TOPOGRAPHY ESTIMATION USING SAR IMAGE POLARIMETRY

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1. INTRODUCTION

Terrain slope variations affect polarimetric synthetic aperture radar (SAR) exploitation by changing the perceived target scattering polarization state. Polarization orientation angle (POA) correction to compensate for terrain effects has been investigated [1-2]. POA rotation can be derived from digital elevation model (DEM) and/or from polarimetric SAR (PolSAR) data through covariance/coherency analysis. A robust analytic model connecting PolSAR data and products (e.g., POA) to terrain characteristics can serve two main objectives. First is to correct/calibrate PolSAR data acquired from different SARs when DEM is available. Second is to model terrain through inverse solution of POAs derived from PolSAR data analysis. The latter can be further used to calibrate other PolSAR imagery.

The abovementioned model or formalism has been developed and is presented here. Effectiveness of the technique in providing both forward (POAs from DEM) and inverse (DEM from POAs) solutions is explored by using imagery example and simulation.

2. DERIVATION OF GENERAL POA SHIFT

The POA shift for a polarimetric SAR operating at an incident angle ϕ, and squint angle θ_{sg} is given by [2]:

$$\theta_{sh}\left(\phi,\theta_{sg},\theta_t,\varphi_t\right) = \tan^{-1}\left(\frac{-\tan(\eta_t)+\dfrac{\tan(\theta_{sg})}{2}\left[\tan(\psi_t)\left(1+\cos(2\phi)\right)+\sin(2\phi)\right]}{\tan(\eta_t)\tan(\theta_{sg})\cos(\phi)+\tan(\psi_t)\cos(\phi)+\sin(\phi)}\right) \tag{1}$$

where target plane azimuth and range slopes are given by:

$$\tan(\eta_t) = -\tan(\theta_t)\cos(\varphi_t) \tag{2}$$

$$\tan(\psi_t) = -\tan(\theta_t)\sin(\varphi_t) \tag{3}$$

and θ_t, φ_t are surface gradient angles. For the present multi-PolSAR scenario, the analytical model need to be generalized for an arbitrary look angle capable of accommodating various PolSARs imaging the same surface slopes from different look angles. Analytical expression [4] that is rather involved can be mathematically presented by:

$$\tan\left(\theta_{sh}^{\alpha}\right)=F\left(\phi_{\alpha},\theta_{sg}^{\alpha},\alpha,\eta_t,\psi_t\right) \tag{4}$$

In (4), α (and sub/sup-scripts) denotes the look angle (and associated coordinates) with respect to the reference frame. Hence, for the reference PolSAR, $\alpha=0$ and (4) reduces to (1).

3. INVERSE SOLUTION FOR SURFACE SLOPE ANGLES

The POA shift can be extracted from PolSAR data (i.e., scattering matrix) using a number of existing techniques (e.g., [1,3]). Exploring these techniques and associated discussions on merits or shortcomings is beyond the scope of current contribution. For current discussion, we assume POA shift is derived from PolSAR data analysis. Thus, for two PolSARs operating at look angles α and β (with respect to the reference frame) and associated incident angles, one obtains θ_{sh}^{α} and θ_{sh}^{β}. Applying (4) and inserting θ_{sh}^{α} and θ_{sh}^{β}, a system of two equations in terms of PolSAR operating parameters $\left(\phi_{\alpha},\theta_{sg}^{\alpha},\alpha\right)$, $\left(\phi_{\beta},\theta_{sg}^{\beta},\beta\right)$, and unknowns η_t and ψ_t (or θ_t and φ_t) is formed. Number of unknowns determines the number of equations (2 in this case) or POA observations required. Although mathematically involved, this system of equations can be analytically (closed-from) solved for surface gradient angles represented by $\theta_t\left(\phi_{\alpha},\theta_{sg}^{\alpha},\alpha,\phi_{\beta},\theta_{sg}^{\beta},\beta\right)$ and $\varphi_t\left(\phi_{\alpha},\theta_{sg}^{\alpha},\alpha,\phi_{\beta},\theta_{sg}^{\beta},\beta\right)$. Using DEM information (DTED STRM level 2), the computed POA rotation ($\tan\left(\theta_{sh}\right)$) for an area close to DRDC campus (Ottawa, Canada) is shown in Figure 2. Actual RadarSAT-2 image (shown in Figure 1) collect specifications, i.e., incident angle $\phi=33.7^{\circ}-36.6^{\circ}$ (near-far), squint angle $\theta_{sg}=0$, and $\alpha=0$ are used for this simulation. To examine the efficiency of algorithm for estimating the slope gradients, a number of arbitrary surfaces are generated using analytical functions to emulate the terrain. Using the analytic surface functions, surface slopes are calculated and POA shifts for 2 arbitrary collects that resemble actual PolSAR operating parameters (e.g., incident and look angles) are generated (4). These POA rotations, that emulate the extracted POAs from PolSAR data in a real scenario, are then ingested to the algorithm to derive surface slope gradients. Objective of this efficiency test is to see if the estimated surface slope angles from POAs (normally extracted from PolSAR data) are close to the ground truth (analytical surface derivatives in this case). Computed surface slope angles exhibit very good agreement with the gradient angles of actual analytic surfaces. Such results indicate that efficiency of the current technique is determined by the accuracy of POA extraction from PolSAR imagery. To have a more quantitative evaluation of this, POA results (Figure 3) extracted from the PolSAR image of previously selected scene (i.e., Figure 1) are compared with POA calculation (Figure 2) of the same area using the actual DEM (i.e., ground truth).

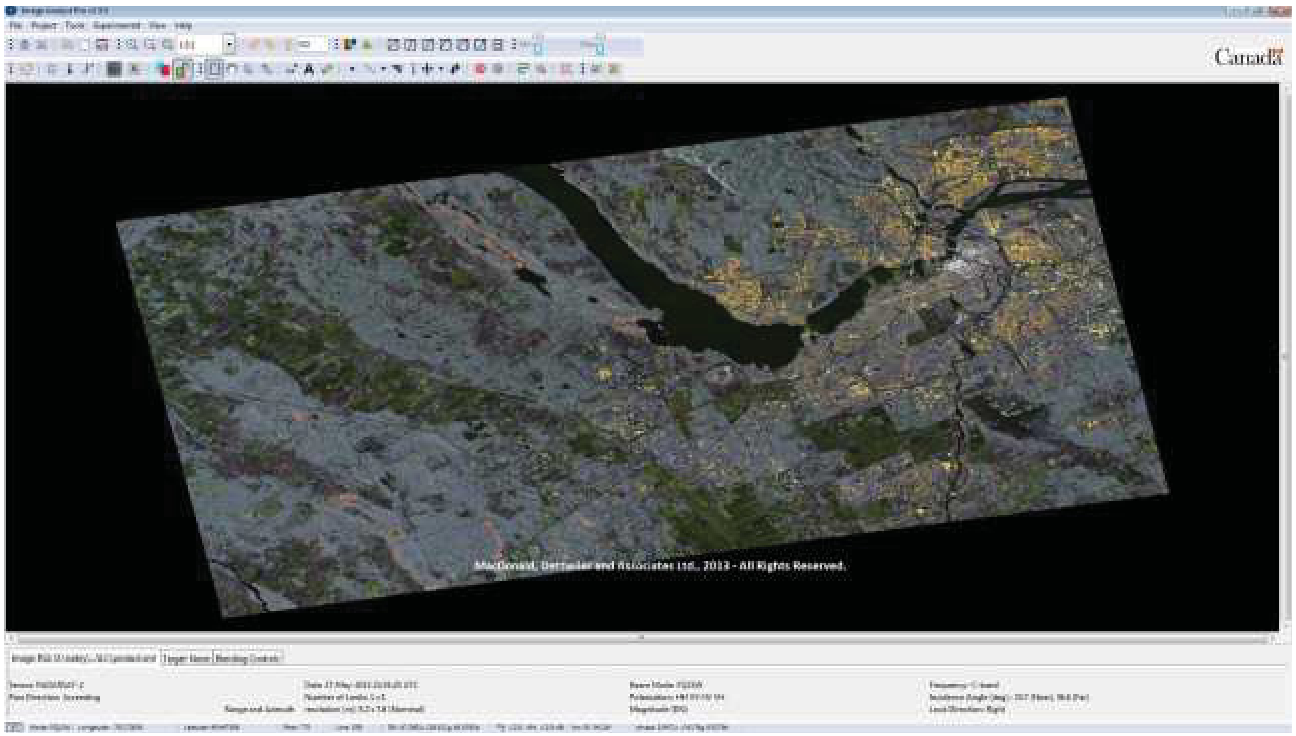

Figure 1.RS2 quad-polarimetric image of test scene incident angle $\phi = 33.7^{\circ} - 36.6^{\circ}$ *(near-far), [R:HH, G:VV, B:HV]*

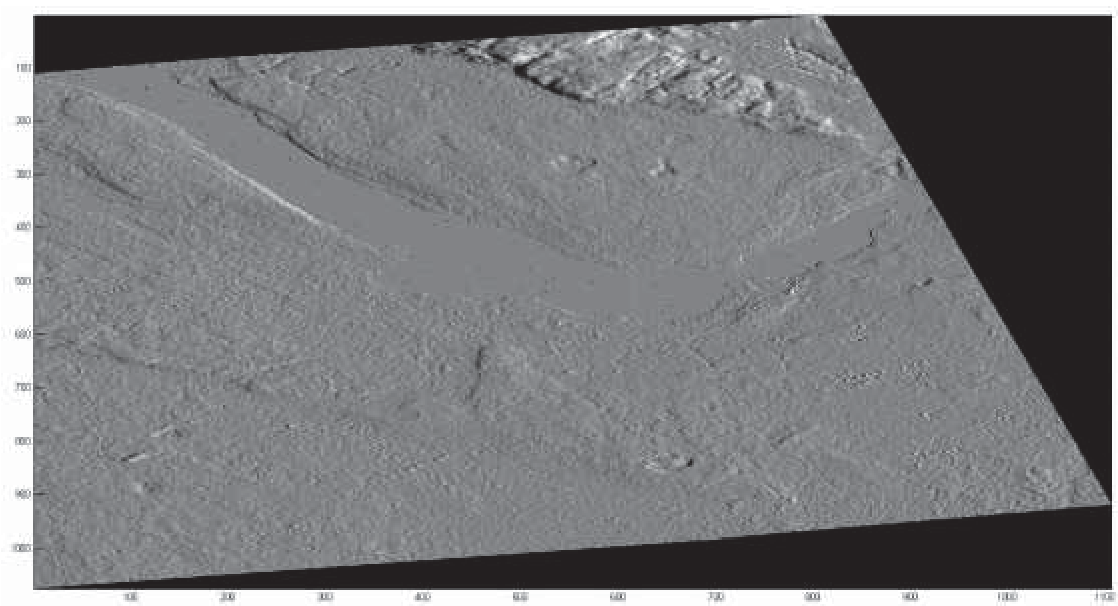

Fig.2. Tangent of polarization angle shift distribution for the test chip

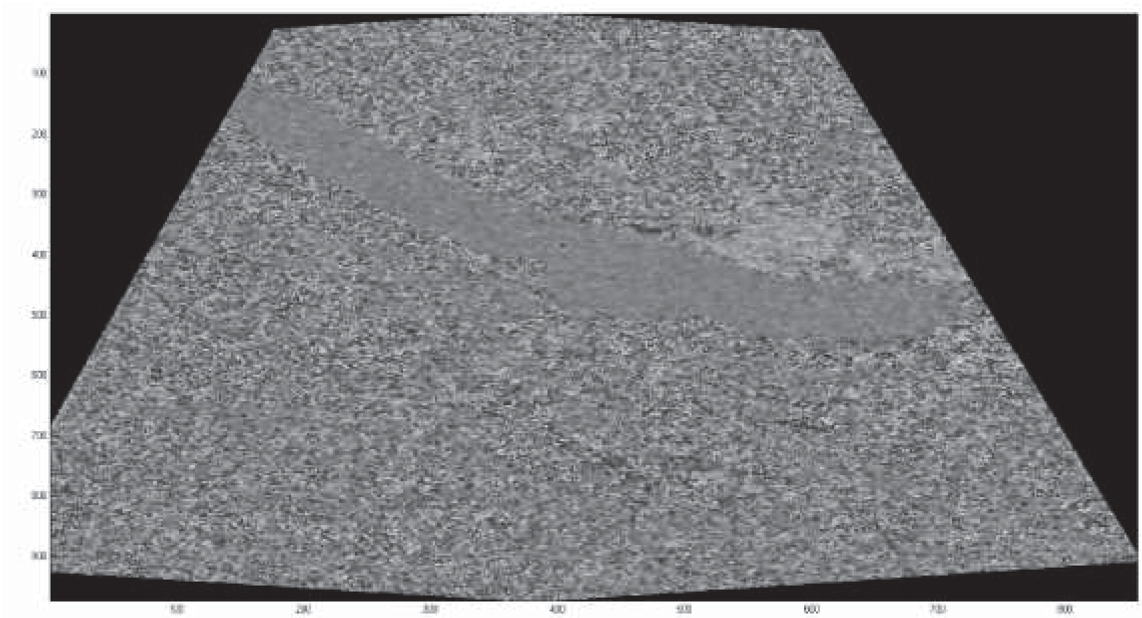

Fig.3. Extracted tangent of polarization angle shift for the common test chip from PolSAR image (Figure 1)

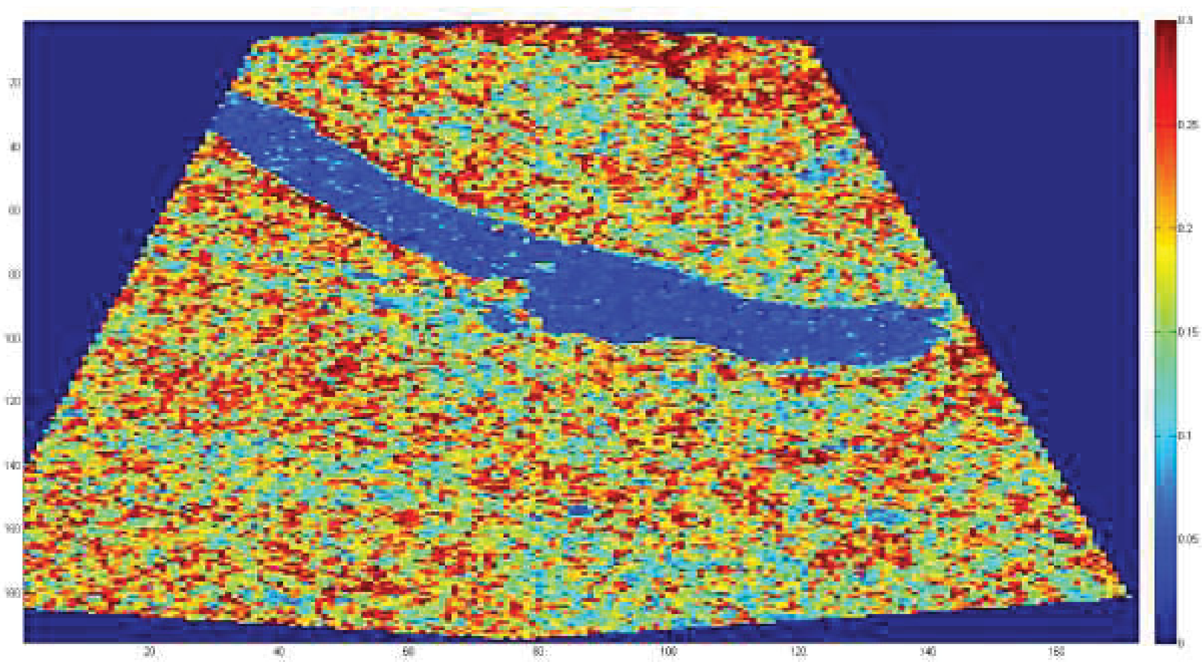

Fig.4. δ POA (rad) defined as the difference between DEM and PolSAR data generated POAs

The difference (i.e., PolSAR-data-generated POA variance w.r.t. the DEM-generated POA) is calculated using *tangent* function expansion and is depicted in Figure 4. Good agreement is observed in water and flat regions. In general, the magnitude of POA variation is found to be within 0 to 0.3 radian (maximum) range. As hinted, the POA calculation error can be attributed to the POA algorithm efficiency and assumptions. Also, PolSAR image resolution, accuracy and recency of applied DEM (i.e., ground truth) can further contribute to the described difference in POA shift results.

4. SUMMARY

We have developed an analytical framework to relate topographical variations to polarimetric SAR data through POA shift estimation. This formalism can be used to compensate polarimetric data for topographical effects, and also, to estimate topographical slope gradients from polarimetric SAR data. Efficiency of the algorithm is explored by using actual DEM for a test area.

5. REFERENCES

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[3] T. L. Ainsworth, D. L. Schuler, and J. S. Lee, "Polarimetric SAR characterization of man-made structures in urban areas using normalized circular-pol correlation coefficients," *Remote Sens. Environ*., vol. 112, pp. 2876–2885, 2008.

[4] R. Sabry, "Terrain and Surface Modeling Using Polarimetric SAR Data Features", in submission to *IEEE Trans. Geosci. Remote Sensing*, 2014.