Multi-parameter monitoring
A general overview

Eliza Calder
State University of New York at Buffalo
What is multi-parameter monitoring?
What are we trying to measure?
What are the problems with it?
Where are we going with it?
Q1: What is multi-parameter monitoring? Why are we interested in it?
Simple thought experiment
Methods: COV Workshop Monitoring Team
Remote sensing

- **Simon Carn** (gas spectroscopy) : Variations of gas species and concentrations over time, source of emissions migrates with time.
- **Simon Carn & Fred Prata** (satellite-based thermal and ash remote sensing) : Little hot spot coalesces with big hot spot, then track movement across town – and it emits a plume of diffuse particles.
- **Nick Varley** (ground-based gas and thermal sensing) : Large object has hot front, and hot gas plume comes out the back of it and that these signatures increase when the object moves.
- **Franco Tassi** (aqueous geochemistry) : may detect some traces in local surface water of a local ‘polluter’.

⇒ Spectral imaging of surface characteristics associated with, or emissions resulting from, the activity.
Geophysicists

- **Greg Waite** (Seismicity): Detect ground tremor generated by the moving bus, when it stops and starts, environmental noise generated by the occupants. Detect the response of the road (brittle failure?) caused by the load of the bus.

- **Jeff Johnson** (Infrasound): Detect engine ‘noise’ (explosions) and perhaps noise associated occupants.

- **Halldor Geirsson and Jo Gottsman** (Ground deformation and geodesy, gravity): Object undergoes lateral displacement, and reassure us object doesn’t inflate or subside.

=> Detecting motion generated by (mostly) internal physical processes.
But…

• No single method can tell us it’s a bus picking up a passenger.

  -> Need to combine approaches, to reduce degrees of freedom.

• No single method knows where the bus came from or what happens to it in the future (so if it were an isolated event we would struggle to understand it).

  -> But repeated observations (different times & places), improve our chances of a better understanding.
Volcanic systems are complicated natural systems

e.g. Miyakejima, Japan

Objective of multi-parameter monitoring is to build an understanding of the internal workings of active volcanic systems with their complex plumbing systems and where material properties change with time.

Based on collecting disparate data sets and making sense of the common story that they tell.

http://staff.aist.go.jp/kazahaya-k/miyakegas/COSPEC.html
Geological Survey of Japan
Q2: What are we trying to measure?

Note: Focus on application not methods

However, Methodology or (technology involved) defines limits of what can practically be measured. Easy to let the methodology guide research

1. Deep plumbing systems
2. Shallow plumbing (explosive, effusive, dome building)
3. Surface Processes (explosive, effusive, dome building)
1. Deep Plumbing (Macroscopic)

Schematic diagram of deep plumbing of a stratovolcano in an oceanic arc setting

Processes
- Rising & ponding of new magmas
- Dike injection
- Interaction with hydrothermal systems

Tools
- Ground Deformation
- Gravity
- Seismics
- Petrology

Important for long-term forecasting of eruptive (and unrest) episodes

Stern (2002, Reviews of Geophysics)
2. Shallow plumbing

Explosive eruptions
- Bubble nucleation, rise, coalescence
- Fragmentation
- Crystal growth/solidification
- Conduit flow
- Conduit convection

Effusive eruptions
- Seismicity
- Infrasound
- Gas spectroscopy
- Thermal remote sensing

Lava-dome eruptions
e.g. Shallow plumbing in effusive systems, Kilauea, Hawaii

Complicated plumbing system
Spatial dimension important
Utility of some methods over others

Gas
Deformation
Gravity
Seismics
Thermal Remote sensing

http://www.albion.edu/geology/geo210_hawaii/Kilauea/Kilauea%20homepage.htm
e.g. Shallow plumbing in lava dome system, Santiaguito, Guatemala

More ‘simple’ plumbing system
Spatial dimension less important
However, magma properties changing with depth, degassing induced crystalization, and high pressures building up.

Santiaguito, Guatemala, from Bluth & Rose, 2004
e.g. Shallow plumbing in effusive systems, Villarrica, Chile

Semi-continuous gas slug ascent and rupture

a. 24 hour period

b. 1 hour period
Palma et al, 2010

Observed explosive events

Observational data is ‘data’ - most usefully captured on timed digital video!

Utility of seismic data limited (short period, single component) but combined with observational data - source of transients clearly linked to surface explosions.
3. Surface processes

- Plume characteristics (proximal/distal)
- Fragmentation
- Degassing
- Lava extrusion characteristics
- Flow processes

Visual Observations/video
Thermal imaging
Gas spectroscopy/imaging
Seismics
Radar
Remote sensing
e.g. Surface Processes in lava dome systems, Soufriere Hills Volcano, Montserrat

Rockfalls

LP-Rockfalls

MBLG.BHZ 200701141141.UTC

20 seconds

MBLG.BHZ 200701081246.UTC

15 seconds
• Seismic record of surface processes (rockfall/pyroclastic flows) provides information on timing, repose, duration, energy, frequency content and data is collected systematically.

• 500,000 rockfalls over 15 yrs

• Used for understanding evolution of dome stability - Provides single best precursor information about dome collapses: 47 Dome collapses > 1 M m$^3$
Rockfalls and extrusion rate
Calder et al., 2002
Other seismic signals as indicator of internal processes

Surface process is telling us about dynamics lava extrusion
Q3: What are the problems?

Required Set of Initial Conditions

- People - involves willingness to collaborate between experts
- Instrument pools
- Active, accessible volcanoes
  - Such as Persistently active systems
    - Stromboli
    - Kilauea
    - Erebus
  - Or Longstanding eruptions
    - Soufriere Hills, Montserrat
    - Santiaguito, Guatemala
    - Mount St Helens
    - Merapi

Do we/can we cover Major Explosive eruptions adequately?
Shallow plumbing in Vulcanian systems

Relatively small, often repetitive

e.g. Monserrat, Galeras, Colima, Santiaguito

Cashman et al., 2006
Chaiten
2008, Chile

Imagen: Chaiten Volcano
NASA 2.jpg

Foto Eric Manríquez T

Imagen del satélite Terra de la NASA

agaudi.files.wordpress.com/2008/05/volcan-chaitén

sobrefotos.com/wp-content/uploads/2008/05
Q3: What are the problems? ..continued

Measuring

Instrument-determined limitations on temporal resolution of data:
- e.g. COSPEC surveys few times/day (now much improved DOAS)
- e.g. Continuous seismic/infrasound etc

Measuring over timescales over which volcanic processes of interest operate:
- Timescale of a sequence of bubbles rising and rupturing in a strombolian system (seconds-minutes)
- Timescale of conduit convection (weeks-months)
- Timescales of injection of new basaltic magma into an andesite magma chamber (months-years)

(will come back to this)
Q3: What are the problems? ..continued

A small list of few big problems

- The logistics of using a common time
- Instruments are filters
- Data don’t always seem to tell the same story
- Often have to measure important things indirectly

- Analysis of large data streams - relatively new problem for geologists (need to become proficient in time series analysis and other statistical tools etc).
Volcanic behaviour (analog signal)

Instruments as filters

Instrument #1
Digitizes signal

Signal is filtered

<table>
<thead>
<tr>
<th>value</th>
<th>address</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>00</td>
</tr>
<tr>
<td>0.3827</td>
<td>01</td>
</tr>
<tr>
<td>0.7071</td>
<td>02</td>
</tr>
<tr>
<td>0.9239</td>
<td>03</td>
</tr>
<tr>
<td>1</td>
<td>04</td>
</tr>
<tr>
<td>0.9239</td>
<td>05</td>
</tr>
<tr>
<td>0.7071</td>
<td>06</td>
</tr>
<tr>
<td>0.3827</td>
<td>07</td>
</tr>
<tr>
<td>0</td>
<td>08</td>
</tr>
<tr>
<td>-0.3827</td>
<td>09</td>
</tr>
<tr>
<td>-0.7071</td>
<td>10</td>
</tr>
<tr>
<td>-0.9239</td>
<td>11</td>
</tr>
<tr>
<td>-1</td>
<td>12</td>
</tr>
<tr>
<td>-0.9239</td>
<td>13</td>
</tr>
<tr>
<td>-0.7071</td>
<td>14</td>
</tr>
<tr>
<td>-0.3827</td>
<td>15</td>
</tr>
<tr>
<td>0</td>
<td>16</td>
</tr>
</tbody>
</table>
Volcanic behaviour (analog signal)

Instrument #1
Digitizes signal

Instrument #2
Digitizes signal

-> 2 Filters, 2 stories

Instruments as filters

<table>
<thead>
<tr>
<th>value</th>
<th>address</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>00</td>
</tr>
<tr>
<td>0.3827</td>
<td>01</td>
</tr>
<tr>
<td>0.7071</td>
<td>02</td>
</tr>
<tr>
<td>0.9239</td>
<td>03</td>
</tr>
<tr>
<td>1</td>
<td>04</td>
</tr>
<tr>
<td>0.9239</td>
<td>05</td>
</tr>
<tr>
<td>0.7071</td>
<td>06</td>
</tr>
<tr>
<td>0.3827</td>
<td>07</td>
</tr>
<tr>
<td>0</td>
<td>08</td>
</tr>
<tr>
<td>-0.3827</td>
<td>09</td>
</tr>
<tr>
<td>-0.7071</td>
<td>10</td>
</tr>
<tr>
<td>-0.9239</td>
<td>11</td>
</tr>
<tr>
<td>-1</td>
<td>12</td>
</tr>
<tr>
<td>-0.9239</td>
<td>13</td>
</tr>
<tr>
<td>-0.7071</td>
<td>14</td>
</tr>
<tr>
<td>-0.3827</td>
<td>15</td>
</tr>
<tr>
<td>0</td>
<td>16</td>
</tr>
</tbody>
</table>
Undersampling processes of interest

Volcanic behaviour (analog signal)

Nyquist rate - Sampling rate has to be twice the highest waveform frequency.

Aliasing: 5 Hz sine is under-sampled, leads to incorrect reproduction of a 1 Hz sine.
Lucky windows and well-placed instruments

15-20 $\mu$rads with 12-18 hour periods

Voight et al., 1997

...Sometimes good data provides a clear picture with minimal analysis
Understanding patterns by converting data to Frequency Domain

\[ x(t) = \sin(2\pi \times 50t) + \sin(2\pi \times 120t) \]

Synthetic signal

FFT analysis (finite Fast Fourier Transform) converts to frequency domain

Same signal with added noise
(also indicates the importance of filtering)
The IAVCEI Commission on Statistics in Volcanology (COSIV)

“to foster statistical analysis of volcanological data. In the last decade or so, researchers have begun to exploit a wide range of analytical and statistical methods for dealing with stochastic and distributed datasets. This represents a major step forward within physical volcanological modeling as we move to a new generation of probabilistic or statistical models. The primary aim of all this new activity is to develop rigorous methods for quantifying the likelihood of outcomes given the set of current and past observations”

-> Link statistical characteristics of data to processes
Q4 : Where are we going ?

• Models of plumbing system and processes Can never represent the full complexity of the natural phenomenon

• Monitoring data/collection community need to work more with modeling community. (e.g. Plume /flow modeling community).

• More proficient at

• Are field data providing information useful for modeling, or are there other important parameters we are lacking information about.
Thank You
Vhub.org is a site for collaborative volcano research and risk mitigation. Use the menus above to browse available simulation tools, data resources and links to all things volcanic.

Want to contribute to VHub? Follow [this link](https://vhub.org) to get started.

**VHUB**  
Collaborative volcano research and risk mitigation

---

**FIND CONTENT BY TAGS**

- **Search**

**Popular Tags:**
- IAVCEI Commission on Monogenetic Volcanism
- Remote Sensing
- Eyjafjallajökull
- Ashfall Graduate Class
- Level: College (Lower level undergrad/nonmajors)
- Level: College (Upper level undergrad/Graduate)
- Tephra
- Resource Type: Course (Multiple Lessons)
- Satellite measurements
- conference
- More tags

Courses, Data Sets/Collections, Educational Materials, Miscellaneous, Offline Tools, Presentations, Publications, Tools, Workshops...

All Categories »

**Uploading your own content! Get started »**

---

**WHAT'S NEW IN RESOURCES**

Kliuchevskoi_1994_timeline  
In Data Sets/Collections, Feb 14, 2012

Research collaboration, hazard modeling and dissemination in volcanology with Vhub  
In Presentations, Jan 31, 2012

Alessandro_24Janmeeting  
In Data Sets/Collections, Jan 24, 2012

Unrest at VUELCO’s target volcanoes  
In Data Sets/Collections, Jan 13, 2012

Hints Dissertation Materials  
In Data Sets/Collections, Jan 12, 2012

Expedicion Geofisica de Santiagoito Blog in Miscellaneous, Jan 11, 2012

See what else is new »

---

**UPCOMING EVENTS**

- **Feb 20**  
  IAVCEI - IAS 4th International Maar Conference: A Multidisciplinary Congress on Monogenetic Volcanism

- **May 21**  
  1st International Congress on management and awareness in protected volcanic landscapes

- **Sep 23**  
  IAVCEI-CCC 4th Collapse Caldera Workshop

- **Nov 19**  
  Cities on Volcanoes 7 (CoV7)

More events »

---

**VHub.org (lectures will be posted)**