EXTRACTING TOPOGRAPHY OF VENUS FROM SINGLE ORBIT MAGELLAN SAR DATA BY USING SUB-APERTURE INTERFEROMETRY. H. Lee and J. V. Morgan, Department of Earth Sciences and Engineering, Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2BP, United Kingdom. Email: hoonyol.lee@ic.ac.uk. Homepage:http://tektite.th.ic.ac.uk/leehy.

Introduction: In the early 1990s Magellan synthetic aperture radar (SAR) imaged almost 98% of the surface of the planet Venus. The orbit of the Magellan satellite was elliptical and the altitude was continuously changing with latitude. This orbit ellipticity has imposed complexity not only in imaging configuration and data processing but also in interpreting the SAR image. In contrast, this research benefits from this ellipticity of the Magellan orbit so that this nuisance turns into crucial factor to extract topography of Venus from a single orbit SAR data by using so called *Sub-Aperture Interferometry*.

Sub-Aperture Interferometry (SAI):

Recent development of SAR interferometry (InSAR) has provided a powerful tool to generate digital elevation map of a target surface by analysing the phase difference $\phi = 4\pi/\lambda\,\Delta r$ between two SAR complex images obtained from slightly different sensor positions (λ: wavelength, $\Delta r = r_1 - r_2$: slant range difference between two SAR acquisitions, see Fig. 1).

Height Sensitivity: There are two components of a baseline vector $\vec{b}$, the vector between two sensor positions, contributing to the sensitivity of the interferometric phase to the height variation: one is the component parallel to the topographic height ($\hat{z}$, unit vector) and the other is the component parallel to the slant range due to squint angle, so that the height sensitivity is given as

$$\frac{\partial\phi}{\partial z} \cong -\frac{4\pi}{\lambda r}\hat{z}\cdot\vec{b} - \frac{4\pi}{\lambda}\frac{z}{r^2}\hat{r}\cdot\vec{b} \qquad (1)$$

where $r = (r_1 + r_2)/2$ and z the target height in the Venus body-fixed coordinates. Magellan SAR operated in burst mode and one burst is composed of hundreds of pulses, giving coherent integration time *S*. Two sub-aperture complex images can be generated with different centre-pulse time offsets s_1 and s_2 and the coherent integration times:

$$S_1 = S - 2|s_1|\ ,\ S_2 = S - 2|s_2|\,. \qquad (2)$$

Then a vector between two center-pulse positions forms a baseline vector $\vec{b}$. Due to the ellipticity of the Magellan orbit, this baseline vector has the component parallel to the height except the time when the orbit passed near periapsis (9.5°N). The second term in (1) can be expressed alternatively using Doppler centroid f_d as $\hat{r}\cdot\vec{b} = \lambda/2\, f_d\,(s_1 - s_2)$. This term also contributes to the height sensitivity when f_d is large, i.e., the squint mode.

Baseline Decorrelation: According to equation (1), one can achieve high height sensitivity by arbitrary increasing the baseline for SAI. However, the baseline is practically limited by the baseline decorrelation that degrades the phase SNR. Complex correlation (or coherence, ρ) of two SAR images linearly degrades as the difference of incidence angles between two images ($\delta\theta$) increases:

$$\rho = 1 - 2/\lambda\,\delta r\cos\theta\delta\theta\,, \qquad (3)$$

where θ the incidence angle and $\delta r = \sqrt{\delta x^2 + \delta y^2}$ the ground resolution in the radar look direction. Also as the baseline increases, the ground azimuth resolution δx increases ($\delta x = V/(f_r S_1)$ where *V*: satellite velocity, f_r: Doppler frequency rate and according to (2)), resulting in decorrelation. The ground range resolution $\delta y = c/(B_R \sin\theta)$ remains the same for both images (c :speed of light, B_R: range bandwidth).

In summary, while high height sensitivity can be achieved by processing sub-aperture radar images with a large baseline, the actual baseline is restricted by baseline decorrelation.

Data Processing for Magellan SAI: Two sets of the sub-aperture SAR complex raw data from a single orbit are processed using deramp compression method [1] with the modified Doppler and range walk (n_w) parameters:

$$f_{d1} = f_d + f_r s_1\,,\quad f_{d2} = f_d + f_r s_2\,,$$
$$f_{r1} = f_{r2} = f_r\,,$$
$$n_{w1} = n_w f_{d1} / f_d\,,\quad n_{w2} = n_w f_{d2} / f_d\,. \qquad (4)$$

Note f_r remains the same for this linear approximation of the Doppler frequency. Range and azimuth compression and co-registration of the two sub-aperture complex images result in the interferometric signal in range-Doppler domain:

$$\eta_1\eta_2^*(r, f) = e^{-j\frac{4\pi}{\lambda}(r_1 - r_2)}\, e^{j2\pi(s_1 - s_2)f}\,. \qquad (5)$$

The first exponent gives the interferometric phase and the second the systematic phase due to offsets, which can be easily removed. The speckle noise can be reduced by ensemble averaging the interferometric phase so that $\phi = \arg < \eta_1 n_2^* >$. Phase unwrapping is not necessary in most cases because the topographic phase is confined within one cycle of the interferometric fringe due to low height sensitivity. The topographic height h is then calculated by dividing the centred interferometric phase by the height sensitivity from (1) and adding the height of the scene center from altimetry data h_a:

$$h(r, f) = (\phi - \bar{\phi}) \frac{\partial z}{\partial \phi} + h_a . \qquad (6)$$

This topographic height map is then georectified into the sinusoidal projection to be added with ones from adjacent bursts, resulting in the multi-look topographic map, using methods similar to FBIDR formation [1].

Example of Magellan SAI: Magellan SAR orbit 2009 raw complex data was processed for SAI using zero-offset ($s_1 = 0$) for master image to maximize the SNR and the non-zero offset for slave image which corresponds to 11% of the number of the pulses for each burst. Fig. 2 depicts the height sensitivity and baseline decorrelation. Fig. 3 shows an area (Lat: 42.7°N, Lon: 298.9°, burst 1500, 25km×35km): (a) is the SAR amplitude image (FBIDR), (b) the interferometric phase fringe with the systematic fringe pattern due to offsets as shown in (5), (c) the multi-look topographic height. Note the topographic phase is confined within one cycle due to low height sensitivity. (d) shows the 3D perspective view of (c) overlaid by SAR amplitude image.

Conclusion: Topography of the Venus's surface is extracted from a single orbit Magellan SAR data using sub-aperture interferometry thanks to the elliptical orbit of the Magellan satellite and squint-angle SAR imaging. Development of algorithms robust to larger baseline for more accurate height measurement is still ongoing.

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Reference: [1] Leung K. et al. (1993) *IGARSS, 3*, 1121-1124.

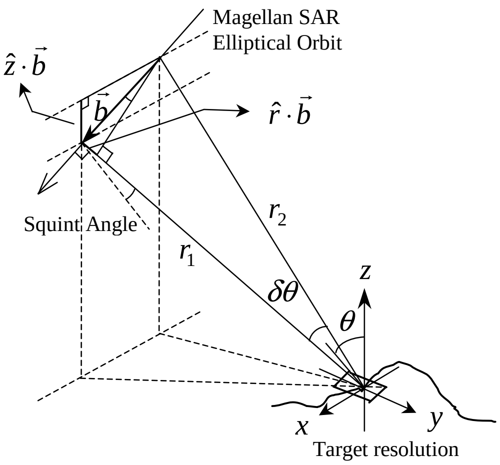

Fig. 1. Geometry of the sub-aperture interferometry (SAI) for Magellan satellite's elliptical orbit.

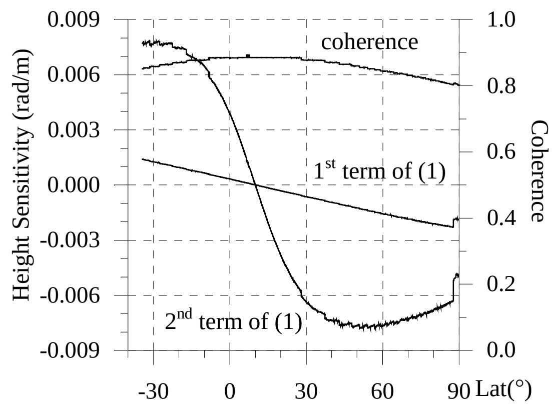

Fig. 2. Height sensitivity and decorrelation for orbit 2009.

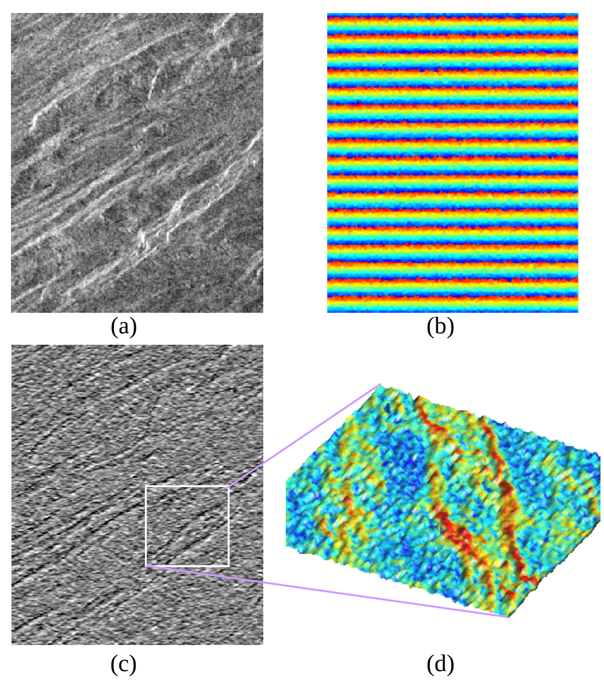

Fig. 3. Example of SAI: (a) SAR amplitude, (b) interferogram, (c) multi-look topography and (d) 3D perspective view.