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MAPPING WEAKNESSES IN THE MISSISSIPPI RIVER LEVEE SYSTEM USING MULTI-TEMPORAL UAVSAR DATA

Mapeamento de Risco Estrutural no Sistema de Diques do Rio Mississippi através de Análise de Dados Multi-temporais do UAVSAR

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ABSTRACT

Levees are extended embankments naturally or artificially constructed that regulate water levels. The Mississippi Levee system in USA dates from early 1900's, and was designed to keep farmlands safe during the flooding. Today it is considered one of the most extensive engineering infrastructure projects in the world. The Mississippi Levee system comprises over 5,600 km of earthen wall structure designed to protect the agricultural areas of the Mississippi River Valley, thus monitoring the physical condition of the levees is vital for flood control. The dynamics of subsurface water events cause continuous damage on levee structures which are not easily spotted prior to the appearance of slough slides or through-seepage. The traditional method used for detecting these events involves physical surveys, always time consuming and expensive. Synthetic Aperture Radar (SAR) technologies are capable of identifying variations in soil properties that are related to the potential for such events. This paper presents a compendium of methods and results of applying the NASA Unmanned Aerial Vehicle Synthetic Aperture Radar (UAVSAR) to the task of identifying problems on Mississippi's earthen levee system. UAVSAR is a multi-polarized SAR system, and the data exploration in this study included both single-look and multi-look records. The team investigated soil moisture, soil electrical conductivity, sand boils, landslide events, and vegetation backscatter. Different feature detection and classification algorithms were tested, including radiometric and textural methods. The levee structure and flood control system is managed by the United States Army Corps of Engineers (USACE), who would benefit from having a unified tool capable of mapping the weakness of the levee segments. The data and methods presented in this paper are incorporated into the Multi-Tabbed Levee Assessment Tool. The solution provides a user-friendly, open-source geospatial platform to perform visualization, manipulation and analysis of SAR data products.

Keywords: SAR, Classification, Flood, Risk.

RESUMO

Dique são barragens extensas formadas naturalmente ou construídas artificial para regular o nível de água. O sistema de diques do Mississippi nos EUA data do início de 1900, e foi projetado para manter as areas agrícolas do Vale do Rio Mississippi seguras no período das cheias. Atualmente ele é considerado um dos mais extensos projetos de infraestrutura de engenharia no mundo, e se estende por mais de 5600 km por meio de barragens de solo compactado. Por isso, o monitoramento das condições físicas de sua estrutura é vital para a eficiência do controle de cheias. A dinâmica dos eventos hidráulicos no subsolo provoca danos contínuos na estrutura dos diques, os quais não são visíveis até o surgimento de deslizamentos de terra ou de vazamentos. Os métodos tradicionais utilizados para detectar tais eventos envolvem levantamentos físicos, os quais são lentos e onerosos. A tecnologia de Radares de Abertura Sintética (SAR) é passível de identificar variações nas propriedades do solo que podem estar relacionadas aos eventos hidráulicos prejudiciais aos diques. Este artigo apresenta um compêndio de métodos e resultados de investigações utilizando dados do NASA Unmanned Aerial Vehicle Synthetic Aperture Radar (UAVSAR) para caracterização dos problemas que afetam a estrutura dos diques do Rio Mississippi. O UAVSAR é um sistema SAR multi-polarizado, para o qual a análise exploratória dos dados contou com medidas do tipo single-look e multi-look. Os autores investigaram umidade do solo, condutividade elétrica do solo, sand boils (minas de água e areia), deslizamento de terra e comportamento reflexivo da cobertura vegetal. No estudo foram utilizados diferentes algoritmos de classificação, para os quais foram testados diferentes técnicas de extração de feições, incluindo métodos baseados em radiometria e em textura. A infraestrutura dos diques do Rio Mississippi, bem como o sistema de controle de cheias é gerenciada pelo Corpo de Engenheiros do Exército Norte-Americano (USACE), quem clama por uma ferramenta unificada para o mapeamento dos segmentos dos diques com potencial para falhas estruturais. Os dados e os métodos apresentados neste artigo foram incorporados ao Multi-Tabblet Levee Assessment Tool, uma solução implementada para prover de forma amigável a visualização, a manipulação e a análise de dados SAR para monitoramento dos diques.

Palavras-chave: SAR, Classificação, Enchente, Risco.

1. INTRODUCTION

Over the entire US, there are over 150,000 km of dam and levee structures of varying designs and conditions. Levees (also known as dikes) are extended embankments naturally or artificially constructed that regulate water levels (see Fig. 1). The artificial constructed earthen levees protect large areas of populated and cultivated land in the United States from flooding (AANSTOOS et al., 2011).

However, controlling the water level of massive hydrologic basins is an enormous task, and the recent flooding of the Mississippi River and its alluvial valley in 2011 was a reminder of just how difficult this task

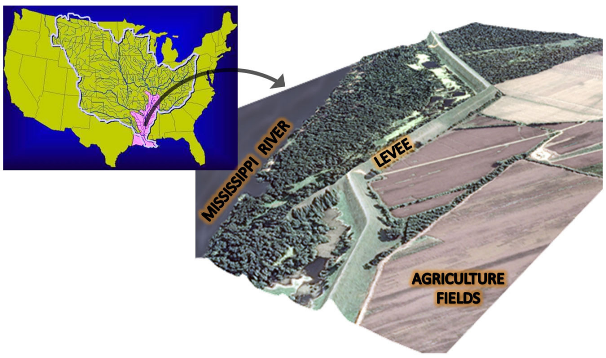

Fig.1 - A section of a levee located in the Lower Mississippi river valley designed to protect agriculture fields from high water events.

can be (BARRY, 1997). According to USACE (2011), the heavy snow melt and rainfall ten times greater than average across the eastern half of the 517,998 km2 Mississippi watershed in spring and early summer of 2011 produced one of the most powerful water discharges in the river's known history. As shown recently with Hurricane Katrina and the floods in the Midwest and along the Mississippi River, the potential loss of life and property associated with the catastrophic failure of dams and levees can be extremely large.

Over the last 100 years of existence, the risks associated with levee failure relative to the risks identified when a particular levee was designed or built have changed considerably. The development of urban areas nearby the Mississippi River and its tributaries, as well as changes in shipping channels and harbors upstream, increased run-off with increased paved area, and other factors have increased and continually change the loads that levees must withstand. Similarly, the changes in land-use adjacent to levees have put more people and high-value real estate at risk from levee failure.

According to Denning (1994), the cost of the damages incurred by the floods along the Mississippi and Missouri rivers in 1993 reached about US $10 billion, and the amount was mostly used to repair damaged levee infrastructure and the affected areas. Today, almost a decade later, the authorities still have limited processes to predict potential risk to communities, prioritize monitoring and methods to monitor the large number of dam and levee structures. In Mississippi alone, hundreds of dams and levees are not currently monitored, and there is no reasonable means to assess the potential risk for catastrophic failure (SERRI, 2012).

It is well known that the dynamics of subsurface water events cause continuous damage on levee structures. The damages caused by subsurface-driven events are not easily spotted prior to the appearance of slough slides or through-seepage (DUNBAR, 2009). The traditional method used for detecting these events involves physical surveys, always time consuming and expensive. Synthetic Aperture Radar (SAR) technologies are capable of identifying variations in soil properties that are related to the potential for such events (AANSTOOS et al., 2011). The L-band SAR is capable of penetrating soil (AANSTOOS et at, 2010, GALLOWAY et al 1998, TABATABAEENEJAD and MOGHADDAM, 2011), therefore it presents potential use for detecting soil moisture changes. The Levee Assessment via Remote Sensing (LARS) project, sponsored by the U.S. Department of Homeland Security, was established to provide improved knowledge about the geophysical condition of levees using UAVSAR data. The overall study investigated soil moisture, soil electrical conductivity, sand boils, and landslide events. This information can significantly improve the allocation of precious resources to inspect, test, and repair the levee segments in most need. The UAVSAR data exploration considered the levee segments in healthy condition as well as unhealthy conditions, where damages were previously reported and provided to the investigation team. A general description of the techniques is available in the LARS Final Report of 2011.

This paper presents a compendium of methods and results of applying the UAVSAR data to the task of identifying problems on Mississippi's earthen levee system. The objectives are to:

- synthesize the approaches developed for identifying electrical conductivity, landslides, sand boils and leaking earthen levees based on soil moisture investigation;
- highlight the efforts toward the prototyping a geospatial framework for performing rapid assessment of the surface and subsurface conditions based on SAR data;

The overall goal of the research project is to develop new methods and software, based on remote sensing, for improving the knowledge of the condition of earthen levees, thus giving levee managers new tools to prioritize their tasks.

2. THE MISSISSIPPI RIVER LEVEE SYSTEM

Humans have built their civilizations next to the water, and the early Americans were no exception. To the settlers of Mid-America, the Mississippi River was one of their most valuable resources. It provided them with a means of transportation for developing commerce and industry, as well as water for crops and irrigation. While settlers enjoyed their ready access to the river, they did not enjoy its ready access to them. Floods frequently swept away their attempts at permanent settlements. The consensus grew that the Mississippi would need to be artificially controlled in order for society to benefit from its proximity (KEMP, 2010).

The Mississippi Levee system is a continuous extended embankment artificially constructed to regulate water levels in the Mississippi Valley. It was built to protect adjacent settlements and farmlands, and today it became an important component of the flood risk reduction in USA. The Mississippi Levee system comprises over 5,600 km of earthen wall structure designed to protect the agricultural area of Mississippi Valley, thus monitoring the physical condition of the levees is vital for flood control.

To better understand the history of the Mississippi Levee, farmers and local community joined efforts to build small levee sections to protect the richest cotton-based economy late in 19th Century. However, the effective construction of the Mississippi Levee System dates from early 1900's. Nowadays, the Mississippi Levee System continues being developed and managed by Federal authorities. Today it is considered one of the most extensive engineering infrastructure projects in the world.

The material used to build the levees have been extracted from nearby borrow pits, and compacted in layers over the time. However, one of the largest problems faced by the levee authorities is the lack of technical information about the levee soil composition beneath the current surface.

It is well known that high water events elevate the pressure in the structure and trigger several problems such as underseepages. The dynamics of subsurface water events cause continuous damage on levee structures which are not easily spotted prior to the appearance of slough slides or through-seepage. If not remediated, the seepage will carry sediment and create pipes, which will increase size over time and collapse the levee structure.

Sand boils and excessive moisture are clear indications of leaking through or under the levee. According to Williams (1974), sand boils are springs that form on the land side of a levee containing a river at extremely high flood stage. Hydrostatic pressure generated by the column of river water exerts a downward force that is too great for the wall material of the river channel to contain, and thus water is forced through the wall material of the channel.

Another significant damage typical in the levee structure is the landslide. Slough slides are slope failures along a levee, which leave areas of the levee vulnerable to seepage and failure during high water events. The roughness and related textural characteristics of the soil in a slide affect the amount and pattern of radar backscatter. The type of vegetation that grows in a slide area differs from the surrounding levee vegetation, which can also be utilized in detecting slides (HOSSAIN et al., 2006). An illustration of slides and sand boils is shown in Fig. 2.

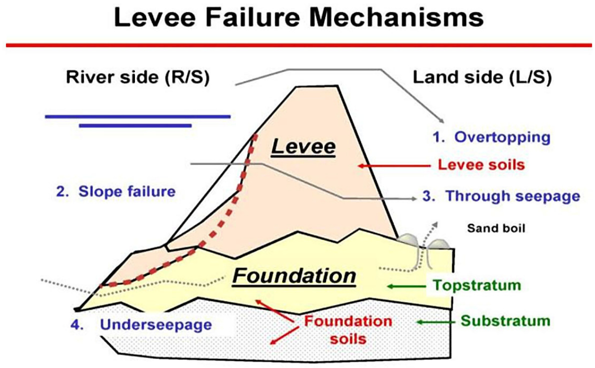

Fig.2 - Illustration of levee failure mechanisms, including slough slides and sand boils (Dunbar, 2009).

Early detection of the occurrence of these events can assist levee mangers in prioritizing their inspection and repair efforts. A remote sensing based solution for their rapid detection would be more efficient and cost effective than frequent on site visits. Furthermore, it may be possible to detect less obvious precursors to the slides and boils themselves by sensing characteristics of the surface soils and vegetation. A working hypothesis of this study is that such characteristics are manifested in the backscatter of polarimetric radar due to its response to spatially variant soil moisture and irregularity in the surface.

SAR technologies are capable of identifying variations in soil properties that are related to the potential for such events. In particular, L-band radar is known to penetrate dry soils up to one meter in depth, and has been used to map surface soil moisture (SHI et al., 1997).

3. THE NASA UAVSAR

The airborne sensor used in this study is the NASA Jet Propulsion Laboratory's Unmanned Aerial Vehicle Synthetic Aperture Radar (UAVSAR). UAVSAR is a polarimetric L-band synthetic aperture radar (SAR), which is specifically designed to acquire airborne repeat track SAR data for differential interferommetric measurements (ROSEN et al., 2006). As shown in Fig. 3, UAVSAR is a compact SAR designed to fly on an airplane or an Unmanned Aerial Vehicle (UAV). According to Lee et al. (2007), the key element for the success of UAVSAR program is the Platform Precision Autopilot, which is a stable platform capable of meeting the requirement of flying in a ten meter tube on a path of up to 200 km long.

The radar is fully polarimetric, with a range bandwidth of 80 MHz (2-m range resolution), and

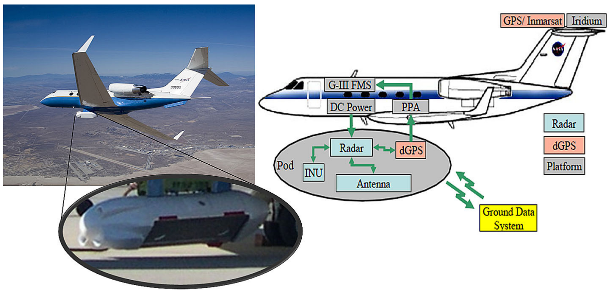

Fig. 3. UAVSAR Aircraft Configuration with a Synthetic Aperture Radar Pod mounted in a Gulfstream III Jet. Source: adapted from LEE et al. (2007).

supports a 16-km range swath flown at a nominal altitude of 13800 m. The antenna is electronically steered along a track to assure the antenna beam can be directed independently, regardless of speed and wind direction. The exceptionally low noise equivalent ?0 (high receiver sensitivity) allows UAVSAR to detect targets with weak radar backscattering cross section and to improve the accuracy of geophysical measurements such as soil moisture and vegetation biomass. The instrument's parameters are listed in Table 1.

UAVSAR is a portable pod-based SAR system instrumented with a phased array, polarimetric, L-band antenna. It is designed to support a wide range of science investigations including geology, vegetation mapping and land use classification, archeological research, soil moisture mapping, and cold land processes. UAVSAR is capable of penetrating dry soil. Using interferometry it is capable of identifying vertical displacements on the order of a few millimeters. Thus it is valuable in detecting changes in levees that are key inputs to the classification system. NASA partnered with MSU to make this instrument available for data collection over our study area and has also provided radar data preprocessing. Fig. 5 illustrates a multi-look

Table 1 - KEY UAVSAR INSTRUMENTS PARAMETERS

Parameter	Value
Frequency	L-band
Bandwidth	80 MHz
Range Resolution	1.8 m
Polarization	Full Quad-Polarization
Raw ADC Bits	12 baseline
Waveform	Nominal Chirp/Arbitrary
Azimuth Steering	> ±20°
Power	> 2.0 kW
Polarization Isolation	<-20 dB
Antenna Dimensions	0.5 m range/1.5 azimuth

and color-composed image computed from three multi-polarized channels in the study area.

4. MATERIAL AND METHODS

Our test study area is a stretch of 230 km of levees along the lower Mississippi River on the western boundary of the State of Mississippi. The area is located between the latitudes 32º02'N and 32º15'N, and between the longitudes 90º41'W and 91º16'W. The effective flight area covered 5,265 km2. The 20-km image swath of the UAVSAR data encapsulated most of the meanders of the Mississippi River and the levee in both sides of the river. However, two flight lines were necessary to cover the extent of the project (Fig. 4).

The UAVSAR images were acquired at five different times between June 2009 and June 2011. The multi-temporal dataset was necessary to investigate the behavior of the levee structure across different seasons (dry, wet). In an ideal scenario, these images allow the investigation to understand differences in the images before and after slides and leaking events. The 2011 flooding of the Mississippi River occurred in May, in the middle of the project. A list of the UAVSAR data is presented in Table 2.

The ground truth data was provided by the USACE. The data included the approximate dates where slides were noticed and repaired, the ground coordinate locations of the slides, the relative levee station number, and the types of materials (lime/sand) used in repair of landslides. This ground truth data were also compared with the optical National Agriculture Imagery Program (NAIP) data to visually confirm

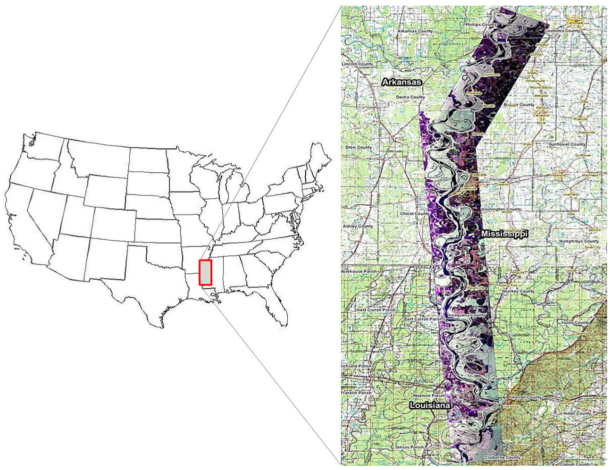

Fig.4 - Study area along the lower Mississippi River. Polarimetric UAVSAR data are shown in false color composite of bands HH, HV and VV as red, green and blue, respectively. Image swath is 20 km; total flight line length is 230 km.

Table 2 - ACQUISITION DATE, LOOKING TYPE AND AZIMUTH DIRECTIONS OF THE MULTIPOLARIZED IMAGES (HH, HV AND VV POLARIZATIONS) ANALYZED IN THIS STUDY

Acquisition	Looking Type	Azimuth
June 16, 2009	Single-look, Multi-look	355º
June 16, 2009	Multi-look	20º
June 16, 2009	Multi-look	200º
June 16, 2009	Single-look, Multi-look	5º
January 25, 2010	Single-look, Multi-look	355º
January 25, 2010	Multi-look	20º
January 25, 2010	Multi-look	200º
January 25, 2010	Single-look, Multi-look	5º
April 28, 2011	Multi-look	355º
April 28, 2011	Multi-look	20º
April 28, 2011	Multi-look	200º
April 28, 2011	Multi-look	5º
June 06, 2011	Multi-look	355º
June 06, 2011	Multi-look	20º
June 06, 2011	Multi-look	200º
June 06, 2011	Multi-look	5º
June 22, 2011	Multi-look	355º
June 22, 2011	Multi-look	20º
June 22, 2011	Multi-look	200º
June 22, 2011	Multi-look	5º

the slide events as unrepaired or repaired classes. The NAIP sensor data for the summer period of 2009 (May-September), and 2010 (May-September) were available for our study region. A total number of 17 slide events were identified. Similarly, USACE provided a list of sandboil events that occurred during the flood of 2011.

5. CASE STUDIES AND RESULTS

The goal of the levee classification algorithm development task was to choose an algorithm and a set of features that demonstrate the ability to identify areas on the levees that have an increased likelihood of being vulnerable to failure under high water conditions and thus merit closer inspection and possible repairs. In this study, we focused mostly on the detection of slump (or slough) slides.

Various tools were used to assess the statistical distribution of the polarimetric backscatter from the levee features. In section 5.1, the landslides are targeted based on the classification of soil conductivity measurements against the polarimetric feature data. The features used include the magnitudes of the polarimetric backscattering coefficients (HH, VV, and HV polarizations), band ratios (HH/VV and HV/VV) and texture features such as window statistics (mean and variance) and wavelet features. For the sand boils classification in Section 5.3, the team applied the RX anomaly detector unsupervised classification algorithm to detect the sand on the levee. The RX algorithm (CHAN and CHIANG, 2002) is a training–free unsupervised classification method.

For training the classification model both the Healthy Levee and Landslide sample vectors are extracted using various feature extraction techniques such as statistical (e.g., mean, variance and standard deviation), wavelet (wavelet energy, wavelet max coefficients, and wavelet max phase), and Grey Level Co-occurence Matrix (GLCM) textural features (energy, homogeneity, entropy, contrast). The parameters of the GLCM features are; Distance '1', angle 900 [-1 0] and 1350 [-1 1]. The spatial window size used her is 5 × 5. Haar wavelet was used as the basis function here based on the application problem. The occurrence of the landside event is discontinuous and therefore a step function such as Haar wavelet is an appropriate choice unlike Symlet or Daubechies (order >=4) wavelets. Potential features for discrimination of the targets of interest were evaluated using both per-pixel and window-based (textural) techniques (GOKARAJU, et. al., 2012). The candidate features were tested with our training data to determine separability between classes of interest. Plots of the Bhattacharyya distance between target classes (target refers to an event of interest on the levee, e.g., landslides and compromised sections of the levee) and the other (background) classes found in the study area were examined to assist in feature selection. Support Vector Machines (SVMs) was used as the feature classification in this part of experimental analysis.

The above candidate classification algorithms were run with sets of these features to further narrow the choices. Owing to the relatively small number of ground-truth pixels available, a leave-one-out cross validation technique was employed to estimate overall classification and target detection accuracies. In this approach, all samples but one (and hence features derived from them) are employed to "train" the classifier, and the sequestered sample is employed for "testing". This is repeated in a round-robin manner until all samples have been tested and classified. Based on the ground-truth for these test samples, a confusion matrix with Kappa accuracy, overall accuracy, target detection accuracy and false alarm rate are calculated (GOKARAJU et. al., 2011 and GOKARAJU, et. al., 2012. A total number of 17 slide events were identified in this period by the available ground truth. The training masks were created for all the slide events and labeled as either repaired or unrepaired by the date of acquisition. The training samples of slides and healthy parts of levee data were obtained from the UAVSAR data using the training masks for further feature extraction analysis. The samples from the healthy parts of the levee around the slide events were considered for the Healthy Levee class.

5.1 Soil Moisture/Electrical Conductivity

Soil moisture changes along a levee and over a period of time can help to monitor and find potential failure indicators such as slides and sand boils around the levee. The soil electrical conductivity estimates the soil moisture, through a well-established relationship with water content in the soil. The radar backscattering coefficients are affected by soil moisture, surface roughness, and incidence angles (FUNG et al., 1992). Several analytical and empirical models have shown relationships between SAR backscatter and soil moisture (DUBOIS et al., 1995; OH et al., 1992). The algorithm includes three steps: (1) the segmentation of the levee area into a 300 meter buffer zone from levee centerline, and removal of the trees using a threshold; (2) the extraction of the backscatter and texture features from each pixel within the buffer; and (3) the classification of soil conductivity using a back propagation neural network (MAHROOGHY et al, 2011). The investigation used UAVSAR for the remote sensor and ground-based conductivity measurements as ground-truth data. The features used include the magnitudes of the polarimetric backscattering coefficients (HH, VV, and HV polarizations), as well as their ratios (HH/VV and HV/VV), along with texture features such as window statistics (mean and variance) and wavelet features. Wavelet features used are the mean and standard deviation of the energy of approximation and vertical, horizontal, and diagonal detail coefficients of a two-level decomposition of each pixel and its neighbors (sliding window size 7). A total of 51 features were extracted at each pixel location and have been used for classification. Details of the neural network architecture used can be found in (MAHROOGHY et al, 2011). Fig.5 illustrates the results.

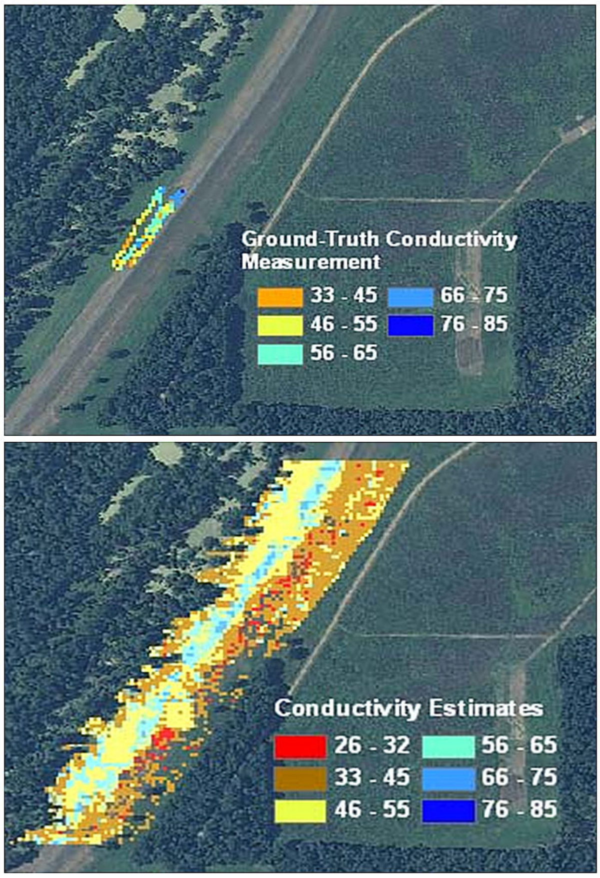

Fig.5 - Soil conductivity measured as ground true and the respective soil conductivity estimated for the study area. Source: MAHROOGHY et al. (2011).

5.2 Landslide Classification

The state-of-the-art kernel based classification technique known as Support Vector Machine (SVM) was adopted for the binary classification of landslides of the levee against the health areas of the levee. The primary goal of SVM is to devise an optimal hyperplane that maximizes the marginal distance from the support vectors of each class (CORTES and VAPNIK, 1995). This optimal hyperplane generalizes well to the other hyperplanes (i.e. infinite possibilities). SVMs use a Radial Basis kernel Function (RBF) kernel to compute the inner product of two nonlinear transformations of original features, without explicitly computing the higher dimensional features, so that a linear hyperplane can do the discrimination (known as kernel trick) (GOKARAJU et. al., 2011). Training masks of healthy areas, unrepaired slides and repaired slides were designed in order to feed the SVM. Masks were digitized for the slide and non-slide areas using aerial images as source for visual reference (Fig. 6).

Training accuracy reached 99.6%, which provided substantial credibility to proceed with the method in other areas (Fig. 7). However the lack of ground truth information about landslides is a limiting factor for the validation of the method. For further details of implementation of SVM, the readers are advised to refer to SERRI (2011).

Fig.6 - Landslides on a levee as seen from the aerial flight, Jan 2010. Lidar optical data provided by USACE (left), UAVSAR data (right).

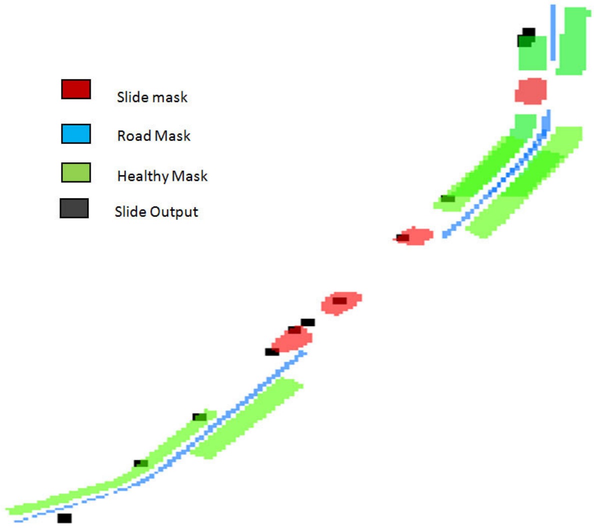

Fig.7 - The classification map output of slides against healthy levee.

The landslides were also explored using other features, including Entropy (H), Anisotropy (A), and Alpha(a). These features were computed from the scattering matrix and coherency matrix of HH, HV and VV polarized bands. H, A and a were used to compute first-order statistical features and used with the Wishart unsupervised classification algorithm to see if it could discriminate landslides from healthy areas of the levee. Some results are shown in Fig. 8. Detailed descriptions of this method and how it was developed for UAVSAR data are available in SERRI (2011) and DABBIRU (2010). The reason these features are used in a separate classification analysis is because H, A and a are considered to be invariant features of the SAR polarization bands with respect to viewing geometry, unlike the other features used above (FREEMAN and DURDEN., 1998).

5.3 Sand Boils

The presence of sand boils on the land side of a levee can be a major concern for stability during flooding. Water begins to move through the soil under

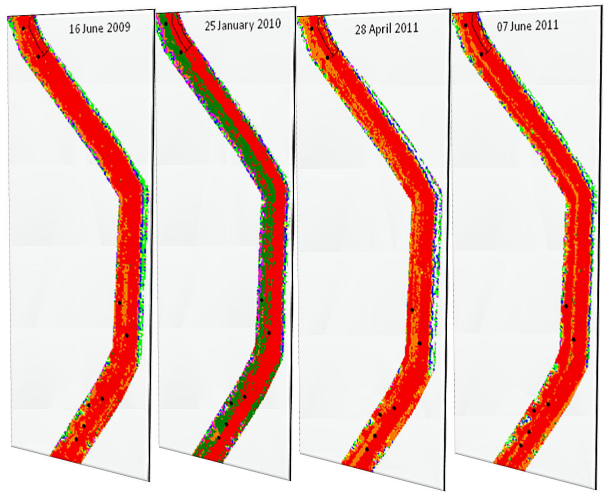

Fig.8 - Wishart H-alpha unsupervised classification analysis performed on four UVASAR images (adapted from SERRI, 2011). Black dots and polygon are slides; colors represent different clusters from the classifier output.

the levee, from the side with high water to the side with the low or no water and it becomes a problem when the water moving under the levee begins to carry soil particles along with it. This will deteriorate the structure of the levee and if enough soil is moved from under the levee, the levee will collapse. Therefore, detecting sand boils on the levee is a critical task in order to fix them before it weakens the levee structure. A grain distribution entropy technique (NAGY, 2012) was developed to identify soil types that have low entropy and articulated that these low entropy soil types could pose the greatest boil hazard. In our study area, most of the sand boils were located under trees on the land side of the levee except a few, as shown in Fig. 9.

Since the radar signal generates significant backscatter from the tree canopy, we considered only the sand boils without the vegetation cover which appeared on the toe of the levee.

Fig.9 - Field photograph of a sandboil obtained during one of the data collection campaign.

For the sand boils characterization, the team applied the RX Anomaly detector classification algorithm (CHAN and CHIANG, 2002) to detect the sand on the levee using the radar backscatter data. The RX algorithm is a training–free unsupervised classification scheme. It detects signatures that are distinct from the surroundings with no prior knowledge. Essentially, the algorithm uses the covariance matrix which calculates the Mahalanobis distance from the test pixels to the mean of the background pixels. Anomalies are detected as pixels having a large spectral distance to the background spectral signatures and thus the sand on the levee was shown as an anomaly (Fig. 10).

The distance measure output by the algorithm indicates how anomalous each pixel is from its neighborhood. This value can be thresholded to identify particular anomalies of interest, but the value of the threshold is application specific and variable. Thus, interpretation of the output is subjective. However, by assigning a color map to the output and adjusting the threshold, areas of sand can be clearly delineated on the levee using this method as can be seen in the figure.

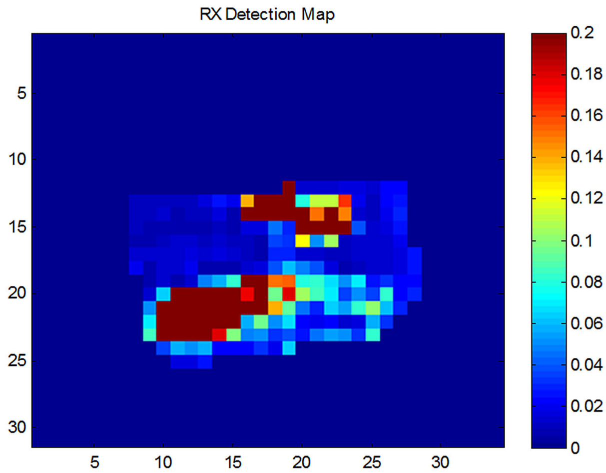

Fig.10 - Classification result for the detection of sand.

5.4 Soil Moisture / Leaking

While testing and prototyping the classification techniques, the team also explored the use of UAVSAR for understanding the behavior of the soil moisture in the farmlands adjacent to the levee. The US Corps of Engineers (USACE), the US Federal Emergency Management Agency (FEMA), and the Mississippi Levee Authorities considered the high water events of 2011 as a typical 100-year flooding. In March 2011, the water level upstream in Cairo, Illinois, had reached 18.6 m and was rising. The situation forced USACE to blow up strategic segments of the main levee to reduce the water flow and relieve the water volume downstream (OLSON and MORTON, 2012; GRAMLING, 2012).

Despite the controlled situation, the situation propelled subsurface water events beneath the levee structure. A large number of sand boils was reported during the peak of the high level water. Similarly, the agriculture fields adjacent to the levee, typically dry, presented excessive wet and high moisture soils.

In order to contribute to a task force, the authors combined a series of geographic data to create a knowledge database for understanding the behaviors of the areas adjacent to the levee. The authors brought to the project key concepts of Object-Based Image Analysis (OBIA) for mining information across different images, such as the 1-meter GSD optical imagery of National Agriculture Image Program (NAIP) of 2007, 2009 and 2010, the LiDAR data, and the UAVSAR data. Details about OBIA are available in Baatz and Schäpe (2000), Baltsavias (2004) and Blascke (2010).

The data exploration levered a series of band ratio and features customized in Definiens eCognition. The idea consisted of analyzing multi-temporal UAVSAR data also using contextual information. It was noticed that the images displayed in the natural backscatter (non-log transformed (dB) as usual for radar data), besides very dark aspect, show high brightness values in certain areas for after flooding images (Fig. 11).

A 2-km buffer zone was created in the east (landward) side of the levee. The area is wide enough to capture changes in soil moisture and leaking. The buffer zone was segmented using the UAVSAR post-flooding image as reference. The segments were analyzed through OBIA, by bridging remote sensing

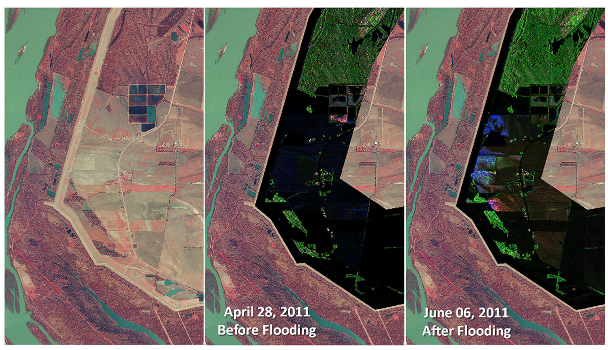

Fig.11 - Color-composed UAVSAR backscatter (HH, HV, and VV polarizations) before and after the flood event of May 2011.

and geoprocessing procedures. The team created a database where statistical and contextual information were tabulated per object (image segment) for all polarization channels of all UAVSAR data and the auxiliary data described above.

The features customized include the original digital numbers from the images, as well as procedures based on dada dimensionality reduction such as principal components. Fig.12 illustrates a color-composite display of the principal components extracted from the multi-polarized UAVSAR data. The high moisture area near the toe of the levee is clearly detected in the principal component 1.

The investigation suggested the areas where VV presents relatively higher backscattering values than the combined HH and HV polarizations represent high moisture areas, and therefore the levee segment nearby is potentially developing under seepage problems.

6. THE LEVEE ASSESSMENT TOOL

The conceptual design for the Levee Assessment Tool (LAT) idealizes a user-friendly piece of software developed in open-source system based on a geospatial platform that is highly interoperable with other related products. However, prototyping a simple but efficient solution based on cutting-edge technology, complex feature extraction algorithms operating on non-commercial SAR data is enormous. In order to make is possible, the development of LAT met the following criteria:

- Input UAVSAR image with no losses of data;
- Develop basic GIS operations such as band stacking, log transformation, noise-removal filtering and subset;
- Operate in an efficient Graphic User Interface (GUI); and
- Incorporate complex feature extraction algorithms.

At first, the software development team has been prototyping and testing high-level user interfaces and utility tools for the ultimate package. A lengthy list of data types and themes emerged which was coupled with a need to show workflow products and results in an organized manner that clearly displayed desired data sets without obscuring important thematic collections. Various aspects of this concept are described and illustrated below.

Trial versions of this interface and some of the utilities were shown to our partners and potential end-users at the USACE and their feedback was solicited and incorporated. Default tabs are provided for Base

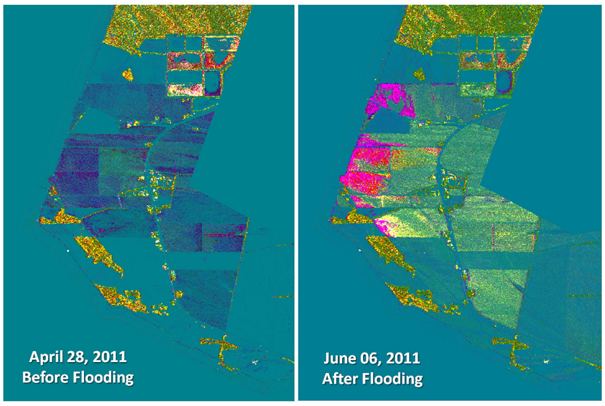

Fig.12 - Color-composite of the UAVSAR before and after the flood event of May 2011 using customized features PC1, PC2 and HV/VV ratio respectively as red, green and blue.

Layers, National Levee Data Base (NLDB) Features, UAVSAR, Classified Data, Segmentation, Aggregation, and Reporting. In the active tab for Base Layers, general layers are shown for boundaries, water bodies, and major rivers. This collection could be significantly expanded to include other base map layers as desired. The National Levee Data Base tab is shown with data depicted for the levee centerline and buffered segments on either side of the levee.

Other data sets such as base image data, soils data, geology and related feature data sets may be added to the view to add valuable insight. In this case, areas with vulnerable soils are depicted by red segments along the levee. Next, the classification algorithms (presented in Session 5) were compiled into executable files in Matlab, and then incorporated into the Levee Assessment Tool. New tabulations were added into the GUI to call the subroutines.

The levee is segmented based on orientation changes and overall length between changes. Thus, for levee areas with frequent changes in orientation, there are numerous segments each containing a segment with nearly consistent azimuth orientation. These segments are created to be used along with levee data, geology, soils, and historical information to assess the prior probability of risk based on physical characteristics and the overall risk characteristics based on historical slides or possible current slides. The levee segments and aggregated results are shown for the area and shaded by risk as presented in the table below. Table 3 presents a general LAT rule base for classifying the levee risk segments, in accordance with the current risk classification scheme used by USACE. Fig. 13 illustrates the results for the segment of interest, which shows preliminary slide feature detection results, using

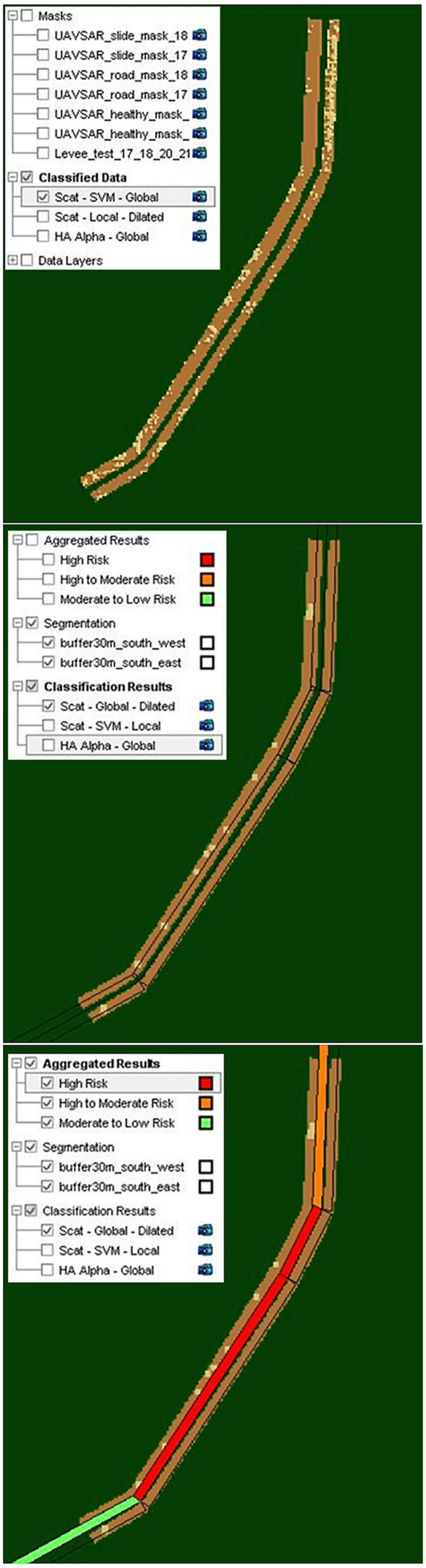

Fig. 13. Study area along the lower Mississippi River. Polarimetric UAVSAR Application of Levee Segment Risk classes. Source: adapted from SERRI (2011).

Table 3 - LEVEE SEGMENT RISK TABLE

Geology Soils	History	Slide Features	Risk Rank	Risk Description
Good	Absent	Absent	1 Green	Low
Poor	Absent	Absent	2 Green	Low-to-Moderate
Good	Present	Absent	3 Yellow	Moderate
Poor	Present	Absent	4 Orange	Moderate-to-High
Either	Either	Present	5 Red	High

our current concept for methods of visualizing levee segment vulnerability (top), the segmented levee for mapping (middle), and the risk classification results (bottom).

LAT includes easy capabilities to copy layers between tabs, assign specific color palettes to classification results, specify a transparency color within a raster and a percent transparency for a layer, and enable 'locking' of zoom and extent among tabs based on current interface and zoom level. Overall development must continue for supporting additional image types, embedding classification tools, providing area-of-interest (AOI) handling and preprocessing, and automating geoprocessing to create segmentation outputs and aggregate results per segment based on class results.

Prototyping efforts have led to a working conceptual model for a LAT which incorporates unique, novel, and innovative results in the form of a tabbed-GIS data management and analysis interface. Capabilities to manipulate, transform, and manage data add power to the application. Ongoing developments are leading to stable software capabilities to work with and process enormous radar data sets to deliver results that depict levee conditions in terms of relative risk.

7. CONCLUDING REMARKS

These research and development activities contribute to the implementation of innovative methods to perform condition assessment and screening procedures for earthen levees. The results combine science and technology with approved methods relevant to regional needs, in a solution with national implications for levee assessment. A prototype was developed for a tool that uses robust technology such as airborne-based SAR, therefore bridging the complexity of radar interpretation and the simplicity of a desired map-monitoring system. was a necessary task to be done.

In this case, the need is for a rapid and efficient way to identify reaches, within large levee systems, that exhibit geotechnical or geologic characteristics that make the reach vulnerable to failure under flood loading. Once vulnerable reaches have been identified, further actions such as more detailed examination or repairs can be focused on these higher-priority sections.

This work contributes to the development of tools, procedures and software that will help levee operators find these potential problem locations. The software developed for this system adheres to the open geospatial data standards that will facilitate its expansion in the future and potential interoperability with other systems. The software is built on an open source, public-domain library of geospatial software known as MAPWINDOWS, which allows one to implement familiar GIS functionality without requiring the end user to purchase a commercial GIS license.

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