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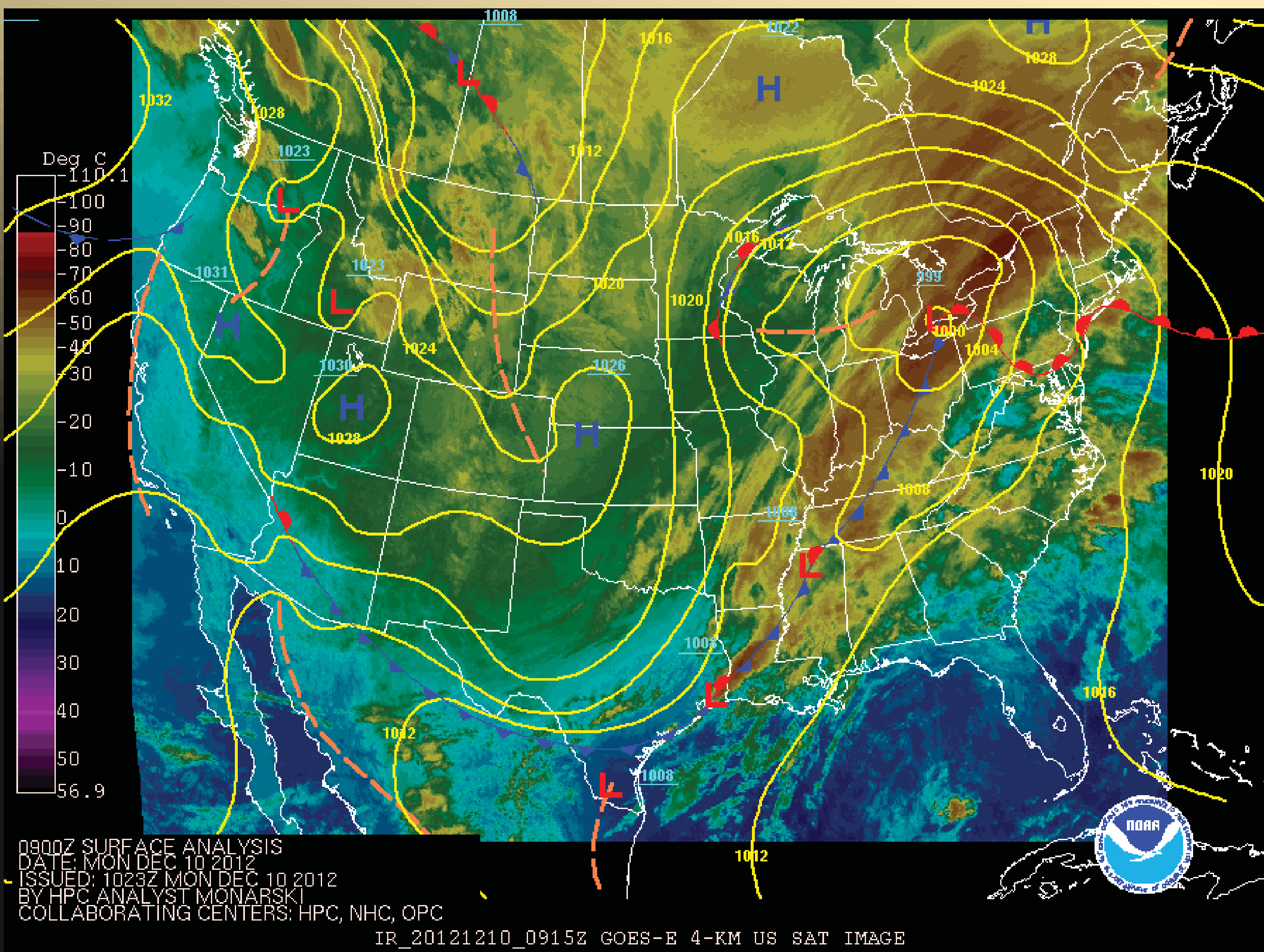

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On the cover: Surface frontal analysis with infrared satellite imagery at 0900 UTC on 10 December 2012. See the associated article, "Use of Mobile Measurements to Investigate Frontal Structures in Mississippi", on pages 170- 182. Photo credit: Loren White.

# Journal of the Mississippi Academy of Sciences

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## Research Articles



## Departments

# USE OF MOBILE MEASUREMENTS TO INVESTIGATE FRONTAL STRUCTURES IN MISSISSIPPI

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## ABSTRACT

Two cases of differently oriented frontal systems within Mississippi are investigated using data from a mobile vehicle-mounted observing system in addition to standard atmospheric data sources. Results highlight the capability of the mobile system to diagnose thermodynamic features at a wide range of spatial scales. Widely recognized frontal characteristics are noted in the data, together with some variations. Variations include a lack of strong relationship between frontal position and rainfall bands when examined at small scales. In one case a seemingly anomalous narrow band of significantly lower humidity was identified within about 20 km of the front. These results are indicative of the need for multi-scale data sources and for careful consideration of departures from classical models of phenomena for specific cases.

**Keywords:** Cold front, temperature, humidity, Mississippi, spatial scales

## INTRODUCTION

Since the earliest of the polar front concept by Bjerknes and Solberg (1922) and the later examination by Sanders (1955) and Shapiro (1984), the detailed structure of atmospheric frontal boundaries has been investigated by various means. In recent decades the capability to measure various parameters by aircraft (Blumen et al. 1996) and remote sensing systems (Bluestein et al. 2017; Demoz et al. 2005; Friedrich et al. 2008a; Geerts et al. 2006; Mahre et al. 2017; Wakimoto and Bosart 2000) has led to advances in understanding processes in and near frontal zones. While each measurement methodology has its specific value in describing some aspect of the atmospheric conditions, little attention has yet been given to the use of mobile (i.e. moving) surface-based observing systems to document horizontal variations across frontal zones (White 2014). This is in contrast to much more widespread use of “mobile mesonets” in studies of drylines and severe storms (e.g. Pietrycha and Rasmussen 2004).

Although atmospheric fronts are most rigorously understood in a three-dimensional physical context and may extend throughout the depth of the troposphere, their character and processes near the earth’s surface are particularly affected by the nature and condition of the surface. In many respects, fronts observed over flat terrain with uniform low vegetation (e.g. U.S. Great Plains) or over oceanic areas may be considered to be ideal simple cases. Frontal interactions with surface processes in rugged terrain or areas of heterogeneous land use mosaics (forest, urban, crops, small water bodies) are naturally more complex and specific to local geography. Although Mississippi does not have true mountains, the physical geography and biosphere interactions are sufficient to impact fronts in various ways.

It has also become clear from studies over the last few decades that even in simple landscapes the classical conceptual models of fronts do not accurately portray the range of structures observed in all fronts or at all stages of their development and weakening (Koch and Clark 1999, Doswell and Haugland 2007). It is within this growing awareness of the wide variety of fronts when viewed in detail that the use of measurements from a mobile observing platform, the Jackson State University Mobile Meteorology Unit (MMU), has been developed to facilitate case studies of fronts in Mississippi.

## DATA SOURCES AND METHODS

The instrumentation used for the Jackson State University MMU were identical to what was reported in White (2014). A Campbell Scientific HMP45C temperature and relative humidity sensor was mounted above the cabin of a standard passenger vehicle within a 41003 Gill radiation shield to minimize direct heating of the sensor by solar radiation. Geographic position was determined by a Garmin GPS16-HVS system. Data were logged at 10-s intervals onto a CR23X datalogger. In post-processing, dewpoint was calculated from temperature and relative humidity. Using altimeter setting interpolated from surrounding synoptic observing stations, other derived quantities such as potential temperature and water vapor mixing ratio were determined. The advantage of potential temperature is to adjust temperatures to a standard pressure (1000 hPa) so that it is conserved for adiabatic vertical motions and directly proportional to internal energy. Similarly mixing ratio is a direct measure of the amount of water vapor in g/kg.

For comprehensive analysis, surface observations from various synoptic and mesonet observing systems have been utilized (White and Finney 2005). These include METAR-encoded ASOS/ AWOS, RAWS, SCAN, and the automated weather stations operated by Jackson State University. National Weather Service NEXRAD radar data were obtained in georeferenced format from the Iowa Environmental Mesonet website (https://mesonet.agron.iastate.edu/) and radiosonde data were retrieved from the NOAA ESRL site (https://ruc.noaa.gov/raobs/). Environmental Mesonet website (https:// mesonet. agron.iastate.edu/) and radiosonde data were retrieved from the NOAA ESRL site (https://ruc.noaa.gov/raobs/).

## DECEMBER 2012 COLD FRONT

Early on the morning of 10 December 2012 a strong cold front extended from a large low-pressure system over the Great Lakes through the Mississippi Delta down to South Texas (Fig. 1). The MMU made a transect between Jackson and Indianola, Mississippi from 0823 to 1205 UTC (2:23-6:05 AM Central Standard Time) to intercept this front. The local synoptic conditions are summarized in Fig. 2.a. The warm air mass southeast of the cold front was typified by temperatures ranging from 16 to 22 C, southerly flow from the Gulf of Mexico, and dewpoints from 11 to 15 C. At the front the wind suddenly shifted to northwesterly and temperatures began to drop, initially by a few degrees but continuing to well below freezing (-5 C) in the Ozarks. The northbound MMU intercept of the front was at 0953 UTC about 15 km south of Indianola. On the return trip it was intercepted about 15 km north of Yazoo City at 1058 UTC, indicating that the front moved at an average of 35 km/hr during the period. Most analysis and discussion will be focused on the northbound transect. In order to focus more directly on conservative quantities, the analysis will be primarily in terms of potential temperature and mixing ratio instead of temperature and dewpoint. The MMU measurements of temperature in context with surrounding station data are summarized in Fig. 2.b.

As demonstrated by the radar reflectivity (Fig. 2.c), most of the transect was in moderate rain. It is of interest that there was no obvious relationship between the intensity of precipitation and the exact location of the front. Since the Gill shield was primarily designed to shelter the temperature/ humidity sensor from solar radiation instead of windblown rain, mobile measurements while in significant rain must be evaluated for the impact of "wetbulbing" (Straka et al. 1996). The concept is that if the sensor itself becomes wetted by blowing rain then it will end up measuring a temperature that approximately corresponds to the wetbulb temperature of an evaporating saturated surface. This is particularly problematic if the actual relative humidity is significantly below 100%, so that evaporative cooling is more effective. To check against wetbulbing, the MMU temperatures and relative humidity were compared against nearby observing stations (KHKS, Mayday, Silver City, and Beasley Lake). Since the effect tends to be cumulative, it would be expected to worsen over time during the nearly continuous rain. Therefore quantitative analysis of the southbound transect is more questionable and the largest impact on the northbound transect should be near Beasley Lake (the northernmost station). The expectation is that wetbulbing should cause the mobile temperatures to be too low and humidity too high. However comparison between Beasley Lake and the closest mobile observation to it indicate that the MMU temperature was 0.25 C higher (well within the expected variation from siting and sensor differences). So it seems that nearly saturated actual conditions prevented any significant evaporative cooling regardless of whether the sensor was wetted. Comparisons at the other stations were similar.

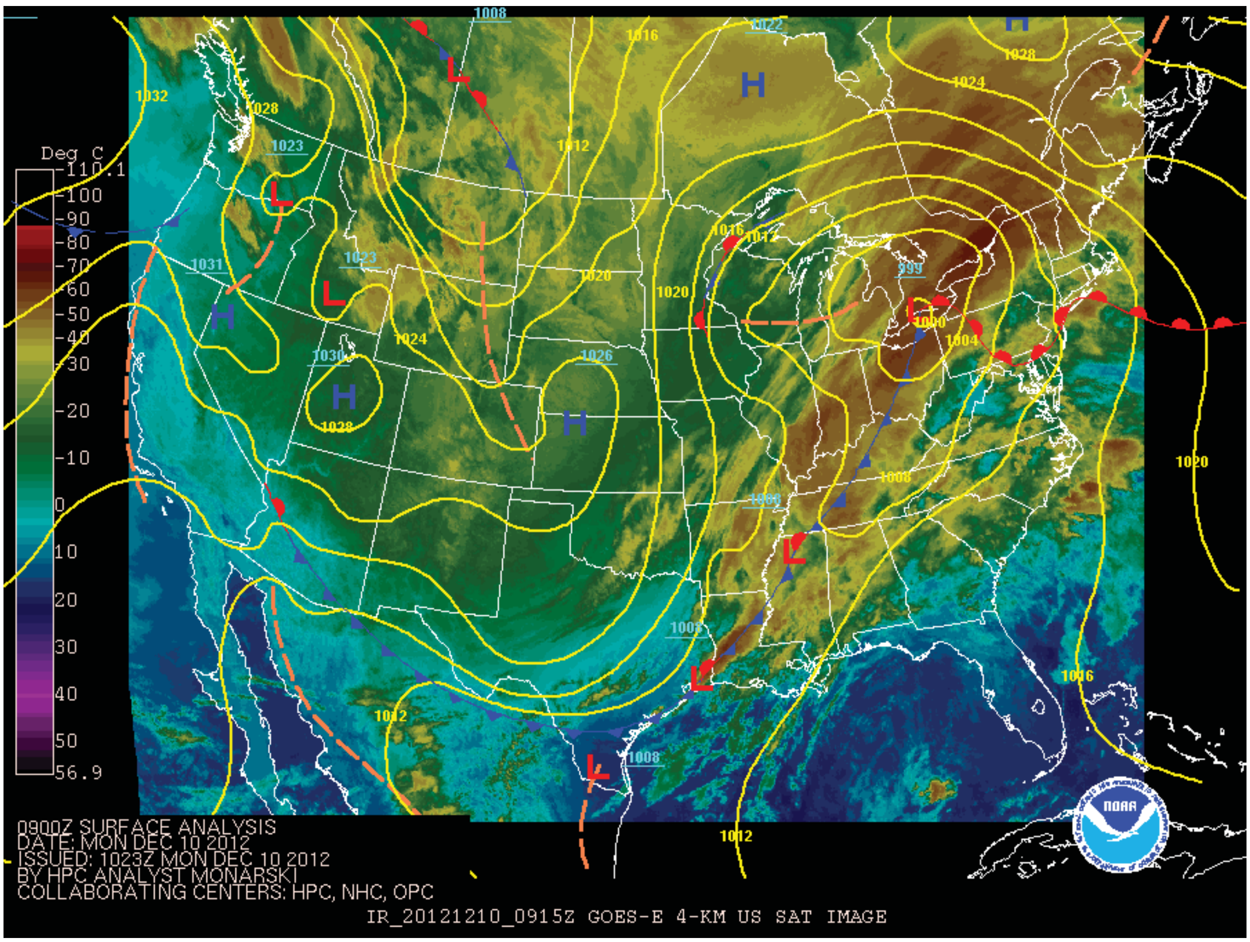
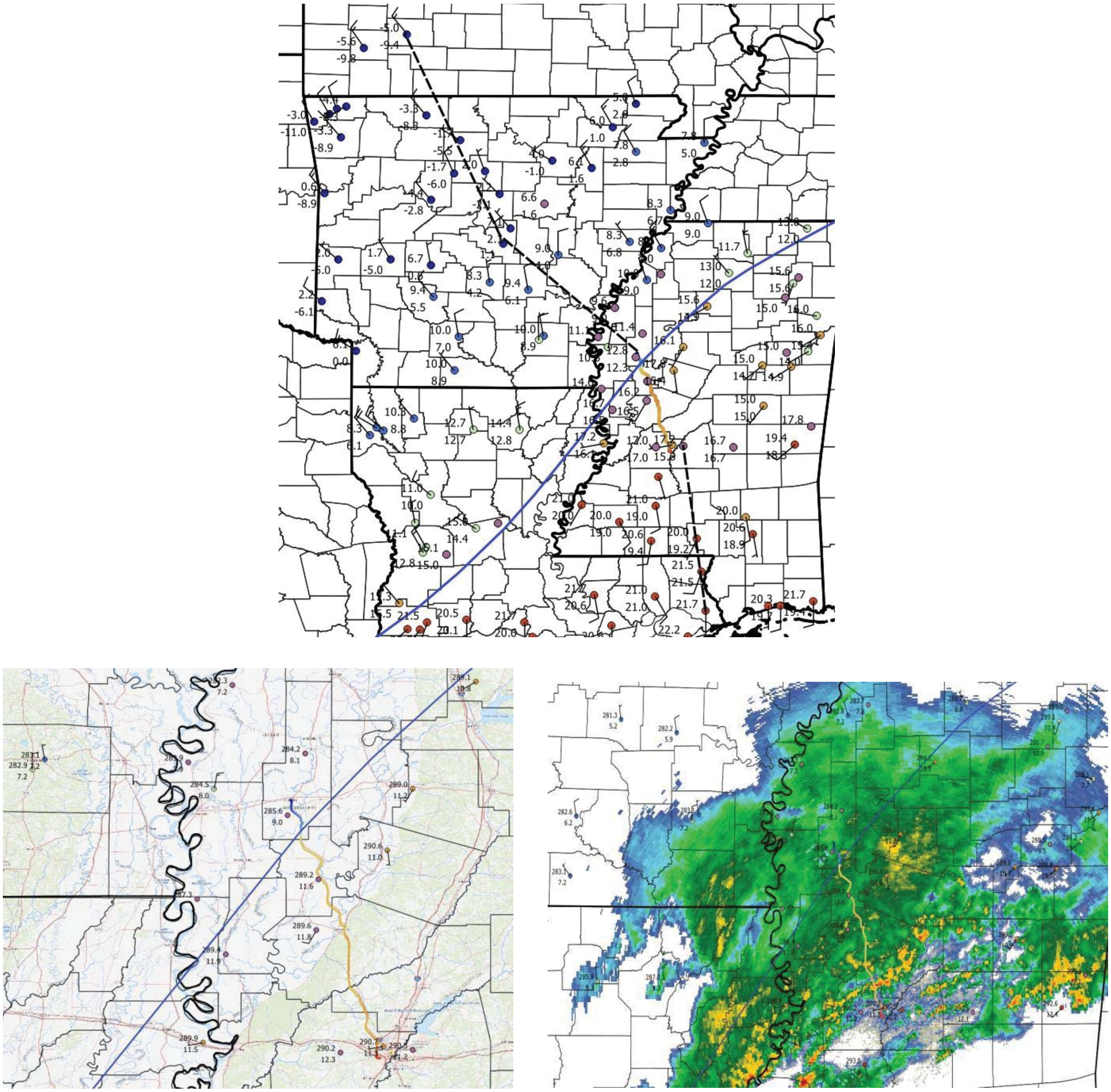



**Figure 1:** Surface frontal analysis with infrared satellite imagery at 0900 UTC on 10 December 2012.

a



(b) (c)

**Figure 2:** Surface weather conditions and cold front analysis from fixed stations and mobile platform, adjusted to time of northbound front intercept (0953 UTC). Thick blue line indicates cold front. **a)** Regional view, with location of cross-section shown by black dashed line. Station temperature in upper left (C); dewpoint in bottom left (C); winds in kt. Temperature from mobile platform indicated by color (red = maximum; blue = minimum). **b)** Local view near mobile transect. Station potential temperature in upper left (K); mixing ratio in bottom left (g/kg); winds in kt. Potential temperature from mobile platform indicated by color (red = maximum; blue = minimum). Note that most SCAN stations in the Mississippi Delta do not measure winds. **c)** Local view with overlay of radar reflectivity from KDGX (Brandon, MS).

Although the time span of the northbound transect was only 1.5 hr, the rapid cooling behind the cold front and effect of the frontal motion itself compound to complicate determination of conditions at a single standard time. Using a combination of temperature comparisons between north and southbound measurement together with station observations, spatially variable temperature tendencies are applied to adjust the northbound data to a standard time at the front intercept of 0953 UTC. The greatest hourly temperature tendency following the front at nearby stations was -4.3 C/hr at Mayday and the greatest from the north/south mobile data was -6.8 C/hr. The raw and adjusted potential temperature are shown in Fig. 3. Ahead of the cold front, the potential temperature is quite uniform between 290-291 K north of 32.4 N. South of 32.4 N (in the Jackson Metro area) a mesoscale thermal boundary was associated with the leading edge of the rain-cooled air. The very sudden drop of potential temperature at approximately 33.3 N corresponds to the position of the cold front. The strongest thermal gradient occurs within the first few km and then varies somewhat on the remainder of the track to Indianola.

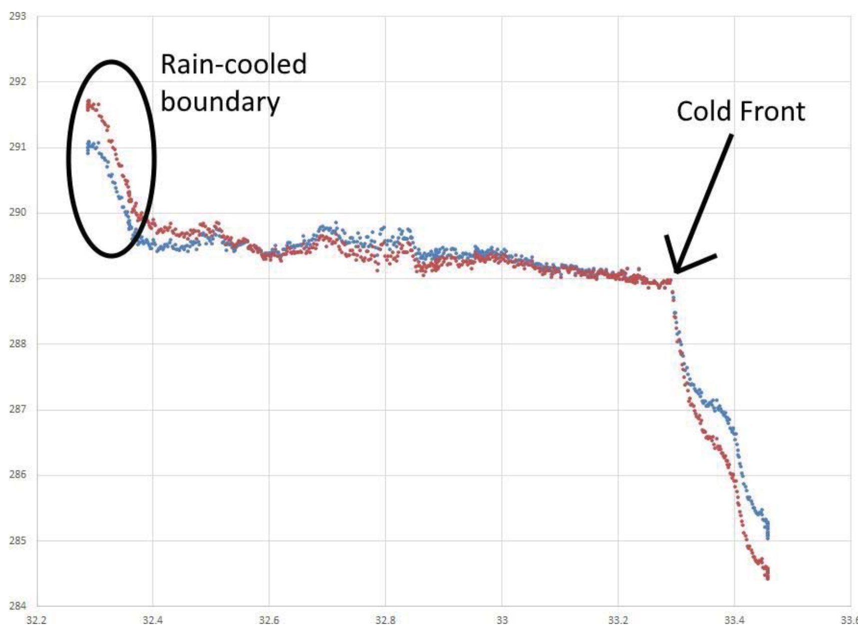


**Figure 3:** Potential temperature from northbound transect: blue = adjusted for tendencies; red = raw. Valid time 0953 UTC, corresponding to northbound front intercept.

To examine the three-dimensional structure of the front, vertical profiles from the 0900 and 1200 UTC initial model conditions of the operational North American Mesoscale (NAM) model were obtained from the READY archive of the NOAA Air Resources Lab (https://www.ready.noaa.gov; Rolph et al. 2017). The grid spacing of the model at the time was 32 km. Profile locations were chosen at nine points extending between the Slidell, Louisiana and Springfield, Missouri radiosonde sites, connecting intermediate radiosonde sites and the endpoints of the mobile transect. To verify that the model adequately matched with observed conditions, the vertical profiles were compared against 1200 UTC radiosonde data (e.g. Fig. 4.a).

For synthesis with the observed surface data, NAM profiles were interpolated to 1000 UTC. Using the combination of NAM profiles, nearby surface observing sites, and MMU data adjusted to 0953 UTC, a cross-section analysis of potential temperature was constructed (Fig. 4b). The pattern matches well with similar frontal analyses (Sanders 1955, Miller et al. 1996, Friedrich et al. 2008), showing a relatively well-mixed layer below 1 km behind the front and a stable layer above (rapidly increasing potential temperature with height) which deepens with distance behind the front. The shallow stable layer from rain-cooled air ahead of the front is evident as well.

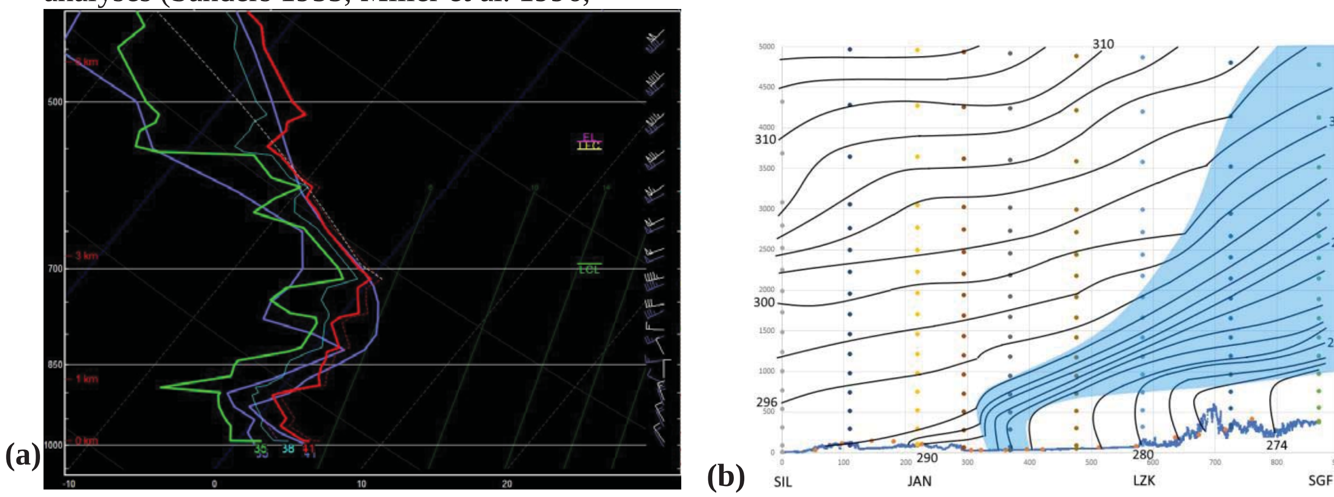



**Figure 4: a)** Skew-T log-p chart comparison of observed and NAM soundings behind cold front for approximately 1200 UTC at KLZK (Little Rock, Arkansas). **b)** Vertical cross-section of potential temperature (K) vs distance (km) at 1000 UTC between Slidell, Louisiana (SIL) and Springfield, Missouri (SGF), from synthesis of surface observations and NAM. Approximate extent of concentrated frontal zone shaded in blue.

## MAY 2014 STATIONARY/COLD FRONT

A very different frontal system was observed on 17 May 2014. In broad terms, a cold front had reached central Mississippi on 16 May, moved back north as a warm front, stalled again, weakened, and then began to strengthen and move south again on the afternoon of the 17th. It was no longer connected to a well-organized low-pressure system and the air to the north of the boundary had moistened after widespread stratiform rain over the previous night (Fig. 5). In the upper troposphere, Mississippi was on the western (inactive) side of a deep trough in the polar jet stream (Fig. 6.a). Closer to the surface (Fig. 6.b) a zonally oriented baroclinic zone stretched from Oklahoma to South Carolina with very little variation of geopotential height and a band of humid/cloudy conditions to the north. The 0000 UTC 18 May (corresponding to 7:00 PM Central Daylight Time on 17 May) surface conditions showed a well-defined wind shift across Mississippi, and temperatures dropping from 24 C to around 14 C in southwest Tennessee (Fig. 7). The afternoon MMU transect from near Holly Springs, Mississippi southward to Jackson (1946 UTC 17 May to 0059 UTC 18 May) did not encounter any rain, so that no consideration of wetbulbing was needed. The slowly moving front was intercepted at 2336 UTC, and data (including station data) are adjusted to this time.

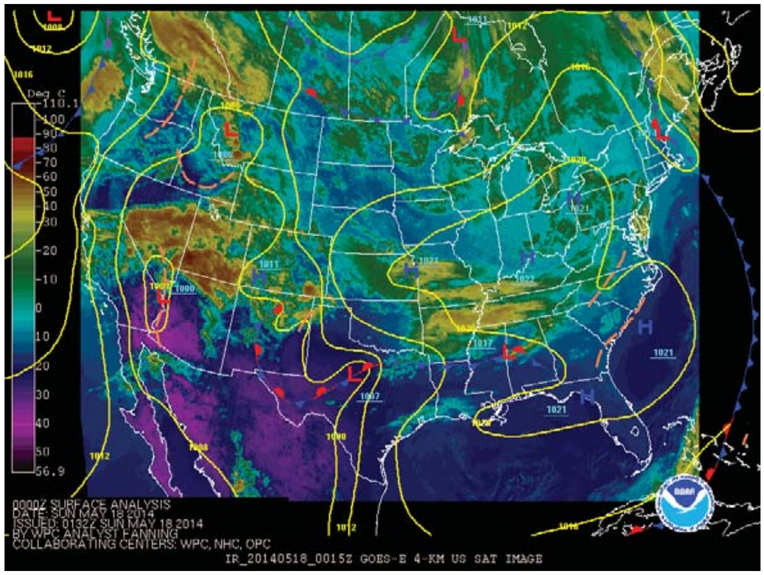
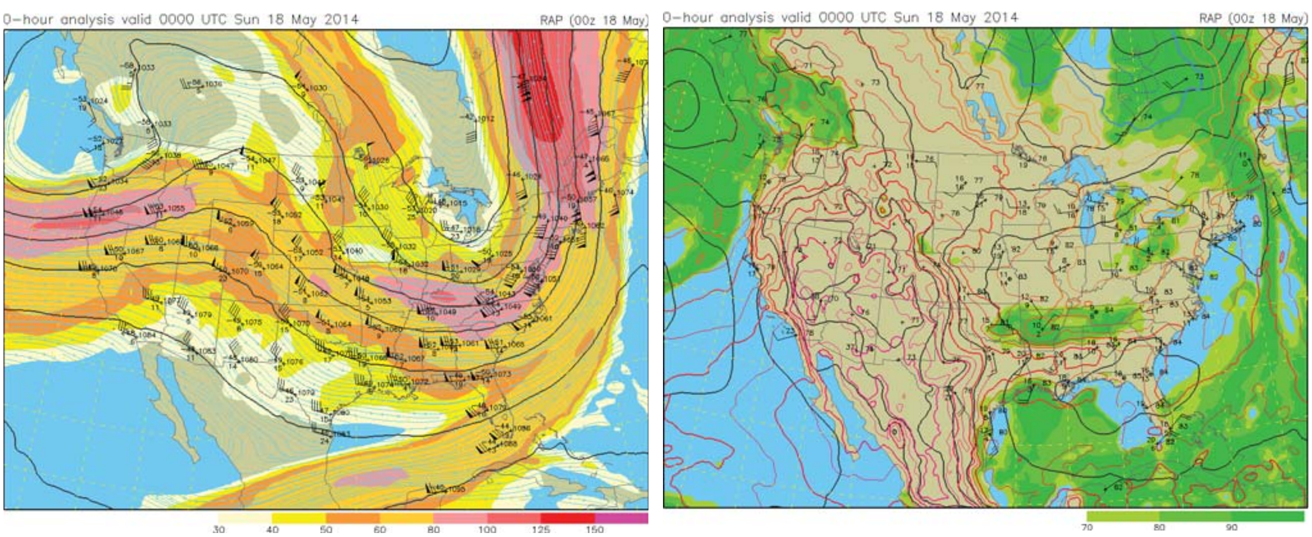


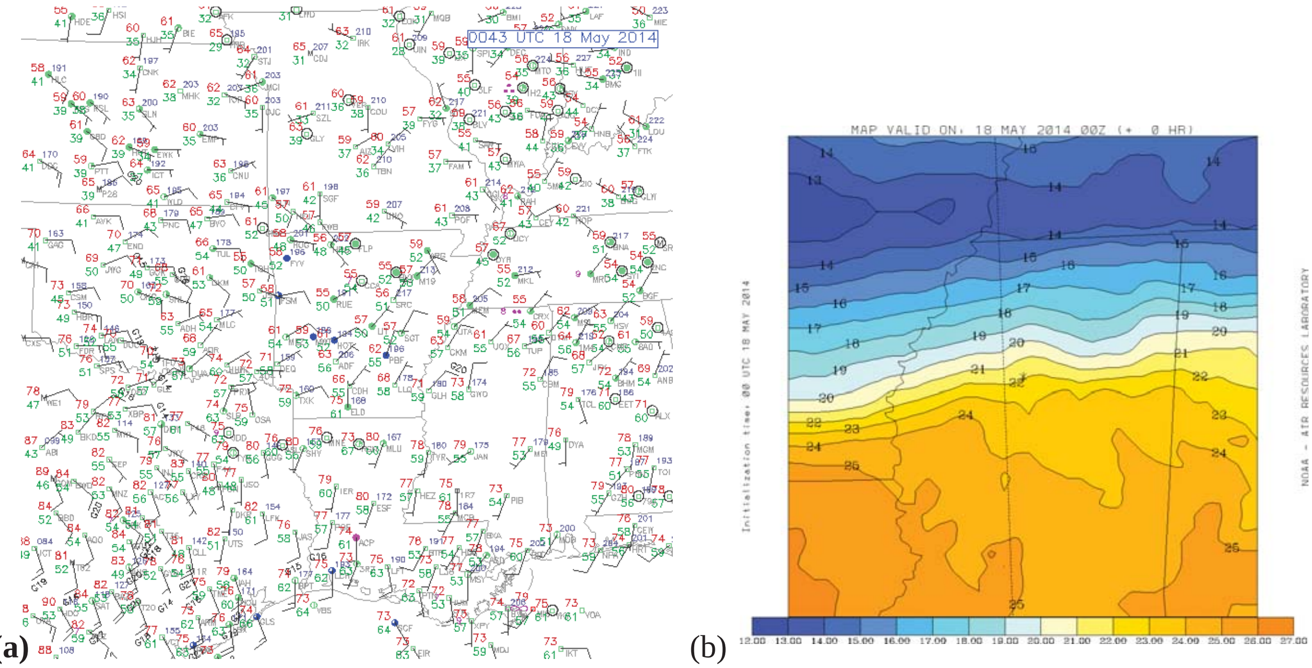

**Figure 5:** Surface frontal analysis with infrared satellite imagery at 0000 UTC on 18 May 2014.




**(a)** **(b)**

**Figure 6: a)** Radiosonde observations at 250 hPa from 0000 UTC 18 May 2014. Jet stream winds indicated by color shading in kt from hourly Rapid Update Cycle (RUC) model initial analysis. **b)** Radiosonde observations at 925 hPa from 0000 UTC 18 May 2014. Isotherms (red contours), geopotential height contours (black), and relative humidity (green shades above 70%) from RUC model initial analysis.

(a)




(b)

**Figure 7: a)** Surface synoptic observations at approximately 0000 UTC 18 May 2014: temperature/dewpoint in °F and winds in kt. **b)** Temperature pattern (°C) at surface over north Mississippi at 0000 UTC 18 May 2014 from NAM initial conditions. Note: Location of MMU frontal intercept is indicated by star.

Movement of the front during the day is shown by the 3-hourly NAM temperature analyses in Fig. 8. At 1500 UTC the southern temperature gradient was located around 33 N. By 2100 UTC it had moved north as a warm front to about 34 N. In the following three hours it again moved south as a cold front to about 33.5 N. It was therefore shortly after the transition back to southward movement that the MMU intercepted the front. Subsequently the front continued to meander back and forth until finally dissipating on the 19th. A distinct confluent wind pattern (Fig. 9) is noted as a favorable frontogenetic influence to at least help maintain the frontal contrast in the absence of other supporting large-scale forcing.

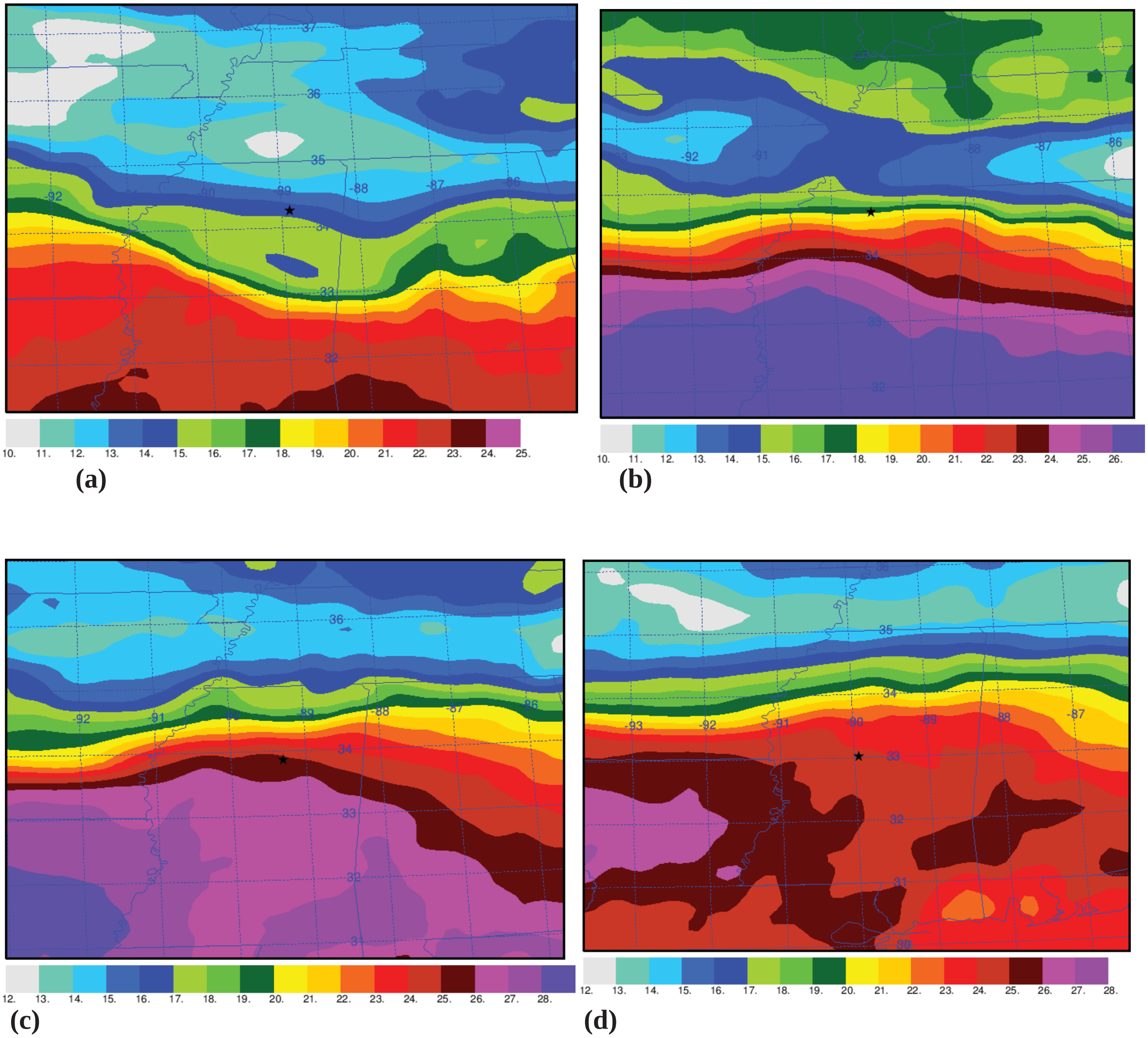


**Figure 8:** Temperature across Mississippi and surrounding states from NAM: **a)** 1500 UTC 17 May 2014; **b)** 1800 UTC 17 May 2014; **c)** 2100 UTC 17 May 2014; **d)** 0000 UTC 18 May 2014.

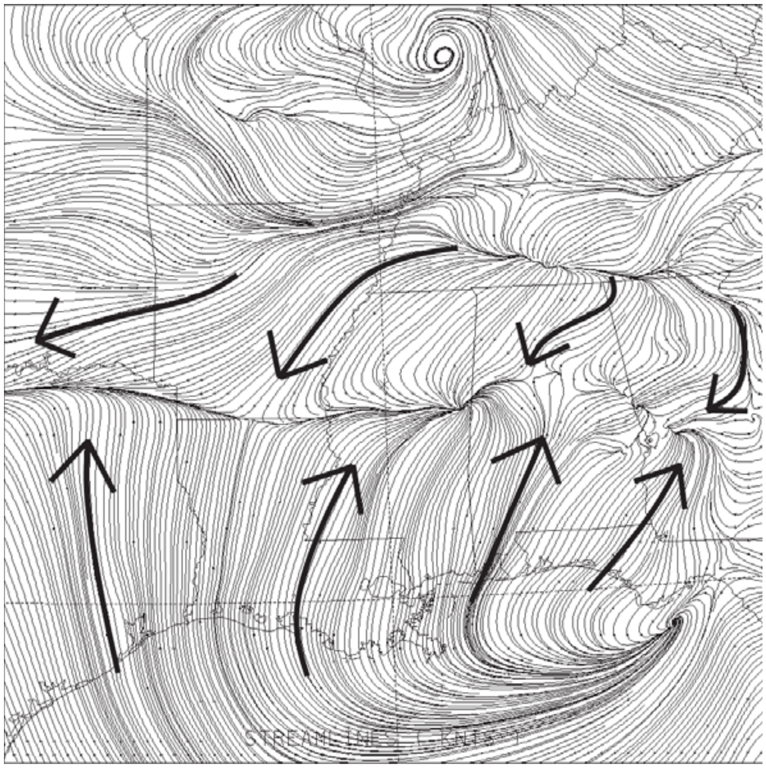
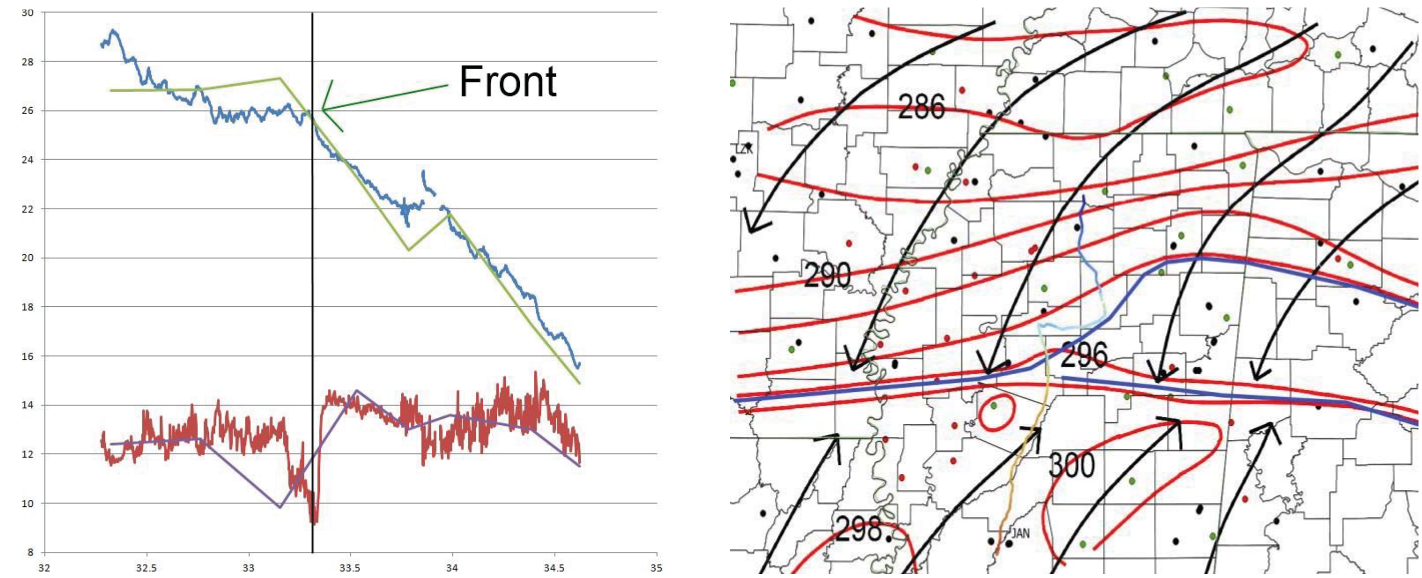


**Figure 9:** Streamlines showing wind flow at surface from NAM at 0000 UTC 18 May 2014.

A few notable features are seen in the mobile data. The variation of temperature and dewpoint relative to latitude is shown in Fig. 10.a, along with a comparison plot using only nearby observing stations. The detail of the mobile data more clearly shows the position of the front near 33.4 N, as well as the presence of a pre-frontal dry slot only about 15 km wide. Although one nearby observing station did indicate the anomalously low dewpoint, this one measurement would likely have been considered suspicious by an analyst in the absence of other corroborating data. Other than this dry slot, there was practically no difference between the prevailing dewpoint on each side of the front. While various researchers have looked at pre-frontal troughs (Schultz 2005), wind shifts (Hutchinson and Bluestein 1998), and drylines, those typically are on a larger scale and tend to be associated with rapidly moving cold fronts instead of a quasi-stationary front. There is not enough information available to determine exactly what this particular feature is or how it formed.

However one interesting clue lies in the regional analysis of potential temperature (Fig. 10.b). While the wind flow shows a single well-defined line of confluence, there seem to be two separate transitions of potential temperature in eastern Mississippi that join into one in the west. This apparent split in the front is a short distance east of the MMU front intercept near Winona, leading to speculation that perhaps somehow the anomalous dry slot is associated with processes related to development of the unusual split pattern in the front. There was no significant deep convection in the region that could have influenced the front at these scales. It may be that these anomalous patterns may relate to a form of discrete frontal propagation by a combination of diabatic and dynamical processes (Charney and Fritsch 1999; Bryan and Fritsch 2000). The visual change of cloud features observed north of the front, within the dry slot, and within the main warm air mass are exemplified in Fig. 11. Within only about 20 km, conditions went from broken low and mid-level stratus to only a few cirrostratus to poorly developed cumulus.




**(a)** **(b)**

**Figure 10: a)** Temperature (blue) and dewpoint (red) vs latitude from mobile system, adjusted to 2336 UTC 17 May 2014. Temperature (green) and dewpoint (purple) from nearby stations. **b)** Manual analysis of wind flow and potential temperature (red) from synthesis of observing stations (dots) and mobile transect. Approximate front positions indicated by blue lines. Potential temperature from mobile platform indicated by color (red= maximum and blue = minimum).

**(a)** **(b)** **(c)**

**Figure 11: a)** Photograph from mobile platform north of front at 2315 UTC, looking to west in Grenada, MS. **b)** Looking to south at 2323 UTC into dry air pocket, from just north of the front. **c)** Looking to east at scattered clouds in warm moist air to south of front and dry air at 2347 UTC.

## SUMMARY

The cases reported here represent two very different frontal scenarios for Mississippi. By incorporating data from a mobile platform crossing approximately orthogonal to the fronts together with various operational data from the surrounding region, similarities and differences in the structure are documented. Experience suggests that much more variety exists among other frontal cases in the region.

Key results from these cases that are in agreement with common conceptual models and previous studies include:

- Very close spatial consistency between the location of thermodynamic change (here understood to be the front) and the location of the confluent wind shift
- A very sudden change of pattern (“first-order discontinuity”) of potential temperature at the front, with continuing decrease for hundreds of km further northward
- Presence of a thermal inversion or layer of increased static stability that connects with the surface frontal zone

Some features which seemed to be relatively unique to the specific cases examined include:

- A relatively loose relationship between frontal position and location of heavy precipitation when examined at small scales (< 50 km) *(Case 1)*
- A narrow pre-frontal dry slot in spite of no significant overall moisture contrast across the front, with possible relation to a frontal split or discrete jump *(Case 2)*

As the JSU MMU system has evolved in the period since 2012, several other types of frontal cases have been observed within Mississippi and other regions. The development of improved data sources and addition of new observing sites have also provided opportunities for continuing analysis to improve understanding and operational applications that address the variety of impacts and uncertainties related to the detailed features of frontal systems within the state.

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## CONFLICT OF INTEREST

There is no conflict of interest to declare.

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# ESTIMATING THE UNDERLYING INFANT MORTALITY RATES FOR SMALL POPULATIONS, EVEN THOSE REPORTING ZERO INFANT DEATHS: A CASE STUDY OF 42 COUNTIES IN MISSISSIPPI

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## ABSTRACT

Infant Mortality is an important population health statistic that is often used to inform health policy decisions. Unfortunately, these data are not typically available for areas with small populations, e.g. rural counties. Borrowing ideas from the Empirical Bayesian approach, a method is presented for estimating the "underlying" infant mortality rates for areas with small populations where the number of infant deaths is either zero or so small that it is subject to a high level of stochastic uncertainty and, thereby, often not reported. The idea is that the underlying rates generated by the estimation method should reflect the intrinsic mortality regimes of these small populations. The method is described and illustrated in a case study by estimating infant mortality rates for the 42 of the 82 counties in Mississippi where reported births were less than 300 in 2015. Among these 42 "small population" counties are eight originally reporting zero infant deaths for 2015, thereby generating infant mortality rates of zero as well. The method described in this paper generates non-zero infant mortality rates for these same eight counties, which are intended to be estimates of the underlying rates for these counties, thereby reflecting their intrinsic mortality regimes. The results of the case study are discussed. Although some judgment is needed with the method, it has sufficient transparency such that estimates can be replicated. While a definitive conclusion is not yet in, the results shown here support the argument that the method can produce reasonable estimates of the underlying infant mortality rates for small populations subject to high levels of stochastic variation and for which infant deaths are often not reported. In this regard, the method described here may assist the state of Mississippi and other jurisdictions in the generation of information about the health status of its small populations and their intrinsic mortality regimes.

**Keywords:** Policy Decisions, Monitoring Health Status, Small Population, Rural Population, Beta Model, Binomial

## INTRODUCTION

The infant mortality rate (IMR) is widely used. It is an indicator not only used as a measure of the risk of infant death but indirectly as an indicator of the availability and quality of health care services, poverty levels, and socio-economic status differentials (Hummer, 2005; Kitagawa and Hauser, 1973; Link and Phelan, 1995; Stockwell, Goza and Balisteri 2005; Stockwell et al., 1987).[1] Because statistical data are often used to guide health policy decisions, it is not surprising that the IMR also is used in this regard (Chen, Oster, and Williams, 2016; Kleinman, 1996; Misra et al., 2004; Stockwell et al. 1987). Moreover, as observed by VanEenwyk and Macdonald (2012), questions concerning health outcomes and related health behaviors and environmental factors often are studied within small subgroups of a population, because many activities to improve health affect relatively small populations. Fortunately, the advent of geographic information systems and high volume, fast computer-based information systems often involving the matching of records from different sources means that this type of information is technically feasible. However, the demand for this information along with the technical feasibility of obtaining it is not always compatible with the need to preserve data confidentiality. This means that even when it is possible to provide data for a small population, it is not always the case that they are, in fact, provided, a situation not often encountered when dealing with large populations (Office for National Statistics, 2015). The Centers for Disease Control, the unit within the US National Center for Health Statistics that reports vital statistics, for example, does not present or publish death or birth counts of nine or fewer or rates based on counts of nine or fewer (in figures, graphs, maps, table, etc.) at the subnational level (US National Center for Health Statistics, no date). In Mississippi, one receives the message "county level detail not allowed" if the online query system of the State Department of Health (MSTAHRS), is used to determine the number of infant deaths by county (http://mstahrs.msdh.ms.gov/forms/imorttable.html). Once this message is "clicked off," infant deaths are presented for the state as a whole.

Data representing small populations are not only subject to limitations posed by confidentiality concerns, they also are subject to high levels of stochastic uncertainty, which typically imply higher levels of measurement bias and lower levels of precision than those typically found in larger populations (Reeske and Razum, 2011; Swanson and Tayman, 2012: 216). Note that in this regard, we use a classic definition of stochastic uncertainty namely that it is the manifestation of a process representing numerical values of some system randomly changing over time (Doob, 1952). As such, even when infant deaths are available for small populations and IMRs can be computed, these rates may not be reflective of the intrinsic (in the demographic sense) mortality regimes affecting the small populations in question.

A typical strategy for dealing with the combination of these issues is to aggregate data for small populations and generate what amounts to an arithmetic average from them. Another strategy is to gain permission to access individual level records, match them, and then construct statistics (Kinge and Kornstad, 2014). This strategy is used, for example, by the California Department of Public Health in developing infant death data (California Health and Human Services Agency, no date). However, this approach can be time consuming and costly to implement and the end result for a given small population at a given point in time may still be subject to a high level of stochastic uncertainty, leading back to the decision to aggregate results across space, time, or both, which is the case with infant death reporting by the California Health and Human Services Agency. [2]

As a means of examining the accuracy and precision issues associated with the stochastic uncertainty affecting data representing small populations, two empirical examples are used, one for an area with a large population and the other for an area with a small population. The large population example is based on the reported 2015 IMR for the state of Washington and the small population example is based on the 2015 IMR for Asotin County, which is one of the smallest in the state of Washington that reported at least one infant death in 2015. The estimated 2015 population for the state as a whole is 7,061,410 (Washington State Office of Financial Management, 2017, Table 3), with 89,000 live resident births (Washington Department of Health, 2016a) and 431 resident infant deaths reported, respectively, for 2015 (Washington Department of Health, 2016b). For Asotin County, the estimated 2015 population is 22,010 (Washington State Office of Financial Management, 2017, Table 3), with 228 live resident births (Washington Department of Health, 2016a) and three resident infant deaths reported, respectively, for 2015 (Washington Department of Health, 2016b). Given these data, the 2015 IMR for the state as a whole is 4.8427 per 1,000 live resident births, while for Asotin County, it is 13.1579 per 1,000 live resident births. Note the striking difference, which leads to the question: Is the IMR for Asotin County really almost three times higher than that for the state as a whole or is it the result of stochastic variation acting on a small population?

To answer this question, we start by with work by Voss et al. (1995) and Swanson and Tayman (2012: 189-190) who viewed the crude death rate of a given area i at a given time t as the marginal probability of death for the area's inhabitants, the distribution of infant deaths in a given area i at a given time t as (approximately) binomial, with parameter d, where

$$d_{i,t} = D_{i,t}/B_{i,t} \qquad [1]$$

where

i = area (i = 1 to n)

t = time

D = infant deaths

B = births

Keep in mind that as this example progresses it will show the effect of the stochastic variation in d (IMR) by using it in conjunction with the reported number of infant deaths in order to (hypothetically) estimate the number of births for the population in question. It is not the actual intent that we are proposing that IMR be used for this purpose; rather, this example is used to illustrate the effect of stochastic variation on small populations. To do this, we start by showing that Equation [1] can be re-written so that the expected number of births at a given time t in area i is:

$$E[B_{i,t}] = D_{i,t} / d_{i,t} \qquad [2]$$

The preceding equation leads to defining the variance of $B_{i,t}$:

$$V[B_{i,t}] = D_{i,t}*(d_{i,t})*(1 - d_{i,t})) \qquad [3]$$

Finally, the coefficient of variation (CV) for $B_{it}$ is defined as

$$CV(B_{i,t}] = [(1- d_{i,t})/(d_{i,t}*B_{i,t})]^{0.5} \qquad [4]$$

As can be seen in Equation [4], the CV is defined as the ratio of the standard deviation to the mean. It is most useful for variables that are always positive, which is the case in the discussion here. In the case of IMR, as the number of births decreases, the size of the CV increases and a large CV indicates that stochastic uncertain is large.

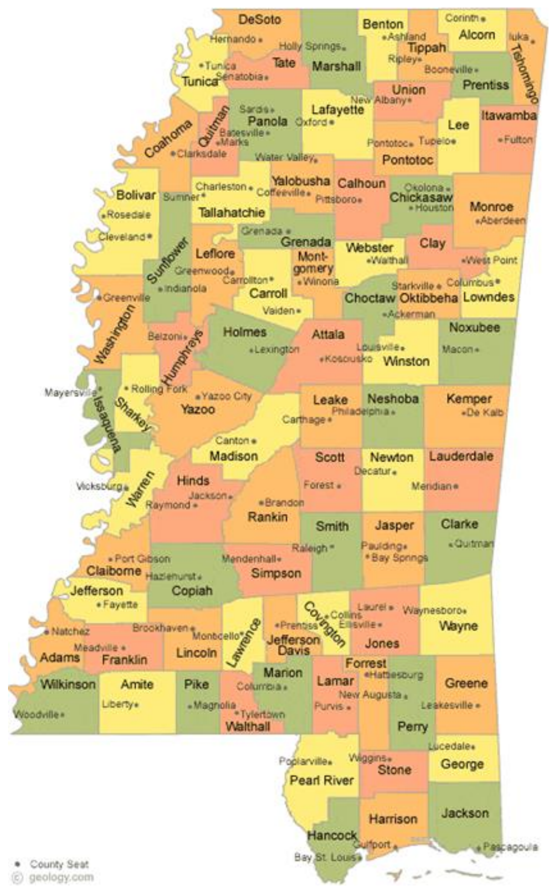
Using equation [3], we find for Washington as a whole that the coefficient of variation for the estimated number of births (using infant deaths and the infant death rate as estimators of the number of births, as shown in the following equation) is $0.04806 = [(1-0.00484)/(431)]^{0.5}$; for Asotin County, the coefficient of variation using its infant deaths and infant death rate as estimators is $0.57354 = [(1-0.01316)/(3)]^{0.5}$. The CV for Asotin County is nearly 12 times the size of the CV for the state as a whole, 11.93 = 0.57354/0.04806. Thus, we expect that over time, the relationship between the number of infant deaths and the number of births for the state of Washington as a whole is far more stable than the case for Asotin County. Put another way, the IMR for Washington State will be much more stable over time than the IMR for Asotin County, providing a much clearer view of the "underlying" IMR for the state and its intrinsic mortality regime than can be expected for Asotin County.

The difference in the CVs for the state of Washington and Asotin County illustrates the stochastic uncertainty inherent in small populations, which implies that reported IMR for a given small population can vary dramatically over time even though there is no substantive change in its respective "underlying" infant mortality rate. Awareness of this situation has led to a range of methods used in developing estimates of the underlying IMRs for small populations. One approach is "non-reporting," which is to simply not report IMRs for small populations, as is the case with the Centers for Disease Control (US National Center for Health Statistics, no date). Unfortunately, this approach discards related information (e.g., reported births) that may be of use in estimating IMRs for small populations – a point to which we return later.

Another general approach is to provide an estimate by embedding small population information within a "larger context," which takes us back to the "aggregation strategy" discussed earlier. This approach is used by, among other agencies, the US National Center for Health Statistics (2018), for which the "larger context" is defined both in terms of time and space. In terms of time, the NCHS data on infant mortality rates by county are aggregated for the period 2007-2015 and in terms of space, counties with small populations are aggregated. One drawback to both approaches is that they are typically yield simple arithmetic averages and neither is specific to the time and county of interest. Related to this issue is the fact that these averages are biased unless appropriate weights or other procedures are used to reduce bias (Voss et al., 1995), steps that may not be feasible in a given situation.

Another "contextual" approach that we refer to as the "representational approach," is taken in this paper. It uses Bayesian ideas, which, unlike the "non-reporting" approach, has the potential to provide estimates of the IMRs underlying small populations, while also avoiding the drawbacks found in the aggregated approach. Another benefit of an approach based on Bayesian ideas is that it is a statistical estimator and, as such, is not in conflict with confidentiality issues. To this end, a publication by Link and Hahn (1996) was used as a guide in generating the approach described, tested, and applied here.[3]

Mississippi is useful as a case study for reasons listed earlier: county level IMRS are not provided at the MSTAHRS site and 42 of its 82 counties reported fewer than 300 births in 2015. These are counties with small populations. Moreover, eight of 42 counties reported zero infant deaths in 2015. Exhibit 1 is a map of Mississippi by county. In addition, the IMRs for many of its counties are among the highest in the United States (Zhang et al., 2007).




Source: Geology.com (no date): https://geology.com/county-map/mississippi.shtml

**Exhibit 1. Map of Mississippi by County**

## METHODS AND DATA

Infant mortality rates measure the proportion of births that result in deaths during the first year of life. As such, they measure the relationship between events (deaths) and trials (births) with the distribution of infant deaths in a given area i at a given time t is (approximately) binomial, with parameter d, where

$$d_{i,t} = D_{i,t}/B_{i,t} \qquad [5]$$

where

$i$ = area ($i$ = 1 to n)

$t$ = time

$D$ = infant deaths

$B$ = births

and is typically described as a beta-binomial random process with a probability mass function defined by two parameters: $\alpha$ and $\beta$. The first parameter, $\alpha$, can be interpreted as the count of the event of interest, which in our case is the number of infant deaths, the number of births in which the infant dies before achieving the first year of life. The second parameter, $\beta$, can be interpreted as the count of "non-events," which in our case is the number of children born who survive to reach one year of age. Note that "rate" = $\alpha/(\alpha + \beta)$, which in our case is equivalent to" infant mortality rate" = infant deaths/(infant deaths + survivors to age 1), which reduces to infant deaths/births. Thus, parameter $\alpha$ is the numerator in the expression defining a rate, and when added together, the parameters $\alpha$ and $\beta$ represent the denominator. Together, the IMR may be re-expressed the IMR as the compound distribution of $\alpha$ and $\beta$ captured in the beta-binomial probability model:

$$\mathbf{IMR = \alpha/(\alpha + \beta) =}$$
$$\textbf{infant deaths/(infant deaths + infant survivors)} \quad [6]$$

Since the IMR may be conceptualized directly using the beta-binomial model, IMRs may be thought of as stochastic processes that occur within each county while also contributing to higher-level meta-populations within which they are nested (Taylor and Karlin, 2001; Graham and Talay, 2013).

A potential number of strategies exist for dealing with small sample size dynamics or confidentiality suppression in making estimates of infant mortality rates. First, one might simply use the national IMR in place of highly-uncertain localized estimates of IMR. This would stabilize estimates for IMR on the local level, but at the expense of potentially masking heterogeneity in IMRs across geographic units. For purposes of capturing spatial patterns in IMR, a main priority in smaller-level analyses, this solution is less acceptable. A second alternative might be to make local adjustments based on judgment. While this may improve estimates overall, especially when judgments are made by applied demographers with significant experience, this approach is subject to the criticism that non-standard methods are applied across different geographies and/or population groupings. With resource allocation decisions often tied to demographic estimates, this solution may not be satisfactory either. An ideal approach would be to utilize a principled method for adjusting local estimates of IMR. Simple model averaging, based on the beta-binomial model represents a viable approach for achieving this goal.

Because it has been established that the IMR constitutes a beta-binomial probability process, think of two estimates of this process as constituting samples of the mean and variance of the underlying process. Therefore, these can be considered as samples obtained from the same underlying mortality process and in averaging them it can be anticipated that a superior estimate of the mean proportion is obtained (Graham and Talay, 2013; Gardiner, 1983; Taylor and Karlin, 2001). As such, the averages of two estimates based on the model may also be averaged as:

$$\mathbf{IMR_{averaged} = (\alpha_1 + \alpha_2)/ ((\alpha_1 + \beta_1) + (\alpha_2 + \beta_2))} \quad [7]$$

where the subscripts (1,2) now represent estimates of death and survivorship counts for two groups. This method can, of course, be extended to k groups as desired. Such model averaging yields an estimate where a larger-scale and representationally-appropriate model IMR is leveraged to make smaller-scale estimates more precise in a manner similar to that observed in the literature on indirect estimation in demography (Brass, 1968; Moultrie et al. 2013, Siegel and Swanson 2004, UN, 1967). Recent attempts to extend indirect estimation based on stochastic process theory have been introduced (Baker et al., 2011) and here this idea is leveraged further in developing indirect estimates of IMR based on model averaging.

***Data***

In regard to Mississippi, we have divided the state's 82 counties into two groups: (1) those with more than 299 births (40 counties), which we use as "large population counties;" and those with less than 300 births (42), which we use as "small population counties." We use the first group as the "representative" set of IMS to which the Beta Model will be fit to their reported IMRs. The division is based on the median number of births, which is 291 for all 82 counties. We adjusted this so that the division occurred at 300 births in order to provide some additional separation between the counties used as the "representative" set and those with the small populations for which we will provide estimated IMRs. Table 1 shows the births, infant deaths, and IMRs for these 40 counties. The infant death dare taken from the 2015 Vital Statistics Report produced by the Mississippi State Department of Health (2016). The birth data are taken from the MSTSAHRS system (Mississippi State Department of Health, 2018).

## RESULTS

The Beta Binomial model procedure found within the "survival/reliability" module of the NCSS statistical analysis package (release 8) was used to obtain the two Beta Model parameters using the infant mortality rates for the 40 counties used as our representative set (see Table 1). The major results of interest found in running this procedure with the data are found as Exhibit 2. Note that there two different estimates of the $\alpha$ and $\beta$ parameters presented in the exhibit, one accomplished by the method of moments and the other by Maximum Likelihood Estimation. The parameters of the latter are used here, namely: $\alpha = 3.649532$, and $\beta = 385.4501$.

Table 2 shows both the reported and estimated IMRs shown in Table 1 for the 42 counties. The estimated IMRs are those found by applying the two Beta parameters in conjunction with reported 2015 infant deaths (including the eight counties reporting zero infant deaths) and reported births by county using the formulas described earlier in the examples for Washington State and Asotin County.

**Table 1. Reported 2015 births, infant deaths, and Infant Mortality Rates for the 40 Counties in Mississippi reporting 300 or more births.**

| Geography | 2015 INFANT DEATHS | 2015 BIRTHS | 2015 IMR |
|---|---|---|---|
| Hinds County, Mississippi | 29 | 3,341 | 8.68004 |
| Harrison County, Mississippi | 23 | 2,740 | 8.39416 |
| DeSoto County, Mississippi | 13 | 2,143 | 6.06626 |
| Rankin County, Mississippi | 8 | 1,849 | 4.32666 |
| Jackson County, Mississippi | 14 | 1,639 | 8.54179 |
| Madison County, Mississippi | 8 | 1,331 | 6.01052 |
| Lee County, Mississippi | 17 | 1,132 | 15.01767 |
| Forrest County, Mississippi | 12 | 1,108 | 10.83032 |
| Lauderdale County, Mississippi | 6 | 1,011 | 5.93472 |
| Jones County, Mississippi | 8 | 995 | 8.04020 |
| Lowndes County, Mississippi | 7 | 827 | 8.46433 |
| Lamar County, Mississippi | 10 | 822 | 12.16545 |
| Washington County, Mississippi | 11 | 702 | 15.66952 |
| Warren County, Mississippi | 4 | 651 | 6.14439 |
| Pearl River County, Mississippi | 2 | 630 | 3.17460 |
| Lafayette County, Mississippi | 9 | 597 | 15.07538 |
| Oktibbeha County, Mississippi | 4 | 549 | 7.28597 |
| Pike County, Mississippi | 8 | 526 | 15.20913 |
| Leflore County, Mississippi | 3 | 494 | 6.07287 |
| Hancock County, Mississippi | 1 | 491 | 2.03666 |
| Panola County, Mississippi | 6 | 480 | 12.50000 |
| Scott County, Mississippi | 4 | 476 | 8.40336 |
| Bolivar County, Mississippi | 2 | 471 | 4.24628 |
| Alcorn County, Mississippi | 4 | 470 | 8.51064 |
| Neshoba County, Mississippi | 7 | 450 | 15.55556 |
| Coahoma County, Mississippi | 3 | 445 | 6.74157 |
| Marshall County, Mississippi | 8 | 413 | 19.37046 |
| Pontotoc County, Mississippi | 2 | 410 | 4.87805 |
| Lincoln County, Mississippi | 8 | 409 | 19.55990 |
| Monroe County, Mississippi | 5 | 403 | 12.40695 |
| Adams County, Mississippi | 1 | 386 | 2.59067 |
| Union County, Mississippi | 2 | 385 | 5.19481 |
| George County, Mississippi | 2 | 374 | 5.34759 |
| Copiah County, Mississippi | 2 | 362 | 5.52486 |
| Tate County, Mississippi | 3 | 343 | 8.74636 |
| Simpson County, Mississippi | 6 | 308 | 19.48052 |
| Sunflower County, Mississippi | 6 | 303 | 19.80198 |
| Wayne County, Mississippi | 2 | 303 | 6.60066 |
| Marion County, Mississippi | 3 | 302 | 9.93377 |
| Prentiss County, Mississippi | 2 | 301 | 6.64452 |

Source: Infant deaths and births are from the Mississippi Department of Public Health (See text and references); the IMRs are calculated by the authors.

**Exhibit 2. NCSS Report of Fit of Beta Model to IMRs for the 40 county "representational set"**

**Beta Distribution Report**

Dataset ...\MS COUNTIES GT 299 BIRTHS.NCSS
Time Variable IMR

Parameter Estimation Section

| Parameter | Method of Moments Estimate | Maximum Likelihood Estimate | MLE Standard Error | MLE 95% Lower Conf. Limit | 95% Upper Conf. Limit |
|---|---|---|---|---|---|
| Minimum (A) | 0 | 0 | | | |
| Maximum (B) | 1 | 1 | | | |
| α | 3.502897 | 3.649532 | 0.7816342 | 2.117558 | 5.181507 |
| β | 369.9701 | 385.4501 | 88.44282 | 212.1054 | 558.7949 |
| Log Likelihood | | -159.952 | | | |
| Mean | 0.00937925 | 0.009379428 | | | |
| Median | 0.00851855 | 0.008552653 | | | |
| Mode | 0.006737762 | 0.006844574 | | | |
| Sigma | 0.004981126 | 0.004880385 | | | |

**Inverse of Fisher Information Matrix**

| Parameter | P | Q |
|---|---|---|
| P | 0.610952 | 64.44287 |
| Q | 64.44287 | 7822.129 |

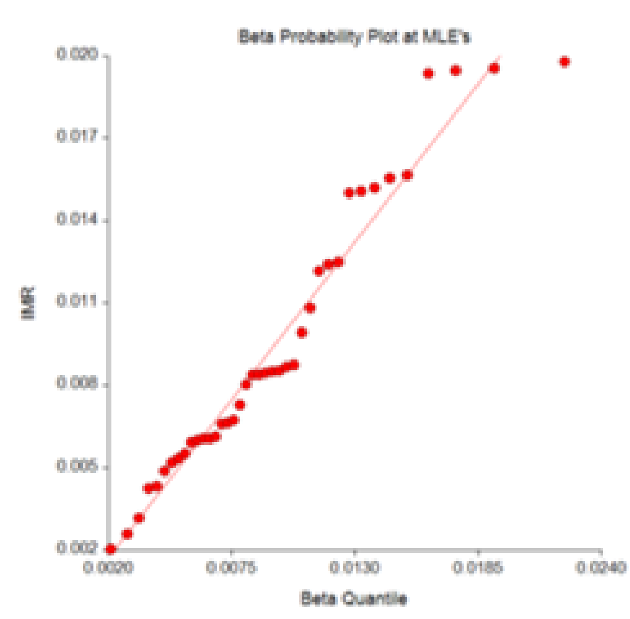


**Table 2. Original (reported) IMRs and Estimated Underlying IMRs for the 42 counties reporting less than 300 births in 2015.**

| COUNTY | ORIGINAL IMR (PER 1000 LIVE BIRTHS) | REVISED IMR (PER 1000 LIVE BIRTHS) |
|---|---|---|
| Amite County | 8.929 | 9.279 |
| Attala County | 16.327 | 12.064 |
| Benton County | 11.494 | 9.766 |
| Calhoun County | 21.505 | 13.301 |
| Carroll County | 0.000 | 7.602 |
| Chickasaw County | 16.064 | 11.988 |
| Choctaw County | 11.494 | 9.766 |
| Claiborne County | 18.692 | 11.388 |
| Clarke County | 10.417 | 9.722 |
| Clay County | 24.896 | 15.314 |
| Covington County | 7.752 | 8.731 |
| Franklin County | 13.158 | 9.997 |
| Greene County | 17.699 | 11.252 |
| Grenada County | 0.000 | 5.605 |
| Holmes County | 8.511 | 9.052 |
| Humphreys County | 20.000 | 11.551 |
| Issaquena County | 0.000 | 9.190 |
| Itawamba County | 0.000 | 5.631 |
| Jasper County | 13.274 | 10.810 |
| Jefferson County | 8.696 | 9.223 |
| Jefferson Davis County | 7.194 | 8.804 |
| Kemper County | 13.514 | 10.040 |
| Lawrence County | 12.422 | 10.270 |
| Leake County | 6.849 | 8.295 |
| Montgomery County | 22.388 | 12.712 |
| Newton County | 17.668 | 12.869 |
| Noxubee County | 6.410 | 8.530 |
| Perry County | 0.000 | 7.058 |
| Quitman County | 37.383 | 15.419 |
| Sharkey County | 0.000 | 8.144 |
| Smith County | 5.682 | 8.228 |
| Stone County | 4.630 | 7.684 |
| Tallahatchie County | 12.821 | 10.364 |
| Tippah County | 7.117 | 8.431 |
| Tishomingo County | 4.926 | 7.853 |
| Tunica County | 15.789 | 11.483 |
| Walthall County | 12.121 | 10.196 |
| Webster County | 27.273 | 13.323 |
| Wilkinson County | 0.000 | 7.508 |
| Winston County | 10.204 | 9.656 |
| Yalobusha County | 0.000 | 6.586 |
| Yazoo County | 17.301 | 12.756 |

Sources: (1) Original IMRS are calculated directly from birth & infant death data available from the Mississippi Department of Health; and (2) Revised IMRs are calculated using the same data but adjusted using the Beta Model parameters and steps described in the text.

## DISCUSSION OF RESULTS

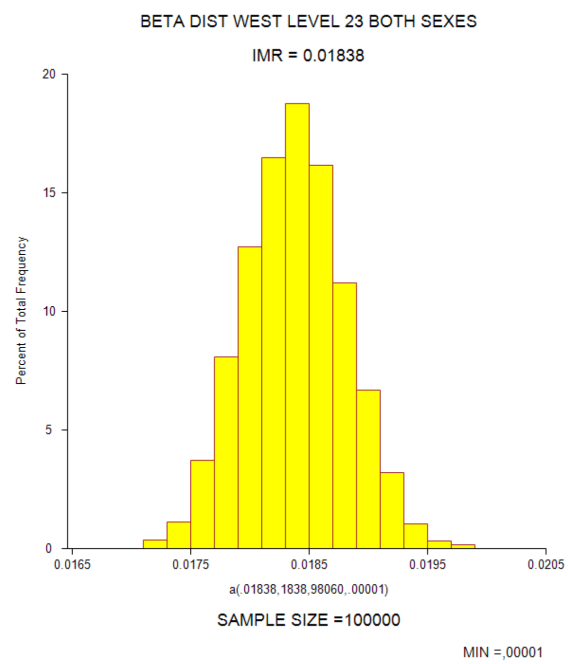
The estimated IMRs for the 42 counties reporting less than 300 births range from 5.605 (Grenada) to a high of 15.415 (Quitman). This range is less than that found for original (reported) IMRs for these same the 42 counties, which is from a low IMR of 0.00 (Carroll, Grenada, Issaquena, Itawamba, Perry, Sharkey, Wilkinson, and Yalobusha counties) to a high of 37.387 (Quitman County). The reduced range for the estimated IMRs suggests that the process used to create them may, in fact, represent the IMRs underlying these counties in that the estimates do not display as high level of variation as found in the original (reported) IMRs. This change in the range suggests a move to a lower level of stochastic uncertainty, which would be more reflective of the intrinsic mortality regimes affecting these counties. This is what the method is intended to do.[4]

### A Validity Test

Given that the method is producing a revised IMR that is likely to be close to the underlying IMR for a small population and therefore reflective of its intrinsic mortality regime, one would expect the method to do this where one could observe the intrinsic mortality regime. Model stable populations afford this opportunity because they have known intrinsic mortality regimes, the model life tables associated with a given set of model stable populations. To examine how the method works in this environment, we employed the IMR associated with a model stable population found in *Manual IV, Methods of Estimating Basic Demographic Measures from Incomplete Data* (1967). For this purpose, we selected the infant mortality rate associated with West Level 23 for both sexes, which shows that of 100,000 births, 98,166 are expected to reach the first birthday. This yields an IMR of 0.0184 = 1 -.98166.

Using the IMR of 0.0184 and a seed population of 100,000, a random sample of 5,000 IMRs was generated using the Beta Model simulation provided by the NCSS statistical system (release 8). The sample is sufficiently large to allow the simulation program the opportunity to generate outliers, which it did. As can be seen in Exhibit 3, the mean is 0.01838 with a standard deviation of 0.000423 and a coefficient of variation equal to 0.02305. The minimum IMR is .016849 and the maximum is .020147.

**Exhibit 3. Descriptive Statistics for the 5,000 Simulated IMR observations**
**Data Simulation Report**
**Histogram Section of Simulated Data**




### Descriptive Statistics of Simulated Data

**Descriptive Statistics of Simulated Data**

| Statistic | Value | Statistic | Value |
|---|---|---|---|
| Mean | 0.01838248 | Minimum | 0.01684878 |
| Standard Deviation | 0.0004237251 | 1st Percentile | 0.01744547 |
| Skewness | 0.07195781 | 5th Percentile | 0.01769227 |
| Kurtosis | 2.934381 | 10th Percentile | 0.0178332 |
| Coefficient of Variation | 0.02305049 | 25th Percentile | 0.01808544 |
| Count | 5000 | Median | 0.01838394 |
| | | 75th Percentile | 0.01866444 |
| | | 90th Percentile | 0.0189272 |
| | | 95th Percentile | 0.01908542 |
| | | 99th Percentile | 0.01937772 |
| | | Maximum | 0.02014658 |

From the 5,000 randomly generated observations, we extracted two sets of data. For the first set, we extracted the initial 40 IMR randomly generated observations from the simulation. For the second, we rank-ordered the 5,000 observations: from high to low and then from low to high, and extracted the 21 highest IMR and 21 lowest IMRs, respectively from them. The idea is that the entire set represents a synthetic population with 82 observations (same number of Mississippi counties) while the second set of 40 simulated IMRs represents the subset of the synthetic population in which IMRs represent “large populations”, and the third set of 42 simulated IMRs represents a subset of “small populations” subject to a high level of stochastic uncertainty. These characteristics mimic the 2015 IMRs reported for the 82 counties of state of Mississippi, where the 40 counties have 300 or more births (large population counties) and 42 counties have less than 300 births (small population counties).[5] The 40 observations are expected to be closer, on average, to the “underlying” IMR of 0.01838 and have less variation, respectively, than that found in the 42 observations. For the set of 40 observations, the mean IMR is 0.01834 and the coefficient of variation is .02152. For the set of 42 observations, the mean IMR is .01844 and the coefficient of variation is .06877. Thus, the set of 40 observations has a mean and a coefficient of variation closer to the mean and coefficient of variation found in the full set of 5,000 observations than does the set of 42 observations.

A Beta model was fit to the set of 40 observations and its parameters were used to revise the IMRs in the set of 42 observations. The expectation is that the revised IMRs will yield a mean IMR closer to that found for the full 5,000 set of simulated observations and that the variation among these revised means will decline, yielding a smaller coefficient of observation.

The results show that the Beta model moved the initial IMR estimates for the 42 observations closer to the underlying IMR. As such, they are more reflective of the West Level 23 mortality regime that is intrinsic to them: the mean of the original IMRs for the 42 observations is 0.01844 while the mean for the revised IMRs is 0.01833, which is closer to the underlying IMR of 0.01838. In terms of variation, the coefficient of variation for the initial set of 14 IMRs is .06877, while that for the revised set is 0.00069. These results support the argument that the method described in this paper is capable of moving IMRs subject to stochastic uncertainty closer to the underlying IMRs and their respective intrinsic mortality regimes.[5]

## CONCLUDING REMARKS

Because of the “representational context” selection, the estimates are subject to judgment. However, even still the entire process is transparent, which means that the results are not subject to arbitrary and capricious judgments that render them difficult to replication. Keep in mind that with a different “representational context,” one will have a different model and different IMR estimates. However, as the validity test indicates, a different model, can be expected to move, on average, the IMRs for the California counties closer to their underlying IMRs, better reflecting their “underlying IMRs.” This argument can be generalized to other potential data sets that could be used to build different beta-binomial models. This feature of the beta-binomial approach suggests that while a model built from a given “representational” data set may move the estimated IMRs closer, on average, to their underlying values, than a model built from a different “representational” data set, even a less-than-optimal model should provide reasonable estimates. This and the evidential support provided by the validity test that, in fact, our method is capable of producing estimates of underlying IMRs, suggests that the method is not only capable of generating reasonable IMR estimates in the absence of reported infant deaths, but that these estimate are valid in terms of the intrinsic mortality regimes affecting small populations. Because these estimates can be efficiently generated by the process described here also suggests that they have the potential to support policy decisions. This and the fact that estimates are valid and can be efficiently generated by the process described here suggests that they have the potential to support policy decisions in Mississippi concerning infant mortality (see., g., Zhang et al., 2007), while keeping time and resource requirements low, characteristics that Swanson and Tayman (2012: 304) suggest are important components in deciding what methods to use in developing estimates.

While the beta-binomial model has been used in medical research (Kim and Lee, 2013; Arostegui, Nuṅez-Antón, and Quintana, 2007, and Young-Xu and Chan, 2006), consumer studies (Chatfield and Goodhardt, 1970), bioinfomatics (Pham et al., 2010) and public health research (Alanko and Lemmons, 1996; Gakidou and King. (2002), it has not found much traction in demographic research. This is surprising on two counts: (1) the components of demographic change, births, deaths, and migration, can all be constructed as rates that are inherently binomial variables; and (2) the method is simple to use, explain, and understand. [6] This paper illustrates one such use with a sub-set of the mortality component, the infant mortality rate. Although the paper focuses on a specific application, namely infant mortality rates for counties with small populations in California, the method can be applied to many other situations where small numbers are present and affected by stochastic uncertainty. As such, it could be used in conjunction not only with other mortality measures such as neo-natality rates, crude death rates, age-specific death rates and cause- specific death rates, but with fertility measures such as crude birth rates and age-specific birth rates. Even more broadly, it could be used with any binomial variable of interest affecting small populations, such as a housing occupancy (or vacancy) rate, employment (or unemployment) rate, cigarette smoking (or non-smoking) rate.

## ENDNOTES

1. Murray (1996) has argued that the infant mortality rate is flawed when it is used as an index of overall mortality (i.e., the mortality regime affecting a given population) and that Disability Adjusted life Expectancy (DALE) should be used in its place. However, it has been pointed out by Reidpath and Allotey (2003) that the infant mortality rate and the DALE are so highly correlated that it merely goes to reinforce the intuition that the causes of infant mortality are strongly related to those structural factors like economic development, general living conditions, social well-being, and environmental factors, and, and such, the infant mortality rate remains a useful and comparatively inexpensive indicator of population health.
2. The following statement is made by the California Department of Health and Huma Services in regard to the infant death made available on its online query system;

   This is a source dataset for a Let's Get Healthy California indicator at https://letsgethealthy.ca.gov/. Infant Mortality is defined as the number of deaths in infants under one year of age per 1,000 live births. Infant mortality is often used as an indicator to measure the health and well-being of a community, because factors affecting the health of entire populations can also impact the mortality rate of infants. Although California's infant mortality rate is better than the national average, there are significant disparities, with African American babies dying at more than twice the rate of other groups. Data are from the Birth Cohort Files. The infant mortality indicator computed from the birth cohort file comprises birth certificate information on all births that occur in a calendar year (denominator) plus death certificate information linked to the birth certificate for those infants who were born in that year but subsequently died within 12 months of birth (numerator). Studies of infant mortality that are based on information from death certificates alone have been found to underestimate infant death rates for infants of all race/ethnic groups and especially for certain race/ethnic groups, due to problems such as confusion about event registration requirements, incomplete data, and transfers of newborns from one facility to another for medical care. Note there is a separate data table "Infant Mortality by Race/Ethnicity" which is based on death records only, which is more timely but less accurate than the Birth Cohort File. Single year shown to provide state-level data and county totals for the most recent year. Numerator: Infants deaths (under age 1 year). Denominator: Live births occurring to California state residents. Multiple years aggregated to allow for stratification at the county level. For this indicator, race/ethnicity is based on the birth certificate information, which records the race/ethnicity of the mother. The mother can "decline to state"; this is considered to be a valid response. These responses are not displayed on the indicator visualization.
3. In addition to ideas taken from the approach described by Link and Hahn (1996), we used ideas from the "stochastic" tradition found in demographic analysis in developing the method we describe in this paper. For an example of this tradition, see Baker, Alcantara and Ruan (2011).
4. Keep in mind that small populations, however defined, with approximately the same total populations may have different age compositions. For example, one may have a relatively large aged population and another a relatively large young population. This simple example is meant to

illustrate the effect of demographic heterogeneity, which can affect measures of mortality (Vaupel and Missov, 2014). In situations where substantial heterogeneity may be present, a model with additional covariates may prove useful because the latter can potentially take into account the effects of demographic heterogeneity.

5. In the validity test, different populations are simulated from a common beta distribution, and the result is that the two sets of populations, large and small, are normally distributed around the intrinsic mean IMR of the "population." The simulation shows that the adjusted IMRs of the small populations move closer the underlying IMR, which indicates that the method works when both the small and large populations represent samples taken from the same underlying population. If the small populations represent a sample from a different population than the sample of large population, then the adjustment may yield a "biased" estimate of the former's underlying IMR. This shows the importance of having a reference set that conceptually represents a sample from the same underlying population as the small population sample. One way to visualize the unbiased and biased outcomes is to picture the case where the method yields: (1) an "unbiased" estimate, which is when the mean IMR of the large populations is between the underlying IMR and the mean IMR of the small populations; and (2) a "biased" estimate when the method does not move the mean IMR for the small population closer to its underlying IMR, which occurs where the mean IMR of the small population is between the underlying IMR and the mean IMR of the large populations.
6. Although Green and Armstrong (2015) discuss simple vs. complex methods in terms of forecasting, their discussion applies here in that the beta-binomial approach falls into the simple methodological category rather than the complex category. Adapting their discussion to methods in general, the work of Green and Armstrong (2015) suggests that while there is no evidence that shows complexity improves accuracy, complexity remains popular among: (1) researchers, because they are rewarded for publishing in highly ranked journals, which favor complexity; (2) methodologists, because complex methods can be used to provide information that support decision makers' plans; and (3) clients, who may be reassured by incomprehensibility. We believe that the argument by Green and Armstrong (2015) can be applied to Bayesian methods, which represents the "complex" alternative to the "simple" Beta-binomial approach. We prefer the Beta-binomial approach, however, not only because of the argument presented by Green and Armstrong, but also because the application of a Bayesian approach can be difficult, effortful, opaque and even counter-intuitive (Goodwin 2015).

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# SURVEY OF ADULT BLACK FLIES (DIPTERA: SIMULIIDAE) FROM TEN SITES IN MISSISSIPPI

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## ABSTRACT

Although there are at least 27 reported species of black flies in Mississippi, little is known about which of these are the primary pest species occurring in the state. The resurgence of black flies in Mississippi over the past decade prompted renewed interest in these blood-sucking pests. The purpose of this study was to survey black flies occurring in Mississippi and analyze their seasonality, distribution, and possible relationship of activity versus various meteorological conditions. Black fly adults were collected by hand netting at ten sites around the state for two years. Upon each visit, data was recorded including date, time, temperature, humidity, sky conditions, and wind speed. A total of 350 adult black flies were collected, returned to the lab, and identified. The two main species collected were *Simulium jenningsi* group (248 specimens) and *Simulium meridionale* (98 specimens). Three other species were rarely collected (4 specimens): *S. parmatum* and *S. tribulatum* and *S. johannseni*. *Simulium jenningsi* was found predominantly from February through July each year, mostly in central, south, and eastern Mississippi, while *S. meridionale* was found from March through July, mostly in the northern Delta region. Analysis of meteorological data indicated that temperature, relative humidity, and sky condition were the main factors affecting black fly flight activity. This study suggests that there are two main pest species of black flies encountered in Mississippi.

**Keywords:** Black flies; Flight activity; Mississippi; Seasonality; Distribution; Meteorologic factors

## INTRODUCTION

One of the first well-documented descriptions of a black fly outbreak in the southern United States occurred in 1859 in Greenville, MS and Clarendon, Arkansas (Webster 1887, 1904) most likely due to the pestiferous black fly species, *Simulium meridionale*. Subsequent sporadic outbreaks occurred in Arkansas, Indiana, Louisiana, Mississippi, and Tennessee from 1874 – 1884, and especially during the spring of 1882, when wild deer were pushed out of swamps by black flies and almost exterminated in Louisiana between the Ouachita and the Mississippi Rivers (Webster 1904). Physicians reportedly verified several human deaths in Louisiana and Arkansas (Webster 1904, Atwood and Meisch 2004). A total of 3,200 head of cattle was lost in a single week in Franklin Parish, Louisiana (Webster 1904).

Beginning in the late 1920s and early 1930s, many reports and complaints were received from Mississippi county extension agents, local veterinarians, physicians, and local farmers about “gnat” attacks. These pests were reported as *Cnephia pecuarum* and *Simulium meridionale*, which prompted Dr. George Bradley’s extensive research on black flies in the South, focusing primarily in the Mississippi Delta (Nations et al. 2016). Black fly problems apparently disappeared from Mississippi until 2008 – 2009, when the Mississippi State Department of Health (MSDH) and the Mississippi State University Extension Service again began receiving complaints from the public about increased human biting incidents and backyard poultry deaths resulting from black flies. Since so little is known about current black fly activity in Mississippi and a lack of statewide expertise on these pests, this study was initiated. In particular, to determine which black fly species are the primary pests in Mississippi, clarify their seasonality and geographic distribution, and attempt to identify meteorological factors affecting their activity.

## MATERIALS AND METHODS

Adult black flies were collected from January 1, 2015 through December 31, 2016 by hand netting for 10 minutes in the exact same way each time, from ten locations around Mississippi, each located by a river or creek. Selection of sites was based on historical reports of black fly problems and a survey of Mississippi State University County Extension Agents (Table 1). Collections (n=180) were made twice per month in the peak of black fly activity, February – July, and only once per month other times of the year, August – January. Field notes of various meteorological parameters were made upon each site visit; however, more precise data were subsequently obtained online from the nearest National Weather Service station for each site. For definition of sky condition, categories previously defined by Weather Underground were used (The Weather Company, wunderground.com).

Any black fly specimens collected were placed in 70% ethanol and returned to the lab for identification using published keys (Stone and Snoddy 1969, Adler et al. 2004); subsamples of each species were sent to Dr. Peter Adler (Clemson University) for confirmation. Voucher specimens of each species are deposited in the Mississippi State University Entomological Museum.

**Statistical Analysis.** Meteorological data were analyzed using the package olsrr (Hebbali 2018) in the R program (R 2019). A stepwise selection method was chosen (both forward and backward), allowing reassessment using partial F tests which emphasized that changing the sites (locations) also changes the importance of meteorological factors affecting black fly activity. The decision threshold to include a given independent variable in each regression was based on $P < 0.05$.

**Table 1. Collection sites for the two-year survey.**

| Collecting Site | County | Nearby body of water |
|---|---|---|
| 1) Near Lula, MS | Tunica | Mississippi River |
| 2) Near Sledge, MS | Quitman | Coldwater River |
| 3) Near Webb, MS | Tallahatchie | Tallahatchie River |
| 4) Near Money, MS | Leflore | Tallahatchie River |
| 5) Greenville, MS | Washington | Mississippi River |
| 6) Vicksburg, MS | Warren | Mississippi River |
| 7) Jackson, MS | Hinds | Pearl River |
| 8) Near Mendenhall, MS | Simpson | Strong River |
| 9) Near Seminary, MS | Covington | Okatoma Creek |
| 10) Near Shubuta, MS | Clarke | Buckatunna Creek |

## RESULTS AND DISCUSSION

A total of 350 black flies were collected during the two-year survey comprised of five species (Table 2). The most commonly collected species was *Simulium jenningsi* group (248/350, 71%), followed closely by S. *meridionale* (98/350, 28.0%). Three other species were only rarely collected – *S. parmatum* (2/350, 0.57%), *S. johannseni* (1/350, 0.29%), and *S. tribulatum* (1/350, 0.29%). *Simulium jenningsi* is a group or complex comprised of at least 22 species (Adler et al. 2004). There are perhaps as many as 10 species of the *S. jenningsi* group that cannot be distinguished morphologically which occur (or can be inferred to occur) in Mississippi. Not all of them are human biters, so this complicates defining their "pest" status. *Simulium meridionale* was mostly collected from sites in northwest and central Mississippi from March through July (peak activity April). *Simulium jenningsi* group was collected primarily from sites in central and eastern, and one location in northwest Mississippi, essentially year-round (peak activity May) (Figures 1 and 2). *Simulium parmatum* was only collected in southeast Mississippi during February and March; *S. tribulatum* was only collected in Warren County during 2015; and *S. johannseni* was only collected in Covington County during 2016. Of note is the fact that we collected no specimens of *Cnephia pecuarum*, one of the most famous black fly pests historically found in Mississippi (Nations et al. 2016, Nations et al. 2018). In a larger, more comprehensive survey of black flies in Mississippi, which included museum specimens, we found no *C. pecuarum* reported in the state after the 1930's (Nations et al. 2018).

**Table 2.** Five species collected during the two-year survey in Mississippi

| # Collected | Species |
|---|---|
| 248 specimens | *Simulium jenningsi* group |
| 98 specimens | *Simulium meridionale* |
| 2 specimens | *Simulium parmatum* |
| 1 specimen | *Simulium johannseni* |
| 1 specimen | *Simulium tribulatum* |

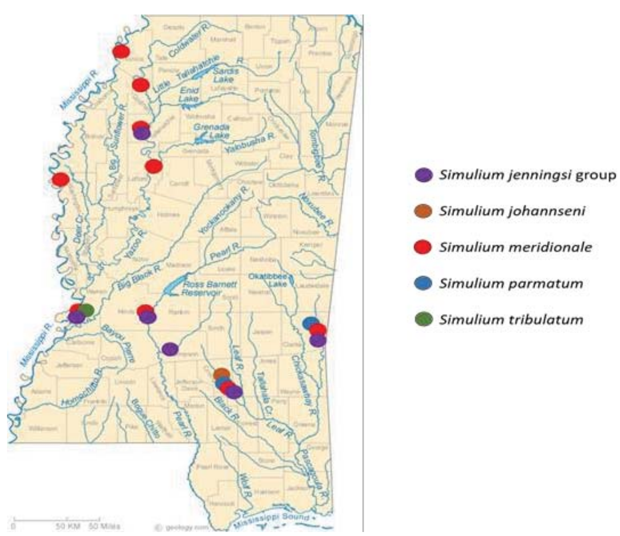


**Figure 1.** Distribution of species collected at 10 sites in Mississippi.

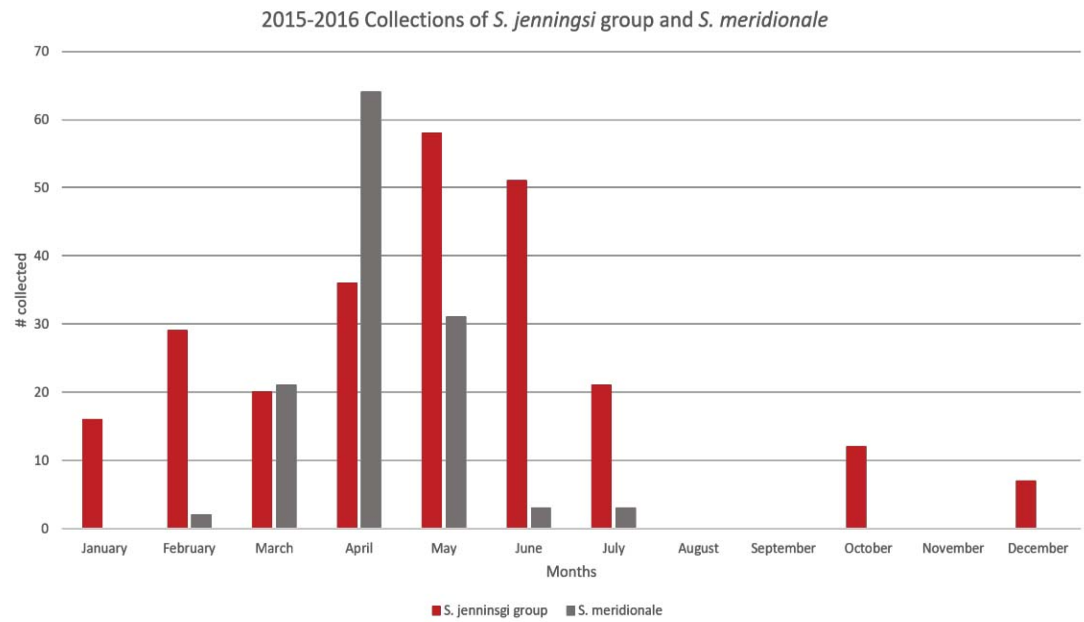


**Figure 2.** *Simulium jenningsi* group and *Simulium meridionale* seasonality for 2015 – 2016.

**Analysis of Meteorological Parameters.** A total of 363 trips were made to the ten collection sites, but only 361 could be analyzed (collection site #6 could not be sampled in 2015 and collection site #7 has missing weather data for March 2016). As for meteorological factors affecting black fly activity, previous research has shown that temperature has an effect of black fly emergence and activity (Bradley 1932, Colbo and Porter 1981, Lake and Burger 1983, McCreadie and Colbo 1991, Adler et al. 2017). Therefore, meteorological factors (humidity, sky conditions, temperature, and wind speed) were analyzed to determine which of these, if any, affected black fly activity. In the stepwise multiple regression analysis (Table 3), variables were selected using predictive models, which were able to estimate *S. jenningsi* activity, at least at some locations. Based on *F* values, the predictive model at location 9 was non-significant for *S. jenningsi*, and at locations 1, 3, 5 and 6 for *S. meridionale*. Temperature and relative humidity were the most important factors affecting *S. jenningsi* activity at locations 8 and 10, respectively (both sites located in south-central Mississippi). Selected models for these locations are: 0.4500 + 0.0090 *x* Temperature [Location 8] and 0.9740 - 0.010 *x* Relative Humidity [Location 10] (Table 3). As for *S. meridionale* activity, sky condition was the most important meteorological factor at location 2 (a site in the Mississippi Delta), while relative humidity was most important at locations 4 and 7 (north and central Mississippi, respectively). Models for *S. meridionale* in these mentioned locations are: 0.019 + 0.015 x Sky condition [Location 2]; -0.104 + 0.003 x Relative Humidity [Location 4] and -0.094 +0.003 x Relative Humidity [Location 7].

**Table 3.** Estimated coefficients of the stepwise linear regression analysis of black fly activity (*Simulium jenningsi* and *S. meridionale*) in relation to meteorological factors at different locations in Mississippi.

| Species | Location | Variable | *C(p)* | *AIC* | *F* value | *P* > *F* |
|---|---|---|---|---|---|---|
| *S. jenningsi* | 8 | Temperature | 0.2250 | 25.1209 | 5.592 | 0.0239 |
| | 9 | Sky Condition | 0.5330 | 31.9427 | 1.183 | 0.2844 |
| | 10 | Relative Humidity | 1.5090 | 35.8669 | 7.257 | 0.0109 |
| *S. meridionale* | 1 | Relative Humidity | 4.4050 | -61.7764 | 3.949 | 0.0290 |
| | | Sky Condition | 1.1890 | -65.3438 | | |
| | 2 | Sky Condition | -0.5520 | -25.1398 | 2.468 | 0.1255 |
| | 3 | Relative Humidity | 0.1850 | -20.5395 | 0.875 | 0.3560 |
| | 4 | Relative Humidity | 1.4230 | -34.4859 | 5.390 | 0.0259 |
| | 5 | Temperature | -0.9630 | -24.5856 | 1.856 | 0.1821 |
| | 6 | Temperature | -0.7200 | -44.8361 | 0.725 | 0.4006 |
| | 7 | Relative Humidity | 1.4230 | -34.4859 | 5.393 | 0.0260 |

These findings are not unexpected – most insects are susceptible to desiccation, so humidity is important and, of course, black flies are unable to fly during cold temperatures. The role of sky conditions is not as clear but has been previously reported as a factor in black fly activity (Wolfe and Peterson 1960, Alverson and Noblet 1976, Martinez-de la Puente et al. 2009). This study indicates that there are two commonly encountered species of black flies in Mississippi; they are active primarily during spring and early summer; and temperature, humidity, and (possibly) sky condition are the main factors affecting their activity. Further research using molecular identification techniques is much needed to distinguish the species make-up of *S. jenningsi* group black flies occurring in Mississippi.

**CONFLICT OF INTEREST:** There is no conflict of interest to declare.

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# SPATIAL STUDY ON THE POLLUTION STATUS OF THE LOWER MISSISSIPPI RIVER

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## ABSTRACT

The Mississippi River is the second longest river in North America flowing from its source at Lake Itasca, Minnesota, through the center of the continental United States to its mouth, the Gulf of Mexico. It is one of the world's major rivers. The objectives of this investigation were to conduct spatial pollution studies on the Lower Mississippi River covering two locations, Port Gibson, and Natchez, MS, to compare the distribution of pollutants in the two areas, to assess the seasonal distribution of pollutants and also to find out if the two river areas met the Mississippi water quality criteria(MSWQC). During the months of early September (summer) and late October (fall) 2015, water samples were collected from the Mississippi River in the areas of Port Gibson, and Natchez. They were taken to Alcorn State University (ASU) Laboratory for examination. The physical, chemical, and biological aspects were examined. For both locations the physical aspects were colorless, with odor(smelly), and partially transparent. The chemical parameters were tested according to the methods indicated in the LaMotte pollution detection kits. A total of twelve chemical parameters were tested and analyzed. They met the MSWQC in both locations with the exception of alkalinity, hardness, carbon dioxide and phosphate. The biological aspects were tested as indicated by Carolina Bacterial Pollution of Water kits. The agar bacterial tests showed that coliform bacteria were present in both locations. These were confirmed by Lauryl Tryptose Broth Fermentation tests. This study showed that the pollution status did not differ much from the two spatial locations even though they are about 72 km apart. A periodic study of this kind is recommended to keep abreast with the water quality status of this important lengthy River.

**Keywords:** Spatial Study, Pollution, Port Gibson, Natchez, Mississippi.

## INTRODUCTION

The Mississippi River is the second longest river in North America flowing from its source at Lake Itasca, Minnesota through the center of the continental United States to its mouth, the Gulf of Mexico (The Missouri River, a tributary of Mississippi River, is about 100 miles longer). It is one of the world's major rivers. (https://www.nps.gov/miss/riverfacts).

Acholonu and his students have conducted studies on the water quality of the Lower Mississippi River and several other freshwater bodies in the State of Mississippi (Acholonu and Harris (2011), Mississippi River; Acholonu et al. (2011), Big Sunflower River and Yazoo River; Acholonu and Hopkins (2014), Pascagoula River; Hopkins and Acholonu(2015), Mud Island Creek and Cole Creek; Acholonu and Vaughan (2015), Big Black River). Although the present study augments their numerous contributions to water quality or pollution studies in the State of Mississippi, to our knowledge, there has never been a spatial study conducted on the lower MS River in the area of Port Gibson, MS and Natchez, MS. This is the first of its kind.

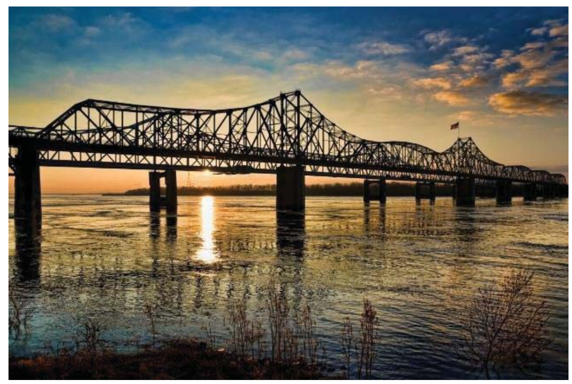
In early October 2015, the Mississippi River received an overall grade of a D+ from the American Watershead Initiative (Kelsing, 2015). The Mississippi River water basin produces more than half of the United States' goods and services and generates a fourth of the country's hydro power (loc.cit). The overall quality of the river water supply also received a low grade. Excess nutrients, mostly nitrates, draining into the Gulf drains the water of oxygen which therefore damages the ecosystem (loc.cit).

Over the years contaminants in the Mississippi River are believed to have increased and are harming the ecosystem. We humans are what we eat. Some of the foods humans eat in this area either come from the Mississippi River or are transported through it. People living in the areas of Port Gibson, MS and Natchez, MS are affected by the river by breathing the air, eating the crops grown in the area and foods from the markets and restaurants, or by fishing in the river. Since the Mississippi River received a grade of D+ in water quality, there was a need to find out how well the River met the MSWQC in Port Gibson, MS and Natchez, MS areas in the Summer and Fall seasons of 2015.

Development of effective national and regional strategies for the management of water quality demands the knowledge of the sources, movement, and storage of contaminants and their reactions throughout the river system (Meade 1990). The contaminants moving through the river system are a major source of what are being introduced into the nations waterways by human activities Therefore, the objectives of this study were to conduct spatial pollution studies on the Lower Mississippi River covering two locations, Port Gibson, and Natchez, MS; to compare the distribution of contaminants in the two river areas; to assess the seasonal distribution of the pollutants and see if the River meets the MSWQC.

## MATERIALS AND METHODS

Samples of water were collected from the Mississippi River in the cities of Port Gibson, MS near the Grand Gulf Military Park and Natchez, MS under the Mississipi River Bridge about 72 km apart (Figures 1a and b). In each city, river samples were collected from three sites approximately fifty meters away from each other as was done by Acholonu and Harris (2011). The Water samples were collected from the Mississippi River during the Summer and Fall of 2015 (early September and late October 2015). The water samples were collected by stepping into the shallow part of the river wearing hip boots. Next, a small clean bucket with a rope tied to it was rinsed three times and thrown as far as possible into the river to collect the river water from a deeper depth. Then the bucket was pulled out and the water sample was poured into clean sterile 590 mL bottles and filled to the brim (Figure 2). After the samples were collected, the temperature of the surface water and atmospheric temperature were taken. The same procedure was used during the Summer and Fall water collections. The samples were taken to the Alcorn State University Laboratory to test the physical, chemical, and biological aspects. The samples were tested chemically according to the methods indicated in the LaMotte pollution detection kits. The results of the LaMotte tests were recorded, analyzed and compared with the Mississippi Water Quality Criteria (MSWQC).



a

b

***Figure 1a:*** *Part of Mississippi River Bridge in Natchez,* ***(b)*** *Mississippi River in Port Gibson*

Tests for coliform bacteria were conducted as indicated by Carolina Bacterial Pollution of Water Kits (Carolina Biological Supply Company) and using nutrient agar and MacConkey agar. The Nutrient agar and MacConkey agar were melted down and 5ml were placed into petri dishes and refrigerated until solid. One milliliter of the water sample was placed onto the petri dishes using a sterile pipette while keeping the lid cracked only enough so that the pipette could enter the petri dish. After that procedure, the petri dishes were labelled and incubated at 36 °C for 24 to 48 hours. They were then observed for bacterial growth. As a confirmatory measure, the Carolina Biological Supply Company Lauryl Tryptose Broth Fermentation tests were also performed as indicated by the manufacturers.

**Figure 2:** Water Sample collected from The Mississippi River in Natchez

## RESULTS AND DISCUSSION

A total of twelve chemical parameters were tested, recorded, and analyzed. For both locations the physical aspects were colorless, malodourous, and partially transparent (slightly turbid). The temperature of the surface water felt slightly cool at 18°C in the summer and 15°C in the fall. The atmospheric temperature during the summer sample collection was 32.2°C, and in the fall 26.6°C. The majority of the chemical parameters tested met the MSWQC. However, MSWQC parameters for alkalinity, hardness, carbon dioxide and phosphate were not met for both locations. In addition, coliform bacteria were present in both locations which was confirmed using the Lauryl Tryptose Broth Fermentation tests.

As indicated from the results, a total of 12 different chemical tests were conducted. For both locations, it is interesting to note that the physical aspects of the water samples were practically the same (colorless, foul-smelling, and partially transparent (slightly turbid)). The temperature of the water was as expected and is seasonal (18°C in the Summer and 15°C in the Fall). Most of the chemical parameters tested met the MSWQC. Parameters that did not meet the threshold for both locations were alkalinity, hardness, carbon dioxide and phosphate. It was noted that the seasons contributed to the contaminants flowing into the river and causing it to degrade over time. From observation, it was surmised that in the Summer months more contaminants flow and spread throughout the river than in the Fall months.

The results for the three sites at each location are represented in Figures 3 and 4 and the average parameter values for each site are listed in Tables 1 and 2.

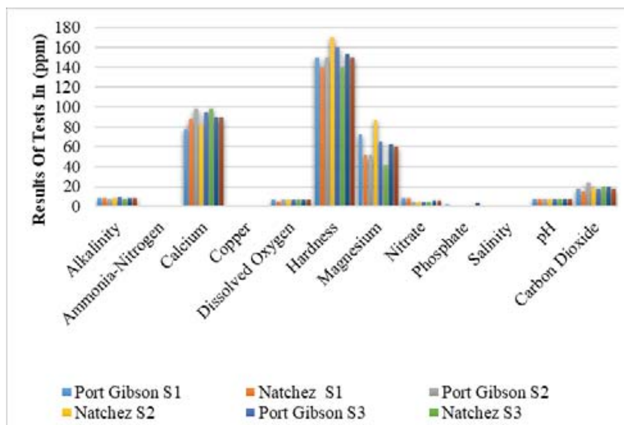



**Figure 3:** Graphical representation of the 12 parameters measured in the Summer 2015 conducted from samples of the Mississippi River water in the Port Gibson, MS and Natchez, MS areas.

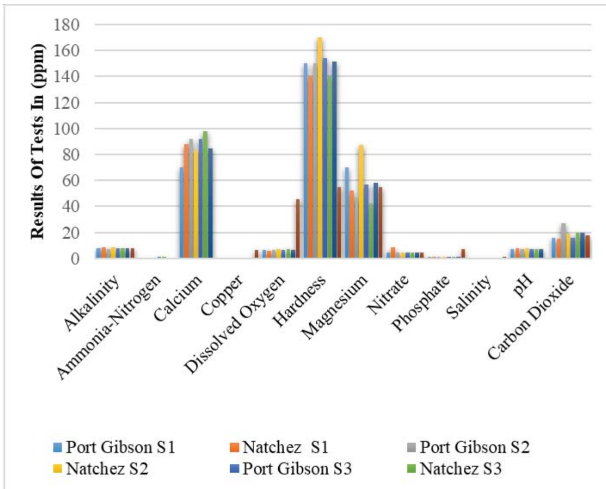



**Figure 4:** Graphical representation of the 12 parameters measured in the Summer 2015 conducted from samples of the Mississippi River water in the Port Gibson, MS and Natchez, MS areas.

Table 1 and Table 2 show the results of the alkalinity tests. The alkalinity test gave different results for each sample area. In the Summer and Fall, alkalinity for both locations exceeded the MSWQC. The average alkalinity for Summer and Fall for Port Gibson, MS was 8.81/7.67 ppm as shown in Table 1. The average alkalinity for Summer and Fall for Natchez, MS was 8.37/7.83 ppm as also shown in Table 2. There was an average difference of 0.44/0.16ppm between both areas in the Summer and Fall for alkalinity. Port Gibson had more alkalinity present in Summer than Natchez; and Natchez had more alkalinity present in the Fall than Port Gibson.

Tables 1 and 2, show the results for water hardness. In the Summer and Fall. hardness exceeded the MSWQC of 50 ppm. The average hardness for Summer and Fall for Port Gibson, MS was 153.3/151.3 ppm while the average for Summer and Fall for Natchez, MS was 150/145.6 ppm. There was an average difference of 3.3/5.7ppm between both areas in the Summer and Fall. Port Gibson water has higher values for hardness in the Summer and Fall than Natchez in both seasons.

As observed by Hem (1985), humans and natural sources contribute chemicals to the dissolved solids of the Mississippi River. The chemicals that contaminate the water can be separated into two groups based upon their electrical charges. The most common chemical positively charged ions are calcium, magnesium, sodium, and potassium. The most common negatively charged chemical ions are bicarbonate, chloride, sulfide and nitrate. The river water hardness concentration increases as more calcium and magnesium ions are dissolved by tributary water flowing over the rocks in the river basins and subsequently into the Mississippi River.

Tables 1 and 2 show the results of the carbon dioxide tests. For the Summer and Fall, carbon dioxide concentration exceeded the 10 ppm for MSWQC. The average carbon dioxide concentration for Summer and Fall for Port Gibson, MS was 20/19.6 ppm as shown in Table 1. The average for Summer and Fall for Natchez, MS were 18/16.3 as shown in Table 2. There was an average difference of 2.0/3.3 between both areas in the Summer and Fall. Port Gibson had a higher carbon dioxide concentration in the Summer and Fall than Natchez (20/19.6 and 18/16.3).

Tables 1 and 2, show the results of the phosphate tests. In the Summer and Fall, phosphate concentration exceeded the 0.01 ppm for MSWQC. The average phosphate concentration for the Summer and Fall for Port Gibson, MS was 3.6/1.0 ppm as shown in Table 1. The average for Summer and Fall for Natchez, MS was 1.0/1.0 ppm as shown in Table 2. There was an average difference of 2.6/0.0 ppm between both areas in the Summer and Fall for phosphate. Port Gibson had higher phosphate levels in the Summer than Natchez; and during the Fall, the results for both locations were similar, 1.0 ppm.

**Table 1.** ***Summer and Fall 2015 chemical parameters results of the Mississippi River in Port Gibson, MS***

| | Site 1 Summer/Fall (ppm) | Site 2 Summer/Fall (ppm) | Site 3 Summer/Fall (ppm) | Average Summer/Fall (ppm) | MSWQC / EPA Standard (ppm) |
|---|---|---|---|---|---|
| Total Alkalinity* | 8.96/8.00 | 7.95/7.00 | 9.52/8.02 | 8.81/7.67 | 3.08/3.02 |
| Ammonia-Nitrogen (NH3) | 0.25/0.25 | 0.1/0.1 | 1.0/1.0 | 0.45/0.45 | 10/10 |
| Calcium (Ca) | 78/70 | 98/92 | 95/92 | 90.3/84.6 | 200/200 |
| Copper (Cu) | 0.0/0.0 | 0.0/0.0 | 0.0/0.0 | 0 | 8.85/6.28 |
| Dissolved Oxygen (DO) | 6.8/6.6 | 6.6/6.7 | 6.6/6.6 | 6.6/6.6 | 4/4 |
| Hardness* | 150/150 | 150/150 | 160/154 | 153.3/151.3 | 50/50 |
| Nitrate | 8.8/4.4 | 4.4/4.4 | 4.4/4.4 | 5.86/4.4 | 10/10 |
| pH | 8.0/7.0 | 8.0/7.0 | 8.0/7.0 | 8/7 | 7.09/9.0 |
| Phosphate* | 2.0/1.0 | 1.0/1.0 | 8.0/1.0 | 3.6/1 | 0.1/0.1 |
| Salinity | 0.05/0.05 | 0.05/0.05 | 0.05/0.05 | 0.05/0.05 | NA |
| Magnesium | 72/70 | 52/47 | 65/57 | 63/58 | 150/ 150 |
| Carbon dioxide* | 18/16 | 24/27 | 18/16 | 20/19.6 | 10/10 |

*Note:* Results are expressed in parts per million (ppm). NA means not available.

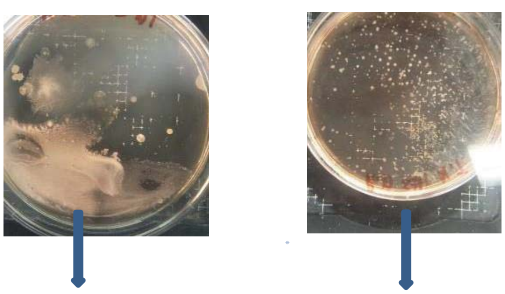
**Table 2.** ***Summer and Fall chemical parameters test results of the Mississippi River in Natchez, MS***

| | Site 1 Summer/Fall (ppm) | Site 2 Summer/Fall (ppm) | Site 3 Summer\Fall (ppm) | Average Summer/Fall (ppm) | MSWQC/ EPA Standard (ppm) |
|---|---|---|---|---|---|
| Total Alkalinity* | 8.6/8.0 | 8.4/7.5 | 8.12/8.0 | 8.37/7.83 | 3.08/3.02 |
| Ammonia-Nitrogen (NH3) | 0.1/0.25 | 0.25/0.25 | 1.0/1.0 | 0.45/1.5 | 10/10 |
| Calcium (Ca) | 88/80 | 83/76 | 98/80 | 89.6/78.6 | 200/200 |
| Copper (Cu) | 0.0/0.0 | 0.0/0.0 | 0.0/0.0 | 0/0 | 8.85/6.28 |
| Dissolved Oxygen (DO) | 5.6/5.0 | 7.2/7.6 | 7.0/6.4 | 6.6/6.3 | 4/4 |
| Hardness* | 140/137 | 170/163 | 140/137 | 150/145.6 | 50/50 |

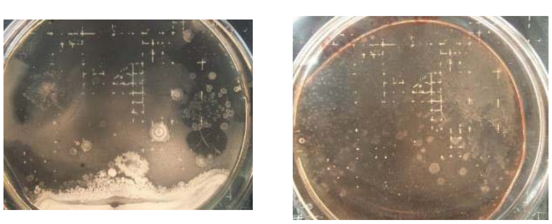
| | | | | | |
|---|---|---|---|---|---|
| Magnesium | 52/47 | 87/80 | 42/37 | 60.3/54.6 | 10/10 |
| Nitrate | 8.8/4.4 | 4.4/4.4 | 4.4/4.4 | 5.86/4.4 | 7.09/9.0 |
| pH | 8.0/7.0 | 8.0/7.0 | 7.5/7.0 | 7.83/7.0 | 0.1/0.1 |
| Phosphate* | 1.0/1.0 | 1.0/1.0 | 1.0/1.0 | 1/1 | NA |
| Salinity | .05/.05 | .05/.05 | .05/.05 | 0.05/0.05 | 150/ 150 |
| Carbon Dioxide* | 15/13 | 19/16 | 20/20 | 18/16.3 | 10/10 |

*Note:* Results are expressed in parts per million (ppm). NA means not available.

Carolina Bacteria test kit containing nutrient agar, and MacConkey agar revealed the presence of bacteria. Nutrient agar is a general medium that supports the growth of a broad range of bacteria, while MacConkey agar supports the growth of most gram-negative bacteria and was used to identify bacteria that are part of the coliform bacteria group (Coliform bacteria are gram-negative; hence MacConkey agar was used to test water samples for presence of coliform bacteria and evidence of microbial water pollution). In comparing the nutrient agar with the MacConkey agar results, more bacteria colonies were present in the nutrient agar than MacConkey agar. In the tests, the bacteria were too numerous to count (TNTC) for both nutrient agar and MacConkey agar. (See Figures 5-7).



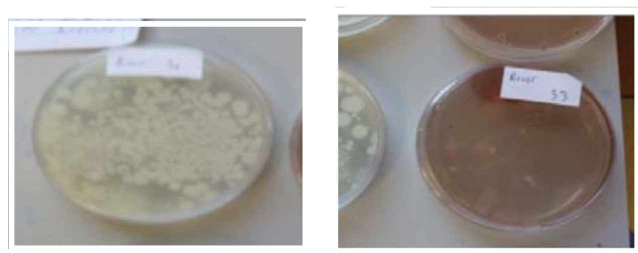
A TNTC TNTC



B

(A) Natchez, MS and (B) Port Gibson, MS Coliform Bacteria Test results

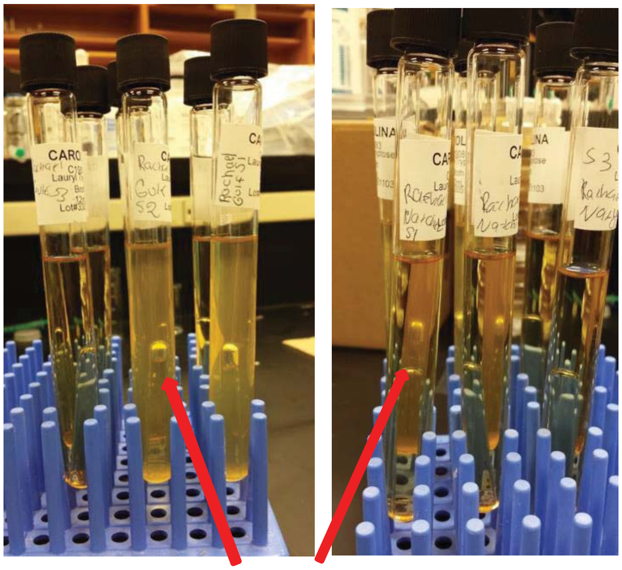
A1 A2



B1 B2

**Figure 6: (A)** Natchez, MS and (B) Port Gibson, MS Coliform Bacteria Test results. The figure shows Fall 2015 bacterial colonies using the Carolina Bacterial Pollution Water Kit (Nutrient Agar (A1, B1) and MacConkey Agar (A2, B2)).

Presence of bacteria was further confirmed by the Lauryl Tryptose Broth Fermentation tests where gas bubbles were seen as evidence (Figure 7). This confirmed the fact that coliform bacteria were present in both river locations and that the water is not potable or sanitary for domestic use.



**Gas Bubble**

**Figure 7:** Lauryl Tryptose Broth Fermentation Tests**.** This figure is showing the results of the Carolina Broth test from Port Gibson, MS (left) and Natchez, MS (right) areas Gas bubbles are present in the tubes of both locations confirming that coliform bacteria are present.

## CONCLUSION

This study was conducted to provide new data that can be used to compare with studies in the future and to help to understand and evaluate the changes in the Mississippi River and determine future progress or lack of it in water quality management in this river. It is recommended that more spatial studies of this nature be conducted to monitor the quality of the Mississippi River in its lengthy course.

**CONFLICT OF INTEREST** Authors have nothing to declare.

## ACKNOWLEDGEMENT

Grateful acknowledgement is paid to Dr. Robert Sizemore, Dr. Voletta Williams and Dr. Marta Piva, professors in the Department of Biology who were helpful in various ways and for guidance and reviewing of the study. Much gratitude is expressed to Dr. Keith McGee, Associate Professor of Biology, for helping through his Mississippi INBRE grant, in the procurement of supplies for the conduction of this study as well as Dr. Donzell Lee, Provost and Executive Vice President for Academic Affairs, ASU. Grateful acknowledgement is paid to Engr. Leslie Okere, Chinaza Okafor, and Adeola Olowokudejo for technical assistance.

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# Author Guidelines

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Research papers are reports of original research. Submission of a manuscript implies that the paper has not been published and is currently at the time of submission being considered for publication elsewhere. At least one of the authors must be a member of the Academy, and all authors are encouraged to join.

**Manuscripts.** Submit the manuscript electronically to the Mississippi Academy of Sciences under your profile in the member location of the website. Please also provide a cover letter to the Editor of the Journal. The cover letter should authorize publication: give the full names, contact information, for all authors; and indicate to whom the proofs and correspondence should be sent. Please notify the Editor on any changes prior to publication.

**Manuscripts must adhere to the following format:**

- One inch margins on 8.5 x 11 inch paper;
- Text should be left-justified using twelve point type;
- Double spaced throughout, including the title and abstract;
- Arabic numerals should be used in preference to words when the number designates anything that can be counted or measured (7 samples, 43 species) with 2 exceptions:
- To begin a sentence (Twenty-one species were found in…)
- When 2 numeric expressions are adjacent in a sentence. The number easiest to express in words should be spelled out and the other left in numeric form (The sections were divided into eight 4-acre plots.).
- Measurements and physical symbols or units shall follow the International System of Units (SI *Le Système international d'unités*) with metric units stated first, optionally followed by United States units in parentheses. *E.g.*: xx grams (xx ounces); and
- Avoid personal pronouns.

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**Format**

**Abstract.** In 250 or fewer words summarize any new methods or procedures critical to the results of the study and state the results and conclusions.

**Introduction.** Describe the knowledge and literature that gave rise to the question examined by, or the hypothesis posed for the research.

**Materials and methods.** This section should describe the research design, the methods and materials used in the research (subjects, their selection, equipment, laboratory or field procedures), and how the findings were analyzed. **For all human and animal studies please indicate Institutional Approval** in this section**.**

**Results.** The text of the results should be a descriptive narrative of the main findings, of the reported study. This section should not list tabulated data in text form. Reference to tables and figures included in this section should be made parenthetically in the text.

**Discussion.** In this section compare and contrast the data collected in the study with that previously reported in the literature. Unless there are specific reasons to combine the two, as explained by the author in the letter of transmittal, Results and Discussion should be two separate sections.

**Acknowledgments.** Colleagues and/or sources of financial support to whom thanks are due for assistance rendered in completion of the research or preparation of the manuscript should be recognized in this section rather than in the body of the text.

**Author Disclosures.** Pleae identify all conflicts of interest. In not applicable please indicate

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**Literature cited.** List references alphabetically. Cite references in the text by author and year of publication (e.g., Smith, 1975; Black and Benghuzzi, 2011; Smith et al., 2010; Smith, 2011a, 2011b). The following examples illustrate the style to be used in the literature list.

Black DA, Lindley S, Tucci M, Lawyer T, Benghuzzi H. A new model for the repair of the Achilles tendon in the rat. J Invest Surg. 2011; 24(5): 217-221.

Pearson HA, Sahukhal GS, **Elasri** MO, Urban MW. Phage-bacterium war on polymeric surfaces: can surface-anchored bacteriophages eliminate microbial infections? Biomacromolecules. 2013 May 13;14(5):1257-61.

Bold, H.C., C.J. Alexopoulos, and T. Delevoryas. 1980. Morpholgy of plants and fungi, 4th ed. Harper and Row, New York. 819 pp

Web-page

- name of author(s) -if known
- title of the work - in quotes, if known
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**Example:**

Ackermann, Ernest. "Writing Your Own Web Pages." *Creating Web Pages.* 23 Oct. 1996. http://people.umw.edu/~ernie/writeweb/writeweb.html 10 Feb. 1997.

**File available by anonymous FTP**

- name of author(s) -if known
- title of the work - in quotes, if known
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**Example:**
American Civil Liberties Union. "Briefing paper Number 5, Drug Testing in the Work Place." 19 Nov. 1992. ftp://ftp.eff.org/pub/Privacy/Medical/aclu_drug_testing_workplace.faq
13 Feb. 1997.

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**Please Tables and Figures at the end of the manuscript submitted.**

**Tables.** Tables must be typed double spaced, one table to a page, numbered consecutively, and placed at the end of the manuscript. Since tables must be individually typeset, consolidation of data into the smallest number of tables is encouraged. A horizontal double underline should be made beneath the title of the table, and single underlines should be made the width of the table below the column headings and at the bottom of the table. Do not use vertical lines, and do not place horizontal lines in the interior of the table. Use footnotes, to clarify possible questions within the table, should be noted by asterisks, daggers, or other symbols to avoid confusion with numerical data. Tables should be referred to parenthetically in the text, for example (Table 1).

**Figures and illustrations.** Figures may be photographs, computer -generated drawings, or graphs and should be placed at the end of the manuscript and referenced in the appropriate place.. All illustrations are referred to as “Figures” and must be numbered consecutively. Illustrations other than those generated by the author(s) must include permission for use and credit to the originator. Each figure must have a complete legend that is typed, double-spaced, on a separate sheet which precedes the figures in the manuscript. Figures should be referred to parenthetically in the text, for example (Fig. 1).

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**Footnotes**. Text footnotes **should not be used**

**Submission Preparation Checklist**

As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

1. The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).
2. The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.
3. I acknowledge that if my manuscript is peer-reviewed and accepted for publication, there will be a paper charge fee of $50/page for **non-Academy members**.
4. The manuscript file is in Microsoft Word format.

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