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MULTI-FREQUENCY SAR UTILIZATION IN MOUNTAINOUS REGIONS IN BULGARIA FOR FOREST BOUNDARIES DETERMINATION WITH IMPACT OF SEASONALITY

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Abstract

This study focuses on an accuracy assessment of the forest boundary layer in a mountainous forest located in the north-west part of Bulgaria. The objective is an accuracy assessment of the forest boundaries determined via three different SAR bands – X, C, and L, whereas which method gives the highest accuracy with respect to seasonality. Polarimetric, interferometric, and time series SAR methods were utilized with POL-SAR images from ALOS PALSAR, bistatic InSAR data from TanDEM-X, and a four-year time series from Sentinel-1. Some SAR images were available in different seasons, allowing estimation of seasonality variations. Validation was performed with 60 points randomly generated. Overall Accuracy (OA) and Cohen's Kappa were calculated to represent the accuracy of the masks. Strong influence of the seasonality was observed because of the higher ground contribution during the forest leaf-off. Frequency also plays a major role in accuracy. Supervised and unsupervised classifications were elaborated to determine forest classes. A Wishart unsupervised classifier was used for POL-SAR data. Assessment showed the highest OA above 90% of the C-band time series forest mask. The L-band mask also showed high accuracy with OA above 89%. The least accurate forest mask with an overall accuracy of 68% belongs to the X-band bistatic InSAR measurement in the winter. In conclusion, the SAR time series from Sentinel-1 showed the highest feasibility in the forest boundaries determination. The polarimetric SAR is better utilized for the purpose of the study. Accuracy is higher for the summer periods when scattering phase centers are higher from the ground, and volume scattering is better delineated from the ground contribution.

Introduction

Forest ecosystems are very important economic and environmental factor, occupying large area of landscapes in hardly accessible terrain, and for this reason they are widely studied via satellite remote sensing methods (Fernandez-Ordonez, et al., 2009). Over the years plenty of scientists have proved the high feasibility of the Synthetic Aperture Radar (SAR) based microwave active systems in studying forest ecosystems. Nowadays vast of methodological SAR approaches exist to derive forest biophysical parameters in depend on frequency (Cloude & Papathanassiou, 1998; Le Toan, et al., 2011; Caicoya, et al., 2012; Santoro, et al., 2011; Santoro, et al., 2015; Kugler, et al., 2014; Stelmaszczuk-Górska, et al., 2018). Deforestation from forest fires, clear cuts and abiotic forest disturbances are general issue in the ecosystem integrity that causes a significant gap in the forest canopy by changing forest boundary (Anev & Marinova , 2021; Antropov, et al., 2021). Impact on forest boundary layer due to changes in the forest structure are well studied by SAR methods (Tomppo, et al., 2019). Radar polarimetry (POL-SAR) have proven sensitivity to the geometric properties of the natural targets (Cloude & Pottier, 1996). Polarimetric decompositions and classifications by JAXA's ALOS PALSAR L-band full polarimetric data are capable to determine forest boundary layer, by means of randomization in the natural scattering media (Dimitrov, 2022). Multitemporal SAR of ESA's Sentinel-1 C-band dual polarization acquisitions also give promising results on studying forest dynamics (Dostálová, et al., 2018). The DLR's bistatic X-band TanDEM-X InSAR mission has proven sensitivity to the active phase scattering centers that determines forest canopy height (Schlund, et al., 2014; Askne, et al., 2017).

In this study elaboration and comparison of three types of forest masks on mountainous test site in the North-West part of Bulgaria is presented. Forest/non-forest (FnF) masks are elaborated by three different SAR methods – Polarimetric (POL-SAR), multitemporal SAR and Interferometric (InSAR). The general objective of the study is accuracy assessment of those three FnF masks and studying the impact on their accuracy. This study is part of the author's PhD study.

Study area

Study area is located at the north slope of west Stara Planina Mountain located in North-West (NW) part of Bulgaria. Two test sites are approached, one is the TS20-„Mijur“, and the other TS21-„Chuprene“. The first one is characterized by mixed coniferous and broadleaf forest, whilst at the second one coniferous forest predominates (Fig. 1).

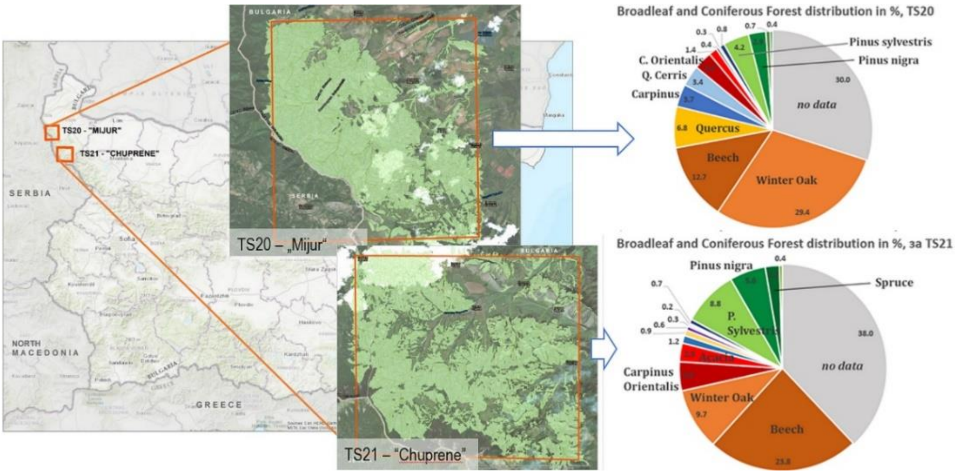

Fig. 1. Test sites with forest cadaster overlaid of TS20 and TS21 in NW part of Bulgaria, by forest type's pie charts

Materials and Methods

Methodology involves: 1) POL-SAR processing of the L-band full-pol polarimetric SAR data from ALOS PALSAR acquired in Spring (2007-05-10) and late Autumn during leaf-off (2007-11-10); 2) time series elaboration from multitemporal SAR four years period of continuous observations, in C-band from Sentinel-1 in dual-pol for, utilizing GRD products (from 2014-10 to 2018-05); 3) InSAR processing of the interferometric bistatic single-pol X-band data from TanDEM-X, available for whole seasons, in the Winter (2014-02-12), late Spring (2018-05-13 and 2018-05-24), and in Summer (2013-08-09).

From the output POL-SAR features with spatial resolution of 25 m, a Wishart unsupervised classification is elaborated. Four thematic classes are dedicated to the forest canopy layer after reanalysis in GIS. Forest classes are confirmed by polarimetric parameters and descriptors derived from POL-SAR decompositions, but also POL-SAR coherences, confirming complete randomization in the natural scattering media (Dimitrov, 2022). From the resulted 4-year long time series from Sentinel-1 in both polarizations, with spatial resolution of 10 m, statistical means are estimated together with the dual-pol Radar Vegetation Index also calculated (Mandal, et al., 2020). Interferometric approach includes coherence and differential interferometric phase component estimation from the bistatic SAR measurements from TanDEM-X (TDX), resulted with spatial resolution of 4 and 12 m (Dimitrov, 2021). The single-pol HHHH intensities from TDX, with the dual-pol intensities from Sentinel-1 (S1), are terrain flattened in Gamma-Nought (Small, et al., 2010). Supervised classifications by means of Support Vector Machine (SVM) algorithm are elaborated from the resulted VV, VH and dRVI estimates from S1, where the forest type is very accurately determined. Geometric distortions are the main reason for bias in the classifications. Unsupervised classifications with the ISO-Cluster algorithm are applied to InSAR output features. Forest masks are determined from the output thematic classes. Outputs are geocoded and exported as GeoTIFF. The last methodological approach considers accuracy assessment of the FnF masks, with randomly generated points in GIS.

Results and Discussion

Derived forest/non-forest masks from ALOS PALSAR in L-band, from S1 in C- and TDX in X-bands, for different seasonality and periods from 2007 until 2018, for test areas of TS20 and TS21, are represented in the next Fig. 2.

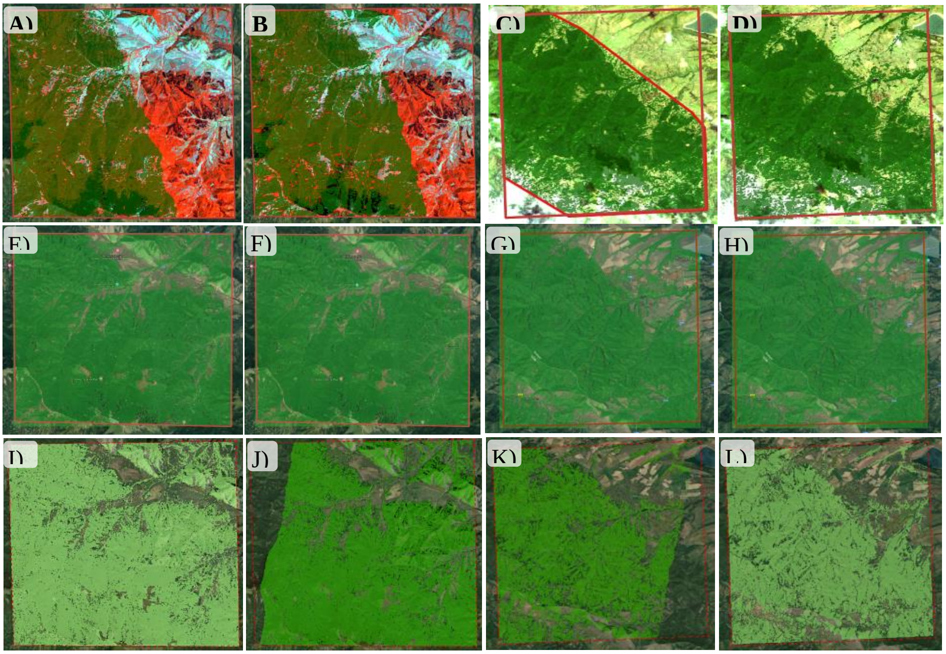

Fig. 2. Derived forest masks, where: from ALOS PALSAR Wishart's unsupervised POL-SAR classifications are: A) TS21 – May (spring), 2007, B) TS21 – November (autumn), 2007, C) TS20 – May, 2007, D) TS20 – November, 2007; from S1 SVM's supervised classifications, are: E) TS21 – Unsupervised, F) TS21 – Supervised, G) TS20 – Unsupervised, H) TS20 – Supervised; from TDX ISO-Cluster's unsupervised classifications are: I) TS21 – February (winter), 2014, J) TS21 – May (spring), 2018, K) TS20 – May, 2018, L) TS20 – August (summer), 2013.

Accuracy assessment is performed by validating both „forest“and „non-forest“ thematic classes in QGIS, by reference imagery from Google Satellite©, but also from Sentinel-2 and Landsat-5 for the time being of SAR acquisitions. At least 60 points are randomly generated for validation, with visual on-screen analysis and statistical metrics calculation, such as Overall Accuracy (OA) and the Cohen's Kappa coefficient (CK), expressed as a percentage (Cohen, 1960) (see Table 1).

Table 1. A common table with validation results from the three SAR band's FnF masks, particularly for both test sites.

L-band mask classes	**TS20 May, 2007**	**TS20 November, 2007**	**TS21 May, 2007**	**TS21 November, 2007**
Overall accuracy [%]	76.08	90.03	88.89	80.77
Cohen's Kappa coeff.	0.5211	0.7664	0.5646	0.3811
C-band mask classes	**TS20 Unsupervised**	**TS20 Supervised**	**TS21 Unsupervised**	**TS21 Supervised**
Overall accuracy [%]	89.75	89.39	85.59	90.63
Cohen's Kappa coeff.	0.7692	0.7321	0.6653	0.6804
X-band mask classes	**TS20 August, 2013**	**TS20 May, 2018**	**TS21 February, 2014**	**TS21 May, 2018**
Overall accuracy [%]	80.01	72.85	68.57	81.43
Cohen's Kappa coeff.	0.6023	0.4751	0.3714	0.6286

From the table above, it is evident that the most accurate forest masks are obtained in L-band for late autumn in TS20 and the C-band multitemporal mask for TS21. The unexpected opposite result between the two test areas could be due to the vegetation type in TS21, where shrubs are generally lower vegetation with respect to TS20. In combination with higher altitudes and snowfall in a more coniferous forest at the test site during SAR acquisition, this suggests increased depolarization and volumetric backscatter. Poor classification accuracy is observed for the CK autumns' FnF mask in 2007 for TS21. Forest type specific for lower altitude at TS20, with almost complete leaf-off in late autumn, brings more ground contribution rather than in spring with leaf-off. This explains the higher accuracy at TS20, in the spring. It could also be stated that frozen conditions increase forest mask accuracy.

High CK is observed for whole FnF masks from S1, as shown in Table 1. It can be stated that the most accurate forest boundary layer is namely determined by the multitemporal long time series in dual-pol C-band SAR measurements. Due to the extreme or almost zero incidence angles by SAR in the mountains, and because of the higher spatial resolution, the unsupervised classification FnF masks from S1 are characterized by scratches, especially in rugged terrain areas.

Due to the higher sensitivity of the X-band to surface roughness and its high spatial resolution, these masks generally resulted in the lowest CK. Despite the highest spatial accuracy suggesting a better determination of the forest boundary layer, the interferometric observables are generally more sensitive to the scattering phase centers height. Therefore, masks generated during the leaf-off period in winter and the transition period in spring yielded the lowest CK, primarily due to the poor delineation of the forest boundary layer and confusion with shrubs and low vegetation. This is evidenced by the summer FnF masks, where estimation is performed in late spring or summer when active phase centers are located higher. Therefore, both summer FnF masks, from acquisitions in August 2013 and May 2018, have the highest accuracy derived from the TanDEM-X InSAR measurements.

To summarize the final accuracy assessment, the chart in Fig. 3 is elaborated with some highlights.

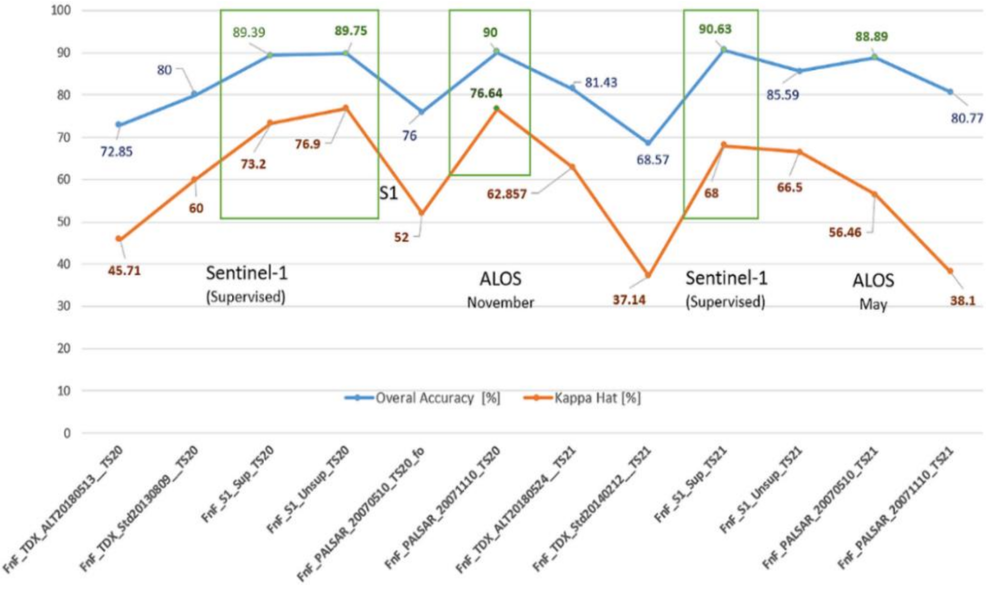

Fig. 3. Final assessment results of FnF masks from the three SAR-bands, methods, and data, having the most accurate masks derived from the S1 multitemporal approach and ALOS PALSAR polarimetric acquisition in frozen conditions

Conclusion

From the conducted analysis, it can be concluded that the highest accuracy is achieved by means of a multitemporal SAR approach in C-band, utilizing Sentinel-1 with dual-polarization, where the overall accuracy (OA) for the supervised approach is above 90%. The longer the time series, the better the results. Seasonality was examined in the L-band full-polarimetric SAR acquisitions from ALOS PALSAR and the bistatic InSAR measurements from TanDEM-X. Analysis suggests that the highest results in L-band are most likely due to the persistence of frozen conditions during acquisition. The highest penetration is found during leaf-off in late autumn and winter, which worsens accuracy due to increased ground contribution. This is thus so in the case of bistatic InSAR measurements from TanDEM-X, which is mainly sensitive to the scattering phase center's height. In those cases, during the leaf-off period, by means of TanDEM-X data, the accuracy of the FnF masks is the lowest one.

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МУЛТИЧЕСТОТЕН ПОДХОД С РАДАРИ СЪС СИНТЕЗИРАНА АПЕРТУРА ЗА ОПРЕДЕЛЯНЕ НА ГОРСКИТЕ ГРАНИЦИ, С ОТЧИТАНЕ ВЛИЯНИЕТО НА СЕЗОННОСТТА

З. Димитров

Резюме

Изследването се фокусира върху оценка на точността при определяне на границата на гората в планинските гори в северозападната част на България. Целта на изследването е определяне на горската маска на гората чрез три SAR честотни ленти (канали) – „X“, „C“ и „L“, и анализ точността на приложения метод за обработка на радарните данни с оглед на сезонността. Използваните данни са POL-SAR изображения от ALOS PALSAR, бистатични InSAR данни от TanDEM-X и четиригодишни времеви серии от Sentinel-1. Някои SAR изображения са налични през различни сезони, което позволява оценка на сезонните вариации. Валидирането е извършено с 60 случайно генерирани точки. Обща точност (OA) и Kappa Cohen – коефициент, са изчислени за оценка на точността на получените маски на гората. Наблюдавана е силна зависимост от сезонността, поради по-високото въздействие на земята през периода на обезлистване на горите. Честотата на радарния сензор също играе важна роля в точността на определянето на границата на гората. Изготвени са както обучаеми, така и необучаеми класификации. Използван е необучаем класификатор на Wishart при POL-SAR данните. Оценката показва най-висока точност (OA) над 90% за маската на горите при данни в C-канал. Маската от данните в L-канала също показва висока точност с OA над 89%. Най-ниската точност на горската маска, с OA от 68%, принадлежи на бистатичните InSAR измервания от X-лента през зимата. В заключение, времевите серии от SAR данни на Sentinel-1 показват най-висока приложимост при определяне на границите на горите. Точността е по-висока през летните периоди, когато на разсейващите центрове са по-високи от земята и следователно обемното разсейване е по-добре разграничено от приноса от земната повърхност при обратното разсейване.