DYNAMIC INTEGRATED GIS ENHANCEMENT AND SUPPORT TOOLS FIRST STEP: ANALYSIS OF AVAILABLE DATA

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Abstract. Already existing Digital Elevation Models (DEMs) contain inaccuracies that prevent them for being reliably used to support decision-making in emergencies. The objective of this paper is to present the framework for a set of Dynamic Integrated GIS Enhancement and Support Tools (DIGEST) that aims to reduce inaccuracies of existing DEMs for “on-the-fly” applications. DIGEST allows a more effective use of DEMs, particularly for management during a natural or manmade disaster. The DIGEST system will be integrated in an existing geographic database, with tools targeted to create quality information for the available data, and to define appropriate scale required for an event simulation based on the limitations of existing topographic data. The new system tools will also dynamically extract features of topographic relevance from the most recent non-photogrammetric visible, infrared and thermal imagery. The extracted features will be employed to detect changes to topographic features in the already available DEMs. Quality enhancement of the DEM will be achieved through the integration of the extracted topographic features using data conflation algorithms. In the current paper, an analysis of widely available DEMs is present demonstrating the potential of DIGEST by focusing on the potential impact on decision-making by using freely available data from the Shuttle Radar Topography Mission and other DEMs available from Geospatial Data Clearinghouse servers established by the Federal Geographic Data Committee (FGDC).

1. Introduction

Geographic Information Systems (GIS) data and Remote Sensing (RS) imagery are widely available at different scales from diverse sources. The data varies in format, scale, and most fundamentally, in the method and time that each of these was gathered. Users often combine these multi-temporal datasets for decision-making purposes regardless of different gathered time, method, scale and format. As an example of the variety of widely available data digital elevation models (DEMs) in various resolutions, scanned images of topographic map, one meter resolution aerial orthophotos, vector line data covering information from political division to vegetation cover, vector surface water data, and land cover in raster format (USGS 2003) are accessible from the U.S. Geological Survey (USGS) through its clearinghouses. Additional imagery data is also available from USGS Earth Resources Observation System (EROS) Data Center, including images from various satellite (USGS 2003). The effective use of these and other geospatial information depends not only on the tools to analyze the data by applying integration and transformation methods on them but also on the consideration of the uncertainties and limitations of the original data.

The main objective of the Dynamic Integrated GIS Enhancement and Support Tools (DIGEST) framework is to reduce inaccuracies of existing GIS and RS dynamically through “on-the-fly” integration of data from diverse sources, acquisition methods and times. Additionally, DIGEST aims to assist the user in a data request by recommending the right data and suggesting the acquisition of new data if there is no data that meets the quality requirements. Given that DEM data are the basis of a series of products, usually with the use of derived data, such as the slope and the aspect information, in the initial version of DIGEST only DEMs will be treated. To achieve DIGEST goals, data quality information and data scale suitability information will be gathered by analysis tools on the existing DEMs. Another DIGEST tool will provide means to extract topographically relevant features from most recently acquired RS imagery coupled and to register images. The integration of topographically relevant features and higher resolution or higher quality elevation information - such as the ones from ground-based Global Positioning Systems (GPS) devices - with already existing DEMs will be executed by an additional tool.

The integration takes place in a georeferenced database, with information about quality, and scale of the process or property to which the data is more suitable, and methods improving quality by incorporating additional information will provide a reliable platform for simulations required for the decision-making process in natural resources or disaster management (Renschler and Harbor 2002).

2. Background

Efforts in the GIS and RS user community are mainly focused at data integration and transformation. Analysis of uncertainty and studies to determine the reliability of the methods applied to the data are not common and only rudimentary tools are included in GIS software packages. Intensive studies since the mid 1990s initiated by (Hunter and Goodchild 1995) provide a series of error estimates using probability theory. DEM data are the basis of a series of products, usually with the use of derived data, such as the slope and the aspect information. Therefore, many of the uncertainty studies deal with DEM. Uncertainty presence in DEM is widely acknowledged (Hunter and Goodchild 1997), for example, the USGS DEM uncertainty is stated for the various scales, with the best defined to have a root mean squared error (RMSE) maximum of one-third of the contour interval (USGS 2003). However, this measure of uncertainty in USGS DEM is not of practical use as spatially distributed information or for mathematical modeling because the RSME is defined over a small number of samples (about 30 points) with the highest requirement being that the sample locations are evenly distributed in the DEM. To overcome this limitation, (Renschler et al. 2002) designed a new RMSE and Model Efficiency (ME) filter values (MEFV) that provide spatially distributed measures of uncertainty in raster data models based on multiple sources of elevation data.

DEM from other sources, such as the one from the Shuttle Radar Topographic Mission (SRTM) are not better in modeling uncertainty, with their data specification demanding that 90% of the points lie within 16 meters accuracy in the vertical dimension and 20 meters in the horizontal plane (Kretsch 2000). In addition, the currently released data often has data gaps and inconsistencies.

During a time of crisis when decision-makers must rely on this potentially uncertain data, the knowledge of the reliability of the data concerning the area of interest will help achieve a better assessment. The definition of the conditions for a data set to be adequate for input in a given model are not based only on uncertainty and but also on the scale of the used data. In the case of the elevation data, scale is related to the effective resolution of the DEM. In hydrological applications, several studies have demonstrated that DEM resolution plays a major role (Hardy, Bates, and Anderson 1999; Horritt and Bates 2001; McMaster 2002). One method to define the adequate scale/resolution for a given problem is to use different scale/resolution combination and select from one of them (Brasington and Richards 1998; Horritt and Bates 2001).

Given that the adequate scale and quality for the data to be used for the assessment of a particular phenomenon is known, if data characteristics do not fulfill the minimum requirements for a proper analysis, methods to enhance a particular data set will be crucial. Enhancement of a data set can be achieved by using additional information from other sources, either a pre-existing easily available dataset or a specially gathered dataset. The integration process is dependent on the georeferencing of the newly available data and synergy with the main data. Georeferencing is dependent on the correct transformation between the reference systems of the main and the new data. The widely used World Geodetic System 1984 (WGS84) reference system relies on controls points common to the other reference system to minimize differences (Kumar 1988).

The correctly referenced additional data can be integrated into the existing data through conflation methods and it can be available in different formats. The first separation for a topographic data is based on the existence of height information. Data without height information can be used to position characteristic features of the terrain such as peaks and pits points or ridge and valley lines, and require some procedure to define an estimate of their heights (Namikawa 1997). Integration of data with height information in punctual, linear, and rectangular grid format should be done considering the relative reliability of the different sources (Kyriakidis, Shortridge, and Goodchild 1999).

The additional information from this latest imagery can be used to improve topographic data quality if the images are correctly georeferenced. Imagery can be georeferenced through automatic registration techniques (Fonseca and Manjunath 1996) using wavelets or contour matching approaches (Fedorov et al. 2003). From these images, linear features that will help improve data quality can be extracted through either segmentation (Munoz et al. 2003) or mathematical morphology techniques (Candeias 1996).

The integration in a georeferenced database of data, its quality information, scale of the event to which the data is more suitable, and methods to improve quality by incorporating additional information will provide a reliable platform for simulations required for the decision-making process.

3. Objectives

The main objective is the development of a series of Dynamic Integrated GIS Enhancement and Support Tools (DIGEST) to reduce “on-the-fly” inaccuracies of existing DEMs in order to be more effective and reliable particular in crisis management. The DIGEST system will be integrated in an existing geographic database, with the tools targeted to create quality information for the available data, and to define the appropriate scale required for an event simulation based on the limitations of existing topographic data. The tools will also dynamically extract features of topographic relevance from the latest non-photogrammetric visible, infrared and thermal imagery, detect changes to topographic features in the already available DEMs, and integrate additional information through data conflation algorithms for quality enhancement of the DEM based on the desired scale of interest. A typical data flow (as shown in Figure 1) will begin with the analysis of existing DEMs to create existing data quality information and provide data scale suitability information. Based on the most recent gathered imagery, topographic relevant features will be extracted and integrated in order to determine and enhance the quality of the preexisting DEM and detect changes.

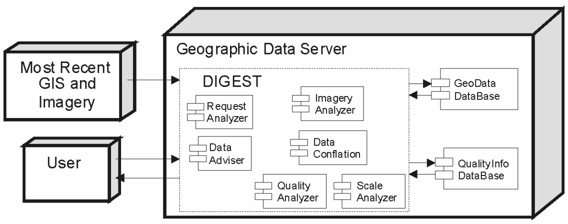

Figure 1. The proposed dynamic DIGEST system integrated in a Geographic Data Server.

4. Approaches

DIGEST will be integrated in a Geographic Data Server that stores the available GIS data and RS imagery in a Geographic Data Database (GeoDataDB). The data and images will have its quality information attached as defined by the Quality Analyzer Tool (QAT). The quality information will be stored in the Quality Information Database (QualityInfoDB). The Scale Analyzer Tool (SAT) will create a knowledge database built from a series of simulations on samples of stored geographic data in different scales. Request Analyzer Tool (RAT) and Data Adviser Tool (DAT) will process user's data request and suggest acquisition of new data if there is no data in GeoDataDB that meets the quality requirements. Imagery Analyzer Tool (IAT) will register the latest imagery and extract topographically relevant features. Data Conflation Tool (DCT) will be responsible for integrating data from imagery and GIS data to existing entries in GeoDataDB.

4.1. Data Quality Analyzer Tool

The DEM quality analysis tool will provide information about the reliability of DEM for each location to which the data applies. Therefore, the format of the quality data to be stored in the Quality Database will be a rectangular grid with values for each cell corresponding to a confidence value. The computation of the confidence value will be based on the existing information about the origin of the DEM, statistical analysis of the DEM, analysis of a set of data derived from the DEM, and comparison among the available DEM for the same region. Figure 2 summarizes the data flow within the Quality Analyzer Tool (QAT).

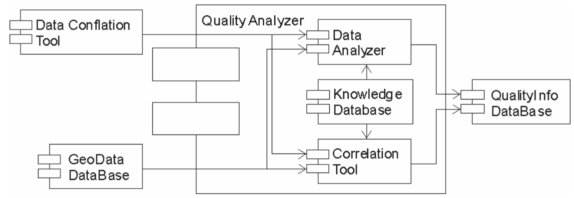

Figure 2. Quality Analyzer Tool (QAT).

A DEM is generated from a set of sample measures from the real world using some instrument. Therefore, the correspondence of the DEM to the real world will depend on the accuracy of the measuring instrument, on the sampling method, and on the interpolation procedures used to fill the regions where samples were not taken. DIGEST will store this extra information in a knowledge database.

The accuracy of the measuring instrument includes the characteristics of the method, and the precision of the location of the measure in relation to a reference. The common methods used to measure elevation are stereographic correlation of aerial photographs, optical satellite images or radar images, direct punctual measuring with traditional survey instruments and Global Positioning Systems (GPS), interferometry of radar images, and laser range detection (LIDAR) systems. Each of these methods influences the resulting DEM in a specific way. Furthermore, the relative positioning of the measure is also unique to each of them.

The sampling method and interval between a pair of samples will affect the DEM quality, with a general rule stating that the closer to a sample, the greater the quality of the DEM being valid. Statistical analysis using geostatistic techniques can be used to calculate this component of the DEM quality.

The effect of the interpolation method used to fill the gap between samples can be determined by analysis of the second and third derivatives of the DEM, and by transformations using either Fourier analysis or wavelets.

An additional component of the DEM quality will be extracted through the analysis of products derived from the DEM. Slope, aspect and curvature of the surface represented by the DEM are major components in most of the simulation methods that use DEM as one of their inputs. By analyzing a set of results from DEMs generated by disturbing a DEM in a controlled way, the locations on the DEM that are likely to affect more largely the simulation result will be considered of being critical regions. Reliability on critical regions will be considered low, allowing following procedures to enhance the quality of these areas.

The last component of DEM quality will be generated by a correlation analysis of existing sets of DEM and of topographical relevant features. The confidence of the DEM will be higher if height values are highly correlated in a region or if the DEM agrees with the topologically relevant features constraints.

4.2. Phenomena Scale Analyzer Tool

A tool to define the appropriate scale required for an event simulation will be created to define the limitations of existing topographic data. The information will be made available during the simulation to give the user the choice of using the available DEM or make an investment towards the acquisition of additional data to create data in the suggested scale.

The tool will analyze the most common results used in a simulation from different scales DEM and define the range of scale for which the simulation would be more realistic. Figure 3 summarizes the data flow within the Scale Analyzer Tool (SAT), where the knowledge database is the central, by providing the expertise used to define the most adequate simulation, and to analyze their results.

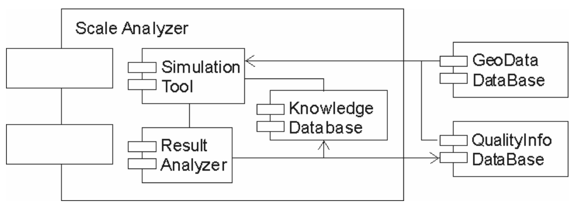

Figure 3. Scale Analysis Tool (SAT).

4.3. Imagery Analyzer Tool

Imagery Analyzer Tool (IAT) will allow the use of imagery to contribute to a better DEM quality by providing means to extract topographic relevant information from imagery. RS imagery provides additional valuable information that does not directly contain elevation values, but is topographically relevant. This supplementary information includes lines and points that correspond to relevant terrain features, to terrain slope, and to terrain aspect. Therefore, terrain relevant punctual and linear features such as the ridge and valley lines will be automatically extracted from imagery using image processing techniques such as image segmentation and mathematical morphology.

The reflectance measured in an optical image is correlated to the angle between the terrain normal vector, the angle of incidence of the sun in the case of an optical image, and to the angle between the terrain normal vector and the direction of the sensor. In a similar way, the strength of radar image signal is dependent on the angle between the terrain normal vector and the direction to the antenna. Additionally a thermal image radiance value is correlated to temperature differences that were originated in the different warming or cooling of the feature dependent on the terrain elevation characteristic. A method to compute the terrain normal vector will be created using the presented principles. The potential of thermal image to contribute to increase DEM quality will be investigated further.

The use of imagery will require the existence of an automatic registration tool to georeferenced data using techniques based on wavelets and contour matching. Figure 4 summarizes the data flow within the Imagery Analyzer Tool (IAT), with the automatic registration and the automatic feature extraction tools delivering topographic relevant features for the Data Conflation Tool.

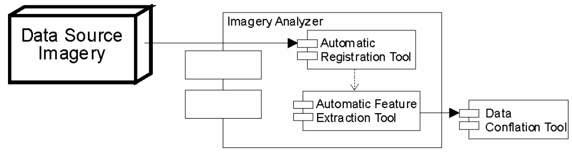

Figure 4. Imagery Analyzer Tool (IAT).

4.4. Data Conflation Tool

When more than one data is available, the additional ones will be integrated to the existing data by the Data Conflation Tool (DAT) in order to yield better quality information. In the case of DEM, information that can be integrated may either contain elevation data or not. Data with elevation can be a DEM from a different source, scale or date. For example, there are public available DEM from USGS, from the Shuttle Radar Topography Mission (SRTM), and from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Different horizontal and vertical accuracies, georeferencing systems, and capture time will be considered in the conflation process.

Punctual elevation data captured using GPS or LIDAR should also be integrated considering the data characteristics, such as the reference system, and the higher precision. Other methods to extract elevation data from oblique and nonmetric images using digital camera have the potential to generate the most up-to-date information for the area, and they will be integrated to the DAT.

Data without elevation information can be used to enhance the horizontal accuracy of the DEM, using the information related to what those points or lines represent. Methods to define the most probable elevation along a line or on a point location based on the neighborhood and terrain local trend will be generated. The information of terrain normal vector will also be integrated, by enforcing the slope and aspect data on the available DEM.

The integration of the additional information will update the quality information associated to the DEM. Critical regions will have increased quality if linear and punctual information is integrated. Other non-critical areas will have a better quality value if the correlations among the different data sources agree with the limits of the accuracy. The integration of information will also allow the creation of a DEM with a new scale that will be more suitable for a given simulation.

Figure 5 summarizes the data flow within the Data Conflation Tool (DCT) and the connections to the Imagery Analyzer Tool (IAT) and the databases.

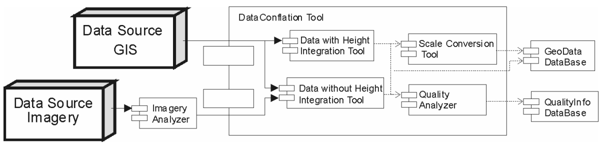

Figure 5. Data Conflation Tool (DCT).

4.5. Integration into a Geographic Database

The tools proposed here will be integrated in a geographic database, enforcing the use of quality information in any simulation. Furthermore, the database can be used to integrate ontological information regarding the data to improve and quantify the DEM quality. A better understanting of the components that lead to the quality information will be achived when the significance of terrain features such as peak, a pit, ridge, valley lines, sampling and interpolation methods is explored.

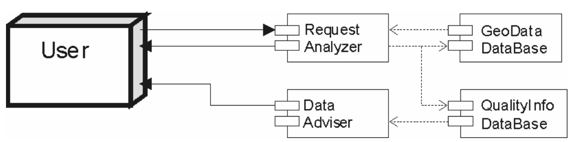

Figure 6. User Access to Geographic Data Server**.**

In Figure 6, the data flow initiated by a user's request is presented, with the request being analyzed and data being sent back to the user if a suitable one exists in the database. If the stored data in not suitable, the information about required improvements will be sent back to the user.

5. Analysis of Available Data for Simulating Volcanic Mass Flows

Modeling of mass flows related volcanic activities is helpful in directing emergency crews on the field during times of crises. One model that treats mass flows events considers the flows as averaged granular flows governed by Couloumb type interactions is the TITAN2D simulation code (Patra et al. 2003). TITAN2D requires topographic information from DEMs. One of the validation sites for TITAN2D is the Volcan de Colima site, 30 Km North of Colima City, Mexico, where there were thousands of mass flows during the 1991-1999 eruption period (Rupp et al. 2003).

Topographic data for the validation relied on freely available data from the Internet. A thorough analysis of these data sources is required to allow useful assessment, given that in a particular topographic situation, the simulation model result may indicate areas of interest with no or low risk for a given scenario. The model output could change dramatically from no risk to high risk with small differences in the elevation data that are in the input dataset. Similarly, if the model predicts values below a safe threshold for a particular area, it may exceed this threshold when another information source is used.

For the Volcan of Colima site, one can acquire DEM data from at least three different sources. They vary on resolution, acquisition time and DEM creation methods. From Arizona Regional Image Archive (ARIA) (Arizona 2003), DEM with 60 meter resolution can be obtained. The area requires two different data sets, that are projected in UTM projection using North American Datum – 1927 (NAD27) and Clarke-1866 ellipsoid. The DEMs are masked to match Landsat World Reference System (WRS).

Another DEM for the Colima area can be obtained from Earth Resources Observation Systems (EROS) Data Center (USGS 2003). These DEMs were generated from the Shuttle Radar Topographic Mission (SRTM), with resolution of three arc-seconds.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor provides capabilities for DEM generation from its along-track stereo sensors. DEM for some regions can be obtained through Earth Observation System (EOS) Data Gateway (USGS 2003). DEM data is available for Colima site in this data server, with 30 meter resolution.

When analyzing DEMs from different sources, resolutions and acquisition time, the main problem is in defining which of them is closer to the real elevation that they represent. The answer to this question is that the DEMs are all uncertain; each of them is one realization of the elevation phenomena, accordingly to the acquisition procedures. Therefore, one can only define the differences among the available DEM.

A valid comparison among the DEMs requires that they are georeferenced to a common projection. The selected projection for Colima site was UTM using International Terrestrial Reference Frame (ITRF) 1992 datum. Since the projection for the ARIA DEM is different, a projection conversion was applied. The ARIA DEM had also to be stitched together based on two available data sets.

The DEM from SRTM is in a latitude-longitude projection, using the World Geodetic System (WGS) 1984, therefore an adequate coordinate transformation was applied. Furthermore, a resolution of 90 meters was defined for the DEM, to loosely correspond to 3 arc-seconds, and the new values were defined by bilinear interpolation. SRTM DEM also contained gaps in areas where the radar signal could not be used to define elevation. A mean value on at least 4 nearest neighbor cells was applied to fill the gaps. The comparison of the ARIA and the SRTM DEM is presented in Figure 7 using contour lines generated from the respective DEMs.

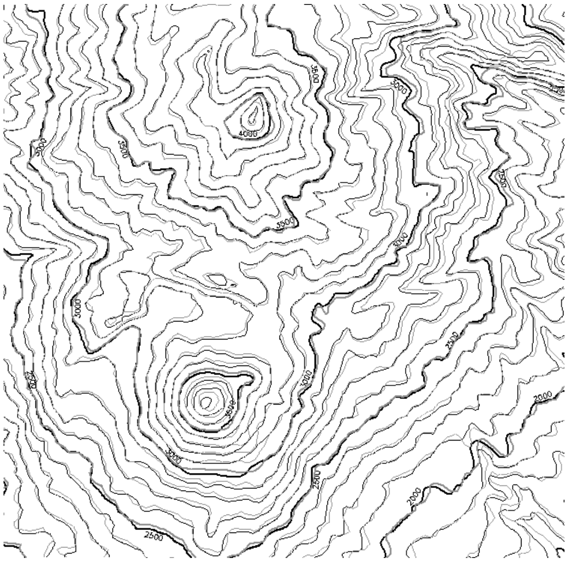

Figure 7. Contour Lines Comparison of ARIA (in black) and SRTM (in gray) DEMs**.**

The comparison shows that the DEM are very similar. The regions where the differences are higher should be better assessed through considerations about the DEM acquisition procedures and time.

The ASTER DEM projection is UTM using WGS-1984 datum and each data set is masked to match the WRS, requiring re-projection and stitching two data sets. ASTER DEMs contain gaps due to lack of correlation between a pair of stereo images. The probable cause is cloud coverage on those areas. Since the gaps are much larger that the ones on the SRTM data, no procedure was applied to fill the gaps. The comparison of the ASTER and the SRTM DEM is presented in Figure 8 using contour lines generated from the respective DEMs.

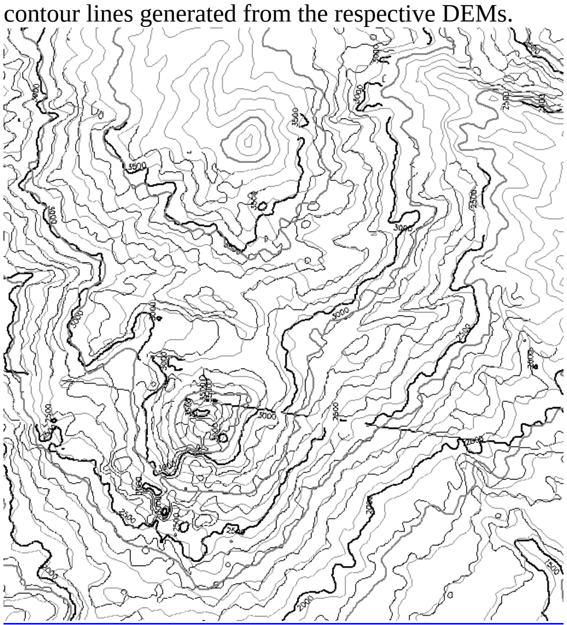

Figure 8. Contour Lines Comparison of ASTER (in black) and SRTM (in gray) DEMs**.**

The areas where the ASTER DEM has gaps have only contour lines in red. The comparison shows that the DEMs are very different, even the two ASTER DEMs have noticeable differences as highlighted by the straight contour lines. Therefore, the use of the ASTER DEM for the simulation is not possible without applying sophisticated methods.

A punctual comparison of the DEM with elevations measured using GPS was also executed for the area. In a field survey, elevations were measured along channel lines using GPS. The comparison of the 100 samples indicates that the ARIA and SRTM DEMs are statistically similar, as shown in Table 1.

Table 1. Comparison with GPS Points.

	SRTM	ARIA
Mean Value	-17.0	-12.7
Std. Deviation	16.7	15.8

The difference mean values are negative as one would expect when comparing DEM with grid cells with 60 and 90 meter resolution to a punctual value inside a channel. This highlighted fact must be considered when integrating measures similar to the one from GPS to available DEMs.

6. Conclusions and Further Developments

To overcome the limitations of existing data uncertainties, the labeling of critical regions within a DEM (or any other data sources) and the presentation of model simulation results with quality measures provides decision-makers with valuable intelligence for better assessment of a particular situation today or possible scenarios in the future. Identification of such critical areas, with their associated confidence quantification, allows systematic improvement of elevation data with more recently gathered data, such as remotely sensed imagery in the visible, infrared and thermal spectrum. Procedures to include these sources have the potential improving the reliability of existing elevation or other spatial datasets.

Particularly in a crisis, the dynamic characteristic of DIGEST will allow automatic improvement of geospatial database through its registration, feature extraction of the latest available data sources, and conflation methods combining all available information sources. Assessment by decision-makers will dramatically improve through recognition of critical areas and suggestion of regions that require new or updated DEM information, enhancement of the DEMs based on most recent RS imagery and availability of statistical confidence of original and enhanced topographical data.

The DIGEST system algorithms and system usability are currently tested with various existing data sets. The various publicly available topographic data and imagery used in modeling highly erosive agricultural watersheds and geophysical mass flows in volcanic landscapes.

The initial analysis of the publicly available DEMs in our example, demonstrated that they are reliable starting points to create a high quality DEM for simulation. Despite the ASTER DEM not being comparable with SRTM DEM, data conflation tools will benefit from the additional information provided by the ASTER DEM, in the worst case by contributing to define the uncertainty data for the reliable DEM.

References

T. U. o. Arizona. 2003. *Arizona Regional Image Archive* 2003 [cited 09/15/2003 2003]. Available from http://landsat.ece.arizona.edu/.

J. Brasington, and K. Richards. 1998. Interactions between model predictions, parameters and DTM scales for topmodel. *Computers & Geosciences* 24 (4):299-314.

A. L. B. Candeias. 1996. Drainage Network Extraction from a SAREX'92 RADAR image. Paper read at Simposio Brasileiro de Sensoriamento Remoto, at Salvador, Brazil.

D. Fedorov, L. M. G. Fonseca, C. Kenney, and B. S. Manjunath. 2003. Automatic Registration and Mosaicking System for Remotely Sensed Imagery. Paper read at Simposio Brasileiro de Sensoriamento Remoto, at Belo Horizonte, Brazil.

L. M. G. Fonseca, and B. S. Manjunath. 1996. Registration techniques for multisensor remotely sensed imagery. *Photogrammetric Engineering and Remote Sensing* 62 (9):1049-1056.

R. J. Hardy, P. D. Bates, and M. G. Anderson. 1999. The importance of spatial resolution in hydraulic models for floodplain environments. *Journal of Hydrology* 216 (1-2):124-136.

M. S. Horritt, and P. D. Bates. 2001. Effects of spatial resolution on a raster based model of flood flow. *Journal of Hydrology* 253 (1-4):239-249.

G. J. Hunter, and M. F. Goodchild. 1995. Dealing with Error in Spatial Databases - a Simple Case-Study. *Photogrammetric Engineering and Remote Sensing* 61 (5):529-537.

———. 1997. Modeling the uncertainty of slope and aspect estimates derived from spatial databases. *Geographical Analysis* 29 (1):35-49.

J. L. Kretsch. 2000. Shuttle radar topography mission overview. Paper read at Applied Imagery Pattern Recognition Workshop.

M. Kumar. 1988. World Geodetic System 1984 - a Modern and Accurate Global Reference Frame. *Marine Geodesy* 12 (2):117-126.

P. C. Kyriakidis, A. M. Shortridge, and M. F. Goodchild. 1999. Geostatistics for conflation and accuracy assessment of digital elevation models. *International Journal of Geographical Information Science* 13 (7):677-707.

K. J. McMaster. 2002. Effects of digital elevation model resolution on derived stream network positions. *WATER RESOURCES RESEARCH* 38 (4).

X. Munoz, J. Freixenet, X. Cufi, and J. Marti. 2003. Strategies for image segmentation combining region and boundary information. *Pattern Recognition Letters* 24 (1-3):375-392.

L. M. Namikawa. 1997. A Method to Estimate Height Values of Break Lines for Triangular Irregular Networks. Paper read at IV Simpósio Brasileiro de Geoprocessamento, at São Paulo, SP, Brasil.

A. K. Patra, A. C. Bauer, C. C. Nichita, E. B. Pitman, M. F. Sheridan, M. Bursik, B. Rupp, A. Webb, A. Stinton, L. M. Namikawa, and C. Renschler. 2003. Parallel Adaptative Numerical Simulation of Dry Avalanches over Natural Terrain. *Journal for Volcanology and Geothermal Research* Submited.

C. S. Renschler, D. C. Flanagan, B. A. Engel, L. A. Kramer, and K. A. Sudduth. 2002. Site-specific decision-making based on RTK GPS survey and six alternative elevation data sources: Watershed topography and delineation. *Transactions of the Asae* 45 (6):1883-1895.

C. S. Renschler, and J. Harbor. 2002. Soil erosion assessment tools from point to regional scales-the role of geomorphologists in land management research and implementation. *Geomorphology* 47 (2-4):189-209.

B. Rupp, M. Bursik, A. Patra, B. Pitman, A. Bauer, C. Nichita, R. Saucedo, and J. Macias. 2003. Simulation Of Pyroclastic Flows Of Colima Volcano, Mexico, Using The Titan2d Program. *Geophysical Research Abstracts* 5 (12857).

USGS. 2003. *ASTER Digital Elevation Model* 2003 [cited 09/15/2003 2003]. Available from http://edcdaac.usgs.gov/aster/ast14dem.html.

———. 2003. *Earth Resources Observation System (EROS) Data Center*. USGS 2003 [cited 06/22/2003 2003]. Available from http://edc.usgs.gov/.

———. 2003. *USGS Digital Elevation Model Data* 2003 [cited 01/16/2003 2003]. Available from http://edc.usgs.gov/glis/hyper/guide/usgs_dem.

———. 2003. *USGS GeoData*. U.S. Geological Survey 2003 [cited 06/22/2003 2003]. Available from http://erg.usgs.gov/isb/pubs/booklets/geodata/geodata.pdf.