The Global Land-Cover Characteristics Database: The Users' Perspective

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Abstract

*A unique global land-cover characteristics database developed by the U.S. Geological Survey has been available to users since mid-1997. Access to the data is through the Internet under the EROS (Earth Resources Observation Systems) Data Center's home page (**http://edcwww.cr.usgs.gov/landdaac/glcc/glcc.html**). Since the release of the database, the data have been incorporated into various environmental research and modeling applications, including mapping global biodiversity, mesoscale climate simulations, carbon cycle modeling, and estimating habitat destruction. Since the early stages of the project, user feedback has provided a means to understand data utility in applications, garner suggestions for data improvements, and gain insights into the technical challenges faced by users. Synthesis of user feedback provided a means to generate a user profile and derive a list of applications-critical criteria for land-cover data. User suggestions have lead to revisions in the database, including label changes, alternative classification schemes, and additional projections for the data.*

Introduction

The last decade has been a uniquely productive era for mapping and modeling of the Earth's surface. There have been substantial improvements in computing technologies, our understanding of global systems, and the availability of improved Earth science data sets. During this period, several new geospatial data sets characterizing the land surface of the globe have been constructed from satellite observations (Eidenshink and Faundeen, 1994; Loveland *et al.*, 1999a; Defries *et al.*, 1995; Hansen *et al.*, 1999). These data sets have been designed to meet the requirements of global change research, such as the U.S. Global Change Research Program (Subcommittee on Global Change Research, Committee on Environment and Natural Resources of the National Science and Technology Council, 1997) and the International Geosphere Biosphere Programme (Townshend, 1992).

The Land Cover Working Group (LCWG) of the International Geosphere Biosphere Programme-Data and Information System (IGBP-DIS) undertook the responsibility for designing and fostering the development of an improved global land-cover database. Through a series of international workshops, the LCWG finalized a strategy and definition for a global land-cover product (DISCover) based on 1-km AVHRR data (Belward, 1996). The U.S. Geological Survey (USGS), in partnership with national and international agencies and universities, has developed a global land-cover characteristics database described in detail by Loveland *et al.* (1999a) and Loveland *et al.* (1999b, in this issue). The database, released for public use in 1997, describes global land cover using a number of classification schemes. One of its layers is the aforementioned DISCover land-cover scheme.

The global land-cover characteristics database is a multilayered, flexible database designed for input into a variety of Earth science modeling scenarios. The database layers, formatted as raster grid images, are distributed free of charge under the EROS(Earth Resources Observation Systems) Data Center's home page: **http://edcwww.cr.usgs.gov/landdaac/glcc/glcc.html**. The on-line interface guides the user through the data selection process. Each user must choose a geographic area of interest (by continent or globally), select a projection (Goode Interrupted Homolosine or Lambert Equal-Area), and then download from the list of ten data sets (Table 1). Documentation files, also found on-line, provide information on image geometry, processing methods, and the various land-cover legends included in the database.

The database contains seven different land-cover products, including DISCover (Table 1). The DISCover product has now been validated, and the results of the validation effort are reported by Scepan (1999, in this issue).

Role of User Feedback in Global Land-Cover Characterization

User feedback (that is, the comments, suggestions, constructive criticism, and requests from the users of the global land-cover database) has played a key role in setting the requirements for the global land-cover effort and assessing the quality and utility of the database through the peer review process. The IGBP global land-cover strategy explicitly called for a validation protocol to assess the accuracy of the DISCover product (Belward, 1996). This process consisted of three primary activities: (1) peer review of the preliminary continental databases, (2) comparisons with other land-cover data sets, and (3) a formal statistically sound accuracy assessment. This three-step strategy starts with the recognition that it is not possible to create a perfect land-cover product. The IGBP recognized that there are a large number of land-cover experts willing to evaluate the global land-cover data sets. The comments received through the peer review process regarding classification accuracy are presented later in this paper. The USGS mapping team used peer review not only to identify and correct classification problems, but also to gain feedback on a wider range of database issues.

The USGS implementation of the IGBP global land-cover strategy is founded on the principle that user feedback provides a means to understand data quality. User feedback has provided a means to understand data utility in applications, collect suggestions on data set improvements, and gather insights into the technical challenges faced by users working with the data. The information gathered from the land-cover data user community has shaped the output product, and will continue to influence

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TABLE 1. DATA FILES IN THE GLOBAL LAND-COVER CHARACTERISTICS DATABASE

Data Description	Data Type
Seasonal Land-Cover Regions	Land-cover classification
Biosphere Atmosphere Transfer Scheme	Land-cover classification
Global Ecosystems	Land-cover classification
International Geosphere Biosphere Programme (DISCover)	Land-cover classification
Simple Biosphere Model	Land-cover classification
Simple Biosphere Model 2	Land-cover classification
U.S. Geological Survey Land Use and Land Cover	Land-cover classification
Digital Chart of the World Urban	Source data
Digital Elevation Model	Source data
Monthly Normalized Difference Vegetation Index	Source data

future efforts to create global and large-area land-cover products.

Work on the global land-cover database began in 1994. The methods for the database construction had roots in an earlier prototype effort to map the land cover of the conterminous U.S. (Loveland *et al.*, 1991; Loveland *et al.*, 1993). An important part of the prototype effort focused on developing a dialog with land-cover data users. In this pilot stage, the primary benefit of collecting input from the data users was to improve understanding of their data requirements in order to better address them. To this end, the USGS hosted a user workshop in 1994. Approximately 20 scientists attended the workshop and reported on their use of 1-km land-cover data. The participants shared their perspectives on the strengths and weaknesses of the conterminous U.S. land-cover data and provided insights into potential improvements to the land-cover characterization process. The research presented at the workshop provided evidence regarding the value of a flexible database strategy for land-cover characterization. Specifically, these scientists endorsed a land-cover database structure that provided options in land-cover data schemes and additional information, such as the source data, to interpolate or extrapolate other biophysical variables. Many of the applications presented during the workshop were reported in a special issue of *Ecological Applications* (Steyaert *et al.*, 1997). The issue included research on weather simulations (Pielke *et al.*, 1997), general circulation models (Fennessy and Xue, 1997), and modeling trace gas emissions (Kinnee *et al.*, 1997; Gunther, 1997).

Mechanisms for Gathering User Feedback

A structured effort to obtain user feedback was implemented for the global land-cover database activity. The global land-cover database users have provided feedback through four different channels of communication. They are

- Informal personal communication (verbal or written),
- Cooperative projects,
- Online user registration form, and
- User survey (via electronic mail).

The first mechanism for feedback consists mainly of informal suggestions from users to members of the project team. Frequently, these comments are gathered in the context of professional meetings, by e-mail, or by telephone. Through this channel, users offer unsolicited observations about the classification content of the database, usually in a local or regional context. Such comments may be based on personal knowledge of the land cover at specific locations or comparison with other existing land-cover data sets.

Cooperative projects with different mapping and modeling applications provided another source for user feedback. In these situations, members of the global land-cover team worked hand-in-hand with database users, fine-tuning or customizing the data in order to fit specific applications. This often resulted in an iterative style of feedback, in which members of the project team interacted with the user to find a solution to the user's problem with the land cover. For example, our work with Forest Resources Assessment 2000 has resulted in a set of forest canopy classes designed to meet the specific requirements of the Food and Agriculture Organization (Zhu *et al.*, 1999). Regional workshops funded under the IGBP START (Global Change System for Analysis, Research, and Training) initiative also provided opportunities for users to examine the utility of the data for regional studies. At such workshops, global land-cover project members worked closely with workshop participants, resulting in a better understanding of their comments on database quality and finding practical solutions. Global project staff have participated in three such workshops to date. They were the Miombo woodland workshop in Kasungu, Malawi, in June, 1998; the IGBP/START land use in Temperate East Asia training workshop in Ulaan Baatar, Mongolia, in June, 1998; and the Southeast Asia START workshop for land-use and land-cover change in Bankok, Thailand, in August, 1998.

Since the initial release of the North America, South America, and Africa databases in 1996, an on-line user registration form has been a part of the global land cover web site. To date, over 650 users from 60 countries have registered (Figure 1). The on-line form allows tracking of basic information about users and their applications and collection of feedback on technical problems and classification errors. In some instances, users have contributed extensive and detailed information about land cover in their region of expertise.

Approximately 18 months after the release of the global land-cover database, a more detailed user survey was sent out using electronic mail to collect more detailed information about the users and their applications of global land-cover data. Nearly 20 percent of the recipients responded to the survey, providing a wealth of information about their applications, concerns, results, and future requirements for land-cover data. We have synthesized information gathered through these four mechanisms to generate a general user profile. The following section provides an overview of the users and their applications.

The Global 1-Km Land-Cover User Community

As stated above, early impetus for the global land-cover database emerged from the land-cover data requirements of the global modeling community (Townshend, 1992). According to our electronic mail survey, one half of the applications for the database are for scientific modeling. Modeling applications incorporating data from the global land-cover database include

- Modeling world agricultural production,
- Mesoscale climate simulations,
- Land surface roughness for modeling wind energy resources,
- Modeling land-cover change and degradation,
- Carbon cycle modeling,
- Hydrologic modeling, and
- Modeling trace gas emissions.

Fifteen percent of the users reported employing the data for mapping applications. Some examples of these applications include

- Assembling an atlas on human demographics and the environment,
- Ecoregion mapping, and
- Mapping global biodiversity.

Another 13 percent use the land-cover data for land management or conservation.

Several examples of these applications are as follows:

- Forest reclamation,
- Determining the effects of land use on ecosystems,

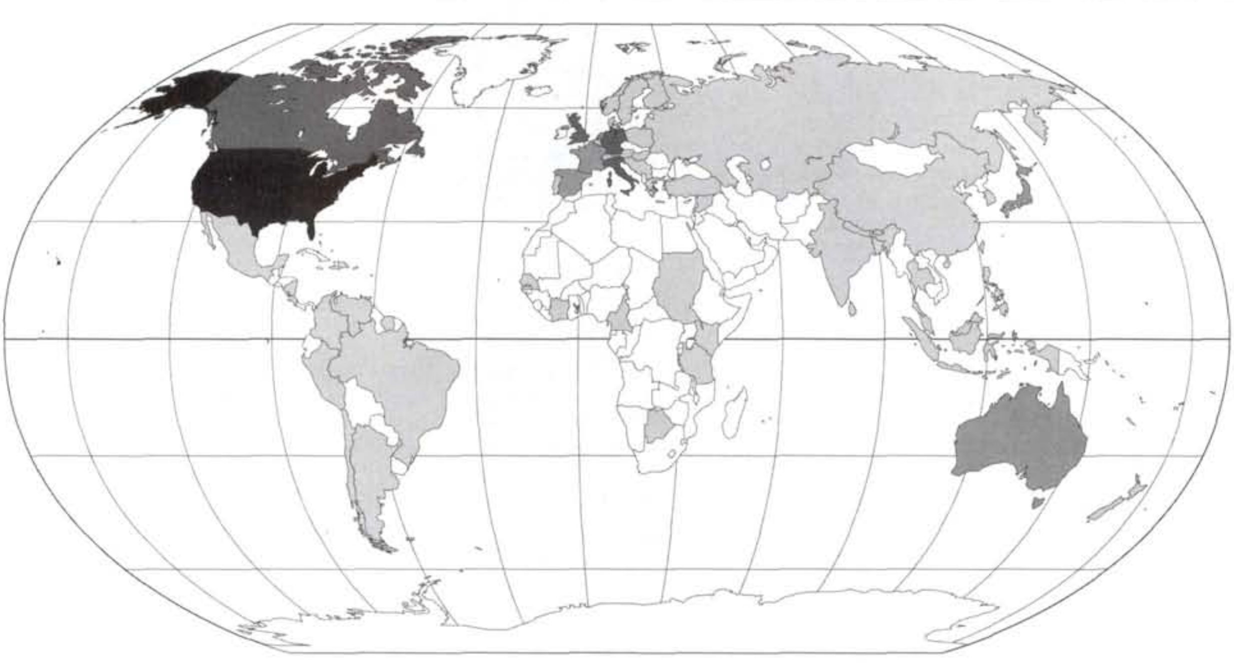

Figure 1. Location of registered database users.

- Planning for habitat conservation, and
- Monitoring migrating birds.

Education represents about 4 percent of the reported database usage, and miscellaneous applications account for approximately 18 percent. These uses include such applications as

- Three-dimensional visualization of the land surface for public education,
- Validating paleoecological vegetation maps,
- Predicting the consequences of power plant accidents, and
- Determinating the critical loads of acid rain for vegetation.

The global land-cover database contains seven land-cover layers or classification schemes (see Table 1). The most commonly used land-cover data set is the USGS Land Use and Land Cover scheme as reported by 25 percent of the user survey respondents. The reasons for this are not yet fully understood. However, this scheme has had a long history of use in the remote sensing community, and its popularity may be an outcome of user familiarity with this land-cover system introduced by Anderson *et al.* (1971). The IGBP DISCover classification is used in 20 percent of the applications. Following closely is the reported usage for the seasonal land-cover regions (SLCR) classification (18 percent), which contains the most detailed thematic land-cover information. Personal communication by project staff with users indicates that many are tailoring the seasonal land-cover regions to suit their own special land-cover data requirements. Many users (42 percent) report using not one, but several land-cover classification schemes for their applications. This supports and reinforces a basic design assumption for the database--that no single classification scheme satisfies all requirements.

The database also contains source satellite data (AVHRR monthly NDVI composites), a digital elevation model (Gesch *et al.*, 1999), and an urban layer from the Digital Chart of the World (Danko, 1992) (see Table 1). Users have also acquired these data for their applications. One half of survey respondents reported using at least one of the source data files in their work.

The users of the global land-cover characteristics database come from a wide variety of public and private sectors. The largest number of users report affiliation to an academic institution (45 percent). Approximately one quarter of the reported users have a government affiliation, with another 13 percent associated with the commercial sector.

The database was designed for applications on global and continental scales, and the majority of the applications (53 percent) fall under these two categories. The proportion of users that reported applying the data to regional-, national-, or local-scale applications is somewhat larger than expected (47 percent). This gives cause for some concern, as the data were not designed to deliver per-pixel thematic accuracy, and thematic errors become apparent at regional and local scales of analyses. In some instances, users are expanding their research from a local scale to a much broader geographical extent. These users typically have access to the land-cover data appropriate for their local study, and they are searching for land-cover data with regional or even wider geographic coverage.

Lessons Learned from User Feedback

The job of creating useful digital land-cover information for the entire land surface of the globe is a challenging one. The methodology, described by Loveland *et al.* (1999a), was rooted in a continental work approach and an analysis strategy based on regions. This working strategy resulted in a database where each region (for example, seasonal land-cover region) was interpreted and labeled as a geographic unit. However, the strategy did not include inspection of each individual pixel. This methodology has produced land-cover data that have validity and consistency at a continental or global scale. However, on regional, national, or local inspection, certain areas show errors in land-cover labels.

Although the comments and feedback offered by the people using the land-cover data have been predominantly positive, several crucial issues have emerged from synthesizing the users' observations. User suggestions may be categorized into comments relating to land-cover reliability and to technical issues. Users typically use more than one source of land-cover information, and they often make comparisons between their data sources to assess the value of a new information source. Users also evaluate land-cover data based on their own personal field experience. These *ad hoc* user evaluations of the data often provided valuable insights into the strengths and weaknesses of the database content and contributed to the revision process.

Feedback on Land-Cover Reliability

Regardless of the scale at which the data are inspected (e.g., local, regional, continental, or global), there are inevitable misclassifications. While the team interpretation process used by Loveland *et al.* (1999a) was designed to produce consistent and reliable results, perfection was never achieved. The IGBP DISCover analysis strategy recognized this, and the methodology specified that peer review would be used to determine strengths and weaknesses and identify necessary classification improvements (Loveland and Belward, 1997). As the continental databases were completed, they were released for public review. The documented continental seasonal land-cover regions and derived land-cover data sets were placed in an Internet-based web site that allowed anonymous FTP access to the data. Interested parties were warned that the data were preliminary, and should be used with caution. Because the comments received could be specific to any one of the seven available continental or global land-cover products, it was necessary to inspect the data set specific to the comments and then determine whether the changes were germane to other data layers.

A considerable volume of peer comments was received through a variety of formal and informal mechanisms. The comments, if corroborated using other evidence, form the basis for future database revisions. Generally, the feedback received can be divided into three groups: (1) local inspections, (2) regional assessments, and (3) global reviews. Local inspections typically came from those using the data for local to regional applications. Comments were often focused on clarifying the content of an individual category in a specific location. The following are comments from anonymous contributors that illustrate the kinds of local inspection input that was received:

- North America class 174, in the mountains east of Bethel, Alaska (60.72508 N and 59.57331 W), is tall and low shrubs.
- I have noticed a problem within the Africa data set. Class number 4 is labeled as cropland with wetland. My guess is that the class is more of an irrigated cropland class.
- In southeastern Brazil, there are some pixels classified as Marsh Wetland (Olson legend 45). The same pixels are classified as SLCR legend 97 (fragmented tropical forest/grassland). This is confusing.
- There appears to be a systematic bias (i.e., probable misclassification) in the Pinyon-Juniper woodlands of northern Arizona. The DISCover classification calls it closed shrubland rather than woody savanna. One could argue that some Pinyon Juniper is actually closed shrubs (greater than 60 percent cover and under 2 meters tall), but not these.
- Most of Lake Chad in the African database is classified as being "barren or sparsely vegetated." This, of course, is true in a sense, but shouldn't you call it water?
- Consider splitting North America class 36. While it is all grassland-shrubland, the shrub-dominated regions should be separated from the grass-dominated regions. In Texas, this region is mesquite, acacia, and grasses (savanna).

While the data sets are not reliable or appropriate for most applications at local levels, the users inspecting the data at this level provided considerable input. Because these comments were typically very specific and dealt with easily identified categories and areas, they were generally easy to verify and address.

Regional-scale feedback was often less specific but still useful because comments often dealt with important regional landscape patterns. Examples include the following:

- A major part of the Netherlands is classified as fields. Other information indicates that it should be grassland.
- We found some inconsistency in several regions of Africa (e.g., Miombo Woodland, Sudanian Woodland, and Tropical Forest in Morocco).
- In the Middle East, you underestimate the extent of dryland cropland. Key wetlands in this region were not mapped.
- There are too many cropland mosaic classes in Europe and not enough forest cover.

Global-scale comments were often very general and typically positive. These types of comments have little value in correcting specific problems but help gauge user satisfaction with the different data sets. Some, however, indicated pervasive problems. Examples include

- Wetlands seem to be under-represented in general in the DISCover data set. This seems to be especially true in South America and Africa.
- You have a consistency problem with irrigation labels. While the North America and Asia irrigated designations look good, you miss significant irrigation developments elsewhere. This is especially noticeable in Spain.

Problems such as these were confirmed during the accuracy assessment (Scepan, 1999, in this issue). Because they are pervasive problems and are related to limitations in the source AVHRR data, they are difficult to correct. While they may not be correctable without major effort, they are important characterizations that must be acknowledged in database documentation because they identify limitations that may be critical for certain applications.

Finally, some comments spanned all geographic venues. The best example of this is the evaluation provided by Philip Tickle, a forestry specialist for the Australia Bureau of Rural Sciences (Tickle, personal communication). In a detailed review of the seasonal land-cover regions for Australia, he focused on discrepancies between the IGBP DISCover estimate of forest cover and his agency's forest-cover statistics. He recommended changes in descriptions of 42 of the 137 seasonal land-cover regions, but concluded other modifications were necessary to improve the representation of forests, woodlands, and shrublands in Australia. He concluded that the continental and global databases would be improved, and the results would have value at multiple scales and venues, if local experts were more involved from the onset of the project.

Feedback on Technical Issues

The technical issues associated with using the data files of the global land-cover database fall into two main phases: (1) accessing the data and (2) data ingest or import. During the downloading phase, users reported running into problems associated with the rate that they were able to transfer files over the Internet, the disk space they had available for file storage, and access to the file compression software. The global land-cover data files are large, ranging from 45 to over 695 megabytes. In order to speed the downloading process, the data may be transferred in a compressed format. The compression routine (gzip) is in the public domain, and users are advised in the documentation as to the source for the software.

Many technical issues for users arise during the data ingest and importing process. The image data are designed for geographic analysis, and users must provide their own image processing or geographic information system software to analyze and manage the data. Therefore, the data are maintained in a generic binary format that can be imported into most software packages. However, because the data are not distributed in a proprietary format, the user must understand the procedures for ingesting data. For some software packages, this entails creating header files and editing them to reflect the correct geometric characteristics of the image files. To facilitate this process, documentation on the web page provides the necessary information that users need to import the data.

Working with the map projection has also been a critical technical issue for many users. The global data sets are all based on the Goode Interrupted Homolosine projection (Goode, 1925). From a cartographic point of view, this projection has several advantages for global data sets. It exhibits equal area grid cell size (that is, each grid cell in the data represents the same area on the ground) and minimizes angular distortion through much of the global land area (Steinwand *et al.*, 1994). Despite these benefits, the Goode Interrupted Homolosine projection is difficult to work with because many image processing software packages do not yet support this projection. As a result, some users have succeeded in developing their own code to reproject the data themselves. There is an algorithm to transfer latitude/longitude coordinates to Goode coordinates available under the AVHRR 1-km page (**http://edcwww.cr.usgs. gov/landdaac/1KM/xy_latlong.html**). In addition to the Goode Interrupted Homolosine projection, each continental data set is distributed in a Lambert Azimuthal Equal Area projection.

Although the majority of users have managed to work through their challenges with the Goode projection, this has had a significant effect on the practical usefulness of the land-cover database. We have noted the high frequency of requests for assistance with the Goode Interrupted Homolosine map projection and for data in alternative projections, most commonly requested is the geographic or Platte Carre projection.

Role of User Feedback for Data Set Revision

Revision Plans

Early in 1999, the validation of DISCover was completed. The results of the validation have now been published (see Scepan (1999) in this issue), and the scientific community can use the results of the accuracy assessment to determine whether the data adequately meet their land-cover requirements. Based on the input from the validation, as well as the wealth of information provided through user feedback, a revision of the global land-cover characteristics database and DISC over will be made.

Revision Process

The revised version of the global land-cover characteristics database and DISCover (Version 2.0) will be produced and released in 1999. Information gathered from a variety of sources will guide the database revision, including (1) the formal validation results, including core samples and confidence sites; (2) user feedback survey results; (3) personal communication with users; and (4) project team evaluation of the land-cover data. Each source provides unique forms of evidence about the strengths and weaknesses of the database.

The revision process will involve refining the current database that uses the 1992–1993 AVHRR data series. The strategy for the revision includes identifying problems with the existing 1992–1993 seasonal land-cover regions that are at the finest thematic detail of the database hierarchy. Many errors, including mislabeling and class confusion, are associated with individual land-cover regions. For the most part, the revision process will focus upon correcting content problems associated with specific seasonal land-cover regions. The updated regions will then be aggregated into the appropriate Global Ecosystem classes. This approach (aggregating corrected seasonal land-cover regions) facilitates consistent mapping to the remaining classification schemes in the database (Loveland *et al.*, 1999a). Other kinds of updates include adding alternative projection options, adding additional land-cover layers and attributes, and updating broad categories such as the urban data (see Table 2). Tables and descriptive documentation will provide the links between each version of the database. Additional components to the update will include metadata files, linkages to the accuracy assessment, and color lookup tables.

Summary

The scientists, modelers, and land managers who work with the land-cover database have contributed a wealth of information through a variety of feedback mechanisms. While it does not provide objective quantitative information on database accuracy, user input is a powerful source for understanding and improving the characteristics of the global land-cover database. This feedback process has been instrumental in gaining understanding as to the utility of global land-cover data in applications; providing suggestions for data set improvements on local, regional, and global scales; and giving insights into the technical challenges faced by the users.

The global 1-km DISCover land-cover database became available to the scientific user community in 1997. Focusing on forming relationships with the data users has been a primary component of the project's success. Early relationships with users, stemming from experience gained with the conterminous U.S. land cover and coordinating with the IGBP LCWG, influenced database methods, structure, format, and content. Continued close ties to the user community should be fostered. We hope to improve future land-cover products by involving the appropriate local agencies, facilities, and individuals through all stages of land-cover data production.

Communication with the land-cover user community has also provided information about their general requirements for

TABLE 2. A SUBSET OF REVISION COMPONENTS

Domain	Revision	Rationale
Global	Latitude/Longitude (Geographic Projection)	Requested by many users, especially the global change modeling community
Global	Coarse Grids (e.g., 50 km, 0.5 degree)	Requested by modeling community
Global	Ocean/Fresh Water Separation	Improvement of BATS, SiB, and SiB2 classification schemes
Global	Urban Layer Update	Improvement of outdated Digital Chart of the World urban information
Global	Federal Geographic Data Committee Vegetation Classification	Requested by the conservation community
Regional	North America/Eurasia Boreal Forest Transition Zone	Corrections associated with the location of high latitude tree-line
Regional	South America Amazon Basin (inclusions of Croplands/Degraded Forest)	Corrections of classes influenced by cloudy data
Regional	Forests in Europe	Corrections of European classification dominated by mosaic classes (i.e., cropland/woodland)

data. The following land-cover data criteria encompass many of the broad applications-critical requirements that have emerged from the land-cover user community:

(1) Land-cover data should be current (that is, not more than 10 years old).
(2) The data should be periodically updated and improved.
(3) There should be complete documentation and metadata available to all users.
(4) A statistical measure of data accuracy should be provided.
(5) The land-cover classification scheme(s) should match the scheme(s) that the user has been working with, or at least be easily converted to a familiar scheme.
(6) The data should be available in the user's chosen projection, or be simple to reproject.
(7) The data should be formatted to provide easy import into the user's software.
(8) Technical support should be provided.

The global land-cover database currently meets many of the above requirements (No. 1, 3, 4, 5, 7, and 8). The upcoming revision of the database will satisfy the second requirement for updated and improved land-cover data. The requirement for alternative projections (No. 6) will also be addressed with the addition of data sets provided in a geographic projection (latitude/longitude coordinates). In addition, many of these criteria highlight the necessity for long-term data management and maintenance. It is not desirable or responsible simply to create global land-cover databases. To meet user needs, a long-term commitment to management, access, applications support, and maintenance is essential. Any plans for future global land cover should take these user requirements into account.

In the coming years, the focus will be on further evolving the methods for designing and creating land-cover databases, providing continuity to the users of land-cover data, and searching for innovative methods for serving geospatial data and metadata. The challenges to provide and manage useful land-cover data that meets the evolving requirements of the global change research community will be met as long as database providers continue to invite user involvement and heed their recommendations.

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