EastCare Spatial Analysis of Air Medical Response During Hurricane Matthew in Eastern North Carolina

by

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Major Department: Geography, Planning, and Environment

Changes in medical cases prior to, during and after Hurricane Matthew are spatially analyzed using data from emergency transport provided by the EastCare Emergency Medicine group. IRB clearance has been received to analyze emergency medical service (EMS) data gathered by the EastCare. Coordinate points delivered from EastCare show the locations where EMS traveled to during a two-week period prior to, during the duration (Oct 8th- Oct 9th) and two-week period after Hurricane Matthew. These data have coordinates of a particular hospital supported by EastCare and will show which air craft response attended to the call. Each call has the following data associated with them: the location of pick-up; the exact time the call; response time; patient zip code; and the type of medical issue. Descriptive and frequency statistics are used to examine differences number of calls, location of calls, types of responses, and types of medical issues vary between the three time periods. Trend surface analyses will be used to map generated from trend surface analyses show differences in the spatial patterns associated with the hurricane compared to the year prior to and after the hurricane (both years with no hurricanes in the area). The results show the 2016 magnitude of calls was significantly higher. Medical calls were also the highest call during 2016 for the 3-da7, 7-day, 15-day, and 30-day period. Patients in the age range of 65 and up were transported the most by air support. A significant hotspot of air pickups in 2016 is identified in the counties

between the Tar and Pamlico Rivers for a full 30 days to only 15 days, 7-days, and 3-days after the storm and this hotspot differs from those identified in non-hurricane years. Referring hospitals pickups also differ in the storm and non-storm periods as after the hurricane there are more pickups in hospitals closes to the Outer Banks. The findings indicate the a distinct geographic change in the location of air pick-ups during a storm period, the older adults and young children/babies are more impacted than other age populations across all time-periods of investigation. However, there is a general increase in the various types of calls regardless of age within the 3-day to 7-day time-period. Hospitals close to the location of the landfall had the highest incidence of pick-up calls compared with the non-hurricane periods investigated.

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M.S Geography

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CHAPTER 1 Introduction

Hurricane Matthew harkened back to the many issues produced during Hurricane Floyd, whereby Eastern North Carolina (ENC) received high winds and life threating flooding. Emergency Medical Services (EMS) teams in communities throughout ENC had to rescue people from their homes and cars by boat and helicopters as floods closed roads and damaged infrastructure. Washington, Kinston, and Goldsboro were among multiple cities that experienced record and destructive flood levels. The extensive nature of flood and storm damage provides an opportunity to investigate the impact of hurricanes in emergency medical responses.

Vidant EastCare (VEC) team is interested in how emergency calls during Hurricane Matthew differ than calls in their "normal" operating conditions. These results have implications to staffing in the emergency room, helicopter teams, and ground-based EMS teams as well as have implications for future planning hospital staff across the area as many calls are transferred from other hospitals in ENC. Here, the magnitude and frequency of call changes in response to a hurricane, the spatial variability in transport locales as a result of a hurricane, the variations in the types of medical cases received and the extent to which age plays a role in the medical calls during Hurricane Matthew are used to investigate the impact of the hurricane on air medical responses.

There are a variety of medical responses that are collected by VEC. A detailed list and definitions of each category of medical cases recorded are provided below.

- Medical – general adult problems which do not require surgery or any other specialty care.
- Burns – Self explanatory

- Cardiac – Any patient with heart problems except for STEMI
- STEMI (ST segment Elevation Myocardial Infarction) this is a patient who is having a heart attack and we can see evidence of the heart attack on the electrocardiogram (heart tracing). NB: Many heart attacks do not show electrical changes, so they are often considered to be smaller, and not as time-critical as STEMIs
- Neonatal – Any patient up to 30 days from birth. Many of these are children who are born prematurely. Normal pregnancy is 40 weeks long, so a child born before 35 weeks is premature.
- Neurological – any problem of the brain or nervous system that is not a stroke. This could be something like multiple sclerosis, or lower limb paralysis that is not the result of injury.
- Obstetric – Pregnancy related problems. Most often premature labor (labor before 35 weeks gestation).
- Pediatric – patients who are over 30 days old but less than 19 years old and who don't meet other specialty problems.
- Stroke – hemorrhagic – These are patients who have a bleeding problem in their brain not related to an injury.
- Stroke – non hemorrhagic – These are patients who have an area of the brain that has been deprived of its blood flow. This is classically what people call a stroke.
- Surgical – A person transferred to be cared for by a surgeon, but without any injury. Someone needing to have their appendix removed would be an example.
- Trauma – Injured patients. Could be from a car crash, fall, or gunshot wound, as examples.

These data provide the foundation of the information used to assess the magnitude and frequency of the cases in response to Hurricane Matthew at 3-day, 7-day, 15-day and 30-day time intervals. The comparison will take place using the same time intervals for the year before and year after Hurricane Matthew. Both years did not experience a direct landfall of a hurricane in ENC.

Description of Hurricane Matthew

Major storms can have a significant impact on the types and number of calls received by VEC. Hurricanes effect access to local areas in eastern North Carolina and therefore, play a significant role in the operations at VEC. Hurricane Matthew was the most powerful storm since Hurricane Floyd to hit the East Coast of the United States during this time (2016). Hurricane Matthew started developing on September 28, 2016. The storm took a surprising turn which caught North Carolina off guard in preparation for the storm.

Forecast and Warning: The general forecasts for Hurricane Matthew fared well for ENC leading into the first days of formation, as the system moved past the Lesser Antilles into the Caribbean. The first indication of forecast uncertainty was when the storm system moved passed Haiti and into the Bahamas. Originally, Hurricane Matthew was projected to make a landfall along the east coast of Florida, but instead tracked along the coastline of the eastern United States. The official forecast track errors for Hurricane Matthew were significantly lower than the mean official errors for the previous 5-year period at all forecast times. Stewart (2017) found that once Hurricane Matthew emerged over the southwestern Atlantic north of the Greater Antilles, there was a sharp right-of-track bias due to expectations that Hurricane Matthew would turn southward around a ridge that was expected to build over the southeastern United States instead of recurving into the mid-latitude westerlies. The sudden change in the cone of uncertainty may

have altered a role in the planning preparations for the storm as many of models showed Hurricane Matthew curving off the Southeast US coastline.

The Impact (During): Throughout Hurricane Matthew's life-cycle, torrential rains occurred over much of the Southeast US, particularly across the piedmont and coastal areas of North Carolina. Rainfall in these areas, according to the National Hurricane Center (NHC) (2016) report, exceeded 10 inches. Stewart (2017) suggested the heaviest rain in eastern North Carolina resulted from a contribution of Hurricane Matthew's tropical moisture, the ongoing extratropical transition that caused the cyclone's rains to favor the northwestern quadrant, and a pre-existing frontal boundary over the far eastern portions of the state. The combination of the aforementioned items contributed to the widespread flooding, given that and the river basins overflowing.

Response (After): The heavy rains from Hurricane Matthew spelled trouble across ENC, especially in the low-lying communities adjacent to river systems throughout the region. North Carolina general health attendants and environmental health specialists came in from unaffected parts of the state to do staff covers, assess offices, and direct well water and septic framework testing in flooded territories (CDC, 2018). The storm related deaths (28 total) and the 19 deaths from drowning in vehicles was particularly high as a result of this event. Office of Public Health Preparedness and Response and the Center for Disease Control (CDC) (2016) mentioned that the greater part of the crisis exercises was facilitated in the state's crisis activities focus, or Emergency Operations Center, where 16 PHEP-subsidized staff logged 921 hours. Moreover, because of previous associations with encompassing states, the state was able to ask for and get 20 general wellbeing medical caretakers from other states within a few hours.

Adding to the hurricane impacts was that many of the hardest hit regions were the poorest districts in the state. This created further difficulties as many of these areas also exhibit higher pre-existing health cases and the lack of financial wherewithal to deal with the additional burden added from various hazards associated with the hurricane. Previous North Carolina Public Health Emergency Preparedness chief Julie Casani, M.D. stated: “You can’t fix these gaps during a disaster when they have been made so much worse, when you are asking people who already don’t have enough to make do with even less (CDC, 2018: 2)”. The socio-economic issues compounded with the aftermath of the hurricane placed further demand on the medical system and the community at large.

The current research literature on EMS air response following a hurricane has focused on a 2 week time period from the start point of the hurricane (Pines, 2018.; Platz et al., 2007; Quinn et. al., 1993). This represents a relatively broad scale view of what is perceived to be the highest impact time period on medical facilities after a hurricane. However, while this time period might work for some locales there is needed to further evaluate the full temporal or spatial consideration of the impact of hurricanes on regional medical infrastructure and personnel. This research should involve a more critical assessment of the impacts of hurricane on both shorter and longer-term response by the regional medical infrastructure and personnel to the hurricane.

The research literature is replete of re is also air transport studies conducted immediately following hurricanes. The air transport network plays a critical role in quickly moving patients in need of rapid or more advanced medical aid than can be provided at local hospital. Furthermore, as flooding is a major issue the ground transportation network may be hampered in transferring patients to regional hospitals thereby making air transport even more critical. Therefore, a need exists to show how helicopter pickups patterns changes in response to a hurricane. This can be

done via a comparison of the period in and around the hurricane with similar time frames during non-hurricane years.

Here, the focus of the current research also is to examine an entire 30-day period around hurricane Matthew as well as finer-scale temporal periods that examine responses at 15-day, 7-day and 3-day period after Hurricane Matthew. ENC's low elevation causes high risk of flooding. While not a major goal of this study, a precursory examination of the rainfall pattern and helicopter pickups in Eastern NC around October 2016 (Fig.1-3) is investigated to place the observations of hotspots of air response activity in the context of the weather/flooding.

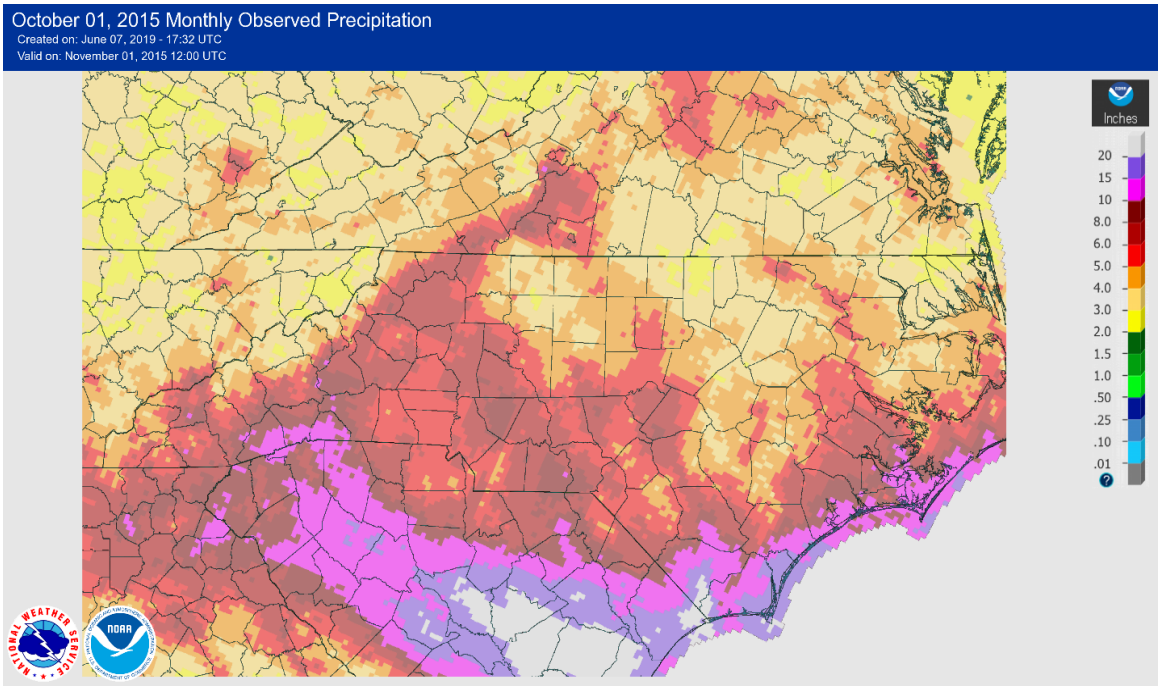


Figure 2 show the annual rainfall for the month of October in 2015

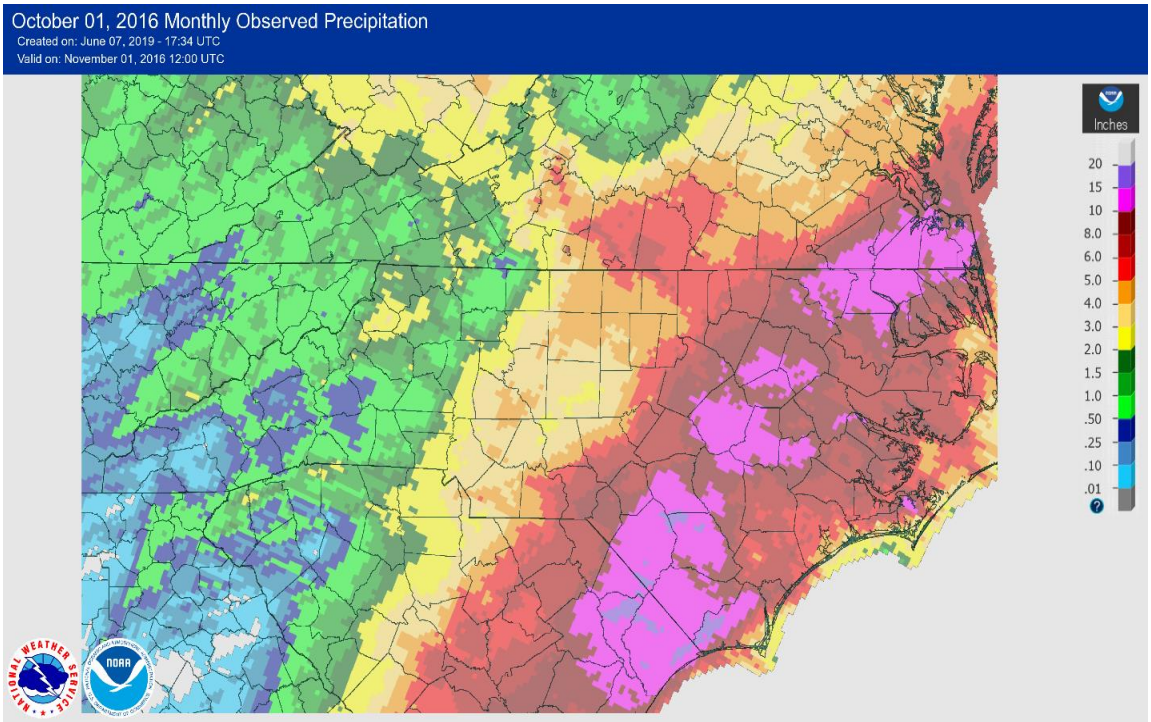


Figure 1 show the annual rainfall for the month of October in 2016

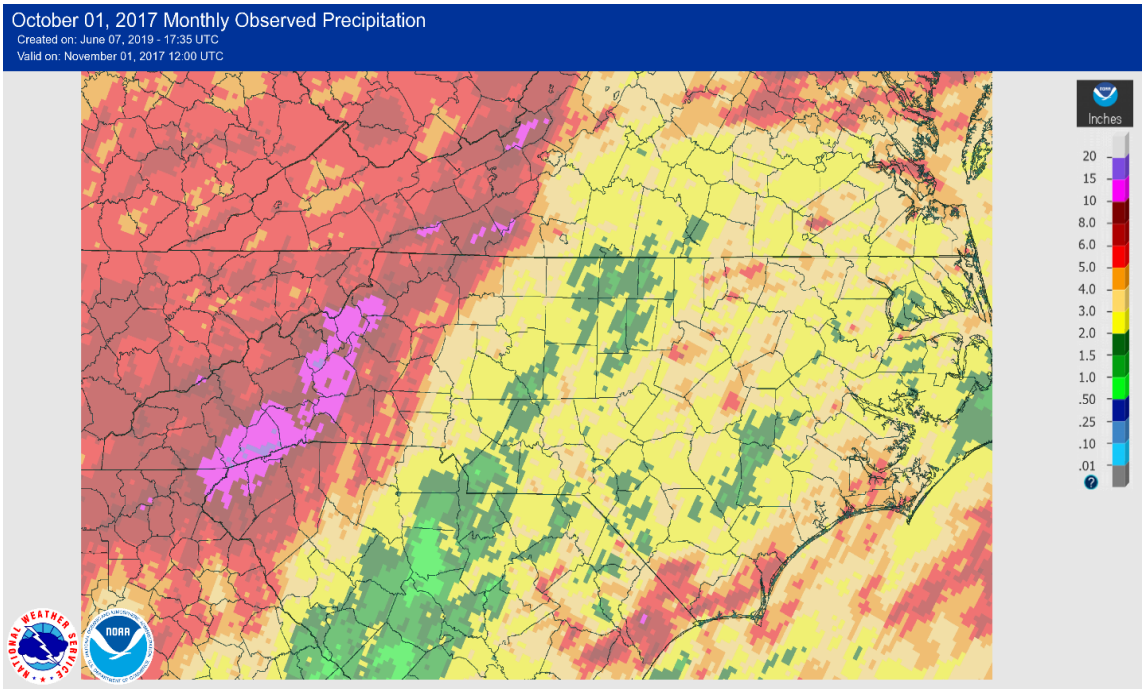


Figure 3 show the annual rainfall for the month of October in 2017

With the data provided from NOAA and Eastcare, the goal is to spot similar trends or correlations with the helicopter pick up of different data category outlined above. The results of this study will help VEC helicopter team to be more prepared on what to expect during a hurricane. The research is also very important because others states that deal with major flooding can also use this research to their advantage of help them during tropical cyclones and extended rainfall in conjunction with snowmelt scenarios (i.e. mid-western USA floods). This work will certainly not provide the definitive conclusions on the air responses immediately following hurricanes, but it will begin to advance the knowledge in this required area of research.

CHAPTER 2: Data analysis and Hotspot Analysis of Helicopter Pickups

Introduction

Overview of EastCare: Vidant EastCare (VEC) was established in 1985. VEC is an advanced critical care transport service that provides both ground and air medical transport for patients in Eastern North Carolina (ENC) (Holcombe, 2015). VEC serves over 29 counties in ENC and works in partnership with Metro Aviation, which operates 2 EC-145 helicopters and 2 EC-135 helicopters. These helicopters are stationed at five bases in Nash, Craven, Wayne, Beaufort and Pitt Counties (Fig. 4). The helicopters cover over a 150 miles radius from the bases and can transport two patients at once during emergencies. VEC provides 12 ground transport ambulance

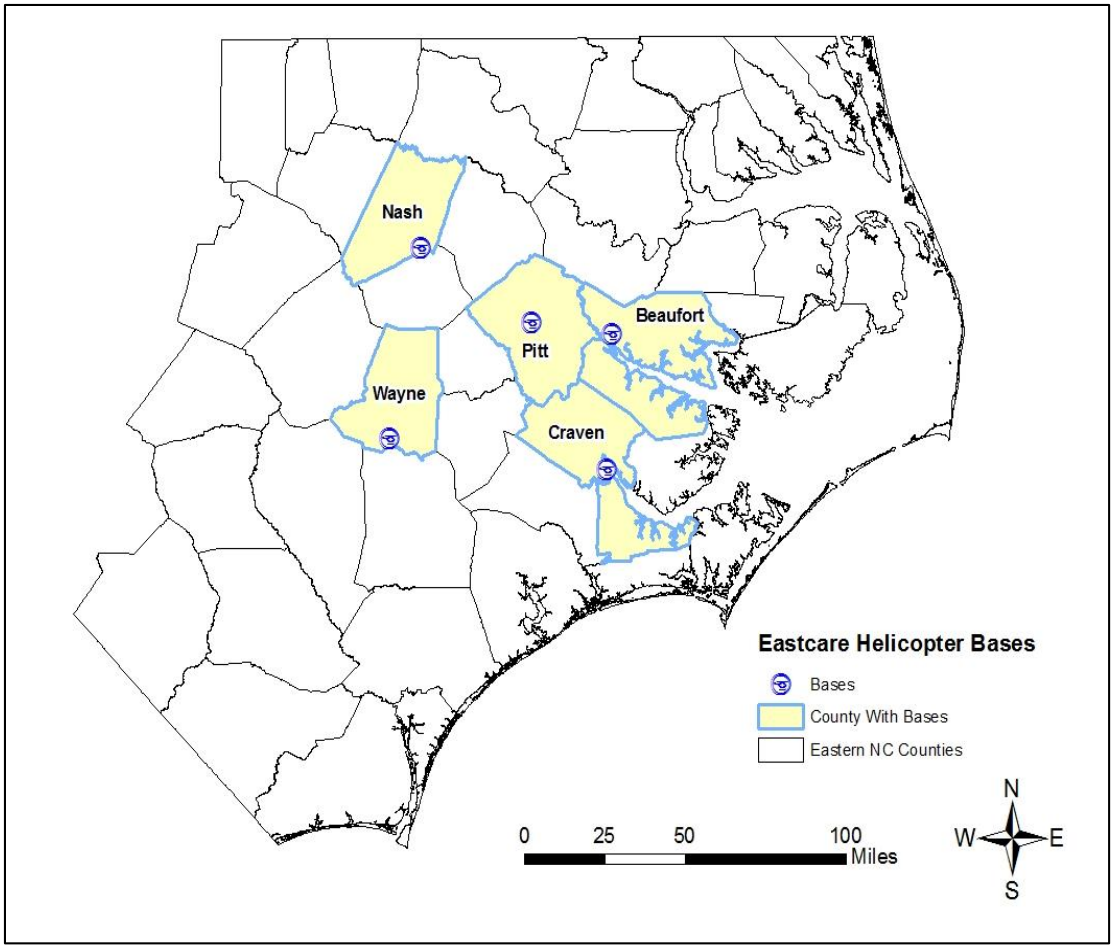


Figure 4 Show the locations of Eastcare's helicopter bases

throughout Eastern North Carolina as well. The locations of the ambulances are in Onslow, Pitt, Duplin, Bertie, and Nash County. The focus of the current study is only on the helicopter bases.

Literature Review

Type of Emergency Calls Expected during Hurricanes Event

The current research is grounded in the disaster epidemiology literature (Noji, 1996; Horney, 2018). As climate changes and populations continue to grow and expand into areas prone to natural hazards the risks increase for people and infrastructure to experience devastating consequences. The science of disaster epidemiology is an approach that lends itself to identifying vulnerable populations, measuring disaster-related morbidity and mortality, examining pre- and post-disaster health status, informing decision-makers on methods to intervene and ways to allocate resources for relief, as well as how to produce more resilient systems (Malilay and Horney, 2018). The current study integrates geographic information systems examine post-disaster impacts on medical responders and regional hospital facilities about the impacts of a hurricane on medical cases, age, and the spatial and temporal variability of air responses (Funk, 2018).

The role of spatial analysis to investigate access to medical facilities has played a significant role in trauma transport literature (Lawson et al., 2012; Vasilyeva et al., 2018; Jansen et al., 2019; Winchell et al., 2019). In general, prior research has used GIS to strongly indicate that trauma deaths were less likely in patients with rapid access to trauma facilities (Lawson et al., 2012). Not only is the response time important, but studies have also shown distinct temporal variations (even over short time-scales) exist in the numbers and types of trauma cases with the aid of geospatial analyses (Jansen et al., 2019). Adoption of geospatial have also been shown to be a critical component of guiding future decisions that can impact healthcare expenditures,

staffing, and patient care (Vasilyeva et al., 2018; Winchell et al., 2019). The literature on spatial analysis and trauma transport highlights the scientific rigor of these approaches for establishing spatial and temporal patterns as well as showing the importance of these analytics to decision-making.

Evidence from previous research on hurricane induced medical responses provide some general insight into the potential demands on the medical system. As would be expected, researchers have found the volume of emergency calls tend to increase rapidly during the week after a hurricane had taken place (Quinn et al., 1993). In 1992, Hurricane Andrew devastated Florida, and a children's hospital had seen a 40 percent increase in patients during the following week after the hurricane (Quinn, et al., 1993). Florida was hit by four consecutive hurricanes in 2004 and after each hurricane, there was an increase in emergency calls during the week the following the storm (Platz et al., 2007). Both Quinn et al. (1993) and Platz et al. (2007) showed significant trends and patterns in injuries during the week after a hurricane with a majority of the patients having open wounds (a trauma call).

Another consideration, after a hurricane, is the capability of hospitals to support patients. Emergency calls can result from a hospital that is unable to support the volume of patients it is receiving following a hurricane. The lack of supplies or staff often result in hospital to hospital transfers to accommodate for the large volume of cases in the wake of the storm. An example of this type of emergency call occurred during Hurricane Irene, when 947 patients had to be transferred from hospitals to new locations due to flood risks in New York (Verni, 2012). In a rural region like ENC, where there is a large regional hospital, a large majority of the transportation to VEC was from smaller regional hospitals in the devastated area after Hurricane Matthew.

Research Questions

Past research and experiences have shown air emergency transportation is impacted in a variety of ways. VEC is one of the main emergency transport teams in ENC. As such, they are attempting to better understand the role of hurricanes in perturbating normal air response calls. Assessing the spatial and temporal variations in calls surrounding Hurricane Matthew in ENC provides an initial understanding of the how the magnitude and types of calls as well as the impacts to various age groups varies between hurricane and non-hurricane periods. The specific research questions to be addressed in the current study include:

1. What spatial patterns are present from EMS pickups during 30-day period around October 8 (Hurricane Matthew [October 8-9, 2016] landfall in ENC) for the years 2015, 2016, and 2017?
2. How do these patterns change if the time-frame is changed to a 3-day, 7-day, and 15-day periods after October 8?
3. Are there discernable changes in the magnitude of calls and types of call categories throughout each 3-day, 7-day, 15-day and 30-day period for the years 2015, 2016, and 2017?
4. What age group is the most effected during the 3-day, 7-day, 15-day and 30-day period, and does this differ from the year preceding and following the hurricane?

Methodology

Study Area

The VEC study area covers most of ENC (Fig. 5). The range for EastCare is from the pediment all the way to the coastal areas in NC. Therefore, incidences in western and central North

Carolina are not considered in the current study. Other hospitals and air medical response teams handle the central and western regions. Although, it should be stated that medical facilities and response teams from central North Carolina also respond to cases in ENC. The numbers presented herein are therefore considered to minimum estimates of the cases handled in ENC.

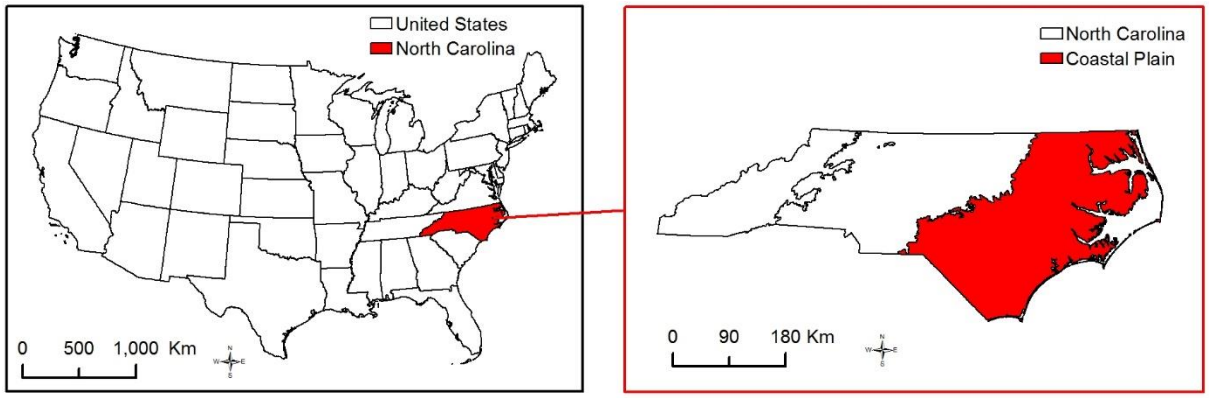


Figure 5 Show the study area of Easter North Carolina

ENC consists of relatively lowing lying topography with elevation varying from sea-level to approximately 182 m. The climate and mineral soils in ENC provide excellent opportunities to grow cotton, grapes, sweet potatoes, tobacco, soybeans, row crops and much more. ENC also boasts the large farms in North Carolina with several farms having 5,000 to 15,000 acres. ENC has a good amount of bodies of water. The Neuse River, Tar River, Alligator River, Cape Fear River, and Albemarle and Pamlico Sounds are a few of many bodies of water located in ENC. All the bodies of water and the coastal settings make ENC particularly vulnerable to flooding and storm surges during a hurricane. North Carolina has rainfall all year long and experiences relatively mild temperature that vary seasonally.

Method: Using SPSS Descriptive Stats/ GIS interpolation.

Statistical Analysis: Descriptive stats are used to assess the different type of injuries captured from the air emergency response data. The descriptive statistics show trends and patterns over

the three periods of investigation designed around Hurricane Matthew. Diaz et al. (2004) and Lerner et al. (1999) showed Hurricanes Irene and Andrew had the same standard injuries in the different regions investigated by each of these studies. The top injuries that occur were cuts or skin infection, falls, and car accidents, which will fall under truma category. The descriptive statistics are used to compare hospitals reffering patients and the types of cases from each hospital during the perviously mentioned specified time-frames. Another variable assessed is the average age and the age category. SPSS is the stats program is used because of it to split the cases in the 30 day period into specific time frames. 3-day and 7-day and 15-day time scales after Hurricane Matthew (October 8) will be an initial point of investgation of the space-time patterns.

GIS Analysis: Three different type of interpolation methods are commonly used to examine spatial trends for the 2016 30 day-period. The three methods are: (1) inverse weighted distance (IDW); (2) radical basis function (RBF); and (3) empirical Bayesian kriging (EBK). IDW is a deterministic local interpolation method that enforce the conditions that the unknown value of a point is influenced more by nearby points than by those farther away. RBF is a series of exact interpolations techniques; that is, the surface must pass through each measured sample valued. EBK is a geostatistical interpolator developed to improved estimation and their errors. Unlike other methods in geostatistical analyst tools that require you to manually adjust parameters, EBK automatically calculate the parameters.

The purpose for comparing different interpolation method is for cross-validation to determine if there any significant patterns to support the hotspots in the data. Another reason to compare interpolation methods is to also determine the best method for mapping out the hotspots. In order to do the mapping a small loop python script was run to calculate every zip code that occur and create count fields for each time period into separate excel sheets. The next

step was to normalize the count field by the total population of each zip code collected from the 2010 census so the data will not be heavily screwed base off the count values. The Excel files are joined to feature classes in ArcGIS v10.6x by the join field tool to make the interpolations possible (Fig. 6). The 2016 30-day data are used in this assessment.

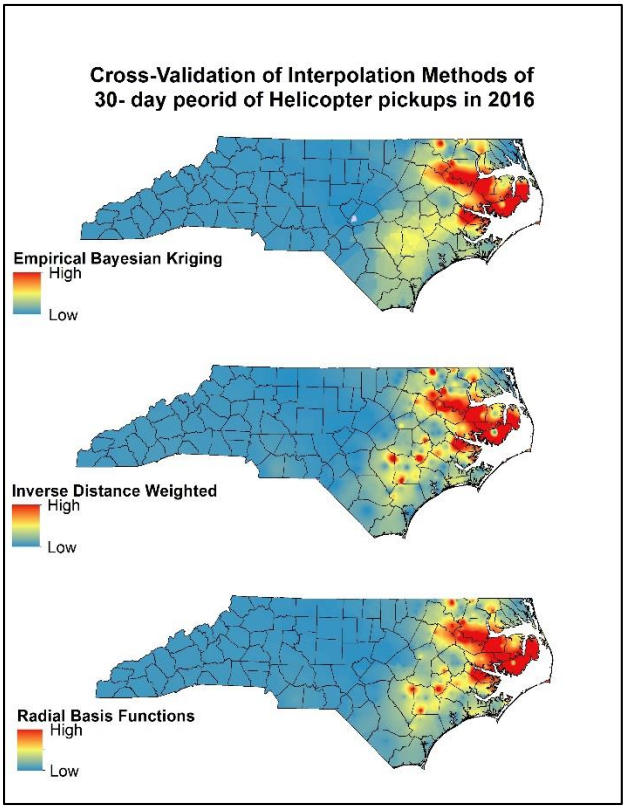


Figure 6. Output from the different interpolation techniques. Thirty days of data centered on October 8th, 2016.

Root mean square error (RMSE) analyses were performed on each of these surfaces and there was not much difference in the error associated with each of the interpolation approaches. The range of the root mean square fell between values of .000730-.00740 with the RBF lowest value of .00730). A qualitative assessment of the three interpolation methods indicates a lower degree of insularity ("bullseye" effect) in data outputs from RBF interpolation (Chaplot et al., 2006) when compared with the IDW. RBF is more reasonable to use because it only uses the values present in the datasets and does not predict values that are heavily weighted on local values as is the case with IDW. The EBK approach generated a smooth surface when compared with RBF and details are lost to the smoothing processes associated with this interpolation approach.

Discussion/Results

The total calls in 2016 for the 30-day period increased significantly when compared with the 2015 and 2017 periods (Fig.7). 20 of the 31 referring hospitals (reporting calls in 2016) in the

area saw higher total calls for the 30-day period after the hurricane when compared to 2015 and 2017 (Fig. 7). Areas prone to major flooding occurred after the hurricane are the locations identified with increased number of calls such as Oslow County, Beaufort County, Duplin County, and Edgecombe County Hospitals. The ability of the regional hospitals to handle the increased volume of calls also played a role in the referrals. The 15-day period saw 21 of the 27 referring hospitals (reporting calls in 2016) having higher total calls after the hurricane when compared with the year prior to and after the storm (Fig. 8). The 7-day period saw 21 of the 31 referring hospitals (reporting calls in 2016) having higher total calls after the hurricane when compared with the year prior to and after the storm (Fig 9). The examination of the 15-day (fig. 8) and 7-day periods (fig. 9) showed areas around the Outer Banks still had large spikes of calls in 2016, but other areas had started to level out in each year averaging around the same number of calls when reducing the time frames to the initial impact of Hurricane Matthew. The 3-day period saw 13 of the 31 referring hospitals (reporting calls in 2016) having higher total calls after the hurricane when compared with the year prior to and after the storm (Fig. 10). The 3 day period (Fig. 10) showed the majority of the hospitals had almost no calls in 2015 and 2017. In 2016, the only area with a significant number of calls was Beaufort County which had 14 out of the 23 calls over 30 days happen within the 3 days after Hurricane Matthew. Chawon county had 5 calls out of the 10 received over 3 days after Hurricane Matthew , but all 10 calls for helcoptor pickup came with in the 7 day peorid after Hurricane Matthew(Fig 9).

The results show the dramatic impacts of the hurricane on hospital referrals whereby 81% (3-day window) and 87.5% (7-day period) of the regional hospitals are referring patients to VEC. The increase would be in accordance with other studies that have found a sharp increase in emergency visits after a hurricane (Miller et al., 2013; Kim, 2016; Pines, 2018). The evidence

suggest the VEC should expect an immediate surge capacity following the hurricane. However, the initial response is only part of the story as referral rates remain very high and still quite spatial dispersed with 77% (15-day period) and 74% (30-day period) of the referring hospitals experiencing much higher than normal referral rates to VEC. This result runs counter to previous studies that showed emergency department visits decreased to the baseline in the study within 7-10 days (Miller et al., 2013; Pines, 2018). However, a review of flood and storm disasters and their impacts on human health corroborate the findings in the current study (Saulnier et al., 2017). VEC must be able to handle an initial large surge of patients coming from all parts of the region, but the surge continues for at least a month and likely longer. The identification of this surge provides important information to assist with preparedness planning, such as building community and health care system relience to hurricanes, properly identifing resource allocations and air service and EMS delivery (Bell et al., 2018).

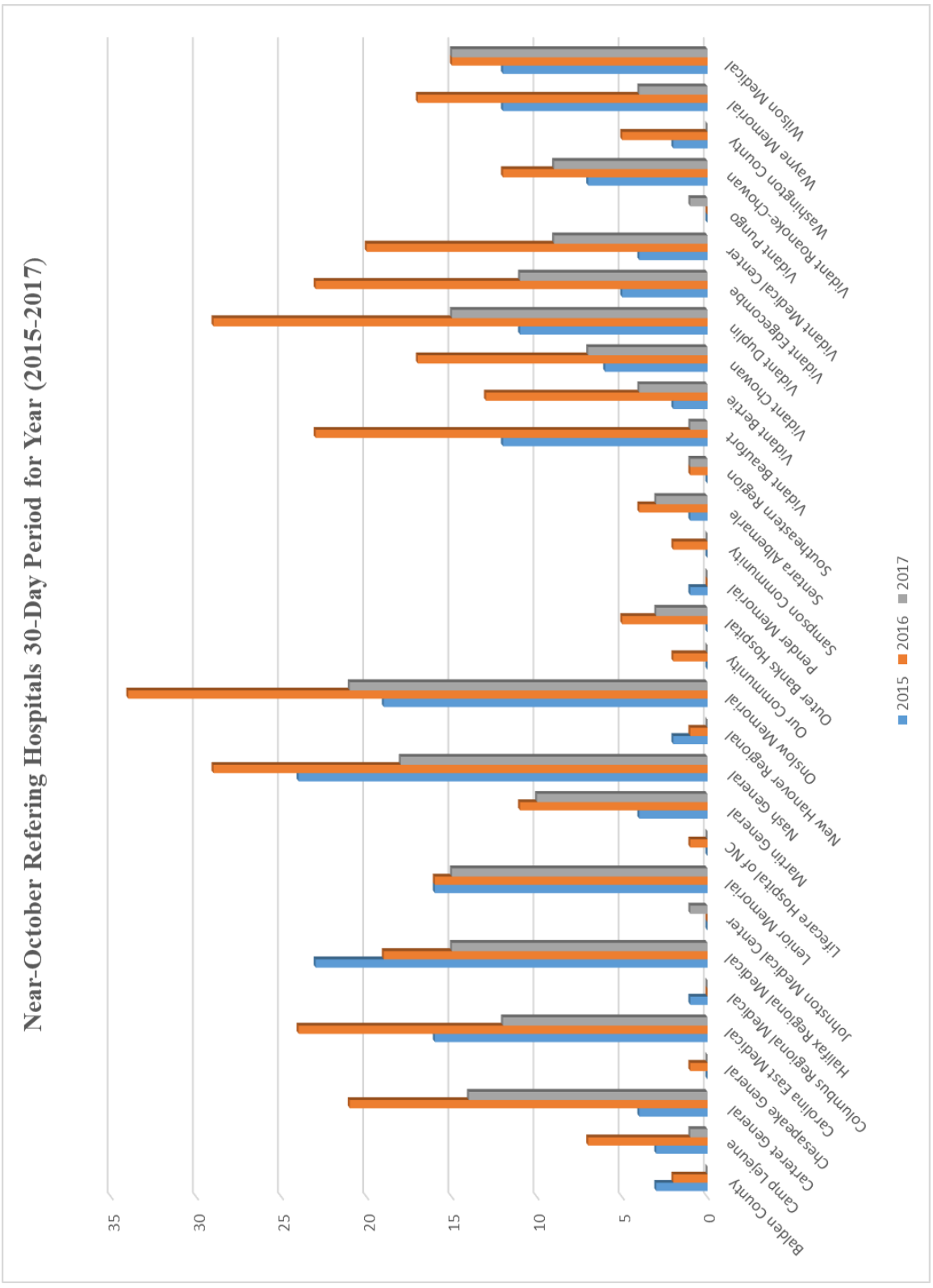


Figure 7 display the 30-day referring hospital calls around October 8th.

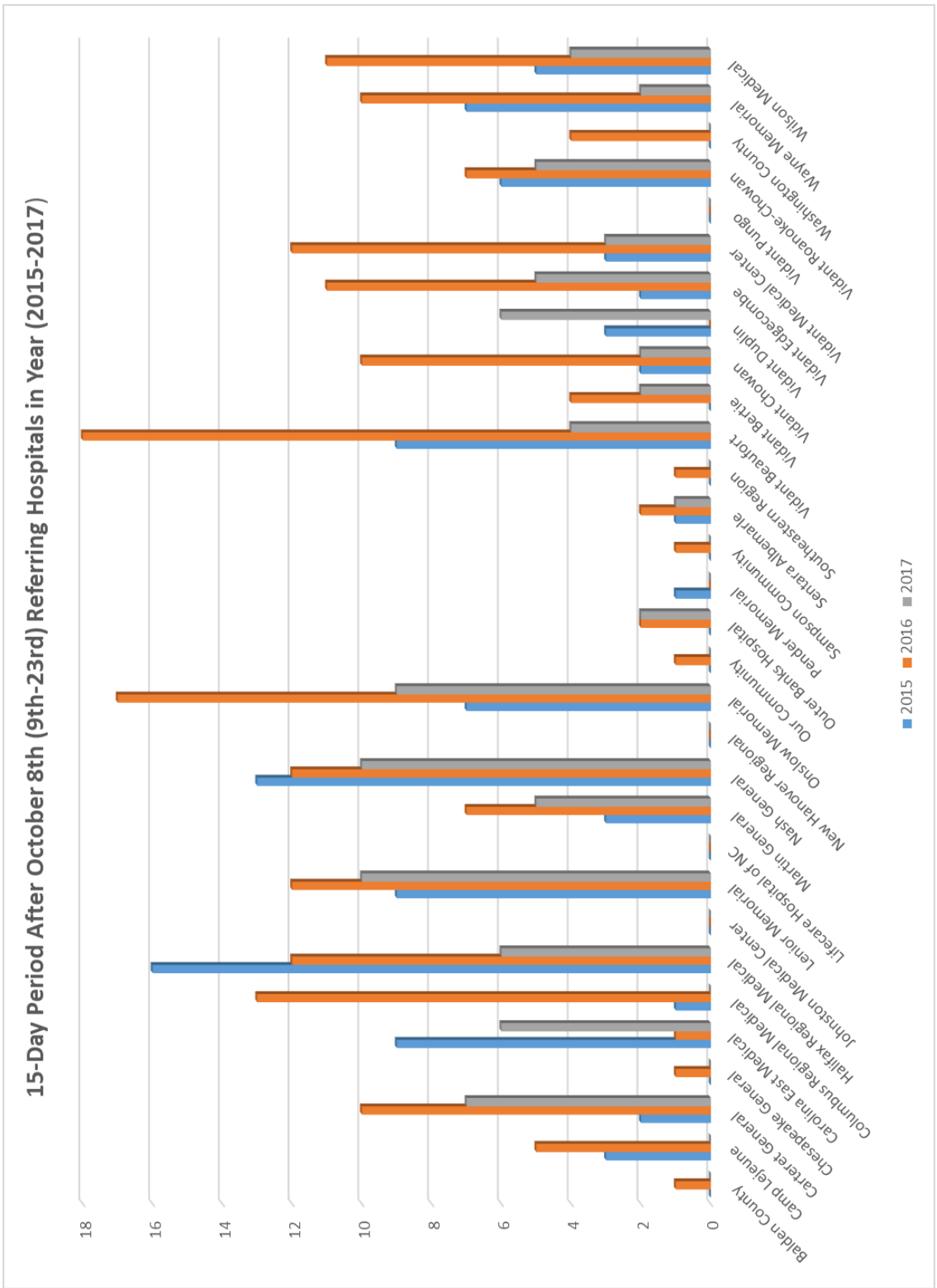


Figure 8 shows the 15-day referring hospital calls after October 8th for year (2015-2017)

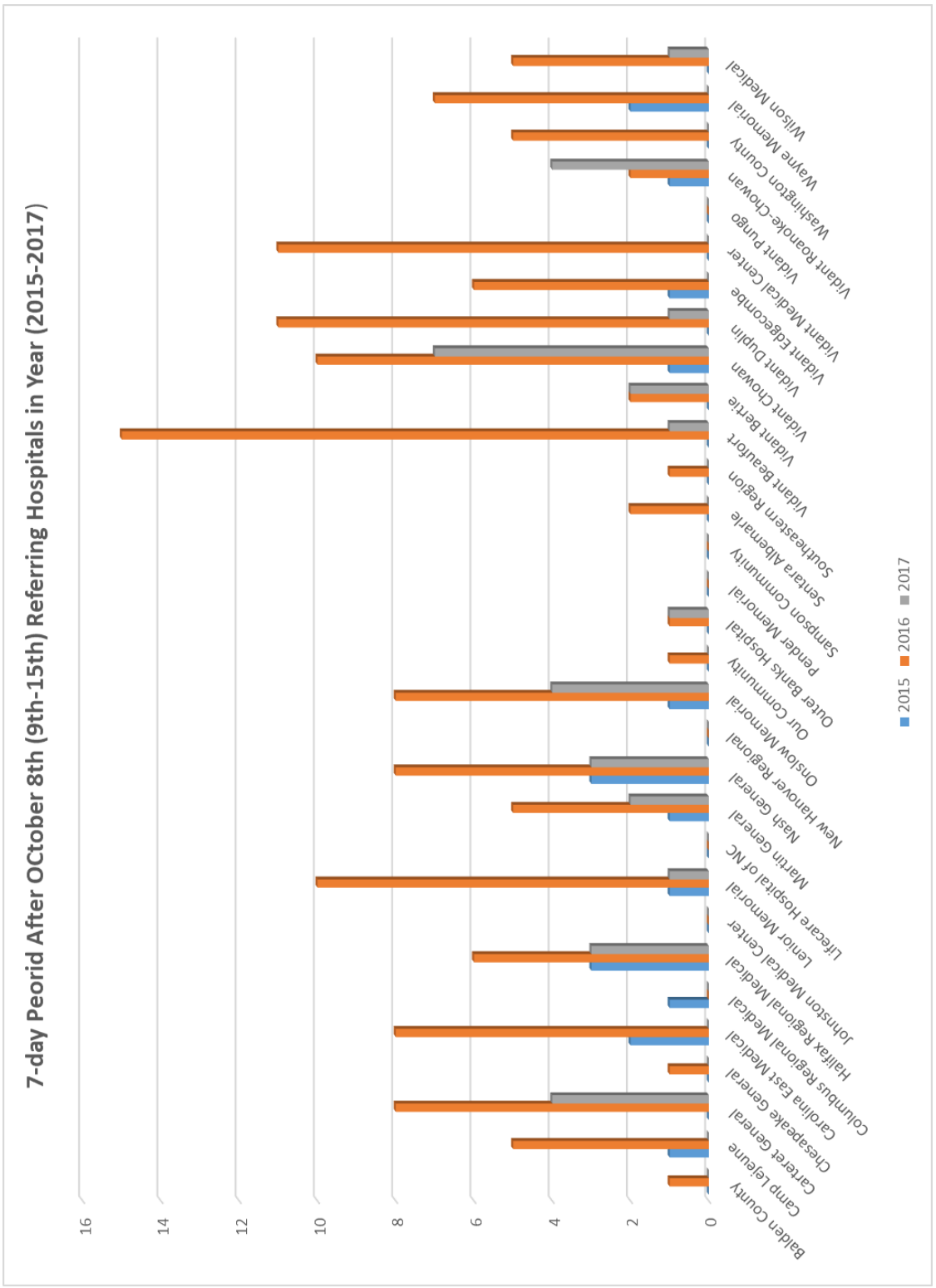


Figure 9 shows the 7-day referring hospital calls after October 8th for year (2015-2017)

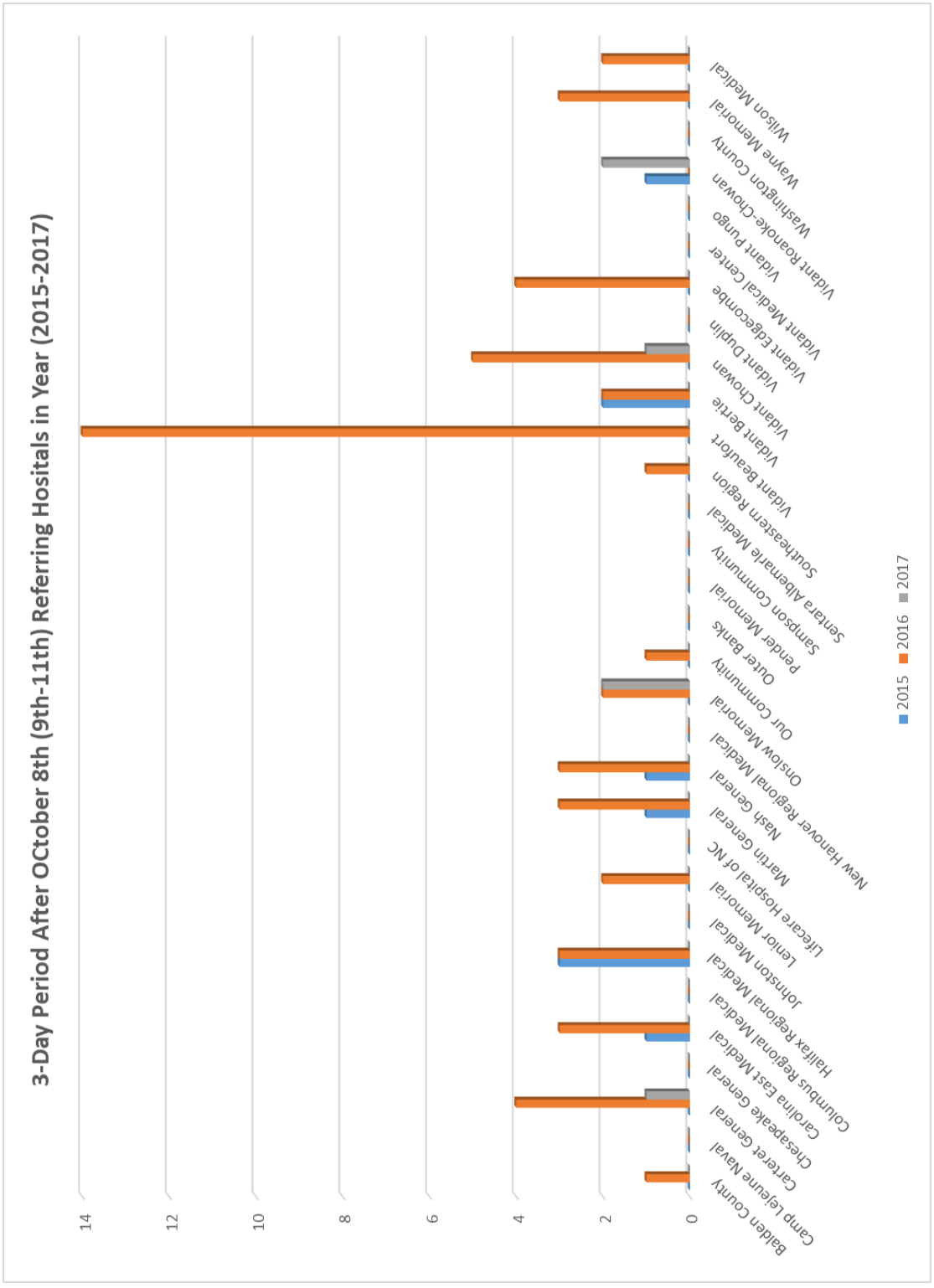


Figure 10 shows the 3-day referring hospital calls after October 8th for year (2015-2017)

Examination of the medical category types shows an increase in the magnitude of all category counts in 2016 when compared with each time period. The leading medical category found over every time peroid (3-day, 15-day, 7day, 30-day) was medical calls (ex. general adult problems that don't require surgery) (Figs. 11-14). Cardiac calls show another significant difference between the hurricane and non-hurricane periods (Figs. 11-14). The cardiac calls in 2016 were almost half of the calls received with 7-day period after Hurricane Matthew (Fig 13). The medical category in 2016 had 32 calls within 3 days after the storm and in the year 2015 and 2017 3-day period there were a total of 4 calls combined for medical pickups (fig. 14). The number of medical call pickups increased by 20 or more transitioning from the 3-day peorid to the 7 day period (figs. 13-14). The same pattern occurred when going from the 7-day period to the 15-day period (figs. 12-13). Throughout the whole month of October over 50 percent of the medical calls came after Hurricane Matthew (figs. 12-13).

Other magnitude increases, but likely not significantly different between the hurricane and non-hurricane periods include trauma (ex. car accidents, falling down, gunshot), pediatric, STEMI, neurological, and neonatal for the 30-day period. The same results are identified for the trauma calls 15-day peorid. Over half of the calls received for truma cases happen 15 days after the storm (figs. 11-12). The last category with significant very closely is pediatric (18 or younger individuals). Within the 7-day period there was 14 calls which is very high when compared to 2015 and 2017 (fig. 13).

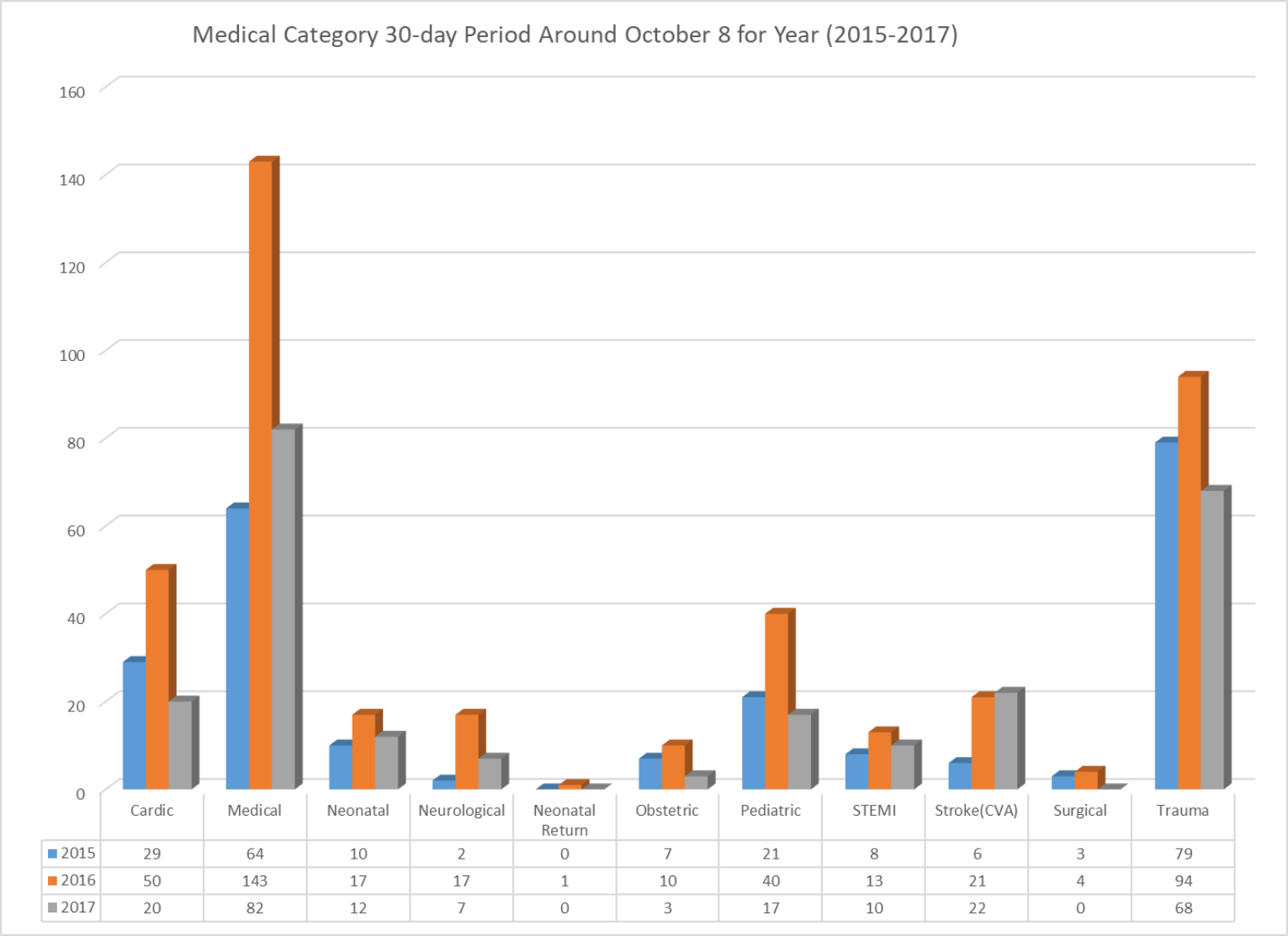
Pediatric referrals are significantly higher for the 3-day and 7-day periods (Figs. 13-14). This finding seems relevant to management and staffings of the VEC facilities as there is clear evidence for a significant increase in pediatric cases immediately following the hurricane when compared with "normal" conditions. There are also higher incidences of stroke calls as well

during the 3-day and 7-day, but these do not seem to be significantly different from the periods of non-hurricanes. Obstetric referrals following the storm also have a similar response as the stroke calls.

There are significant differences in the patterns of the age of patients requiring assistance between the hurricane and non-hurricane periods under investigation (Figs. 15-18). Patients 55 and above and 65 and above expereince peristently higher referral rates over all 4 time periods under consideration in the current study. The 30-day period also exhibits signifcant increases in the referrals for age categories 45 to 54, 25 to 34, and 5 and under (Fig. 15). The 3-day period following the storm sees significant increases across all age categories except the 25 to 34 category (Fig. 18). The 3-day pattern remains relatively consistent over the first week after the hurricane except the 18 to 24 category does not show a significant difference over this period (Fig. 18). By the 15-day period, only the 25 to 34, 55 and above and 65 and above (Fig. 16).

Analyses of the various age categories highlight a clear high response rate in all age categories immediately following the hurricane, minus the college age and young adults. Older adults seem to be most heavily impacted by a hurricane in terms of their referral rates. This finding is corroborated by other studies related to natural disasters where chronic diseases in older adults place these individuals at higher risk because the disaster leads to disruption of health care and exacerbation of the chronic disease (CDC, 2004; Aldrich and Benson, 2008; Bell et al., 2018). Miller et al. (2013) also identified a higher rate of injuries to individuals 69 years and older immediately following Hurricane Irene in ENC. Secondarily, young children also seem to have high referral rate across the entirity of the periods under investigation, but these referral rates have a bimodal nature to their distribution that is centered on the earlier and later periods of referral.

Not examined in the current study, but a common theme in many other studies is the fact there is an increase in emergency room visits preceding the hurricane landfall. Miller et al. (2013) and Pines (2018) both identified spikes prior to the hurricane that were larger than normal visits, but not of the same order as those received after the hurricane. This trend while not as significant as the post-hurricane impacts could also impact the VEC operations and should be examined in further detail.



	Cardic	Medical	Neonatal	Neurological	Neonatal Return	Obstetric	Pediatric	STEMI	Stroke(CVA)	Surgical	Trauma
2015	29	64	10	2	0	7	21	8	6	3	79
2016	50	143	17	17	1	10	40	13	21	4	94
2017	20	82	12	7	0	3	17	10	22	0	68

Figure 11 Shows the 30-day period around October 8th of type of medical calls that occured

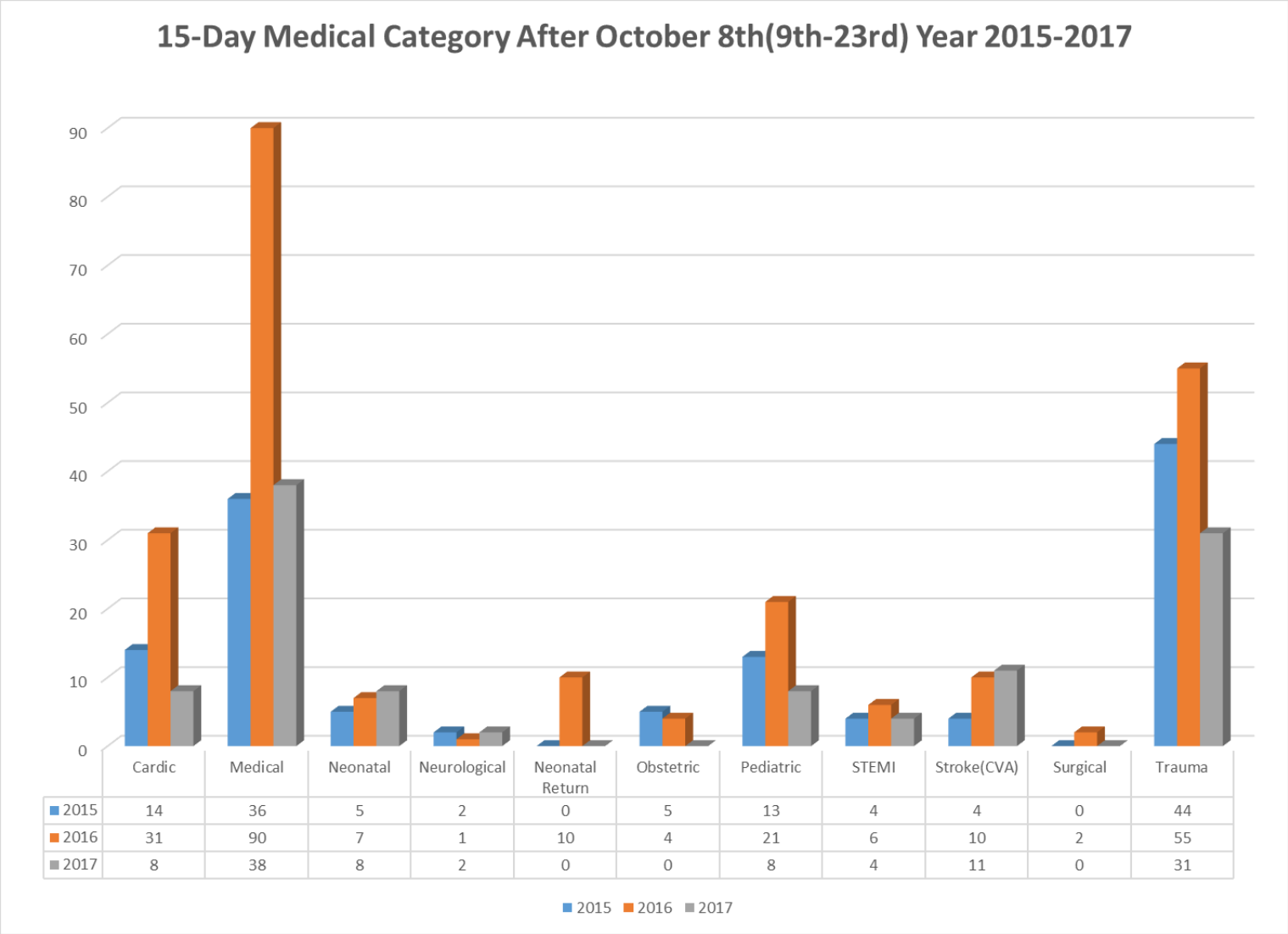
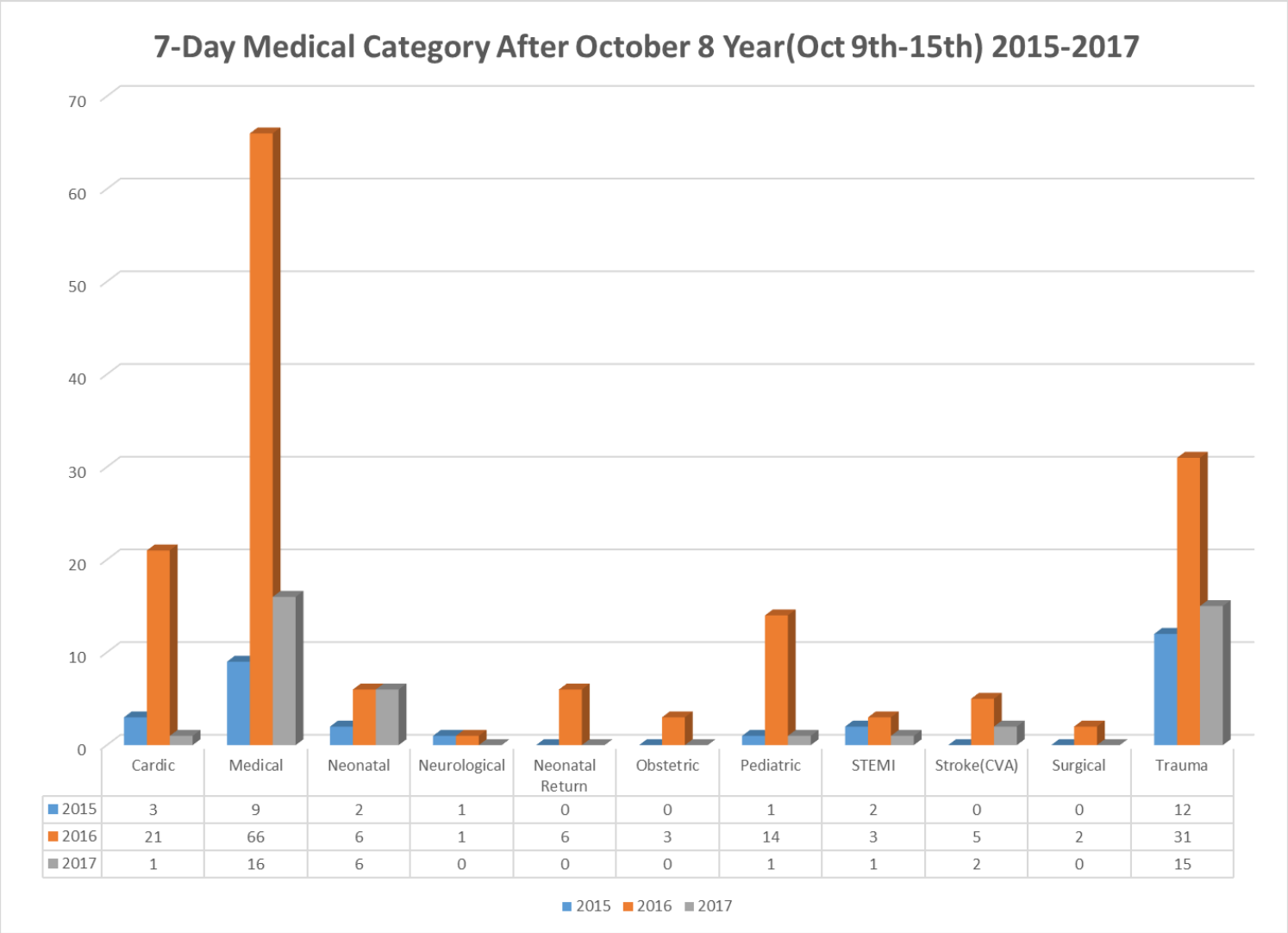
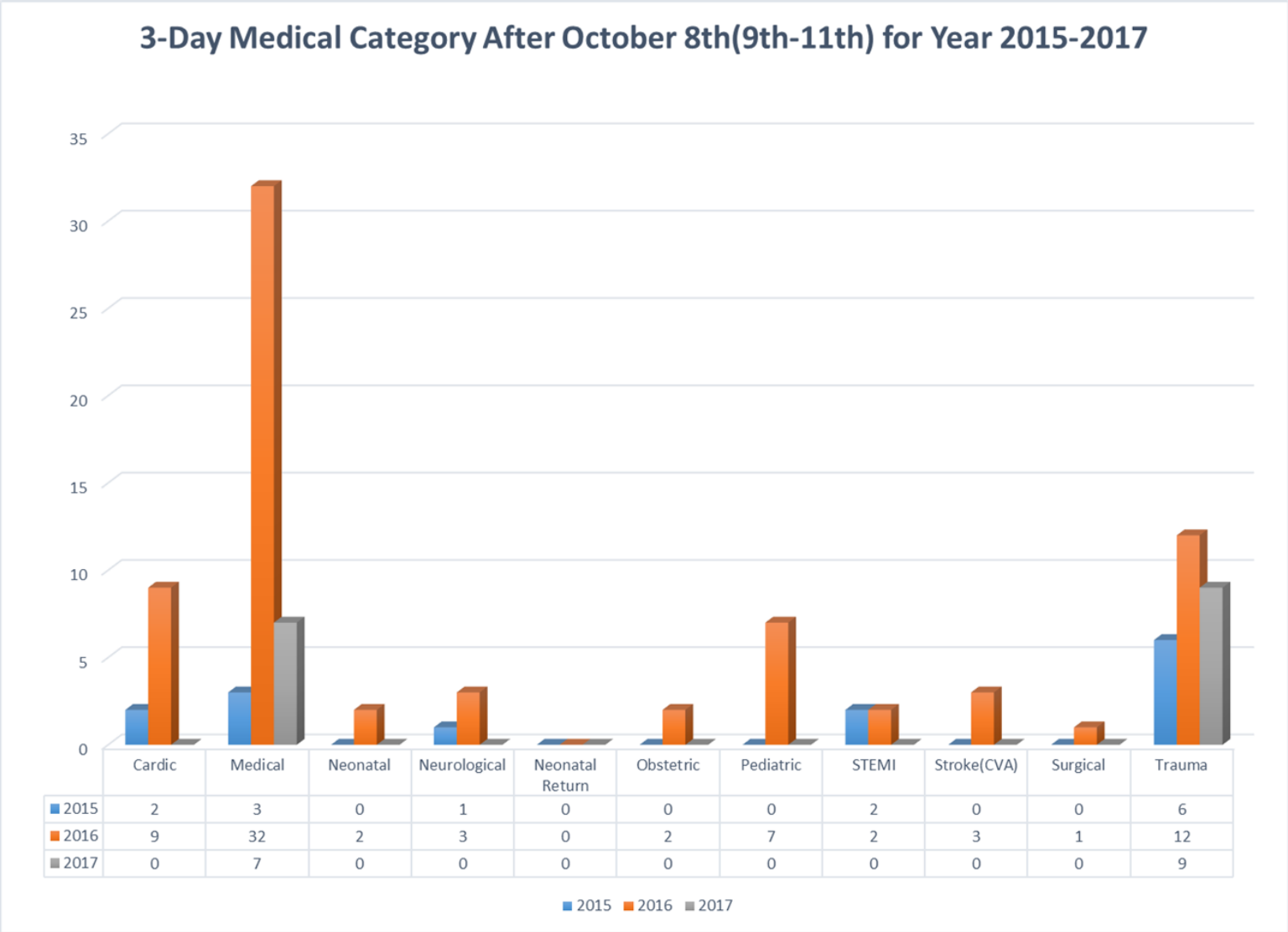


Figure 12 shows the 15-day period after October 8th of medical calls that occur.



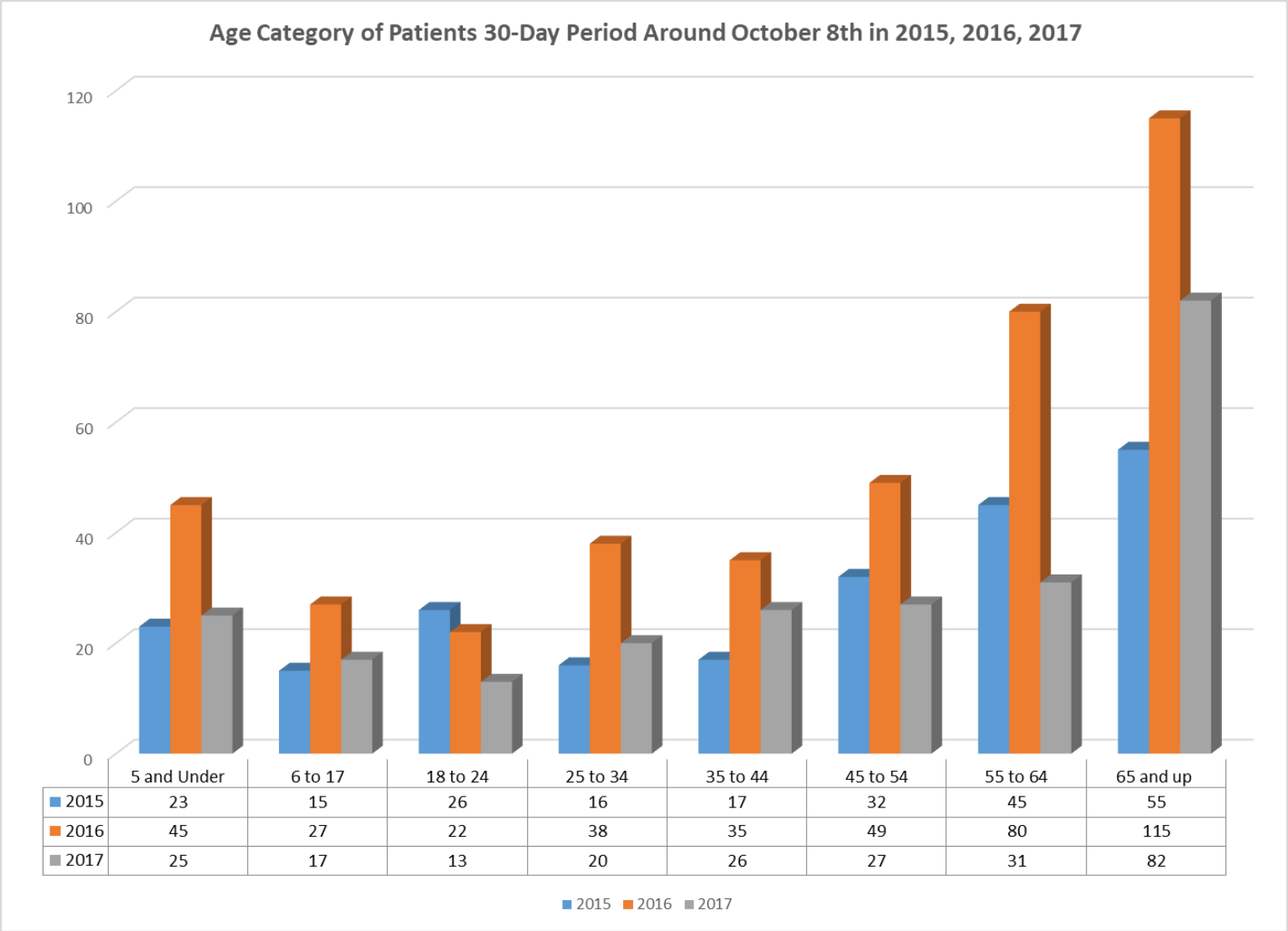
	Cardic	Medical	Neonatal	Neurological	Neonatal Return	Obstetric	Pediatric	STEMI	Stroke(CVA)	Surgical	Trauma
2015	3	9	2	1	0	0	1	2	0	0	12
2016	21	66	6	1	6	3	14	3	5	2	31
2017	1	16	6	0	0	0	1	1	2	0	15

Figure 13 shows the 7-day period after October 8th of medical calls that occur.



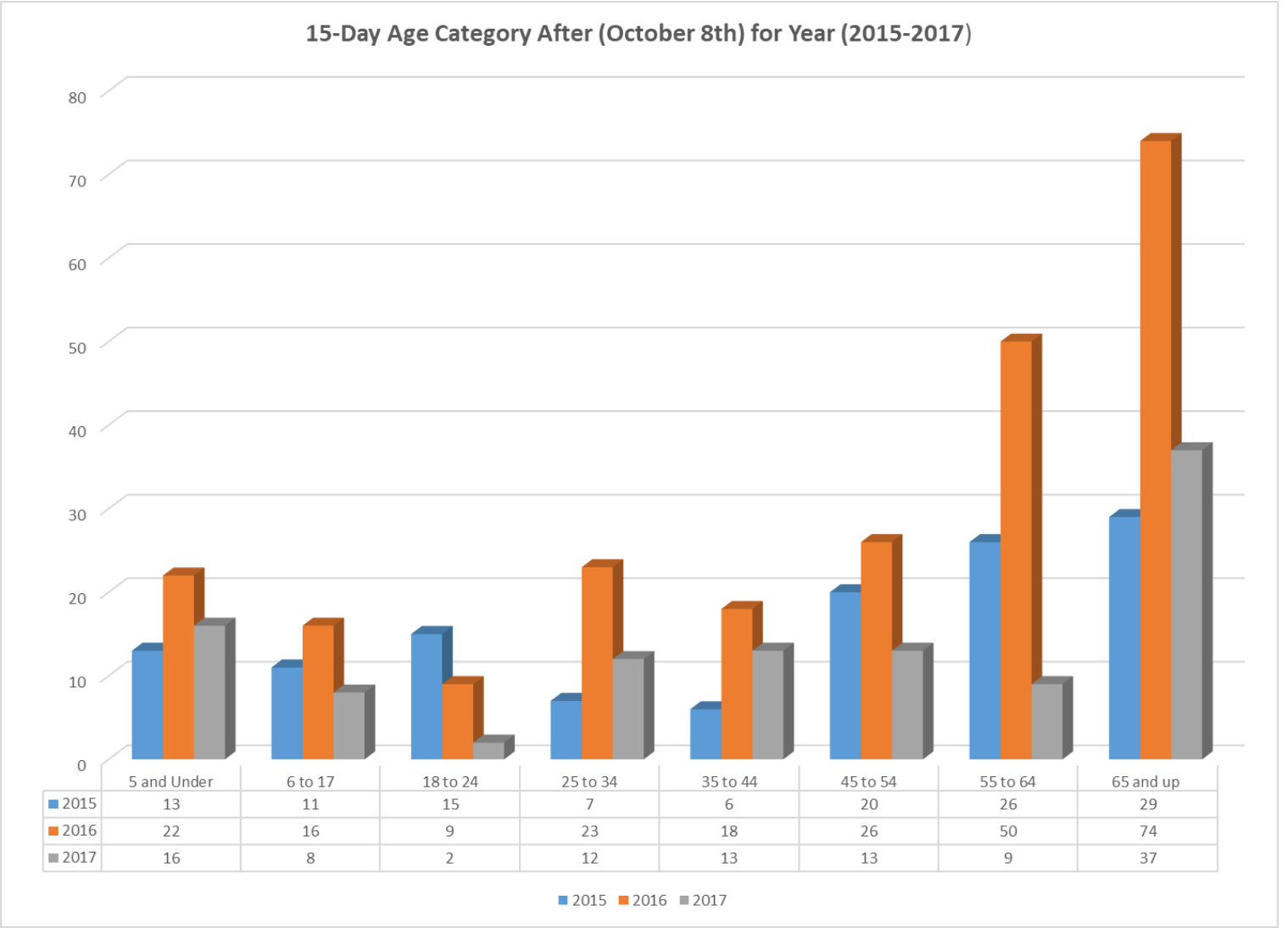
	Cardic	Medical	Neonatal	Neurological	Neonatal Return	Obstetric	Pediatric	STEMI	Stroke(CVA)	Surgical	Trauma
2015	2	3	0	1	0	0	0	2	0	0	6
2016	9	32	2	3	0	2	7	2	3	1	12
2017	0	7	0	0	0	0	0	0	0	0	9

Figure 14 shows the 3-day period after October 8th of medical calls that occur.



	5 and Under	6 to 17	18 to 24	25 to 34	35 to 44	45 to 54	55 to 64	65 and up
2015	23	15	26	16	17	32	45	55
2016	45	27	22	38	35	49	80	115
2017	25	17	13	20	26	27	31	82

Figure 15 displays the age of the total patients that transported to hospitals by helicopter during the 30-day period around October 8th



	5 and Under	6 to 17	18 to 24	25 to 34	35 to 44	45 to 54	55 to 64	65 and up
2015	13	11	15	7	6	20	26	29
2016	22	16	9	23	18	26	50	74
2017	16	8	2	12	13	13	9	37

Figure 16 display the age category of patients that was transported by helicopters during the 15-day period after October 8th

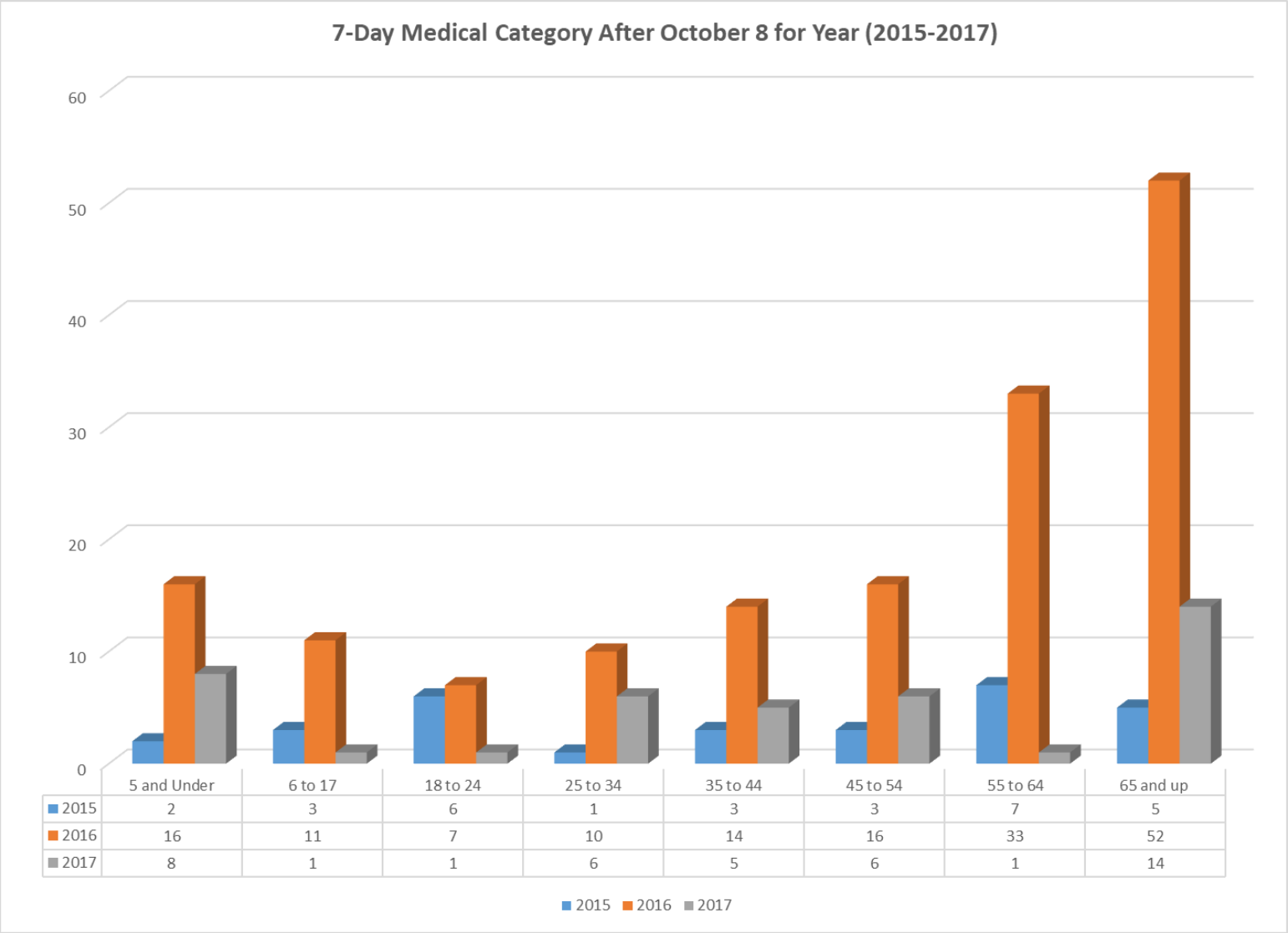
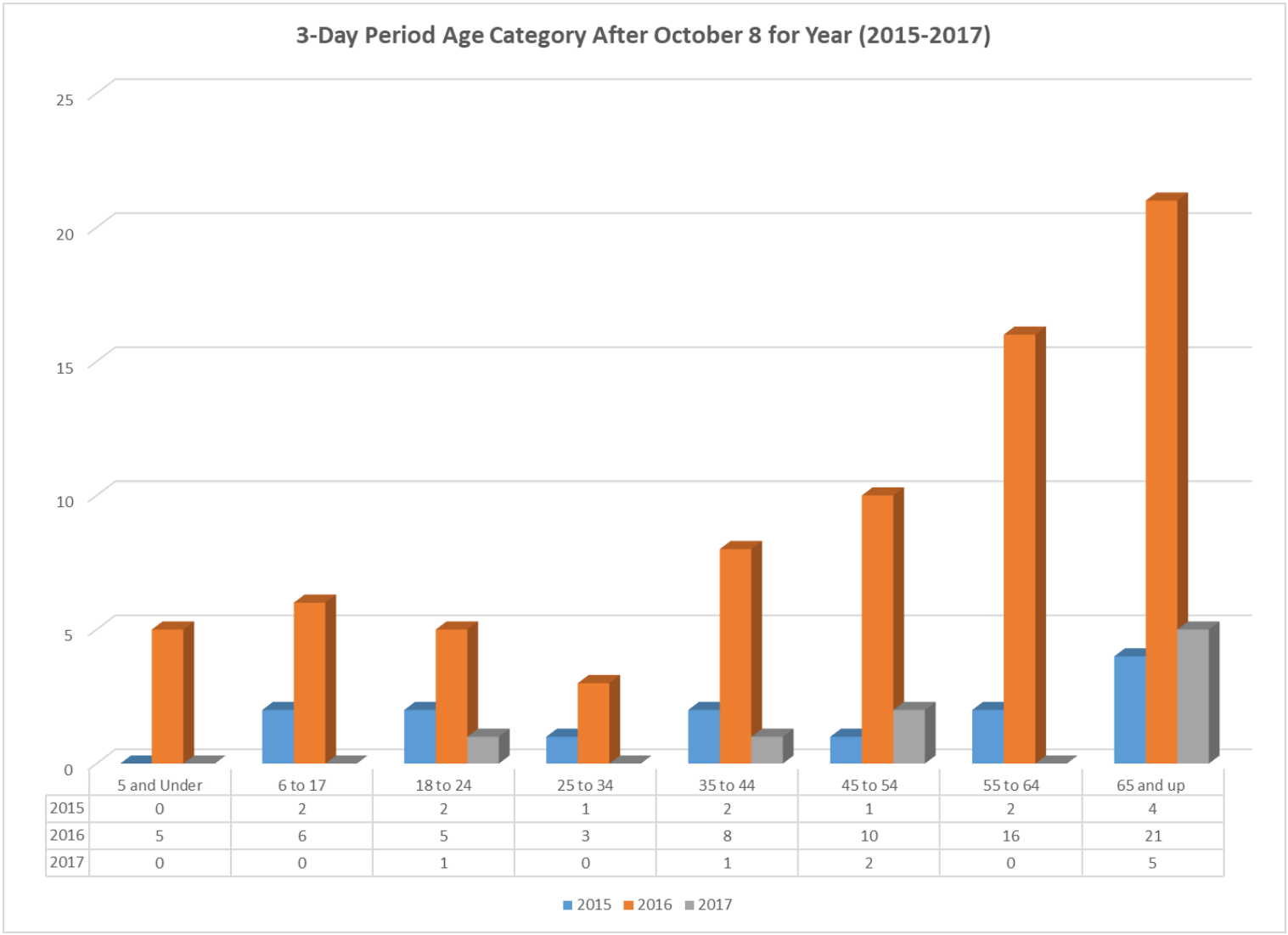


Figure 17 display the age category of patients that was transported by helicopters during the 7-day period after October 8th



	5 and Under	6 to 17	18 to 24	25 to 34	35 to 44	45 to 54	55 to 64	65 and up
2015	0	2	2	1	2	1	2	4
2016	5	6	5	3	8	10	16	21
2017	0	0	1	0	1	2	0	5

Figure 18 display the age category of patients that was transported by helicopters during the 3-day period after October 8th

Trend surface maps show the emergency call intensities across eastern North Carolina for each 30-day, 15-day, 7-day and 3-day periods for all years under investigation in the current study (2015, 2016, 2017) using RBF by the patient zip code. Because majority of the points came from referring hospitals, using the exact coordinates points will only have bull eyes effects over the hospital location and the data would show heavy bias to the referring hospital. The results highlight distinct spatial patterns are present in medical responses between the 2015, 2016, and 2017 (Fig. 19). A large, elongated hotspot occurs after the hurricane along the Pamlico Sound and there are also significant hotspots on the Outer Banks (Fig. 19). Onslow, Beaufort and Bertie Counties are also areas where there are large numbers of patients from following Hurricane Matthew. Lower intensity and lower call volumes are identified in these areas for 2015 and 2017 when compared with 2016(Fig. 19). The results corroborate the findings from the referring hospitals shows high values where the hotspots or patients zip codes are located (Fig 7).

When examine the RBF interpolation from the different times period, the 2016 hot spots are located in the same area for the 15-day, 7-day and 3-day (Figs.20-22), but the spots become more concentrated to a center area around the outer bank of Dare, Hyde, and Beaufort County. When reducing the days after the storm. This pattern reveals the destinations that need the most support on initial impact of a hurricane. The same areas were also impacted significantly during Hurricane Floyd which was the last major storm since Matthew to demolish the ENC. Two years later Hurricane Florence had hit the eastern NC had broken previous flood records set b both Floyd and Matthew and demolish the same area. The 3 deadliest hurricanes in NC all devastated the same area in eastern NC when it came to flooding and EMS had to transport family to shelters or hospitals. Also, another factor that is displayed is that patients from outside of ENC are located in ENC during and after the hurricane. This likely represents people who were

traveling to the storm area to protect valuables, property, or to clean up after the storm. Another factor is college towns around these areas may have led to people outside of eastern NC to get hurt. Mt. Olive College, College of the Albemarle, Elizabeth City University, and East Carolina University are all colleges that are in hotspots areas of each year.

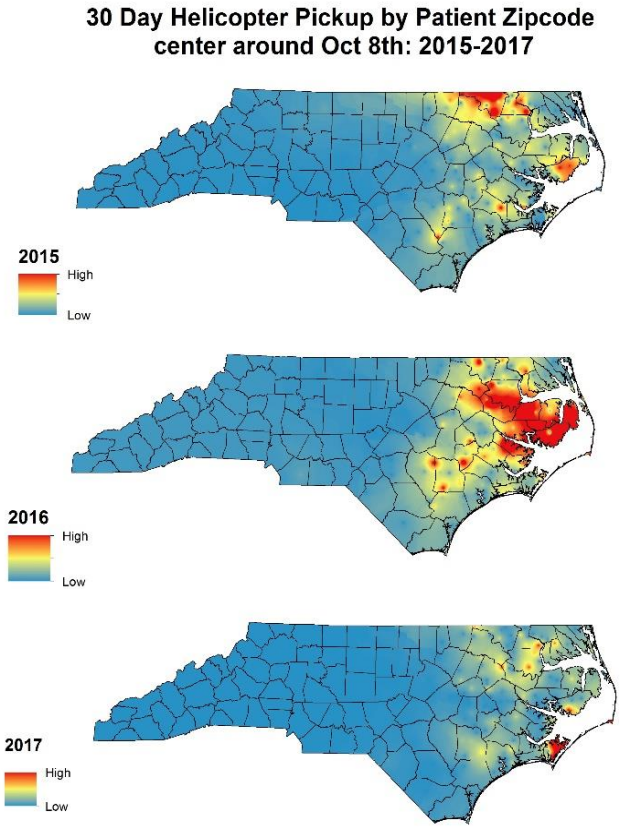


Figure 19 displays 30-day hotspots results of Hurricane Matthew

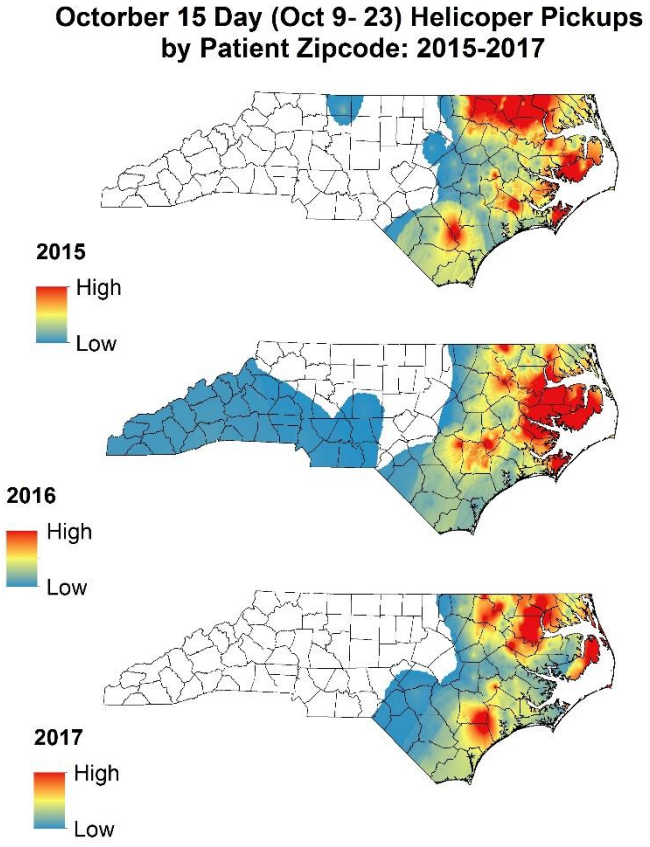


Figure 20 displays 15-day hotspots results of Hurricane Matthew

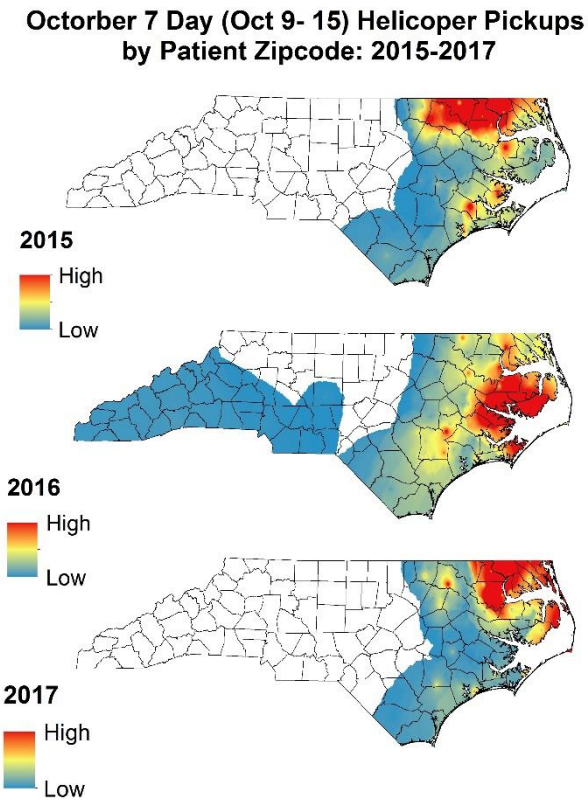


Figure 21 displays 7-day hotspots results of Hurricane Matthew

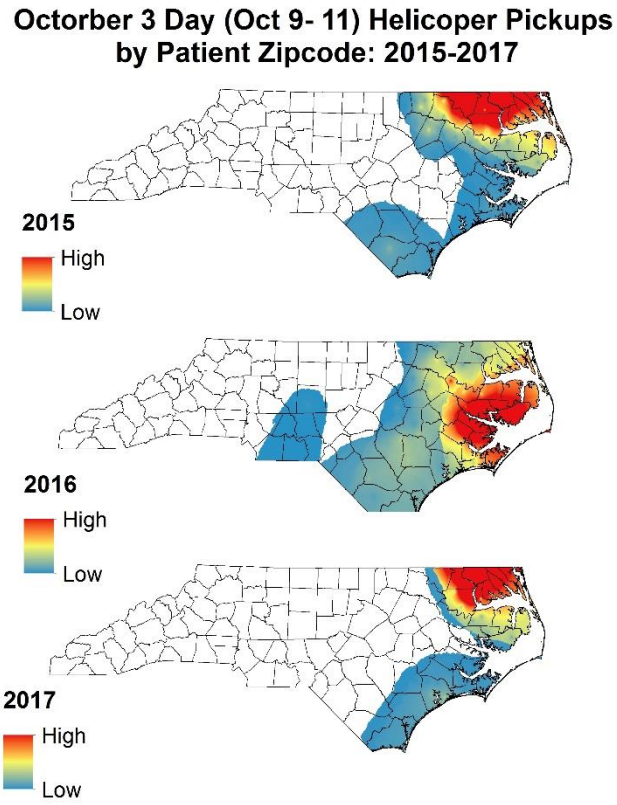


Figure 22 displays 3-day hotspots results of Hurricane Matthew

Conclusion

The goal of the research was to explore spatial and temporal patterns of the effects of Hurricane Matthew had on air medical transport. The magnitude and frequency of calls were markedly different across the medical categories for each analyzed time period (30 day, 15-day, 7day, and 3-day). In general, the shorter time-frames show hot spot areas become more concentrated around the Outer Banks and Pamlico sounds immediately after Hurricane Matthew. The year preceding and following the hurricane show a similar pattern whereby the majority of VEC flights happen close to the boarder of Virginia. These hotspots may be occurring in 2015 and 2017 because of the Chesapeake VA hospital have a contract with VEC. The main findings

show Dare, Beaufort, Bertie, and surrounding counties close to the Outer Bank and Pamlico Sound need to be a focus during hurricane since those are usually the hardest hit areas. These finding also correlates with the rainfall figures(figs.1-3) in chapter 1. The same areas also had a large spike in rainfall averages from only seeing perception averages of 3-4 inches in 2015 and 2017 but in 2016 areas on the outer bank was recording averages of up to 10 inches of rainfall for the month of October. The results corroborated findings in previous studies that medical calls are the most frequent during hurricane regardless of the different time periods. Some of the hardest challenges of this study are to make accurate hotspot interpolations of the exact location of the patient but because of the regulation of the IRB the patient zip code had to be used to have a range of error to predict the hot spot locations.

This study can also lead to future studies with using the ground EMS pickups to see how it correlate with the EastCare helicopter pickups. A goal moving forward is to make sure hospitals and emergency centers are more prepared for the most impacted medical category and the various in the various age groups impacted during hurricane from the results in Figure (7-14). Also because of the finding showing areas just outside of the Outer Bank (Bertie, Beaufort Lenoir etc.) emergency management can monitor counties that have issues with sustaining operations during the next hurricane event (fig 16-18). Last major plan is to increase staff in the hospitals and supplies that have the most transfer to reduce the emergency personal having to risk their own lives during dangerous environments (figs 4-8).

CHAPTER 3: Summary

Summary Statement

The findings from the current study identify important insights into the questions regarding to helicopter pickups in Eastern during hurricanes events. The initial question addressed in this research was how spatial patterns of helicopter pick-ups change in the wake of a hurricane. Significant differences were identified in the emergency air pickups across ENC were identified immediately following Hurricane Matthew in comparison similar days in years prior and after during the Hurricane Matthew. Both 2015 and 2017 were years without hurricanes. The central, northern part of ENC is a common location where helicopter transport is required during non-hurricane years. During Hurricane Matthew, the Outer Banks and areas experiencing the heaviest rainfall during the hurricane were the main hot spots for helicopter pickups. This results in a complete shift in the pick-up area to the south and east for this particular hurricane.

One issue covered in the research literature was how long can the impacts pressures of a hurricane be on medical facilities and personnel? While a consensus was not found in the literature, several studies showed substantial impacts on medical facilities and personnel extend for two weeks after hurricane makes landfall. This hypothesis was explored for Hurricane Matthew and its impact on the helicopter response teams. Significant differences were identified in the spatial patterns of calls for 3-day, 7-day, 15-day and 30-day time periods immediately following Hurricane Matthew. The findings also indicate significant differences in the magnitudes of calls and the magnitudes of different call responses (another research question often addressed in the current research literature) for the helicopter crews. While some of these results support the conclusions of existing literature, it should be noted that in current study area, the impacts of Hurricane Matthew extended well beyond the two-week timeframe generally

considered to be the window of concern by previous researchers. This finding has significant implications for VEC helicopter crews and emergency medical staff because significant higher magnitudes of call and significant differences in call responses extend out to at least 30 days after the hurricane. This means the VEC helicopter crews and emergency medical staff might have to prepare and plan for increased calls and patient numbers and these impacts to the medical system for a month or more following a hurricane. This highlights the need for increased staffing and medical supplies for extended periods after a hurricane makes landfall.

A final concern addressed in the current research was do hurricanes impact all age groups in a similar manner in terms of the magnitude and types of medical responses? There is general agreement that younger and older age members of communities are going to be disproportionately impacted in the event of a hurricane. Often a strong positive correlation with the age range of 65 and older has been found in the previous work. The results in the current study show the elderly class was consistently impacted throughout the 30-day period of analysis. However, all other age classes, except for the 18 to 24 age class, were found to have increased magnitudes of calls throughout the study period. The magnitudes were not as high in many cases as they were for the age class 65 and older. The 18 to 24 class seemed to fair much better immediately following the hurricane than other groups. The results support much of the conclusions of previous researchers examining the impacts of hurricanes of populations and medical responses.

This work represents one of the first studies on emergency management to show spatial and temporal extent of a hurricane on a regional hospital and air response team. The impacts of the hurricane extend beyond what has normally been perceived as the window significant impact to the medical community. The study has also been designed to use spatial analyses to provide a

novel view of how a hurricane changes the hotspots of air responses in ENC. While this work has advanced our understanding emergency air medical responses following a hurricane, more research is needed to fully understand the importance of helicopter pickups in ENC in a longer-term context. The goal of the longitudinal study would be to provide more information to support and predict planning for future emergency responses.

Limitations/Purposed Future Research

As with most studies, there are limitations to what can be extrapolated from the current study. These range from number of hurricanes that can be evaluated to the data available as a result of HIPAA Privacy Act, and in the current study the ability to access emergency ground transportation data. While these items do not in any way detract from the findings of the current research, they do provide an opportunity to examine how to improve on the study in the future.

The current research has only focused on a single hurricane. This does not permit the researcher to make broader statements about air responses following hurricanes in ENC as hurricanes are an omnipresent hazard in the region and very seldom do hurricanes take the same track. Future research need to identify if the same results and spatial patterns are present in the same area when hurricanes approach Eastern NC along different tracks. If the impact areas of different hurricanes are similar, then it will strengthen the credibility of the current research.

The hotspot analysis in the current research was further limited by mapping with patient zip codes because of constraints placed on the researcher during ECU's IRB process. The spatial resolution of census block analyses might be considered in future research. In this scenario, the researcher could use the exact pickup points by counting each point that fall in the census block which would make the hotspots maps more detailed. While the overall gross patterns are likely

not to change in current study, this style of work would lend itself to more accurate comparisons over multiple hurricanes.

The recovery time is very short for a hurricane because areas could be struggling to recover and get harm indirectly due to the storm over a period of time. One idea would be looking at flooding from storm surge and rivers overtopping their banks and their impacts on road closures. Road closures have a significant impact on emergency ground transportation and therefore, certain regions where road closure are extensive are going to have to rely more on airborne medical teams to respond to calls. These patterns could be tracked by examining NCDOT road closure data. Furthermore, closure may also impact ground pick-up times and might be more efficient for airborne teams to pick-up individuals in cases where drive times from rerouting associated with road closure becomes an issue. A limitation in the current study was to not have EMS ground response data or helicopter travel times. This shortcoming is important. Future research should compare travel times in the event where road closures could determine whether ground response or flight response would be the most efficient for certain emergencies.

The current research has highlighted critical information of hurricane impacts to ENC. More work is needed and data available to explore this and other emergency response patterns in ENC. Hopefully this research will encourage others to continue to investigate emergency management in ENC and others area to aid in developing communities that are more resilient to impacts of hurricanes.

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APPENDIX A

Projects Requiring IRB Review vs. Quality Improvement, Quality Assessment, or Quality Assurance: A Worksheet to Assist in Determining When IRB Review is Required

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Use this worksheet to help determine whether a proposed activity or project involving humans or their individually identifiable information is considered research needing IRB review or a quality related activity that would not require IRB approval.

	True	False
The PRIMARY purpose of the proposed activity or project is to learn about or learn from existing care to IMPROVE what is done here at the local institution with regard to patient outcomes, efficiency, cost, patient/staff satisfaction, etc.	☒	☐
The activity or project would be carried out even if there was no possibility of publication in a journal or presentation at an academic meeting. (**Please note that answering "True" to this statement does not preclude publication of a quality activity.)	☒	☐
The activity or project falls under well-accepted care practices/guidelines.	☒	☐
The activity or project involves no more than minimal risk procedures meaning the probability and magnitude of harm or discomfort anticipated are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.	☒	☐

If **any** of the above answers is "False", a submission for IRB approval is most likely needed. If all the above answers are "True", then it is very likely that IRB approval is not required. Please contact the Office of Research Integrity and Compliance (ORIC) with any questions at 252-744-2914 or umcirb@ecu.edu. If you would like the ORIC to verify that an activity or project is not human subject research, please provide this form along with a summary of your activity to the ORIC at umcirb@ecu.edu and the following page will be completed and returned to you for your records.

Project title: Effect of Hurricane Matthew on EastCare operations

Summary of activity including information about project aims/objectives, methods for carrying out the project and information about data to be collected (you may instead attach documentation describing your proposal):

The project will use data from EastCare flights performed in the aftermath of Hurricane Matthew (2016) to see what effect, if any, the hurricane had on the response pattern of EastCare aircraft. The index year will be compared to a similar time period from the year prior to the hurricane (2015) and the year after the hurricane (2017). This information will include both the sites of the calls and the nature of the calls. All personal identification will be stripped from the data prior to analysis. The analysis will include the use of descriptive statistics and geographic information system technology. The primary goal of this will be to refine the response of EastCare to future significant weather events. A secondary goal will be to describe this information in a journal article.

*** The ORIC will contact you if any further information is needed to make this determination. Please note that if the ORIC determines the activity is not human subject research, then any presentation, publication, etc. should not refer to the activity as "human subject research", "exempt research" or "expedited research".

ORIC Determination:

☑ Not Human Research: The ORIC has determined that based on the description of the project, approval by the IRB is not necessary. Any changes or modifications to this project may be discussed with the ORIC at that time to ensure those changes do not elevate the project to human research that would need IRB approval.

☐ Human Research: This project requires review by the IRB prior to initiation. An application in the electronic IRB submission system should be submitted.

ORIC Staff Signature: Suzanne Spanow **Date:** 12-6-18