COMPARISONS OF FLOOD AFFECTED AREA DERIVED FROM MODIS AND LANDSAT IMAGERY

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ABSTRACT

During the first few weeks of June 2008, the Midwest experienced a weather system that dropped large amounts of rain across the region. In southern Indiana the Wabash and White Rivers went several feet above their flood stage and many people were displaced from their homes and businesses. This study uses the event as a test case for comparisons of resolutions and data from the MODIS and Landsat 5 TM sensors. A k-means classification scheme is created to cluster the data to identify the flood region in the imagery. Calculations are then made to estimate a flood area for each resolution. A statistical study is then performed to analyze false positive and false negative rates using the Landsat imagery as "ground truth". The results of the area estimate and statistical study support a claim that coarse resolutions, 1 and 2 kilometers, provide the most accurate measuring of area in large scale flood events, but the overall location of the fine details of the flood are lost. The finer resolutions (500 and 250 meters), while more accurate about locations of fine details, have a higher false positive and false negative rates that raise questions about their ability to effectively use this classification scheme to measure overall area. The conclusions of this research promote further questions as to what resolutions could be effectively used gain an accurate map and measurement of the inundated area's extent.

1. INTRODUCTION

During a flood event, the need for more immediate satellite imagery is increased by demand from emergency resources. Lower resolution satellite imagery has the ability to adequately map an inundated area more rapidly than that of a high resolution satellite that may only pass a specific point every 12-14 days according to USGS Landsat technical specifications. This paper will discuss that ability to map a flooded area using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery and compare it to the results gained from higher resolution Landsat 5 TM data. The higher resolution data will be used as a "ground truth" of the inundated area.

Specifically, this research addressed two questions. First, how does the estimate of flood affected area vary when analyzed using a variety of sensors and resolutions? Second, how does the flooded fraction estimated from the MODIS imagery compare to the "ground truth" provided by the high-resolution Landsat data? By answering these questions the hope was to progress towards goals of effectively mapping seasonally inundated wetland areas for climate modeling applications as well as providing insight into the variability of using different sensors and resolutions for rapid flood mapping. The benefits of that rapid mapping would provide knowledge to emergency resources and scientists to better measure and predict the consequences of a major flood event or inundation season (Galantowicz, 2002).

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2. BACKGROUND

2.1 Southern Indiana Flooding

The flood event used for this case study occurred during the early part of June 2008 in Southern Indiana. Heavy rains across the Midwest on June 6th and 7th left many parts of region with up to 11 inches of rain. The week following this event included major flooding, especially from the Wabash, White, and Embarras rivers. The flood affected portion of the Wabash River runs primarily along the Indiana-Illinois border from about half the length of the western border of Indiana southward to the Kentucky border. This study focuses on that portion of the river as well as the areas of the White and Embaras rivers that intersect with it.

During the event 29 counties in Indiana were declared major disaster areas by the federal government with 23 of them put into a state of emergency by the state government. Early estimates of $126 million in damage were reported with a total of up to $1 billion if the cost of clean-up and agricultural losses are included (Hicks, 2008).

The flood imagery for both the Landsat and MODIS were retrieved for 11 June 2008 which corresponded with the peak time of flooding shown by the Figure 2.1. The non-flooded imagery was retrieved for 14 April 2010, a time in which the river discharge levels closely matched those present before the flooding occurred in June 2008. This date was used because of the lack of available cloud-free and matching imagery before the flood.

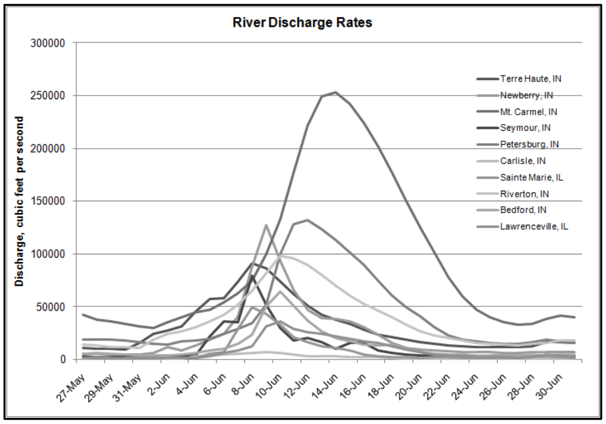

Figure 2.1 USGS Streamflow data for gauge locations during the flood event

2.2 Satellite Imagery

Data from two different sensors were used in this case study, the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Landsat 5 Thematic Mapper sensor. The MODIS sensor is a multispectral instrument aboard the NASA Earth Observing System (EOS) Aqua Satellite launched in May 2002 (Salmonson, 2004). It provides imagery at varying resolutions from 250 meters to two kilometers at 36 different bands. The bands used in this study were 1, 2, and 7 with bandwidths of .620 - .671 µm, .841 - .876 µm, and 2.105 – 2.155 µm respectively. The corresponding spectral radiances were 21.8 Wm^{-2}–µm-sr, 24.7 Wm^{-2}–µm-sr, and 1.0 Wm^{-2}–µm-sr respectively. Bands 1 and 2 were available at 250 meter resolution while band 7 was available at 500 meter resolution. This information was courtesy of NASA/GSFC, MODIS Rapid Response and NASA MODIS Website. These bands were chosen because of the availability of the imagery from the MODIS Rapid Response Website as well as contrasts that the imagery provides between water, land, and vegetation. The reflectance of water with these wavelengths makes the water in the image appear black. Aqua also provides an image including the same specific point once every 1-2 days.

The Landsat 5 Thematic Mapper Sensor provides 7 spectral bands at with pixels of 30 meters in size. The bands used in this study were 3, 4, and 5 with bandwidths of .63-.69 µm, .76-.90 µm, and 1.55 -1.75 µm respectively.

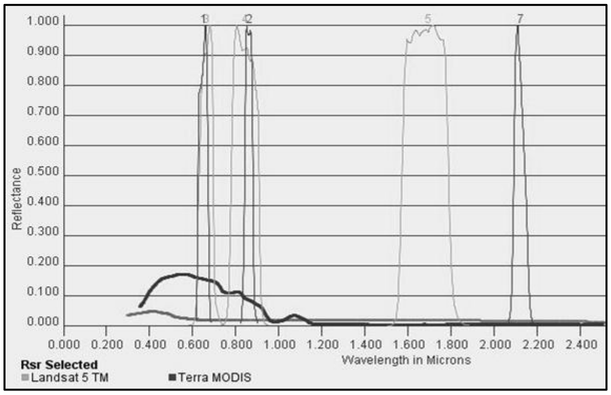

Figure 2.2) Displays the wavelengths of all bands used from the MODIS and Landsat 5 TM sensors. Also shown is the reflectivity of both clear water and turbid water. MODIS bands used are 1, 2, 7 (dark grey) and Landsat bands used were 3, 4, 5 (light grey). Image retrieved from the Spectral Viewer software on the USGS website.

These bands were chosen because of similar reasons to the MODIS imagery. They provided a distinct contrast of water, land, and vegetation that was easily distinguished by the classification scheme used in this study. The figure 2.2 provided shows the band's wavelengths along with the reflectance from water.

3. METHODOLOGY

3.1 K-means Classification Scheme

To obtain a complete estimate of flood area based on the MODIS and Landsat area the satellite data needed to be classified into clusters. The technique used to perform this classification was a k-means clustering analysis. The basis for this classification found a nominal number of centroids within the data to identify significant clusters (Huang, 1998). This classification is effective at separating various colors and because of that it is able to cluster together land cover types. The scheme is able to identify water, dirt, clouds, and different types of vegetation. The more complex in color and variety the image was the more centroids and clusters were needed to properly classify each land cover type. This method, when used correctly, would identify all water and flooded areas in the specified region of data.

The input for this classification scheme was the 3 bands used from each satellite platform. For the MODIS data those bands were 1, 2 and 7 and for the Landsat it was bands 3, 4, and 5. These bands were chosen because of the reasoning discussed in the previous section. From this input a matrix was created combining all 3 bands together. The k-means scheme then performed its classification in which centroids were identified and all points were classified based on their distance from a centroids location. The centroids are identified by a process that locates points that have a minimal mean distance from the rest of the data. The MODIS imagery required 6 clusters compared to the 3 for Landsat due to the increased complexity of the MODIS data. MODIS included clouds, more varieties of vegetation and a larger area overall during classification. The Landsat was simpler in its identification of centroids because of the lack of clouds and other noise in the imagery.

Once the clusters are identified, objective analysis was performed on the resulting data. Direct comparisons were used between a raw image of the satellite data and the cluster determined to be water. This determination was made my identifying the cluster with the lowest centroid number in the data out of a 256-color range. This lowest centroid corresponded to the water cluster because water was always the darkest color (black) and the lowest centroid value in a 256 value color scheme From the objective visual comparisons made with the satellite imagery, performance of the classification scheme was determined. Imagery of known flood areas were used to compare against the classification results of water. The figure 3.1 below shows an example of that comparison.

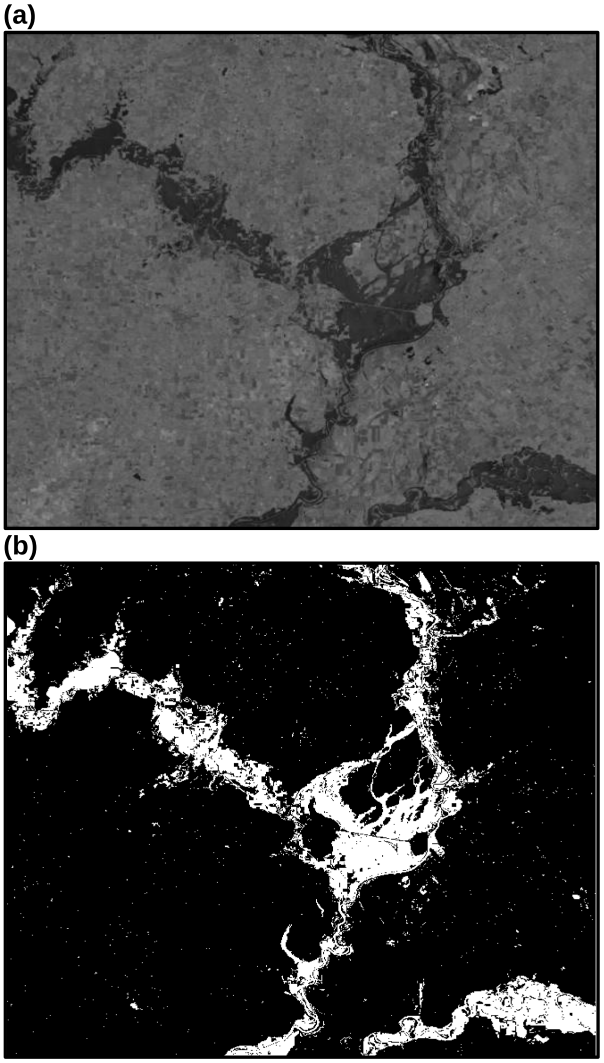

Figure 3.1) (a) Displays a grayscale image from a RGB layered image of bands 3, 4, and 5 of the Landsat 5 TM sensor at 30m resolution. (b) Image of completed classification of water in the Landsat imagery. Both images are at 30m resolution. Images are approximately 60km by 60km.

After the classification is determined to be accurate, a count of the pixels is necessary for a flood affected area calculation. This process was made simple because of the ability to separate the classification results into individual cluster matrices. Each pixel is given a binary value in which it is considered part of the cluster or not. The binary numbers were used to identify pixels that were considered part of the classification for water. Every binary "on" pixel was considered 100% water by the classification scheme for MODIS. The location of each pixel in the water cluster was recorded for spatial analysis and area calculations.

3.2 Spatial Analysis

Once the location of each pixel considered flooded in the classification matrix was identified and recorded, spatial analysis could be performed to obtain an area for each flooded pixel. This process resulted in a total flood affected area calculated from the sum of areas of each flooded pixel. The method used to obtain an accurate area for each pixel was a map projection of the satellite data. Projecting the imagery will result in latitude and longitude values for the boxes that surrounded the pixels. The projection for the MODIS imagery was a Platte Carree projection while the Landsat data used a Universal Transverse Mercator (UTM) zone projection.

With the resulting latitude and longitude ranges a simple MATLAB operation calculated the total area covered by the pixel. This operation output the fraction of the Earth that is within the latitude and longitude box. A simple unit conversion and area calculation was then performed to obtain an area in square kilometers. This process is repeated for each pixel until a total flood area can be calculated for each resolution.

3.3 Flood Fraction Comparison

Following the resolution and sensor comparisons of flood area, a statistical study was performed to analyze the flooded fractions obtained when comparing a classified MODIS binary pixel to the classified Landsat data of the same size and location. The goal of this analysis was to measure the performance of the MODIS data to map and measure the flooded area by analyzing false negative and false positive ratios.

The process of obtaining a flood fraction comparison between the data required the latitude and longitude boxes from the classified MODIS pixels. A uniformly random sample of 10,000 pixel boxes from each of the MODIS resolutions was overlaid onto the classified Landsat data. The Landsat date returned a fraction of flood coverage in the box area. Figure 3.2 shows an example of the boxes retrieved from the flooded pixels of classified MODIS 2 kilometer imagery overlaid onto band 5 of the Landsat imagery.

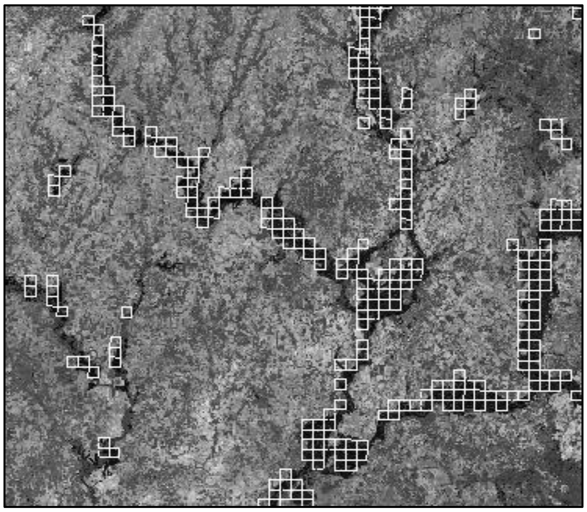

Figure 3.2) An overlay of the identified latitude and longitude boxes from the 2km MODIS imagery. The boxes represent the flooded pixels in the imagery. The boxes are approximately 2km by 2km. They are overlaid on an image of band 5 of the Landsat 5 TM 30m resolution data.

With the flood binary value available for each box, a comparison can be drawn between that value and the fraction of area in the box considered flooded by Landsat. From the MODIS information there are only 2 result options, flooded or non-flooded. The Landsat information produces a fraction result with a value between 0 and 1. The next step was to observe the false positive and negative rates that the comparisons between the two sets of data produced.

In the study a false positive was considered a situation in which the MODIS binary pixel was "on" or flooded and when the Landsat returned a fraction of flood coverage in the same area of less than .4. A false negative was defined as when the MODIS binary pixel was "off" or non-flooded and when the Landsat returned a fraction of flood coverage greater than or equal to .4. The group of false negatives and positives were then separated into two groups each. The false positives were divided by what the actual flood fraction values was. One group was boxes with flood fractions less than .1 and those with flood fractions greater than or equal to .1. The false positives were divided in a similar way but between those with fractions less than .7 and those with fractions greater than or equal to .7. This separation helped to give an idea of the confidence of false positive and negative ratios.

Overall, the ratios helped to determine the performance of the MODIS data and classification scheme to accurately measure the flooded area.

4. RESULTS

4.1 Resolution and Sensor Comparisons

The first set of results to analyze was the performance of the MODIS satellite imagery to produce an accurate estimate, according to the Landsat ground truth, of flood affected area. By estimating the area covered by every flooded pixel from each of the four resolutions of MODIS imagery, a total area can be calculated. The 250 meter resolution was included even though band 7 of the imagery was only in the 500 meter resolution. This may have led to more error but the classification scheme including two other bands in the 250 meter resolution may have avoid major error in the classification and calculation of area. This fact was considered when analyzing the results of both the area calculation and flood fraction comparison.

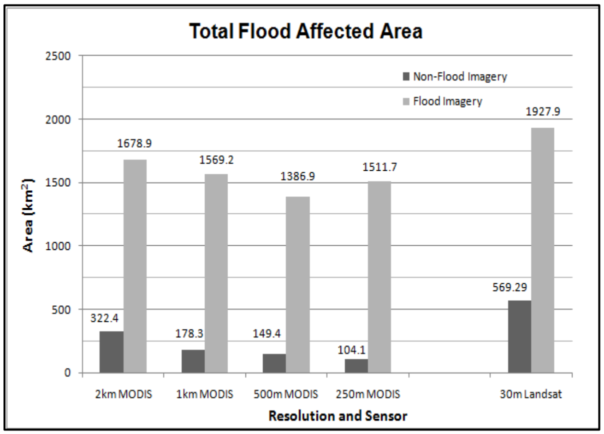

Figure 4.1 Shows total flood affected area derived from both the MODIS resolutions and Landsat data for both the flooded and non-flooded scene. Area is displayed in square kilometers.

Figure 4.1 displays the total flooded area from both the flooded imagery and the non-flooded imagery. Both sets of MODIS data from the two days show a decrease in total water area as the resolution becomes finer. The one exception is the 250 meter resolution during in the flood imagery. This total area shows a slight increase from the 500 meter resolution, closely matching the 1 kilometer resolution. Also shown on the figure is a data column for calculated Landsat area both the flooded and non-flooded imagery. This was considered the “ground truth” in all comparisons and discussions. All of the MODIS resolutions in both situations, flooded and non-flooded, estimate a lower flood affected area than the ground truth Landsat data.

4.2 Flood Fraction Statistics

After the calculation of flood area was performed and analyzed, the second study was initiated to observe the flood fraction comparison. Following the process previously described, values were obtained for false positive and negative ratios. Figure 4.2 below displays the rates in their four groups for both the flooded and non-flooded sets of imagery. The figures show a general increase in false positive and false negative ratios as the resolutions become finer.

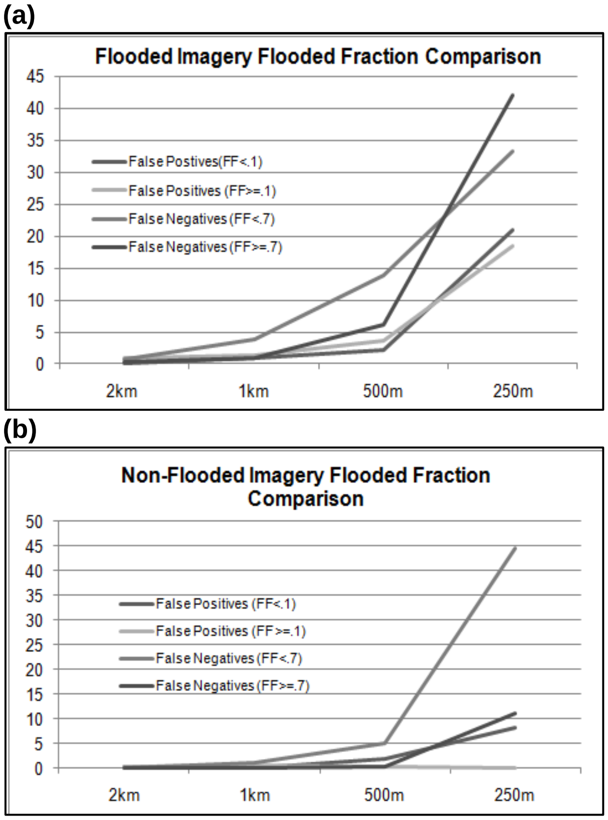

Figure 4.2 (a) (b) Presents the two false positive and two false negative rates of each of the four MODIS resolutions and for both of the (a) flooded imagery and (b) non-flooded imagery

One note about the results, the 250 meter resolution was included so the large increase from the 500 meter resolutions may be skewed in a way that is in error. This was taken into account during the analysis of the results. Even with this fact, the ratios still show an overall increase from the coarse resolutions to the fine resolutions. The ratios are at low levels in the coarse resolutions (1 and 2 kilometers) and increase in size as the resolution gets finer.

5. DISCUSSION

5.1 Trends of Resolution Comparison

By observing the results and graphs presented in the previous section it is apparent that trends are present in the flood area values. The decreasing total area as the resolution of MODIS becomes finer is a trend that has many possible explanations. The consensus drawn from this research is that as the resolution gets finer and as the pixel size gets smaller the total area from a binary "on" or flooded pixels also gets smaller. So, while the total number of flooded pixels increases as the resolution gets finer and more details of the flood area is resolved, the extra area falsely considered flooded is no longer included in the estimate. The false area is the non-flooded area included from a large pixel, especially in the 2 kilometer size, that is considered flooded when the classification scheme considers an entire pixel 100 percent flooded. In truth, this area is not completely inundated with water but is included in the flooded area because the classification scheme only produces a binary value for the entire pixel. This fact adds extra area to the overall flood size estimate.

With the noted errors in the 250 meter resolution data, it is important to note the higher probability for a skewed value for flooded area estimate. But with that in mind, another reason for the increase in area from the 500 meter resolution would be the ability for the 250 meter data to better resolve smaller features of the flood. The inclusion of smaller channels, lakes, and rivers would increase the area significantly. This corresponds to the increased flood area seen with the Landsat data. The inundated area estimate for Landsat is higher in both the flood and non-flood cases. This is attributed to the Landsat 5 TM 30 meter resolution and its ability to resolve fine details of the flood region. Variability along the edge of rivers, lakes, and channels can alter the flood area in significant ways.

5.2 Flood Fraction Statistical Results

Based on the flood fraction comparison results, the performance of the MODIS imagery and classification scheme to effectively map and measure the flood area can be determined. The low false negative and positive ratios of the coarse resolutions, 1 and 2 kilometers, displayed in Figure 4.2 show that these resolutions produce an accurate measurement of the flood area using the classification scheme. In the case of 500 meter resolution, the low false positive ratios for both divisions and the low false negative ratio for the boxes with a fraction greater than or equal to .7 shows an ability for that set of data to also effectively measure the flooded area. The elevated false negative ratio for boxes with a flood fraction less than .7 translates to increased error when calculating the flood area with the 500 meter resolution.

The analysis of performance of the coarse resolutions also took into account the fact that there was an increase in non-inundated area included in the total flood estimate. This occurs when a large (2 kilometer) MODIS pixel box was considered flooded even with a low true flooded fraction. So while the flood area estimate of these coarse resolutions may be closer to the Landsat "ground truth" estimate, it may not be because of an accurate measurement of the exact location and size of the inundated area. The inclusion of non-inundated area in the pixels that are used for the flood area estimate could counteract the exclusion of the finer details of the flood location and terrain characteristics. The values of flood area may be more accurate but the reasoning behind the value may be in error.

The addition of the 250 meter resolution data shows elevated values of false negative and false positive ratios that would eliminate this set of imagery from being able to accurately measure flood area. The increased error is assumed to be from the fact that one of the bands, band 7, is at the 500 meter resolution and is being compared with bands 1 and 2 at 250 meter resolution. Also, one other option for the increased ratios is the lower margin for error when using the smaller 250 meter resolution pixel boxes. The small size limits the amount of possibilities for flood fraction values and increases the effect that a single Landsat pixel would have on the overall flood fraction of the box. For example, a 250 meter resolution pixel box would have 1/64th the amount of Landsat pixels included in the overlaid MODIS box than that of a 2 kilometer pixel. This limited amount of pixels to retrieve a flooded fraction from could increase the error.

6. CONCLUSIONS

The discussion presented in the previous section allows for conclusions to be made about the comparison of resolutions with MODIS and the flood fraction comparison between the two sensors. From the results of the resolution comparison, the consensus is that while the inundation area estimates for the more coarse resolutions may be accurate in terms of the number being similar to the "ground truth" Landsat estimate; it may not be accurate for the correct reasons. The inclusion of non-flooded area from a pixel with a low flood fraction adds extra area considered flooded to the overall estimate. Also, with the discussed errors in the 250 meter resolution imagery, it is hard at this time to understand if the increase in accuracy of the area estimate from the 500 meter data is from a better ability to resolve fine details or if it comes from errors in the resolution comparison and classification. The fact that Landsat has the highest flood estimate points to the 250 meter resolution's ability to better resolve fine details of the flood, but study needs to go into this belief before a concrete idea can be established. From the resolution comparison by itself, it is unclear as to which resolution has the highest performance when mapping and measure the flood extent.

When including the statistical study that focuses on flood fraction comparisons, the results reveal an idea about the more accurate resolution with the classification scheme created in this research. The relatively low false negative and false positive ratios of the coarse 1 and 2 kilometer resolutions comparisons reveal an overall accuracy of the classifications scheme in these cases. The large amounts of data points available in each pixel box to create an accurate flood fraction for comparison led to these low rates. The 500 meter resolution also showed promise except for the increased false negative rate in both the flooded and non-flooded cases. The 250 meter resolutions shows elevated false positive and false negative rates which points to large inaccuracies in the classification scheme with this data. Again, the errors noted with the 250 meter data present a challenge in understanding the reasoning behind these inaccuracies. Also, the limited amount of Landsat points inside a MODIS pixel box lowers the margin for error when calculating a flood fraction. This statistical study by itself shows a higher accuracy in the coarse resolutions when using this classification scheme. While this result is surprising it was properly explained by this research.

With the addition of these results, this overall study concludes that even with the knowledge that extra non-inundated land may be added when a MODIS pixel with a low flood fraction is considered 100% flood by the classification scheme, the coarse resolutions provide the most accurate estimate of inundated area. The low false positive and negative ratios of the 1 and 2 kilometer resolutions back up this claim. They explain that the addition of non-inundated area is minimal during the classifications scheme and calculation of the overall flood estimate. While this research was based on one flood event, the technique used for classification and estimation of flood area could be easily adaptable to over regions and events. The results in this study are a stepping stone towards mapping of short and long term events that have large implications with local populations and global climate

7. ACKNOWLEDGEMENTS

The authors acknowledge AER for their technical and administrative support. The resources used at AER were essential to the completion of this research. We also acknowledge the Purdue University and University of Oklahoma's IT department. The computer usage of Mathwork's MATLAB with this project was substantial and could not have been completed without their resources.

Kevin Van Leer would like to John Galantowicz and his helpful mentoring throughout this research process. His guidance and patience made it an enjoyable and educational experience. Finally, the authors acknowledge the National Weather Center REU program and the Center for Analysis and Predication of Storms for opportunity to perform this research and for this experience that has untold long and short term benefits.

This material is based upon work supported by the National Science Foundation under Grant No. ATM-0648566. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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