Skogssällskapet

Slutrapport

Projektrubrik: Mapping of state and changes with time series of satellite radar data for future forestry planning / Kartläggning av tillstånd och förändringar med tidsserier av satellitradardata för framtidens skogsbruksplanering
Huvudsökande: Henrik Persson
Projektets löptid: 2021-04-01 –2024-01-31

Populärvetenskaplig sammanfattning

The research project investigated time series of X-, C-, L- and P-band synthetic aperture radar (SAR) data, separately and in combination. The data were acquired from the satellites TanDEM-X, Sentinel-1 and ALOS/-2, and from airborne campaigns. They were used for tree height and above-ground biomass (AGB) estimation and their change over time.

The impact of field plot area and extraction region area on the relation between TanDEM-X InSAR data and forest variables was investigated in [1]. Here, it was found that the correlation between forest variables and phase heights were the highest when extracting phase heights from areas multiple times larger than those of plots of 7 m or 10 m radii.

A forest change study using Sentinel-1 C-band SAR for estimating clear-cuts registered by harvesters was published [2], and another study addressed the polarimetric use of X- and C-band SAR data for mapping biomass across years [3]. In [3], biomass estimation using polarimetric decomposition of X- and C-band polarimetric SAR data were compared, with accuracies of around 60 t/ha, but with the X-band results indicating some saturation (loss of sensitivity) at high biomass values.

In [4], a correction of canopy penetration depth was applied to time series of TanDEM-X phase heights to assist in detection of silvicultural treatments. In the study, a time series of 24 TanDEM-X acquisitions in Remningstorp covering two growth seasons were analyzed in conjunction with detailed treatment records of the test site. Clear-cuts were more clearly detectable with canopy penetration depth correction, and thinnings showed a decrease in height compared to untreated plots on average, while not distinguishable from them on the individual level.

In 2023, the paper [5] was completed, where forest site index and age were predicted using time series of TanDEM-X phase heights, using only a DTM and the correction applied in [4] to estimate tree top height from the phase heights. The time series have been used to map forest changes under impact of clear-cuts, pre-commercial and commercial thinning, or forest with no management actions – natural growth. Site index and age were unbiasedly predicted, and when forest age was known, site index was predicted with an uncertainty comparable to that of the field measured site index values.

The year 2023 also included a conference paper [6] and a manuscript [7] published in the doctoral thesis [8] and it has been submitted to a scientific journal. Both [6] and [7] address the measurements of forest biomass changes using SAR, and specifically the contribution of different polarization channels and polarimetric measures to prediction quality. Finally, the most important work was the successful defense of the PhD thesis [8] by Ivan Huuva in December 2023.

Resultat

The proposed research has advanced the state-of-the-art by developing new methods and algorithms for mapping state and change of tree height, diameter, basal area, stem volume and AGB, and the

retrieval of site index from time series of SAR data. The methods developed can be used as the basis for proposing appropriate silvicultural treatments in forest planning. The change studies included detection and mapping of clear-cuts, thinnings, growth, and site index estimations. The research has been based on data from the advanced SAR missions TanDEM-X, Sentinel-1, ALOS/-2, and airborne campaign data, and they were evaluated against field reference data from hemiboreal and boreal forests at different scales (plot, stand and county level).

Using the work package designations in the application, the publications in the project constitute deliverables in the work packages A-C and E.

WP A. Forest variable estimation – time series

Papers [1 – 7] contribute to mapping of state and change of forest variables.

WP B. Mapping of clear-cuts and thinnings

Papers [2],[4], [6] and [7] contribute to detection of clear-cuts and thinnings. Paper [2] addressed this problem using freely available Sentinel-1 data. Paper [4] investigated the visibility of clear-cuts and thinnings in TanDEM-X phase heights and the usefulness of a penetration depth correction in the task.

WP C. Mapping of forest growth

Papers [5 – 7] contribute to the quantification of forest growth using X- and L-band SAR data. Paper [5] quantified forest growth by using time series of X-band data to estimate the height growth behavior of dominant trees, from which the site index and age could be predicted. In papers [6] and [7], AGB change, including both biomass loss from thinning or clear-cuts and biomass increase from growth, was predicted using bi-temporal L-band SAR.

WP D. Large-area mapping

This WP has not been possible to carry out in a successful manner. The Sentinel-1 B satellite has been malfunctioning since 2021 and other global SAR satellite data have not been found feasible. The launch of the American-Indian NISAR satellite in 2024 is expected to change this.

WP E. Weather and seasonal effects

In papers [4 – 7] an, precipitation and temperature data from meteorological measurements concurrent with the SAR acquisitions were analyzed to determine conditions conducive to reliable InSAR measurements of forest variables. Paper [6] evaluated a backscatter intensity correction intended to correct for moisture differences between acquisitions. The correction was previously developed using airborne data within the PhD project of Ivan Huuva.

[1] Huuva, I., Persson, J., Wallerman, J., and Fransson, J.E.S. 2021. Impact of plot size and extended extraction regions of TanDEM-X phase height in relation to forest variables. In IGARSS 2021, Virtual Symposium, Brussels, Belgium, 11-16 July, 2021, pp. 6720-6723. Published.

[2] Mukhopadhyay, R., Lindberg E., Ekström, M., Persson, H.J., Nilsson, M., 2022. Rapid mapping of final fellings using Sentinel-1 data for a boreal forest test-site in Sweden. Abstract accepted and work presented at ForestSAT 2022, Berlin, Germany 29 Aug -3 Sep, 2022.

[3] Persson, H.J., Mukhopadhyay, R., Huuva, I., Fransson, J.E.S. 2022. Comparison of boreal biomass estimations using C- and X-band PolSAR. In IGARSS 2022, Hybrid Symposium, Kuala Lumpur, Malaysia, 17-21 July, 2022. Published.

[4] Huuva, I., Persson, H.J., Wallerman, J., and Fransson, J.E.S. 2022. Detectability of silvicultural treatments in time series of penetration depth corrected TanDEM-X phase heights. In IGARSS 2022, Hybrid Symposium, Kuala Lumpur, Malaysia, 17-21 July, 2022. Published.

[5] Huuva, I., Wallerman, J., Fransson, J.E.S., and Persson, H.J. 2023. Prediction of Site Index and Age Using Time Series of TanDEM-X Phase Heights. Remote Sensing, 15, 4195. Published.

[6] Huuva, I., Persson, H. J., Wallerman, J. L., Ulander M. H., and Fransson, J. E. S. 2023. Prediction of Hemi-Boreal Forest Biomass Change Using Alos-2 Palsar-2 L-Band SAR Backscatter. In IGARSS 2023, Pasadena, CA, USA, 2023, pp. 3326-3329, Published
[7] Persson, Huuva, I. 2023. Polarizations and Polarimetric Measures in Biomass Change Prediction using ALOS2 PALSAR-2 data. Published in thesis [8] and submitted to the scientific journal Remote Sensing.
[8] Huuva, I. 2023. Estimation of change in forest variables using synthetic aperture radar. Doctoral Thesis No. 2023:98, Acta Universitatis Agriculturae Sueciae.

Målbeskrivning

The project has generally reached the goals successfully and in addition to the seven scientific publications, contributed to the successful graduation of a PhD – Ivan Huuva. The time line has been a bit delayed but with the permitted extensions, the project has been completed successfully. The change of project leader and supervisor in 2022 boosted the project and contributed to the successful completion.

Kommunikation och nyttiggörande av resultat

The PhD thesis has been announced on the web page of SLU, shared on X, and the defense was live streamed and available to the public. The nailing of the thesis was a public occasion at the university. The scientific works have been included in the annual reports of SLU and the company Gamma remote sensing (co-supervisor of the PhD student), presented at conferences and in scientific journals as listed below:

- Oral presentation of paper [1] at IGARSS 2021, virtual symposium, Brussels, Belgium, 11-16 July, 2021
- Oral presentation of paper [4] at IGARSS 2022, hybrid symposium, Kuala Lumpur, Malaysia, 17-21 July 2022
- Oral presentation of paper [4] and early results of [5] at Kvarken Space Eco final meeting, Vaasa Finland, September 2022
- Poster for paper [6] presented at IGARSS 2023 in Pasadena, California, USA, July 2023
- Journal Paper: Prediction of Site Index and Age Using Time Series of TanDEM-X Phase Heights. Published in Remote Sensing, 15, 4195, 2023.
- Poster for paper [6] presented at Joint PI meeting of JAXA earth observation meeting 2023
- Doctoral Thesis No. 2023:98, Acta Universitatis Agriculturae Sueciae. Estimation of change in forest variables using synthetic aperture radar. https://publications.slu.se/?file=publ/show&id=126586
- Doctoral thesis defense in SLU 7 Dec, 2023 (also live streamed).