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InSAR Studies of Alaska Volcanoes

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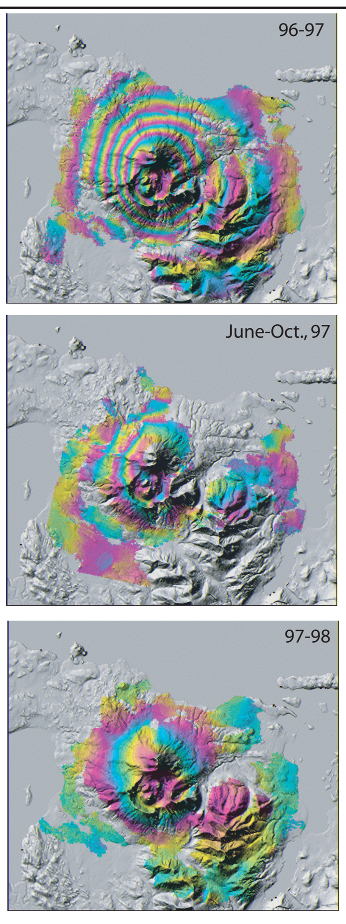
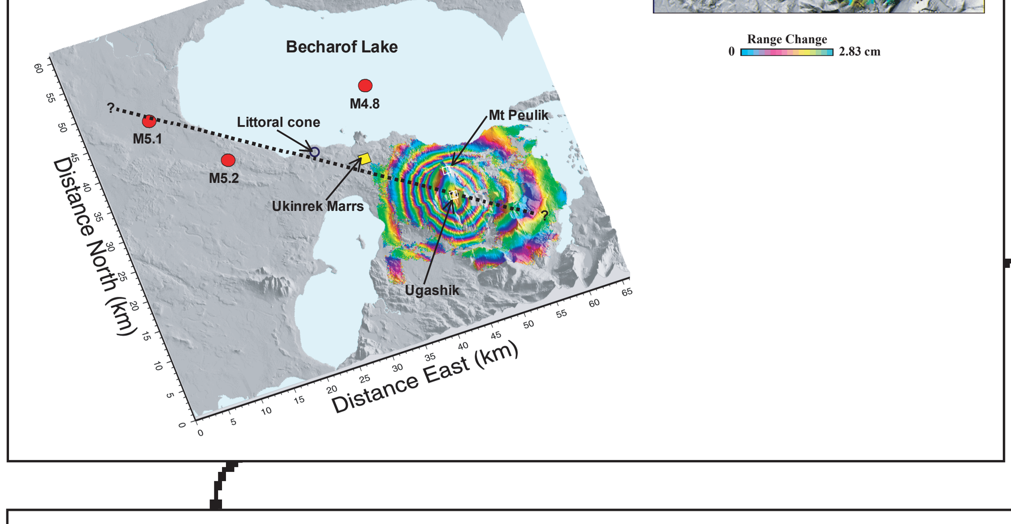
Peulik

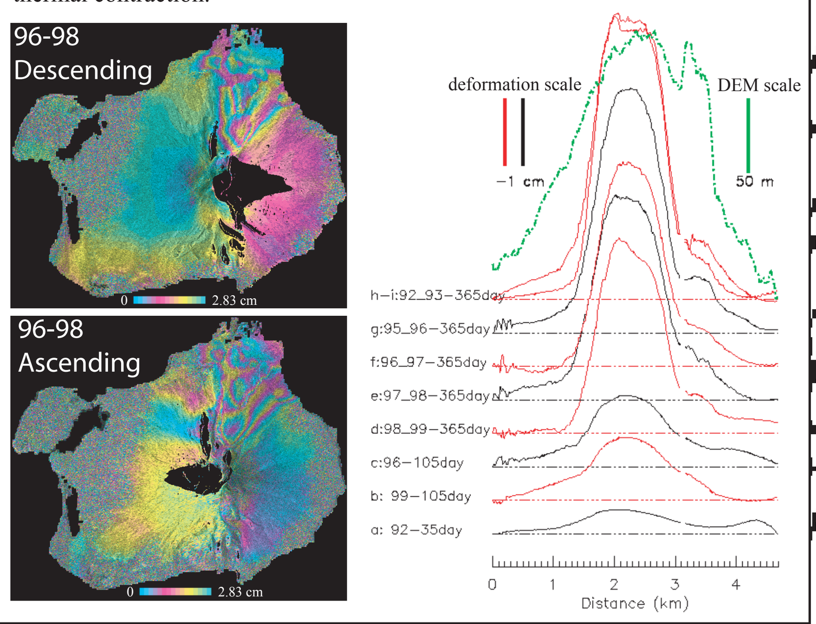
A series of InSAR images that collectively span the time interval from July 1992 to August 2000 reveal that a presumed magma body located ~6.6 km beneath the southwest flank of Mount Peulik volcano inflated ~0.05 km^3 between October 1996 and September 1998. Peulik has been active only twice during historical time, in 1814 and 1852, and the volcano was otherwise quiescent during the 1990s. The inflation episode spanned at least several months, because separate interferograms show that the associated ground deformation was progressive. An intense earthquake swarm, including three ML 4.8-5.2 events, began on May 8, 1998 near Becharof Lake, ~30 km northwest of Peulik. More than 400 earthquakes were recorded in the area through October 19, 1998. Although the inflation and earthquake swarm occurred at about the same time, the static stress changes we calculate in the epicentral area due to inflation beneath Peulik appear too small to provide a causal link. The 1996-98 inflation episode at Peulik confirms that satellite radar interferometry can be used to detect magma accumulation beneath dormant volcanoes at least several months before other signs of unrest are apparent. This application represents a first step toward understanding the eruption cycle at Peulik and other stratovolcanoes with characteristically long repose periods.





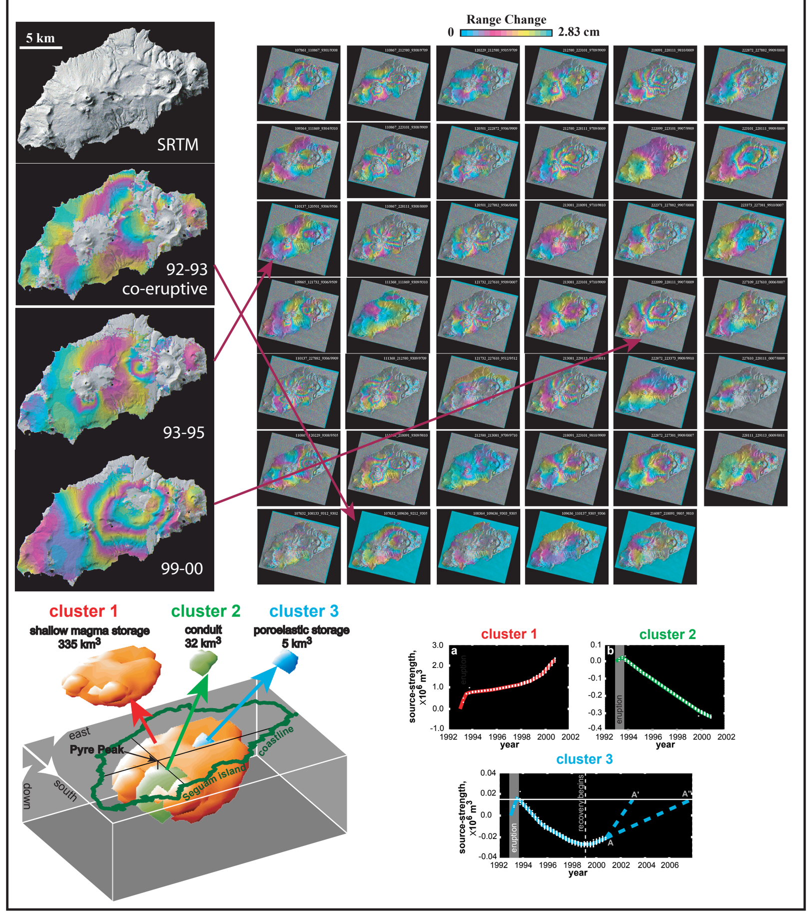
Augustine

Augustine volcano consists of a central dome and lava flow complex, surrounded by pyroclastic debris. InSAR images show that the pyroclastic flows from the 1986 eruption have been experiencing subsidence at a rate of about 3 cm per year, most of which was caused by thermal contraction.



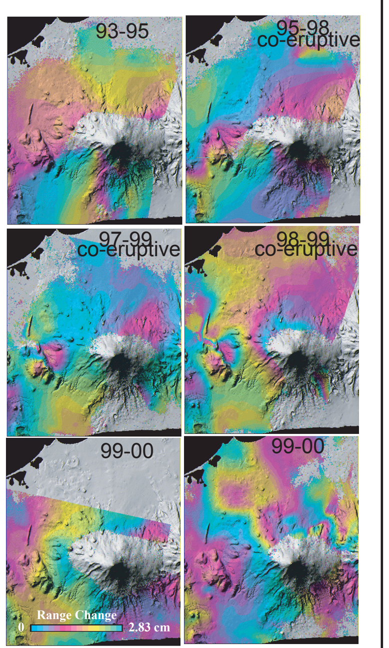
Seguam

Seguam Island consists of two late Quarternary calderas. The western caldera, Pyre Peak, dominates the western half of the island and has been the site for eruptions in this century, which occurred in 1901, 1927, and 1977. Most recently, Pyre Peak erupted during late December 1992-August 1993. Thirty InSAR images, spanning various intervals during 1992-2000, document co-eruptive and post-eruptive deformation of the 1992-1993 eruption on Seguam Island, Alaska. A procedure that combines standard damped least squares inverse methods and collective surfaces, identifies three amorphous clusters of deformation point-sources. Predictions generated from these three point-source clusters account for both the spatial and temporal complexity of the deformation patterns of the InSAR data. A model that combines magma influx, thermoelastic relaxation, poroelastic effects, and petrologic data accounts for the transient, interrelated behavior of the source clusters and the observed deformation. Basaltic magma pulses, which flow into a storage chamber residing in the lower crust, drive this deformational system. A portion of a magma pulse is injected into a system of dikes in the upper crust and remains in storage during both co- and post-eruption intervals. This injected magma degasses and the volatile products accumulate in a shallow poroelastic storage chamber. During the eruption, another portion of the magma pulse is transported directly to the surface via a conduit roughly centered beneath Pyre Peak on the west side of the island. A small amount of this magma remains in storage during the eruption and the post-eruption thermoelastic contraction ensues.



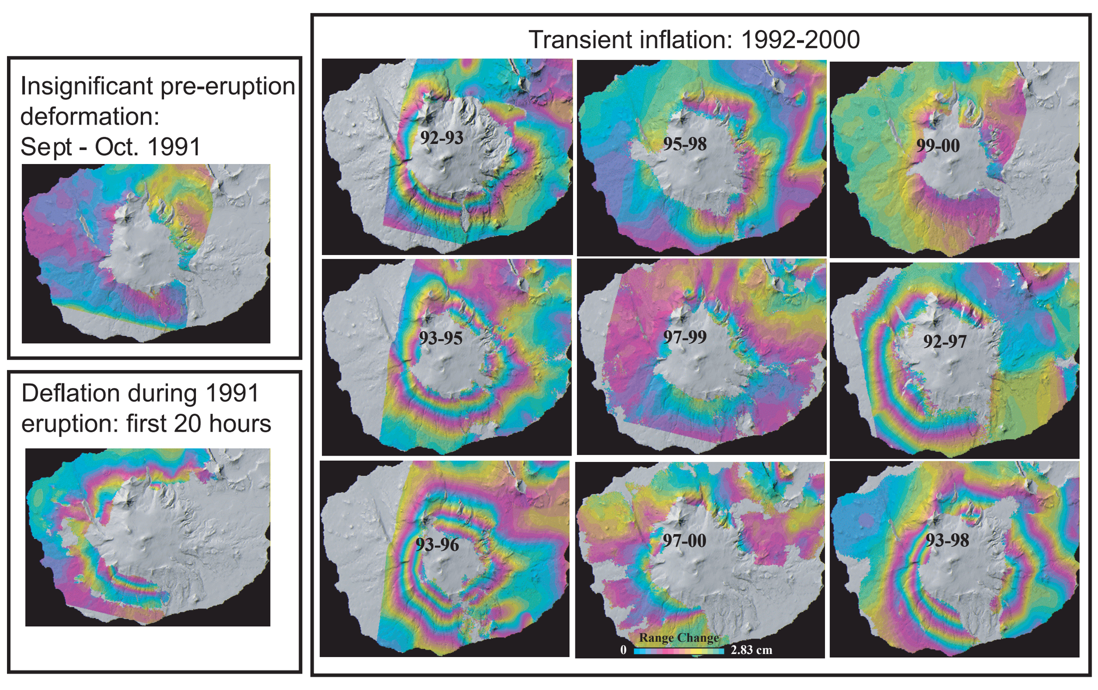
Shishaldin

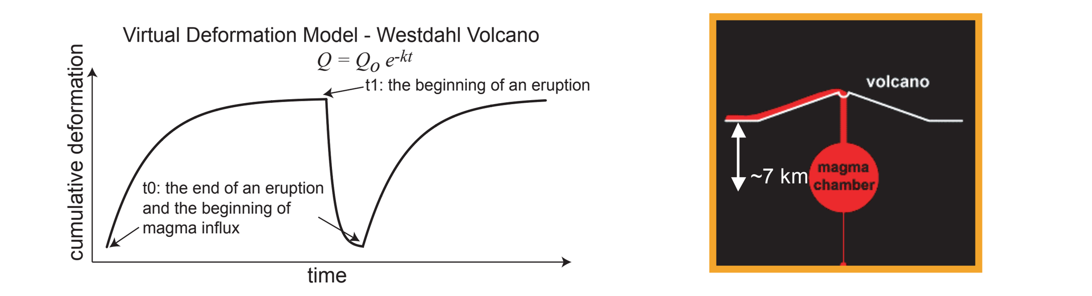
Shishaldin volcano is the third most active and the tallest volcano in the Aleutian arc. The summit area (~5 km radius) is covered by snow and ice most of the year, and therefore does not maintain coherence for C-band ERS interferograms. No significant deformation was observed in the coherence areas before, during and after the 1995-96 and 1999 eruptions from interferograms with one- or multiple-year intervals. This suggested three possible scenarios: 1) no significant pre-eruptive and co-eruptive deformation was associated with these eruptions; 2) pre-eruptive inflation was balanced by co-eruptive deflation, thus no net displacement could be observed; 3) the magma source is very shallow and magma strength is small so that deformation could only occur over the region of lost coherence. Viewing the size of the 1995-96 and 1999 eruptions, and the last interpretation is the least likely one of the three.



Westdahl

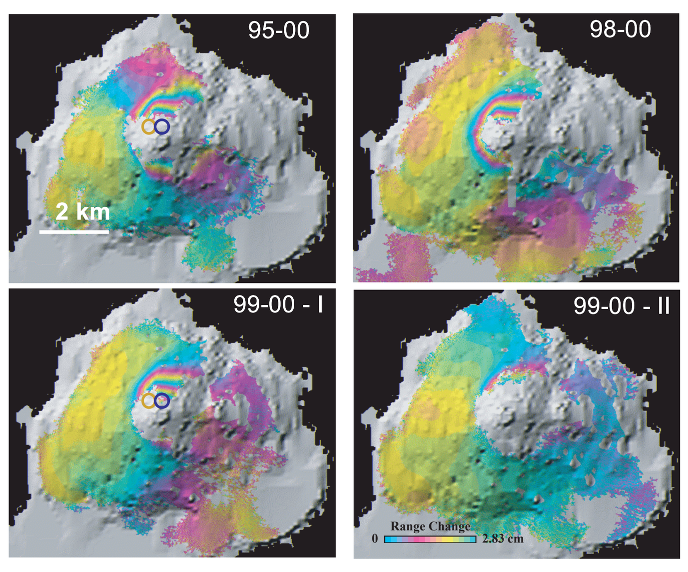
A series of InSAR images that span the time period from 1991 to 2000 show that Westdahl volcano, Alaska, deflated during its 1991-92 eruption and is re-inflating at a rate that could produce another eruption within the next several years. The rates of inflation and deflation are approximated by exponential decay functions with time constants of about 6 years and 2 days, respectively. This behavior is consistent with a deep, constant-pressure magma source connected to a shallow reservoir, located ~ 6 km below sea level, by a magma-filled conduit; the magma flow rate through the conduit is governed by the pressure gradient between the source (or surface) and the shallow reservoir.





Kiska

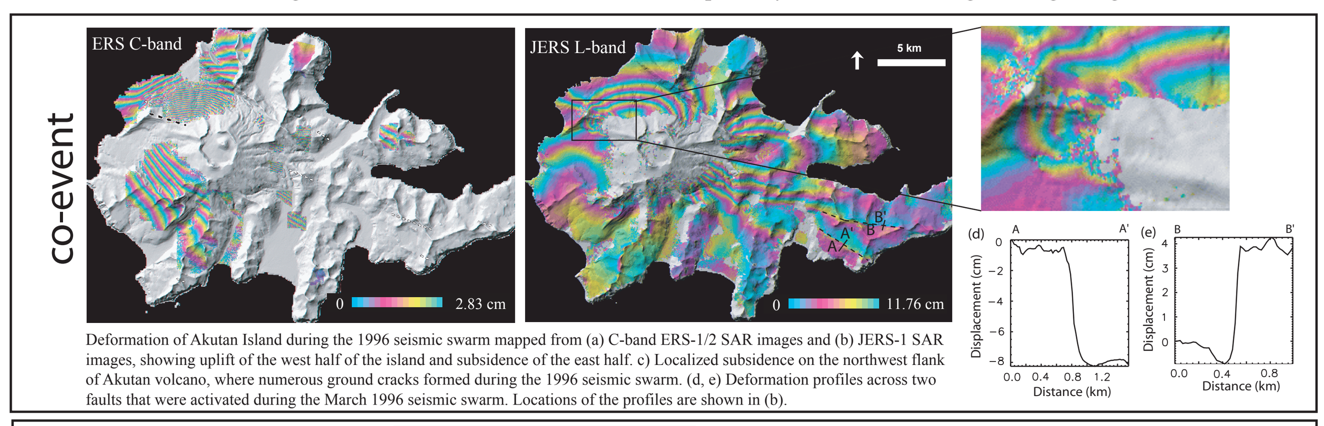
Sequential InSAR images of Kiska show that a circular area about 3 km in diameter centered near the summit subsided by as much as 10 cm from 1995 to 2001, mostly during 1999 and 2000. A Mogi-type deformation model suggests that the source is within 1 km of the surface. Based on the shallow source depth, the copious amounts of steam during recent eruptions, and recent field reports of vigorous steaming and persistent ground shaking near the summit area, we attribute the subsidence to decreased pore-fluid pressure within a shallow hydrothermal system beneath the summit area.



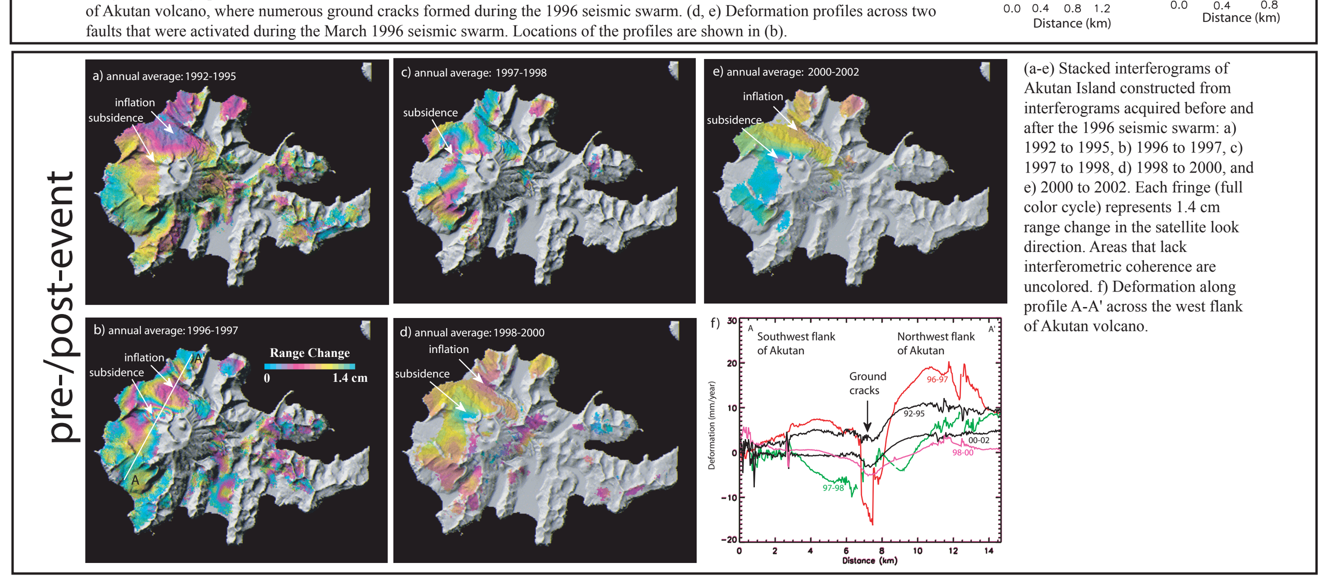
Location of observed steaming vent
Surface projection of inferred source

Akutan

In March 1996, an intense earthquake swarm beneath Akutan Island, Alaska, was accompanied by extensive ground cracking but no eruption of Akutan volcano. Radar interferograms produced from L-band JERS-1 and C-band ERS-1/2 images show uplift associated with the swarm by as much as 60 cm on the western part of the island. The JERS interferogram has greater coherence, especially in areas with loose surface material or thick vegetation. It also shows subsidence of similar magnitude on the eastern part of the island, and displacements along faults reactivated during the swarm. The axis of uplift and subsidence strikes about N70°W, which is roughly parallel to a zone of fresh cracks on the volcano's northwest flank, to normal faults that cut the island, and to the inferred maximum compressive stress direction. A common feature of models that fit the deformation is the emplacement of a shallow dike along this trend beneath the volcano's northwest flank. Both before and after the swarm, the northwest flank was uplifted 5-20 mm/year relative to the southwest flank, probably by magma intrusion. The zone of fresh cracks subsided about 20 mm during 1996-1997 and at lesser rates thereafter, possibly because of cooling and degassing of the intrusion.



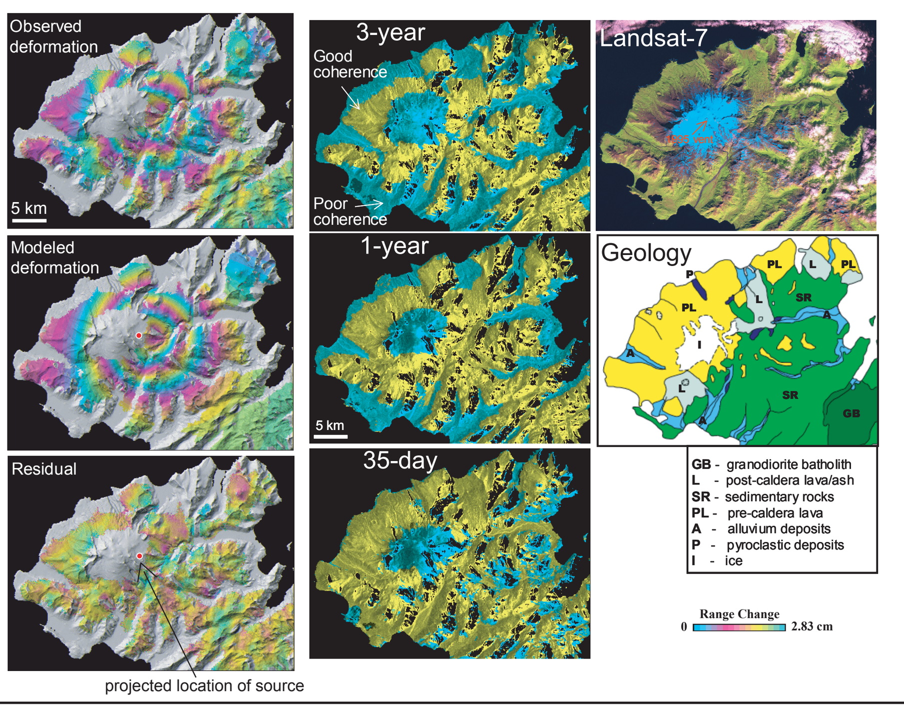
Deformation of Akutan Island during the 1996 seismic swarm mapped from (a) C-band ERS-1/2 SAR images and (b) JERS-1 SAR images, showing uplift of the west half of the island and subsidence of the east half. c) Localized subsidence on the northwest flank of Akutan volcano, where numerous ground cracks formed during the 1996 seismic swarm. (d, e) Deformation profiles across two faults that were activated during the March 1996 seismic swarm. Locations of the profiles are shown in (b).



(a-e) Stacked interferograms of Akutan Island constructed from interferograms acquired before and after the 1996 seismic swarm: a) 1992 to 1995, b) 1996 to 1997, c) 1997 to 1998, d) 1998 to 2000, and e) 2000 to 2002. Each fringe (full color cycle) represents 1.4 cm range change in the satellite look direction. Areas that lack interferometric coherence are uncolored. f) Deformation along profile A-A' across the west flank of Akutan volcano.

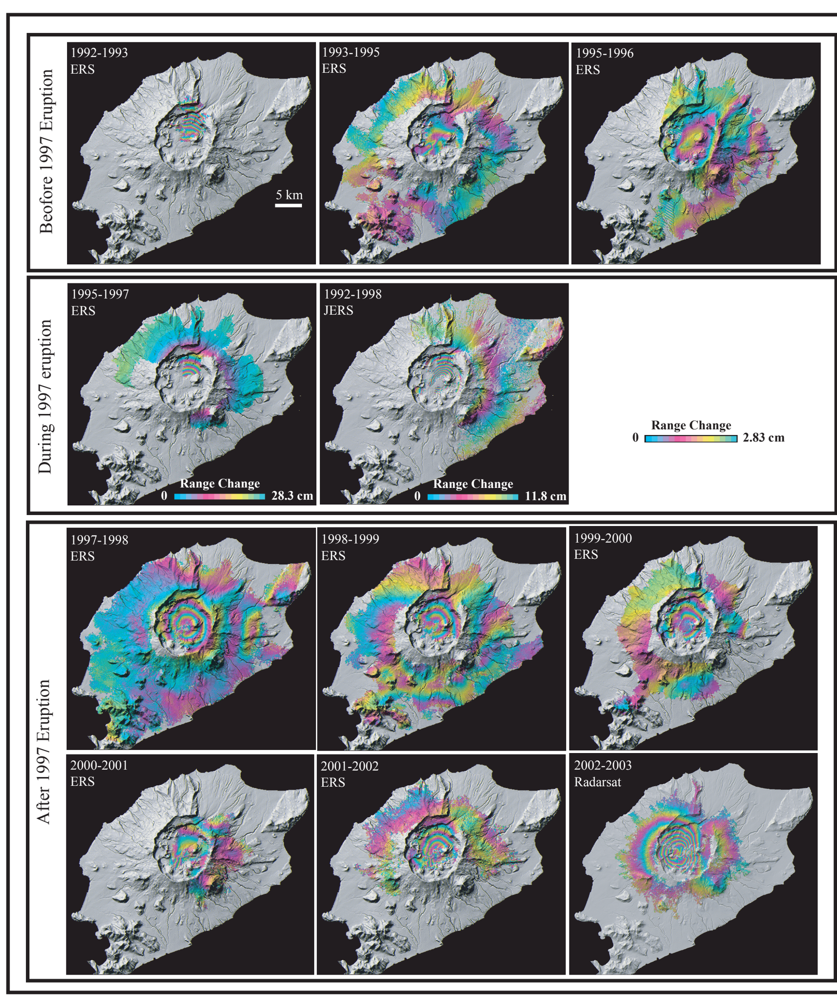
Makushin

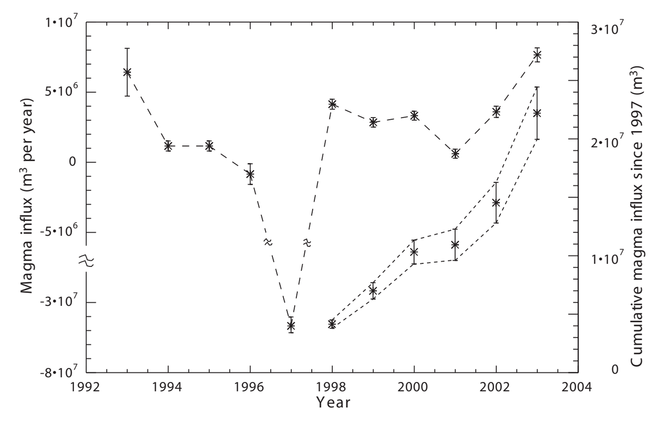
Pilot reports in January 1995 and geologic field observations from the summer of 1996 indicate that a relatively small explosive eruption of Makushin, one of the more frequently active volcanoes in the Aleutian arc of Alaska, occurred on January 30, 1995. Several independent radar interferograms that each span the time period from October 1993 to September 1995 show evidence of ~7 cm of uplift centered on the volcano's east flank, which we interpret as pre-eruptive inflation of a ~7 km deep magma source. Subsequent interferograms for 1995-2000, a period that included no reported eruptive activity, show no evidence of additional ground deformation. Interferometric coherence at C-band is found to persist for 3 years or more on lava-flow and other rocky surfaces covered with short grass and sparsely distributed tall grass, and for at least 1 year on most pyroclastic deposits. On lava-flow and rocky surfaces with dense tall grass, and on alluvium, coherence lasts for a few months. Snow and ice surfaces lose coherence within a few days. This extended time frame of coherence over a variety of surface materials makes C-band radar interferometry an effective tool for studying volcano deformation in Alaska and other similar high-latitude regions.



Okmok

Okmok volcano, located in the central Aleutian arc, Alaska, is a dominantly basaltic complex topped with a 10-km-wide caldera that formed circa 2.05 ka. Okmok erupted several times during the 20th century, most recently in 1997; eruptions in 1945, 1958, and 1997 produced lava flows within the caldera. 80 interferometric synthetic aperture radar (InSAR) images (interferograms) were used to study transient deformation of the volcano before, during, and after the 1997 eruption. Point-source models suggest that a magma reservoir at a depth of 3.2 km below sea level, located beneath the center of the caldera and about 5 km northeast of the 1997 vent, is responsible for observed volcano-wide deformation. The pre-eruption uplift rate decreased from about 10 cm/year during 1992-1993 to 2~3 cm/year during 1993-1995 and then to about -1~-2 cm/year during 1995-1996. The post-eruption inflation rate generally decreased with time during 1997-2001, but increased significantly during 2001-2003. By the summer of 2003, 30~60% of the magma volume lost from the reservoir in the 1997 eruption had been replenished. Interferograms for periods before the 1997 eruption indicate consistent subsidence of the surface of the 1958 lava flows, most likely due to thermal contraction. Interferograms for periods after the eruption suggest at least four distinct deformation processes: (1) volcano-wide inflation due to replenishment of the shallow magma reservoir, (2) subsidence of the 1997 lava flows, most likely due to thermal contraction, (3) deformation of the 1958 lava flows due to loading by the 1997 flows, and (4) continuing compaction of 1958 lava flows buried beneath 1997 flows. Our results provide insights into the pluming system of Okmok volcano and the post-emplacement behavior of lava flows.





Estimated magma supply for the shallow reservoir as a function of time from 1992 to 2003. Incremental magma flux estimates (connected with dashed line) reveal annual supply dynamics. The vertical axis on the left applies to this curve. Error bars are 1-standard deviations. Cumulative magma storage following the 1997 eruption (with 1s bounds) is shown in the lower right portion of the plot. The vertical axis on the right applies to the cumulative curve, which suggests that 30-60% of the volume erupted in 1997 (based on co-eruption interferograms) has been replenished.

Augustine
Peulik
Aniakchak
Shishaldin
Westdahl
Akutan
Makushin
Okmok
Seguam
Kiska

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