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A new SPOT4-VEGETATION derived land cover map of Northern Eurasia

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Abstract. The European Commission's Joint Research Centre and the Russian Academy of Science's Centre for Forest Ecology and Productivity have produced a new 1 km spatial resolution land cover map of Eurasia from 1999 SPOT4-VEGETATION data. The legend is designed to serve users from science programmes, policy makers, environmental convention secretariats, non-governmental organizations, development-aid projects and the national forest service. The 1999 map is also being updated as part of an international exercise to map Global Land Cover for the year 2000. This Letter describes the map legend, the image classification method, the map accuracy assessment process and presents the land cover map.

1. Introduction

Global change science, implementation of environmental treaties and development programmes increasingly need up-to-date global land cover maps. This is particularly so for Northern Eurasia. The Eurasian Boreal zone includes some of the most remote, inaccessible and infrequently mapped ecosystems of our planet, yet the zone plays an important role in the functioning of the Earth system and is a focus for many economic activities. The land cover is also highly dynamic, with many thousands of square kilometres of forest burning each year (Grégoire *et al*. 2002), but accurate measurement of these changes is hampered by a paucity of land cover inventory information. Indeed, the last forest inventory for much of North Eastern Russia is more than 50 years old (Strakhov 2001). This Letter describes the map legend, image processing and classification methods, the map accuracy assessment process and the land cover map for the Eurasian region.

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Table 1. The Eurasia land cover map classes.

(A) Forests: tree canopy cover is $>20\%$ and height >5 m
1. Evergreen Needleleaf Forest: the genera *Picea* and/or *Abies* and/or *Pinus* account for at least 80% of the area covered by trees.
2. Deciduous Broadleaf Forest: the genera *Betula* and/or *Populus* are dominant, though other broadleaf trees such as *Alnus*, *Quercus* and *Tilia* occur in small numbers.
3. Needleleaf/Broadleaf Forest: needleleaf species account for 60–80% of the area covered by trees, broadleaf 20–40%.
4. Broadleaf/Needleleaf Forest: broadleaf species account for 60–80% of the area covered by trees, Needleleaf 20–40%.
5. Mixed Forest: needleleaf and broadleaf trees present in roughly equal proportions.
6. Deciduous Needleleaf Forest: the genus *Larix* accounts for at least 80% of the area covered by trees.

(B) Shrublands: shrub canopy cover is $>20\%$ and height <5 m
1. Needleleaf Evergreen Shrubs: the species *Pinus pumila* is dominant.
2. Broadleaf Deciduous Shrubs: the genera *Betula* and *Alnus* are dominant.

(C) Grasslands: tree and shrub canopy cover $<20\%$
1. Humid Grasslands: herbaceous vegetation with a growing season >5 months.
2. Steppe: herbaceous vegetation with a growing season of <3 months.

(D) Wetlands: permanent mixture of water and vegetation
1. Bogs and Marsh: *Sphagnum* moss and lichens, or rushes and sedges are dominant.
2. Palsa Bogs: ridge–hollow complex of small water bodies $<0.5\,km^2$ and *Sphagnum*.
3. Riparian Vegetation: follows watercourses, seasonally flooded, mixture of herbaceous and woody vegetation, growing season >4 months.

(E) Tundra: treeless, growing season of 1.5–2.5 months, lichens, mosses, sedges, shrubs and heath present in varying proportions
1. Lichen and Moss: dry regions, lichen and moss are dominant.
2. Swampy Tundra: waterlogged in summer months.
3. Heath: woody vegetation, dwarfed shrubs and Ericaceae family dominant.

(F) Other vegetation types and complexes
1. Recent Burns: burn scars <4 years old. May contain dead trees, some pioneer vegetation types may be present.
2. Croplands: agriculture following a bare soil, crop cover, harvest, bare soil cycle.
3. Forest–Natural Vegetation Complex: combination of forest types with grassland or shrubland, cover types present in similar proportions.
4. Forest–Cropland Complex: combination of forest types with Cropland, cover types present in similar proportions.
5. Cropland–Grassland Complex: combination of Cropland with grassland, both cover types present in similar proportions.

(G) Non-vegetated land cover types
1. Bare Soil and Rock: never has vegetation cover of any kind.
2. Permanent Snow/Ice: snow/ice present throughout the year.
3. Water Bodies: open water fresh or salt including seas, lakes, reservoirs and rivers.
4. Urban: buildings, roads and other structures of anthropogenic origin.
5. Salt-pans: bare soil with high salt content.

2. The land cover map legend

The Eurasia land cover map legend contains 26 classes grouped into seven categories identified on the basis of forest management and global change science requirements. Details of the classes are provided in table 1.

3. Methodology

The map is based on standard SPOT4-VEGETATION products. S10 composites collected throughout 1999 are used. These contain reflectance values for the individual VEGETATION channels, Normalized Difference Vegetation Index (NDVI) values and angular data selected on the basis of the maximum NDVI value over 10-day periods. The VEGETATION Users' Guide provides further details of these data (VEGETATION 2002).

There are some drawbacks to the use of S10 products for land cover mapping in high latitudes. Extreme variations in sun–target–sensor geometry, persistent cloud, and extensive snow cover are among the most pronounced. Sensor malfunction, particularly in the short wave infrared (SWIR) brings additional problems. There are also advantages. Top-of-canopy reflectance values in four spectral regions and a pixel-to-pixel co-registration error less than 300 m between dates allow the spectral temporal dimensions to be exploited without losing spatial detail. Mapping began with data pre-processing and advanced data product generation to address the limitations and exploit the spectral/temporal characteristics of the data.

Processing began with the elimination of pixels affected by cloud/shadow and anomalous pixel values caused by sensor defects from each S10 product (Bartalev *et al*. 2000). The 'cleaned S10 products' were then used to produce *Seasonal Mosaics* for spring (April to June), summer (June to August) and autumn (August to October) by averaging the pixel values in each of the red, near-infrared (NIR) and SWIR channels in each time period. Overlap was needed because although the region exhibited a marked north–south climatic gradient, this was a continuous, rather than discrete process. The seasonal mosaics captured the spatial variations in onset, peak and end of growing season. A *Surface Anisotropy Relative Linear Index* (SARLI) was computed using a linearized version of the Rahman–Pinty–Verstraete Bi-directional Reflectance Distribution Function model (Engelsen *et al*. 1996). A *Snow-Cover* (SC) product, which documents the duration of snow cover for each pixel, was obtained from Normalized Difference Snow Index images for each cleaned S10 product using the methods of Hall *et al*. (1995). Water absorption at SWIR wavelengths and high reflectance from vegetation at NIR wavelengths were exploited to create a *Bi-spectral Gradient Wetness Index* (BGWI) by computing the directional angle from the point corresponding to pure water with the points occupied by each pixel in the SWIR–NIR feature space. The difference of actual NDVI values in a time-series from a periodical function fitted to the same series was used to derive a *Wave-Likeness Index* (WLI). This emphasized the difference between the phenological cycle of natural vegetation and anthropogenically influenced cycles (i.e. agriculture).

When applied to the three seasonal mosaics, the image segmentation algorithm ISODATA gave 150 clusters. Some clusters could be ascribed to a single land cover class but most could not. The specialized indices were used to resolve these ambiguities. The BGWI was employed to assign clusters to either wetland or dryland cover types, WLI separated cropland from other land cover types, *Snow Cover* was used to localize classes belonging to the tundra groupings, SARLI separated the deciduous forest and humid grassland, and also *Picea* and *Abies* dominated evergreen needleleaf forest and palsa bog classes. Figure 1 summarizes the image pre-processing and classification steps. Figure 2 (and cover) shows the

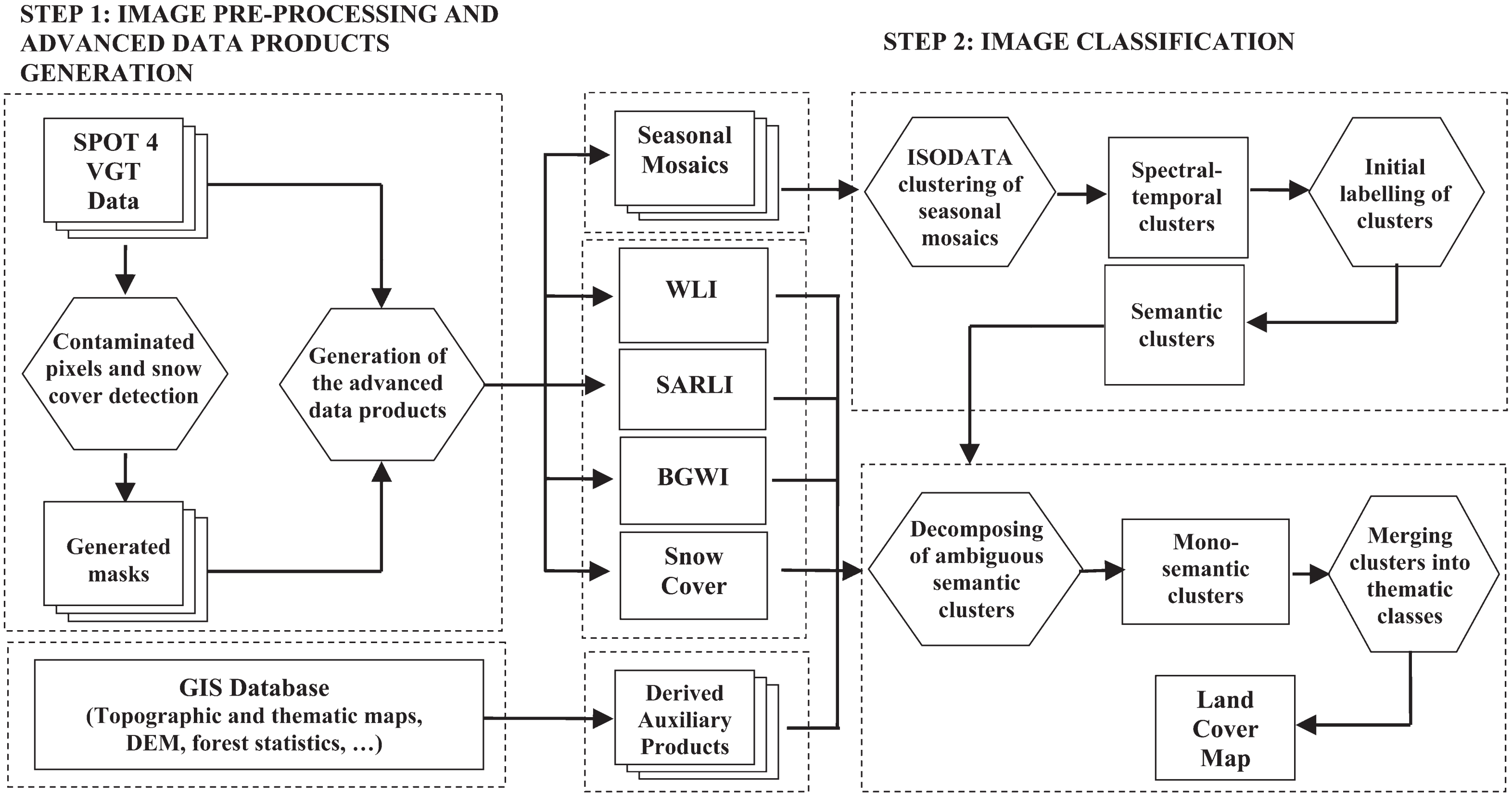

Figure 1. Logical chart of SPOT4-VEGETATION data processing and analysis for the Northern Eurasia's land cover mapping.

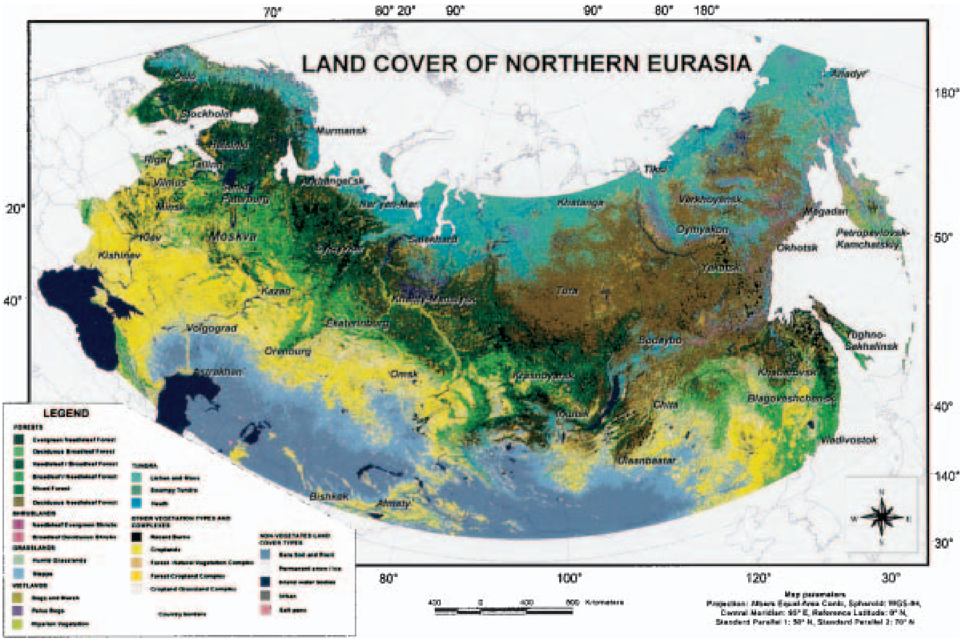

Figure 2. Land cover map of Northern Eurasia derived from SPOT4-VEGETATION satellite data.

resulting land cover map for the Eurasian Boreal zone. Detail from Central Siberia can be found on the cover of this issue.

4. Map accuracy assessment

Checking by regional experts and a formal process of accuracy assessment based on a sample of fine spatial resolution satellite imagery (Scepan 1999) are underway. Additional input to expert checking is welcome, and offers should be made directly to the authors. As a first step, the percentage forest cover from the map for each administrative region of the Russian Federation was correlated with the official forest cover statistics (figure 3). Whilst this does not allow us to assign statistically significant measures of accuracy for all land cover classes, the R^2 of 0.93 for forest classes gives us confidence in the map's thematic reliability.

5. Conclusions

The map presented here (figure 2) provides comprehensive 1999 land cover information for Eurasia according to a regionally optimized legend. However, we are aware that logging, insect damage, industrial pollution, gas/oil production, mining, wind-throw and urban/industrial development as well as extensive fires drive land cover change in this region. There is thus a need for regular land cover inventory. Also, regional maps, such as this, need a global context for global change science and international conventions among others. To provide continuity and global context, this regional map is being updated for 2000 as part of an international partnership producing a Global Land Cover database for the year 2000. The 1999 map will incorporate fires mapped as part of the GLC2000 project (Grégoire 2002). The recoding of regrowth following 1999 fires and accounting for

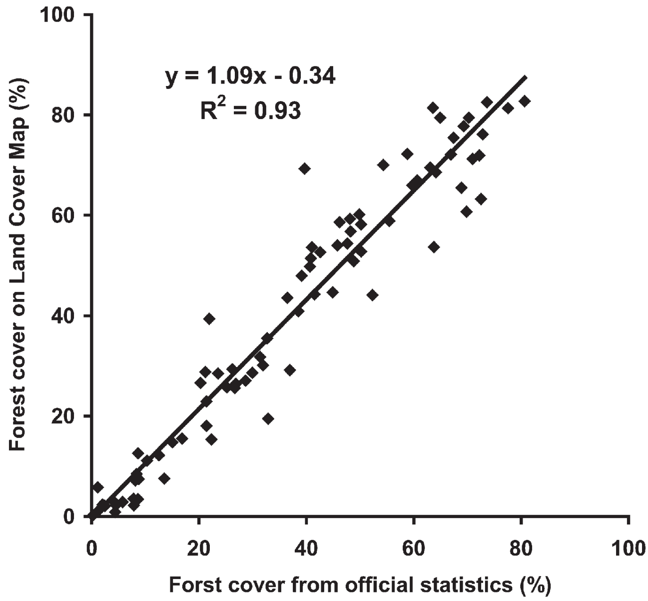

Figure 3. Comparison of forest cover percent estimates for the Russian Federation's administrative subjects derived from the land cover map of Northern Eurasia and Forest State Account's data corresponding to 1 January 1998.

other drivers of land cover change will be addressed as part of the systematic global validation exercise planned for the GLC2000 maps, and the UN Food and Agriculture Organisation's Land Cover Classification System is being used to translate the regionally optimized legend of this map to the global legend of the GLC2000 product.

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