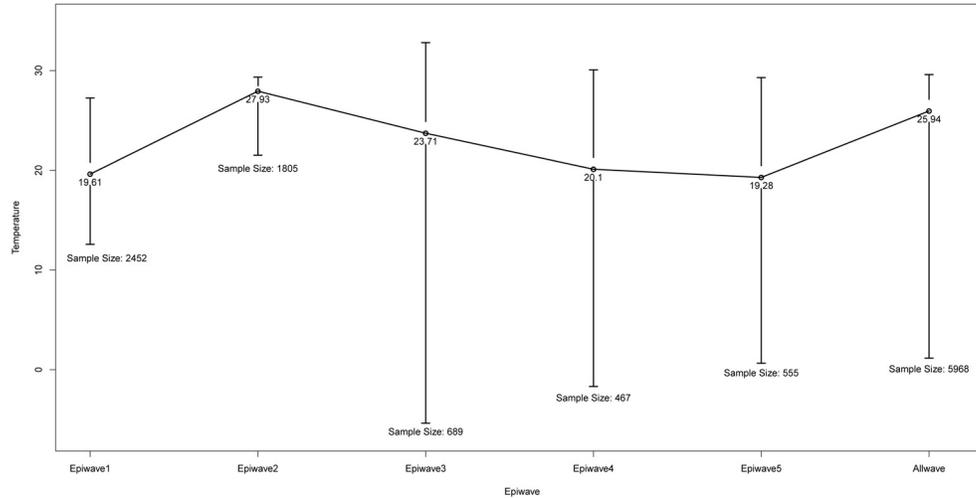

Figure2 Temperature change for the five epidemic waves of global H5N1 outbreaks

H5N1 outbreaks for the above six epidemic waves were depicted in the country-based global maps. For EW1 and EW2, the outbreaks were mainly located in the Southeast Asia, and EW2 was much more limited in what may have been a residual epidemic following EW1. However, H5N1 outbreaks began to spread widely from EW3. The epidemic seems to have gradually weakened, but the spatial coverage was still very wide, even for the weakest EW6 (Figure 3).
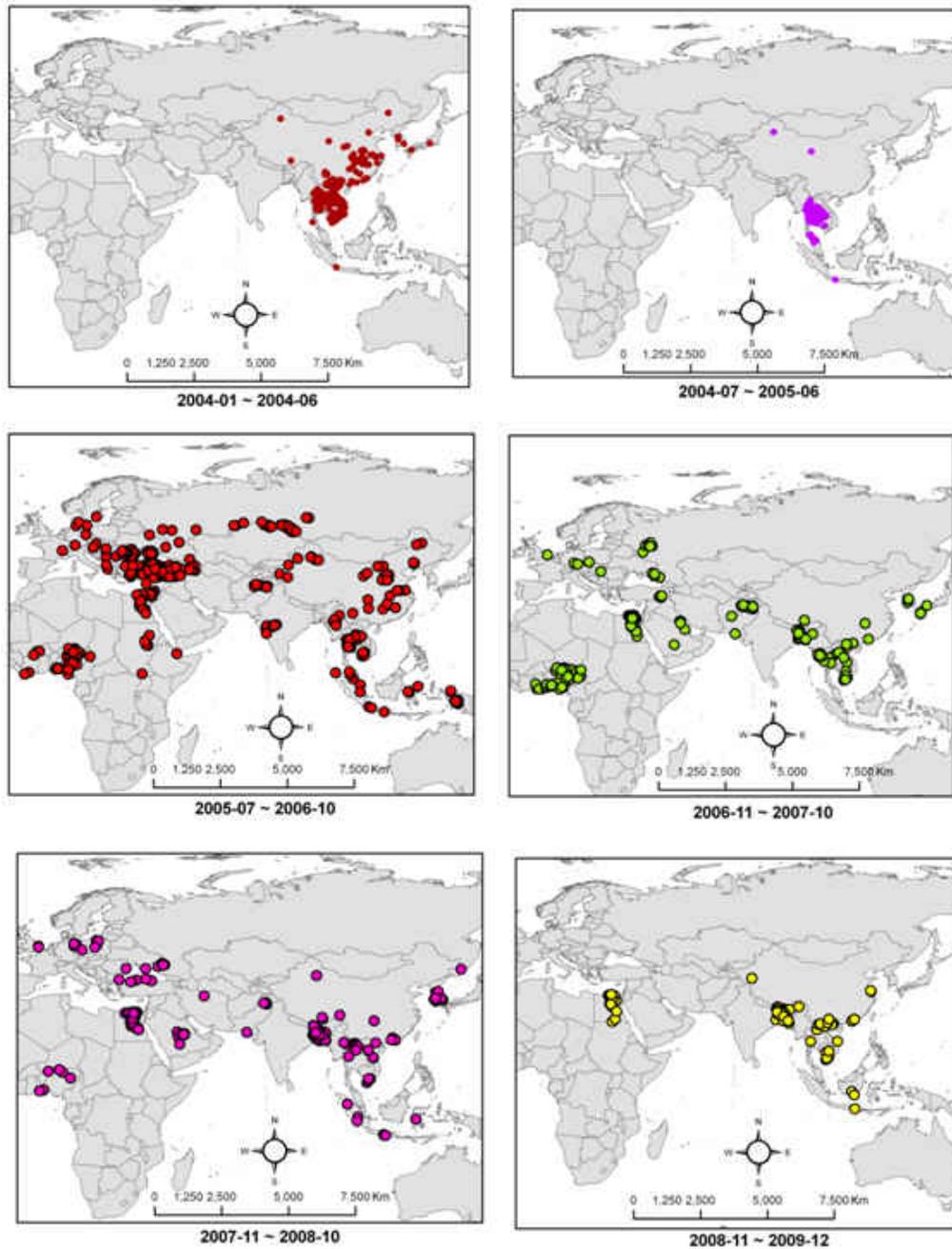
Figure3 Spatial distribution of global H5N1 outbreaks for six sequential epidemic waves

4. DISCUSSION AND CONCLUSION

In this study, we obtained the relatively complete datasets of global H5N1 outbreaks and discussed the potential impacts of temperature on H5N1 outbreaks. To our knowledge, there are only a few studies on reported H5N1 outbreaks on a global scale (Kilpatrick et al., 2006; Si et al., 2009), all of which only analyzed a short-term dataset before 2006; no studies have been done on the impacts of climate change on H5N1 outbreaks.

From 2004 to 2009, six epidemic phases were roughly determined. It was found that the H5N1 outbreaks were mainly concentrated in the winter and early spring (from October to March), suggesting a seasonally higher risk of infection (Si et al., 2009). We can also see that the starting dates of epidemic waves varied, indicating that temperature may be an important factor in the outbreak period, although the temporal pattern of H5N1 outbreaks might have been influenced by disease-control activities (Minh et al., 2009). Current measures might successfully control the epidemic strength of H5N1 outbreaks, but they did not change its epidemic cycles. The outbreak numbers are reduced gradually after EW3, but the sporadic H5N1 outbreaks are still widely distributed in space. Europe has obtained good results in controlling H5N1 outbreaks, and no outbreaks occurred in EW6; however, outbreaks were still reported in both ends of the general transmission routine. So the potential risk of H5N1 outbreaks across the world was not decreased along with reduced outbreaks. This fact requires more attention because H5N1 outbreaks could easily rebound to the previous level if current control measures were lessened or people's risk consciousness was weakened.

Based on comparisons of air temperature between different epidemic waves, we infer that the wide temperature ranges of H5N1 outbreaks at different epidemic waves are similar. We think the determined temperature range used in this study is reasonable because the validation results showed that all the outbreaks in EW6 were located in that range. This may mean that H5N1 outbreaks can occur in extensive regions if other necessary conditions are met. There are two different regions that need more attention at different periods: Central Africa and Central Asia. They may become the most risk regions in future. In addition, current control measures for H5N1 outbreaks seem to only have short-term effect in successfully reducing the outbreak numbers, and are not very efficient in compressing the outbreak regions and alter the epidemic regularity of H5N1. Efficient long-term control strategies should be explored for sustainable control of H5N1 outbreaks.

Acknowledgements

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