Internationales Symposion
INTERPRAEVENT 2004 – RIVA / TRIENT

THE OBSERVATION OF PROTECTION FORESTS IN CRITICAL ZONES USING REMOTE SENSING DATA
SCHUTZWALDBEOBACHTUNG IN KRITISCHEN ZONEN UNTER VERWENDUNG VON FERNERKUNDUNGSDATEN

Klaus Granica[1], Mathias Schardt, Manuela Hirschmugl, Heinz Gallaun

ZUSAMMENFASSUNG

Die Erfassung und Beobachtung von Veränderungen der Landoberfläche in Alpenregionen ist ein wichtiger Faktor in der Beurteilung von Gefährdungspotentialen. Es müssen mögliche Gefahren frühzeitig erkannt und damit die Sicherheit für die Bewohner und Touristen erhöht werden. In diesem Zusammenhang stellt die Beobachtung des Zustandes und der Entwicklung von Schutzwäldern eine dringliche Aufgabe zur Beurteilung möglicher Risiken dar. Die Fernerkundung eignet sich vor allem in den abgelegenen und schwer zugänglichen Regionen in besonderem Maße für ein großflächiges Schutzwaldmonitoring. Die beschriebene Untersuchung konzentriert sich auf die fernerkundungsgestützte Ableitung der für das Schutzwaldmonitoring wesentlichen Bestandesparameter, wie Überschirmung, Baumarten und Altersklassen, aus SPOT4 Satellitenbildaufnahmen. Darüber hinaus wird untersucht, ob und mit welcher Genauigkeit mit den hochauflösenden SPOT5 Daten auch Parameter erhoben werden können, die für eine Risikobeurteilung von Flächen außerhalb des Waldes eine Rolle spielen.

Key words: Gefahren, Klassifizierung, Fernerkundung, Wald, Verkehrsrouten.

ABSTRACT

Continuous monitoring of larger areas in the Alps using remote sensing technologies helps to spot changes even in the most remote valleys or along critical zones and to identify potential hazards early, thus improving the safety of residents and tourists. The monitoring of protection forests proves to be a significant task for the evaluation of risk potentials in an alpine environment. It is, therefore, important to obtain knowledge about the condition and development of these forested areas. The objectives of these investigations were put on the ascertainment of the most important forest parameters, i.e. crown coverage, species types and age, by means of satellite technology on stand level. For this purpose the potential of SPOT4 satellite data have been analysed, compared and evaluated. In a next phase it is foreseen to examine the potential of the high resolution SPOT5 data for the classification of parameters outside forests, which can play a role in risk analysis.

Key words: hazards, classification, remote sensing, forest, transportation lines.

---

1 Forschungsgesellschaft JOANNEUM Research, Institute of Digital Image Processing, Wastiangasse 6, A-8010 Graz (Tel.: +43-316-876-1713, Fax: +43-316-876-91713; email: klaus.granica@joanneum.at)

INTRODUCTION

Natural disasters are an age-old problem that occur regularly in alpine regions, posing a major threat to the safety of settlements and transport routes as it is impossible to predict exactly when and where a disaster will occur. An increasing number of rock falls, mud slides, avalanches, floods and windfalls in recent years have shown that natural disasters may even strike areas that have generally been considered safe. Not all natural disasters are triggered by local events. Many are caused by developments in regions that are remote from the site of the catastrophe. Frequently they are the result of human activities that have a negative impact on the environment, such as the felling of protection forests, the construction of new roads and tracks, changes in the density of stocking, the rerouting of rivers and streams, and pollution originating in industrial areas which adversely affects alpine vegetation.

Continuous monitoring of larger areas in the Alps using remote sensing technologies helps to spot changes even in the most remote valleys and to identify potential hazards early, thus improving the safety of residents and tourists. In the following it is presented how SPOT satellite data can be used to derive important information for the evaluation of the condition of the environment, and specifically the protection forest. The derived layers will subsequently be used in a decision support system (DSS) for the improvement of risk analysis.

The Forestry Services in Austria are responsible for the protection forests in the high mountain regions of the Austrian Alps. For long term planning the provincial governments have installed Geographical Information Systems (GIS) using different raster and vector based data, but they are lacking of country wide uniform data. Remote sensing derived forest parameters have been shown to be operational in the past. In several applications it has been demonstrated that with these data it is possible to differentiate forest parameters as species composition, natural age and crown coverage (Schardt, 1997; Schardt and Schmitt, 1996; Granica et al., 2000). These parameters have been derived using SPOT4 or Landsat TM data.
For the present application, four SPOT4 multispectral scenes were recorded. In a further phase, SPOT5 data with 10m und 2.5m spatial resolution will be analysed for their potential to derive parameters related to risk analyses mainly land-use, geology, geomorphology, and hydrology. Concerning the forest, a comparison based on the previous results will be made to show, if and how much the improvements are from SPOT4 to SPOT5 data.
The region selected for this investigation covers the province of Salzburg, except the eastern part called Lungau. The missing part will be ascertained in the second phase by SPOT5 data. The province covers four eco-system regions and the elevation. ranges from 400m to 3700m a.s.l. It is foreseen that the results will be integrated into the Decision Support System, which has been designed to enhance the safety in mountainous regions.

METHODOLOGY

The methodology had to be adapted to the specific conditions in the testsite, especially in terms of georeferencing and radiometric correction. The respective processing steps will be described in the following.
Standard image processing and GIS software packages have been used, i.e. ERDAS Imagine and Arc/Info, for the performance.

Satellite and Reference Data

The simultaneous recording of four SPOT4 satellite scenes on 2nd August 2001, covering an area of app. 14.400km², was a prerequisite for the classification of such a large region. Otherwise, it would have been much more difficult to compensate the different radiometric and illumination parameters in the single images.
Because of the high variability in the test site in terms of elevation and species composition and to the broad range of parameters and their combinations to be investigated a large amount of reference data were obtained by stereo interpretation of CIR and truecolor aerial photo interpretation. The total number of classes comprised fifteen different species types, five crown coverage categories, and six age categories. Taking this into account, altogether around 1200 sites were delineated, interpreted and digitised into the database.

Data Pre-Processing

Because of the heterogeneous conditions in the region, from hummocky to highly-relief terrain, extraordinary diligence was necessary on the selection of high-sophisticated pre-processing tools in terms of geometric and radiometric preparation. Especially the mosaicking of four satellite scenes had to be performed carefully.

Geometric Correction

To fulfil the high standard in the roughed terrain a parametric geocoding approach (Raggam, 1991) has been applied on the SPOT4 scenes. For this purpose, the RSG (Remote Sensing software package Graz, 1998), which is a software module in ERDAS Imagine, was used. The process was based on a Digital Elevation Model (DEM) with 25m x 25m ground resolution.

Radiometric Correction

The radiometric correction has been performed in two steps, firstly the image calibration and secondly the topographic normalisation.

1. Image Calibration or Radiometric adjustment: Again two different approaches have been evaluated: absolute calibration with coefficients provided by Spot-Image and relative calibration with linear regression.
2. Topographic normalization: In this second step the images had to be normalised for the illumination effects. The strong relief not only affects the geometric properties of an image, but also has a significant impact on the illumination and the reflection of the image area. This effect is caused by the local variations of view and illumination angles due to terrain, and thus, is particularly critical for applications in high mountain regions (Colby; 1991; Hill and Mehl, 1995; Meyer et al, 1993). Therefore, identical forest covers might be represented by significantly different intensity values, depending on their orientation and on the position of the sun at the time of data acquisition. Thus, it was a prerequisite to apply a topographic correction on the data, using a Digital Elevation Model (DEM).

Nomenclature

The nomenclature for the classification task was defined with regard to the national definitions of forest. The following classes have been selected:

Crown coverage (five classes): up to 30 %, 31 – 50 %, 51 – 60 %, 61 – 80 %, 81 – 100 %.

Age (six classes): clearings, culture, thicket, pole, timber, old timber, and an undefined class for dwarf mountain pine and green alder.

Tree Types (fifteen classes): this category is defined through the percentage of coniferous (i.e.: sum of coniferous / (sum of coniferous + sum of broadleaf). Pure tree types consist of more than 90 % of this particular species:

- spruce (including fir);
- larch;
- spruce/larch [if larch is between 90-60%];
- spruce/larch [if larch is between 60-30%];
- spruce/larch [if larch is between 30-10%];
- spruce/larch/pine [if larch or pine is between 30-10%];
- pine;
- spruce/pine [if pine is between 90-60%];
- spruce/pine [if pine is between 60-30%];
- spruce/pine [if pine is between 30-10%];
- mixed class: coniferous with broadleaf [if coniferous is between 89-75%]
- mixed class: coniferous with broadleaf [if coniferous is between 74-51%]
- mixed class: broadleaf with coniferous [if coniferous is between 50-26%]
- mixed class: broadleaf with coniferous [if coniferous is between 25-11%]
- broadleaf [if the percentage of coniferous is –less than 10%]

Outside of forest the most relevant land cover parameters have to be derived, in terms of geologic, tectonic and geomorphologic features, as well as hydrologic parameters.

Signature Analysis

A signature analysis was performed, using a number of bands and channels derived from SPOT4 data. The parametric signatures are based on statistical parameters (e.g. mean and covariance matrix) that are derived from training samples. Statistics were derived for each training site, as well as independently for each verification site, and an analysis of their histograms and spectral curves was made. Additionally, analyses were performed, using ellipse diagrams and scatter-plots. A signature separability analysis of the defined classes was computed, which measured the divergence or statistical distance, between signatures (in this case the Jeffries-Matusita Distance and Transformed Divergence). A contingency matrix was computed and applied only on selected signatures of the pixels in the training set, for the evaluation of the correct classified pixels.

Classification

Based on the results from the signature analysis a classification was performed, using the Maximum Likelihood classifier. To improve the accuracy and to account for the different terrain characteristics various classification approaches have been applied, e.g. the inclusion of the height effect. The Maximum Likelihood decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the classes have normal distributions. The classifier takes most variables into consideration and takes the variability of classes into account by using the covariance matrix.

RESULTS AND DISCUSSION

Results Geocoding

A precision parametric geocoding was applied to the four SPOT4 bands. To obtain a large coverage of 120 km width the SPOT4 sensor has the opportunity to record with two sensors simultaneously. Thus, in a first step the two scenes from the same sensor were mosaicked, resulting in two stripes, i.e:

- Scene 061-253 and scene 061-254 → scene1
- Scene 063-253 and scene 063-254 → scene3

The geocoding for the two stripes were computed with the RSG software package using 202 control points (see Table 1 and Table 2), resulting in an accuracy within the sub-pixel range.

Tab1: Punktresiduen der geokodierten Szene 1.
Tab1: Point Residuals of the Geocoding of Scene 1.

```
POINT RESIDUALS                     IMAGE: K:\scene1
Units of residuals: PIXEL            X = Along Track, Y = Across Track
RESIDUAL STATISTICS
 Control points:  84     Res-X     Res-Y    Res-XY
---------------------------------------------------
              RMS         0.57      0.53     0.78
              MEAN       -0.02      0.04      0.66
              STD         0.57      0.53      0.41
              MIN        -1.65     -0.98      0.03
              MAX         1.78      1.79      2.12
             |MIN|        0.01      0.01      0.03
             |MAX|        1.78      1.79      2.12
```

Tab2: Punktresiduen der geokodierten Szene 3.
Tab2: Point Residuals of the Geocoding of Scene 3.

```
POINT RESIDUALS                     IMAGE: K:\scene3
Units of residuals: PIXEL            X = Along Track, Y = Across Track
RESIDUAL STATISTICS
 Control points: 118     Res-X     Res-Y    Res-XY
---------------------------------------------------
              RMS         0.90      0.43     1.00
              MEAN        0.00      0.00      0.86
              STD         0.90      0.43      0.50
              MIN        -1.99     -1.06      0.07
              MAX         1.99      1.00      2.17
             |MIN|        0.00      0.01      0.07
             |MAX|        1.99      1.06      2.17
```

The geocoding results showed, that a high accuracy were achieved (see Tables above). As most of the area covers mountainous terrain the requirements on a proper georeferencing could be seen as fulfilled.

Adjustment of Neighbouring Scenes

To allow classification of all four SPOT4 scenes with same statistical parameters derived from one set of training areas, radiometric calibration of the neighboured scenes has been performed. This processing step is required for operational application, as acquisition of training data is the main effort for classification, and independent classification of the separate satellite scenes would therefore significantly increase efforts and costs. However, radiometric correction is a critical processing step, as also small differences in radiometry can lead to miss-classification of forest-parameters.

Scenes within one track, which are acquired with from the same sensor need not be calibrated and can directly be appended. Radiometric calibration has therefore be applied for left track and right track scenes. As reference scene, right track (s3) has been selected.

As already mentioned the four scenes were recorded by two sensors simultaneously on the same platform, resulting in different radiometric values. In a first step these differences between the two scenes had to be corrected. Two approaches have been evaluated, firstly, **absolute calibration** with coefficients provided by Spot-Image, and secondly, **relative calibration** with linear regression.
For the relative calibration, a region covered with forests / rock / agriculture in the overlap area of left and right track were selected. As geometrical shifts in the order of one pixel size remain between the two geo-referenced image tracks, aggregation within 7x7 pixel windows with mean-value has been applied, which leads to a more stable regression as shown in below figure.

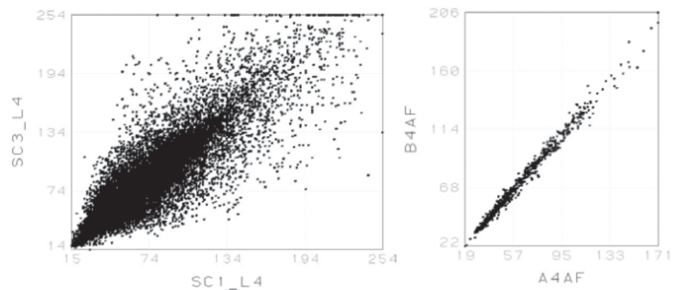

Abb1: Scattergramm von Band 4 im Überlappungsbereich der beiden Szenen. Links, original (nicht aggregierte) Pixelwerte; rechts, Pixelwerte aggregiert mit 7x7 Fenster und Mittelwerten.
Fig1: Scatter-gram of band 4 between left and right track in overlay region. Left, original (not aggregated) pixel-values, right, aggregated within 7 x 7 pixel windows with mean-value.

The results in Tab3 show that the approach using the linear regression (LinReg) yielded differences of less than one greyvalue, whereas the approach using the Calculation Coefficients (CalCo) came to more than 3.5 greyvalues difference. Consequently, the latter approach was omitted.

Tab3: Numerischer Vergleich der Berechnungsarten CalCo und LinReg.
Tab3: Comparison of the Results for CalCo and LinReg.

	mean LinReg.	stdv. LinReg.	mean CalCo	stdv CalCo	mean s3.(referenc e szene)	stdv s3 (referennce szene)	Difference LinReg - Ref	Difference CalCo - Ref
Band 1	71.743	8.643	72.731	8.721	71.423	8.707	0.32	1.308
Band 2	51.311	10.341	50.435	10.400	51.369	10.552	-0.058	-0.934
Band 3	67.749	21.289	67.720	21.439	67.524	21.060	0.225	0.196
Band 4	61.619	18.482	58.739	17.884	62.422	19.004	-0.803	-3.683

Tab4: Ergebnisse der relativen Kalibrierung für Waldgebiete.
Tab4: Results of Relative Calibration for Region mainly covered by Forests.

Band	mean ref.scene	stdv ref.scene	mean cal. scene	stdv cal. scene	grey-value difference
1	71.4	8.7	71.7	8.6	- 0.3
2	51.4	10.6	51.3	10.3	0.1
3	67.5	21.1	67.7	21.3	- 0.2
4	62.4	19.0	61.6	18.5	0.8

The critical point in this processing step was to reduce the differences between the two images as much as possible. Above results show, that mean grey-value differences in forested areas in all bands are below 1 digital number (DN). This difference can be seen to be suited for classification, as signature uncertainties are expected to be in the same range or above. After the performance of the linear regression, a mosaic was generated (see Fig2), which was the source for all following processes.

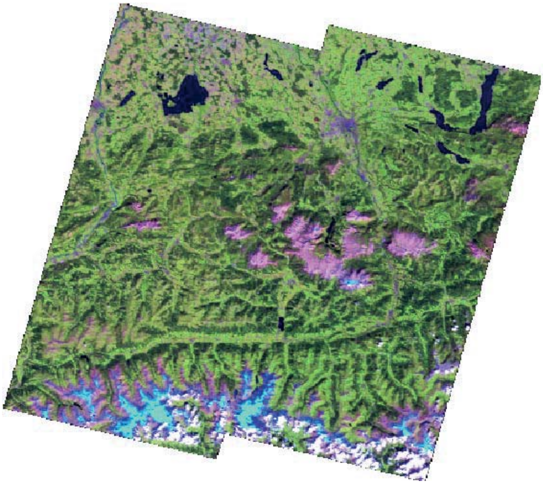

Abb2: Ergebnis nach erfolgter radiometrischer Anpassung und Mosaikierung.
Fig2: Showing the Mosaic of the Four SPOT Scenes after Radiometric Calibration.

Results Topographic Normalization

From the experience gained from several previous projects in the Alpine region the Minnaert correction model proved to be best and therefore was applied. For estimating the Minnaert constant, only forested areas, that fulfilled following requirements, were used:

- species types: spruce or broadleaf
- crown coverage of more than 80%
- timber age class

For the calculation of the Minnaert constant, 42 coniferous and 67 broadleaf areas were used. These sites were selected from the ground truth data delineated on CIR aerial photographs. The Minnaert constants, which result from the regression analysis within these reference areas, were then used for the topographic normalisation of the whole image.

For a classification within this magnitude it is an important step to reduce the efforts of reference data recording on one hand, but also to maintain a minimum amount of reference data on the other hand. These requirements can only be fulfilled if a topographic normalisation is performed. The achieved results satisfied the expectations, although it is obvious that the used digital elevation model (DEM) had not the desired quality, i.e. with a better DEM the results could be improved.

Results Signature Analysis

Separation of Spruce and Larch
The results of the signature analysis can be considered as satisfactory for the separation of larch trees from other species. As spruce and larch are often mixed up, it was necessary to define three mixed classes (see above). The feature space image in Fig3 displays the four main species (i.e. spruce, larch, pine and broadleaf). The NIR (near infrared) values are plotted on the x-axis and the MIR (mid infrared) values on the y-axis. The good separation of larch and spruce stands in the MIR band can clearly be seen.

Separation of Coniferous and Broadleaf
The separation of the four mixed coniferous / broadleaf classes was not strictly possible, but their distribution shows a clear trend, ranging from a low to high percentage of coniferous.

Similar findings were derived from the analysis of mixtures with larch. Once more, it can be stated that a higher share of coniferous leads to decreasing greyvalues in the NIR band.

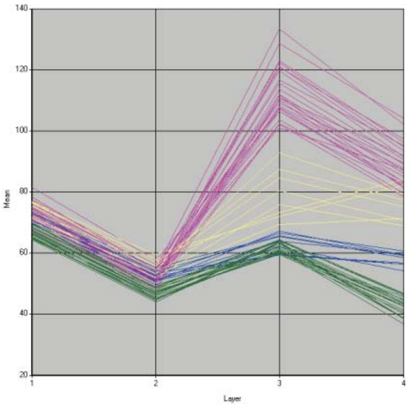

Abb3: Spektralkurven der 4 Hauptbaumarten (grün =Fichte, blau=Kiefer, gelb=Lärche, magenta=Laub).
Fig3: Spectral Curves of the 4 Main Tree Species (green=spruce, blue=pine, yellow=larch, magenta=broadleaf).

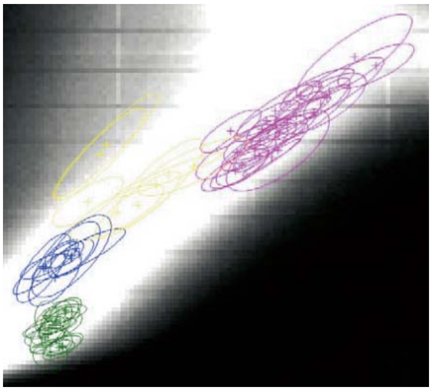

Abb4: 4 Hauptbaumarten im Merkmalsraum (grün=Fichte, blau=Kiefer, gelb=Lärche, magenta=Laub).
Fig4: Feature Space Image of the 4 Main Tree Species (green=spruce, blue=pine, yellow=larch, magenta=broadleaf).

Larch Stands
It can be stated that pure larch can be separated from pure spruce with a high probability. Within the group of larch stands a distinct separation of the two upper larch classes (i.e. 60%-90% share of larch and more than 90% larch) is not possible with high accuracy. The main

influence on their spectral behaviour comes from the understory if the crown coverage lies below 60% (e.g. in case of forest pasture with larch), which is in the majority the case for larch. Another important drawback was the too little number of larch stands.

Pine Stands

The separation of pine from the other species was possible, but with limited accuracy due to the same problem: the little number of reference sites.

Dwarf Mountain Pine

Dwarf mountain pine is distributed irregularly throughout the high mountain parts, often in the so called stunted forest zone. It is very often mixed up with larch or green alder. In this region the occurrence of rocks influenced the reflection of these stands, either within the stands or by over-radiation of the surrounding. These are maybe some of the reasons why the reflectance of this species has a high variance in the feature space, which makes it difficult to separate from other species.

Age Classes

The age classes could be separated with higher accuracy (see Fig5 and 6) than the crown coverage classes for coniferous. However, the separation for broadleaves is more difficult and can in general be considered to be derived with lower accuracy.

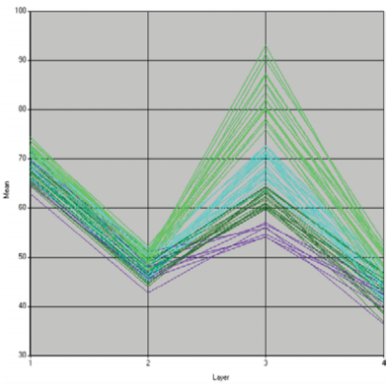

Abb5: Spektralkurven der Altersklassen für Fichte voll überschirmt (violett=Altholz, dunkelgrün=Baumholz, cyan=Stangenholz, hellgrün=Dickung).
Fig5: Feature Space Classes for Spruce Age Classes (violet=old timber, darkgreen =timber, cyan=pole, green=thicket).

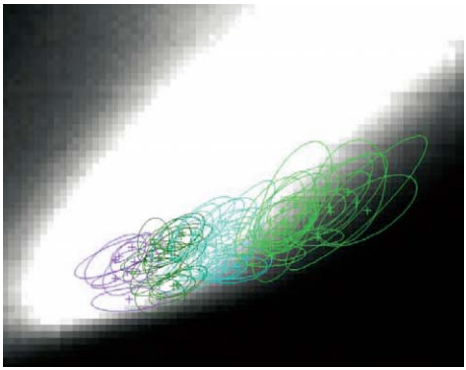

Abb6: Altersklassen im Merkmalsraum für Fichte voll überschirmt (violett=Altholz, dunkelgrün=Baumholz, cyan=Stangenholz, hellgrün=Dickung).
Fig6: Feature Space Classes for Spruce Age Classes (violet=old timber, darkgreen =timber, cyan=pole, green=thicket).

Results Classification

The whole classification process is an iterative one, therefore, the input variables were changed, e.g. without probabilities, with probabilities, or using feature space plots. For the classification the Maximum Likelihood classifier was applied.

From the statistical point of view the derived contingency matrices were determined from the training sites. Although this is only an indirect measure of the accuracies, it gave following numbers:

Parameters	Overall Accuracy in %	Kappa
Species Type	79.08	0.73
Crown Coverage	83.81	0.74
Age Classes	91.03	0.63

Although the classification results were satisfactory in general, some problems still remain and have to be investigated with the new SPOT5 data. In the following some of them are discussed:

- Broadleaf old timber was sometimes classified as thicket or pole due to the difficult assignment of age classes in broadleaves.
- Some of the smaller open areas were assigned to broadleaf, if it was covered by dense shrubs or similar vegetation, i.e. fern, vaccinium, rhododendron, because they reflect spectrally very similar.
- Stands with lower crown coverage, i.e. less than 50%, are sometimes classified as broadleaves or pine and with higher crown coverage. The reasons for these effects can be found in the occurrence of understory: green alder and rhododendron on one hand and dwarf mountain pine on the other hand. The influence of very young trees in these stands could not be observed due to the lack of very accurate reference.
- Pure pine stands could not be differentiated owing to the lack of reference sites and based on the fact that this species is underrepresented within the region.
- Dwarf mountain pine and swiss stone pine (pinus cembra) are often mixed up.
- Dwarf mountain pine can not be classified with high accuracy based on solely spectral features.
- Generally, crown coverage is classified higher if dwarf mountain pine grows within a stand.
- Spruce branches which are covered with lichen can be misclassified.
- If different age classes grow within a stand, the age class will often be assigned to older age class.

In Fig 7 the result for the parameter species distribution is displayed. Although this example shows only a few percentage of the entire classified region it demonstrates nicely the strong potential for large area monitoring.

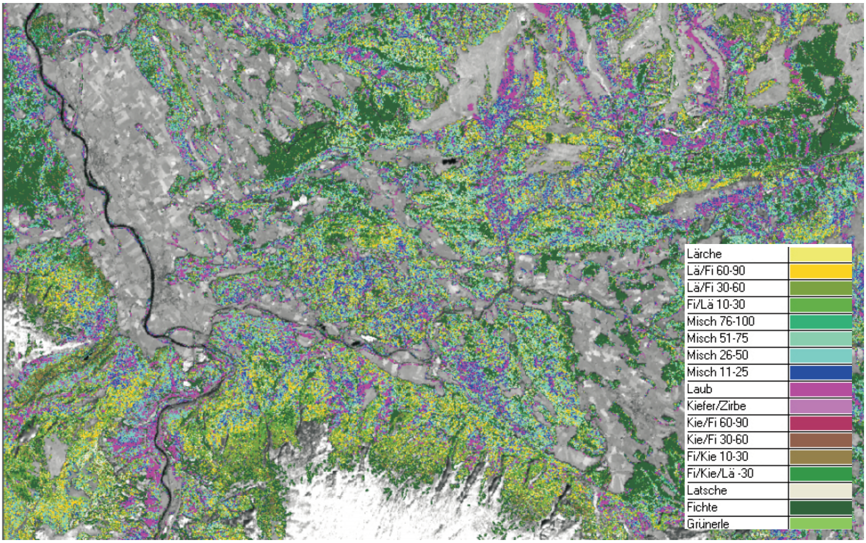

Abb7: Ausschnitt aus der Klassifikation für die Kategorien Baumarten und Baumartenmischungen.
Fig7: Classified Categories for Species Types.

CONCLUSIONS AND OUTLOOK

This application demonstrated that it is possible to obtain surface information from SPOT4 satellites with sufficient accuracy. However, to overcome the above listed problems some more research has to be done. Therefore, it must be emphasized that not only spectral features are to be considered as the only source, but also textural and object oriented information should be integrated for the parameter derivation. It has to be investigated how very high resolution data are appropriate to fill this gap.

The obtained results enable the planning personnel of the Forestry Service of Salzburg to integrate the derived quantitative forest parameters into their GIS. The planning and controlling of the protection forests demand a detailed and expanded inventory and monitoring capacity. The availability of the SPOT4 sensor can fulfil some of these demands.

After the ascertainment of the forest parameters it is foreseen to use the SPOT5 data for the derivation of the tectonic, geologic, geomorphologic and hydrologic parameters. The obtained results will be integrated with some other information into a decision support system, which is developed within a national project called HANNIBAL, to investigate and finally evaluate the risks for such hazards as mass movements, snow avalanches, and torrents in mountainous terrain.

ACKNOWLEDGEMENTS

The authors gratefully thank the Landesforstdirektion of Salzburg and especially Mr. Wilfried Luckel and Mr. Franz Klaushofer, for their funding, collaboration and support. They also have to thank the Austrian Federal Ministry of Traffic, Innovation and Technology for its funding.
They thank the Landesbaudirektion Tirol, Federal Office and Research Centre for Forests (BFW), and the National Park Hohe Tauern for providing ancillary data.

LITERATURE

Buchroithner, M.F. and Granica, K. (1997): Applications of Imaging Radar in Hydro-Geological Disaster Management: A Review. Remote Sensing Reviews, Vol. 16, Harwood Academic Publishers, Graz/Dresden, pp. 134.

Colby J.D., 1991: Topographic normalization in rugged terrain. Photogrammetric Engineering and Remote Sensing, Vol. 57, No. 5, pp. 531-537.

ERDAS 1997. Field Guide, Fourth Edition, U.S.

Granica, K. und Schmitt, U. (1993): Feasibility Study in the Use of Satellite Remote Sensing as a Fast Reaction Tool for Natural Disaster Relief, Proc. 25th ERIM International Symposium: Remote Sensing and Global Environmental Change, I-604 - I-610, Graz, Austria.

Granica, K., Schardt, M. and Gallaun, H. (2000): Monitoring of Protection Forests by Means of SPOT4 Satellite Data, 20th EARSeL Symposium, 14th – 16th June, 2000, Dresden, Germany, to be published.

Hill, J. & Mehl, W. (1995): Improved forest mapping by combining corrections of atmospheric and topographic effects in Landsat TM-imagery. Sensors and Environment Applications of remote sensing, Askne, 1995 Balkema, Rotterdam, ISBN 90 5410 5240.

JOANNEUM Research 1998. RSG in ERDAS Imagine. TOUR GUIDE, Version 2.0, 1997.

Meyer P., Itten K.I., Kellenberger T., Sandmeier S. and Sandmeier R., 1993: Radiometric correction of topographically induced effects on Landsat TM data in an alpine environment. ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 48, No. 4, pp. 17-28.

Raggam, J., Strobl, D., Buchroithner, M.F. and Almer, A. 1991. RSG-Workstation Software for Geometric Multisensor Data Processing. ISPRS Conference, Digital Photogrammetric Systems, September 3-6, Munich, pp. 313-325.

Schardt, Mathias, Klaus Grancia, Heinz Gallaun, Michaela Ziegler, Andreas Wimmer, Roland Wack (2002): Assessment of Forest Parameters by Means of Remote Sensing for Protection Forests Planning and Controlling, Int. Symp. Ecological and Economic Benefits of Mountain Forests, Innsbruck, Sept. 15th-18th, 2002.