SURFACE CHANGE DETECTION AT VENUS: THE REQUIREMENTS AND POTENTIAL FROM EARTH ANALOG STUDIES. P. J. Mason[1], R. C. Ghail[2], G. Gallardo i Peres[1], S. Banham[1], P. McVann[2], C. Knight[2], N. Davidova[1], A. Moreira[3], P. D'Incecco[4], S. S. Bhiravarasu[5], I. Lopez[6], J. Brossier[4], M. Yu Zolotov[7], J. Filiberto[8], and G. Di Achille[4].
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Introduction: The forthcoming Venus missions (EnVision, VERITAS and Venus Orbiter Mission) provide the opportunity to detect inter-mission changes in Synthetic Aperture Radar (SAR) imagery across a 40-year time gap since Magellan, and intra-mission changes within the periods of the new missions. Achieving reliable inter-mission change detection will not be straight forward, however, since the radar instruments have differing viewing geometries, wavelengths and spatial resolutions, and we therefore need to consider carefully how best to undertake such efforts.

Repeated high-resolution radar imaging with consistent viewing geometry will allow direct comparison of features, to pick up morphological and backscatter patterns associated with physical and potentially compositional surface changes. Such comparison demands precise image co-registration and reliable image feature matching, and these rely on topographic data of comparable resolution to ensure that geometric and terrain distortions in SAR imagery are removed. Also needed are robust methods to identify and extract real feature changes in an effective, automated way, for repeatability and to save time.

There is growing indirect evidence of recent volcanic activity on Venus [1-8] but to fully understand the likely character of surface changes, the use of analog sites and Earth Observation data is needed [9]. To characterize the full variety of geomorphologic feature-type changes we might expect (volcanic, tectonic, erosional, depositional, impact etc), cases are needed where change is occurring at suitable spatial and temporal scales and where plentiful repeated images exist in archive. Hence we are using freely available global Sentinel-1 (and other) SAR data at a series of sites to develop automated change detection approaches.

Challenges: Accurate feature matching relies on ortho-rectified images (terrain corrected and co-registered), so that features can be properly compared. Ortho-rectification is especially critical in inter-mission change detection cases where the sensors' observation geometries of specific targets a likely to differ. The existing Magellan GTDR products have too coarse spatial resolution (4.641 km/pixel) and contain too many errors to allow reliable ortho-rectification. Hence, the delivery of topography data from EnVision and VERITAS missions will be of critical importance. With different look direction and varying look-angles to maintain local incidence angles, Magellan SAR data were in no way optimized for change detection, which makes any comparison of features with Magellan data challenging. Intra-mission change detection for EnVision and VERITAS suffers the same requirements but their images should be acquired with consistent viewing geometry and resolution [10, 11]. Differing wavelengths and polarisations also offer challenges but they also offer the possibility to characterise the surface materials and to detect subtle changes in roughness, compaction or cementation, mineralogy, physical weathering, and subsequent burial or material removal.

Methods: The new missions will deliver repeated imagery of comparable spatial resolution (e.g. 30 m/pixel for EnVision's VenSAR and VERITAS' VISAR). EnVision offers the chance to image a region of interest three times during its nominal mission, as well as high-resolution (10 m/pixel) images, and thus the potential to further repeat-image a particular location, if the hint of a change is observed and further detail is required. Repeated imaging offers the most direct route to change detection, yet SAR amplitude variations can be very subtle and complex, and they may or may not reveal newly created features (Figs. 1a and 1b), making direct visual comparison an inefficient and ineffective way to locate changes. Here we explore image ratio (for non-coherent change detection), Repeat Pass Interferometry (RPI), and coherence estimation as ways to detect, measure, and characterise changes in surface features at a series of analog sites.

Image ratio. Reliable change detection from repeated images requires comparable spatial resolutions which, for images acquired by different instruments, on different missions, potentially several decades apart, inevitably involves different equivalent number of looks (arising from variable degrees of multilooking), and perhaps different wavelengths and polarisations. Using the histogram of the ratio between the two images allows the isolation of changes as a separate histogram population of pixel values, enabling automated extraction [12]. This technique will be especially relevant for inter-mission change detection cases where there is no coherence between repeat images.

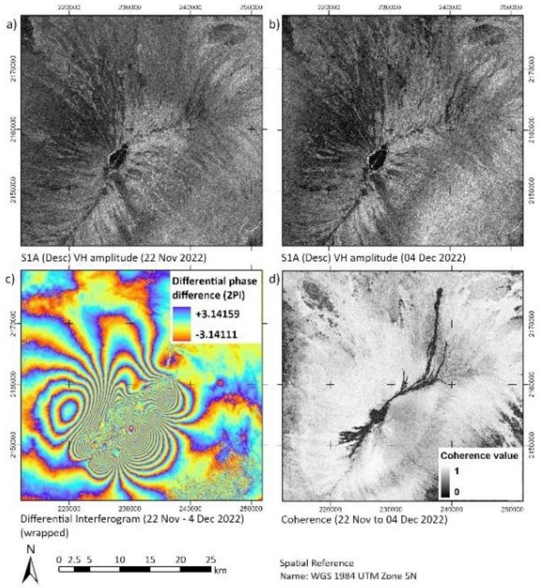

Figure 1. The power of SAR coherence illustrated in Sentinel-1 SAR images of Mauna Loa, Hawaii, Nov/Dec 2022: Amplitude images from a) 22 Nov and b) 04 Dec show the challenge of identifying newly erupted lava flows; c) differential interferogram showing associated ground deformation (phase fringes corresponding to several tens of centimetres of Line-of-Sight ground displacement across the volcanic edifice); and d) SAR coherence showing almost zero coherence values across the newly erupted lava flows.

Repeat Pass Interferometry. RPI offers two ways to measure and detect feature changes: Differential Interferometric SAR or DInSAR (the differential phase difference between coherent SAR images) [13] and SAR coherence (a measure of local spatial correlation between coherent images) [14] (Figs. 1c and 1d).

Together these provide highly effective and precise methods to measure changes in ground morphology and to detect progressive or sudden alteration of the arrangement of ground scattering objects. Coherence offers the opportunity to provide some temporal constraint on the rate of change, since coherence loss is cumulative in time. Another advantage is that coherence does not rely on accurate topographic data, but only on the existence of two coherent SAR images of the same location. Whilst EnVision's orbital configuration does currently allow systematic RPI acquisitions, it is expected that there will be opportunistic times and locations during the nominal mission where interferometric baselines are suitable and RPI will be achievable; it is hoped that targeted RPI will be achievable in an extended mission.

Initial results and prospects: We use a series of Earth analog sites to illustrate the requirements, potential and limitations for effective change detection using amplitude images, image ratio, DInSAR and coherence estimation techniques (Fig. 1). The examples we draw on here are mainly from volcanic landscapes but we will extend this to desert landscapes. Recently erupted lavas in Hawaii and Iceland allow the examination of multiple SAR images from Earth Observation archives. We also combine field observations of surface roughness with multi-scale topographic data (from LiDAR and drone data) and airborne X-band and S-band SAR collected by the DLR *F-SAR* system in Iceland in 2023, to better understand the physical and backscatter characteristics of new, old, and partially buried lava flows.

Figure 2. Varied surface textures in pahoehoe lava flows near Grindavik, Iceland (erupted Mar 2024).

Conclusions: We acknowledge that detailed geologic mapping is a vital pre-requisite benchmark for the state of existing surface features on Venus. Our fieldwork has revealed that surface morphology and textures across new erupted lava flows of identical composition are far more complex than initially anticipated (Fig.2), and that change detection from amplitude images alone will be challenging. Hence, there is an urgent need for the development and refinement of robust change detection methods, and for simulation of EnVision's and VERITAS' image products to test them.

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