Introduction
Santa Ana Volcano, also known as Ilamatepec, located at 13°50’ N and 89°37’ W rises approximately 2,381 meters above sea above sea level. It is the highest and also considered the most active volcano in El Salvador with its most recent eruption in October, 2005. The Santa Ana volcanic complex (fig. 1) is composed of Izalco, Coatepeque caldera, Cerro Verde, the Santa Ana stratovolcano and several other nearby domes. The complex is situated at the southern margin of the Median Trough (an extensional graben that runs parallel to the Pacific Coast) and the intersection of a NW-SE trending regional fault system. Following an eruption in 1904 the crater has been occupied by a small lake that fluctuates in temperature and composition. Gas bubbling and fumarolic emissions are also observed within the crater.

Current monitoring of Santa Ana Volcano consists of two remote seismic stations, monthly visual observations and bi-monthly temperature and composition measurements of the crater-lake and fumarole field.

In an endeavor to augment the monitoring efforts, collaboration between El Servicio Nacional Estudios Teritoriales (SNET) and Michigan Technological University has developed a GPS Network and strategy to monitor surface deformation at Santa Ana Volcano.

Figure 1. The Santa Ana Volcanic Complex and Coatepeque Caldera. Map provided by SNET
Data Collection and Processing
Our equipment consists of a Trimble 5700, 24 channel, dual frequency RTK receiver; customized, 550 mm, spike-mount tripod; two precision bubble levels; Zephyr Geodetic antenna; and one Continuous GPS (CGPS) base station. The network consists of an array of 12 points surrounding the volcano and the Coatepeque Caldera, which also transects the regional faults.

At each site we embedded a stainless steel pin – measuring roughly 150 mm long by 15 mm diameter with a small (sub-millimeter) indentation – into solid rock, rock walls or a brick and cement edifice. The steel pin ensures that the 550 mm tripod is installed in the exact same location during each site occupation.

Figure 2. Drilling the hole to install the steel rod. Photo provided by Hans Lechner

Figure 3. Installing the steel pin with Hilty epoxy. Photo provided by Hans Lechner
Figure 4. Leveling the spike-mount tripod at Finca Santa Elena above Lago Coatepeque. Photo provided by Hans Lechner

Figure 5. The spike-mount tripod and Zephyr Geodetic Antenna with Volcan Santa Ana in the background. Photo provided by Hasn Lechner
We use differential GPS and a static survey method to monitor vertical and horizontal surface deformation by acquiring data on a monthly basis at one to two hours per site using a 30-second sample rate. Based on our preliminary baseline data, we expect to achieve sub-10mm precision and we hope to achieve sub-5 mm precision at our farthest site, 9 km from the base station.

To establish our baseline and determine our achievable precision using this type of GPS strategy, a multiday campaign was completed in September of 2009. We installed and occupied the sites closest and farthest from our CGPS base station for a 20-24 hour period. The data was then sent by FTP to University of Wisconsin at Madison where it was processed and analyzed by Professor Chuck Demets and Neal Lord in the Department of Geology (Figs. 6 and 7). The data was divided into 20 minute segments so that the repeatability of precision could be determined at a minimum site occupation time of 20 minutes. The results show that the closest site at Finca Santa Elean, approximately 1.5 km from the CGPS station has a north and east baseline component that is repeatable to under 3 mm and a vertical baseline component under 7 mm. The farthest site at Aguila, which is approximately 9 km from the CGPS station, had a north and east baseline component of 7.6 mm and 9.0 mm respectively and a vertical of 27.4 mm. It was therefore determined that all stations should be occupied for a minimum of one hour and two hours, if possible, for the sites within 5-10 km from the base station. Doing so should make it possible to achieve sub-5 mm precision for all 12 sites in the network.

During the last week of every month we commence a four day data collection campaign that takes us to all 12 sites surrounding the volcano. There are currently 2 sites at the crater of the volcano, which require a full day to access and occupy. The remaining ten sites are then accessed and occupied in a two or three day period, depending on the weather and duration of each session.

The data is recorded and saved on an internal CompactFlash memory card within the Trimble 5700 receiver. Once the monthly campaign is complete the data is transferred to a computer hard drive at the SNET office where it is then converted from the raw data into RINEX data exchange format. Once we download and convert the data collected from our CGPS base station we then process all the data using Trimble Total Control and Trimble GPSurvey 2.35 software.

Currently, we have only been able to process the data from the baseline campaign completed in September, 2008 and from the monthly campaigns completed in February and March, 2009. As I am still learning to use and understand the data processing software, it is too early to say if there has been any measurable deformation between the above mentioned dates.

**Purpose and Expected Results**

During my remaining time a Peace Corps Volunteer in El Salvador I will continue to collect process and analyze GPS data through October, 2009. At this time it is much too early to develop expectations regarding the outcome of this study. However, I can say with certainty that we expect to see either measurable deformation or no measurable deformation whatsoever. While that statement may seem somewhat dubious, it is without a doubt that either outcome will aid in our understanding of the volcanic processes occurring at Santa Ana Volcano. This study and either potential outcome should provide further insight and answers to some of the questions surrounding the 2005 eruption, such as the nature of the eruption. Was it phreatomagmatic or
phreatic? Meaning was juvenile magma involved in the eruption or was it the result of the hydrothermal system? Was the eruption the beginning, middle or end of the observed 100 year eruption cycle for this volcano? Are lake level fluctuations at Lago Coatepeque variable from one side to the other and if so is this the result of differential surface deformation?

While not volcanoes demonstrate surface deformation preceding, during or following an eruption it is believed that a majority of volcanoes do exhibit some form of surface movement before an eruption. By developing this type of GPS network for monitoring deformation of the volcanic complex we believe that we will be able to develop a greater understanding of the dynamics and dimensions of the magma chamber. If measurable deformation is found, it may be possible to use various numeric models, such as Mogi source model, to make assumptions regarding the spatial characteristics of the magma source. It may also be possible to correlate tectonic activity and regional strain with magma intrusion.

If we are able to more accurately predict magma movement at depth it would be a valuable tool to recognize volcanic unrest and possibly forecast eruptions with greater accuracy; this in turn could reduce risk and vulnerability for the millions of people living in the shadow of Santa Ana volcano. Lastly, it is hoped that this GPS network will serve as starting point for a more comprehensive geodetic network on the Santa Ana volcanic complex and a model for future networks on Central American volcanoes.
Figure 6. Standard deviation for North, East, and Vertical components from baseline campaign in September, 2008, for Aguila (AGLA) the farthest site from the CGPS station. Provided by Professor Chuck Demets, University of Wisconsin.
Figure 7. Standard deviation for North, East, and Vertical components from baseline campaign in September, 2008, for Finca Santa Elena (FSEL) the closest site to the CGPS station. Provided by Professor Chuck Demets, University of Wisconsin.