Differential GPS as a Monitoring Tool on Volcano Santa Ana (Illamatepec) and the Coatepeque Caldera, El Salvador

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Project goals

• Feasibility of short GPS occupations of dense volcano network with ~100-km-square footprint.
• What are measurement precision and accuracy in near-tropical conditions for mix of inter-site baseline lengths?
• What is characteristic inter-eruption behavior of this volcanic complex?

Why use differential GPS instead of precise absolute positioning?

1. Multiple sources of positioning uncertainty cancel (or nearly so) over short distances, yielding precise relative position estimates for short occupation times of ~1 hour.
2. Can thus establish and feasibly occupy numerous nearby sites within small-footprint networks.
3. Data processing strategy less difficult than for high-precision absolute positioning.

<table>
<thead>
<tr>
<th>GPS ERROR SOURCES</th>
<th>TYPICAL RANGE ERROR</th>
<th>DGPS (CODE) RANGE ERROR ~100 KM REF-REMOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV CLOCK</td>
<td>1 M</td>
<td></td>
</tr>
<tr>
<td>SV EPHemeris</td>
<td>1 M</td>
<td></td>
</tr>
<tr>
<td>Selective Avail.</td>
<td>10 M</td>
<td></td>
</tr>
<tr>
<td>Troposphere</td>
<td>1 M</td>
<td></td>
</tr>
<tr>
<td>Ionosphere</td>
<td>10 M</td>
<td></td>
</tr>
<tr>
<td>Pseudo-Range Noise</td>
<td>1 M</td>
<td>1 M</td>
</tr>
<tr>
<td>Receiver Noise</td>
<td>1 M</td>
<td>1 M</td>
</tr>
<tr>
<td>Multipath</td>
<td>0.5 M</td>
<td>0.5 M</td>
</tr>
<tr>
<td>RMS Error</td>
<td>15 M</td>
<td>1.6 M</td>
</tr>
<tr>
<td>Error * PDOP~4</td>
<td>60 M</td>
<td>6 M</td>
</tr>
</tbody>
</table>

PDOP=Position Dilution of Precision (3-D) 4.0 is typical
1. Tectonic Setting

Funk, J., et al., 2009
I. Tectonic Setting

Funk, J., et al., 2009
II. Eruptive History

Coatepeque
• 7 x 8 km collapse caldera
• 3 Plinian eruptions between 40 – 70 ka produced ~24 km³ of pyroclastic material
• Dome and cone growth inside and on the rim along ring faults
• Current hydrothermal activity

Izalco
• 1770 – 1966 almost continuous lava flows and Strombolian eruptions
• Passive degassing at fumaroles in crater

Santa Ana (Illamatepeqec)
• Phreatic and phreatomagmatic eruptions over the last 500 years.
• 1904 VEI 2
• 2005 VEI 3
• Passive degassing at fumaroles in crater
• Acidic lake within the crater and active hydrothermal system

Parasitic Vents
• NW-SE fault system
• Cinder cones and phreatomagmatic craters
• 1722 lava flow from San Marcelino
III. Methods

Continuous station SNJE
- Installed by DeMets (NSF) with SNET in 2006 for tectonic/EQ studies and as GPS infrastructure for studies of El Salvador’s volcanos.
- Three other cGPS sites installed for reference at Volcan San Salvador, caldera Ilopango, and Volcan San Miguel

Differential network site criteria
- On or within 1 km of target of interest (volcano or caldera)
- Encircle target for good spatial sampling
- Baselines shorter than 10 km
- Span tectonic pull-apart structure
- Unobstructed sky view down to 15 degrees above antenna plane
- Geologically stable
- Accessibility and permission

Resident GPS security at SNJE base station hut
III. Methods
B. Differential network
III. Methods

B. Our network

13 station network
- 1 fixed base station installed/operated by SNET/DeMets
- 12 differential “rover” stations

Campaign data
- Several days to occupy whole network
- Six to eight 1-2 hr-long occupations per site during experiment
- Two 20+ hour measurements at stations FSEL and AGLA

Equipment
- Base station - Trimble NetRS receiver
- Rover Trimble 5700 receiver
  - 24 channel, dual frequency, 30 second sample rate.
- Trimble Zephyr geodetic antenna
- Fixed elevation (55 cm) spike mount tripod
- 12 volt car battery
- Anchored benchmarks
SNJE base station – is it stable?

13°52’05.698930” N
89°36’02.49129” W
1660.191 m

Position and velocity of SNJE known to
- 1 mm horizontal
- 3-5 mm vertical

North in mm
East in mm
Vertical in mm

CA rate (horizontal line) is 4.92 mm/yr
Site rate (sloped line) is 6.1+/− 0.7 mm/yr : WN & FN = 2.1 & 2.0 mm

CA rate (horizontal line) is 11.84 mm/yr
Site rate wrt ITRF05: 5.1+/− 0.8 mm/yr : WN & FN = 3.6 & 3.5 mm

Site rate wrt ITRF05: −2.2+/− 1.2 mm/yr : WN & FN = 6.2 & 5.9 mm

2007  2008  2009  2010  2011
III. Methods

D. Data Processing and reduction

Data Processing Strategy using Trimble Geomatics Office software

- Single pair calculation from base to rover
- Site tropospheres ASSUMED to be the same
- 15° elevation mask

![Baseline Components from SNJE to LAKE](image-url)
Precision estimated from repeatability of interstation baselines

SHORTEST BASELINE is 1.9 km
1-sigma repeatability of 4 mm in latitude for 30-minute sessions over single 24-hr period
1-sigma repeatability of 13 mm in elevation for 30-minute sessions over 24-hr period
Longest baseline is 9.6 km
1-sigma repeatability of 8 mm in latitude for 30-minute sessions over single 24-hr period
1-sigma repeatability of 27 mm in elevation for 30-minute sessions over 24-hr period
Repeatability vs baseline length:

1) Short baselines (< 4-5 km) – can repeat latitude and longitude estimates with 5 millimeter precision for 30-minute station occupations
2) Short baselines – can repeat ELEVATION estimate to ~12 mm for 30-minute occupations
3) Long baseline (> 5 km) – repeatability in horizontal coordinates (lat/lon) increases to ~10-12 mm
4) Long baseline repeatability in elevation increases to ~30-35 mm

5) For differential work, recommend keeping baselines shorter than 5 km if precisions better than 1 cm (10 mm) are desired.
6) Elevation: Further complication is that for baselines with large elevation differences (>several hundred meters), assumption of common tropospheres may break down.
SAVC faults and microseismicity. Seismic data provided by SNET. Known faults are from Weber and Wiesemann (1977).
North component of site motion relative to reference site SNJE
East component of site motion relative to reference site SNJE
Vertical site motion relative to reference site SNJE

**Volcano and other sites**

- AGLA 9657 m
- ESCL 7974 m
- FESP 4772 m
- TSBL 4591 m
- CRSE 4001 m
- CRSW 3674 m

**Sites near caldera lake**

- MLPA 7437 m
- MTBL 6582 m
- LSPL 4835 m
- PDRF 4409 m
- LAKE 4063 m
- FSEL 1889 m

Dates: 2008 - 2009
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