Meteorological and Geographic Relationships to West Nile Virus in the Southern Plains

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ABSTRACT

The West Nile Virus has plagued the Southern Plains of the United States since arriving in 2002. This study aims to examine meteorological and geographical relationships between the WNV from 2002-2012. Average weekly precipitation, wind magnitude, temperature, and soil moisture were acquired through NCEP/NCAR reanalysis and examined on a 2.5-degree grid spacing. Land use data was acquired through National Agricultural Statistics Service's Cropland Data Layer and analyzed on ArcMap 10.1. WNV cases numbers were converted into county incidence rates using 2010 U.S. Census population data. Heavily irrigated agriculture in the Texas and Oklahoma panhandles and west-central Kansas predisposes the region to higher incidence rates, especially the cotton growing regions in Texas. Winter temperature moderately correlated with the following season's WNV incidence rates with colder winters suppressing WNV activity and vice versa. The highest WNV incidence rates occurred when average weekly temperatures were between 25 and 30 degrees C from June to September. When average weekly temperatures began exceeding 35 degrees C, WNV activity decreased thus revealing a high temperature threshold. These results show land use dominates continuous WNV activity in the western half of the study region while seasonal meteorological conditions explain yearly WNV variability.

1. Introduction

In 2012, Kansas, Oklahoma, and Texas witnessed an unprecedented outbreak of WNV with 1,971 cases (CDC 2012). Dallas, TX alone reported 371 cases prompting government officials to commence aerial sprayings. Afterwards, Dallas County officials faced scrutiny for the use of these pesticides (Huffington Post, 18 Sept. 2012), since the chemicals could cause health problems of their own. Better understanding of WNV in the Southern Plains may help officials be prepared before an epidemic. Previous studies have examined small geographic areas like cities and counties, but few studies address larger areas. Fewer still have studied WNV in the Southern Plains. This study seeks relationships between weather, land use, and WNV in Kansas, Oklahoma, and Texas to inform better public health decisions.

Since its arrival in the U.S., many studies have sought insight into which environments are most conducive to WNV outbreaks. Temperature and moisture have been found to have significant impacts on the vectors that transmit WNV, though sometimes the exact findings conflict. Although mosquitoes require standing water for larval growth, precipitation is only weakly correlated with increased mosquito growth and activity (Chuang et al. 2011; Paz & Albersheim 2008). Drought, on the other hand, has been linked to rises in WNV reports due to limiting water resources and causing both mosquitoes and birds to congregate around small pockets of water (Paz and Albersheim 2008). Rainfall following a drought also corresponds to increases WNV infection rates (Ruiz et al. 2010). Moisture values other than precipitation, such as relative humidity and soil moisture, have also been suggested to lead to increases in mosquito populations, and by extension, increases in disease transmittal (Chuang et al. 2012; Ruiz et al. 2010).

Research of temperature has shown even stronger relationships. Temperatures above 21 degrees C quicken the gonotrophic cycle, which is the period of egg production and feeding in female mosquitoes (Chuang, T. et al., 2012; Ruiz et al., 2010). Although a warm temperature correlation may seem intuitive to common mosquito experience, laboratory experiments have shown that extreme heat can prompt lethargy in mosquitoes. Temperatures above 39 degrees C are fatal to some mosquitoes. The higher temperatures rise, the more quickly mosquitoes die, with female mosquitoes unable to withstand temperatures of 48 degrees C and higher longer than a minute (Horsfall 1955).

Examination of WNV in the Southern Plains is necessary because summer temperatures in the region have been known to top 40 degrees C.

Winter temperatures also may exhibit promising leads to understand WNV in the South. Mosquitoes in the *Culex* genus are the primary carriers of WNV in Kansas, Texas, and Oklahoma. These mosquitoes are known to hibernate in the winter (Andreadis et al. 2010). Evolving to local conditions, hibernating mosquitoes are accustomed to average winter temperatures but are sensitive to deviations in those average temperatures (Chuang & Wimberly 2012), with warmer temperatures causing mosquitoes to cease hibernation early (Reisen et al. 2010).

This study used these findings as a base point to study with the intention to confirm and expand the results to be applicable to the Southern Plains. In addition, land cover was also considered because of the notion that mosquitoes can evolve to location-specific norms. Geographic information may show insight into local conditions that might contribute to WNV trends that meteorology alone could not explain.

2. Methodology

Three components were needed in this study: meteorological data, land use data, and WNV reports. State epidemiologists from Kansas, Oklahoma, and Texas, provided a list of all individual cases recorded between 2002 and 2012, the time span that WNV has been west of the Mississippi River. Weekly totals for each county were calculated from this list as well as yearly totals. Using 2010 Census data, these totals were converted into incidence rates. That is, the number of cases was divided by the population of each county as reported in the 2010 U.S. Census. Although this assumes that population is constant when it is not, the Census data was used to estimate proportions of infected individuals for each county relative to surrounding counties.

Many studies have used mosquito data to look at the spread of WNV, but doing so involves placing traps in different parts of the research area. Because this project covers a wider geographic area than many other studies, this would be unrealistic to do. Furthermore, the limited number of mosquito traps makes it difficult to generalize this point-specific data to larger geographic areas. On the other hand, WNV reports may be underreported since symptoms often resemble influenza (ISU 2009). Also, reports are recorded only by county, so doing specific location-based analysis is not possible with this method.

National Centers for Environmental Prediction/National Center for Atmospheric Research (Kalnay 1996) reanalysis weekly averages of surface air temperature, vector wind, precipitation (converted from precipitation rate), and 0 - 10 cm soil moisture data were downloaded from the Earth System Research Laboratory (ESRL) website. Weekly averages were thought to be useful because a study of WNV in Israel (Paz 2006) concluded that persons would be diagnosed with WNV 3 to 9 weeks following an anomalous weather signature; most are diagnosed 5 to 7 weeks after the anomaly. Using weekly data allows the application of a lag (a 5-week lag was used in this study) to be applied to the data to match the WNV incidence peaks to certain weeks. Furthermore, the Centers for Disease Control and Prevention (CDC) produces a weekly morbidity and mortality report. Weekly data provides results on a temporal scale consistent to what is currently being used by public health organizations.

The NCEP/NCAR meteorological data are projected onto 2.5-degree grids. This means that a single grid covers several counties (see Figure 1). Because of this, incidence rates were calculated for each grid space by summing WNV totals of each county within a particular grid and dividing by the total population of all of those counties. When meteorological data were used, the corresponding grid incidence rates were also used. These data were used to plot time series, plot yearly total incidence rates over specific meteorological variables, and make simple regressions using the least squares method.

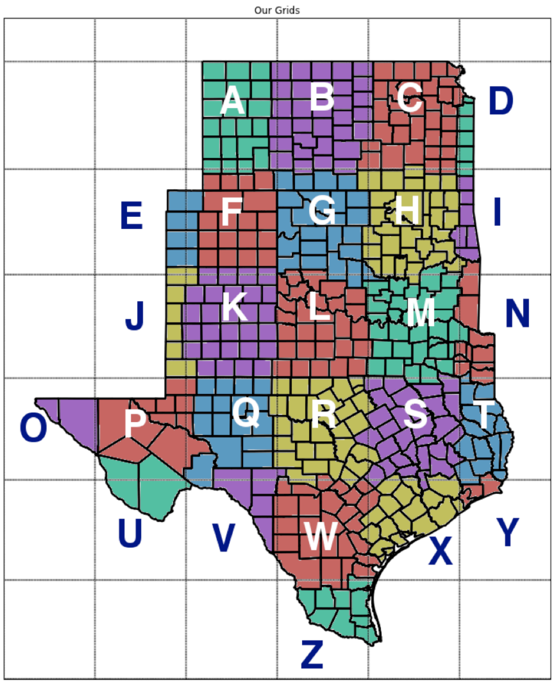

Fig 1: This map shows how the study area was divided into grids, based on the 2.5-degree grid spacing of the NCEP/NCAR reanalysis model.

Geographic features were analyzed using ArcGIS 10.1. Yearly incidence rates were plotted in ArcMap 10.1 along with land use data from the United States Department of Agriculture National Agricultural Statistics Service. The Cropland Data layer uses moderate resolution satellite and agricultural ground truth to derive a crop-specific land cover data layer (NASS). Undesirable land types like barren land were removed to obtain a clearer image of crop types in agricultural regions. The Zonal Statistics Table in ArcMap was used to calculate simple land use statistics for each county in Kansas, Oklahoma, and Texas.

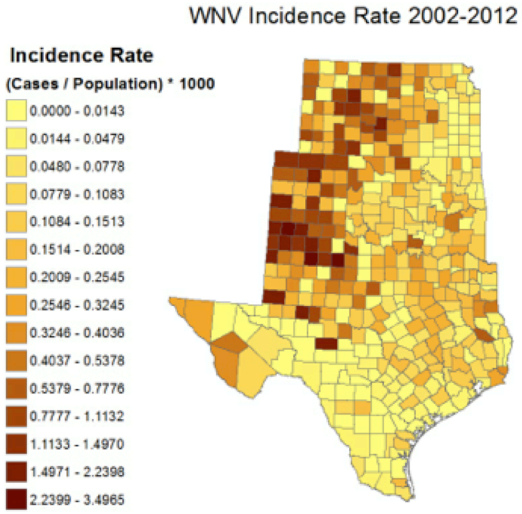

Fig 2. Total incidence rates per county from 2002-2012

3. Results

Media attention is usually focused on outbreaks in metropolitan areas that draw large case numbers, but when incidence rate is taken into account, ten-year composites (Figure 2) show that the highest incidence rates occur in the west. Time series of western grids and eastern grids, however, do not appear to offer an explanation for the higher incidence rates to the west. Instead, as the example time

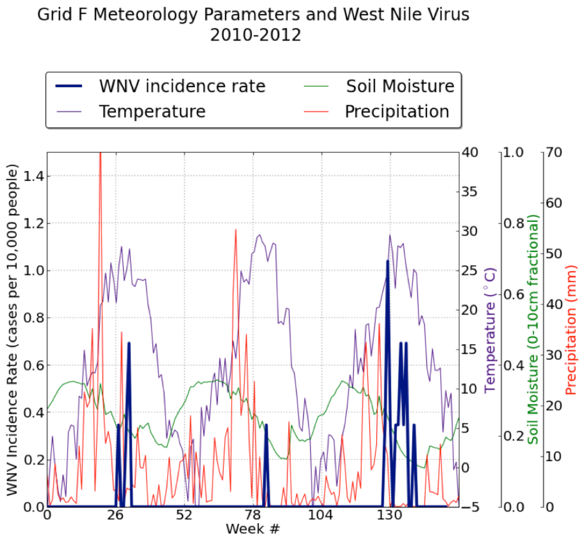

Fig 3. The total WNV incidence rate from 2010 to 2012, where week 0 is the first week of 2010, week 52 is the first week of 2011, and week 104 is the first week of 2012.

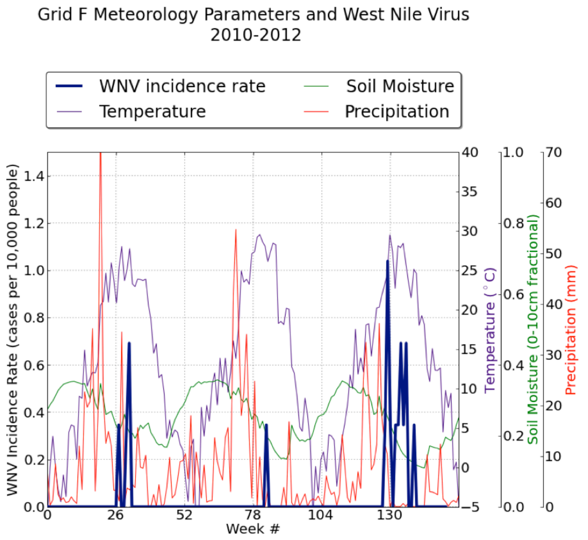

Fig 4. The total WNV incidence rate from 2010 to 2012, where week 0 is the first week of 2010, week 52 is the first week of 2011, and week 104 is the first week of 2012.

series for grids F and H in Figures 3 and 4, respectively show, similar trends in incidence timing occur. Spikes in incidence rates do not necessarily occur following the weeks of heaviest rainfall, but they do tend to be preceded by some rainfall. The peaks tend to occur in warmer seasons, and also during a period of decreasing soil moisture – though not at the minimum. Initially, one of the guiding hypotheses to explain peaks in incidence was that the peaks would correspond to increased precipitation and high soil moisture content, with soil moisture being a proxy for shallow, pools of water where mosquitoes could lay eggs. In fact when looking at the western grids, precipitation did not seem to influence the timing of incidence peaks according to original suppositions, and the rise in incidence during periods of negatively sloped soil moisture values most likely has more to do with increased temperature that would also lead to more evaporation.

Not only were the meteorological trends illustrated by the time series similar, but western counties are also notoriously dry. Thus, meteorology could not account for higher incidence rates consistently in the High Plains each year. Geography, however, offers a promising explanation. The western part of the Southern Plains is used to grow cotton and corn among other crops (see Figure 5). These areas, however, do not receive enough rain to support the agricultural practices, so farmers must irrigate, especially for cotton. Irrigation likely creates puddles in which mosquitoes can breed, and farm workers

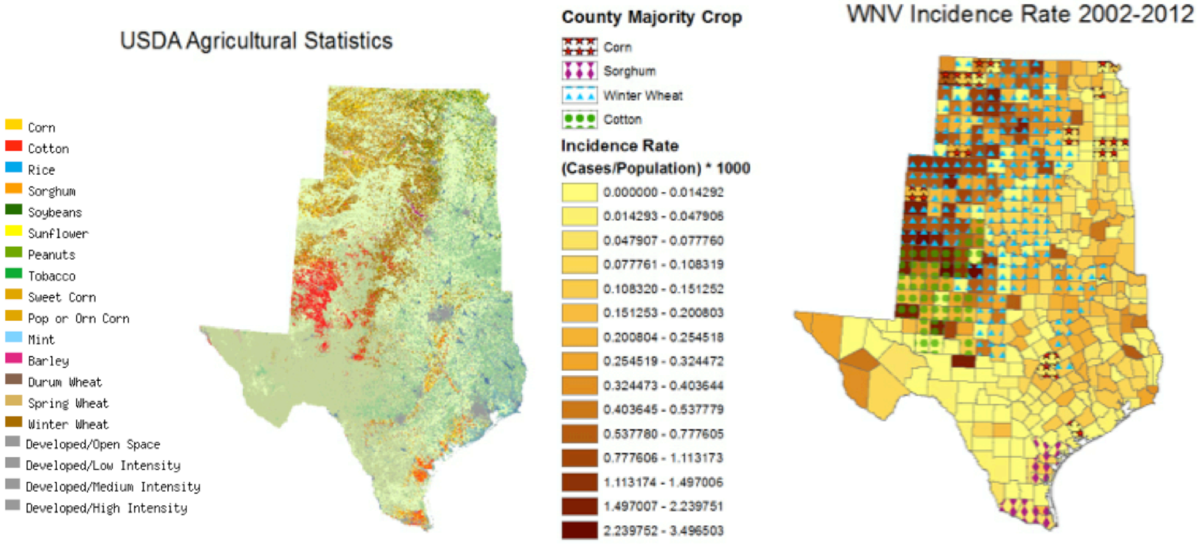

Fig 5. (left) National Agricultural Statistics Service’s Cropland Data Layer. (right) Majority crop type per county (corn, sorghum, winter wheat, and cotton) overlaid on total incidence rates from 2002-2012.

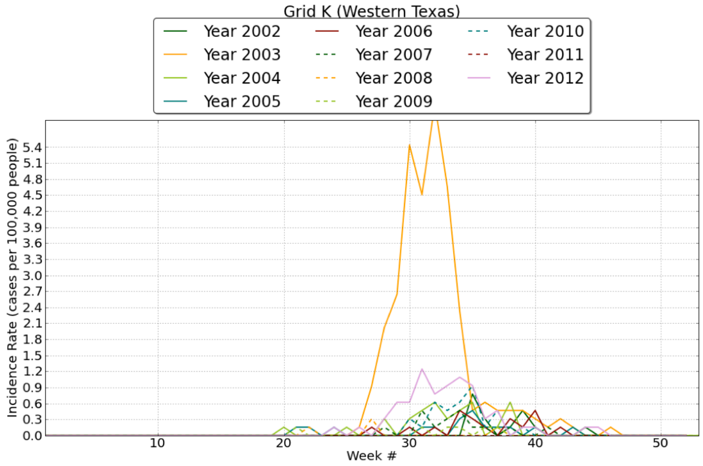

Fig 6. Time-series of WNV incidence rates in western Texas plotted for 2002-2012. Week 0 is the first week of each year. WNV is active from around May 6th –November 12th with maximum activity from June 24th-September 30th.

who spend hours outside each day risk being bitten. Within the 436 county study region, there are 33 counties that grow primarily cotton with an average incidence rate in the 88th percentile of highest incidence rates. The average cotton-planting season in Texas is most active from April 8 - June 7 with harvesting most active from September 13 - December 21. This coincides well with the average WNV season in western Texas starting in the end of July and lasting to the beginning of October (see Figure 6) (NASS 2010). These findings that link high WNV incidence rates to irrigation are consistent with two prior studies that examine irrigation practices in El Paso, Texas (Cardenas 2011) and in north-central Colorado (Eisen et al. 2010).

Irrigation aside, eastern parts of Kansas, Oklahoma, and Texas still experience a lot of inter-year variability in WNV incidence rates. A partial explanation can be found in winter temperature anomalies. Composites of anomalies in average winter temperature produced by the NCEP/NCAR reanalysis for the three years that make of

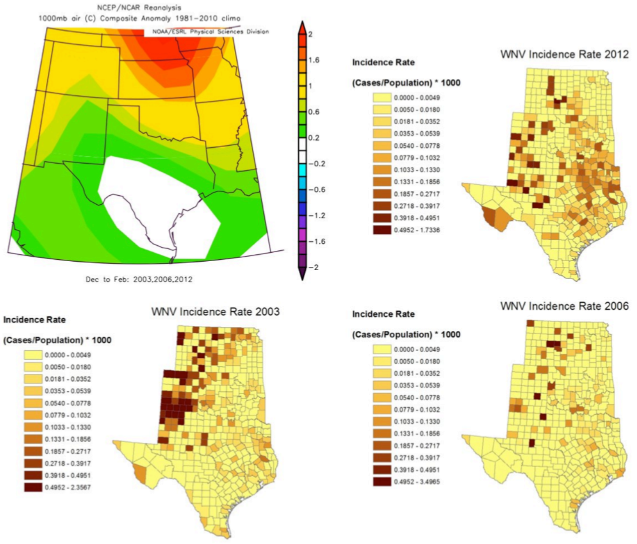

Fig 7. (top-left)The average winter (DJF) temperature anomalies of the years with the three highest incidence rates (top-right) The yearly incidence rate for 2012 over the region (bottom-left) The yearly incidence rate for 2003 over the region (bottom-right) The yearly incidence rate for 2006 over the region.

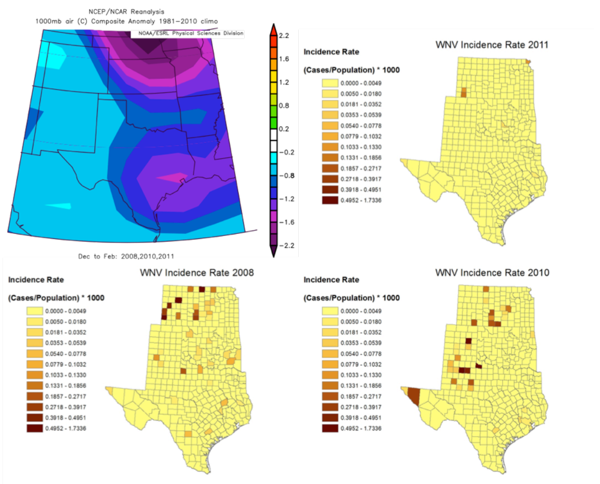

Fig 8. (top-left):The average winter (DJF) temperature anomalies of the years with the three lowest incidence rates (top-right):The yearly incidence rate for 2011 over the region (bottom-left):The yearly incidence rate for 2008 over the region (bottom-right)The yearly incidence rate for 2011 over the region.

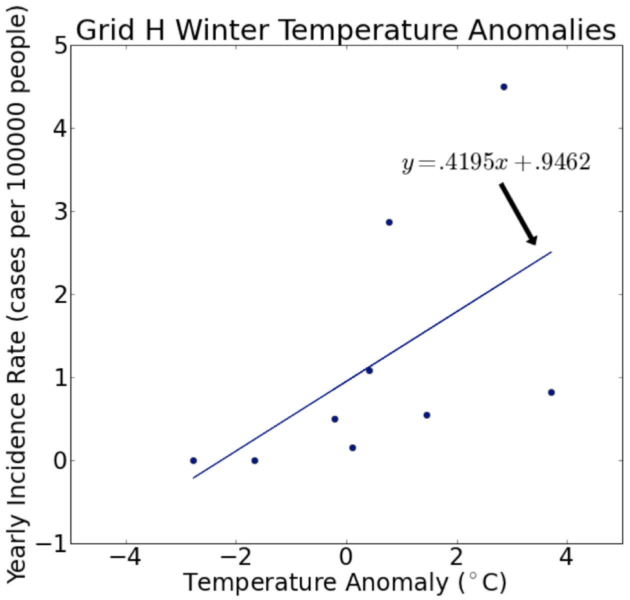

Fig 9. Yearly incidence rates for Grid H plotted against winter temperature anomalies.

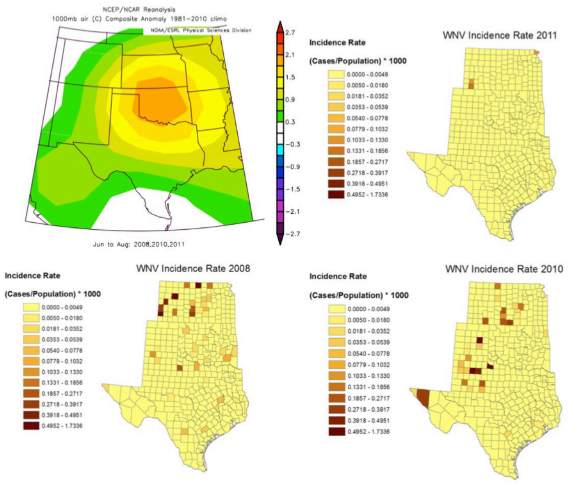

Fig 10. (top-left):The average summer (JJA) temperature anomalies of the years with the three lowest incidence rates (top-right):The yearly incidence rate for 2011 over the region (bottom-left):The yearly incidence rate for 2008 over the region (bottom-right)The yearly incidence rate for 2011 over the region.

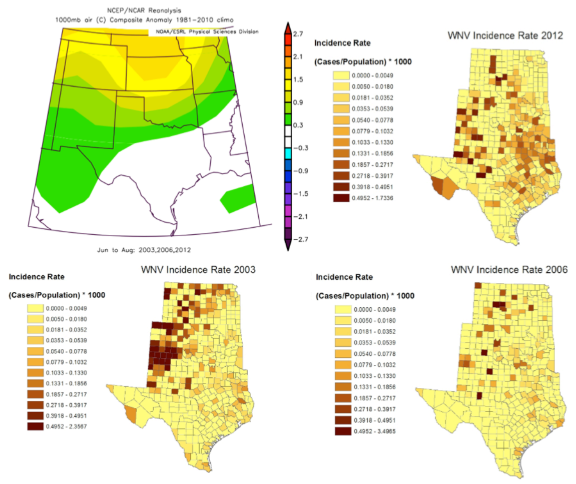

Fig 11. (top-left):The average summer (JJA) temperature anomalies of the years with the three highest incidence rates (top-right):The yearly incidence rate for 2012 over the region (bottom-left):The yearly incidence rate for 2003 over the region (bottom-right)The yearly incidence rate for 2006 over the region.

top quartile of highest incidence rates (2003, 2006, and 2012; Figure 7) and for the three years that make up the bottom quartile (2008, 2010, and 2011; Figure 8) contrast markedly. Cool anomalies dominate the eastern portion of the Southern Plains for the bottom quartile, and warm anomalies were present in for the top quartile. This not only lends support to the Chuang and Wimberly (2012) study, but it also links the observed effects of winter temperature anomalies on mosquitoes to region-wide WNV outbreaks. When examining winter average weekly temperature anomalies compared to yearly WNV incidence rates, a clear relationship is apparent. Using the least squares method, it was determined that the average coefficient of the correlation between the two is .325. Figure 9 shows this relationship for Grid H, which suggests that cool winter temperature anomalies lead to smaller WNV outbreaks while warm winter temperature anomalies result in more WNV activity over the year.

An examination of summer anomalies does not prove as telling as winter anomalies, though. Figures 10 and 11 show the summer average temperature anomaly composites for both the bottom and top quartiles respectively. The composite for the bottom quartile show a slightly higher anomaly, but does not contrast as sharply with the top quartile as the winter composites did. In fact, when the anomalies of individual years are considered (Figures 12 and 13), it can be seen that both high years and low years, respectively, experience cold and warm summer anomalies. The time series have illustrated rises in temperature at the same time as rises in incidence rate, so this relationship must be explained by actual average temperature values rather than by the anomalies in those values. Scatter plots (Figure 14) of incidence rates versus temperatures for the grids show that incidence rates rise above 0 when the temperatures are between 20

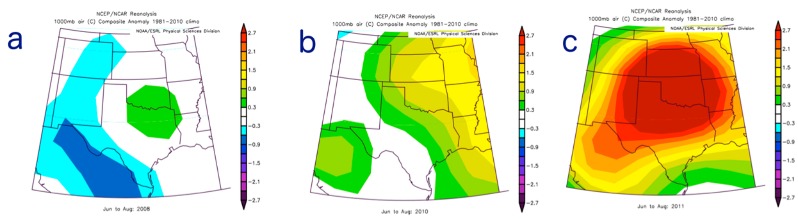

Fig 12. Summer Temperature Anomalies for the region vary widely over the lowest three years: a) 2008, b) 2010, c) 2011.

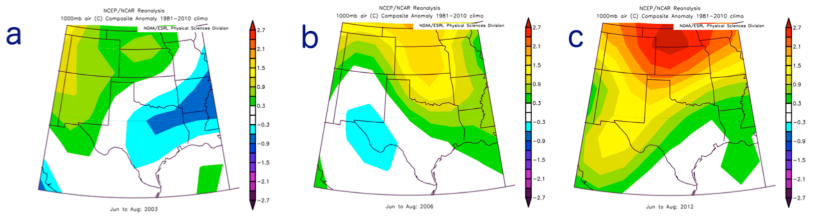

Fig 13. Summer Temperature Anomalies for the region vary widely over the lowest three years: a) 2003, b) 2006, c) 2012.

and 35 degrees C. The highest incidence rates can be found when the average temperature is between 25 and 30 degrees C. This range of values supports previous research findings that temperatures above 21 degrees C are conducive for mosquito activity (Chuang et al. 2012, Reisen et al. 2010). When average weekly temperatures are over 35 degrees C, individual days may have reached above 39 degrees C, temperatures detrimental to mosquito health (Mayne 1930). Although not conclusive, this may suggest that even temperatures below the theoretical threshold could slow the spread of WNV.

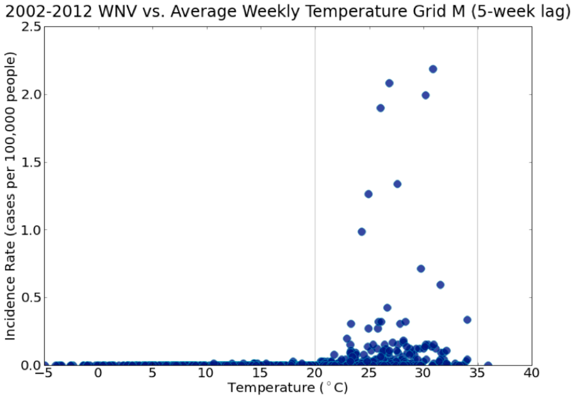

Fig 14. Plot of incidence rates versus temperature for Grid M.

Results for the other variables considered were somewhat less conclusive. Scatter plots of incidence rates versus precipitation (Figure 15) for the eastern portion of the study area, unaffected by irrigation, show incidence rates at varying levels of precipitation rather than clustering around specific amounts. Peaks in incidence, as mentioned before, occur during declines of soil moisture. It may be inversely related to WNV, but favorable temperatures likely drive this relationship. Finally, the NCEP/NCAR wind data did not prove to be useful because wind varies greatly over time and space. Because of this, the weekly-averaged wind speeds for 2.5-degree grids do not illustrate any correlations. Thus, no conclusions can be drawn from this data.

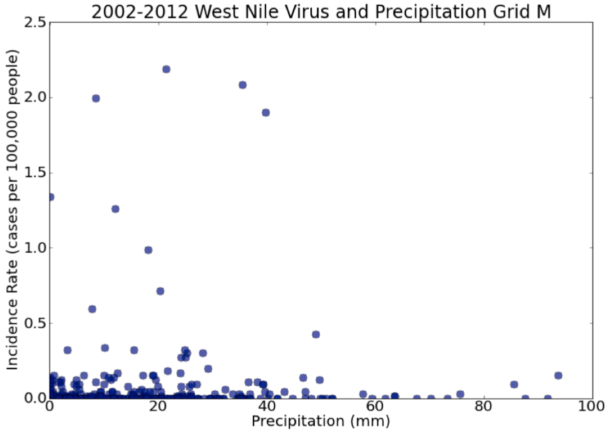

Fig 15. Plot of incidence rates versus precipitation for Grid M.

4. Discussion

At this point, only limited, quantitative statistical work could be done. In the future, the qualitative leads found in this study should be regressed over time and space. If the relationships prove to be statistically significant, functions can be used to predict WNV outbreaks before they occur.

Even stronger relationships may be found if the meteorological data were on smaller scales. At the start of the study, higher resolution data was not for 2002-2012 for each variable. Now, however, the NCEP North American Regional Reanlysis (NARR) can interpolate data to .3-degree grid cells for all 10 years used in this study. Daily data is also available so incidence rates can be tied to an individual day's conditions rather than to weekly averages.

Other variables should also be studied. This study did not take into account what kinds of effects humidity might have on the spread of WNV. If some relationship existed, it may contribute to an understanding of outbreaks along Gulf Coast regions. One variable that may prove to be useful in evaluating precipitation and wind effects together is apparent temperature. Additionally, variables that account for cumulative effects, such as number of days of a temperature above or below a certain level or number days of rainfall, may give additional insight to future studies.

Even without the additions of the data described above, some key results were still found. Perhaps most significantly, this study can add motivation for decreasing irrigation in the High Plains. The water currently used to irrigate crops in western Kansas, Oklahoma, and Texas comes from the Ogallala aquifer. This aquifer is quickly being depleted (Wagner, 2012), and continuous irrigation is not only unsustainable, but also increases the risk of contracting WNV. Changes in farming practice may be beneficial to public health in the region. For instance, sorghum requires substantially less irrigation for growth and maintenance (Allen & Musick 1993). There are 10 counties that primarily grow sorghum with a mean incidence rate in the 37th percentile of highest incidence rates, placing them at lower risk for the virus. Future work should be done to develop a predictive index for the West Nile Virus in the southern plains that takes into account land use and seasonal temperature anomalies, as well as weekly temperature averages and precipitation.

5. Acknowledgements

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