Photogrammetrie • Fernerkundung • Geoinformation 2/2005, S. 147–156, 3 Abb., 3 Tab.

Native Forest Mapping in Patagonian Andes Based on Optical Satellite Imagery

JOSE D. LENCINAS & MARIA F. FARIAS, Esquel/Argentinien

Keywords: remote sensing, forest mapping, Patagonian Andes, Nothofagus forests, classification, SPOT data

Summary: Data derived from optical satellite sensors have been increasingly utilized as a source of data to inventory native forests in Argentinean Patagonia, mostly due to the difficulty of accessing vast, rugged areas, where native forests are placed. This study focuses on the classification process applied to map native *Nothofagus* forest, as well as the identification of the critical factors that affected it. The study area corresponds to the watershed of La Plata and Fontana lakes, covering 1,256 km^2. Both types of SPOT 4 sensor data, multispectral and panchromatic mode, were used. A combination of supervised classification and a binary hierarchical procedure was utilized. The classification revealed a total area of 44,484 ha of Lenga (*Nothofagus pumilio*) forests and 5,791 ha of Ñire (*Nothofagus antarctica*). The classification accuracy for Lenga class was better than that for Ñire (95% and 80% of user's accuracy respectively). Some justifications for these results and recommendations for future classifications are given.

Zusammenfassung: *Waldkartierung für die Patagonischen Anden auf der Grundlage von optischen Satellitenbildern.* Optische Satellitensensoren werden im argentinischen Patagonien immer häufiger als Datenquelle für Inventuren in Naturwäldern herangezogen, da diese vorwiegend ausgedehnte Flächen unzugänglichen, gebirgigen Geländes bedecken. Die vorliegende Studie behandelt den Klassifikationsprozess zur Kartierung von *Nothofagus*-Naturwäldern sowie die Identifizierung dafür kritischer Faktoren. Das Untersuchungsgebiet umfasst das Einzugsgebiet der Seen La Plata und Fontana mit einer Fläche von 1256 km^2. Zum Einsatz kamen sowohl multispektrale als panchromatische Daten des Sensors SPOT 4, die Klassifizierung erfolgte in Form einer Kombination von überwachter Klassifikation und einer binär-hirarchischen Methode. Das Ergebnis zeigte eine Gesamtfläche von 44.484 ha Lengawäldern (*Nothofagus pumilio*) und 5.791 ha Ñirewald (*Nothofagus antarctica*). Die Klassifikationsgenauigkeit für Lenga lag mit 95% höher als für Ñire mit 80% „user's accuracy". Einige Erklärungen der Ergebnisse sowie Empfehlungen für zukünftige Inventuren werden gegeben.

1 Introduction and objective

The large extent and inaccessibility that characterize the natural forests in Patagonian Andes have led surveys to be done by means of remotely sensed data. The first inventory of native forests in Patagonia was carried out in 1986, based on analogue products from Landsat MSS and black and white aerial photographs at scale 1:60 000 (IFONA 1986). Later, classical techniques, such as aerial photography, have demonstrated not to be cost-effective in Patagonia, therefore, the mapping of forests has been based chiefly on satellite imagery. Data acquired by Landsat TM have been the most commonly used. Vegetation thematic maps from Patagonia are available mostly at scale 1:250 000, and only for a few small commercial forested areas at scale 1:100 000. Federal and provincial programmes related to environmental issues and regional foresters have an increasing special need for forest maps at scales from 1:25 000 to 1:100 000.

Topography, specially in mountainous regions like Patagonian Andes, causes geo-

1432-8364/05/2005/0147 $ 2.50

metric and radiometric distortions to satellite sensor data. Digital elevation models (DEM) with proper spatial resolution are not yet available in Patagonia. On the other hand, publications about the geometric correction of satellite imagery using map-derived ground control points (GCPs) have reported sub-pixel accuracy (FORSTER et al. 1988, MICHAELIS 1988), but large-scale maps from Patagonia do no exist, and the available 1 : 100 000 topographic maps date from the 1960s. Both natural and man-made land changes have converted these existing maps into obsolete material, therefore, they are not a reliable source from which to extract GCPs. When neglecting the atmosphere influence, the topography-induced differential illumination is the most important scene related effect in Patagonian Andes. In order to minimize it, a DEM with at least the same spatial resolution than that of the scene, is an absolute requirement (ITTEN et al. 1992). The current local limitations for correcting the geometric and radiometric impact of topography are the major reasons for the slow development of automatic classification approaches of satellite imagery. The classification of satellite data is still done manually, and therefore, accuracy has never been measured (LENCINAS 2001).

This study was the first phase of a project focused on the land use planning for the watershed of lakes La Plata and Fontana. For this, it was essential to inventory the native forests of Lenga (*Nothofagus pumilio*), which is the main tree species in the region. Time constraints due to the advanced summer season would not allow a carefully planned forest inventory. In addition, the low available budget needed of a quick and accurate forest mapping, with minimum costs of field work.

The objective of this study is to determine efficiently the stratum of Lenga forests at scale 1 : 50 000.

2 Study Area

The study area corresponds largely to the watershed of lakes La Plata and Fontana in Province of Chubut, Patagonia, Argentina. This area lies between 44° 44′ S and 45° 03′ S, and 71° 20′ W and 72° 04′ W, on the eastern side of the Andes range. It stretches 57 km from east to west and 20 km from North to South, covering 1256 km^2 (Fig. 1). The main tree species is Lenga (*Nothofagus pumilio*), which appears in pure stands from the lakeshores up to the tree line. In areas that are sheltered from the wind, Lenga trees can reach up to 26 m in height, whereas in snowy areas that suffer from very strong winds, mainly near the tree line, they form shrub forests. Lenga forests have a complex pattern of structure types, and 90 % of the stands have multiple canopy layers (LENCINAS 2002). The second tree species in order of importance in the area is Ñire (*Nothofagus antarctica*). It has a shrubby appearance and is found in lower areas of shallow soils, or it appears before other species in the ecological succession after fires.

The relief is mountainous and rugged, with very steep slopes. The main ridges of the Andes, with the highest summits in the area, run along the west side of the study area, over Mount Dedo (2020 m), north of lake La Plata and Mount Catedral (2062 m) to the south. The lakes' level lies at approximately 900 m a.s.l. The area is almost inaccessible. There are two main roads running along the north and south banks of lake Fontana, up to River „Unión“, which links both lakes. There are also a few forest roads used for skidding, which are mostly in poor maintenance condition and only a few of them are passable with cross-country vehicles.

Precipitation in the study area falls mostly as snow and varies significantly, from about 2500 mm yr^{-1} in the western part of the area to 500 mm yr^{-1} over the eastern part.

3 Materials and Methods

3.1 *Satellite sensor and ancillary data*

The digital data used in this study were acquired on January 1, 1999 by SPOT 4. An image in multispectral Xi mode and an image in monochromatic P mode were purchased. Both of them had been preprocessed

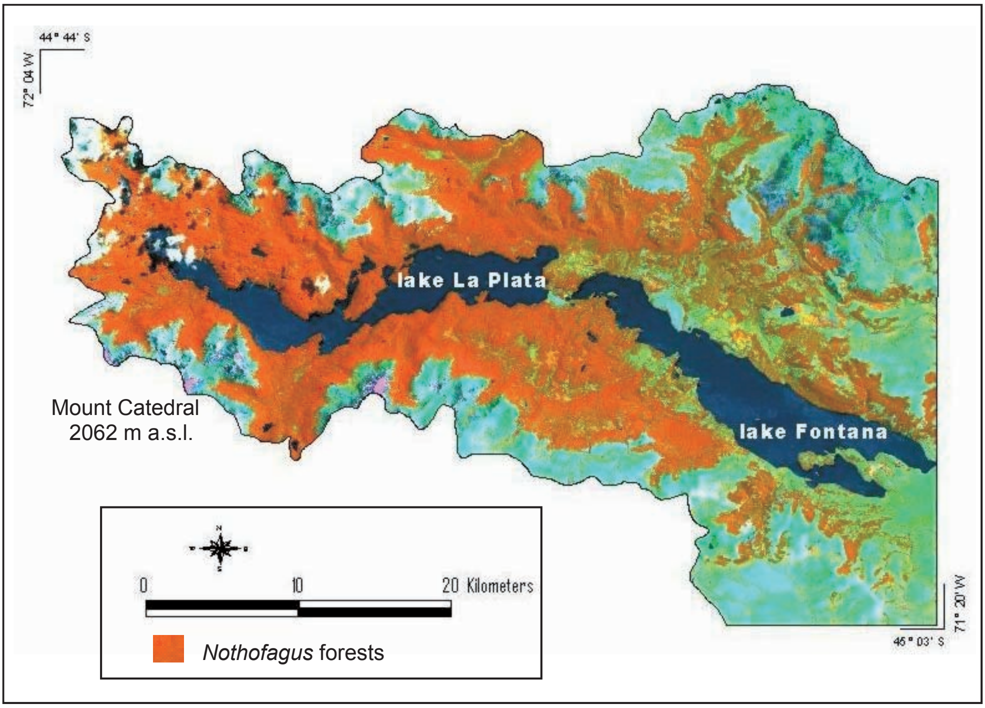

Fig. 1: An enhanced SPOT 4 scene (Bands 3,4,2) of the study area.

to the 1B level and contained a minimum amount of cloud cover. The geometric and radiometric quality of the images were excellent. System corrections did not cause duplicate lines. No radiometric errors due to possible failures of the sensor system were found. Summer images were required in order to optimize the spectral contrast between vegetation and other surfaces such as bare soils and water, and to minimize the topographic influence on the illumination.

As a large part of the vegetation in the northern shore of Lake Fontana was razed by a fire in February 1999, a Landsat TM image from March 1999 was purchased by CONAE (Comisión Nacional de Actividades Espaciales, Argentina), in order to identify and map the burnt area.

A DEM from the study area was generated, based on the digitized topographic maps at scale 1:100 000. The model was then converted to raster and resampled to 20 m, i.e. the same as the SPOT data resolution. However, the true spatial resolution of the generated DEM is 250 m (SIEBERT 2001).

3.2 *Hardware and Software*

GCPs were collected using Trimble GeoExplorer II portable receivers. These data were subjected to differential correction by means of Trimble Pathfinder software, version 2.11. The processing of the remotely sensed data and the DEM was carried out on a Silicon Graphics O2 R5000 work station, using ERDAS Imagine 8.3 software at CIEFAP (Patagonian Andes Forest Research and Extension Centre). The DEM was generated with ArcInfo 7.2 (Unix) at the Department of Biometry at the Georg-August-University of Göttingen, Germany.

3.3 *Geometric corrections*

The GCPs that can be extracted from the existent topographic maps at scale 1:100 000 should be considered as poorly accurate (the accuracy for both X and Y coordinates is about 100 to 150 m). Because point accuracy had to be at least 10 m, GCPs were acquired and corrected differentially (SA distortion still existed by the time). Geometry of satellites and obstructions to satellite signals had been taken into account so as to make the conditions of acquisition of as high quality as possible (August et al. 1994). Data were collected with a PDOP (positional dilution of precision) mask of six, a signal-to-noise ratio threshold of five, and an elevation mask of 15 degrees. Data used as reference in the differential correction were obtained from a portable receiver, previously set as a base station, placed at a first-order National Geodetic Survey control point. While the base station was operating, 500 sequential fixes (continuously logged at a rate of approximately one per second) were collected by the rover at each location of interest. Differential correction was computed in the laboratory.

In order to obtain accurate GCPs, sites must be chosen carefully on the image and then measured on the ground (Clavet et al. 1993). The Xi image was found to be more suitable for this purpose than the P image, because of the high contrast among land, vegetation and water features. In the study area there were only a few identifiable locations created by human intervention (e.g. intersections of roads, bridges) that could be chosen as GCPs. However, there were some natural features that could be clearly identified on the image, such as intersections of small streams, edges of water bodies, islands, river outlets and small tree patches. For the field work, several colour prints were made from the SPOT Xi image with identifiable pixels. The field workers needed to make use of all-road vehicles, trekking and boats to reach the selected points.

35 GCPs and check points, distributed as uniformly as possible, were surveyed in the area between the lake's shore level and 1150 m a.s.l. Due to the difficulty of access and the high costs implied, no points were taken at the highest altitude.

The SPOT Xi image was rectified by means of a second-order affine transformation method, using 26 ground control points. For the resampling, a nearest neighbour interpolation was applied. The P image was registered to the Xi image using 30 GCPs. A subset from the Landsat TM image was also registered to the SPOT Xi image to map the burnt area.

3.4 *Radiometric corrections*

Since reliable data concerning visibility and relative humidity to correct the atmospheric effects were not available, a haze removal technique on the dark value principles (Chavez 1975) was applied. Digital numbers were then converted to reflectance values. To compensate the topographic influence on the illumination, a radiometric DEM-based approach would have been necessary (Teillet et al. 1982). As the generated DEM had low spatial resolution, a DEM-based approach was not used. Instead, a vegetation index (Xi3-Xi4) was produced within the classification scheme, to minimize for topographic effects.

3.5 *Masking*

Clouds: Clouds and their shadows in the SPOT Xi image were masked out by visual interpretation.

Water: The water boundaries digitized from the topographic maps did not correspond exactly to the actual conditions, due to the small scale of the maps and the natural timely variation of the lakes shore. Nevertheless, in order to improve the visual interpretation, a water mask had to be generated. First, the PCA method was used to merge the information contents of Xi and P data. This method maintains the original spectral information (Welch & Ehlers 1987) or produces only slight distortions (Chavez et al. 1991). The water mask was then derived by means of a pixel-by-pixel visual interpretation of the 10 m merged data. The new generated polygons representing water bodies were compared to the polygons extracted from the digitized topografic maps.

Forest type	Xi1		Xi2		Xi3		Xi4	
	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Lenga forest	1	0,2	1,2	0,3	21,7	3,3	8,5	1,2
Lenga shrubs	1,1	0,3	1,6	0,3	25,3	3,1	10,1	0,9
Nire	2,1	0,5	2,9	0,6	15	1,3	12,1	0,9

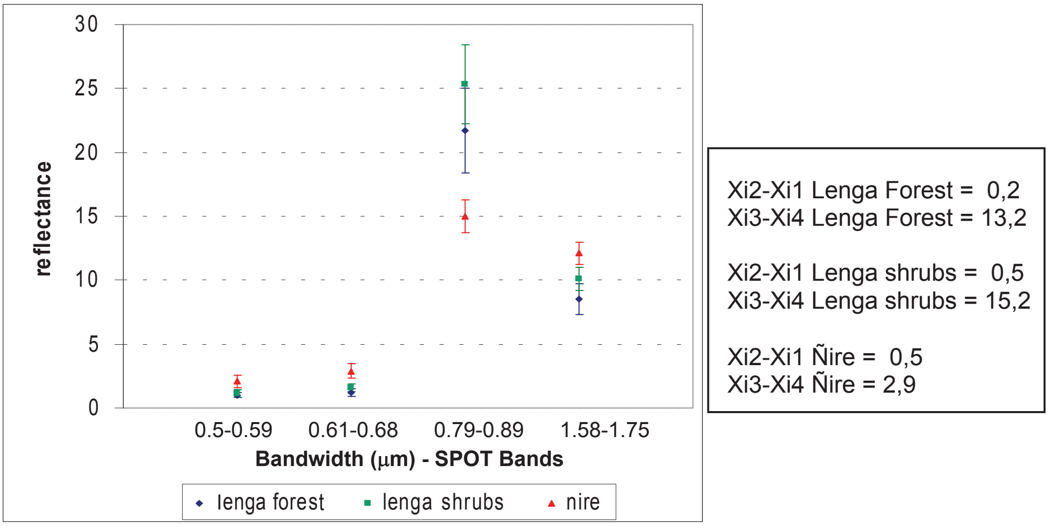

Fig. 2: Comparison of the reflectance of Lenga, Lenga shrubs and Ñire for all SPOT bands. Error-bars show the strength of overlap. Standard deviation of the reflectance values, as well as differences between bands for the forest types are shown in separate boxes.

Vegetation: To mask out the non-vegetation class, the Transformed Vegetation Index (TVI) (Deering et al. 1975) based on the Xi data bands was applied.

3.6 *Spectral profiles analysis and training area selection*

In order to analyse the reflectance of the vegetation classes of interest, their respective spectral profiles were extracted. The vegetation classes were: Lenga forests, Ñire forests and Lenga shrubs. The latter group refers to Lenga forests with a shrubby appearance, which is found at high altitudes (i.e. above 1150 m a.s.l.). To determine the spectral profiles based on spectral SPOTs bands of these vegetation classes, thirty point samples for each class were taken randomly. Then, the mean of each thirty-sample group of reflectance values was extracted, for all spectral bands. Finally, the absolute difference among the reflectance values for bands Xi3 and Xi4 was calculated for all classes. Fig. 2 depicts the spectral profiles for each class, mean value and standard deviation, and the absolute differences among the values for all bands.

The training areas for each vegetation class were selected on the basis of prior surveys and knowledge of the study area. Five training areas were selected for grasslands, five training areas for Ñire forests, and eight for Lenga forests. Each training area was represented by a 4 × 4 pixel matrix. The statistic contents of the signature file aided to the determination of their separability in the multi-dimensional attribute space.

3.7 *Classification process and ground data*

A combination of a supervised classification utilizing the maximum likelihood algorithm and a binary hierarchical procedure was used in this study (see Fig. 3).

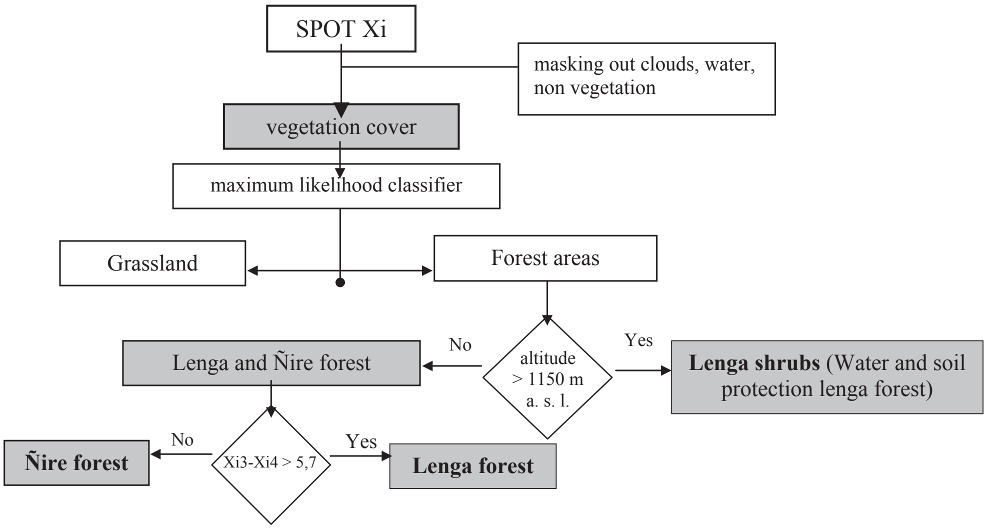

Fig. 3: An overview of the classification process.

The vegetation cover class was the result of multiplying the SPOT Xi data by the cloud, water and non-vegetation masks. For the classification, the SPOT bands Xi2, Xi3 and Xi4 were used and the signatures were considered with all classes set to equal probability. Those bands correspond nearly to the TM3, TM4 and TM5 bands and are the most suitable for forest cover mapping (Horler & Ahern 1986).

As shown in Fig. 3, the vegetation cover was segmented into forest areas (Lenga and Ñire) and grassland areas, by using the maximum likelihood classifier.

An ANOVA test showed that Lenga forest, Lenga shrubs and Ñire could be considered as different populations, significant at 0.05 level, for SPOT bands 3 and 4.

In order to set a threshold value to discriminate Lenga from Ñire forests in the classification process, the difference Xi3-Xi4 was calculated for the maximum and minimum values of three standard deviations from the mean value of each class. The minimum value for the synthetic band difference for Lenga forest was 6.4; whereas the maximum value for Ñire class was 4.1. The mid value 5.7 between these extremes was set as a threshold to differentiate Lenga forest from Ñire classes.

Altitude data, derived from the DEM, was included as additional information, in order to solve the overlap between Lenga and Ñire forest classes with Lenga shrubs class, when considering only the spectral values.

The determination of the burnt area was accomplished through a visual digitizing on the Landsat TM image, whereas the assessment of the affected types of vegetation was derived from the automatically classified SPOT data.

3.7.1 *Accuracy assessment*

Results of a per-pixel classification should be considered as point classifications, and the validation should be based on the sampling of individuals pixels (Janssen & Van der Wel 1994). The thematic accuracy was assessed by comparing samples of the classification result with ground reference data. Neither up-to-date aerial photographs nor thematic maps from the study area were available. Ground truth data were available only from the Lenga forest areas. In 1996, the native commercial forests of Chubut Province were inventoried, by using a systematic sampling method. Nineteen clusters were installed in potentially commercial

Lenga forests (stand mean height > 10 m), which were placed between the lakes level and 1200 m a.s.l. The sample units were clusters, square tracts of 300 m × 300 m, containing a circular sample plot of 500 m^2 in each vertex. In 1999 were installed 44 clusters in order to carry out a forest inventory and the sample units were square tracts of 60 m × 60 m (Lencinas 2002).
Because of time constraints, 11 samples were generated using random sampling, as reference data for Ñire forests. Then, they were inspected in the field during the fieldwork, which was primarily meant for collecting ground control points. Furthermore, the surveys was mainly focused on the mapping of Lenga forests rather than Ñire forests.

From an error matrix, overall producer's and user's accuracy were calculated. To glean as much information from the error matrix as possible (Congalton 1991), Kappa$_{hat}$ coefficient was computed.

4 Results

4.1 *Rectification*

A RMS of 0.26 pixels (5,2 m) was obtained in the rectification of the SPOT Xi data. A positional accuracy of 15m was determined by comparing the result of the rectification with checkpoints. It should to be kept in mind, that the obtained precision refers to the range of elevation covered by the GCPs. The P image was registered to the Xi image attaining a RMS of 0.2 pixels (2 m). The subset of the Landsat TM image was also registered to the Xi image, with a RMS of 0.9 pixels (27 m).

4.2 *Masks*

The areas with water bodies digitized from topographic maps were compared visually to the water mask derived from satellite sensor data. Differences in position of the shoreline of up to 120 m were assessed. The surface of the major lake of the study area, lake Fontana, measured on the topographic map was 8 307 ha whereas the water mask made from the satellite data showed 8 196 ha, which indicates a difference of 111 ha. The reason for the differences is the dubious precision of the topographic maps, due to the year of creation and small scale. In addition, being they so old (form 1949) it is highly probable that the shape and position of the shore line have changed with time.

4.3 *Classification of the vegetation*

The *Nothofagus* (Lenga and Ñire) forests cover an area of 50 275 ha, of which 44 484 ha are Lenga forests and 5 791 ha are Ñire forests (Tab. 1). 2600 ha of the total forest area were burnt.

4.4 *Accuracy assessment*

Information about the accuracy of Lenga and Ñire classes are shown in Tabs. 2 and 3.

Tab. 1: *Nothofagus* forest in the study area.

Forest strata	Area (ha)
Lenga shrubs (above 1150 m a.s.l.)	18 870
Lenga forests (under 1150 m a.s.l.)	24 900
Ñire	3 905
Lenga*	714
Ñire*	1 886

* Burnt areas

Tab. 2: Error matrix of the forest classification derived from the SPOT Xi data.

	Reference data		
Classified data	Lenga	Ñire	Row total
Lenga	63	3	66
Ñire	2	8	10
Column total	65	11	76

Tab. 3 Parameters for the evaluation of the error matrix.

	Producer's accuracy	User's accuracy	Overall accuracy	K_{hat} coefficient
Lenga	96 %	95 %	93 %	72 %
Ñire	72 %	80 %		

The producer's and user's accuracy for the Lenga class were fairly good and for Ñire were relatively low. It was confusing when it came to discriminate Ñire and Lenga classes, because the user's accuracy for Ñire was 80 %. The overall classification accuracy was 93 %, and the K_{hat} statistic was 72 %.

5 Discussion

Satellite data
The pushbroom system of Spot's HRVIR sensor allowed the acquisition of digital data of high geometric and radiometric quality.

GPS
In Patagonia, the use of GPS technology has improved the accuracy of those maps produced on the basis of satellite data. With the acquired GCPs by using GPS, a database has been implemented. This will surely diminish the costs of future surveys for the rectification of imagery as well as accuracy assessments in the area.

The distortions caused by relief displacements on the images could not be removed. These distortions are not eliminated neither during the system correction nor during the geocoding with polynomial transformations (ITTEN et al. 1992).

Masks
The differences found in the form and localization of water boundaries extracted from topographic maps and those derived from analogue interpretation of Xi-M merged data, are due to cartographic generalization and actual changes of water bodies. The water mask derived from Xi-M data was more suitable for the processing of the satellite data.

DEM
Despite the fact that the generated DEM could not be used as a basis for radiometric corrections, it was utilized as ancillary data in order to identify vegetation strata according to different altitudes above the sea level. SIEBERT (2001) generated a DEM for an area in Patagonia by means of P images from SPOT 4 but the costs are still very high. A concrete possibility for Patagonia region is to create DEMs from ASTER data (ECKERT & KELLENBERGER 2002).

Radiometric Correction
The applied radiometric corrections were not successful, since the shapes of the „reflectance" values do not correspond to green peak, typical for green vegetation, and the average reflectance in band Xi1 is too small (see Fig. 2). Worth is mentioning that OCHSNER (2003) obtained fair results utilising ATCOR3 (RICHTER 2001) for correcting a Landsat 7 scene from a mountainous Patagonian region.

Accuracy
Although the producer's accuracy for Lenga class was rather good, it was not high for Ñire class (72 %). There are patches of Ñire forests with similar structure (trees of 11 m height) than Lenga forest. Provided that no assessment of accuracy for classifications has ever been done nor publicated in Patagonia, there are no parameters to establish a comparison. The values of the overall accuracy (93 %) and Kappa coefficient (72 %) indicate that the agreement in the classification was good, better than one obtained by chance. These results must be however considered with extreme care, since the sample size for the reference data was not optimal. CONGALTON (1991) suggests that a good rule of thumb is to collect a minimum of 50 samples for each category in the error matrix. Reference ground pixels for the grassland category were not considered and therefore could not be included in the error matrix. Thus, new reference samples would have to be taken for all the established classes in future works concerning digital classification of satellite data.

Classification
JAAKKAOLA et al. (1988), TOMPPO (1988) and HAGNER (1990) concluded that Landsat TM was more appropriate than SPOT1 to map and extract vegetation parameters. Unlike SPOT 1, SPOT 4 has an additional spectral channel, which increases significantly its overall suitability for mapping vegetation.

The procedure applied to classify vegetation in this study represents one of the pioneer steps aimed to develop a methodology that could be reproduced automatically, for Patagonian Andes area.

The results of the classification process for SPOT data are promising and quite adequate for mapping Lenga forests in this area. Durrieu (1995) concluded that forest mapping can be done at scale 1 : 50 000 from SPOT data. A thematic forest map from the study area at scale 1 : 50 000 was generated. This represents an up-to-date improvement on the existent vegetation maps, which are at a coarse scale of 1 : 250 000.

6 Conclusions

SPOT multispectral data allow the generation of thematic maps with improved and more detailed information than the old fashioned and small scale forest maps in Patagonia. In Patagonia, GPS receivers are currently the most adequate and sometimes the only way of collecting GCPs for the geometric correction of satellite sensor imagery with high and medium spatial resolution. It is extremely important to generate DEMs effectively, in order to correct geometrically and radiometrically digital data from satellite imagery and to integrate them to the classification process as well. In order to count on reliable information about the accuracy of the classifications it is important to achieve a proper sampling of the reference data. This study shows just a small part of the great challenges that remotely sensed data analysts and developers have yet to face, in order to map and monitor the extensive Andean-Patagonian forests.

7 References

August, P., Michaud, J., Labash, C. & Smith, C., 1994: GPS for environmental applications: accuracy and precision of locational data. – Photogrammetric Engineering & Remote Sensing, **60** (1): 41–45.

Chavez, P.S., 1975: Atmospheric solar and MTF corrections for ERS digital imagery. – Proceedings of American Society of Photogrammetry Convention, Phoenix, Arizona.

Chavez, P., Stuart, C. & Anderson, J., 1991: Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. – Photogrammetric Engineering & Remote Sensing, Vol **57** (3): 295–303.

Clavet, D., Lasserre, M. & Pouliot, J., 1993: GPS control for 1 : 50 000-scale topographic mapping from satellite images. – Photogrammetric Engineering & Remote Sensing, **59** (1): 107–111.

Cochran, W.G., 1972: Stichprobenverfahren. – Berlin.

Congalton, R., 1988: A comparison of sampling schemes used in generating error matrices for assessing the accuracy of maps generated from remotely sensed data. – Photogrammetric Engineering & Remote Sensing, **54** (5): 593–600.

Congalton, R., 1991: A review of assessing the accuracy of classifications of remotely sensed data. – Remote Sensing of Environment, **37:** 35–46.

Deering, D.W., Rouse, J.W., Haas, R.H. & Schell, J.A., 1975: Measuring forage production of grazing from Landsat MSS data. – Proceedings 10th International Symposium on Remote Sensing of Environment, Ann Arbor: ERIM, **2**: 1169–1178.

Durrieu, S., 1995: Experience of remote sensing in forestry. – New Tools for Agriculture and Forestry Statistics, Porto, October 1995.

Eckert, S. & Kellenberger, T., 2002: Qualitätsanalyse automatisch generierter digitaler Geländemodelle aus ASTER Daten. – DGPF, Band **11**: 337–345.

Forster, B.C., Trinder, J.C., Carroll, D., Farrington, R. & Kwoh, L., 1988: Mapping and urban multi-experimental assessment of SPOT-Mapping results. – SPOT 1 Image Utilization, Assessment, Results. Cepadues-Editions, Tolouse, France, 1289–1295.

Hagner, O., 1990: Computer aided forest stand delineation and inventory on satellite remote sensing. – Proceedings SNS/IUFRO workshop in Umeâ, 26-28 February, 94–105.

Horler, D.N.H. & Ahern, F.J., 1986: Forestry information content of Thematic Mapper data. – International Journal of Remote Sensing, **7:** 405–428.

IFONA (Instituto Forestal Nacional), 1986: Precarta Forestal Nacional. – Provincia del Chubut.

Itten, K.I., Meyer, P., Kellenberger, T., Leu, R., Sandmeier, S., Bitter, P. & Seidel, K., 1992: Correction of the impact of topography and atmosphere on Landsat TM forest mapping of alpine regions. – Remote Sensing Series **18**, Zürich.

JAKKOLA, S., POSO, S. & SKRÄMO, G., 1988: Satellite remote sensing for forest inventory. Experiences in the Nordic countries. – Scandinavian Journal of Forest Resources **3:** 545–567; Stockholm.

JANSSEN, L.F. & VAN DER WEL, J.M, 1994: Accuracy assessment of satellite derived land-cover data. A Review. – Photogrammetric Engineering & Remote Sensing, **60** (4): 419–426.

LENCINAS, J.D., 2001: Untersuchungen zur Entwicklungsplanung für die Naturwaldbestände an den Seen la Plata und Fontana in den patagonischen Anden. – Cuvillier Verlag, Göttingen, Germany, ISBN 3-89873086-7.

LENCINAS, J.D., 2002: Stand volume estimation from satellite data employing two-phased sampling. TS 35. – 29th International Symposium on Remote Sensing of Environment, Abril 2002, Buenos Aires, Argentina.

MICHAELIS, M., 1988: A geometrical analysis of SPOT data. SPOT 1 Image Utilization, Assessment, Results, Cepadues-Editions, Tolouse, France, 1235–1243.

OCHSNER, P., 2003: Waldbestandes-klassifikation mit Landsat-7 ETM+ Daten in Chubut, Patagonien. – Diplomarbeit, Geographisches Institut der Universität Zürich, 70 S.

RICHTER, R., 2001: Atmospheric and topographic correction: Model ATCOR 3. – DLR-Deutsches Zentrum für Luft- und Raumfahrt, Wessling, Deutschland.

SIEBERT, A., 2001: Untersuchungen zur Erfassung topographischer Informationen aus SPOT-Daten. – Magisterarbeit, Georg-August-Universität Göttingen, Germany.

TEILLET, P., GUINDON, B. & GOODENOUGH, D., 1982: On the slope-aspect correction of multispectral scanner data. – Canadian Journal of Remote Sensing, **8** (2): 84–106.

TOMPPO, E., 1988: Standwise forest variable estimation by means of satellite images. – Proceedings of the IUFRO Subject Group 4.02.05 Meeting in Finland, University of Helsinki, Department of forest mensuration and Management, Research Notes **21:** 103–111.

WELCH, R. & EHLERS, M., 1987: Merging multiresolution SPOT HRV and Landsat TM data. – Photogrammetric Engineering & Remote Sensing, **53** (3): 301–303.

Anschrift der Autoren:

Dr. JOSÉ DANIEL LENCINAS
M Sc. MARÍA FLORENCIA FARIAS
Remote Sensing and GIS Lab, CIEFAP
Ruta 259, km 4, CC 14,
9200 Esquel, Argentina
Tel./Fax: ++54-2945-453948
e-mail: JDLencinas@gmx.net
florenciafarias@hotmail.com

Manuskript eingereicht: November 2004
Angenommen: Januar 2005