Progress Report

Risk Assessment and Advance Warning for Landslides in Brazil

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Kicking off

The project "Risk Assessment and Advance Warning for Landslides in Brazil" was awarded by SEG in July of 2011. It took a couple of months to handle all the paperwork and contracts between the University of Houston and SEG. Even with some pending items to finalize the paper work it was decided that Laura Azevedo would go to Brazil in August of 2011 to kick off the project and try to get the support from local institutions. Laura went to Brazil in the end of August and she scheduled two main meetings: one with the academia and one with the government and politic agents.
Organizational meetings
Organizational meeting 1 - academia

- Attendees: several professors and students (of civil engineering, hydrology, geology, geophysics and meteorology) that currently work or were willing to volunteer. There were about 40 people from four different universities from Rio: UERJ, UFRJ, UFF and PUC;
- Location: Universidade Federal do Rio de Janeiro;
- Date: Aug/2011.
Organizational meeting 1 – points discussed

• At the time of the organizational meetings the available Digital Elevation Model (DEM) data for the cities in the Regiao Serrana had resolution of 1:25,000. For a few basins, a DEM with resolution of 1:10,000 exists, however it is still too low resolution for the purposes of our project;

• Some of the professors from UFRJ were ordering higher resolution DEM maps for specific basins between the cities of Teresopolis and Nova Friburgo for their own research. They estimate it should take at least 3 months for the DEM maps to be ready after placing an order;

• Basically, in all affected areas in the region there are many projects concerning education of the population. Each city in the region is divided in many communities. Each community have what is called 'community leaders', which are the people working with government agencies to help organizing meetings and preparation procedures in general for the population in case of a disaster event;
Organizational meeting 1 – points discussed

- There are several governmental institutions working directly with the population, such as: Departmento de Defesa Civil (Department of Civil Defense), Corpo de Bombeiros (Fire Department), Servico Geologico de Estado do Rio de Janeiro (Geological Service of the Rio de Janeiro State);

- As we mentioned in the project proposal, there are already alarm systems that are all based on empirical precipitation data;

- Even though there are professors working in collaboration with government agencies, there seem to be a gap between government and academia. For instance, professors claim that they have informed government agencies about the importance of having higher resolution DEM maps for the region, and that no precise studies can be done without such maps. However, the only way professors can obtain these maps are through funds from their individual projects. Some of these projects are funded by government agencies and others by the industry;

- It was discussed the importance of having an online source, like a website, that could list all projects involving the landslides in the Regiao Serrana. This database would include projects from academia, government, volunteer organizations, etc. And it includes technical as well as humanitarian projects and information;
Organizational meeting 2 – government

- Attendees: a total of 30 participants from government and politic agents and a few members from academia. The participants included: municipal and state environmental agents, civil defense and fireman, as well as other interested agents from other departments;
- Location: the meeting was held at the Secretaria de Planejamento e Gestão do Estado do Rio de Janeiro (SEPLAG);
- Date: Aug/2011.
Organizational meeting 2 – points discussed

- Our project was introduced to the audience. The participants explained all the work done by the different entities that were present;

- The Secretaria de Estado de Planejamento e Gestao (SEPLAG) suggest to organize a symposium so we could gather everyone working on landslides in Rio de Janeiro. This symposium just happened and we currently preparing a report.
Organizational meetings – conclusions

The main conclusions for our project that came out of the organization meetings are:

- Hydrological basin is the unit for landslide studies in the Regiao Serrana. Therefore, the next step for us is to decide how many basins we can study and then choose them. In order to choose the basins, we will go to the field as soon as possible, with Professor Nelson Fernandes from UFRJ and his group, to discuss all the possibilities given our budget;

- After choosing the basins, we need to buy high resolution DEM maps;

- We are going to work with SEPLAG in organizing the symposium mentioned above.
First visit to the field
First visit to the field

In Jan/2012 Gabriela Melo took a two-days long visited to the Regiao Serrana of the Rio de Janeiro State. Our guide and leader was Prof. Nelson Fernandes from UFRJ. Him and his students took us to visit the three main affected cities: Petropolis, Teresopolis and Nova Friburgo. The goal of this visit was to choose the basins we are going to work on in our project.

Choosing the basins was very difficult. The Regiao Serrana is formed by tens of cities and hydrological basins. The basins have problems of different nature; some basins suffer from a large number of landslides, others have very few landslides but very violent flash floods capable of moving boulders of meters in diameter, others have a combination of both problems. Besides the landslides, there are many slopes prone to different kinds of rock failure (as opposed to soil failure). This is also a big problem since there are many houses/buildings that were (and still can) be damaged by these rock failures. We discuss these points in more detail below.

We chose four basins for which we are obtaining a high-resolution DEM for: Vale do Cuiaba, Posse, Salaco, and Vieira.
The chosen basins
The chosen basins
Vieira

- The major problem in this basin was a flash flood. The extent of the runout was nearly 10Km. The debris carried by the flow include boulders of diameters of the order of a few meters. The rocky cliffs on the highest part of the basin served as one of the sources of these boulders due to rock failure. Excavated material from past debris flow was also added in to the flow making it strong and destructive. From these excavations on the marginals along the drainage of the basin reveal material from past flows, showing how such events are recurrent and periodic. Lastly, Vieira had a few landslides near the top of the basin that also contributed with some material to the flow. On the lower part of the basins where water and finer material accumulated, the level of the water reached over two meters above the ground level.

- There are reports (including a Master's thesis from a student from the Universidade Estadual do Rio de Janeiro (UERJ)) on the geology, geography, and conditioning factors of the landslides and mass flow on Vieira that we can use as a starting point (Lima et al., 2011).

- Vieira is mostly a rural area. The local economy is mostly based on the production of greens and herbs. The basin is greatly recovered currently, most houses were renewed and the plantations are back. The problem is that these houses are on the exact same place as before, so another disaster with life losses can potentially occur.
The general work plan for Vieira is:

- Estimate soil thickness or layers of different materials along the basin. All the buried boulders from past flows make it the overburden over the bedrock really heterogeneous and scattering, making it difficult to apply shallow geophysics. While we discuss the most probably efficient way to estimate soil thickness in this basin, we can get local estimations based on landslide scars and on the excavations that are still visible in the area;

- Measuring hydraulic conductivity on the same locations where soil thickness was estimated would be important for modeling as well;

- Using all the field data, calculate stability and simulate mass flow and runout potential for this basin.
Vieira

Map of landslide scars (in brown) and mass/debris flow (in red) in Vieira. This figure is from Lima et al. (2011).
Vieira basin. Rural community formed by herb and greens small farms.
Vieira

Top of Vieira basin showing the location of the start of the mass flow. Figure from Lima et al. (2011).
Vieira

Near the top of Vieira basin showing large boulders that got stuck along the path of the mass flow. Figure from Lima et al. (2011).
These images of Vieira basin were taken about a week after the disaster. It shows the width of the debris flow in comparison to the houses. Pictures are from Prof. Nelson Fernandes during a helicopter overfly.
Vieira

Lower part of Vieira basin where floods occurred. Note the water level on the house on the left picture.
Cuiaba, Posse, and Salaco
Cuiaba, Posse

- Cuiaba, Posse and Salaco are adjacent basins. While the major problem in Cuiaba and Posse were the flash floods (with some landslides), the major problem in Salaco were the landslides. We will first focus on Cuiaba and Posse here (due to similar characteristics) and then on Salaco.

- Similarly to Vieira, the main problem in Cuiaba and Posse were the flash floods and massive mass/debris flow. However Cuiaba and Posse had more landslides. Also, Cuiaba and Posse were much more populated basins and there were many more life losses in these basins. Many bodies were never found and are likely to still be buried beneath all the immense remaining amount of debris still present is these places.

- One of the challenges in working in Cuiaba and Posse is to reproduce the former drainage system that was in place before the disaster. Even though the marks of destruction are still very present along these basins, the original scenario was largely altered, making it hard to map the mass/debris flows. This mapping involve extensive interviews with the local survivors, which is pretty much the sole source of information in this respect.
During our primary field work we talked to a number of locals that still live in these basins. According to them, it started to rain on the evening of Jan/11/2011. Around 1am of Jan/12/2011 the power went down in these basins. The loud noise and strong ground vibrations were heard all the way until about 3am or 4am which is when it stopped raining. It was only when the sun rose in the morning that the locals could see all the destruction, including the large amount of human bodies (which in these two basins the number of lost lives is almost 1000). The amount of material mobilized by the flash flood is impressive. The mass flow mobilized boulders, material from landslides, trees and vegetation in general, cars, debris from houses and other constructions, etc. However, the fact that the main event of this disaster occurred late in the night when the power was down was of great importance since it made it even more difficult for people to find safe places to take shelter. The locals say that it took them a while to understand what was happening since nearly none of them have experienced such an event in these locations in their lifetime.

As far as our project is concerned, we ordered DEM maps for both Cuiaba and Posse but we will focus our efforts on Posse, since it is smaller, before we work on Cuiaba.
Cuiaba, Posse

- Basically, we intend to perform the same work on mapping conditioning factors, as done for Vieira basin in Lima et al (2011) (the authors claim that the work on Vieira took approximately 17 days of field work).

- On the field we will:
  - Estimate soil thickness (or layers of different material). Soil thickness spatial variability can be primarily estimated from the landslide scars and the excavations along the rivers. Similarly to Vieira, the excavations exposed boulders from past flash flood events that also mobilized larger boulders, suggesting that these extreme rain events are periodic. The actual period of these events is unknown and seem to vary between tens to hundreds of years;
  - Collect data on hydraulic conductivity on the same locations where soil thickness was estimated;
  - Using all the field data, calculate stability and simulate mass flow.
Cuiaba

Image of the highest part of the Cuiaba basin. There were more landslide scars in Cuiaba than in Posse. Image from Megadesastre da Serra Report - DRM - RJ - Brazil.
Cuiaba

Map of largest landslide scars and mass/debris flow in Cuiaba. Image from Megadesastre da Serra Report - DRM - RJ - Brazil
Image of the highest part of the Posse basin. Note the landslide scars.

Image from Megadesastre da Serra Report - DRM - RJ - Brazil
Posse

Map of largest landslide scars and mass/debris flow in Posse. Image from Megadesastre da Serra Report - DRM - RJ - Brazil
Posse

Image of a couple of days after the main disaster in Posse. Image from website [1].
Posse

Images of Posse after the disaster. Image from Joao Paulo – UFRJ, Brazil.
Salaco

Salaco is a small basin where there were tens of landslides and floods in its valley. It seems to be small enough for us to do the geophysical campaign and use it as the pilot basin for our project. It has rain gauges that are included in the alarm system. Another reason why we chose Salaco is because it is near other two important ones, Cuiaba and Posse, so we optimize getting the DEM for all these locations in one single satellite image. Salaco was highly damaged and is one of the places that is still under high imminent risk of landslides. While some of the debris was removed, in general the destruction marks are all over the place. There are many condemned homes but a lot of people still live there. It is a somewhat “poor” area.
We plan to start by producing the same work on conditioning factors, as done for Vieira. Since it is a small basin (area of about 5Km2), we chose Salaco to perform the geophysical surveys. On the field we will:

- Estimate soil thickness (or layers of different material). Soil thickness spatial variability can be estimated from the landslide scars and excavations. We can use that info to cross-check with the results from seismic, electrical, and GPR surveys;
- Collect data on hydraulic conductivity on the same locations where soil thickness was estimated;
- Using all the field data, calculate stability and simulate landslides.
Salaco

Salaco

View of one of the hill slopes of Salaco basin showing a few landslides. Image from Megadesastre da Serra Report – DRM – RJ – Brazil.
Salaco

Landslides on hill slopes in Salaco basin two days after the main disaster. Images were taken by Prof. Nelson Fernandes during a helicopter flight over the region.
The MIT-UFRJ research project

Landslide modeling and prediction for the Regiao Serrana of the Rio de Janeiro State in Brazil
Since this project is highly multidisciplinary, the geophysics and geomorphology team members from MIT together with the geography/geomorphology team members from the Brazilian university UFRJ put together a project proposal for a three-years long parallel project by adding a research component to the GWB project. The project was accepted and it is co-funded by the Centro Nacional de Pesquisa e Desenvolvimento do Brasil (CNPq) and the MISTI Seed Fund program from MIT. The Brazilian agency, CNPq, will fund three Brazilian PhD students for 6 months as exchange students at MIT, one Brazilian post-doc for 2 months at MIT, and three short trips for Brazilians professors and researchers to visit MIT. The MIT MISTI Seed Fund program has already financed five trips to Brazil for MIT team members to attend meetings and participate in field work in Brazil. The total grant for this parallel project is over $100K. This grant can be used for travel expenses only.

This parallel project has also the goal of enhancing collaboration between the two universities and it is one way to guarantee the continuation of the GWB project after the two-years duration. Next, we present the abstract of the approved proposal.
Abstract:

Every year, many states in Brazil suffer severe social and economic problems due to landslides and debris flows triggered by heavy rain. These events often claim many lives, and cause widespread damage to buildings, roads, and utilities such as electricity, telephone systems, sewers, and drinking water. One of the most recent examples of such disasters is a series of landslides, debris flows, and floods that struck the Regiao Serrana of the Rio de Janeiro state in Brazil in January 2011, with 856 confirmed deaths, 518 missing, and over 30,000 destroyed homes. These events in the Rio de Janeiro state are considered the worst natural disasters in the history of Brazil, and the United Nations ranked them among the worst natural disasters in modern history. Unfortunately, landslides continue to pose a major risk to the safety of the communities in this region.

The goal of this project is to help mitigate such disasters by combining efforts to model and characterize landslide hazards being developed at MIT and at the Universidade Federal do Rio de Janeiro. We plan to apply the combined methods to sites in the Regiao Serrana of the Rio de Janeiro state, with the aim of improving the reliability of models of landslide occurrence. Our results will provide information that can be used to reduce the risk to life and property associated with landslides in Brazil and elsewhere, including warning local populations of high risk areas, aiding in potential evacuation preparations, and monitoring the construction of new structures in these areas.
The MIT-UFRJ research project

Remarks:

In practice, the MIT-UFRJ research project will work on the same sites as the GWB project, i.e., Salaco, Posse, Vieira, and Cuiaba basins. The landslide modeling efforts being developed at MIT and at UFRJ will applied and tested on these basins. This greatly adds to the humanitarian/application characteristics of GWB project; while in the GWB project we will use currently available software for modeling, the MIT-UFRJ project will take a step further combining and testing the research modeling methodologies being developed at both universities. This should increase the accuracy of the results delivered by the current landslide models.
Field work
On Apr/2012 Gabriela Melo went to Brazil to participate in the first field work campaign. This field work took approximately eight days. The main goals were to get started with the mass flow mapping at Posse and collect GPR data at Salaco. The field team spent approximately two days for visiting and planning. These field trips were guided by Prof. Nelson Fernandes from UFRJ. We re-visited all the basins chosen for our project: Vieira, Cuiaba, Posse, and Salaco.

It is important to mention that two days before the field work started, there were a series of rain triggered landslides in the city of Teresopolis, which is the city where Posse and Salaco are located. The city was alarmed and chaotic. The field conditions were really tricky, both because of the recent landslides and the fact that it rained most of the days.
Field work - GPR

First, the geophysics team went to Salaco for two days to collect the first round of GPR data. The field geophysics group was from the Universidade Federal Fluminense (UFF) and it was composed by Prof. Marcelo Cetale and students Jonne Clay Vidal, Leonardo Alexandre, and Felipe da Cruz Pimentel Moreira Santos.

The GPR data is currently being processed. We show here a raw profile to demonstrate the quality of the data.

Field conditions on Salaco basin one day before GPR data was collected.
Field work - GPR

View from the top of Salaco basin. The terrain is very fragile along the whole basin.
Field work - GPR

View from the top of one the dirt roads where one of the GPR profiles was collected. At one end of the road we see the Geophysics students from UFF dragging the GPR antenna.
Field work - GPR

The figure on the left shows the raw data for the GPR profile collected on the road shown in the figure above. Fortunately for us, there was a cut adjacent to the road, figure on the right, showing part of the subsurface. This cut will be used for interpreting the profile. In general, for the other roads for which the subsurface is not exposed, we will go back to field to collect core samples to help us with the interpretation of the data.
Field work - GPR

Due to weather conditions and equipment availability we could only collect 8 lines of GPR data. However we mapped all possible roads where we can possibly collect data on future field campaign. We also mapped relevant points of exposed subsurface that we can use for interpretation. We can see example of such roads and locations on these figures.

We will try to have one more Geophysical field work this year. Our goal is to collect more GPR data and to do the first resistivity profiles. The equipment for doing the resistivity profiling was recent fixed and it seems to be working. We will be also collecting core samples for locations with no subsurface exposure as much as possible. We are still trying to figure out where to obtain seismic equipment. We were supposed to use the equipment from UFF but as it turns out it is not suitable for the field conditions at Salaco.
At Posse basin we started the mapping of the mass/debris flow at Posse. In the field were: Geology/Geomorphology postdoc Ken Ferrier and PhD student Paul Richardson from MIT; Professor Nelson Fernandes, PhD students Lucia Silva and Joao Paulo Araujo, undergraduate students Beatriz Braga and Marcelo Alvear, all from Geography Department at UFRJ. The goal for this field work at Posse was to register the current conditions of the basin (information that is necessary for modeling future events and access current risks) and to talk to the population to try to identify the conditions right before and right after the disaster (information that is necessary to test the models). It is worth to mention that we also have collaborators from various government departments, such as the Rio de Janeiro State Geological Survey (DRM), that have useful information about the area.

Here we briefly present figures showing the current conditions of the Posse basin. A more detail report on that will be prepared by the team after all the data is collected.
As previously mentioned, the major problem in Posse was the violent mass/debris flow. The different materials in the flow mainly come from: boulders located at the highest part of the basin, material from landslides along the basin, excavated material from past mass/debris flows. On the left we have a picture of the highest part of the basin showing many lose boulders and. The right picture shows one of the landslides that contributed with material to the flow.
Field work - mapping

The team hiked down from the top to the bottom of the basin trying to follow the path of the flow. The photo on the left shows the highest part of the basin reachable by car. The picture on the right shows a small part of the flow path.
Field work - mapping

This picture shows another part of the mass/debris flow path. Note the broken pipes, fallen trees and excavated walls along the path.
Field work - mapping

Here we see a few of the landslides that occurred on the basins.
Field work - mapping

Continuing going down the basin the size of the boulders start to decrease as can be seen on these pictures.
Field work - mapping
Field work - mapping

Houses that were destroyed in the disaster. Note the water level on the walls.
Field work - mapping

This house was in the middle of the debris flow.
Digital elevation model

As discussed above, we bought satellite data to generate a Digital Elevation Model for the four basins of our project. We received the stereo pair images in the beginning of Jul. It took approximately four months for the company GeoEye to be able to take the images with clear skies. We are now working on generating the DEM models from the stereo pairs. The picture below is one of the satellite images.
Next steps

- Generate the DEM models;
- Perform the second geophysical field work campaign. We will collect more GPR and resistivity data at Salaco while we figure out the seismic equipment;
- Compile all the available information for writing a report on the mapping of the mass/debris flows. The mapping team will most likely have to return to the field;
- Use all the information as inputs in the landslide and mass flow computer models.
There are several youtube videos showing the landslides and floods in Rio de Janeiro in 2011. Here are a few links:

- http://www.youtube.com/watch?v=vnX9d5Pxpn8&feature=related
- http://www.youtube.com/watch?v=nLXpa8krtkU&feature=related
- http://www.youtube.com/watch?v=9XsYJgULFJA&feature=related
- http://www.youtube.com/watch?v=riXszzYQu3Y&feature=related
- http://www.youtube.com/watch?v=YHvBwofW_So&feature=related
- http://www.youtube.com/watch?v=WqP2Qx2Zlq4&feature=related
- http://www.youtube.com/watch?v=ph5NnxkCUQ00&feature=related
- http://www.youtube.com/watch?v=JB3pGNpl1Kk
- http://www.youtube.com/watch?v=Uo-W_DqC3so&feature=related
- http://www.youtube.com/watch?v=3eVvFgCMVjc&feature=related
- http://www.youtube.com/watch?v=Dkn1vhCFspI
- http://www.youtube.com/watch?v=JEQL86AJZ7A
- http://www.youtube.com/watch?v=iGXbhCNy1mc&feature=related
References

- Megadesastre da Serra Report - DRM - RJ - Brazil

Websites: