ENVISAT MERIS for country-wide estimates of forest and mountain vegetation in Sweden

H. Reese[*], S. Joyce, H. Olsson

Remote Sensing Laboratory, Department of Forest Resource Management and Geomatics, Swedish University of Agricultural Sciences, SE-901 83 Umeå, SWEDEN– (Heather.Reese, Steve.Joyce, Hakan.Olsson)@resgeom.slu.se

Abstract – Reflectance-calibrated MERIS data were used to classify Swedish land cover. Three MERIS full-resolution scenes from the same date covered Sweden in one swath. Mountain vegetation was handled as a separate stratum. Clusters from unsupervised classification were identified using photo-interpreted 1-km² samples from the new National Inventory of Landscapes in Sweden (NILS). Coarse classes fitting FAO's LCCS scheme were classified. Discriminant analysis of classes and MERIS spectral responses identified bands 3, 5, 9 and 14 giving the best result for non-mountain vegetation, but for mountain vegetation, bands 5, 7, 9 and 14 were preferred. The MERIS Terrestrial Chlorophyll Index (MTCI) was investigated, but gave no advantage in classification. Comparing the classification to the Swedish Land Cover data gave 58% and 63% overall accuracy for mountain and non-mountain, respectively. There was no indication that the many narrow spectral bands in MERIS significantly improved the possibilities for classification in the boreal zone. Furthermore, problems with geometry and misalignment with water masks in the level-2 product were noted.

Keywords: MERIS, land cover classification.

1. INTRODUCTION

The Medium Resolution Imaging Spectrometer (MERIS) is a sensor onboard the ESA ENVISAT satellite. MERIS pixels in full resolution mode have a nominal ground resolution of 260m x 290m. The sensor registers 15 narrow spectral bands in the blue to NIR range (Rast *et al*. 1999). MERIS is originally designed for ocean color monitoring, however the sensor is also being proposed for terrestrial applications in national to global scales (Verstraete *et al*. 1999). Interesting features of MERIS for such applications are the many narrow spectral bands, enabling red edge detection, and also the good signal to noise ratio for dark targets like vegetation (Gower and Borstad, 2004).

1.1 Objectives

The aim of this paper is to investigate the feasibility of using MERIS for large area land cover mapping in the boreal zone. Global land cover studies with MERIS and similar sensors (e.g., GLOBCOVER, www.gofc-gold.uni-jena.de/sites/globcover.html) are often carried out by centrally located groups with limited access to ground truth. Thus, the present feasibility study is motivated by the fact that we are a national group with more access to ground truth data within our national territory than is normally available for an international consortium in a production phase.

The classification accuracies obtained, as well as the practical problems occurring when using MERIS for land cover classification are reported. This includes an attempt to improve the classifications using the MTCI surrogate red edge index (Dash and Curran, 2004).

An unsupervised classification to derive land cover classes from the MERIS data was carried out. Field data for identification of clusters was taken from the newly started National Inventory of Landscapes in Sweden (NILS) in which a nation-wide sample of 1 km² quadrates are photo interpreted. Furthermore, identification of preferable band combinations for the classification was done using supervised discriminant analysis of the MERIS data against aggregated NILS data. The accuracy of the unsupervised classification was judged by comparison to the Swedish Land Cover (GSD) classification.

1.2 The ENVISAT MERIS sensor

The MERIS sensor consists of 5 separate CCD arrays with optical modules that cover a combined 68.5° field of view for a swath width of 1150km at nadir. Standard MERIS products available to end users are designated full resolution, with a nominal ground resolution of 260m x 290m, or reduced resolution which are 4X4 block averages of the full resolution product. Scene sizes are 575km or 1150km square for the full resolution and reduced resolution products respectively. Radiometric processing is available to top-of-atmosphere radiance (level 1) or geophysical quantities including surface reflectance over land (level 2).

1.3 The Swedish landscape

The forests of Sweden cover 22.6 million ha of the 41.0 million ha land area (Skogsstyrelsen, 2003), with primarily boreal forests in middle and northern Sweden, and more dominated by broad-leaved species in the south. Forestry is a dominant activity in Sweden, both privately and commercially with around 3 billion m³/ha cut per year (Skogsstyrelsen, 2003). The mean stand size is approximately 2 ha in the south and 10 ha in the north of Sweden. The mountain area of Sweden covers approximately 4.4 million ha and is dominated primarily by heath vegetation. Wetlands cover 4.6 million ha and agricultural land covers 3.5 million ha (Skogsstyrelsen, 2003).

2. DATA

2.1 MERIS

Among the scenes available from summer 2003, we were able to obtain three full resolution level-2 (surface reflectance) scenes from orbit 7548 track 480 acquired on the 10th of August, 2003. The band wavelengths were programmed for the standard MERIS band settings, but lacked bands 11 and 15. The three scenes were generally cloud free except for along the northeast coast and the eastern coastal areas in the south. Together the scenes cover the total land area of Sweden.

According to the MERIS Product Handbook (ESA, 2003), the MERIS reflectance samples calculated from raw data are relocated to a MERIS Product Grid with a central column oriented along the satellite orbit path projected on the earth surface. Geo-positioning of MERIS samples in the product grid is accomplished using tie points derived from the calculated satellite position and arranged so they are evenly spaced along the satellite swath. The data in the product grid is originally nearest-neighbor (NN) resampled from the MERIS raw data by interpolating between these tiepoint positions.

We were able to re-project the MERIS scenes to the Swedish National Grid (RT-90) by first converting the supplied tie-point positions from WGS84 to RT-90 coordinates, and then warping the images by triangulation between tie-point positions. We chose triangulation since the tie-point grid is dense (every 64 MERIS pixels) and accurately located. Resampling was done with a cubic convolution kernel to an output grid resolution of 250m. This seemed to result in good geometric accuracy when compared to other map data and other precision corrected satellite images. Some artifacts and position errors are unavoidable due to the fact that the level-2 product is already NN-resampled from the raw data and terrain correction is calculated from a coarse resolution DEM. After re-projecting the three scenes from 2003-08-10 onto the Swedish National Grid, we mosaicked the three scenes for the same satellite track to cover all of Sweden.

2.2 NILS

NILS is a part of the national environmental monitoring activities of the Swedish Environmental Protection Agency (EPA) and includes all terrestrial environments. NILS is carried out through a nationwide random (systematic) sample of 631 quadrates (Esseen et al., 2003). The "landscape quadrate" is 5x5 km and inventoried every 5 years. NILS is based on aerial photo interpretation and field measurements focused on a 1x1 km quadrate in the center of each landscape quadrate. The inventory is based on over 100 variables collected for each sample. The photo-interpretation is made from 1:30 000 scale orthophotos and records a smaller number of variables than the field survey. At the time of this study, 60 photo-interpreted quadrates were available. Due to issues of scale concerning the NILS and MERIS data, the field plots were not used in this project.

2.3 Swedish Land Cover Data

The National Mapping Agency distributes the Swedish Land Cover Data (GSD) which has been developed from Landsat data. It has 59 land cover classes which correspond to the FAO classification scheme and has a mapping resolution of 1 to 5 ha. The GSD dataset has an area-weighted overall accuracy of 74% (Röst and Ahlcrona, 2004). The EU-CORINE land cover classification is a generalization that was derived from this product.

2.4 Forest regeneration boundary

A vector layer which represents the boundary in Sweden between productive and non-productive forest land known as the "regeneration boundary" created by the Swedish Forestry Board was used.

3. METHODS

3.1 Unsupervised classification

Due to the limited number of photo-interpreted quadrates available at the time of the project (60 quadrates out of 631), an unsupervised classification was chosen for testing MERIS's potential in mapping of terrestrial vegetation. Clouds were masked from the mosaicked image, and a single image consisting of bands 3, 5, 7, 8, 9, 10, and 14 was then divided into two images: one of the mountainous area in western Sweden, and the other of non-mountainous forested area. The forest regeneration boundary was used for this purpose.

For each separate image an ISODATA clustering was run with 40 clusters each. Using the NILS plots overlayed on the MERIS data, classes were assigned from the NILS plots to the clusters. Since there were not sufficient quadrates to assign all clusters, the MERIS data and the 5x5 km orthophotos from which the NILS data are interpreted were also consulted. The classification scheme was based on Swedish Land Cover Data/CORINE classification system. For the mountainous area, these classes are bare rock, grass heath, other heath, alpine meadow/willow, coniferous forest, deciduous forest, snow/ice and water. For the non-mountain forest areas classes were coniferous forest, sparse coniferous forest, deciduous forest, mixed forest, clearcut, wetland, agriculture, urban and water.

3.2 Discriminant analysis

To investigate the discrimination of different land cover classes with MERIS data, a supervised discriminant analysis was run using assigned classes from the NILS data and the spectral response from the corresponding MERIS pixel. The NILS photo-interpretation covers a 1x1 km square, which corresponds to an area of 16 MERIS pixels. Approximately one or two MERIS pixels could be associated with a single land cover type from each NILS quadrate. This was done manually, not automatically. Fifty-four plots were chosen for the non-mountain area and 25 for the mountain area. Different band combinations, including the MERIS Terrestrial Chlorophyll Index (MTCI; Dash and Curran, 2004), were tested in the discriminant analysis. MTCI is a surrogate red-edge position index which is basically calculated as a ratio using the standard position for MERIS bands 10 (center at 753.47 nm), 9 (center at 708.43 nm) and 8 (center at 680.90 m).

3.3 Accuracy Assessment

Random plots were created for each of the two classifications in order to make an accuracy assessment using the Swedish Land Cover Data as "ground truth."

4. RESULTS AND DISCUSSION

4.1 Unsupervised classification

The result of the accuracy assessment for the mountain area is shown in Table 1 and the non-mountain forest area in Table 2. The overall accuracy for the mountain classification was 58% and for the non-mountain forest classification, 63%. There is however, an apparent over-classification of the dominant classes in each classification; heath is over-classified in the mountainous area, while coniferous forest is over-classified in the non-mountain forest area. While the cause has not been closely investigated, it is at least in part due to the coarse resolution of the MERIS pixel. As a comparison, Clevers et al. (2004), obtained a 50 % overall accuracy for a seven class MERIS land cover classification of the Netherlands.

Another classification problem in the non-mountain forest image was that of deciduous forest. Due to the less prevalent and often smaller areas of deciduous forest in Sweden, combined with the problem of cloud cover in the southern broad-leaved dominated area of Sweden, the classification and accuracy for the deciduous class was under-represented.

	Rock	Gr. heath	Ot. heath	Meadow	Conif.	Decid.	Snow/Ice	Wetland	Water	Total N	Correct%
Rock	2	1	1				1			5	40
Gr. heath		2	1							3	67
Ot. heath		1	12			3		3		19	63
Meadow			1	0						1	0
Conif.					4	1		1	1	7	57
Decid.			2	1	2	5		1		11	45
Snow/Ice							0			0	0
Wetland								0		0	0
Water									4	4	100
Total N	2	4	17	1	6	9	1	5	5	50	
Correct %	100	50	71	0	67	56	0	0	80		
Overall	58%										

Table 1. Result of the mountain area classification with GSD data as columns and the MERIS classification in rows.

	Conif	Sp Conif	Decid	Mixed	Clearcut	Wetland	Agric	Urban	Water	Total N	Correct%
Conif	24	5	1	1	1	4	1			37	65
Sp Conif	4	9	1	1		1				16	56
Decid			4		1		1			6	67
Mixed	2		1	0	2	1				6	0
Clearcut			1		9		2			12	75
Wetland						2				2	100
Agric					2		1			3	33
Urban								0		0	n/a
Water									8	8	100
Total N	30	14	8	2	15	8	5	0	8	90	
Correct %	80	64	50	0	69	25	20	n/a	100		
Overall	63%										

Table 2. Result of the non-mountain forest area classification with GSD data as columns and the MERIS classification in rows.

The pixels labeled as mixed forest tended to be mixes of all cover types often in a very heterogeneous landscape with mixes of forest, clearcuts and wetlands. The wetland class was also easily mixed with other cover types, perhaps due to spatial resolution as well as spectral similarity to other cover types, and suggests the utility of a wetland mask for better separation. In a similar light, agricultural fields and clearcuts were easily confused with each other, most likely due to their spectral similarity, and either aggregating the two into a class of "lacking vegetation" or using a map mask will help this division.

In the mountain area, the confusion between wetlands and heath was so large that a wetland class was not identified in the mountain classification, and it indicates the need to classify the wetlands separately in some manner. There was a surprising confusion between alpine birch and sparse coniferous forest near the mountain border. There may be a need to use a more precise boundary to separate the mountain area from the productive forest land area.

In summary, the classification was satisfactory overall for coarse land cover classes, however, certain problems due in part to the spatial resolution of the pixel need to be resolved to obtain a better classification. The classification is shown in Figure 1.

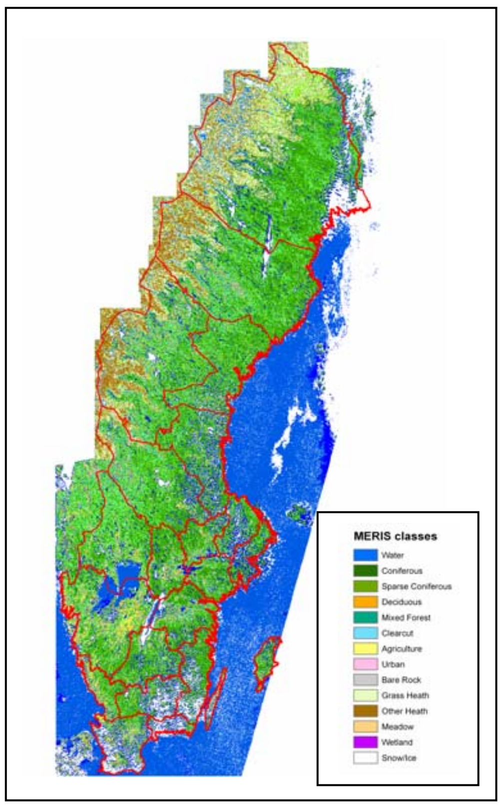

Figure 1. Land cover classification of the MERIS data.

4.2 Using the NILS data

The NILS photo-interpretation covers a 1x1 km square, which corresponds to an area of 16 MERIS pixels. Due to the heterogeneous nature of the landscape, it was not an easy task to identify different "pure" land cover types in the MERIS classification. Usually, one or two MERIS pixels could be associated with a single land cover type from each NILS quadrate. This association of the NILS data with the MERIS data was done manually, not automatically. Good geometric correction of the MERIS data is absolutely necessary for combination with the NILS data; however, this wasn't always the case, as is discussed in the next section.

The results from the discriminant analysis showed that the band combination giving the best class discrimination for the non-mountain areas was bands 3, 5, 9, and 14. In this combination, the class assignment was made with an overall 76% accuracy. For the mountain area, bands 5, 7, 9 and 14 gave the best class discrimination with 84% correct class assignment (no wetland class is present here because it was not identifiable in the mountain NILS quadrates). When the MTCI was included in the discriminant analysis for either mountain or non-mountain areas, the class assignment was not improved (84% for bands 5, 7, mtci, 14, and 74% for bands 3, 5, mtci, 14, respectively). It appeared that inclusion of band 9 was sufficient information as compared to calculating MTCI. When all plots for both mountain and non-mountain areas were considered together, the class assignment fell to 60% correct assignment, with the largest problems in discriminating the coniferous class and the wetland class.

4.2 On the MERIS data

During the course of this work we encountered several problems with the MERIS data that made it difficult to use for the intended purpose. The image geometric precision derived from the tie point grid appeared quite good at first glance, with good alignment with other map data along coastal areas. However, when trying to use MERIS data together with the NILS plots, it was clear that the geometry could be off locally, especially in areas with significant terrain. This is due to the fact that the tie points are derived from orbit parameters without the use of ground control, the method for handling horizontal displacement due to terrain is rather coarse, and the product grid is already nearest-neighbor resampled. In some cases the NILS plots were clearly displaced by several pixels when overlaid on the MERIS image. Such a displacement makes it difficult to relate the MERIS samples to field data and rules out the use of spectral mixture analysis.

We also encountered radiometric artifacts near lakes where it appeared that different reflectance calculation parameters are used over land versus water. It appeared that the water mask used was rather course and in some cases poorly located, resulting in significant areas of erroneous reflectance values in the vicinity of inland lakes, coastlines, and especially in the mountain areas.

4.3 Future directions

Sensors such as MERIS, which have good radiometric properties but limited spatial resolution, provide data which could be used to drive large area biophysical models. They also provide a source of multi-temporal data, which could show the spectral development over the vegetation season and between years. With this in mind, research using coarse resolution satellite data is important for preparation in utilizing the next generation of weather satellite data such as NPOESS VIIRS.

5. CONCLUSIONS

The land cover classification of MERIS data into broad land cover classes similar to those used in international classification schemes such as FAO's LCCS gave a result of 58% and 63% accuracy for the mountain and non-mountain strata respectively. Division into strata for mountain and non-mountain areas improved the classification, but an even more precise boundary (such as that from CORINE) may improve the classification. In Sweden, the forest and agricultural land are managed by patches on the order of 5 ha in mean size. Thus, MERIS data might be better used to mirror and follow trends on a more aggregated level. However, in the mountain areas of Sweden, land use is dominated by reindeer herding and tourism, and the landscape is not managed in small patches. In the mountains the vegetation season is short, the cloud frequency is high, and there is limited access to image data. Thus, sensors like MERIS may be well-suited for monitoring the mountain areas, more-so than for managed forest land.

Some of the factors influencing the classification results in this study include the heterogeneous landscape in Sweden, the confusion of similar land cover types such as agricultural fields and clearcuts, the scale issues that arise when using reference data such as 1 km^2 photointerpretation with coarse scale satellite data, and the necessity of good geometry in the MERIS data. Good geometry of the MERIS data is necessary if map masks or spectral mixture analysis is to be used in future work.

It could not be shown that the many narrow spectral bands of MERIS significantly improved the land cover classifications. Neither could it be proven that a red-edge measure (MTCI) improved the classification. Furthermore, in this study there were some technical problems with the level-2 MERIS data, such as limited geometric accuracy and misalignment of the water mask used during the radiometric calibration.

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