Alabama Disasters: Leveraging NASA EOS to Explore the Environmental and Economic Impact of the April 27 Tornado Outbreak

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The disastrous tornado outbreak in Alabama on April 27, 2011 greatly impacted the economy of the state. On record, the tornado outbreak was the second deadliest tornado outbreak in U.S. When considering the agricultural and value-added activities such as food and timber processing, farm inputs, manufacturing, transportation, and retail sales, the dollar value of Alabama agribusiness annually exceeds $40 billion (NASS, 2011). This research aims to examine how the timber and agriculture damage affected the state economy of Alabama and will be used to aid in long-term economic recovery. ASTER imagery was used along with ground-truthed NASS (National Agriculture Statistics Service) crop location records to verify the economic impact tornadoes had on the agricultural economy of the state. This swath damage can be calculated by correlating tornado path with NASS statistics on crop yield, precisely showing the fields affected and dollars lost to this disaster. Not only can this be executed manually using ENVI and ArcGIS, but also through the use of Python, a programming language that has the ability to automate the process, creating a product for initial damage assessment.

I. APRIL 27, 2011

The devastating effects of the April 27th, 2011 tornado outbreak will be felt by Alabamians for years to come. The most destructive and deadly tornado outbreak in the state's history was responsible for 248 deaths as well as the destruction of 25,553 homes. Despite the fact that the first warnings of severe weather and tornadoes were issued days prior to the initial tornado touch down, the strength of this storm system created major obstacles for emergency response efforts as well as long term rebuilding efforts.

The use of geographical information systems and remote sensing has proved to be extremely useful in disaster preparation and response in recent years. National Aeronautics and Space Administration Earth Observing Systems (NASA EOS) have been used extensively to predict and analyze the effects of natural disasters on landscapes, ecosystems, and societies. This research focuses on utilizing NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery and GIS to illustrate and quantify the effects of the April 27th tornado outbreak on the agricultural and forestry sectors of the Alabama economy.

According to the National Agricultural Statistics Service (NASS), these sectors correspond to a dollar value of over $40 billion annually for the state (NASS, 2011). The findings of this research can be applied to future agricultural forecasts and provides a methodology for determining initial damages in the wake of natural disasters. The partners in this collaborative effort were the Farm Service Agency of the United States Department of Agriculture, the Short-Term Prediction Research and Transition Center (NASA SPoRT), and the United States Geological Survey. As tools for response and recovery following the April 27th outbreak and storms like it, the methods explained here allow for analysis of the impact of tornadoes on vegetation health.

Using imagery from NASA's ASTER satellite, the Normalized Difference Vegetation Index (NDVI) was performed at 30 meter resolution on and around a number of tornado paths in central and northern Alabama. This index allows the user to quantify the health of vegetation in these areas and provide a visual representation of the tornadoes' effect on chlorophyll content. This remotely sensed product is used in conjunction with detailed crop location data from the National Agriculture Statistics Service (NASS) to generate potential loss estimates in this important facet of the state's economy.

Response and recovery efforts such as those often practiced by the partner organizations of this study may employ the methodology outlined here for such estimates and to better understand the impact of tornadoes on ecosystems and the plant life that helps fuel them. This research also explored how the programming language Python can be used to automate the calculations within the image processing and GIS software ENVI and ArcMap in order to provide a quicker analysis and response in the wake of a disaster. In the future, this process may be converted to web-based operation to serve as a tool in localized economic recovery.

II. METHODOLOGY

Data was downloaded from the USGS EROS (Earth Resource Observation Science Center) at eros.usgs.gov. ASTER images were obtained for the study area from in the Direct Pool option from ASTER MODIS. The ASTER data aquired all fell between the dates of May 4, 2011 through June 12, 2011. The NASS records was for the year of 2011. The Data Pool is the publicly available portion of the LP DAAC online holdings. Data Pool provides a direct way to access files and are available at no cost to the user. Specifically "AST_LIB.3" data was chosen for its high resolution and atmospheric corrections. The crop data layer (CDL 2011) was obtained from the U.S.Department of Agriculture (USDA) National Agriculture Statistics Service (NASS), derived mainly from AWiFS imagery. This ancillary data from NASS (National Agricultural Statistics Service) was obtained for the year 2011 from http://nassgeodata.gmu.edu/CropScape/. This resource contains crop specific categorization of the 30 meter resolution digital imagery for crops. It is broken down by season and crop type, as well as forest, timber and other non edible industries ecologically produced.

Tornado swaths were acquired from NOAA-NWS (National Oceanic and Atmospheric Association National Weather Service out of their Birmingham offices, online shapefiles acquired at http://www.srh.noaa.gov/bmx/?n=event_04272011gis. These data contain the Lat/Long extend of each tornado and swath (width) variations for each tornado that touched down in the entire state of Alabama.

The data manipulations were performed in two geospatial processing softwares, ArcGIS and ENVI. The first step in the data process was layer stacking the ASTER imagery, saving it as 8 bit .tif with a color-table, this conversion allows the file to be opened and viewed in ArcGIS. Once loaded and projection confirmed additional layers were added in order to determine the extent of the study area. This was entirely dependent on the visibility of the downloaded ASTER imagery. The additional layers consisted of the statewide tornado swaths and the NASS cropland data layer. Once added, the projections of all three data sources needed to be the same for further manipulation. The only file that was necessary to change in ArcMap was the tornado swaths, the other two data projections were specified at the time of download.

The min and max (x,y) were found for each tornado and the land cover (ASTER imagery) was clipped to those dimensions. Groups of tornadoes withing the same ASTER tile were also clipped for further processing in ENVI. In ENVI the necessary ASTER scenes were mosaicked together. Generally 2-3 were mosaicked for each track. An NDVI was calculated [B2-B1] / [B2 + B1] where B2 = 3N and B1 = band 2 of the ASTER imagery. The vector file (tornado track) was then opened in ENVI. This tornado swath was used to create two masks. One where the tornado(s) was masked and the other where the area outside of the swath was masked. These masks were then applied to the NDVI and then brought back into ArcMap. After being brought into ArcMap the process of 'zonal statistics as table' was run on the masked images. These statistics included an area affected calculation, minimum, maximum, range, average and summation of NDVI values inside and outside of the track. The NDVI values were used to obtain an estimate of direct losses, the area calculation was compared to published records from the Forest Service (obtained through FSA) which calculated dollars lost to the timber industry in Alabama.

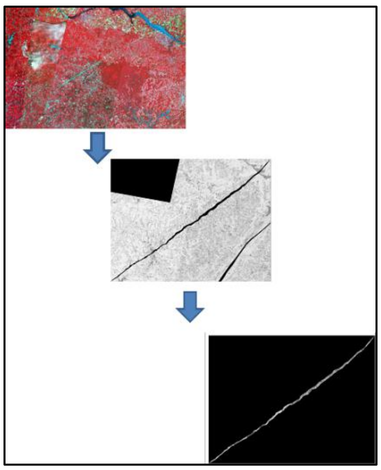

Figure 1: ASTER-NDVI (Tornado Mask) and NDVI swath only

Using the Python programming language, a program was created that automated the methodology described above. The program uses the arcpy library for the Python language, which uses the tools available within ArcMAP. The program also uses the Tkinter library to construct a Python based widget that allows the end users to select individual tornadoes from this study. Then, the program calculates the value of the NDVI for the region within the tornado swath and for the region outside of the tornado swath. First, this tool imports the arcpy library to access the tools available for ArcMAP, and imports the Tkinter library to build the widget. Then, the tool opens a map document to work within, the layer of NASS crop data, and Band 2 and Band 3N ASTER images of the user specified region. The pixel values of Band 2 and Band 3N are converted to the float data type to prevent any rounded errors. Next, the Band 2 and Band 3N ASTER images are clipped to fit the exact extent of the tornado of interest. The Extract by Mask tool is used to create a layer of the region only within the tornado swath for each of the Band 2 and Band 3N images. Then, the NDVI for the region inside the tornado swath was calculated from the Band 2 and Band 3N images generated by the Extract by Mask tool. Next, the Python tool masks out the tornado swaths from the clipped region by setting the tornado shape files to null values and subtracting them from Band 2 and Band 3N clipped images. The program then uses the masked Band 2 and Band 3N images to calculate the NDVI outside of the tornado swaths. Finally, the program uses the Zonal Statistics As Table tool to calculate and create tables that displays the statistics for the NDVI values inside and outside of the tornado swaths.

III. DATA ANALYSIS:

Analysis primarily revolved around the zonal statistics run in ArcGIS. This combined the NASS records, NDVI analysis and tornado swath damage to determine the health of the vegetation inside and outside of a particular tornado swath. In this way, specific crops affected were found. Using Excel, graphs were produced to show the disparity in values between damaged and 'non' damaged areas. This study only took into account landcover directly in the path of the tornado and excluded damage due to straight line winds, flying debris or other destruction associated with tornadoes. The statistics showed the mean, maximum and minimum NDVI for each crop class within the tornado path. The NDVI can then be correlated to crop yield.

Another less nuanced analysis was performed correlating NASS records with tornado swaths. This analysis assumed that everything in any tornado path was completely destroyed. It did not take into account strength of tornado (EF scale) or variations in path/swath. It provided a very rough initial estimate for land cover affected. The analysis outlined previously was more detailed and accurate. This was done in order to show the benefits of using NASA datasets to retrieve more accurate results.

Previous research focused on the environmental factors which may contribute to where tornadoes form. We used remotely sensed data from ASTER satellites from USGS, to evaluate the relationship between land use/land cover and the occurrence of tornadoes in Northern and Central Alabama.

The research outlined above from Fall 2011, was analyzed by combining the classified data with the tornado tracks from 2000 to present. This portion of the research was conducted in ArcGIS. First, a classified image from ENVI was loaded into ArcMap along with merged tornado tracks from 2000 to present. The area of destruction due to the tornado tracks was estimated to be 1 mile on either side of the .shp file for the tornado track. This estimation was calculated using buffer analysis, which was then projected to match the classified image. The next step was determining the landcover underneath the buffered image. This was performed by calculating the land cover type underlying the one mile buffer from the previously defined classes in the ENVI sessions. The ArcMap function from spatial analyst's tabulate area was used for this step of the project. This calculation in ArcGIS made the connection between tornado path destruction and land cover type possible.

The results were confirmed by the program created in Python, which calculated nearly identical NDVI values to the original methodology, and what differences that did exist between the two methodologies were well within an order of magnitude of both sets of data. This difference came from the original methodology using two platforms, ENVI and ArcMAP, to process the data while the Python program used only ArcMAP. The program was hard coded for data that was locally available on our team's computers, however the code can be converted for use by end users by simply changing the directory.

Additionally, published accounts from the Forest Service support the claims from this study which highlight the impact the tornadoes had on the timber industry. The data from the Forest Service included data from all tornadoes from April 27, 2011 while our research focused on the impact of eight tornadoes, so as expected the area calculated by ArcMAP of impacted forests are less than the area reported by the Forest Service. For example, within Cullman County the Forest Service reported that 4,623 acres of forest were damaged. Assuming that all forests are considered damaged within the tornado swath from the tornado included in our study from Cullman County, the total area of damaged forests as calculated by ArcMAP was 2,988.92 acres. Also, using the example from the Alabama Cooperative Extension System paper by Daowei Zhang (Zhang, 1998) that showed the value of an acre of timber to be $1,180, the value of one acre of timber was applied to the total acreage found by ArcMAP. This puts the estimated loss to be $3,526,925.60. The Forest Service reported that total value for the damaged timber was $5,617,351.79. Our study did not include the second tornado that went through Cullman County so the lower value is expected but the evaluation does correlate well between the two data sets.

The graphs displaying NDVI values show an obvious disparity between NDVI reflectance of specific crops inside and outside of the tornado tracks (outside path in red; inside in blue). The intensity of the tornado is also shown through the NDVI analysis, the stronger the tornado the greater difference in NDVI readings. This directly correlates with crop health, and hence yield. This analysis performed NDVI readings on 9 of the 62 tornadoes that touched down. The research limited its study to tornadoes ranging from EF2-EF5 in scale. This is true for annual species, but not for perennial or longer lasting land covers (e.g. hardwoods). Many of the graphs show the crops with long life spans were hit hardest. This is of interest because of the time it will take for these cultivars to replenish. A typical hardwood takes anywhere for 10-30 years to grow to maturity, a pecan or peach tree have similar maturation schedules. All analysis show significantly healthier vegetation outside of the tornado swath, with NDVI readings between 10%-50% difference in and outside. The difference is specific to track, intensity and duration of the system over the landcover. All of the resulting graphs have detailed information on landcover affected by 10 tornadoes. These tornadoes were chosen because of the inherent differences in strength. This study wanted to be sure to see the difference in the vegetation health in and outside tornado swaths for different sized tornadoes. Graphical depictions of vegetation health can be found under the 'Results' section.

Published accounts from the Forest Service support the claims from this study which highlight the impact the tornadoes had on the timber industry. If it is assumed that all crops are lost and nothing is replanted, then using the pixel count for crops within tornado swaths can be found. For instance,the NASS map has a resolution of 0.22 acres to one pixel. Within the Hackleburg/Phil Campbell EF 5 tornado on the NASS map, there were 10,192 pixels or 2,242.24 acres of cotton. Using the yield reported by the USDA (http://www.usda.gov/nass/PUBS/TODAYRPT/crop1111.pdf), there would have been 1,639,077.44 pounds (819.53872 tons) of cotton produced by the crops lost; costing approximately $135,650.05 (http://www.indexmundi.com/commodities/?commodity=cotton&months=12). Likewise, within the Havkleburg/Phil Campbell EF 5 tornado on the NASS map, there were12,708 pixels or 2,795.76 acres of corn were caught in the swath of the tornado. Given the USDA yield of corn for Alabama (http://www.usda.gov/nass/PUBS/TODAYRPT/crop1111.pdf), there were 299,146.32 bushels or 10,470.1212 tons of corn lost to the tornado; costing approximately $3,230,870.00 (http://www.indexmundi.com/commodities/?commodity=corn&months=12).

The assumption that all crops within the tornado swaths were lost, was an overestimate. Crops would have been lost within the scar of significant tornadoes, but it is more likely that some of the crops within the swath would have been salvageable for reaping later in the season, especially those in weaker tornadoes. However, this assumption does provide a rough estimate for the cost to farmers. This assumption may be more applicable with timber farms, where it may take years to regrow the trees lost.

The published records from the Forest Service showed 199,488 acres of various timber types lost to the April 27th attack (Steadmon interview, 2012). The calculations done in ArcGIS showed 239, 036 acres lost, a difference of 39, 548 acres. Other crop types outside of timber reserves account for this difference. Due to the timing of the attack, late April, many crops such as corn, soybeans, or cotton had only recently been planted. Furthermore, many farmers who had planted by April 27 were able to replant after the attack were able to make up for any distress their crops might have endured. The timberland does not have this luxury due to the long germination and establishment of this resource. Therefore, this research focused on timberland affected more so than traditional crop cultivars. From these numbers calculations can easily be performed to correlate retail prices for land cover and acres lost.

Even with the radically different analysis, the results for landcover type affected from last semester correlated with the statistics run on landcover health in and outside of the tornado swath using NDVI analysis. There were two different classifications schemes performed on ASTER images for the previous semesters' project. The Maximum Likelihood supervised classification yielded greater detail in land cover than the unsupervised K-means. This is shown in the graphs which show percentage of total land cover affected by tornadoes. Individual stats for different classification schemes revealed different results.

IV. ERRORS & UNCERTAINTIES

There were several factors that were not addressed by the methodology, that need to be acknowledged. The methodology does not take into account the effect of damage resulting from debris and the debris' varying effects based on tornado strength. Also, the methodology does not answer for the varying climatological factors associated with some of the larger regions associated with the stronger tornadoes, such as soil moisture and topography.

This analysis did not take into account surrounding damage from wind, debris or other tornado associated problems. It limited the study to crops directly in the path of tornadoes, not accounting for industry or infrastructure affected. This analysis gives a preliminary result of crop vigor just after a tornado outbreak. However, it does not take into account any precautions farmers might have taken in regards to an event like this, such as late planting, crop insurance claims or other crop processes that might limit the impact of a tornado event. Additionally, the NDVI found on the ASTER imagery was not compared to any other published NDVI, such as MODIS 16 day composite. Also, the Forest Service does not have published prices of the fluctuating timber prices in Alabama. With further investigation and partnerships, the dollar amount could be verified with this information.

Spring of 2011 had its errors and uncertainties; the scope of our project did not include climate variables and soil moisture which limits any firm conclusions from the study results. This is an exploratory analysis and results of the study may be important for delineating high risk areas for tornadoes and disaster management. The study will also highlight the use of remote sensing techniques and GIS applications in research for tornadogenesis and possibly for disaster management.

It should be noted that the Python program automates the process to calculate the NDVI, but uses only the ArcMAP platform. The original methodology passed images between two platforms, ArcMAP and ENVI. The NDVI values and statistics produced by the Python program may have negligible differences from the original methodology. It is possible that these differences are due to the use of multiple platforms in the original methodology and possible minor projection issues that could exist between the NASS layer and the ASTER layers.

V. FUTURE WORK:

Future work would include spending a great deal of time to determine a specific phenology for specific cultivars in order to study a crop throughout its growing cycle and more accurately determine the stress of storm systems on crops. Future work should also include a detailed literature survey to find the relationship between decreased NDVI reflectance and decreased yield in specific crops which could be future work in itself: a specific crop could be monitored daily and NDVI performed for each stage of a crop under specific growing conditions recorded. This could be done for multiple locations with individual variables that govern the health of a crop (nutrient levels, solar insolation, precipitation, etc.) are isolated. A crop phenology could be created from this, so that any time a disaster strikes the damage estimate outlined above will be greatly accurate.

Additionally, this analysis could easily be performed using MODIS 16 day NDVI composite or VIIRS (Visible Infrared Imager Radiometer Suite) data on the NPP satellite. With a solid methodology this could be an interesting study with new data from NPP.

The Python program could have additional factors appended into its calculations. For example, market values of specific crops, such as cotton or timber, could be included in the calculations to show a possible correlation between change in NDVI and economic cost of lost of said crops, rather than leaving that to the end-user to calculate as in the current methodology. This would prove valuable to the end-user for insurance purposes and further work could be done to convert the Python program into an tool that could be downloaded or an application that could be used from a website for wide-spread use and calculation of economic loss. In future studies of natural disasters, such as droughts, floods, and hurricanes, satellite imagery could be used to evaluate changes in NDVI values of crops and combined with market values validate economic loss and insurance claims.

VI. CONCLUSIONS:

The violent series of tornadoes that tore across the southeastern United States in April 2011 had a lingering effect on vegetative health and the timber industry. Natural disasters of this magnitude and scale are difficult to recover from because of the myriad aspects of life and economy they impact. However, with the use of Remote Sensing and GIS, communities can perform damage assessment more easily with regards to the vegetative environment.

Remotely sensed data from satellites provides large spatial coverage and frequent temporal quantitative data for land cover change and use assessments. Consequently, using this type of data helps expedite disaster response efforts and has the capacity to help communities assess damage and recover more quickly and efficiently through the support of local organizations and government efforts.

However, there were several factors that were not addressed in the methodology that need to be acknowledged. The methodology does not take into account the effect of damage resulting from debris and the debris' varying effects based on tornado strength. Also, the methodology does not answer for the varying climatological factors associated with some of the larger regions associated with the stronger tornadoes, such as soil moisture and topography.

This study focused on the April 2011 tornado paths in the state of Alabama and emphasized the positive impact satellite imagery can have in assessing counties with tornado damage to vegetation and highlight potential future risks in disasters of this magnitude. In particular, this research highlighted the benefits of utilizing NASA EOS data in disaster management with assistance from our partner organizations at the Farm Service Agency, SPoRT, and EMA. This research has shown the benefits of using NASA EOS data for initial damage assessment and accuracy of damage estimates. The resources used included ASTER products in ENVI and ArcMap, NASS cropland data layer, NWS tornado swaths, and the programming language Python to give the general community a way to access and use NASA data. It is helpful spreading the user base and teaching our end users and partners more about the benefits and importance of geospatial data.

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