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Tectonic, volcanic and human activity: ground deformation signals detected by multitemporal InSAR techniques in the Colima Volcanic Complex rift (Mexico)

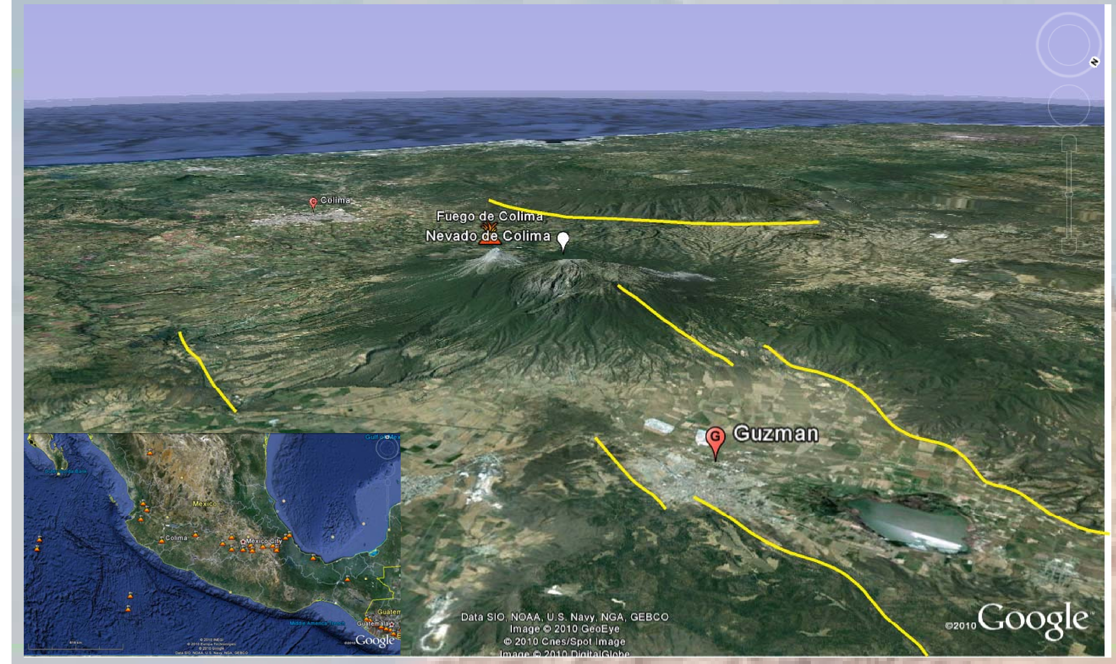
Carlo Alberto Brunori (1), Christian Bignami (1), Elisa Trasatti (1), Salvatore Stramondo (1), Francesco Zucca (4), Gianluca Groppelli (3), Gianluca Norini (2), Lucia Capra (5), Enrique Cabral-Cano (6) & Bertha Marquez-Azua (6)
carloalberto.brunori@ingv.it
(1) Istituto Nazionale di Geofisica e Vulcanologia, (Roma, ITALY), (2-5) Università degli Studi di Milano-Bicocca (Milano, ITALY), (3) C.N.R. – Istituto per la Dinamica dei Processi Ambientali, Milano, Italy,(4) Università di Pavia - Dip.Scienze della Terra (Pavia, ITALY)
(5) Universidad Nacional Autonoma de Mexico, Queretaro, Mexico,,(6) Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, Ciudad Universitaria Del. Coyoacan,

Introduction

The evolution of volcanoes is strictly related with their substratum and the regional tectonics. The link among morphology, geology and structure of volcanic edifices and the geological-structural characteristics of the basement is important to understand hazardous phenomena as flanks eruptions and lateral collapses of volcanoes.

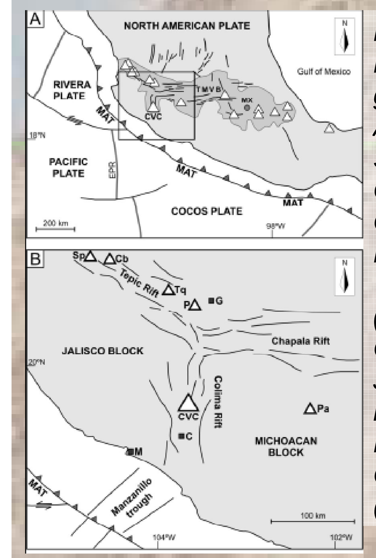
The Colima Rift is an active regional structure, N-S oriented and more than 100 km long, 10 km wide. This rift is filled by a ~1 km-thick sequence of quaternary lacustrine sediments, alluvium, and colluvium, mostly underling the about 3000 m thick volcanic pile of the Colima Volcanic Complex (CVC). The CVC located in the western part of the Trans-Mexican volcanic belt.

In addition to the regional structures curved faults, roughly E-W oriented, are observed on the CVC edifice due to the spreading of the volcano moving southward on the weak basement. So in the CVC edifice and surrounding area we can observe the interaction of regional structures and volcanic moving southward on the weak basement.



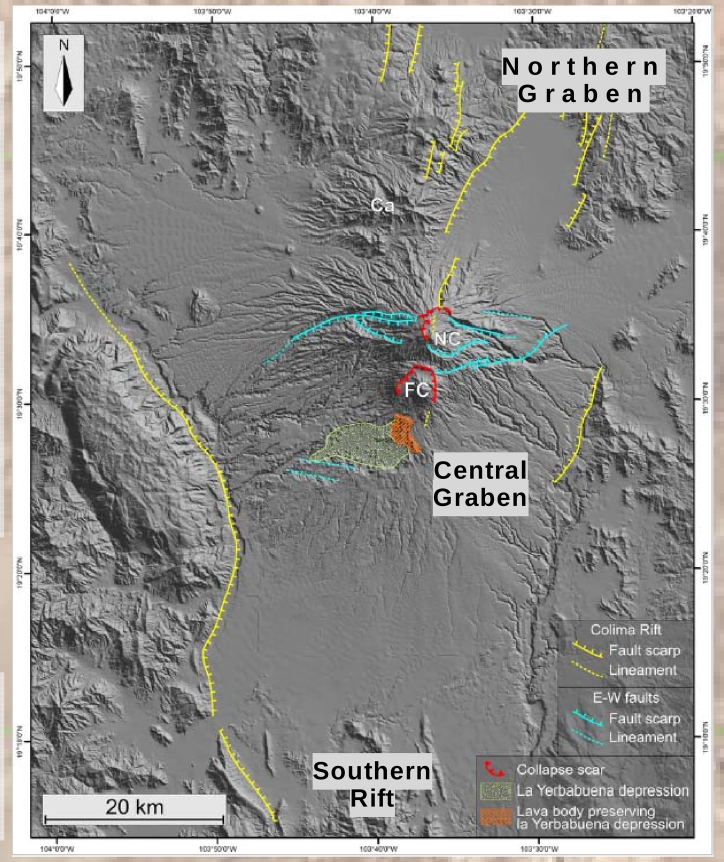
Aerial view from north–east of the Colima Volcanic Complex (CVC) with morphotectonics. In the close-up, the Colima Volcanic Complex located in the western part of the Trans-Mexican volcanic belt.

To measure displacements due to magma movement at depth and interaction of regional structures and volcanic ones, SAR interferometry has proven to be a reliable method; however, andesitic strato volcanoes like the CVC remain difficult to survey using this technique. The main causes are their specific geometry (steep topography), which induces strong tropospheric artefacts, environmental conditions (e.g.,mainly vegetation, ash and/or snow cover), leading to a loss of coherency.



*Here on the left **(A)** the location of the Trans-Mexican Volcanic Belt (TMVB) in the geodynamic framework of North and Central America. Triangles show major volcanoes. Solid black lines are major faults. MX: Mexico City. MAT: Middle American trench; CVC: Colima Volcanic Complex; EPR: East Pacific Rise.*

*(B) Sketch map with the location of the Colima-Tepic-Chapala triple junction and the Jalisco and Michoacan blocks. **Cb**: Ceboruco; **Pa**: Paricutin; **Tq**: Tequila; **Sp**: San Pedro; **P**: Primavera; **C**: Colima City; **G**: Guadalajara City; **M**: Manzanillo City. (from Norini et al. 2010)*



Here on the right a morphotectonic map on a shadow relief image showing the evidences of neotectonics and volcanotectonic features in the Colima Rift and the CVC. Ca: Cantaro volcano; NC: Nevado de Colima volcano; FC: Fuego de Colima volcano.

The Colima Rift

The Colima rift extends in an overall north-south direction from the triple junction to the Pacific coast, near Manzanillo. This rift consists of three morphologically defined subrifts: the northern Colima graben, the central Colima graben, and the southern Colima rift (top left figure).

The northern Colima graben is located between the triple junction and the Colima volcanoes (Cantaro, Nevado de Colima, and Volcan Colima).

The central Colima graben, like the northern Colima graben, also exhibits a north-south orientation.

It forms a 50- to 60-km-wide graben/half-graben extending from Volcan Cantaro to the La Cumbre fault zone located just south of the city of Colima.

The southern Colima rift extends from the La Cumbre fault zone to the Middle America Trench. Unlike the northern and central parts of the Colima rift, the southern Colima rift trends northeast-southwest. The CVC is affected by a distinct set of E-W-trending volcanotectonic normal faults, radiating from the summit area and restricted to the volcanic edifice itself. The E-W structures originated from the spreading of the volcano moving southward on its weak basement. The observed deformation of the CVC and surroundings results from the interplay between the active N-S-trending regional tectonics and the southward spreading of the volcano over its basement forming an E-W-oriented volcanotectonic graben

Processing

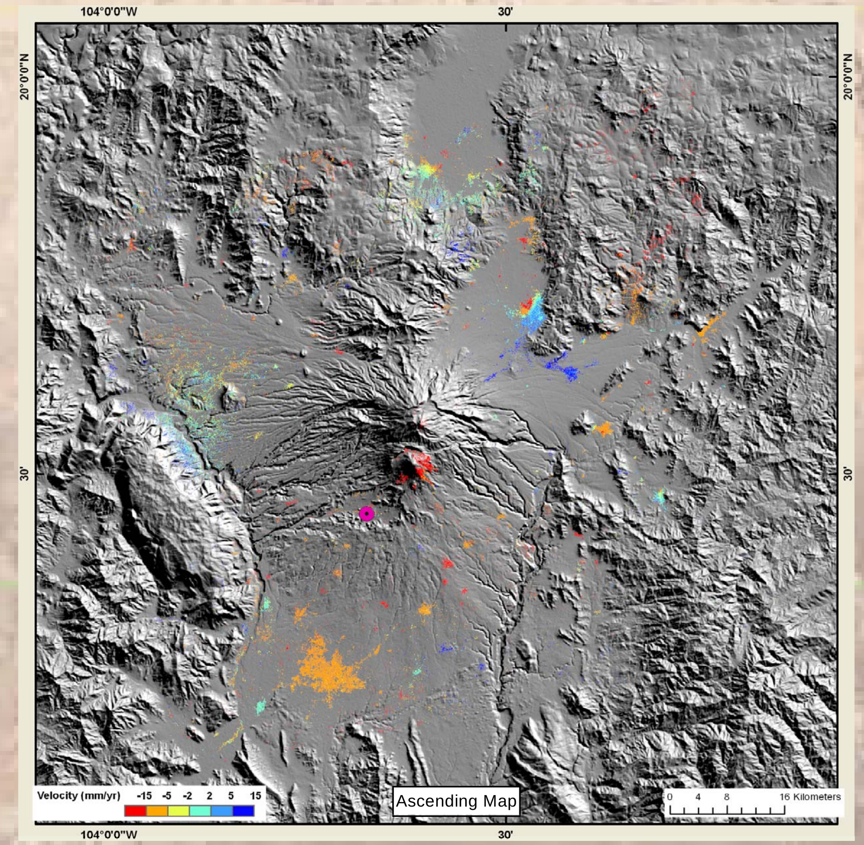
Ascending pass – track 48	
Master image	12/11/2004
N° of point scatteres for PS	22689
N° of point scatteres for Sb	35502
N° of point scatteres for C-MTI	56003
Descending pass – track 155	
Master image	26/8/2005
N° of point scatteres for PS	49365
N° of point scatteres for Sb	63040
N° of point scatteres for C-MTI	97701

We have applied a new multitemporal Advanced-InSAR (A-InSAR) technique known as StaMPS/MTI (Stanford Method for Persistent Scatterers /Multi Temporal InSAR) [Hooper, 2008] to measure surface movements over the whole investigated area. To this aim we used a dataset of 29 ENVISAT ASAR images, in image mode swath IS2 and VV polarization, either along ascending or along descending acquisitions.

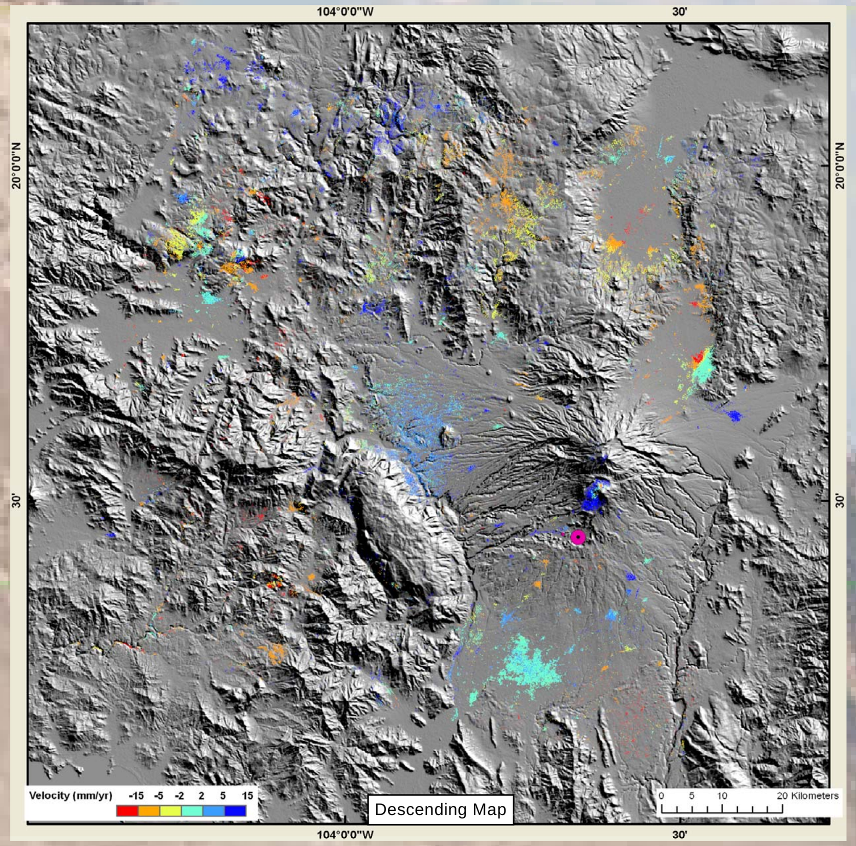
The ascending data span from17/01/2003 to 26/05/2006, whereas the descending acquisitions range from 24/01/2003 to 14/12/2007. StaMPS/MTI implements two A-InSAR approaches, PS (Persistent Scatterers) and Small Baseline, besides the combined method (C-MTI). The result of C-MTI application are two velocity maps one for each orbit. Even though A-InSAR techniques have proven to be reliable tools to measure displacements due to magma movement at depth and the possible interaction of regional structures and the volcanic one, however, andesitic strato volcanoes like the CVC remain difficult to survey because of some in situ characteristics. Indeed, besides the steep topographic relief which induces strong tropospheric artefacts and layover areas, the specific environmental conditions (e.g., dense vegetation, ash and/or snow cover) lead to coherence loss. The velocity maps from C-Band ASAR data clearly show a sparse distribution of coherent targets over the whole scene outside urban areas and along the volcanic edifice. Furthermore the sparse scatterers density leads to phase unwrapping artifacts. In order to face such issue the scene has been shared in subframes.

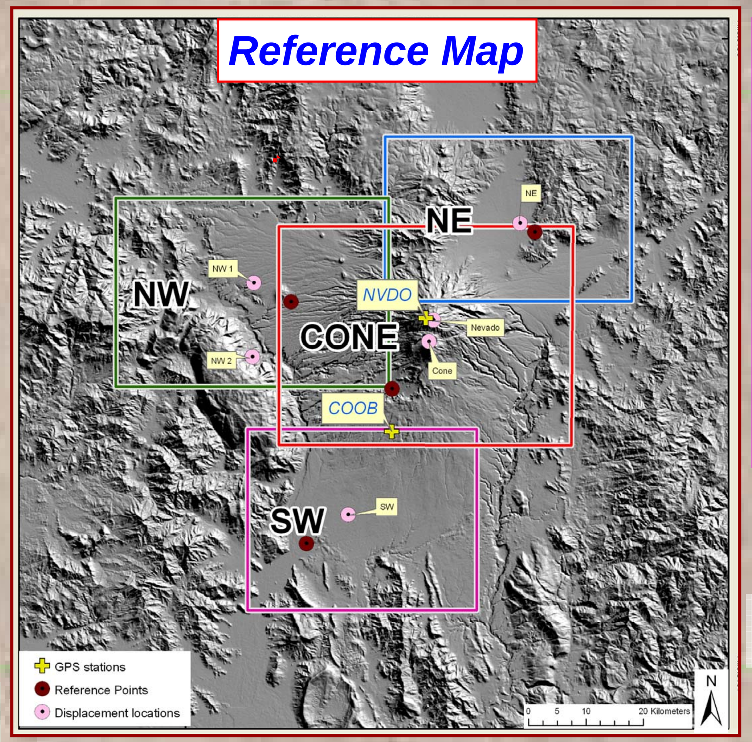
***Top left image**: the area surveyed by ascending and descending satellite orbits;*

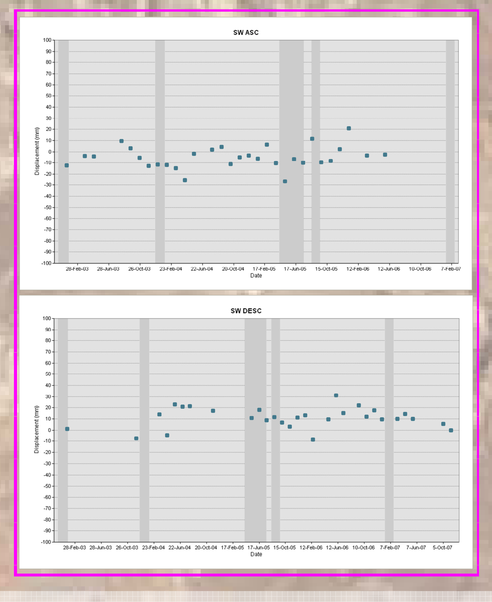
***Bottom left image**: reports some details about the processing for each method and orbit direction*.



LOS (Line Of Sight) surface velocities from Envisat data measured by StaMPS/MTI along ascending (left) and descending (right) paths. Positive (blue) velocities mean the surface movement is toward the satellite (satellite-to-ground distance decreases), while negative (red) numbers mean LOS distance has increased along time. Reference point for both processing is in fuchsia.



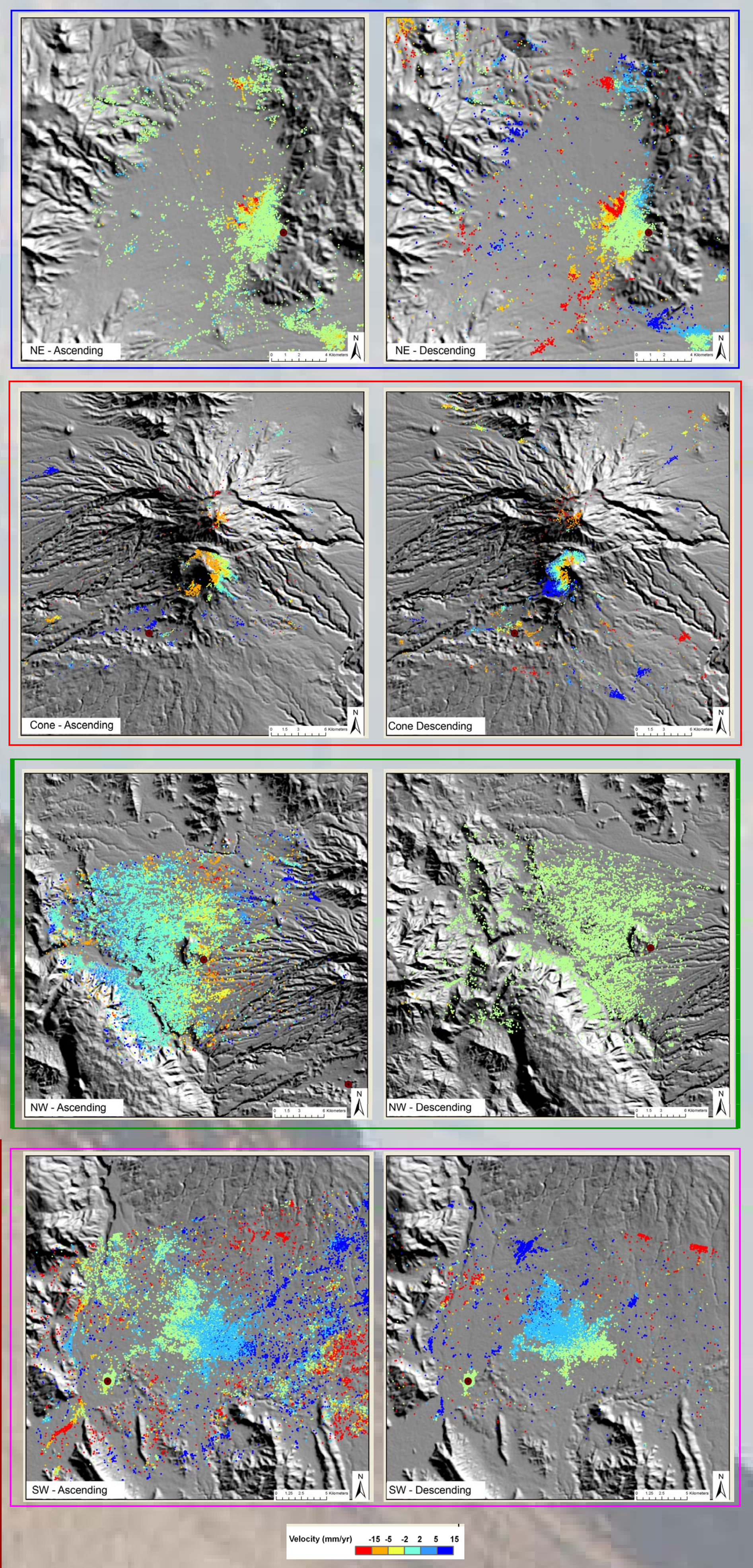




In the Reference Map, the extension of the CVC zones processed separately. The reference points for each unwrapping process are in brown. Pink points show the location of time series reported in the graphs. The graph represents the displacement time series and are grouped by a fence with the color of the zone in the map. The time series of red highlight a deformation trend for both Colima cone (Fuego) and Nevado

Yellow crosses are GPS benchmarks.

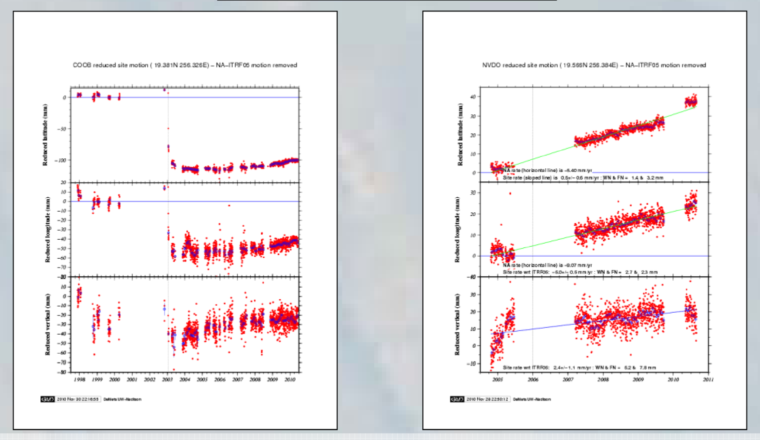
The grey bands represent periods of volcanic activity of the Fuego the Colima except for the first one (on the left, in the 2003) that is referred to the tectonic activity related to January 21st 2003 (M 7.6) (located outside the study area).



Figures above are the four sub frames as in left map. Results of processing ascending and descending data are shown for each.

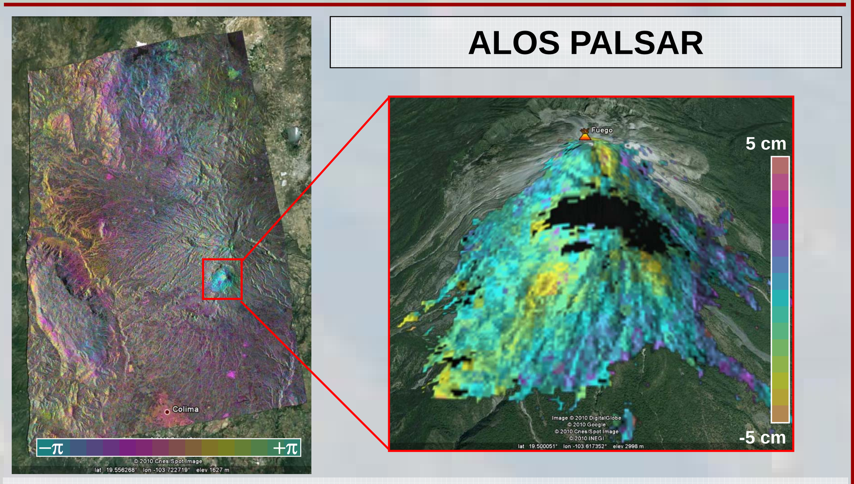
Work In Progress

GPS time series



The GPS benchmarks (yellow crosses in REFERENCE MAP) are in general disagreement with C-MTI time series. This is apparent for NVDO (see Nevado asc and desc time series for comparison) that shows an uplift and an horizontal vector toward NE. Further analysis about the role of strain accumulation at regional scale are needed. The superimposition of the volcanic signal and the tectonics deformation may be the reason of the inconsistency GPS-InSAR.

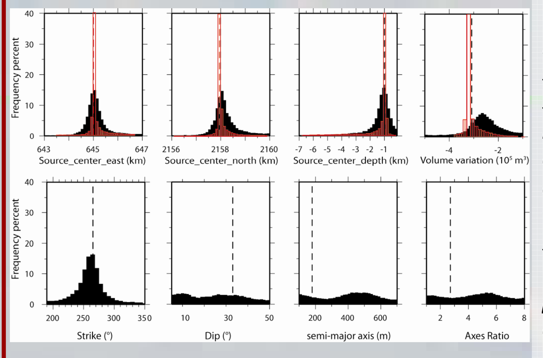
ALOS PALSAR



Two PALSAR scenes (2007 Aug 29 and 2010 Jun 06) are used to analyze the long term deformation with L-band interferometry. The wrapped interferogram is shown in the left figure and on the right a detail of the Fuego summit (aerial view from south). A possible deflation of about 2.0 cm, has been measured on the summit of Fuego (yellow areas in the right image). The displacement is in the LOS of PALSAR, on ascending orbit.

Modeling of Fuego the Colima

We try to interpret the observed rate velocities from the ENVISAT SAR time series supposing the action of a small de-pressured source. We use two different models: spherical point-source (Mogi 1958) and spheroidal finite source (Yang et al., 1988).



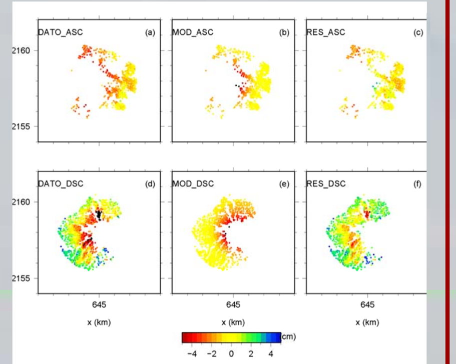
Frequency Histograms

Black results, spheroidal source, red results, Mogi source. Both sources are located below the edifice center, at about 1 km of depth. Also the volume variation is similar for both sources, about -3 105 m3. The spheroid additional parameters (orientation and dimension) are not well resolved.

Comparison with observed data

Both the spherical and the spheroidal sources fail in interpreting the observed data at the Feugo de Colima (summit), since the residuals with data are very high, and much deformation is unmodelled.

Future models should take into account (at least) the presence of prominent topography and decoupling faults on the volcano.



Discussion

We have applied the Hooper's multi-approach to a complex, but really interesting and intrigues, volcanic area like the CVC in order to face at least two issues: to go deeply inside a sophisticated multi temporal interferometric approach for detection and mapping of terrain deformation, while on the other hand to put attention over CVC to understand if and how tectonic processes and volcanic cycle interact in space and time. Later on to make concerns about the relationship between volcanic building and the basement. Finally, based on results of recent field works (Norini et al.2010) to test a subsequent morpho-structural model. Several notes must be underlined before moving to the interpretations. In particular we have not taken care how the topographic modification due to volcanic activities (eg. lahars and debris) and slope failure during the investigated time may have influenced the result. We selected a point within each of the four areas and the time series are shown. Point in blue rectangle refers to an urban area, close to an active fault. Therefore the measured deformation (about 70 mm in roughly 4 years) might be the result of water extraction (a seasonal signal is probably) and active tectonics. The selected point in the red area centered on the volcanic cone highlights two different trends from ascending and descending time series. Both measure a subsidence but discrepancies are probably due to horizontal deformation caused by the local extensional regime. In synthesis we can observe:

- the general deflation of top portion of the cone as in Pinel et al.(2007), and the subsidence of Nevado the Colima.
- deformative pattern of the NW and SW zones (respectively central and southern rift) do not clearly describe the structure.
- the deformation patterns in the northern rift near Ciudad Guzman with an evident ground subsidence most of which probably ascribable to the compaction of the sediments of the lake. The deformation pattern in this area could be also due to presence of extesional structures that border the northern rift.

References

- A.Hooper (2008): A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches. GRL,VOL.35,L16302,doi:10.1029/2008GL034654,2008
- J.B. Murray, L.K.Wooller (2002): Persistent summit subsidence at Volcan de Colima, Mexico, 1982-1999: strong evidence against Mogi deflation. Journal of Volcanology and Geothermal Research 117 (2002) 69-78
- G. Norini, L. Capra, G. Groppelli, F. Agliardi, A. Pola, A. Cortes (2010): The structural architecture of the Colima Volcanic Complex JGR, In Press
- V.Pinel, A.Hooper, S.DelaCruz-Reyna,G.Reyes-Davila and M.P.Doin (2007): Study of the deformation field of two active Mexican stratovolcanoes (Popocatepetl and Colima volcano) by time series of insar data. Proc. of FRINGE 2007

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