Why UAVSAR?

Satellite data (figure on right) can provide global coverage at fixed repeat intervals (depending on satellite).

UAVSAR is deployed annually (in current study) with the possibility to return for temporally dense observations in the event of a significant volcano eruption crisis.

Satellite InSAR data of Okmok volcano Alaska illustrating the inter-annual build-up to the 2008 eruption and the larger 2008 co-eruption deflation. **Left top**, post-1997 eruption volume change and ESA Envisat interferogram showing the 10-15 cm inflation in prior year (lower left) to the July 13, 2008 Okmok, Aleutians eruption (max VEI ~4). **Right**, InSAR data and volume change decay plot for the months following the initial eruption. [Lu et al., 1998, 2005a, 2010; Lu and Dzurisin, 2010].
UAVSAR acquired under 1st phase of funding (2009-2011)

- Alaska-Aleutians (2009-2012)
- Western U.S. Cascades (2009-2012)
- Yellowstone (2009-2011)
- Hawaii (2010-2012)
- Central America (2010-2011)
Pacaya Volcano Guatemala

Slope instability?
(spans May 2010 eruption)

2010-2011 UAVSAR interferogram
Pacaya Volcano Guatemala

2010/01/29-2010/02/11
UAVSAR data
Pacaya Volcano Guatemala

Slope instability?
(≈2 week interferogram)

2010/01/29-2010/02/11 UAVSAR interferogram
Proposed Volcano Flight Plans in Japan

- Volcanoes will be imaged from opposite flight directions in most cases (some will also be flown at 90° for ~3D resolution)
- Repeat interval 1 year
- Possibility to return earlier in case of significant precursory evidence for a future volcano eruption
Colombia UAVSAR data from March 2013 flights already processed to polarimetry data products (map on right)

Example over Galeras Volcano
Colombia

Polarimetry UAVSAR image from Purace volcano
Ecuador
Peru

UAVSAR lines flown in 2013: all volcanoes imaged from opposite flight directions
Examples from Kilauea Volcano

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Hawaii InSAR tracks (A) and (B) Kilauea/E Rift focus area around Kamoamoa eruption (fissures in red, courtesy T. Orr, HVO, GPS sites green dots)
DI Events: January 2010

Kilauea Caldera Deflation-Inflation events

A TSX
B TSX
C UAVSAR

UWE electronic tilt meter

SAR acquisitions
Eruption started late afternoon March 5 (HST) with Pu`u `O`o tilt (deflation) starting 30 min prior to Kilauea tilt (deflation)
Near-real time COSMO-SkyMed data

1st interferogram on March 7, ~12 hrs after acquisition
UAVSAR spanning eruption

UAVSAR interferograms, (Jan 2010 – May 2011), 1.4 years, spanning the March 5-9, 2011 eruption

uavsar.jpl.nasa.gov for more info.
The March 2011 Kilauea Fissure Eruption

UAVSAR plus satellite InSAR and GPS data were used to constrain the detailed dike opening models and dike volume history shown in the next slide.

Figure 1. Maps of Hawaii, Kīlauea Volcano, and the Kamoamoa eruption area. (A) Satellite and airborne SAR processed scenes: in red, ALOS tracks, green, COSMO-SkyMed, black, TerraSAR-X, and blue, UAVSAR. (B) Close-up view of Kilauea, showing GPS sites (green dots), tilt meter sites (red dots), and the Kamoamoa fissures (red lines). Dashed box shows the interferogram area and the smaller solid box is the area shown in (C). (C) Close-up view of the fissures and lava flows.

Figure 2. UAVSAR interferograms for the dashed box area in Fig. 1B. Each interferogram is from a different viewing directions as indicated by the aircraft heading (gray) and look direction (black) arrows and their near to far range ground incidence angles.
Interferograms ending March 6-11

- ALOS t598 2011/01/19-2011/03/06
- CSK ASC 2011/02/11-2011/03/07
- ALOS t287 2010/12/07-2011/03/09
- CSK DESC 2011/02/14-2011/03/10
- CSK ASC 2011/02/03-2011/03/10
- ALOS t601 2011/01/24-2011/03/11
- TSX t24 2011/01/04-2011/03/11

L-band (ALOS) better coherence vs X-band (but higher noise over bare rock)

Unwrapped interferograms: 12 cm/cycle ALOS; 1.5 cm/cycle TSX and CSK
The March 2011 Kilauea Fissure Eruption

Dike models give a detailed view of the dike complexity and details that help explain the simultaneous feeding of the dike from sources beneath both Kīlauea Caldera and Pu‘u ‘Ō‘ō.

Figure 3. InSAR + GPS constrained model side views of dike opening for three dates: March 6, within 24 hours of the eruption start (ALOS); March 11, after the end of the eruption (ALOS, CSK, TSX); and early May (UAVSAR). The models show growth in amount of opening and area and suggest the dike was fed from its deeper limb plunging to the left and a shallower limb to the right.

Figure 4. Dike volume increase as a function of time for the dates with InSAR data and models. Following the end of the eruption (March 9) there was continued dike volume increase as shown by the March 10-11 model and the UAVSAR constrained May models.

Figure 5. Conceptual model for the Kilauea magmatic system related to the summit caldera source, the Pu‘u ‘Ō‘ō conduit, and the ERZ conduit thought to exist below 3 km depth. Model for March 6 is shown, red arrows show our interpretation of magma feeding the dike intrusion from the ERZ conduit from the up-rift limb of the dike and from the Pu‘u ‘Ō‘ō conduit in the down-rift direction.
Post-diking deformation...
InSAR time series 2010.5 – 2012.2

Kilauea summit (A)

Kamoamoa (B)

*CSK swaths cut from original width
Post-diking deformation from InSAR time series

- TSX t24
- CSK DESC
- CSK ASC

LOS shifted (cm)

May 5
Jan 9
UAVSAR flights

May 5
Jan 9
UAVSAR flights


year
displacements

UAVSAR flight dates shown by green/red lines through U time series. TS shown for only a subset of GPS sites on map.
(right) Three independent interferograms. (left) Stack of the three interferograms.
(right) Three independent interferograms. (left) Stack of the three interferograms.
Starting model

Model set-up was designed to address the type of process observed by Desmarais and Segall (2007):

- near vertical dikes in starting model
- horizontal detachment fault
Post-diking TSX, CSK, UAVSAR, GPS

- 27°-69°
- 30°
- 39°
- 40°
- 22°-72°

Data
Synth
Resid

TSX
CSK

UAVSAR

NUPM
KAMO
WAOR
LEA
DKIT
PG2R
PGFR
PGF4
PGF5
PGF6
PGF7
KTPM
NPW
OHI

HALR

Easting (m)
Surface Displ. (m)
Post-diking MCMC modeling

Starting model

MCMC model after $10^6$ iterations
Co-eruption $\Delta \sigma$ viewed from W

Sill opening promoted

Shallow dike opening inhibited, but in area of complex stress change

Positive Szz promotes opening of horizontal sills

Positive Syy promotes opening of vertical dikes
Comparison with past dikes

Models of 2011 and 1997 post-diking (Desmarais and Segall, 2007) are quite different, with the latter finding deeper (2-4 km) opening compared to both shallow dike opening and deep sill opening.

Surface traces of recent dikes (from M. Poland)

Fig. 5 Dike parallel cross section of both the 1.96 m uniformly opening 30 January 1997 intrusion dike and the cumulative distributed slip modeled in this study

Desmarais and Segall, 2007
Future directions

UAVSAR needed for volcano rapid response:
- Need dense temporal sampling when system is most dynamic
- Need for low-latency data
- Need to characterize signals to drive models that will improve forecasts

Current efforts in the Pacific “Ring of Fire” are designed to lay the foundation for future volcano eruption response.

Need topographic change for effusive eruptions, including lava domes

Copahue Volcano, Southern Andes

RADARSAT-2 showing ~1-year inflation leading up to the December 2012 eruption

Mean velocity map for smoothed solution. Fringe rate is 2 cm/yr.

RADARSAT-2 interferograms courtesy S. Samsonov, CSA; TS processing by P. Lundgren, JPL
InSAR time series for one year (late July 2010 – August 2011) of COSMO-SkyMed data. (A) Ascending track mean velocity (5 cm/yr color cycle). Arrows indicate approximate locations of time series shown in (C) and (D). (B) Descending track mean velocity. (C) Point time series for Kilauea caldera and (D) for points near the Kamoamoa dike eruption. The March 2011 fissure eruption shows sharp deflation at Kilauea until mid-2011, whereas (D) shows post-dike transient. Plus (+) signs are unsmoothed time series, circles are time series with a temporal triangular filter width of 3 weeks. Ascending data time series are shifted relative to the descending data. A and B in (C) and (D) refer to series from (A) and (B).

Arrows show Kilauea summit deflation and ERZ opening due to March 2011 fissure eruption.
Pre-eruption deformation

Precursory deformation south of Kilauea caldera in the 3 weeks prior the Kamoamoa eruption are several fringes at X-band and would only be about half a fringe at L-band.
Summary

• UAVSAR applied to active volcanoes has been successful in constraining dike opening of the 2011 Kamoamoa eruption, Kilauea volcano, Hawaii.
• Post-diking deformation from multiple look directions from UAVSAR are important for constraining deep dike accommodation.
• Local deformation at volcanoes such as Pacaya Volcano, Guatemala, provide important insight into edifice deformation and slope hazard.
• Future repeat observations in Japan and South America expand background observations that will provide the basis for responding to future large eruptions in the Pacific Rim.

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