Applications of Geographic Information Systems and the Global Positioning System

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INTRODUCTION

Geologists use maps, more than other scientists, to analyze, interpret and display information. Despite this heavy reliance on maps, the details of cartography and the production of maps have not traditionally been taught in Geology programs. With the advent of digital mapping technology, and particularly Geographic Information Systems (GIS) which allow the production of digital maps that can not only store and present data, but answer questions about the data, today's geoscientist needs to understand the intricacies of cartography. The Global Positioning System (GPS) allows geoscientists to acquire georeferenced locations in the field, but they must understand the precision of such locations, and the relationship between those locations and maps with varying datums and projections.

The ability to generate accurate digital maps is essential for the geoscientist working in concert with other scientists, engineers, planning and regulatory bodies and government agencies. The GIS team at the Texas Parks and Wildlife Department (TPWD) told me that geologists tend to be the most difficult scientists to work with because most are unwilling or unable to generate map data with formats, accuracy and documentation required by state regulations.

The goal of this project was to develop in the students (and faculty) the expertise to work effectively with GIS and GPS technologies. That expertise was then applied to service-learning projects involving national, state and local government agencies.

TECHNOLOGIES

Cartography The generation of a "flat" map, whether on paper or a computer screen, from the complex surface of the three-dimensional Earth, requires a series of mathematical operations. The first of these is the representation of that complex surface by a smooth mathematical model. For most mapping, the area of interest on the Earth's surface is modeled by an ellipse of rotation, or ellipsoid. The major and minor axes, and origin and orientation of the ellipsoid are chosen to most closely fit that particular portion of the Earth's surface. A particular ellipsoid together with a particular origin and orientation is known as a datum. The geographic coordinates of a point on the Earth, that is, the latitude and longitude of that point, **are not constant, but depend on the choice of datum!** Hundreds of datums are used around the world for mapping in different political regions and scales. Most mapping in the U.S. has been done with the North American Datum 1927 (NAD27), but a major effort is underway to migrate to the newer NAD83 datum. This means that in most cases, some data is in one, some in the other datum. In the continental U.S., a point of constant latitude and longitude can move over 100 meters with this change of datum.

Once a datum is chosen, geographic (angular) coordinates of points are determined. Converting these geographic coordinates to Cartesian coordinates for display on a planar surface is carried out with a map projection operation. Since relative locations of points on a curved three-dimensional surface cannot be perfectly reproduced on a planar surface, all map projections introduce distortions. Some map projections preserve the shape of objects but distort their relative areas. Other map projections preserve relative areas at the expense of shapes. Some map projections preserve neither relative area nor shape, but try to balance the distortions. The appropriate choice of projection depends on the goal and scale of the mapping.

For many small to regional scale projects (< 100 km) the Universal Transverse Mercator (UTM) projection is employed. Like the more familiar Mercator projection, UTM projects the chosen datum onto a cylinder which is then "unrolled" to produce a planar map. Unlike the familiar Mercator projection, UTM cylinders are parallel to the Earth's axis. When used near the closest meridian of intersection, UTM projections are conformal (preserve shape) and nearly equal area. A different cylinder is used for each 6° of longitude. Each cylinder is called a UTM zone, with zones numbered from 1 to 60 moving east from 180° longitude. For example, Big Bend National Park is within zone 13, while San Antonio is within zone 14. UTM coordinates are in meters, with northing measured from the equator, and easting measure from the central meridian of each zone, where the central meridian is assigned a "false" easting of 500,000 meters to assure that no coordinates are ever negative.

GIS Geographic Information Systems are digital databases of georeferenced information. Data is stored in the form of map layers or themes. Each layer contains one type of data which can include both spatial and non-spatial components. The spatial component is stored in a map layer in either a vector or raster form. Vector layers are suited to discrete spatial objects such as roads, streams, land parcels or political boundaries. Raster layers are suited to continuous data such as elevation or yearly rainfall.

Spatial data for our projects came in three forms. GPS data we gathered for ourselves in the field. These data were acquired in the datum and coordinate system used by the GIS. Digital data from existing GIS or other sources. This included digital elevation models (DEM) from the USGS, GIS layers from the NPS or other governmental agencies. These data often needed to be transformed from one datum and coordinate system to another. The final source of spatial data was existing hard-copy maps. These needed to be digitized. Digitizing for a GIS requires detailed knowledge of the datum and coordinate system of the existing map. Next the map must be registered with known geographic coordinates. Finally, special digitization techniques are used to ensure the accurate georeferencing of information. For example, adjacent polygons must be digitized so that shared vertices have identical geographic coordinates so that overlap or gaps do not occur.

Both vector and raster layers can include related non-spatial data stored in some database format. For example, a vector layer of land parcels might include a database giving the name, address and phone number of the land owner. No wonder taxing agencies love GIS! These non-spatial data are known as attributes. In developing a GIS, careful attention to development of attribute tables is as critical as the spatial mapping effort.

Finally, a good GIS layer also includes metadata. Metadata files contain documentation of the sources and reliability of the data contained in the layer. Generation and recording of metadata is essential if the GIS is to be useful for long periods of time and by persons not involved in the gathering or assembly of the data.

GPS The Global Positioning System is an amazing tool for geolocation which is fast becoming a part of everyday life, and must also become a standard tool in the geosciences. Autonomous GPS has an accuracy of about 100 m (95% of positions will be within 100 m of true position). Much of this scatter is due to Selective Availability (SA), intentional clock and ephemeris errors introduced into the system by the US military to degrade the accuracy of the system. The next most significant factor is the travel path of signals through the Earth's ionosphere. Both of these sources of error, along with some other smaller sources, can be removed by employing differential GPS (DGPS). In DGPS, satellite data is recorded simultaneously by a base station and a rover. Since the base station is fixed, apparent movement there is due to SA, ionosphere, and ephemeris errors. As long as the rover is near the base station, these errors are the same at both locations and can, therefore, be removed from the rover positions. This results in much more accurate positions of the rover relative to the base station.

Several forms of DGPS are used. L1/CA code phase DGPS uses the pseudo-random digital code broadcast by the GPS satellites to carry out differential correction. Depending on the receiver, this can result in an accuracy of between 50 cm and 3 m. Code phase processing requires the base station be within 200-300 km of the rover. Carrier phase differential processing uses the 1.6 GHz carrier frequency of the pseudo-code to further improve accuracy. Depending on receiver, software and occupation time, rover accuracy can be as good 1cm, but the base station must be within 11 km of the rover. For example, with our Trimble units, a 10 minute occupation results in 20 cm accuracy.

When differential corrections are carried out on recorded data after-the-fact it is referred to as post-processed DGPS. It is also possible to carry out differential corrections in real time, if the differential correction data can be broadcast to the rover. Real-time differential correction signals are available for free from U.S. Coast Guard beacons, or for a fee from satellite services such as Omni-Star. For locations far from coasts, such as the Big Bend region of Texas, satellite services are essential for real-time differential work. Submeter accuracy in real time is achieved with satellite differential correction.

PROJECT SYNOPSIS

Students and faculty arrived in San Antonio, Texas, on June 15, 1998, and were housed at Trinity University and nearby facilities. The first week of the project consisted of a rapid introduction of GIS software and concepts. Students worked a series of exercises designed to introduce them to both vector and raster based representation of maps, and the analysis tools available with different data representations. We also investigated the mysteries of cartography, including map datums and projections, the production and classification of digital elevation models (DEMs) and the use of remotely sensed imagery as input to GIS. In addition to these indoor activities, we took two field trips to examine the local geology and Edwards aquifer system, including a visit to Natural Bridge Caverns for an up close and underground look at this dynamic aquifer system.

During the second week of the project, students got a chance to work the with "ugly underbelly" of digital mapping. The vast majority of the work on any GIS project is the assembly of data into a consistent set of map layers having the same projection and datum. Students digitized hard copy maps, acquired the software and developed the ability to acquire and manipulate DEMs and carried out both projection and datum conversions on map data. Two visitors added to the week's activities. Christopher Blakely from Texas A&M presented his work with using GIS to produce hurricane and storm surge risk and evacuation maps for the Texas gulf coast. Jack Howell from Easy Drive Corporation demonstrated the use of Trimble GPS hardware and software for both code and carrier phase differential GPS positioning.

The third week was spent at Big Bend National Park. Students worked on a variety of projects of importance to the National Park Service. Most of the week was spent gathering GPS data. Students mapped a wetland that is in the preliminary stages of reclamation, spring systems near the wetland, backcountry campsites, the ruins of an early 20th century farming community in the park, and a basaltic intrusion complex in folded Cretaceous units in the park.

The final ten days in San Antonio were spent developing a GIS for each project. In addition to the projects in Big Bend National Park, one student team worked on developing a GIS for Government Canyon State Natural Area near San Antonio. This natural area on the outskirts of San Antonio is now being developed by the state park service for both conservation and recreation. The area sits astride the environmentally sensitive Edwards Aquifer recharge zone. Another team of students developed a GIS for the Spring Creek watershed in Northfield, Minnesota. Their work in San Antonio was augmented with field work in Northfield in August.

STUDENT PROJECTS

Government Canyon State Natural Area Erika Cohen and Lela Prashad constructed a GIS for Government Canyon State Natural Area, a new unit of Texas Parks and Wildlife Department (TPWD) on the outskirts of San Antonio. Starting with layers provided by the TPWD, they took an engineering contour layer and generated first a triangulated irregular network (TIN) layer, and from that a detailed DEM of the park. This DEM is much more accurate and detailed than DEMs available from the USGS and other sources. With their DEM, they generated a detailed drainage basin layer for their GIS. Using real-time differential GPS positioning, they established a network of ground control points that they then used to accurately georeference a SPOT XS multispectral satellite image of the park. They processed the image to produce a Normalized Differential Vegetation layer showing the density of vegetation in the park. Their analysis continues as they investigate the relationships between bedrock, slope and aspect, basin size and geometry and vegetation density in the GCNA.

Spring Creek Watershed, Northfield, Minnesota Miriam Krause and Joanna Reuter developed a GIS for the Spring Creek watershed which covers 27 square kilometers of land, including Carleton College, housing developments in the city of Northfield and surrounding farmland. In addition to assembling and converting data sets from state and local agencies, they extended existing map layers with additional attributes, imported and georeferenced a Landsat TM image, and field checked and extended map layers with differential GPS positioning. They generated an improved DEM of the watershed by removing spurious sinks from the USGS DEM, then reintroducing true sinks related to ponds, lakes and wetlands. This improved DEM was used to develop a watershed basin layer. Hardcopy maps of Northfield's storm sewers were used to digitize the catchments of the storm sewer outlets along Spring Creek. The final GIS will be used by students, researchers and city planners to understand the impact of changing land use in this watershed.

Big Bend National Park Taylor Schildgen and Grant Kaye used code phase differential GPS to map the contacts of a basaltic intrusive complex in the northeast corner of the park. The resulting map was used to georeference a Landsat TM image of the area. The TM image was processed to enhance the visibility of the extent of the intrusive body. USGS DEMs of the area were mosaiced and the georeferenced image was draped in three dimensions over the DEM. The resulting model allows a clear interpretation of the geologic relationships in the area and resulted in the clear delineation of a previously unmapped fault.

Calvin Woods, Chevaun Alford and Michael McGlue mapped boundaries of a wetland along the Rio Grande river at Rio Grande Village using differential GPS. In addition, Chevaun and Michael mapped two spring systems upstream of the wetland. This mapping will establish the baseline for reclamation of the wetland by the NPS. A GIS of the wetland area was constructed that included georeferenced DEM and NDVI images from Landsat TM data. Existing hard copy geologic maps of the area were digitized. The datum and projection was converted to match the other GIS layers. It was found that geographic reference points printed on the existing geologic map of the park are incorrect. Preliminary results also suggest that two faults, which control the springs in the vicinity of the wetland, may be mismapped.

Angie Dudek, Jason Nicholas and Jonathan Hausmann used differential GPS to map a series of resources for the NPS. Back country campsites in the Chisos Mountains were mapped. The GPS data was used, in conjunction with digital orthophoto quarter quadrangle (DOQQ) data to georeference a Landsat TM image with a mosaiced DEM of the area. The resulting GIS suggests that several existing maps of trails and campsites contain errors resulting from reliance on airphotos.

The second resource mapped was the ruin of the village of Terlingua Abaja. This early 20th century farming village was established along the banks of Terlingua Creek. The farmers supplied food to the mining town of Terlingua. They also cut down a large stand of cottonwood trees that lined the creek, selling the wood to the miners. Terlingua Abaja was abandoned, but the loss of the cottonwoods has destabilized the channel of the creek in the area. Using both carrier and code phase differential GPS, the remaining foundations of most of the buildings were mapped. The GPS maps were registered with Landsat TM images, DOQQs and DEMs. The resulting maps suggest that the irrigation system at Terlingua Abaja may have had other sources of water than Terlingua Creek.

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