Global land cover mapping using data from Earth Observing Satellites; Current status and future perspectives

Alan Belward, Hugh Eva

European Commission, Joint Research Centre, 21020 Ispra (VA), Italy
Email: alan.belward@jrc.it, hugh.eva@jrc.it

Land Cover Information - Earth System Modelling and Policy Users'

Over 70% of the Earth's surface is ocean. The oceans store and move heat, fresh-water, gases, and chemicals as part of the Earth's climate system; see for example the well-documented El Niño phenomenon and the global thermohaline conveyor belt. The 30% or so of our planet that usually sits above sea-level also plays an important role in the functioning of the Earth system. Vegetation accounts for 99% of the Earth's total biomass, and the reports by the Intergovernmental Panel on Climate Change (IPCC) to the UN Framework Convention on Climate Change (UNFCCC) and others have shown that land surface processes too affect the exchange of energy, gas and water with the atmosphere (Sellers *et al.* 1997).

The nature of the land cover (water-bodies, vegetated, snow and ice, barren, artificial) will determine the way in which the land surface interacts with the atmosphere. Climate models use a number of variables to describe the land surface processes; albedo, roughness, evapotranspiration, carbon exchange and aerosol emissions. Measuring these variables consistently on the global scale is not currently possible (GCOS 2003), but they can be inferred from land cover type, especially if the land cover classification scheme is constructed to meet this objective. And of course cover can - and usually does - change with time; the changes to land cover - plant growth and differentiation, land management practices, fire, disease, windthrow and pests - have the capacity to alter climate but also respond to climate; hence the scientific interest in monitoring global land cover.

Of course our policy-makers address climate issues, and indeed the policy in this domain is heavily driven by science (Agrawala 1999), so policy makers can be seen as users of global land cover data destined for Earth system models. But changes to climate and changes to land cover also affect the land's capacity to support human life, and alter the biological diversity of specific regions of our planet. Our policy-makers have produced various pieces of legislation to protect biodiversity, encourage sustainable (and legal) use of resources and to realise humanitarian/development-aid programmes.

Accurate information on land cover helps to develop sustainable development policies and strategies at different levels, and helps measure the impact and effectiveness of management actions associated with these policies. A good example is the need for monitoring and transparency called for in the recent Forest Law Enforcement, Governance and Trade (FLEGT) action plan developed by the European Commission (EC, 2003). This document emphasises the role remote sensing from space can play in assuring transparency and accountability to any forest cover monitoring programme. However, descriptions of global land cover attuned to climate, earth system and biogeochemical cycle models won't always meet such users' needs; the biodiversity policy user is more likely to want to know where bamboo-forest communities are than where a more generic class such as evergreen-broadleaved-forest may be found, the FLEGT user wants to know if a forest has some protected status, or is part of a legal logging concession.

Whether for science, or for policy, generating global land cover maps is not a trivial task, and the myth that the maps we want are readily accessible, up-to-date, accurate and inexpensive to produce continues to persist (Estes and Mooneyhan, 1994). Before any land cover map can be drawn suitable observations on which to base a description of the distribution of land cover have to be made, the legend used to describe the land cover must be established, map-accuracy protocols put in place and someone has to turn the basic observations into a map according to the agreed legend. Nevertheless, progress is being made, and global land cover maps are increasingly available. This paper describes past global land cover mapping activities and outlines future initiatives.

Past Experience

Humans have produced cartographic representations of their immediate environment throughout history (the search for the earliest map continues -the city map of Çatal Höyük is the oldest-known at present, dating from around 6,200 BC): the Pythagoras school of philosophers (c.a. 500BC) suggested the Earth was a sphere; the Hereford "Mappa Mundi" had been drawn by around AD 1290; Gerhard Mercator had produced his globe by 1541; by the 1850s balloons (and pigeons) were being used to carry cameras for use in land surveys; Wilbur Wright (well, his passenger – L.P. Bonvillain) provided the first aerial photograph by 1908, and by 1957 the launch of polar orbiting satellites provided the opportunity for space-borne cameras, capable of imaging every part of the Earth's surface.

The early maps tended to be topographic, rather than thematic (though in the 1560s the Mughal Empire used maps of cultivated and uncultivated land as a basis for taxation); and indeed thematic maps depicting global land cover are still comparatively rare. Since 1972 the Landsat Earth observing satellites have provided imagery useful for creating thematic maps showing the land cover of our planet. But global maps, treating all parts of the world equally, and representing actual land cover over a fixed, contiguous period of time only became available in the 1990s. The first of these was begun at the end of the 1980s to meet the needs of the International Geosphere Biosphere Programme (IGBP) (Townshend 1992).

The IGBP's land cover map, called DISCover, was produced from data obtained from the Advanced Very High Resolution Radiometer (AVHRR). The AVHRR observations used for this work were made between 1992 and 1993. The data had a nominal 1 km resolution and were obtained through the coordinated efforts of 23 receiving stations from around the world. (At this time, due to limited on-board satellite recording capacity, 1 km data were only available for limited regions; or when in line-of-sight of a ground receiving station). Data processing, image analysis and final classification to a single global legend, consisting of 17 classes, were carried out during the 1990s; the validated data set was published towards the end of the decade (Loveland *et al.* 1999). The legend was defined to meet the needs of the global biogeochemical modelling community (Running *et al.* 1994) with additional reviewing by the IGBP core projects that would use the final data base. More than 100 individuals from thirty nations participated in the DISCover project in its stages from conception and design through to implementation. These participants came from seven international organizations, twenty-six research institutes and academic organizations, twenty-one national agencies, centres and/or laboratories and seven industrial groups (Belward *et al.* 1999).

By the time the DISCover product was complete it described land cover as it was some five years previously; and the database is now over ten years old. Yet the IGBP map continues to be used in land-atmosphere processes studies (*e.g.* Kucharik *et al.* 2000) and the AVHRR archive it was based on has subsequently been used to create other global land cover products (Hansen *et al*. 2000). The AVHRR was designed to provide data to the meteorological community, and was not optimised for mapping land cover (whether vegetated or not). Nevertheless the experience with the AVHRR has paved the way for a whole generation of satellite borne sensors designed specifically for global studies of the terrestrial surface.

New Earth Observing Capabilities Supporting Global Land Cover Mapping

The VEGETATION instrument onboard the SPOT4 satellite launched in 1998, the MODIS sensors on the TERRA and AQUA satellites, the SeaWiFS sensor, GLI on the ALOS II satellite, and the MERIS sensor on the ENVISAT platform all offer improved geometric, radiometric and spectral performance over the AVHRR for global land cover mapping. Suitable data are the start, but as DISCover amply demonstrated, suitable data processing and data distribution strategies and facilities are equally important – this is often referred to as the ground segment. By and large these systems have dedicated ground segments that process and distribute the data. This processing includes steps such as radiometric correction of the data to account for instrument calibration drifts, atmospheric corrections and geometric corrections – all essential precursors of a successful land cover mapping exercise.

The availability of data from the ground segments of VEGETATION and MODIS data have already led to successful new global land cover mapping projects. And advanced plans for using MERIS data for these purposes are now also in hand. These projects and programmes are discussed below.

New Global Land Cover Maps

DISCover was created to the specifications provided by a clearly identified scientific constituency, the IGBP. For this reason the map's legend was optimised for use in specific modelling activities. And the legend is still used to produce global land cover maps from MODIS data. Using the same land cover legend as IGBP, the Moderate Resolution Imaging Spectro-radiometer Land Discipline Group (MODLAND) has generated regular land cover map updates, at 1 km resolution since mid-2000 (Friedl *et al.* 2002). The DISCover legend though has some limitations for describing land cover relevant to specific regions and is not always regionally optimised for use in resource planning and management. An alternative approach to land cover mapping aiming to satisfy both modeling and policy users was tried at the end of the 1990s - the Global Land Cover 2000 project (Bartholomé and Belward 2004).

The Global Land Cover 2000 (GLC2000) database aimed at creating a two-tier product - a map that was both regionally optimised and globally consistent. The database was created in 18 different production regions by an international partnership coordinated by the European Commission's Joint Research Centre.

Groups of partners from a particular region had responsibility for establishing the legend that best served their region's priorities for land cover information. For example the Eurasian map depicts palsa bogs, the South America database includes bamboo dominated humid forests. Regionally specific classes like these have less significance in other parts of the world – they may not even be present - and so require alternative representation in the global product. The UN Food and Agriculture Organization developed the Land Cover Classification System (LCCS) to analyse and cross-reference regional differences in land cover descriptions (Di Gregorio and Jansen 2000). LCCS describes land cover according to a hierarchical series of classifiers and attributes. These separate vegetated or non-vegetated surfaces; terrestrial or aquatic/flooded; cultivated and managed; natural and semi-natural; life-form; cover; height; spatial distribution; leaf type and phenology. Coding each class with LCCS allows a map legend to be progressively more detailed for the regional and in some cases national level users, yet is also traceable to a single consistent global legend. The global scale GLC2000 legend documents 22 land cover types, chosen to accommodate the aggregation of all classes represented in the more detailed regional scale products, and to provide continuity with previous maps by providing traceability to the IGBP classification system used in the original 1992 land cover map.

The range of ecological and physical conditions encountered on the global scale means that one image classification method is unlikely to be optimum for all regions. Using different sub sets of the global satellite image archive either in terms of time periods and / or spectral bands, and different image classification methods can lead to improved regional classifications. The GLC2000 project adopted a "regionally tuned" approach where each continental / regional product was produced independently with the lead scientists taking responsibility for the choice and implementation of image classification methods. However, all regions used daily data from the VEGETATION sensor on board SPOT 4 covering the period 1st November 1999 to 31st December 2000. This data set was made available by the VEGETATION programme partners (Centre National d' Etudes Spatiales, Swedish National Space Board, Italian Space Agency, Belgian Office of Science and Technology and European Commission).

The VEGETATION sensor acquires data using a push-broom system. This maintains a spatial resolution of 1.15 km across the whole swath. These data have been geometrically corrected to give a pixel-to-pixel registration of better than 300 metres, and then resampled to a 1 km pixel. They contain the four spectral channels as top of canopy reflectance, the NDVI and angular information (VEGETATION 2002).

Most of the regional maps have been published independently of the global product (*e.g.* Bartalev *et al.* 2003, *Eva et al.* 2004, Latifovic *et al*. 2004, Mayaux *et al.* 2004) though the global database users' also have access to the original regional coding applied to each pixel. The GLC2000 database and the more detailed regional products are freely available to science and policy users. Figure 1 illustrates the Republic of Ireland and the United Kingdom as extracted from the global database.

Figure 1. Republic of Ireland and Great Britain extracted from GLC 2000 data base: The legend and map have been simplified for printing in black and white, though the figure does illustrate the general level of detail available in this 1 km resolution, global data base.

Future Global Land Cover Mapping Activities

The MODLAND programme will continue to develop and release land cover products at 1 km resolution for the lifetime of the MODIS system. This includes the product mapped to the IGBP legend. Defries and co-workers at the University of Maryland have also developed new products mapping land cover expressed as continuous-fields, *e.g.* percent forest cover. Initially this work was based on the original IGBP's AVHRR data base (Defries *et al.* 2000), though is also being applied to 500 metre resolution MODIS data (Hansen *et al.* 2003).

Building on the success of the GLC 2000 project the European Space Agency has launched the GLOBCOVER initiative as part of the ESA's Data User Element (DUE). The DUE programme aims at supporting Servicing Industry, Research Laboratories and User Communities for the operational provision of Earth Observation products to targeted user communities. GLOBCOVER will develop a service to produce a global land-cover map for the year 2005 from 300m fine-resolution mode MERIS data (Achard and Arino 2004). The new product will offer far greater spatial detail (Figure 2. shows the difference in spatial detail expected from the GLOBCOVER programme in comparison with the published GLC 2000 database) and is expected to provide more thematic detail. Preliminary discussion with the data set's potential users' including FAO, UNEP, IGBP and GCOS highlighted the need for more attention to; wetland classes for biodiversity and greenhouse gas emission calculations; agricultural areas including crop area and separating irrigated / non irrigated land for food security planning and water use / ground water mining calculations; wet and dry season class extents for inland fisheries / aquaculture planning and for monitoring locust breeding habitats; forest species occurrence/abundance information for both sustainable forest management and biodiversity; much more attention is needed to mapping artificial surfaces (including urban areas), for use in hydrological and climate models as well as demographic studies and urban development monitoring; river delta ecosystems for coastal zone management issues such as biodiversity loss, public health and pressure on agriculture through salination. The thematic legend of any final product should again be compatible with the FAO Land Cover Classification System (LCCS).

Conclusions

Global land cover mapping at medium to coarse resolutions is becoming more and more reliable; reliable in terms of product quality, in terms of availability of data on which to create the maps and reliability in terms of institutions willing to take on the task. This is just as well, because the demand for global land cover information continues to grow. For example, the GCOS 2nd report on the adequacy of the global observations for climate, submitted to the Conference of the Parties to the UNFCCC, highlights the importance of sustained land cover information because the spatial pattern of land cover is critical information for determining the capacity of biodiversity to adapt to climate change, because changes in land cover force climate and because land cover is used as a surrogate for other important climate variables. The GCOS implementation plan, called for by the Parties (COP 9, 2003), states that new land cover maps should be produced at 250 – 1 km resolution every year, and high resolution -50 metre- every five years. Although this paper shows that progress towards satisfying the demand for moderate resolution products is reasonably well met, the high resolution maps don't exist, and question marks hang over the long term availability of high-res. imagery…so there is still plenty of work to be done.

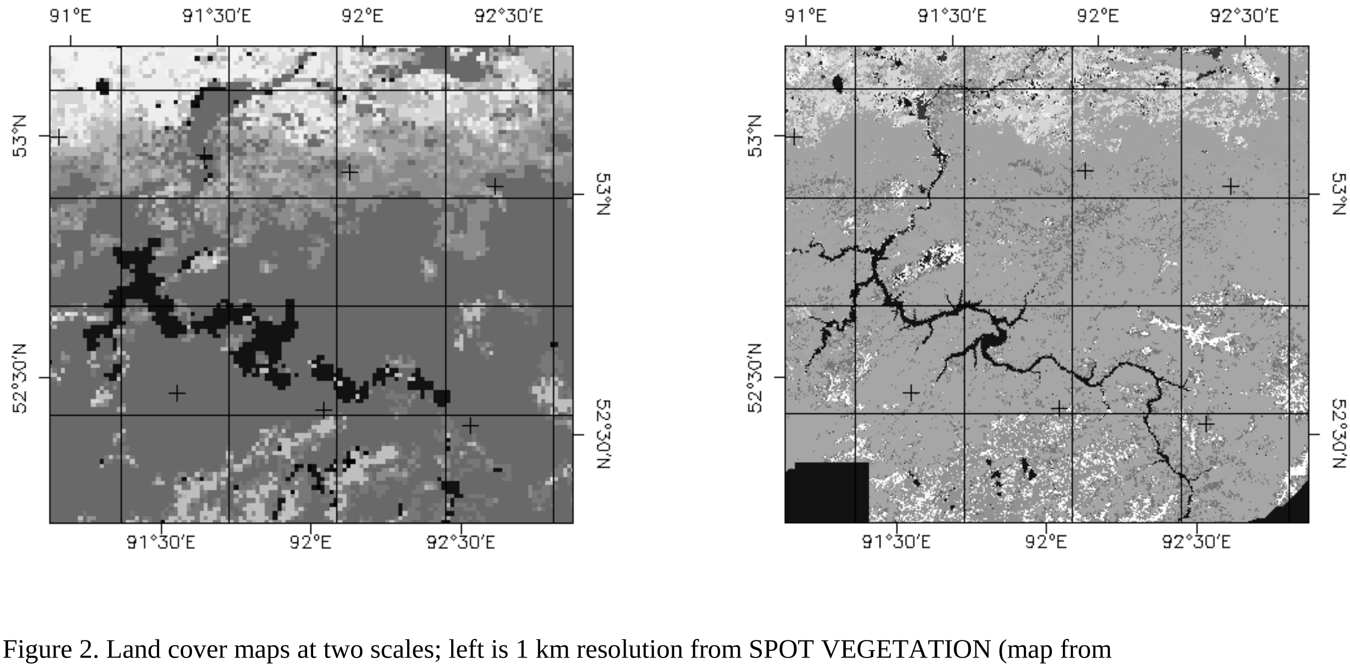

Figure 2. Land cover maps at two scales; left is 1 km resolution from SPOT VEGETATION (map from GLC2000 project); right is equivalent area derived from 300m MERIS (map from University of Wales, Swansea SIBERIA II project). Comparisons concerning thematic content are not offered here and no legends are presented

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