MULTI-ECOREGION VEGETATION MAPPING USING COMBINED ERS/JERS SAR IMAGERY

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Abstract

Up to today, there is no method developed for consistent global vegetation mapping and a global vegetation map, showing the actual distribution of vegetation on earth at a larger scale, is non existent, although urgently needed e.g. for climate change modelling. Radar is known to be very sensitive to vegetation structure and biomass. In a three year study at the University of Michigan the potential of the existing orbital SAR imaging systems JERS-1 and ERS-1/2 for vegetation mapping has been investigated. Both sensors have mapped the global land masses within a period of four years. Using the complimentary characteristics of frequency (L-, C-Band) and polarization (hh, vv), a classifiaction scheme was developed to produce vegetation maps at a scale of ca. 1:200,000. Imagery from seven test sites throughout North- and South America from different ecological environments ranging from desert to rain forest was analyzed in respect to consistency of vegetation backscatter from similar structural classes and applicability of a unique classification procedure. This paper summarizes preprocessing steps, classification approach and results of combined classification in 5 of 7 test sites. The usefulness and limitations, mainly through backscatter variations in calibration and changes in vegetation cover and moisture, will be discussed.

Keywords: ERS, JERS, Physiognomic Vegetation Classification, Global, Calibration, Hybrid Unsupervised/Supervised, Multitemporal.

Introduction

With the launch of Radar remote sensing satellites in 1991 (ERS-1, ESA, Europe), 1992 (JERS-1, NASDA, Japan), and 1996 (RADARSAT, CCRS, Canada, ERS-2, ESA, Europe) Synthetic Aperture Radar (SAR) imagery with near global coverage is now available from all these sensors.

In a study conducted at the University of Michigan, the potential of combined ERS-1 and JERS-1 SAR (Table 1) imagery for regional to global scale vegetation cover classification is investigated.

Satellite	ERS-1	JERS-1
Launched by	ESA, Europe	NASDA, Japan
in	July 1991	April 1992
Frequency	C-Band, 5.3 Ghz	L-Band,1.25Ghz
Wavelength	5.6 cm	23 cm
Polarization	VV	HH
Resolution	30m	18m
Incidence Angle	23°	35°
Swath width	100km	80km
Orbit	polar	polar

Table 1: *Sensor characterisitics.*

The basic idea behind the study is to use the complimentary information of ERS-1's C-Band, vv-polarization, and JERS-1's L-Band, hh-polarization. Both bands show different response in the backscatter behaviour of vegetation, mainly driven by the physical (structural) and electrical properties of the illuminated objects. Hence the study focusses on the development of a radar classifier based on the assumption that structurally and electrically similar vegetation, no matter where it appears on earth should have similar backscattering behaviour. Since radar is an active sensing system with constant illumination geometry and well known transmit/receive power spectra, radar imagery can be calibrated to a very high degree of accuracy, thus allowing the comparison of backscattering values (σ^o) over time and space.

Image Composites from seven test sites in different ecoregions, ranging from midlatitude forests, prairie, desert areas, to tropical rain forest were classified. It will be pointed out which preprocessing steps were applied to geometrically and radiometrically calibrate the imagery acquired by both sensors.

1. The Testsites

Figure 1 shows the location of the test sites used in the study. The tests sites were selected to get a representative cross section through various biomes and to have good ground truth available without too much extra effort. Two of the test sites reported here were super sites (Raco, Cabaliana) for the Shuttle Imaging Radar campaign in 1994 (SIR-C/X-SAR) and five test sites are part of the NSF network of Long Term Ecological Research sites (LTER).

Figure 1: *Locations of the test sites.*

Raco, Michigan (46 ° 25'N 85 ° 00'W) is a test site managed by the University of Michigan, Radiation Laboratory. 80 forest stands and many pasture and wetland areas have been biometrically surveyed over the course of five years. All forest test plots are at least 4 ha in size. They encompass mainly pines (jack pine, red pine, white pine) and northern hardwoods (sugar maple, red maple, aspen, beech) at different growth stages. Wetlands and agricultural areas were surveyed.

Kellog, Michigan (42 ° 28'N 85 ° 27'W) is a forested site under investigation by the Kellog Biological Station. The forest composition is similar to the Raco test site with scattered stands of pines, oak-hickory and beech-maple deciduous midlatitude forest, wetlands and agriculture.

Cedar Creek, Minnesota (45 ° 24'N 93 ° 12'W) Natural History Area is operated by the University of Minnesota in cooperation with the Minnesota Academy of sciences. It lies at the boundary between prairie and forest and is a mosaic of uplands dominated by oak savana, prairie, hardwood forest, pine forest, and abandoned agricultural fields and of lowlands comprised of oak and cedar swamps, acid bogs, marshes and sedge meadows.

Konza Prairie, Kansas (39 ° 05'N 96 ° 35'W) is managed by Kansas State University to provide an array of burning and grazing treatments (mainly buffalo) to facilitate ecological research. Lowland areas have patches of native prairie grass species, especially big bluestem, indian grass, little bluestem, and switchgrass which grow up to 2-3 m during the summer. Some gallery forests are dominated by bur and chinguapin oaks with green ash, hackberry, elm and black walnut.

The **Jornada Experimental Range, New Mexico** (32 ° 30'N 106 ° 045W) research conducted by the New Mexico State University focusses on five habitat types: black gamma grassland, creosote bush scrub, mesquite duneland, tarbush shrublands and playa. The playas are dominated by a variety of grasses and found in lowlying, periodically flooded areas.

Cabaliana is not included in the classification at this stage, Sevilleta will be used as an overall testing site and is also not included in the classification at this point.

2. Scene Selection

Both ERS-1/2 amd JERS-1 have imaged the earth's land surface since launch with their SAR instruments. ERS-1 and the follow-up sensor ERS-2 have covered all land masses, meanwhile several times. Hence, for many regions multitemporal ERS-1/2 images are available. As of March 1996 JERS-1 has imaged 97% of the land surfaces, but with a lower repetition rate than ERS-1/2.

Besides the availability of scenes for the test sites from both sensors, three major criteria were considered when selecting scenes for the study;

2.1 Seasonality

It was decided to select scenes during the peak of the vegetation period, if applicable. Especially frozen, leaf off, and post-harvest conditions alter the radar signal significantly. This fact can be used when incorporating multitemporal datasets into the classification approach, which has been done for the Raco test site. Selecting the peak of the vegetation period conforms with the proposed standard for vegetation classification (see Section 5). In this proposal, vegetation cover is to be measured during the phenological peak of the vegetation period.

2.2 Moisture Conditions

Radar is well known to be sensitive to moisture changes in canopy as well as in the underlying soil. Hence, a careful selection of scenes from relatively dry periods (no rain on and a couple of days before the image acquisition) helped to minimize shifts in the signal due to soil moisture changes and intercepted rain on the vegetation canopy and stems. Wet conditions significantly alter backscatter and hence affects the classification accuracy. However, in tropical environments precipitation is to be expected almost always, which might lead to the necessity to treat tropical regions under the assumption of wet conditions. This is to be further investigated.

2.3 Scene Overlap

This selection criteria is two-fold: time and space.

Since the imagery is acquired from two different satellites, scene combinations are prefered that

-maximize the area covered by both sensors and

-minimize the time span between the two acquisition dates, whereas preference is to be given to scene combinations of the same vegetation period rather than being from the same year, but from different phenological stages.

For all seven test sites it was possible to select scenes with good scene overlap and acquisition date differences ranging from 1 to 42 days (Table 2).

Test Site	ERS-1	JERS-1	Days Difference
Cabaliana	06-OCT-93	03-OCT-93	3
Cedar Creek	10-SEP-94	09-SEP-94	1
Jornada	18-MAY-94	06-APR-94	42
Kellog	29-JUL-92	07-AUG-92	8
Konza	25-JUN-94	31-JUL-94	36
Raco	17-AUG-92	07-AUG-92	10
Sevilleta	28-APR-94	6-APR-94	22

Table 2: *Acquisition Dates.*

3 .Preprocessing

In order to generate absolutely calibrated ERS/JERS-1 SAR image composites, a preprocessing chain was designed and implemented at the University of Michigan Microwave Image Processing Lab.

The input products delivered from the German Processing and Archiving Facility (ERS-1) and RESTEC, Japan, (JERS-1) were the Precision Image (ERS-1) and Level 2.1 (JERS-1) product.

Both products are delivered in ground range projection with 12.5 m pixel spacing, corrected for their specific antenna pattern and range spreading loss. An *area term* correction, based on a reference ellipsoid is done for the JERS-1 Level 2.1 data and was undone, when using a DEM for the local angle of incidence calculation.

To perform tape reading, orthorectification, radiometric calibration, and the generation of the value added products (layover/shadow masks, local incidence angle map) software was developed at the University of Michigan, partly in cooperation with the Vexcel Corp., Boulder, Colorado [Ref. 1].

For the radiometric upgrading the "Edge Preserving Optimized Speckle" (EPOS) filter was made available by the University of Karlsruhe, Germany [Ref. 2].

3.1 Orthorectification

The orthorectification software used is based on the theory published in [Ref. 3,4]. For both ERS-1 and JERS-1 fairly accurate orbit data are available and were refinded using ground control points. Those were collected using USGS 1:100,000 Digital Line Graph (DLG) data and GPS measurements. It was expierienced, that a minimum of 4 ground control points was sufficient for refinements of the orbit information and first-order point transformations during the final orthorectification run. A critical quality criteria is the resolution and accuracy of the DEM data. For all but the Cabaliana test site, the USGS 1:100,000 hypsography data could be used to generate 25m pixel spacing raster DEMs. The results for the geometric correction of the images were satisfying using the USGS 1:100,000 data. However, better resolution DEMs at a scale of 1:50,000 would be preferable if better geometric quality is desired. The use of USGS 1:250,000 DEM raster data resulted in insufficient accuracies and almost no layover or shadow regions could be detected using this coarse resolution DEM.

During the process of geometric correction value added products are generated. The layover/shadow mask marks areas where the SAR layover/shadow effects occur. These areas need to be excluded from classification. The local incidence angle map gives for each pixel the incidence angle of the radar beam with the surface normal. This information is used for the radiometric "area term" correction and can be used for further incidence angle dependent analysis of the backscattering coefficient.

3.2 Radiometric Calibration

The radiometric calibration of the ERS-1 and JERS-1 imagery is another critical preprocessing step, considering the intention of multi-site classification using a classifier based on absolute backscattering values. Throughout the past years progress has been made in the calibration of SAR imagery and today accuracies are considered to be less than 0.7 dB. For ERS-1 and JERS-1 accuracies have been reported to be on the order of 0.5 dB [Ref. 5,6]. Calibration equations for ERS-1 and JERS-1 used in this study are published in [Ref. 1].

3.3 Radiometric Upgrading

To reduce the speckle noise a two step process was chosen to be adequate for the purpose of vegetation classification. This process results in a reduction of the +/-1 σ -variance around the mean backscatter from 5dB down to 0.1dB. Since the total dynamic range of the imagery is on the order of roughly 20dB, significant noise reduction is important. By increasing the *effective number of looks*, the filtering reduces resolution, which is estimated to be circa 75m after the filtering process.

The first step in the process is the application of the EPOS filter which is designed to preserve edges while reducing the noise in homogeneous areas to a very high degree. To further remove point targets (e.g. vehicles, power masts, antennas, etc.) and edge noise, which was not removed by EPOS, a 5x5 median-filter was applied to the imagery consequently. Influences in the backscatter through local incidence angle variations are also averaged through this process.

4.Classification

The classification approach chosen for the project emerged from the intention to eventually realize a consistent global vegetation classification tool, if the results show promising accuracies. With that idea it became clear, that the classification process had to be somehow unsupervised, since single scene training was not considered an option.

Besides the choice of the image classification procedure, also the vegetation classes have to be chosen to be meaningful with respect to global vegetation characterization. A good basis for that is the recently proposed standard for vegetation classification. This standard is discussed by many US federal agencies and ecological groups under the leadership of the *Federal Geographic Data Committee* [Ref. 7]. From a radar perspective, this classification scheme seems to fit very well with the radar sensitivity to biomass and structural attributes of vegetation, since it is based on plant physiognomy, phenology, percent cover and environmental factors, esp. hydrologic modifiers.

Within the vegetation classification framework described in Table 3, a hybrid unsupervised/supervised classification of the SAR image composites was carried out as follows.

From 148 polygons in five test sites (not included at this stage were Cabaliana and Sevilleta) the mean backscatter of vegetation was measured from a training population. As can be seen from Figure 2, a fairly good separation for level 1 classes is given, mainly driven by JERS-1. At level 4, some distinction between needleleaf and broadleaf, as well as wetland classes is introduced mainly through ERS-1 backscatter characteristics. However, ambiguities exist, especially between the classes in the transition zone of different biomass levels like shrubland/tree canopy and shrubland/herbaceous. Needleleaf wetland forests are generally confused with deciduous forests.These distinctions seem fairly difficult to resolve with just the two likepol sensors and monotemporal analysis.

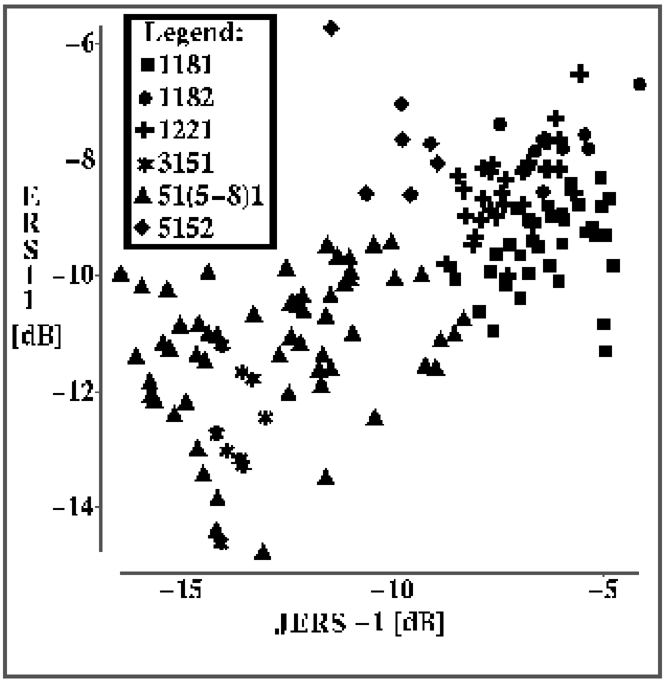


Figure 2: *JERS/ERS scatterplot of backscatter values measured from 148 polygons in five test sites from various ecoregions.*

Using the ISODATA algorithm, each image composite was clustered unsupervised and cluster signatures were calculated. With the minimum distance rule, these cluster signatures (means of ERS-1 and JERS-1) from all test sites (C) were classified using the measured signatures (means) from all training polygons (P).

$$Class_{Cluster_c} = Class_{Polygon_p} \qquad (1)$$

where p is determined from

$$min[(\sigma^o_{c_{ERS}} - \sigma^o_{p_{ERS}})^2 + (\sigma^o_{c_{JERS}} - \sigma^o_{p_{JERS}})^2]_{p=1}^{P} \qquad (2)$$

where

p = 1,..., P, no. of measured polygons,

c = 1,..., C, no. of unsupervised clusters

No pixels were left unclassified at this stage, but investigations on meaningful distance thresholds are currently carried out.

The pixels from the classified clusters were then tested against the testing population from the known polygons. Table 4 shows the overall classification result for level 1 in the 95% range. At level 4 (Table 5), the classification result is significantly lower, showing confusion within the forest classes as well as the herbaceous categories. Herbacous wetlends however could be identified with 99% accuracy. In a multitemporal study, using an additional JERS-1 scene (21-OCT-92) in the Raco test site, a level 4 distinction between forest categories (upland conifers, lowland conifers and deciduous) was achieved with an accuracy of ca. 80%.

Level	Code	FGDC Proposed Standard	SAR Sensitivity
Level 1		**Physiognomic class:**	
		Peak % cover in Upper Strata, Average Vegetation Height	
	1	Closed Tree Canopy	(Woody) Biomass
	2	Open Tree Canopy	Macro-Structure of
	3	Shrubland	Vegetation
	4	Dwarf Shrubland	"Main/Small Stems"
	5	Herbaceous	
	6	Non-Vascular	
Level 2		**Physiognomic Subclass**	
		Leaf phenology	
	1	Evergreen (e.g. *Tree Canopy*)	Multitemporal Observations
	1	Perennial (e.g. *Herbaceous*)	
	2	Deciduous (e.g. *Tree Canopy*)	
	2	Annual (e.g. *Herbaceous*)	
Level 3		**Physiognomic Group**	
		Leaf Morphology, Climate	
		e.g *Closed Tree Canopy:*	
	1-6	Broadleaf	(Woody) Biomass
	7-9	Needleaf	Micro-Structure of
		e.g. *Herbaceous* (Temparate Climate)	Vegetation
	5	Plain Grassland	"Foliage"
	6	with a Tree Layer	
	7	with a Shrub Layer	
	8	with a Dwarf Shrub Layer	
Level 4		**Formation**	
	1	Dry Conditions	"(Soil) Moisture"
	2	Wet Conditions	
	1181	Closed Evergreen Needle-Leaf Forest in a Temparate Climate, Dry Conditions	Example for a
	5171	Temparate Grass Canopy with a Tree Layer, Dry Conditions	Level 4 Classcode:

Table 3: *SAR sensitivity to a hierarchical vegetation classification scheme based on plant physiognomy as proposed by the US Federal Geographic Data Committee. In each hierarchical level new physiognomic modifiers are introduced. Additional modifiers (e.g. climate, natural/planted) exist, however without a direct link to SAR sensitivity. Additional geographic knowledge for local adaption of SAR derived vegetation maps is necessary.*

Absolut Pixel Counts:

	1	3	5	9	
1	2536	0	60	0	2596
3	0	149	40	0	189
5	104	61	4847	0	5012
	2640	210	4947	0	7797

Percentages:

	1	3	5	9	
1	97.7	0.0	2.3	0.0	97.7
3	0.0	78.8	21.2	0.0	78.8
5	2.1	1.2	96.7	0.0	96.7
	96.1	71.0	98.0	-1.0	96.6

Table: 4 *Level 1 classification accuracy for 148 testing polygons in five test sites (for classcodes see Table 4, 9 stands for unclassified). Rows: true class, columns: ERS/JERS classified. 95.5% is the ratio of correct classified pixels over total pixels. The unbiased accuracy (mean of the diagonal in the percentage matrix) is 89.2%, the kappa coefficient is 0.91.*

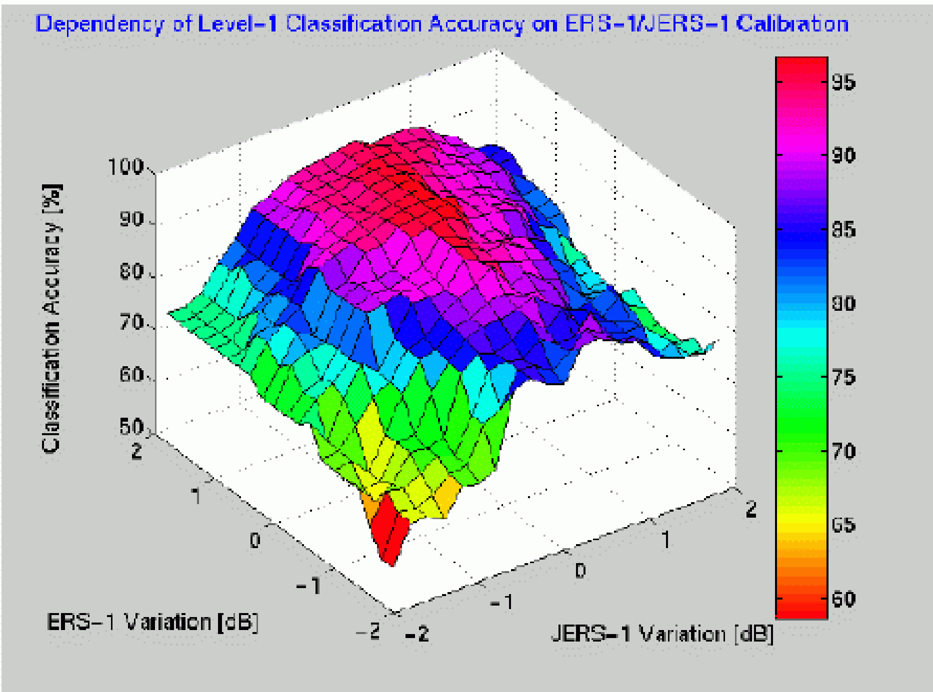
Absolut Pixel Counts:

	1181	1182	1221	1331	3151	5151	5152	5161	5171	5181	9999	
1181	894	0	318	0	0	4	0	47	1	0	0	1264
1182	33	12	126	18	0	0	0	0	0	0	0	189
1221	79	68	880	73	0	2	3	1	2	0	0	1108
1331	0	0	35	0	0	0	0	0	0	0	0	35
3151	0	0	0	0	149	40	0	0	0	0	0	189
5151	42	0	30	0	50	3767	92	27	59	36	0	4103
5152	0	0	7	0	0	2	620	0	0	0	0	629
5161	22	0	1	0	0	10	0	76	10	11	0	130
5171	1	0	0	0	11	82	0	0	16	0	0	110
5181	1	0	0	0	0	3	0	0	2	34	0	40
	1072	80	1397	91	210	3910	715	151	90	81	0	7797

Percentages:

	1181	1182	1221	1331	3151	5151	5152	5161	5171	5181	9999	
1181	70.7	0.0	25.2	0.0	0.0	0.3	0.0	3.7	0.1	0.0	0.0	70.7
1182	17.5	6.3	66.7	9.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3
1221	7.1	6.1	79.4	6.6	0.0	0.2	0.3	0.1	0.2	0.0	0.0	79.4
1331	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3151	0.0	0.0	0.0	0.0	78.8	21.2	0.0	0.0	0.0	0.0	0.0	78.8
5151	1.0	0.0	0.7	0.0	1.2	91.8	2.2	0.7	1.4	0.9	0.0	91.8
5152	0.0	0.0	1.1	0.0	0.0	0.3	98.6	0.0	0.0	0.0	0.0	98.6
5161	16.9	0.0	0.8	0.0	0.0	7.7	0.0	58.5	7.7	8.5	0.0	58.5
5171	0.9	0.0	0.0	0.0	10.0	74.5	0.0	0.0	14.5	0.0	0.0	14.5
5181	2.5	0.0	0.0	0.0	0.0	7.5	0.0	0.0	5.0	85.0	0.0	85.0
	83.4	15.0	63.0	0.0	71.0	96.3	86.7	50.3	17.8	42.0	-1.0	82.7

Table: 5 *Level 4 classification accuracy for 148 testing polygons in five test sites (for classcodes see Table 4, 9999 stands for unclassified). Rows: true class, columns: ERS/JERS classified. 82.7% is the ratio of correct classified pixels over total pixels. The unbiased accuracy (mean of the diagonal in the percentage matrix) is 58.4%, the kappa coefficient is 0.75.*



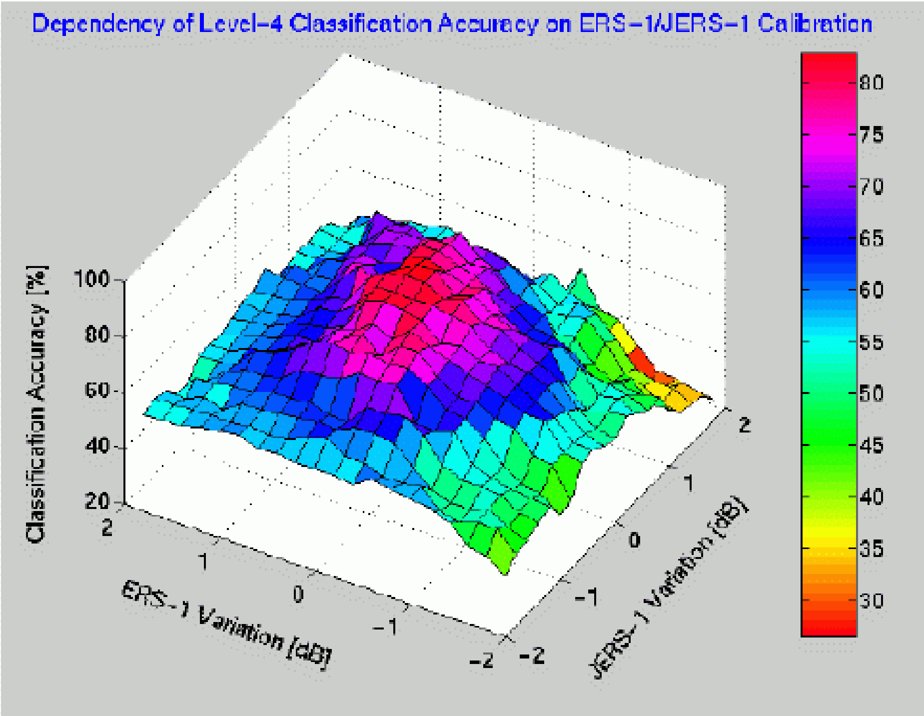


Figure 3: *Dependency of the classification accuracy on the variance (sensor calibration and/or landcover changes) of the backscattering coefficient σ^0 from ERS-1 and JERS-1. Top: Level 1, indicating a strong dependency on JERS-1. Bottom: Level 4,indicating a strong dependency on both sensors.*

The sensitivity of the process to uncertainties in the backscattering values was simulated with 441 classification runs variing the unsupervised generated cluster means from -2dB to +2dB in 0.2dB steps around the originally calculated clustermeans. The results of this simulation are shown in Figure 3. It clearly can be seen, that the level 1 classification results are mainly sensitive to changes in the JERS-1 backscattering values with the main drop in accuracy at ca. +/-1dB. The influence of ERS-1 backscatter variation is of minor importance. However, at level 4, the significant drop in classification accuracies is shown for both sensors equally at ca. +/-0.5dB .

Conclusions

It was demonstrated, that a framework of physiognomic vegetation classification is meaningful for radar characterization of vegetated terrain on a global scale. Using ERS/JERS-1 composites from peak vegetation periods shows for five test sites in North America >90% classification accuracy at level 1 and ca. 60% at level 4. Some class ambiguities between classes proposed by the *US Federal Geopgraphic Data Committee* exist at level 4 and seem unresolveable with a monotemporal (i.e. same season) ERS/JERS-1 composite. Great improvements in classification accuracy were achieved through the use of an additonal JERS-1 scene from late fall in the Raco test site. The inclusion of a tropical scene is under investigation, where the generally wetter conditions seems to introduce ambiguities to be resolved. It also was shown, that backscatter variation through calibration and changes in vegetation cover and moisture influence the classification results in different ways. At level 1 the accuracy is mainly sensitive to JERS-1 variations, indicating the higher L-Band sensitivity to the macro-structure of vegetation. The main drop in accuracy occurs at approx. +/-1dB . At level 4, both C- and L-Band show equal sensitivity with the main drop in accuracy at ca. +/-0.5dB , which imposes limitations on class distinction at this level.

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