Spring 4-9-2003

Search and Recovery of the Space Shuttle Columbia: A Geospatial 1st Responder Perspective

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I was settling in for the spring semester in the days preceding the loss of the Space Shuttle Columbia, and I felt mentally alert and intellectually crisp. Then the unthinkable happened. As the disaster unfolded, I was caught up in a situation where all of my geospatial skills, knowledge, and experience as well as my extensive field science experience were stretched, tested, and utilized in an unparalleled situation. During the first two weeks of the event, I personally mapped search and recovery efforts in a GIS environment for over 250 hours. I didn't get but two hours sleep in the first 50 hours. I mapped.

SATURDAY MORNING FEBRUARY 1ST, 2003

The day started cool with a hint of frost in the bottoms. The sunrise filtering through the tall pines promised a beautiful day. I live in northeastern Nacogdoches County and as is my custom, I arose early and took my four dogs on a long walk through the woods to Naconiche Creek, about a mile behind my house. The first thing that I noticed was that it got very quite. The noisy early morning critters and the dogs had fallen silent, so I stopped walking. Then it hit. The loudest blast that I have ever heard just about knocked me down. I saw the trees sway, and I felt the concussion. The dogs scattered to the four directions, and I noticed that I was running. The first blast was still booming and rumbling when a second blast hit. Then a third hit, a fourth, a fifth, and on and on it blasted, boomed, and rumbled. It was a terrible noise. The time was 8:00 am.

I felt like I was moving in slow motion. My feet were running towards the house as fast as I could go but my mind had slowed down and was processing every possible scenario for creating such a terrible sound. When I got home, the rumbles were still echoing. The neighbors had come out at the booming and said that the shuttle was passing overhead that morning. We live in an area where the shuttle routinely passes over on its way to landing in Florida. So it is not unusual to watch the shuttle and hear its sonic booms. I have seen it come over several times, but this time I knew that something was not right. With a sinking heart, I knew what had happened, and I knew that mapping products were going to be needed. As I kissed my family good-bye and settled down for the 15-minute drive to SFASU, I looked down at the car's clock and was surprised to see that it was only a little past 8:15 am.

THE SEARCH FOR COLUMBIA BEGINS

Upon arriving at the Forest Resources Institute (FRI), I immediately started plotting a current satellite image map of Nacogdoches County. Not knowing the scope of the disaster, I concentrated on Nacogdoches only. As the first satellite map begin to roll off the plotter, I begin to compose a new map with roads, streams, and physical features over the satellite base. Meanwhile, the first map composition was continuously being plotted, resulting in dozens of copies, until it was replaced by the updated version, a process that was to be repeated many times.

At this stage, FRI's staff begins to arrive and a flurry of map production begins. The next set of maps to be produced consisted of annotated road maps for Nacogdoches County over a plain base (i.e., highway map). During this time SFASU's Geography Department's Humanities Urban Environmental Sciences (HUES) GIS Laboratory agreed to coordinate and process field GPS data collection while FRI agreed to develop and produce map products. The first set of satellite based locator maps were packaged up and delivered to the Nacogdoches County Emergency Operations Center (EOC) by Dr. Kroll (FRI's Director). The time was 9:15 am and within the next couple of hours volunteer GPS teams begin to assemble at FRI and HUES labs to coordinate their data collection strategies. By mid-day, volunteer GPS crews were being dispatched with law enforcement and emergency personnel to record precise locations and collect data on each find.

Dr. Kroll called from the EOC to tell us that the official word was that debris was all over the City and the County and that we were to crank up to full production with mapping products to be delivered to the EOC every couple of hours.

That is when I remembered that the College of Forestry had just purchased a high-resolution multispectral satellite image of the city that was captured January 4, 2003. I quickly utilized the current Quickbird image to setup a base map of the city with annotated features, but before I could get very far in production, the Nacogdoches County 911 call sheets begin to arrive. Somewhere around 10:30 am we begin to set up mapping environments for ingesting the 911 report data. We then started the tedious task of placing points at reported debris locations.

The Quickbird high-resolution image was the first base map for showing debris locations within the city limits that was produced for the EOC. Through out the day other street line maps were produced showing the growing pattern of debris within the city. Meanwhile, GPS teams that had been dispatched to aid Law Enforcement agencies in mapping debris in the city and county begin to call in preliminary coordinate locations that were quickly added to our maps.

Jeff at FRI during the shuttle disaster.

DEVELOPMENT OF THE BASE SEARCH VECTOR

By early afternoon I begin to notice a linear pattern in the mapped debris data. The mapped city locations showed a greater density toward the south and we had very few reports north of the city. Although the city locations dominated the map there were a few mapped points farther out in the county that suggested that populated locations were reporting debris. As the day went on, I became determined to try and find out the true spatial nature and extent of the event. Earlier I had noticed that populated places like Cushing, Garrison, or Martinsville had few reports compared to the dozens from Douglass, Melrose, and Chireno. Lufkin and Angelina County had a few reports, as did the counties to the north, but the reported debris pattern trended across Nacogdoches toward the southeast and the adjacent counties of San Augustine and Sabine. We also had reports of debris on the ground west of Nacogdoches in Anderson and Cherokee counties.

While we were mapping the Nacogdoches County 911 call sheets, I noticed that there were quite a few calls without addresses. I had attributed these to cell phone usage. The calls to the 911 dispatchers confirmed that many folks grabbed their cell phones as they ran out of the house to see what had happened and there was not a way to triangulate the locations of these calls. On closer inspection I noticed that some of the 911 calls, with the majority being out in the county, listed an approximate location as described by the caller to the dispatcher. While looking through these calls I realized that I knew generally where quite a few of the descriptions were referencing.

I grew up around here and I've hunted, fished, and hiked over large areas of East Texas. Professionally I've traveled to remote locations of East Texas to conduct cultural or biological research, and I'm familiar with where people live and don't live in East Texas. When I realized that we were not getting reports from some areas and getting lots of reports in other areas and that across Nacogdoches County the reports were roughly following Highway 21 from west to east I became concerned that we were seeing a population bias in the reporting. Since we had a disproportionate amount of preliminary information from the city and a dearth of information for the county, I became resolute in trying to map the county 911 reports that just had a general description.

Using an old Nacogdoches County highway map that listed both the newer county road numbers and the old colloquial names of the county roads, I was able to start mapping the generalized locations. The calls listed places like the watermelon patch on Brewers Ferry Road, Old Spanish Bluffs, Nacolina Lodge, Oil Springs, a ¼-mile down Skillern Cemetery Road, and Buckshot Road at Big Oak. Some listed descriptions like the second white house past the

Nazarine Cemetery that could only be located by using analysis from detailed aerial photography.

Using a best-fit approach, I slowly begin to fill in the county. When combined with the addressed city data, the first debris scatter model for Nacogdoches County was developed. This model definitely showed a spatial trend to the debris locations and appeared to be population and spatially definable. This was approximately 2:00 pm in the afternoon of the first day.

By this time I was convinced that we were beginning to see the first true spatial pattern to the debris locations. But I was concerned because I honestly expected the injury and fatality calls to begin to roll in and until this point there had been none. It didn't seem conceivable that no one on the ground got hurt, and I was hesitant to explore the spatial pattern. I remember thinking that I had better not announce that I had detected a debris pattern that suggested a discrete direction because I was afraid that the mapping process that showed the pattern would be misunderstood and misrepresented. So I waited.

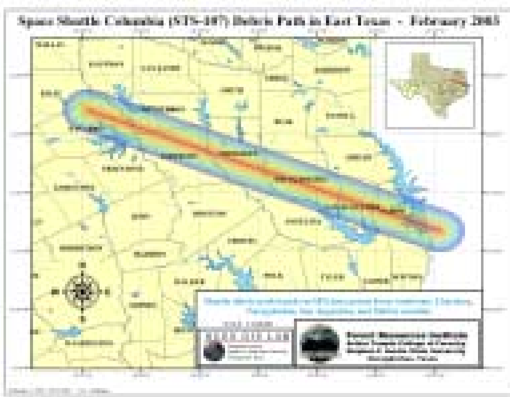
I slowly got over my uncertainty and when I found the time, I ran a simple least squares linear regression against the coordinate pairs of the relative locations of reported debris in the county to quickly see what the trend of the debris scatter model was. When I displayed the regression back in the GIS it showed a linear trend to the spatial pattern with a bearing of 109º relative to the shuttle's reentry flight path. I called this the Base Search Vector (BSV). The BSV represented a best fit of data showing the debris trend. In an attempt to display the magnitude of the debris scatter from the BSV centerline I developed a 20-kilometer radial buffer with rainbow coloring signifying debris density. The first maps to incorporate the BSV encompassed only Nacogdoches County and were delivered to the EOC by 4:00 pm.

As evening enveloped the first day's search effort, some of the GPS volunteers returned to FRI to download raw GPS data for correction and processing at the HUES lab. This was when I first learned that the HUES Lab had a geospatial team down in San Augustine County. So we begin to produce locator maps for San Augustine County in mass like we had for Nacogdoches County. As the night wore on we continued to produce locator maps by the dozens. We started developing a county template for standardizing additional map production, and as corrected GPS data became available from the HUES Lab we quickly added it to our maps. This continued throughout the night and into the early morning.

THE MAPPING CONTINUES

Before daylight early Sunday morning, February 2nd (Day 2), the HUES geospatial team left for San Augustine County taking dozens of locator maps and leaving their previous days corrected GPS data. By mid-morning we received a GPS data set of 115 points from researchers of the Center for Space Research (CSR) at the University of Texas in Austin that was for Anderson County. I took both data sets into my GIS and begin exploratory data analysis to identify the relationships between the additional counties GPS data and my modeled BSV for Nacogdoches County.

The correlation of data became quite clear very quickly and I was able to extend, without hesitation, the BSV in both directions from Nacogdoches County to Toledo Bend Reservoir in the southeast and to the western boundary of Anderson County in the northwest. After a great deal of thought on how best to present the spatial trend while expressing the extent and magnitude of the disaster, I settled on the extending the BSV buffer map of Nacogdoches County. These maps were produced over a base of current Landsat satellite images to highlight the BSV and the rainbow density buffer. Eventually these maps showed the debris trend and scatter encompassing eleven counties of East Texas. About two-dozen maps were produced and delivered to the Nacogdoches EOC by mid-morning of Day 2. At a briefing on the afternoon of the second day, they were presented to the international press by Dr. Kroll and Nacogdoches County Sheriff Thomas Kerss to represent the scope of the disaster.



Media map produced February 3rd, 2003.

During Day 1, FRI had established a high-speed data transfer connection with CSR, using SFASU's Internet-2 technology, for the transfer of large satellite image files. Early Monday morning, February 3rd, FRI staff used the Internet-2 technology with a video link to put out a call for additional Geospatial professional volunteers to a statewide GIS Users Conference being held in Austin that week. Volunteers with geospatial experience from across the state and the nation responded and came at their own expense to help. Many SFASU and College of Forestry friends, alumni, and students responded with help and support after hearing of the tragedy.

The days became a blur after this as our GIS mapping took on a somewhat routine role. Typically the day started at 4 or 4:30 am with map preparation for delivery to the 7:00am EOC briefing and proceeded into a daily process of map composing, data mining, data processing, and spatial analysis. There would be another flurry of activity just before the afternoon EOC briefing but usually it was relatively quiet until the search teams returned after dark with their GPS data. Spatial analysis would extend into the early hours of the next morning, and if it was necessary, the new information was presented on maps for the following morning briefing.

During the fourteen days of FRI's involvement, I considered myself lucky if I could slip away and go home to say hi to my family and maybe get an hour and half's sleep. Some nights were spent in a sleeping bag underneath the plotter so that when the plot finished it would fall on me and wake me up. There wasn't much time for rest because I knew that at first light, hundreds of volunteer searchers would begin to comb the woods of East Texas looking for Columbia and her crew. And I knew that they would need current maps with information from the previous nights analysis.

Over the long days of the event, I remember being surprised that the original BSV was continuing to be validated. It was originally conceived as the direction for a first look based on the best fit of data at that time. I never dreamed nor could I have conceived that the BSV would continue to be validated day after day. Of course at the local level the search varied in direction and distance but as an overall landscape trend it continued to be accurate to within a mile to a mile and a half.

CUSTOM SEARCH AND RECOVERY MAPS

Customized Search and Recovery (SAR) maps were produced in mass for local Law Enforcement agencies, NASA, the FBI, the NTSB, the EPA, FEMA, and numerous state agencies involved in the early SAR efforts. Most SAR maps incorporated current satellite imagery or current aerial photography from a variety of sources as a base. Most of these maps were small field maps (i.e., 8.5 x 11) with a customized search grid overlaid on some sort of imagery. We would also overlay the grid on standard USGS topographic maps for easy reference. Hundreds of these custom search grid maps were produced nightly and distributed in the morning to field SAR personnel.

Types of maps produced included 400-meter SAR grids for the Navy dive teams at Toledo Bend Reservoir, flight grids for experimental SAR aircraft, flight SAR grids encompassing 5 states for the Civil Air Patrol, ever changing FBI SAR special interest area grids, and navigation maps for SAR staging personnel, horseback, and 4-wheeler teams. We continued to map around the clock working in shifts to produce maps in mass. Over the course of the event I estimate that we created and produced over 50 different custom map types. Although I did not keep a record of the types and numbers of the maps produced, the number easily reaches the thousands. On one day alone we used nine 100-foot rolls of paper.

The success and effectiveness of these many hundreds of custom search maps is documented through the continued nightly requests that we received. The importance of custom SAR maps cannot be overstated. The need was so great during this time that both FRI and HUES as well as the College of Forestry emptied their GIS labs of all available equipment and established three Forward Mapping Centers (FMC). One in San Augustine, one in Hemphill, and one at Six Mile bait camp on Toledo Bend Reservoir. A large number of geospatial volunteers, computer hardware, GIS software, local high-resolution data, and high-speed connectivity were managed and facilitated by FRI's staff who worked and drove incredibly long hours.

HIGH-RESOLUTION SATELLITE IMAGERY

As search and recovery efforts continued during the first few days of the event, I begin utilizing a suite of remote sensing images to visualize and map the current conditions of the impacted areas. The most important of these was high-resolution IKONOS imagery captured around noon of 1 February. Space Imaging, a commercial satellite company, had out of their genuine concern for aiding in the SAR and the technological tools that they could offer, had tasked their IKONOS satellite to move out of its assigned orbit to pass over Nacogdoches less than 4-hours after the explosion and loss of Columbia. Within the next few hours, the satellite downloaded raw data to a relay station in Europe, sent it over high-speed data lines to the US where it was processed, and delivered it to NASA early Sunday morning, Day 2.

The IKONOS imagery was provided to FRI by NASA, and allowed me to visually inspect the Base Search Vector (BSV) in advance of SAR teams. In selected areas, I was immediately able to see broken tree crowns, broken branches, or general disturbances in the forest cover. Most noticeable were bright signatures in the forest canopy indicating highly reflective material, both on the forest floor and the forest mid- and upper canopies.


Shuttle debris in forest cover.

Use of IKONOS imagery by FRI enabled SAR teams, from cadaver dog teams to experimental aircraft pilots, not familiar with the East Texas terrain, to utilize current information about specific areas with a high probability of locating shuttle debris. Many of the debris fields located by FRI yielded significant amounts of material of special interest to NASA.

STAND-DOWN

On Thursday February 13th (Day 13), NASA announced that the remains of all 7 astronauts had been recovered and that SAR efforts would shift from a State response to a Federal response. At 5:00 pm on Day 14 state agencies were asked to "stand-down" by FEMA. All GPS, mapping, and SAR operations were shifted to Federal operations in Lufkin. After 14 days it was over. It seemed to end like it started, abruptly and without warning. Suddenly I looked up and it was over. I don't know where the days went. Yet, what we accomplished in the first couple of days of the event was to be repeated up and down the debris path with great success.

By the time the Federal GIS response could become fully operational, SFA Geospatial 1st Responders had completely integrated the GIS data collection, mapping, and analysis reporting protocols and procedures into the massive SAR efforts. We were able to "pass-off" an already established and proven geospatial disaster information flow process seamlessly to FEMA and Homeland Security operations. The monumental search and recovery efforts were to last for 3.5 months involving more than 180 Federal, State, and Local agencies with more than 25,000 searchers, covering the largest ground search in the world of almost 750,000 acres, and recovering an unprecedented 39 % of the shuttle's remains, enough for NASA to identify the probable cause of the mission's failure.

CONTINUED ANALYSIS

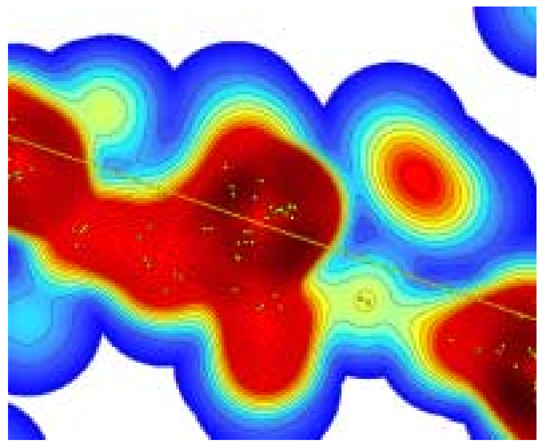
After the crisis subsided, P.R. Blackwell, Information Scientist at FRI, revisited the BSV work to see how additional data would affect the analysis. Datasets were selected representing available data on Day 1, Day 2, Day 3, Day 4, Day 12, Day 14, and Day 26. The temporal spacing of the selected datasets reflected FRI's involvement in the recovery effort. The data from Day 1 through Day 14 consisted of verified, precision GPS coordinates, collected and processed at SFASU. Day 26 data were from the Shuttle Interagency Debris Database (SIDD) maintained by FEMA at the Disaster Field Office (DFO) in Lufkin. These data include all reported debris locations, including many that were erroneous. The data were processed at FRI by correcting obvious errors such as reversed latitude/longitude and mismatched coordinate systems. Erroneous records that could not be corrected were deleted, as were all points falling outside Texas. Ordinary least squares regression analysis was performed on each dataset.

Resulting values from this analysis were used to create vectors for each of the regressions and their 95% confidence intervals. These were plotted on a map along with the original BSV. P.R.'s results showed a general trend to the south with a negative rotation as additional debris locations are added. Comparing the original BSV against the February 26th dataset shows the trend lines crossing in western Nacogdoches County. This was expected as the original dataset was heavily weighted with Nacogdoches County data. Maximum worst case offset was less than 2.3 kilometers over a five county region.

Although the original BSV was calculated very early in the recovery and included a tiny subset of the eventual debris dataset, it was a remarkably accurate predictor of the total debris field. The availability of an accurate model of the Columbia debris field so early in the recovery demonstrates the power of geospatial technology when applied to disaster recovery operations.

DENSITY ANALYSIS FOR LONG RANGE ENVIRONMENTAL IMPACTS

Reported debris from the Space Shuttle Columbia was in all shapes, sizes and quantities across a vast area of Texas. GPS volunteers using both consumer grade and higher precision GPS units mapped the general debris scattered across most of three counties in East Texas. The precision GPS coordinates have a horizontal accuracy of better than 1-meter while the consumer grade GPS units are considered to be accurate to within 30-meters. A GPS data dictionary was created, standardized and deployed with attribute fields to be populated with pertinent information about each find.



Debris density model.

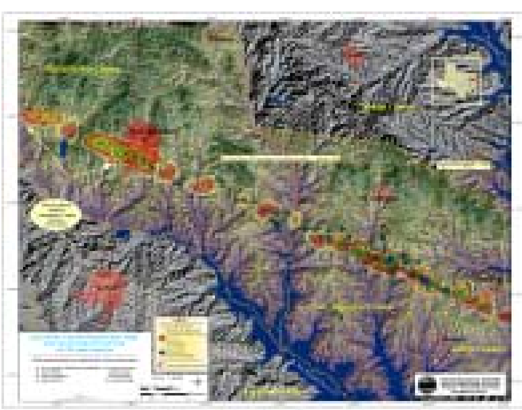
In an effort to quickly define potential areas of long-term environmental concern, I developed a model of high probability for encountering shuttle debris by assigning weighted values based on material type, size and amount. Over 2,000 precision GPS points were extracted from the database and filtered through multiple regression equations. Consumer grade GPS points that fell within the 95-percentile of the base regression of the original 2,000 precision points were extracted, leaving 7,000 debris records for use in the model. Several iterations of Exploratory Data Analysis (EDA) were performed to identify the best area presentation. I eventually selected a Radial Bias Function as the best landscape presentation of shuttle debris locations by magnitude. Radial Bias Function (RBF) is a deterministic exact interpolation technique for creating smooth 3D surfaces from a large number of data points. RBF uses a tensioned spline that passes through all weighted sample points. RBF captures the global trend while highlighting the local variation; however, no prediction errors or uncertainties are calculated.

Magnitude of debris was calculated using differential weighting that increased by location precision, amount of debris collected, and size of debris collected. For example, a record that was located using precision GPS in which greater than 20 pieces of large debris are confirmed to have been collected, outweighed by stratified orders of 10, the consumer grade GPS locations where 1 piece of small debris was collected. Using this spatial modeling technique, high probability areas have been delineated with a high degree of precision across Nacogdoches, San Augustine and Sabine counties.

Density mapping provides a method of identifying concentrations of materials across the debris field. When combined with landscape aspect and slope, geologic structures, soil series, wetlands or water features and land cover type or vegetation cover, this model is robust enough to predict areas of environmental concern with a high degree of confidence. These areas should be monitored for long-term environmental impact.

FINAL

In July, P.R. and I combined our density and regression analysis onto a single map that shows, for better landscape level visualization, the RBF surface draped over a U.S. Geological Survey (USGS) 10-meter Digital Elevation Model (DEM). We entered this composite map in the Environmental Systems Research Institute's (ESRI) 23rd Annual International Users Conference map competition where we placed Second for Best Analytical Presentation.



Columbia debris density map.

I have been pleased to be able to give back just a little of what I learned here at SFASU over 10-years ago. As an undergraduate in the early 1990s, I took Dr. Vic Whitehead's first graduate level remote sensing class. I also conducted undergraduate GIS research at the Tucker Center with the blessing of Dr. Kent Adair that garnered a national award for undergraduate research in the Social Sciences. I took Dr. Ken Watterston's soils class, much to my dismay, and I worked with many environmental and forestry professionals from the College of Forestry on applied field projects, all of which helped prepare me for searching for the Columbia.

I was the first to arrive at the FRI, but within a short time I was joined other FRI staff and volunteers who worked the entire 14-days as well. We became a tight GIS triage team working under extreme pressure, yet we were able to accomplish an unimaginable feat. By the end of Day 1 and confirmed on Day 2, we were able to map shuttle debris locations with such precision that we were able to predict, with an extremely high level of confidence, a Base Search Vector (BSV) where the remains of critical components and items of special concern to NASA could be found. We mapped, performed spatial analysis, and produced search and recovery map products 24 hours a day from minutes after the event until we were asked to "stand-down" on Day 14.

It was a great honor to work with such dedicated geospatial professionals. I am proud and honored to have played a small part in this unparalleled search and recovery effort. Using my GIS, remote sensing, and fieldwork experience, I was able to assist Nacogdoches and SFASU in responding to this national disaster.

AFTER THOUGHT

Early in the event I entered the first day's notes, the first rough draft copies of the BSV maps, and composition copies of final BSV maps into the State Archives at the East Texas Research Center (ETRC). I also had the opportunity to hand deliver a set of the first debris rainbow maps to the National Archives in Washington D.C., but most of all, I take great pride in the fact that the BSV proved to be a valuable guide as a significant indicator of the shuttle debris field, and that the SAR was successful in the recovery of the Columbia's crew and enough of the shuttle's remains (i.e., 39%) for NASA to identify the cause of the mission's failure.

In retrospect, it is amazing what we accomplished as Geospatial 1st Responders. The tools, data, and local expertise were in place waiting to be utilized. We adapted to ever changing situations, we persevered through grueling hardships, and we overcame insurmountable obstacles to provide the best quality information that a GIS could develop. It was an incredibly stressful time. As the rest of the nation and world mourned and worked through the grief of the loss of Columbia and her crew, we were unable participate. We mapped. Our strength came from the knowledge that our science was an absolutely critical component in the search and recovery effort. We had a job to do, and we were the only ones who could do it.

Jeff Williams
Graduate Research Assistant
Forest Resources Institute

Jeff returned to Nacogdoches and Stephen F. Austin State University after many years working in the private environmental consulting industry in Austin. He also served for several years as a geospatial scientist for Texas Parks and Wildlife Department's Resource Protection Division, and he was instrumental in establishing the U.S. Geological Survey's National Biological Information Infrastructure presence in Texas. Jeff is a geospatial scientist who specializes in remote sensing and GIS application development for natural resource monitoring and management.

Jeff is currently employed as a Graduate Research Assistant at the Forest Resources Institute (FRI) of the Arthur Temple College of Forestry. FRI is the prototype Regional Geospatial Service Center for East Texas and serves as a data repository and processing hub for Texas geospatial data. For the past 11 months, Jeff has been utilizing remote sensing techniques for analyzing forest cover and forest management practices, over a 30-year span, for determining the geographical extent of forest cover types, age, and fragmentation of the very same East Texas forests where the Columbia crashed.