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CSIR SATELLITE APPLICATIONS CENTRE: EARTH OBSERVATION SERVICE CENTRE PROGRESS REPORT: GLOBAL LAND COVER MAP SA

PREPARED FOR:

CHIEF DIRECTORATE OF SURVEYS AND MAPPING

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CONTENTS

TABLES

FIGURES

1. INTRODUCTION

The sustainable management of natural resources has become a fundamental aspiration, hence the constant need for exact and up-to-date resource data (Van der Merwe 2005). The repeated compiling of applicable and advanced spatial information on the distribution of land cover resources is crucial in dealing with important environmental questions. This spatial information presents a better understanding of natural resource utilization problems and forms the foundation for the identification of appropriate strategies for sustainable development (Kidane 2004). However, the flexibility and rate with which such data are produced are fundamental. In this framework, satellite remote sensing has been one of the most successful methods for land cover data acquisition and is therefore decidedly appropriate for many challenges that are related with the spatial distribution of phenomena on the earth's surface. The spatial and temporal distribution of land cover consists of a key dataset for a wide range of studies in the physical and social sciences, as well as government agencies for land planning purposes (Stefanov, Ramsey & Christensen 2001). Satellite remote sensing is essential for continuous monitoring, change detection and mapping of land cover data (Burrough 1993, Kidane 2004).

The launch of the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra (December 1999) and Aqua (May 2002) observation satellites started a new phase in essential studies, such as environmental, climate, vegetation, pollution, global warming, and many other important economic and environmental issues (Justice *et al.*, 2002). The two MODIS instruments provide both a morning (MODIS Terra) and afternoon (MODIS Aqua, Equatorial time: 13:30) measurements. Significant enhancements were made to MODIS with regard to better spatial resolution, more spectral bands and enhanced radiometric calibration in comparison to previous coarse resolution satellites. MODIS consist of 36 spectral bands, a 12-bit radiometric resolution and a 23 330 km wide field of view, which make it a significantly improvement to any other global coverage moderate/coarse resolution satellites for monitoring and mapping. The objective of MODIS is therefore to provide a comprehensive series of global observations of the Earth's land, oceans, and atmosphere in the visible and infrared regions of the spectrum.

2. TRANSLATION OF AGGREGATED CLASSES

2.1 Methodology

The LCCS system consisted of a dichotomous and hierarchical phase. The dichotomous phase followed strict rules and consists of three levels. A reclassification of SANS 1877:2004 classes to the dichotomous phase classes was straightforward. A reclassification of the NLC2000 classes to classes defined in the hierarchical LCCS phase was not that easy and workshops organized by the CDSM attended by SAC employees were required to reach consent on a suitable translation.

2.2 Results

The translation of NLC2000 classes to LCCS and GLCN classes was done before spatial aggregation of the NLC2000 product, as thematic aggregation of related NLC2000 classes is necessary before a MODIS classification product simulation can take place (Appendix A).

3. AGGREGATION OF NLC2000 LAND COVER

3.1 Methodology

The aggregation of the NLC 2000 to conform to the LCCS requires, insight into technical aspects on the generation of the previous NLC 2000 product, the LCCS, mapping and GIS fundamentals. The NLC 2000 product has been generated from imagery with a higher spatial resolution and should form the basis for a simulation of a MODIS derived land cover product with a minimum mapping unit of 1km x 1km. A two-step approach was undertaken:

1. A maximum statistical filter was run over the 30m NLC2000 product after weighting the classes according to importance, the product was resampled to 250m spatial resolution.
2. A majority statistical filter was then run over the resulting 250m product; the product was then resampled to 1000 m.

3.2 Results

The translated and aggregated resample 250m and 1000m spatial resolution NLC2000 Land cover products were compiled with eighteen (18) LCCS/GLCN classes. The results are tabulated in Appendix A and represented in Figure 1.

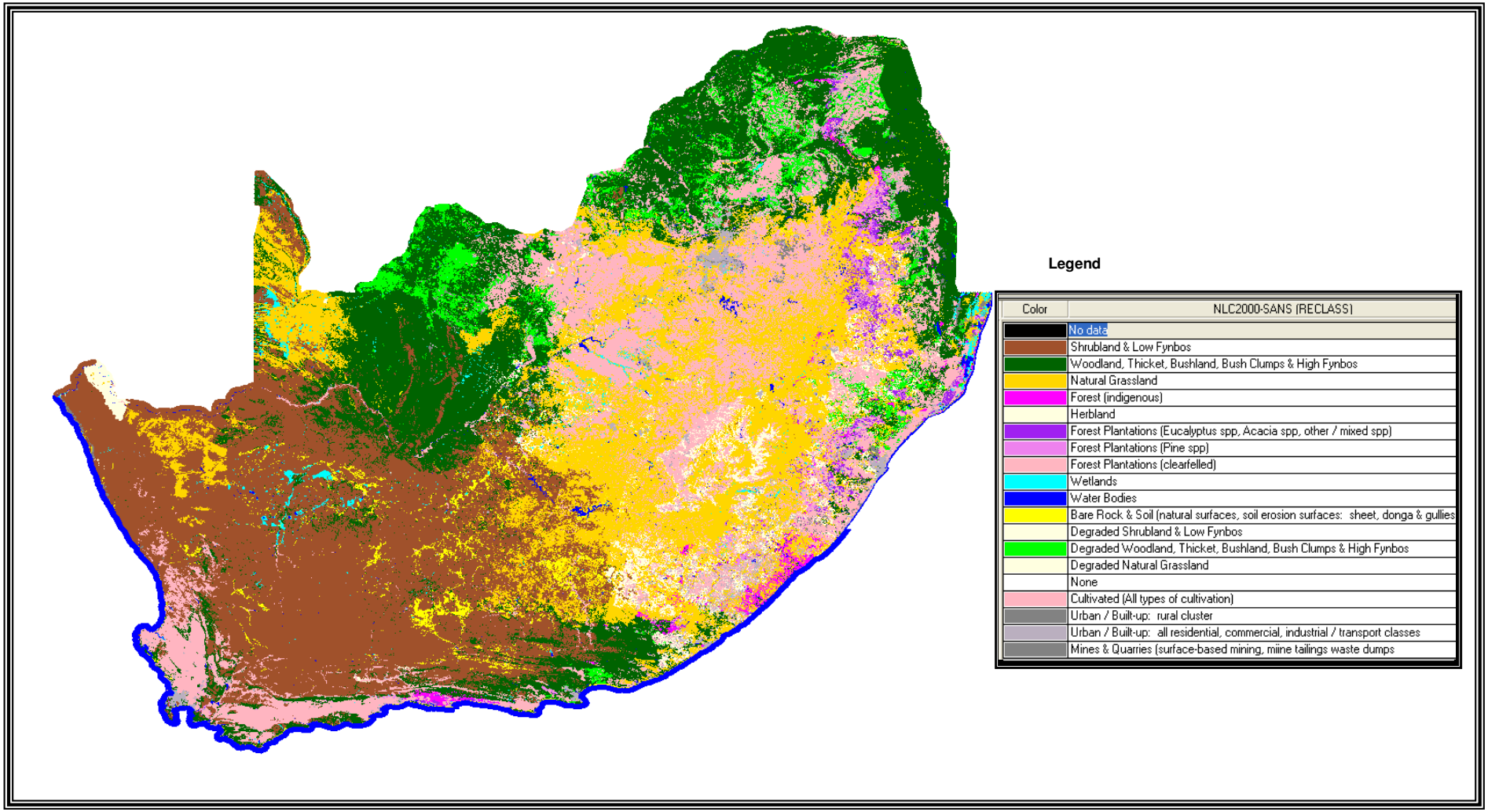

Figure 1: Aggregated NLC2000 Land Cover Classes

4. UPDATE OF AGGREGATED CLASSES USING MODIS IMAGERY

4.1 Data and Methodology

A huge advantage of using MODIS imagery for a Land Cover classification is its high temporal revisit time and the availability of a wide range of higher-level products developed for standard distribution. Land cover classes can be described in terms of their reflectance behavior over time often referred to as phenology.

The spatial resolution of satellite remote sensing data has an important influence on the accuracy that can be achieved in land cover classification. The extent of errors is a function of the spatial resolution, the original size of the land cover classes as well as the spatial patterns of the classes (Moody & Woodcock, 1994). Thematic classes can be defined by hard rules with discrete properties defined by the data, or probability associations with value gradients defining classes in terms of association probability. This classification is often referred to as fuzzy and gives an indication of the stability and reliability of the classification and is why it is being preferred by the scientific community. This product entailed a pixel based fuzzy classification produced by statistically derived rules. The MODIS land cover classification was purely pixel based and provided as 1km raster grid.

MODIS imagery (version 004) has been released in the Sinusoidal projection, which is not totally supported by most existing software packages. Native MODIS data files are stored in HDF-EOS (Hierarchical Data Format – Earth Observing System), a file format that does not currently have wide support. The MODIS Reprojection Tool (MRT) supports different versions and projections. The MRT software is designed to help work with MODIS data by mosaic and reproject MODIS image tiles into more standard map projections. The mosaic images were reproject into the Albers Conical Equal Area projection and resampled with the Cubic Convolution resampling Type. The images were then imported into ERDAS IMAGINE software.

The methodology followed was mostly dependent on the 250 m MODIS data products in order to have a closer approximation of the resolution of the NLC2000 than the 500 m or 1 km bands available. This involved the creation of various derivatives (variables) of the multi-temporal MODIS products (e.g. NDVI/EVI) signal per pixel and use of these

derivatives in the decision-tree-type Knowledge Classifier in ERDAS IMAGINE 9.1 to create land cover classes compatible with those used in the NLC2000. The derive variables were chosen specifically to characterize the phenology of vegetation, as reflected by the multi-temporal NDVI/EVI signal, which could be related to land cover types. These were the same classes as set out in the aggregated and reclassification of the NLC2000 above.

The next step was the process of collecting training areas for multivariate analysis to determine which variable (MODIS product) is suitable for the decision-tree-type Knowledge Classifier. The aggregated NLC2000 resample product (250m resolution) was used for collecting the training areas. The area covered by each land cover class was calculated from this product and inversely represented on a raster layer. A constant was added to a randomly generated raster layer, which in turn was multiplied with this class frequency raster layer. The allocation of the dominant class in this area to the sample point was selected via a GIS spatial process. The values were extracted as vector points from this dataset representing areas to be analyze for further statistical analysis.

The final step was to make use of a decision-tree method through the Knowledge Classifier in ERDAS IMAGINE 9.1. The modular expert systems approach is flexible as it allows for the alteration and enhancement of individual rule-based simple models, while incorporating satellite and GIS data (Kidane 2004). In this method the developed expert classification model consists of hierarchical levels of simple and combination models (Figure 2).

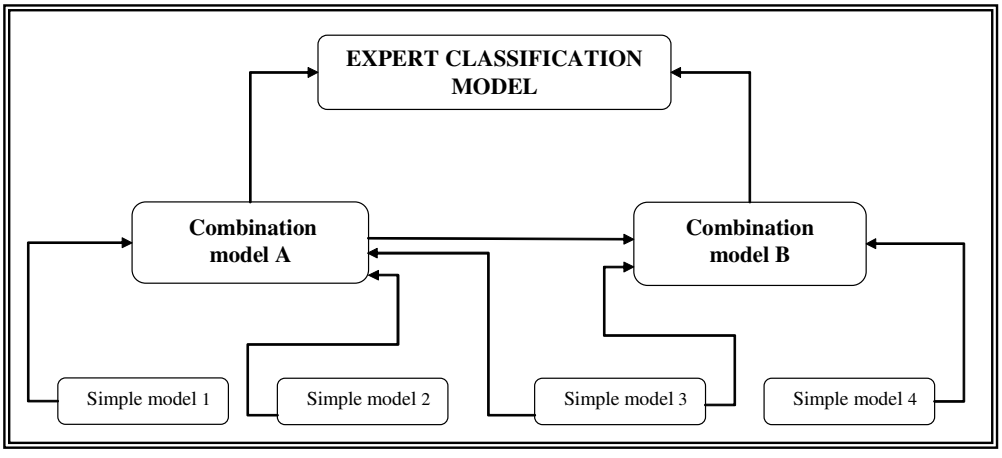

Figure 2: Expert classifier model structure

Simple models represent the lowest level of the expert classifier structure (minimum NDVI, seasonal positive chance in EVI and PCA values). Simple models output results that can be used by combination models (spatial operation model). Simple models use certain algorithms and/or rules. Rules are simply recipes that can be followed to create the land cover data product. They have a condition part that can contain one or more prototype clauses and an action part that creates the data product (Argialas & Harlow 1990).

The decision-tree type of classification was performed on the time-series data generated for the period (June 2005 to June 2006). The use of the Knowledge Classifier necessitates and allows for an improved understanding of the behaviour of the multi-temporal MODIS products (e.g. NDVI/EVI) signature of various land cover classes.

4.2 Results

4.2.1 Processed Satellite Remote Sensing Products

A wide range of MODIS data-products, EarthSat and SPOT5 images were acquired and processed. The MRT Tool was used to process the MODIS data tiles (4 tiles for each composite):

1. **MOD09A1:** Twenty (20) Surface reflectance Image Composites (500m, 8day composites, June 2005, September 2005, December 2005, March 2006, Bands 1-7) - Obtained from EOS Data Gateway, USGS (Table 1).
2. **MOD09Q1:** Twenty (20) Surface reflectance Image Composites (250m, 8day composites, June 2005, September 2005, December 2005, March 2006, Bands 1-2) - Obtained from EOS Data Gateway, USGS (Table 1).

Table 1: MODIS Surface Reflectance

Band	Λ (μm)	Resolution (m)
1	0.62-0.67	250
2	0.842-0.876	250
3	0.459-0.479	500
4	0.545-0.565	500
5	1.230-1.250	500
6	1.628-1.652	500
7	2.105-2.155	500

3. **MOD12Q1:** One (1) Land cover type Image Composite (1000m, Yearly-2004, Land Cover Type 1-5) - Obtained from EOS Data Gateway, USGS.
4. **MOD13A1:** Twelve (12) Vegetation Indices Image Composites (500m, 16day composites, range from June 2005 to June 2006, Bands - NDVI, EVI, NIR, MIR, BLUE, RED) - Obtained from EOS Data Gateway, USGS.
5. **MOD13A3:** Twelve (12) Vegetation Indices Image Composites (1000m, monthly composites, range from June 2005 to June 2006, Bands - NDVI, EVI, NIR, MIR, BLUE, RED) - Obtained from EOS Data Gateway, USGS.
6. **MOD13Q1:** Twenty four (24) Vegetation Indices Image Composites (250m, 16day composites, range from June 2005 to June 2006, Bands - NDVI, EVI, NIR, MIR, BLUE, RED) - Obtained from EOS Data Gateway, USGS.
7. **MODSAVI:** Twelve (12) Vegetation Indices Image Composites (500m, monthly composites, range from January 2004 to January 2005, NDVI) – Obtained from CSIR-Meraka.

For each MODIS data composite, a name convention was followed to standardized the data analysis and classification processes and for future reference. Figure 3 explains the naming convention for the original file names. The naming convention of the new file names is presented in Figure 4.

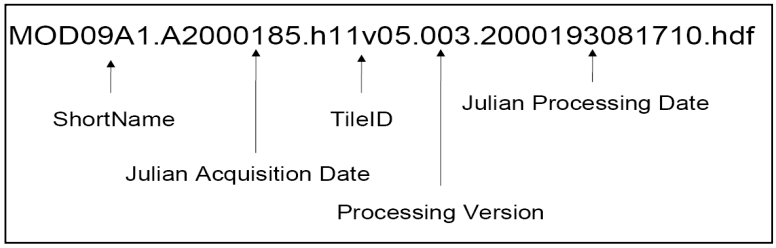

Figure 3: Naming convention of the original file name

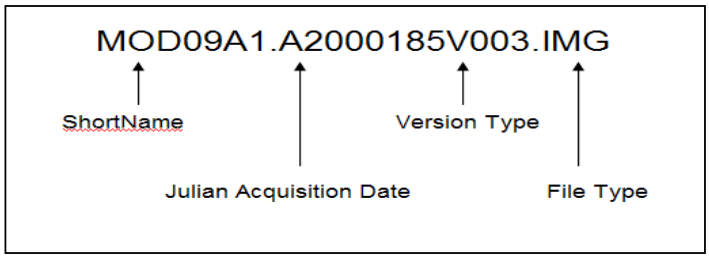

Figure 4: Naming convention of the new file name

8. EARHTSAT Images: (15m spatial resolution) - Obtained from CSIR-SAC.
9. SPOT5 mosaic Image: (2.5m spatial resolution) - Obtained from CSIR-SAC.

4.2.2 Processed GIS Products

GIS spatial data layers were acquired and processed (e.g. reproject and mosaic) to define a set of spatial operations for the Land cover classification model:

1. SRTM DEM (60m spatial resolution)
2. Topographic analysis - Aspect and Slope layers (percentage and degrees) were derived from the DEM.
3. Additional ancillary vector data, e.g. Vegetation map of SA, nature reserves borders and game parks, towns, roads, etc.

4.2.3 Collection of Training Areas

The 1000 randomly generated vector samples which were calculated, representing statistically sufficient samples for the training areas of each Land cover class (minimum of 40) to be classified

4.2.7 Processed and selection of Satellite Remote Sensing Products (variables)

The statistical derivatives (metrics) that were developed from the MODIS products time series and applied in this decision-tree classification included:

1) **PCA** (MOD09A1 & MOD09Q1 – Surface reflectance, 8 day composites),
2) **Maximum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
3) **Minimum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
4) **Median NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
5) **Standard deviation NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites)
6) **Monthly Positive and Negative change in NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites) during the year,

7) **Seasonal Positive and Negative change in NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites)
8) **Summer Maximum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
9) **Summer Minimum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
10) **Winter Maximum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
11) **Winter Minimum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
12) **Spring Maximum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
13) **Spring Minimum NDVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
14) **Maximum EVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
15) **Minimum EVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
16) **Median EVI** (MOD13Q1 – Vegetation Indices, 16 day composites),
17) **Standard deviation EVI** (MOD13Q1 – Vegetation Indices, 16 day composites)
18) **Monthly Positive and Negative change in EVI** (MOD13Q1 – Vegetation Indices, 16 day composites) during the year,
19) **Seasonal Positive and Negative change in EVI** (MOD13Q1 – Vegetation Indices, 16 day composites)

The statistical derivatives (metrics) that were developed from the 500m and 1km MODIS products time series were also calculated, but the above-mentioned outperformed the other values in terms of being useful for classification.

4.2.8 Knowledge Engineer and classification

The knowledge engineer in ERDAS Imagine 9.1 (Figure 5) is an efficient and powerful tool that can run several models to produce a single classification result. It implements a decision tree approach (rule-based system) to perform the classification.

Each of the simple and/or combination models (spatial operation models) in the modular expert system is designed to identify a single land cover type. The data layers (variables) used in the model need to be suitable explanatory variables of the response variable (land cover type). Explanatory variables could be spectral or ancillary data, continuous or categorical. Explanatory variables must be statistical analyzed to find which thresholds best

identify the land cover type under analysis. The classification structure and thresholds developed on the variable values were the results from the multivariate statistical analysis.

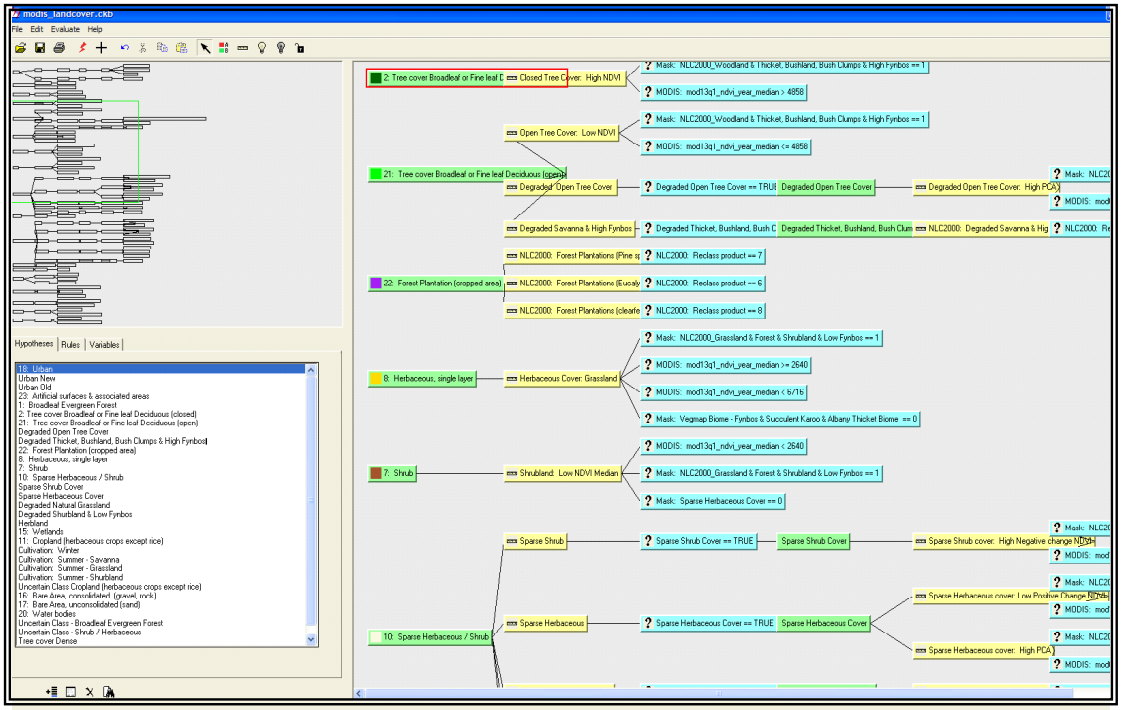

Figure 5: Example of the knowledge engineer window

The knowledge engineer has certain restrictions. It firstly does not allow the use of separate conditions in the hypotheses and secondly, the hypotheses must use input layers (variables) with the same geographical extent and pixel resolution and the pixels must have values to identify a single land cover type. The problem was solved, executing each hypotheses separately and by applying different masking rules.

The combination models were implemented in ERDAS modeller where the intermediate steps were simplified using separate spatial operations (e.g., calculate statistical derivatives or variables, calculate indices, aggregation of NLC2000 classes, derive filter and masking variables, etc.) and the resulting spatial layers were aggregated into appropriate classes to match the Global land cover classes. The knowledge engineer was also used to combine all the results into one final land cover layer.

4.2.9 Hypotheses (Global land cover class)

Selected spatial operations are required to represent the land cover classification model. The land cover classification model is defined by the progression and combination of the simple and/or combination models.

4.2.6.1 Hypotheses 1: Broadleaf Evergreen Forest

In South Africa indigenous forests can be grouped in various types of forest such as the southern Afrotemperate, northern Afrotemperate, northern mist-belt, southern mist-belt, scarp, southern coastal, northern coastal, lowveld riverine, swamp, mangrove, and licuati sand forests (Kidane 2004, Mucina *et al.* 2003).

The Broadleaf Evergreen Forest can be defined as: the main layer consists of broadleaved evergreen closed to open trees with a crown cover between 100% and 40%. The height is in the range of >30 – 3m (Appendix B).

For Hypotheses 1 (Figure 6), Broadleaf Evergreen Forest were identified using a combination of simple models, explicitly high yearly median NDVI values and masking rules, which included natural vegetation classes of the aggregated NLC2000 spatial layer, with confidence values to support the rule. Another masking rule was applied to identify pixels not as natural vegetation but falling within this Hypotheses boundary was excluded.

4.2.6.2 Hypotheses 2: Tree cover Broadleaf and/or Fine leaf Deciduous (closed)

Hypotheses 2, Tree cover Broadleaf and/or Fine leaf Deciduous (closed) consists manly of broadleaved and/or fine leaved deciduous closed to open trees. The crown cover is between 100% and 45% and the height is in the range of >30 – 3m (Appendix B). This class consist of the aggregated Woodland with Herbaceous layer and Closed to open medium to high Shrubland (Thicket) classes of the aggregated NLC2000 product (Appendix A).

For Hypotheses 2 (Figure 6), Tree cover Broadleaf and/or Fine leaf Deciduous (closed) were identified using simple and a combination model with rules, explicitly a medium to high yearly median NDVI and a combination of a masking rule which included the aggregated

NLC2000 spatial layer (class: Woodland with herbaceous layer and Closed to open medium to high shrubland (Thicket)). The Hypotheses was further improved using medium to high yearly median EVI values and with confidence values. The confidence values are higher in the case of the NDVI rule, to the benefit of the outcome of the Hypotheses.

These rules gave an improvement of the previous NLC2000 product of the classes Woodland and Thicket, Bushland, Bush clumps & High Fynbos. The result divided the old classes in terms of a density class, namely a 100% to 45% cover class.

4.2.6.3 Hypotheses 21: Tree cover Broadleaf and/or Fine leaf Deciduous (open)

Hypotheses 21 (Figure 6), Tree cover Broadleaf and/or Fine leaf Deciduous (open) consists manly of broadleaved and/or fine leaved deciduous closed to open trees. The crown cover is between 45% and 1% and the height is in the range of >30 – 3m (Appendix B). This class consist also of the aggregated Woodland with Herbaceous layer and Closed to open medium to high Shrubland (Thicket) classes of the aggregated NLC2000 product (Appendix A).

For Hypotheses 2, Tree cover Broadleaf and/or Fine leaf Deciduous (open) were identified using simple and combination models with rules, such as a low to medium yearly median NDVI, to map a medium to low density class (45% to 1%). Another simple model was applied, making use of high PCA values to map degradation in this land cover class.

A masking rule was applied to identify pixels of the degraded classes, Trees with Shrubs and Woodland with Herbaceous Layer but falling within this Hypotheses boundary were included (Appendix A). The Hypotheses was further improved using low to medium yearly median EVI values with higher confidence values in the case of the NDVI rule to the benefit of the outcome of the Hypotheses.

4.2.6.15 Hypotheses 7: Shrub

Shrub land is vegetation dominated by low, woody, self-supporting, multi-stemmed plants, branching at or near the ground. The tree height range of shrub land is between 0.2 and 2 metres, and with a total tree cover of less than 0.1% (CSIR 2000).

The main layer of the Hypotheses, Shrub consists of closed shrub land. The crown cover is more than 70-60%. The main layer can also consist of open shrub land, with a crown cover between 70-60% and 20-10% (Appendix B).

For Hypotheses 7 (Figure 6), Shrub was identified using explicitly a low yearly median NDVI simple model and a masking rule which included natural vegetation classes of the aggregated NLC2000 classes, to identify the relevant pixels, but falling within this mask boundary was included. A masking rule was applied to identify pixels as sparse herbaceous cover but falling within this Hypotheses boundary was excluded.

4.2.6.16 Hypotheses 8: Herbaceous, single layer

The main layer consists of closed herbaceous vegetation and with a crown cover of more than 70-60%. The height is in the range of 3 – 0.03m and the vegetation consists of one single layer. The main layer can also consist of open herbaceous vegetation with a crown cover more than 70-60% and 20-10%. The height is in the range of 3 – 0.03m and the vegetation consists of one single layer (Appendix B).

Grasslands or the Herbaceous, single layer have little vegetation cover and they show significant NDVI seasonal variation, becoming more vigorous in the summer due to higher rainfall.

For Hypotheses 8 (Figure 6), Herbaceous, single layer was identified using a medium yearly and seasonal change median NDVI simple rules and a masking rule which included natural vegetation of the aggregated NLC2000 classes, such as Herbaceous and Shrubland to identify the relevant pixels, but falling within this mask boundary was included. Another masking rule was applied to identify pixels in Biome classes (Vegmap product), such as Fynbos,

Succulent Karoo & Albany Thicket, but falling within this Hypotheses boundary was excluded.

4.2.6.17 Hypotheses 10: Sparse Herbaceous/Shrub

The main layer consists of sparse herbaceous vegetation and with a crown cover between 20-10% and 1%. The main layer can also consist of sparse shrubs with a crown cover between 20-10% and 1%.

For Hypotheses 10 (Figure 6), Sparse Herbaceous/Shrub was identified using a combination of different simple and combination models. Sparse Shrub cover was identified using a lower yearly negative change in NDVI values with a masking rule to identify relevant pixels which included natural vegetation of the aggregated NLC2000 classes, such as the continuous closed to open Shrubland (Thicket) and degraded classes. Sparse Herbaceous cover was identified using simple models, such as a low yearly positive change in NDVI and high PCA values with a masking rule included the aggregated NLC2000 classes, continuous closed to open Herbaceous vegetation and degraded classes.

A simple model and rule with confidence values were applied to identify pixels from the aggregated NLC2000 classes, interrupted closed to open forbs and park like patches of sparse forbs but falling within this Hypotheses boundary was included in this Hypotheses.

4.2.6.18 Hypotheses 11: Cropland (herbaceous crops except rice)

A defined area is covered by herbaceous crops. Cultivated lands include fallow areas, which have similar spectral characteristics as degraded lands. Cultivated lands that may be found are mostly constituted seasonal commercial or subsistence farming.

For Hypotheses 11 (Figure 6), Cropland (herbaceous crops except rice) was identified using a combination of different simple models with confidence values. Winter Cropland was identified using high seasonal positive change in NDVI values with a masking rule which included the aggregated NLC2000 class, cropped areas, to identify the relevant pixels, but falling within this mask boundary was included.

Summer rainfall cropland in the Grassland and Savanna biomes was identified using a high yearly positive change in NDVI values with a masking rule included the Biomes of the Vegmap, Grassland and Savanna. Summer rainfall cropland in the Shrubland biome was identified using a medium to high yearly median NDVI with a masking rule included the Shrubland biome. Higher confidence values were applied to the cropped areas class of the aggregated NLC2000 product to benefit the outcome of the Hypotheses.

4.2.6.19 Hypotheses 15: Wetlands

The environment is significantly influenced by the presence of water over extensive periods of time (Appendix B). A variety of wetlands occur in South Africa, which include saltmarsh, reedpan and highveld wetlands, which can be cover with vegetation or not. The majority of the wetlands are geographically scattered and the individual wetlands are small in coverage. The vegetated wetlands have similar spectral appearance to the surrounding non-wetland vegetation, and because of the coarse resolution of the MODIS products and limitation in project time it was difficult to identify the wetlands in smaller extent. The completeness of the wetland class of the aggregated NLC2000 spatial layer, made it possible to use this class with confidence for the model and rule to classify Hypotheses 15, Wetlands (Figure 6).

4.2.6.20 Hypotheses 16: Bare Area, consolidated (gravel / rock)

The land cover consists of consolidated material(s) (Appendix B). Bare areas and rocks are naturally exposed sand, soil or rock with no or very little vegetation cover in any season. This category excludes agricultural areas without crop cover (CSIR 2000).

For Hypotheses 16 (Figure 6), Bare Area, consolidated (gravel / rock) is identified using a combination of high PCA and yearly negative change in NDVI values and a masking rule which included the aggregated NLC2000 class, Bare Rock & Soil (soil erosion surfaces), to identify the relevant pixels, but falling within this mask boundary was included. Higher confidence values were applied to the aggregated NLC2000 class.

4.2.6.21 Hypotheses 17: Bare Area, unconsolidated (sand)

The land cover consists of unconsolidated material(s) (Appendix B). Beach sand is characterized by negative NDVI and high brightness. For Hypotheses 17 (Figure 6), Bare Area, unconsolidated (sand) is identified using a combination of high PCA and negative yearly NDVI values and a masking rule which included the aggregated NLC2000 class, bare rock & soil (natural surfaces), to identify the relevant pixels but falling within this mask boundary was included. Higher confidence values were applied to the aggregated NLC2000 class to benefit the outcome of the Hypotheses.

4.2.6.22 Hypotheses 18: Urban

Urban is defined as primarily non vegetated areas containing less than four percent vegetation during at least 10 months a year. The environment is influenced by the edaphic substratum and the cover is artificial and a result of human activities (Appendix B).

The Urban land cover class is difficult to isolate from the MODIS satellite imagery. This type of built-up area is characterized by high intra-pixel spectral variability as well as inter-pixel variation. The presence of a combination of vegetation and hard surfaces makes the class heterogeneous.

For Hypotheses 18 (Figure 6), Urban is identified using a combination of simple and combination models, such as PCA values, with different buffer distances to identify urban extent and urban change. Masking rules, such as the aggregated NLC2000 class, urban, to identify the relevant pixels, but falling within this mask boundary was included. Higher confidence values were applied to the aggregated NLC2000 class.

4.2.6.23 Hypotheses 20: Water Bodies

Water Bodies in the modelled area included dams, lakes, rivers and the ocean. In terms of its spectral characteristics water has low overall brightness and low reflectance near infrared. For Hypotheses 20 (Figure 6), water bodies were identified using a combination of simple

models and rules, explicitly a low yearly minimum NDVI and the water class of the aggregated NLC2000 spatial layer, with a higher confidence value.

4.2.6.24 Hypotheses 22: Forest Plantation (cropped area)

The most generally planted trees in South Africa are trees such as pine, eucalypts, wattle and indigenous species. The forest plantations (cropped area) class include all forests that are systematically planted, commercial and primarily composed of exotic trees.

Forest Plantation (cropped area) is defined as permanently cropped with rain fed broadleaved evergreen tree crop(s) dominant crop: wood and timber - Eucalypt (Eucalyptus, Pinus, Acacia and mixed spp.) crop cover: plantation(s) (Appendix B).

Forest plantations show low seasonal NDVI variation and are less textured than indigenous forests. It was difficult to identify texture from the coarse resolution of MODIS. The yearly median NDVI values could be used with a combination of the aggregated NLC2000 product. The different forest plantations have similar spectral appearance and it was impossible to distinguish among the different forest plantation classes. The different forest plantation classes of the aggregated NLC2000 were thrown together and used as a masking rule during the classification (Figure 6).

4.2.6.25 Hypotheses 23: Artificial surfaces & associated areas

The Artificial surfaces & associated areas consist of rural settlements, or industrial and/or other area(s), such as built-up surface based mining and/or waste dump(s)/deposit(s) (Appendix B).

Mines and quarries include active or non-active mining areas that may be underground or sub-surface. The sub-surface mining includes hardrock and sand quarries as well as opencast mining (coal) (CSIR 2000). This land cover class is heterogeneous and pixels of this land cover class can therefore be confused with other classes such as urban areas and bare area, consolidated (gravel / rock).

For Hypotheses 23 (Figure 6), Artificial surfaces & associated areas is identified using masking rules, such as the aggregated NLC2000 class, mines & quarries and rural settlements, to identify the relevant pixels, but falling within this mask boundary was included.

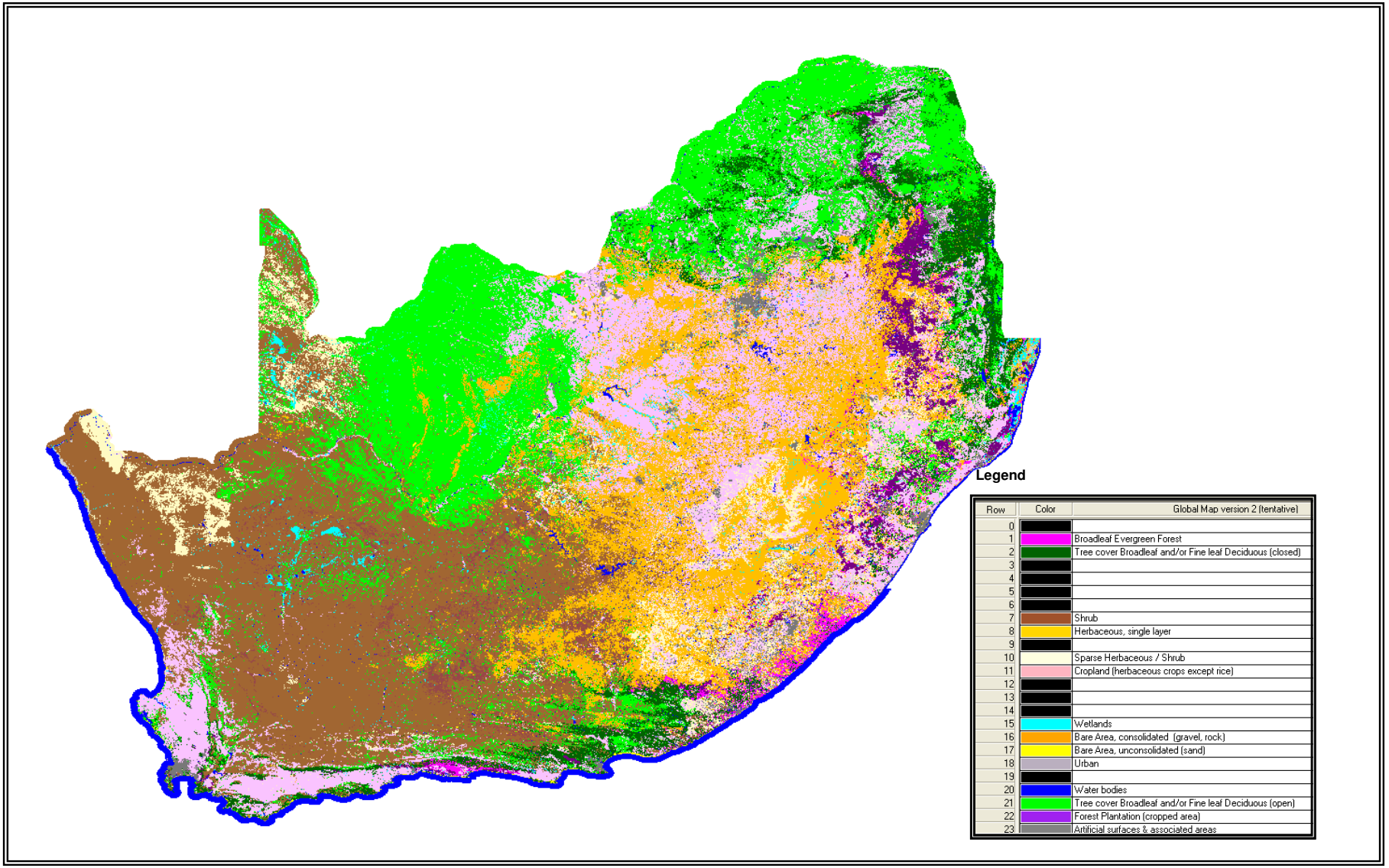

Figure 6: MODIS Land cover product (250m)

5. STATISTICAL ANALYSIS OF SPATIAL AND THEMATIC ACCURACIES

5.1 Methodology

5.1.1 Spatial accuracy

The Global Map Version 1.2 Specifications have been obtained and studied closely by SAC so that an adherence to these specifications can be guaranteed. EarthSat imagery conforming to 1:250 000 spatial accuracy tolerances was compared to the MODIS products, allowing an error vector collection via cross correlation describing both the error severity and direction. Spatial accuracy is described on the basis of statistical analysis of residuals between the x and y coordinates between a reference and input image. The mean error as well as standard deviation between observations form the basis for a spatial accuracy assessment which is described as $X + \sigma$ for a 65% confidence interval and $X + 2\sigma$ for a 95 % confidence interval. Thirty (n=30) of these error vectors were collected and calculated evenly over the different MODIS products providing sufficient information for a statistical analysis and characterization of positional error. The operator accuracy was also calculated, using the difference (e.g. different seasons or months) of a specific MODIS product, allowing a description in both the error severity and direction of the operator.

5.1.2 Thematic accuracy

Classification accuracy assessment from high-resolution imagery is both efficient and cost effective as samples can be collected randomly over the imagery providing less bias than a field visit based ground truthing exercise. Land cover classes are distributed unevenly and in different proportions over a landscape. Systematic or random sampling thus leads to an over-sampling of dominant classes and under-sampling of minority classes. A stratified random sampling gives the best cost benefit ratio providing sound statistics.

The area covered by each land cover class were calculated and inversely represented on the raster layer (250m MODIS Land cover product), during the process for validating the Land cover classes. The smallest class was validated with a minimum of 34 and the largest class with a maximum of 63 samples points. A total of 600 values were extracted as vector points from this dataset representing areas to be verified for manual inspection. High-resolution

satellite imagery such as Landsat 7 and QuickBird were interpreted into LCCS/GLCN classes around each sample point with at least a circumference of 2 km being visible to the interpreter. The dominant class in this area to the sample point was allocated from the Satellite Images.

Thematic accuracies are described in an error matrix and define the producer's accuracy, consumer's accuracy, and error of omission, error of commission, overall accuracy and kappa index. The 600 evenly distributed spatial error vectors collected from the imagery were used in a statistical analysis (Table 3).

5.2 Results

5.2.1 Spatial accuracy

The EarthSat images (15m resolution) were processed (e.g. mosaiced, reprojected and resampled with the Cubic Convolution resampling Type) for the purpose of this task. The spatial accuracy (e.g. $X + \sigma$ for a 65% and $X + 2\sigma$ for a 95 % confidence interval) of each above mentioned MODIS product was therefore calculated (Table 2). The operator accuracy was also calculated and is presented in Table 2.

Table 2: Spatial accuracy between the EarthSat images (reference), MODIS and NLC2000 products (input images)

INPUT IMAGES	SPATIAL ACCURACY		OPERATOR ACCURACY	
	$X + \sigma$	$X + 2\sigma$	$X + \sigma$	$X + 2\sigma$
MOD09A1 (500m)	678.4	726.7	307.2	329.4
MOD09Q1 (250m)	376.4	399.5	153.6	164.7
MOD13A3 (1000m)	978.3	1039.1	614.4	658.7
MOD13A1(500m)	543.9	583.0	307.2	329.4
MOD13Q1 (250m)	268.3	286.2	153.6	164.7
MOD12Q1 (1000m)	1234.4	1366.9	614.4	658.7
MODSAVI (500m)	405.7	437.2	307.2	329.4
NLC2000 (250m)	266.9	286.2		

5.2.2 Thematic accuracy

The thematic accuracies of the MODIS Land cover product (250m Product) were calculated after the image classification and are presented in Table 3. An Error matrix (Confusion matrix) was subsequently drawn up to compare ground observations as reference with the classified image as illustrated in Table 3. The sum of all plots per class is indicated below and along the side of the main table for the image and reference dataset respectively. An evenly sampling of each class is noticeable in Table 3. Together with the total accuracy, a Consumers accuracy (CA%) and Producers accuracy (PA%) has been calculated per class displayed to the bottom and right of the table respectively. These are expressed as accurately classified samples indicated in green, divided by the sum of all records for that class. Furthermore the Error of Ommision (EO%) and Error of Commision (EC%) i.e. error introduced by omitting or not allocating a point to a certain class, or allocating it incorrectly to a certain class respectively were calculated. The EO% is expressed as the sum of all omitted or not identified points by the total number of reference points per class. The EC% in turn is expressed as the sum of all incorrectly allocated points to a class divided by the total number of actual allocations to the class.

Misclassifications are visible from the matrix and are marked in red.

- "Bare areas, unconsolidated (sand)" (17) classified as "Bare areas, consolidated (gravel, rock)" (16). These 2 classes are difficult to separately spectrally. These two "Bare area" classes (16 &17) have been under classified and allocated to Sparse Herbaceous / Shrub (10). This is due to the high spatial and spectral correlation of these classes.
- Shrub (7) also has been allocated to Sparse Herbaceous / Shrub (10). Rangeland condition varies dependent on rainfall and grazing regimes.
- "Cropland (herbaceous crops except rice" (11) classified as "Herbaceous, single layer" (8) and vice versa. These 2 classes are nearly impossible to separately spectrally and the occurring of shifting cultivation between planted grassland and maize.
- "Tree cover Broadleaf or Fine leaf Deciduous (closed)" (2) classified as "Tree cover Broadleaf or Fine leaf Deciduous (open)" (21) and vice versa. This could be attributed to the fuzzy definitions of the original NLC2000 classes especially in terms

of discriminatory data properties. These two classes are derived from the aggregated NLC2000 Woodland with herbaceous layer and Closed to open medium to high Shrubland (Thicket) classes, which are separated in two density classes by the MODIS products during the rule-base classification.

Certain high accurate classifications are visible from the matrix and are marked in blue.

- The "Forest Plantation (cropped area)" (22) class is expectable high, because all the different types of Forest Plantation could not be separate spectrally and are thrown together as a result of the rule-base classification process.

A Kappa index takes into account the agreement between the reference and classified image that could have occurred purely by chance and is thus a better descriptor of the classification result. The kappa value can range between 0.0 – 1.0. A value > 0.7 indicated a reliable classification, while < 0.7 a poor classification. For this analysis an expected frequency (*ef*) of agreement by chance is calculated with Formula 1 below.

$$ef = \frac{row\_total * col\_total}{overall\_total} \tag{1}$$

The Kappa value is then calculated with Formula 2 below, where *a* represents correctly classified samples and *N* the total number of samples.

$$K = \frac{\sum a - \sum ef}{N - \sum ef} \tag{2}$$

The resulting Kappa index of 0.72 indicates a satisfactory result.

Table 3: Condensed error matrix for a representation of accuracies

	Classified image														Total	PA %	EO %	EC %
Reference	1	2	7	8	10	11	15	16	17	18	20	21	22	23				
1	27	2		2		1	1						3		36	75	25	3
2		26	1		1		2	1				10			41	63	37	39
7			51		6		2					4			63	81	19	14
8		2		39		5	1			1		4	1		53	74	26	19
10			2		30	3	3					1		2	41	73	27	68
11			1	3	1	38	2					5	2	1	53	72	28	23
15		1		2		1	26		1			2	1	2	36	72	28	53
16			2		8		3	20	1	1	2				37	54	46	14
17					9		1	4	17			3			34	50	50	15
18			1		2	1				29				4	37	78	22	5
20							3				36				39	92	8	8
21		10	2	1	1	1	1					42			58	72	28	3
22	1			2									34		37	92	8	19
23		1								1		1		32	35	91	9	26
Total	28	42	60	49	58	50	45	25	19	32	38	72	41	41	600			
CA %	96	62	85	80	52	76	58	80	89	91	95	58	83	78	Correct	447		
															Accuracy	74.5		

$$ef = \frac{row\_total * col\_total}{overall\_total}$$

Expected frequency of agreement by chance														Total chance agreement
1.7	2.9	6.3	4.3	4.0	4.4	2.7	1.5	1.1	2.0	2.5	7.0	2.5	2.4	45.2

$$K = \frac{\sum a - \sum ef}{N - \sum ef}$$

Kappa = (447 - 45.2) / (600 - 45.2)

0.72

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7. Appendix A: Translation and Aggregation of Weighted NLC2000 classes to LCCS/GLCN classes

NLC Code	NLC2000	Weighted & LCCS Code	LCCS	GLCN Code	Global Map vers. 2
1	Forest (indigenous)	4	Closed Trees with Shrubs	1	Broadleaf Evergreen Forest
2	Woodland (previously termed 'Forest and Woodland ')	2	Woodland with Herbaceous Layer	2 & 21	Tree cover Broadleaf and/or Fine leaf Deciduous (closed) & Tree cover Broadleaf and/or Fine leaf Deciduous (open)
3	Thicket, Bushland, Bush Clumps & High Fynbos	2	Closed to Open Medium To High Shrubland (Thicket)	2 & 21	Tree cover Broadleaf and/or Fine leaf Deciduous (closed) & Tree cover Broadleaf open)
4	Shrubland & Low Fynbos	1	Continuous Closed to Open Shrubland (Thicket) // Continuous Closed to Open Shrubland (Thicket) Floristic Aspect: Proteaceae, Ericaceae and Restionaceae	7	Shrub
5	Herbland	5	Interrupted Closed to Open Forbs // Parklike Patches Of Sparse Forbs	10	Sparse Herbaceous/Shrub
6	Natural Grassland (previously termed ' Unimproved Grassland ')	3	Continuous Closed to Open Herbaceous Vegetation // Sparse Herbaceous Vegetation	8	Herbaceous, single layer
7	Planted Grassland (previously termed ' Improved Grassland ')	16	Continuous Closed to Open Herbaceous Vegetation - Planted Grassland (natural or exotic grass species)	11	Cropland (herbaceous crops except rice)
8	Forest Plantations (Eucalyptus spp)	6	Permanently Cropped Area With Rainfed Broadleaved Evergreen Tree Crop(s) Dominant Crop: Wood and Timber - Eucalypt (Eucalyptus spp.) Crop Cover: Plantation(s)	22	Forest Plantation (cropped area)
9	Forest Plantations (Pine spp)	7	Permanently Cropped Area With Rainfed Needleleaved Evergreen Tree Crop(s) Dominant Crop: Wood and Timber - Pine (Pinus spp.) Crop Cover: Plantation(s)	22	Forest Plantation (cropped area)
10	Forest Plantations (Acacia spp)	6	Permanently Cropped Area With Rainfed Tree Crop(s) Dominant Crop: Wood and Timber - Acacia (Acacia spp.) Crop Cover: Plantation(s)	22	Forest Plantation (cropped area)
11	Forest Plantations (other / mixed spp)	6	Permanently Cropped Area With Rainfed Tree Crop(s) Dominant Crop: Wood and Timber - Other wood/timber – Mixed Crop Cover: Plantation(s)	22	Forest Plantation (cropped area)

12	Forest Plantations (clearfelled)	8	Permanently Cropped Area With Rainfed Tree Crop(s) Crop Cover: Plantation(s) - Clearfelled	22	Forest Plantation (cropped area)
13	Water bodies	10	Artificial Perennial Waterbodies // Perennial Natural Waterbodies	20	Water Bodies
14	Wetlands	9	Natural And Semi-Natural Aquatic or Regularly Flooded Vegetation	15	Wetlands
15	Bare Rock & Soil (natural surfaces)	11	Bare Rock(s) // Bare Soil And/Or Other Unconsolidated Material(s)	17	Bare Area, unconsolidated (sand)
16	Bare Rock & Soil (soil erosion surfaces : dongas / gullies)	11	Bare Rock(s) Erosion: Water Erosion – Gully // Bare Soil And/Or Other Unconsolidated Material(s) Erosion: Water Erosion – Gully	16	Bare Area, consolidated (gravel / rock)
17	Bare Rock & Soil (soil erosion surfaces : sheet)	11	Bare Rock(s) Erosion: Water Erosion – Sheet // Bare Soil And/Or Other Unconsolidated Material(s) Erosion: Water Erosion – Sheet	16	Bare Area, consolidated (gravel / rock)
18	Degraded Woodland	13	Trees with Shrubs – Degraded // Woodland with Herbaceous Layer - Degraded	21	Tree cover Broadleaf and/or Fine leaf Deciduous (open)
19	Degraded Thicket, Bushland, Bush Clumps & High Fynbos	13	Closed to Open Medium to High Shrubland (Thicket) - Degraded	21	Tree cover Broadleaf and/or Fine leaf Deciduous (open)
20	Degraded Shrubland & Low Fynbos	12	Continuous Closed to Open Shrubland (Thicket) - Degraded // Continuous Closed to Open Shrubland (Thicket) – Degraded Floristic Aspect: Proteaceae, Ericaceae and Restionaceae	10	Sparse Herbaceous/Shrub
21	Degraded Herbland	None	Interrupted Closed to Open Forbs - Degraded // Parklike Patches Of Sparse Forbs - Degraded	None	None
22	Degraded Natural Grassland	14	Continuous Closed to Open Herbaceous Vegetation – Degraded // Sparse Herbaceous Vegetation - Degraded	10	Sparse Herbaceous/Shrub
23	Cultivated, permanent, commercial, irrigated	16	Permanently Cropped Area With Irrigated Herbaceous Crop(s) // Permanently Cropped Area With Irrigated Shrub Crop(s) // Permanently Cropped Area With Irrigated Tree Crop(s)	11	Cropland (herbaceous crops except rice)
24	Cultivated, permanent, commercial, dryland / rainfed	16	Permanently Cropped Area With Rainfed Shrub Crop(s) // Permanently Cropped Area With Rainfed Tree Crop(s)	11	Cropland (herbaceous crops except rice)
25	Cultivated, permanent, commercial, sugarcane	16	Permanently Cropped Area With Rainfed Herbaceous Crop(s) Dominant Crop: Industrial Crops - Sugar Cane (Saccharum officinarum) // Permanently Cropped Area With Irrigated	11	Cropland (herbaceous crops except rice)

			Herbaceous Crop(s) Dominant Crop: Industrial Crops - Sugar Cane (Saccharum officinarum)		
26	Cultivated, temporary, commercial, irrigated	16	Irrigated Herbaceous Crop(s) Dominant Crop: Other Food Crops – Annuals	11	Cropland (herbaceous crops except rice)
27	Cultivated, temporary, commercial, dryland / rainfed	16	Rainfed Herbaceous Crop(s) Dominant Crop: Other Food Crops – Annuals	11	Cropland (herbaceous crops except rice)
28	Cultivated, temporary, semi-commercial / subsistence, dryland	16	Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	11	Cropland (herbaceous crops except rice)
29	Cultivated, temporary, semi-commercial / subsistence, irrigrated	16	Small Sized Field(s) Of Irrigated Herbaceous Crop(s)	11	Cropland (herbaceous crops except rice)
30	Urban / Built-up : residential	18	Urban Area(s)	18	Urban
31	Urban / Built-up : rural cluster	17	Urban Area(s) Built-Up Object: Other - Rural Settlement	23	Artificial surfaces & associated areas
32	Urban / Built-up : residential, formal suburbs	18	Urban Area(s) Built-Up Object: Other - Residential, Formal Suburbs	18	Urban
33	Urban / Built-up : residential, flatlands	18	High Density Urban Area(s) Built-Up Object: Other - Residential, flatlands	18	Urban
34	Urban / Built-up : residential, residential mixed	18	Urban Area(s) Built-Up Object: Other - Residential, Mixed	18	Urban
35	Urban / Built-up : residential, hostels	18	High Density Urban Area(s) Built-Up Object: Other - Residential, hostels	18	Urban
36	Urban / Built-up : residential, formal township	18	Urban Area(s) Built-Up Object: Other - Residential, Formal Township	18	Urban
37	Urban / Built-up : residential, informal township	18	Urban Area(s) Built-Up Object: Other - Residential, Informal Township	18	Urban
38	Urban / Built-up : residential, informal squatter camp	18	High Density Urban Area(s) Built-Up Object: Other - Residential, informal squatter camp	18	Urban
39	Urban / Built-up : smallholdings – Woodland	2	Scattered Urban Area(s) Built-Up Object: Other - Smallholdings	2 & 21	Tree cover Broadleaf and/or Fine leaf Deciduous (closed) & Tree cover Broadleaf and/or Fine leaf Deciduous (open)
40	Urban / Built-up : smallholdings - Thicket, bushland, bush clumps	2	Scattered Urban Area(s) Built	2 & 21	Tree cover Broadleaf and/or Fine leaf Deciduous (closed) & Tree cover Broadleaf and/or Fine leaf Deciduous (open)
41	Urban / Built-up : smallholdings - Shrubland & low fynbos	1	Scattered Urban Area(s) Built	7	Shrub

42	Urban / Built-up : smallholdings - Natural Grassland	3	Scattered Urban Area(s) Built	8	Herbaceous, single layer
43	Urban / Built-up : commercial – mercantile	18	Industrial And/Or Other Area(s) Built-Up Object: Commercial Area (e.g. Warehousing, Wholesaling, Retailing)	18	Urban
44	Urban / Built-up : commercial – educational, health, IT	18	Non-Linear Built Up Area(s) Built-Up Object: Other: Educational, Business Development Centres, Social Services, etc.	18	Urban
45	Urban / Built-up : industrial / transport – heavy	18	Industrial And/Or Other Area(s) Built-Up Object: Heavy Industrial Area (e.g. Ores, Timber, Coal, Chemicals, etc.) // Industrial And/Or Other Area(s) Built-Up Object: Other - Transport Areas (incl. airports, train stations, ports, etc.)	18	Urban
46	Urban / Built-up : industrial / transport – light	18	Industrial And/Or Other Area(s) Built-Up Object: Light Industrial Area (Design, Assembly, Finishing, Processing, Packaging of Products) // Industrial And/Or Other Area(s) Built-Up Object: Other - Transport Areas (incl. airports, train stations, ports, etc.)	18	Urban
47	Mines & Quarries (underground / sub-surface mining)	18	Industrial And/Or Other Area(s) Built-Up Object: Other - Underground / sub-surface mining	18	Urban
48	Mines & Quarries (surface-based mining)	19	Industrial And/Or Other Area(s) Built-Up Object: Other - Surface based mining	23	Artificial surfaces & associated areas
49	Mines & Quarries (mine tailings, waste dumps)	19	Waste Dump(s)/Deposit(s)	23	Artificial surfaces & associated areas

7.2 Appendix B: Description of the GLCN classes

Code	Global Map Class	Description
1	Broadleaf Evergreen Forest	The main layer consists of broadleaved evergreen closed to open trees. The crown cover is between 100% and 40%. The height is in the range of >30 – 3m.
2	Tree cover Broadleaf and/or Fine leaf Deciduous (closed)	The main layer consists of broadleaved and/or fine leaved deciduous closed to open trees. The crown cover is between 100% and 45%. The height is in the range of >30 – 3m.
21	Tree cover Broadleaf and/or Fine leaf Deciduous (open)	The main layer consists of broadleaved and/or fine leaved deciduous closed to open trees. The crown cover is between 45% and 1%. The height is in the range of >30 – 3m.
7	Shrub	The main layer consists of closed shrub land. The crown cover is more than (70-60%) // The main layer consists of open shrub land. The crown cover is between (70-60%) and (20-10%).
8	Herbaceous, single layer	The main layer consists of closed herbaceous vegetation. The crown cover is more than (70-60%). The height is in the range of 3 – 0.03m. The vegetation consists of one single layer. // The main layer consists of open herbaceous vegetation. The crown cover is more than (70-60%) and (20-10%). The height is in the range of 3 – 0.03m. The vegetation consists of one single layer
10	Sparse Herbaceous/Shrub	The main layer consists of sparse herbaceous vegetation. The crown cover is between (20-10%) and 1%. // The main layer consists of sparse shrubs. The crown cover is between (20-10%) and 1%.
11	Cropland (herbaceous crops except rice)	A defined area is covered by herbaceous crops.
15	Wetlands	The environment is significantly influenced by the presence of water over extensive periods of time.
16	Bare Area, consolidated (gravel / rock)	The land cover consists of consolidated material(s).
17	Bare Area, unconsolidated (sand)	The land cover consists of unconsolidated material(s).
18	Urban	Primarily non vegetated areas containing less than four percent vegetation during at least 10 months a year. The environment is influenced by the edaphic substratum. The cover is artificial and a result of human activities.
20	Water Bodies	The land cover consists of artificial water bodies. // The land cover consists of natural water bodies.
22	Forest Plantation (cropped area)	Permanently Cropped Area with rain fed Broadleaved Evergreen Tree Crop(s) Dominant Crop: Wood and Timber - Eucalypt (Eucalyptus, Pinus, Acacia and mixed spp.) Crop Cover: Plantation(s)
23	Artificial surfaces & associated areas	Urban Area(s) Built-Up Object: Other - Rural Settlement. // Industrial And/Or Other Area(s) Built-Up Object: Other - Surface based mining. // Waste Dump(s)/Deposit(s)