COMPARISON OF THE TANDEM-X RESPONSE BETWEEN VERTICAL AND HORIZONTAL ORIENTED VEGETATION

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ABSTRACT

The results of a two-year precision agriculture project have clearly demonstrated that TanDEM-X can successfully classify crops morphology through cultivation period. It has been found that TanDEM-X mission is capable of tracking the crop height, and the accuracy of the height estimation depends on the crop morphology, which causes a diversity between canopy top and acquisition phase center. In this work, in addition to interferometry with single polarized channels, polarimetric-interferometric acquisitions have been employed to figure out phase center diversity. The analysis showed that there is a diversity between height estimations from HH and VV polarized interferometric channels, which can reach to 10 cm in the reproductive stages of the crops.

***Index Terms*—** Agriculture, co-polar phase difference (CPD), TanDEM-X, SAR

1. INTRODUCTION

Height is the most important biophysical parameter in determining ecophsiological status of forests and crops. Because of its importance, forest height estimation has been studied many times by making use of remote sensing technologies, especially with Synthetic Aperture Radar (SAR). Considering the amount of applications, it can be concluded that interferometry and polarimetric interferometry (PolInSAR) has been successfully applied to forest height estimation. Despite their popularity in forestry applications, in the context of precision farming, these methods have been rarely applied.

Interferometric SAR (InSAR) information, which is a direct function of the canopy height, i.e. not an indirect function as back-scattering information, provides an additional instrument to canopy studies with the sole cost of two SAR images. From an agricultural application point of view, the interferometric phase for operational canopy height calculation requires a particular system configuration. The shorter wavelengths attenuate faster (get weaker), which makes them optimum for canopy height applications due to the scattering close to top-canopy layer. Additionally, since the plant is temporally growing, two acquisitions at different dates will provide a very low coherence, causing unstable phase information. To overcome this limit, the acquisitions must be commanded at the same time. TanDEM-X mission supplies these two key parameters close to the optimum case for crop-height estimation from space, which was not feasible before. An analysis of TanDEM-X capability in assessing canopy heights was performed in [1] with temporal HH polarized acquisitions. This study shows that TanDEM-X images have a great potential in mapping canopy height through all the plant growth stages.

Among all space-based SAR sensors, TanDEM-X has provided a canopy height information directly with interferometric method. However, the strong variability in the location of the phase center through the canopy still has to be considered. In this work, which is detailed in [2], the performance of TanDEM-X mission in canopy height monitoring in the context of polarimetric diversity will be discussed. In addition to temporal HH-polarization analysis in [1], temporal behavior of canopy height estimation from VV-polarized acquisitions will be discussed.

2. STUDY AREA AND PROBLEM DEFINITION

The test site is located in the Turkey side of the Maritza river, which is especially suitable for irrigated farming according to its topography and water sources. There are thousands of paddy-rice fields spreaded in this area. In the region, sowing method is direct seeding by broadcasting. To monitor the agricultural fields TanDEM-X data stack was collected by German Aerospace Center [1] in 2012. Ground measurements were conducted in 2013 and 2014 to characterize the crop's morphology through its growth stage. This paper is not aimed to calculate the height estimation accuracy, it is more aimed to characterize the temporal behavior of interferometric phase center due to the polarization and top of the canopy. This is the reason the simultaneously conducted ground-based records are not essential.

InSAR based vegetation height measurements were analyzed a stack of 9 HH and VV dual polarization TanDEM-X images acquired through cultivation period with 11 days temporal resolution. Even though canopy-top layer height measurements were from 2014 in-situ campaign -as in Fig. 2-, the temporal behavior of crop is almost same with previous year measurements [1], i.e., though the phenological growth, canopy height increases continuously until the maturation stage. In maturation stage, the decrease of the top-canopy height is observed due to the tassel and dryness.

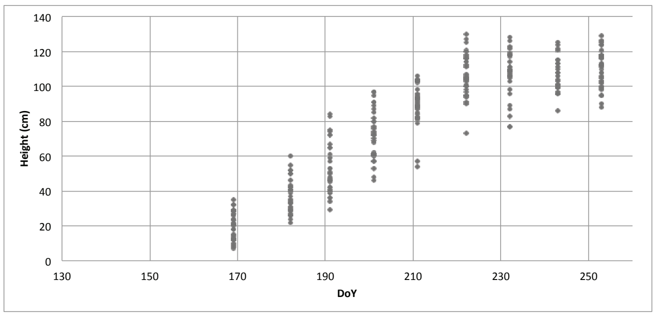


Fig. 1. Temporal behavior of ground-based records of top canopy height measurements in 2014.

Defining the border of agriculture filed is as important as defining phenology of the crops in precision farming applications. To do is, coherence and intensity based thresholding and morphology based algorithms were applied to full scene as summarized in Fig. 2. Considering the flooded sowing, $\%95$ percent accuracy can be reached in defining the border of paddy-rice fields. For illustration purpose of a response of flooded sowing in SAR imagery, the coherence map obtained at HH channel TanDEM-X data is shown in Fig. 2.

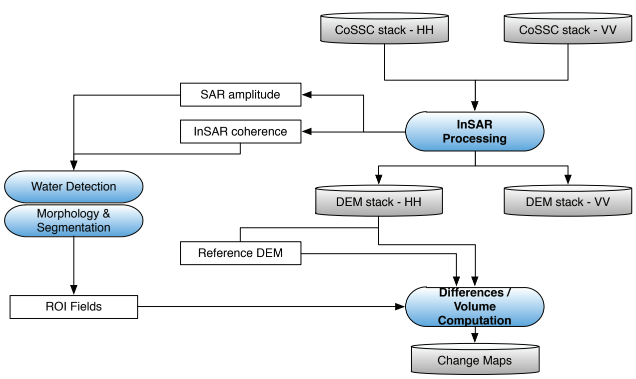


Fig. 2. Block diagram of automated agricultural field segmentation as in [1].

After automated processing based on morphological filtering, the temporal elevation information was obtained at a field scale by bistatic X-band interferometry with HH and VV polarized channels. To conduct this study, the elevation estimations are analyzed for 50 fields. At a first glance to Fig. 4

Fig. 3. As an example of the coherence response of flooded agricultural fields in TanDEM-X images, making the segmentation of the fields very precise.

(each field is shown by a different color), elevation measurements from HH and VV polarized TanDEM-X data seem to yield a very similar temporal trends, which are in accordance with ground measurements. However, the temporal plot of the coherence values of the measurements give hints about the presence of underestimation diversity based on polarization. Here, it is to be noticed that in interferometric applications, spatial baseline -related to the sensor acquisition geometry- is one of the most important parameter. Since the HH and VV polarized images are acquired on the same time, the underestimation diversity is then directly related to attenuation of the polarized channels, as can be seen in the coherence plot of the measurements, see Fig. 5. As expected temporal

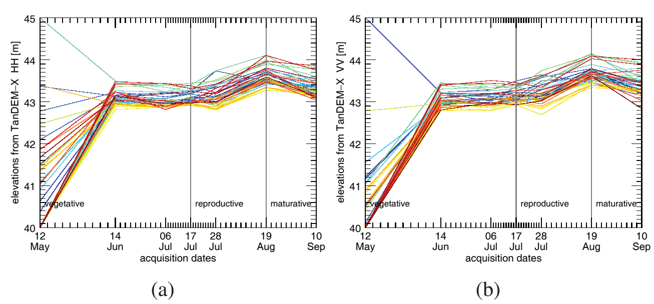
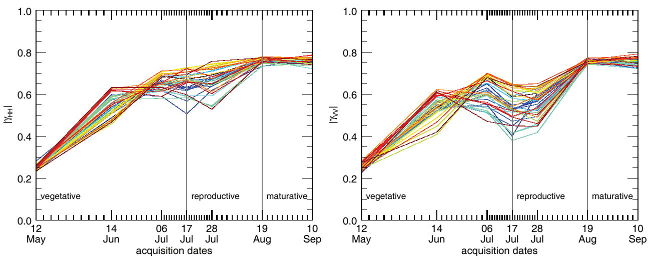


Fig. 4. An inventory of topographic surface changes through the 50 selected agricultural fields: the value of multi-temporal elevation measurements from TanDEM-X HH (a) and VV (b) channels [2].

trend of coherence values are good enough to estimate crop heights, which change depends on crop morphology and polarization. Note that only when the fields were flooded -just after sowing-, coherence values were less than 0.4 among all the fields, indicating the presence of doubtful elevation information. However, in the context of precision farming this unreliable information may indicate that agricultural fields are in the germination stage.



(a) (b)

Fig. 5. The reliability information of the elevation measurements in Fig. 4 based on their coherence values with HH (a) and VV (b) polarized channels.

The transition dates on Fig. 4 and Fig. 5 were estimated based on paddy-rice back-scattering trend through its morphological development [3, 4], the actual transition dates were not known and it is not possible to have this information for each automated detected fields. According to these assignment, it can be said that the variation of the elevation measurements from HH and VV polarized channels was apparent for the end of vegetative and the beginning of reproductive stages.

3. RESULTS AND DISCUSSIONS

In order to figure out the temporal differences between measurements from HH and VV polarized TanDEM-X data, the sample statistics was used as in Fig.3. Fig.3 presents the mean and the standard deviation of the elevation differences obtained from the agricultural fields monitored in Fig. 4. Regarding the temporal trend in Fig. 3, the maximum crop height difference is obtained in the reproductive stage. It can be easily noticed that with the beginning of leaf development, the elevation difference continues to increase until the late reproductive stage, and then starts to decrease and converges to zero after harvesting. The mean and the standard deviation of the elevation difference obtained from the acquisition on 12^{th} of May were 0.85 m and 2.04, respectively. These statistical results agree with the mean coherence (~ 0.25) value and the mean-sigma-nought ($\sim -23dB$) value on that acquisition day, indicating irrigated farming practice.

The main findings of this work can then be listed into the following.

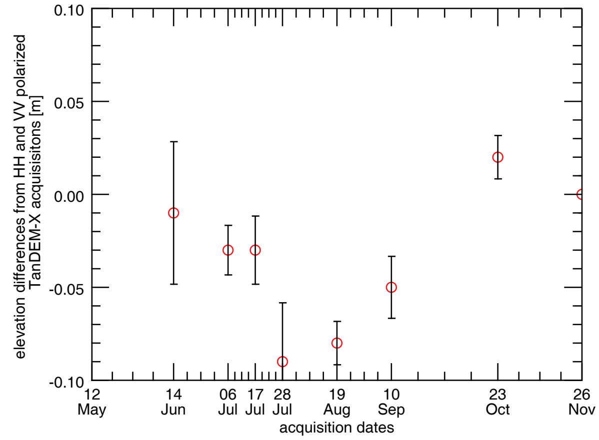


Fig. 6. Temporal sample statistics of the difference between the elevation measurements from HH and VV polarized TanDEM-X acquisitions among the neighbor paddy fields. It is to be noticed that the measurements calculated from the observations on 12^{th} of May were not seen on the figure considering their unreliability based on the morphology of the crops.

- According to the co-polar elevation differences plot in Fig. 3, interferometric phase center in VV channel is more close to top-canopy layer compared to the HH one. Especially in reproductive stage this difference can reach to more than 10 cm. However, regarding the reliability of the acquisitions (coherence values) as in Fig. 5, the elevation accuracy is larger with HH acquisitions than the VV ones, as the coherence values are higher.

- On the contrary to reproductive stages, for the beginning of reproductive and maturation stages the elevation accuracy performances are almost same for both polarization.

- The exploitation of TanDEM-X data for crop mapping purposes provide great competitive advantage compared to the other sensors due to its interferometric information additionally to back-scattering one.

This study will be complemented by the other height retrieval methods like PolInSAR approach. Additionally to interferometry and PolInSAR, radiative transfer theory, which models the backscattering response from crop, will be implemented to the same data set to figure out the phase center diversity through phenological growth of the crops.

4. ACKNOWLEDGEMENT

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