Forest Biomass Inversion from SAR using Object Oriented Image Analysis Techniques

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Abstract— **Recent advancements in object oriented image classification provide possibilities to investigate new approaches for inversion techniques for synthetic aperture radar (SAR) images to derive bio-/geophysical parameters, like forest biomass. A study was performed on ERS and JERS SAR data in the Raco test site in Michigan. Both data sets were acquired within 10 days during summer 1992. Ground reference data were available from 80 forest stands with biomass ranges from early regrowth to mature stands for various pine species. Ecognition software was used to perform image segmentation. It was found that the software generated excellent image objects which correlate spatially well with existing stand boundaries and ecological units. However, the SAR data needed to be pre-filtered to reduce the influence of speckle to achive better segmentation results. Also, improved segmentation was found when ERS and JERS data were used jointly in the segmentation process. Mean backscatter values of the 4 hectare test stands were compared with the mean backscatter of the larger image objects which contain the test stands. A comparison of the 4 ha test stands with the image objects containing these stands showed a signal correlation with an r^2 of 0.89. The derivation of biomass was then compared using the stand data only or the image objects only. While the r^2 values were about 0.1 higher for the stand derived regression equations, virtually the same model coefficients (slope, intercept) were achived with the biomass regression with stand data and image object data. This shows, that models which are developed on carefully selected stand data can be transferred to image objects which resulted from prior segmentation of the SAR data.**

I. Introduction

The concept behind object oriented image analysis is that semantic information which is necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relationships. Compared to standard pixel-based classifiers, image objects are extracted in a previous segmentation step. Objective of this study was to compare biomass regression models generated from well surveyed, homogeneous forest stands and their respective SAR backscatter values with models based on image objects which would be correlated with the same ground data.

II. Test Site and Reference Data

The Raco test site (46°25'N 85°00'W) lies in the transition zone of northern temperate forests and boreal forests and encompasses parts of the Hiawatha National Forest in the Upper Peninsula of Michigan. Main communities are northern hardwood (maple, beech, hemlock, fir), upland pine (red pine, white pine, jack pine) and lowland conifer (spruce, cedar, tamarack) communities; some row-crop and hay-production agriculture occurs. Homogeneous forest stands usually exceed 10 ha in size.

Over eighty forest stands and many pasture and wetland areas have been biometrically surveyed over the course of five years between 1991 and 1995. All forest test plots are at least 4 ha in size. Details on the ground reference data are found in [1].

TABLE I

Climatic and phenological situation on ERS-1/JERS-1 SAR image acquisition dates. Local time is approx. 11.30 am for all data-takes.

Sensor	Date	Phenologic Status	Precip. [mm]	Temp. [°C]
ERS-1	17-AUG-92	Peak	0	23
JERS-1	07-AUG-92	Peak	0	24

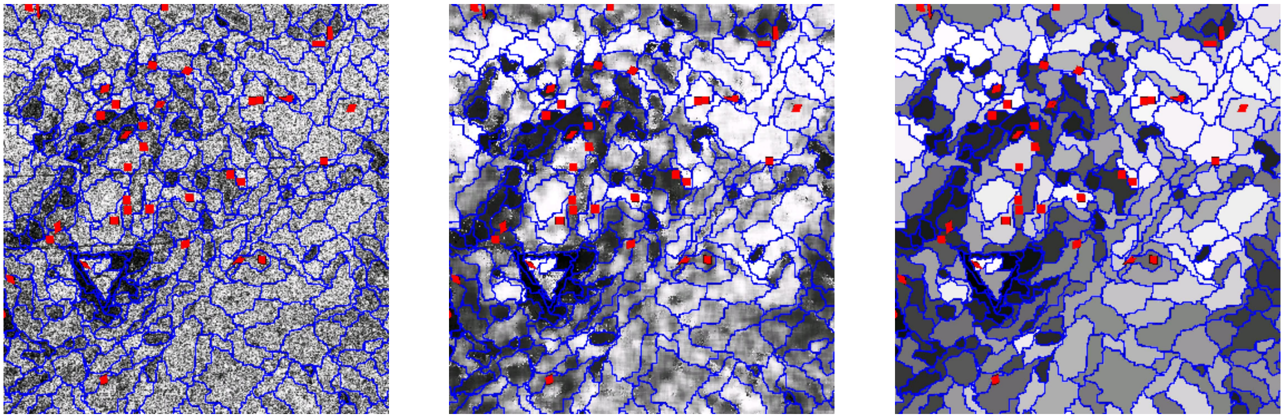
III. ERS/JERS-1 SAR Imagery

Test test site was imaged with the ERS-1 and JERS-1 SAR sensors during Summer of 1992. Both scenes were acquired at the peak of the phenologic growing season with foliage fully deployed. At the time of the data takes, ground conditions were dry without moisture stress (Table I).

The ERS-1 PRI and JERS-1 Level 2.1 products were geocoded, radiometrically calibrated, and speckle filtered as described in [2] and [3]. The resulting image data were spaced at 25 m x 25 m pixel resolution.

IV. Image Segmentation

Image objects were generated using the segmentation algorithm implemented in the eCognition software package [4]. The segmentation procedure detects local contrasts and works on highly textured data like SAR imagery. The segmentation algorithm within eCognition is based on a bottom-up region growing technique. Starting with one-pixel objects, larger segments are formed through a pairwise clustering process. The underlying optimization procedure minimizes a weighted heterogeneity *nh* of resulting image objects, with n = size of a segment, and h = heterogeneity measure. In iterative steps a pair of adjacent image objects is merged if it stands for the smallest growth of the defined heterogeneity. A threshold is



(a) Unfiltered (b) Speckle Filtered (c) Image Object Means

Fig. 1. Segments generated from joint ERS/JERS segmentation shown overlayed on JERS data in the Raco test site.

defined by a **scale parameter** which controls the stop of the process if the smallest growth exceeds it.

To avoid fractally shaped borderlines in image objects, which are most predominant in highly textured data like SAR data, the **spectral heterogeneity criterion** is mixed with a **spatial heterogeneity criterion**. The heterogeneity as a deviation from a **compact shape** is described by the ratio of the de facto border length and the square root of the number of pixels forming the object. An additional criterion of describing the shape heterogeneity is the ratio of the de facto border length and the shortest possible border length given by the bounding box of an image object parallel to the raster. Applying this criterion optimises the **smoothness of the shape** of image objects.

In summary, the multi-resolution segmentation process in eCognition is guided by four parameter settings: (1) Scale parameter (SC), (2.1) tone criterion (T), (2.2) shape criterion (SH), with sub-criterions (2.1.1) compactness (C), and (2.2.2) smoothness (SM). T, SH, C, and SM values range between 0 and 1, where T + SH = 1, and C + SM =1.

The segmentation settings for the JERS/ERS data were found emperically through visual interpretation of the image objects. Segmentation tests were preformed on the unfiltered SAR data, the speckle filtered SAR data, on individual ERS and JERS channels, and on the combined channels with equal **channel weights**. Segmentation on the unfiltered data did not yield satisfying results as the processing time was prohibitively slow with estimations of several tens of hours before the process would have finished. While segmentation on the individual channels yielded satisfying results reflecting the image shapes in the particular channel, the best result was achieved when using the data combined with the settings listed in Table II.

For a JERS image subset, the resulting segments are shown in blue color in Figure 1. The 4 ha sized test stands are shown in red rectangular shapes. It can be notized, that the segment boundaries are generally enclosing single stands, although in some cases two stands fall within a segment. In all of these cases, it was verified that the forest type, structure and biomass of the corresponding stands was almost identical. As can be seen from Figure 1(a), the unfiltered data show a strong effect of speckle noise although the shapes of clearcut areas, dark runways of a triangular airport, as well as some forested areas of gray to bright areas are visually distinguishable. The speckle filtered data (Figure 1(b)) show good correspondance with the segment boundaries although some tonal variation, particularely in the larger segments is evident.

TABLE II

PARAMETER SETTINGS FOR THE SEGMENTATION OF THE JERS/ERS DATA WITH ECOGNITION.

Scale	Tone	Shape	Compactness	Smoothness
10	0.75	0.25	0.9	0.1

The main object feature used for the biomass model comparison in this study was the mean value of the image segments (Figure 1(c)). In 60 image objects the difference of the mean values generated from the unfitered and filtered data had a range from -0.39 to 0.25 dB for the JERS data, and -0.61 to 4.41 dB for the ERS data. The mean difference for both data sets was 0.03 and 0.07 for JERS and ERS respectively. The high difference values in the ERS data were only present in two image objects where the speckle filter seemed to smooth some point targets which were avaraged with neighbouring areas.

V. BIOMASS RETRIEVAL FROM IMAGE OBJECTS

Initially, to determine the backscatter similarities between the surveyed forest stands and the image objects, the mean backscatter values for all stands were compared with the mean backscatter values of the image objects which contained the respective stands. A regression analyis showed that the stand and corresponding object backscatter values were highly

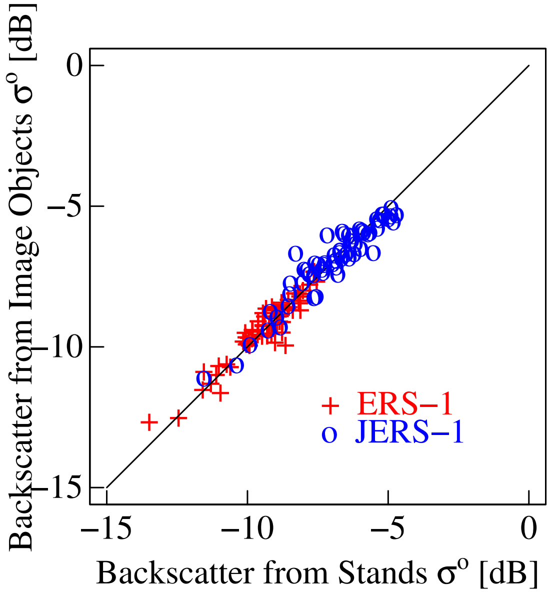


Fig. 2. Comparison of mean backscatter values measuerd from stands and within the image objects containing these stands.

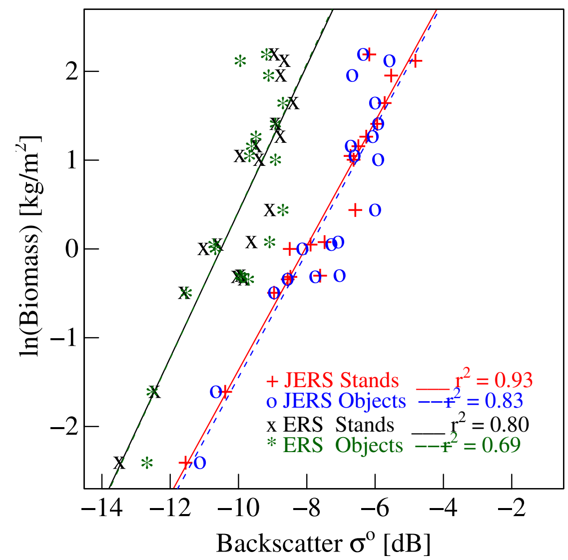


Fig. 3. Comparison of biomass regression models derived from stand and image object backscatter values.

correlated with an r^2 value of 0.89 for both ERS and JERS data (Figure 2).

Since biomass regression models are yielding better results when applied on a single species or structural group with equal growth pattern ([5]), the following results are generated from studying 17 jack pine stands in the test site. The regression models based on the stand and image object data are shown in Figure 3. The models were log-log based models where backscatter in dB was correlated with the natural logarithm of the biomass data: $ln(biomass) = a_1 * \sigma^0 + a_0$ with a_0 and a_1 being intercept and slope of the linear regression model. For the image objects, a weighted regression model was applied, where the weights were the standard deviations of the JERS and ERS backscatter values within the image segments. Applying these weights increased the correlation coefficients by 0.04 for both SAR data sets.

The following results were achieved with the regression from stands and image objects: 1) JERS correlation showed an r^2 value of 0.83 for the image objects compared to 0.93 for the stands data regressed against the stand biomass data. The slope for both regression models is quasi identical with a slight difference in the intercept which suggests a small bias in the means of the image objects. 2) ERS correlation showed a r^2 value of 0.69 for the image objects compared to 0.80 for the stands data. Here, slope and intercept were both identical.

Hence, although a somewhat lower correlation coefficient was achieved when using the image objects in the regression models, the similarity of the models suggest, that biomass models can be generated on well surveyed stands and applied to the image domain based on image objects which best reflect the spatial pattern of forest stands and ecological units.

VI. Conclusion

Image object generation with eCognition yields segments for SAR data which are generally homogeneous enough to represent land cover segments which correspond to homogeneous areas on the ground. Pre-processing of data with a speckle filter is mandatory in order for the segmentation algorithm to work successfully. Comparison of the regression models from the image object data and stand data shows that virtually identical log-log regression models resulted from correlation with stand biomass data. This means that image object oriented biomass inversion from SAR can be trained on surveyed forest stands and applied to larger segment data, thus avoiding pixel based inversion which generally performs much poorer. Further studies are needed to determine optimal segmentation parameter settings which were so far based on visual interpretation.

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