DEVELOPMENT OF THE UNITED STATES NATIONAL LAND COVER DATABASE: EXPERIENCE FROM 1992 AND 2001 IMPLEMENTATION[*]

Limin Yang

Visiting Scientist
U.S. Geological Survey, Earth Resources Observation and Science Center
Sioux Falls, SD, USA - lyang@usgs.gov

KEY WORDS: Land Cover Database, CART, Image Analyses

ABSTRACT:

The Multi-Resolution Land Characteristics (MRLC) Consortium is a group formed by the U.S. federal agencies in 1990 to purchase Landsat 5 Thematic Mapper imagery for the conterminous U.S. and to develop a National Land Cover Dataset (NLCD 1992). The NLCD 1992 was completed in 2000. In 1999, a second-generation MRLC (MRLC 2001) consortium was formed to purchase three dates of Landsat 7 Thematic Mapper Plus (and some Landsat 5) imagery for the entire United States and to coordinate the production of a comprehensive National Land Cover Database (NLCD 2001). The NLCD 2001 was completed in April 2008. The NLCD 1992 and NLCD 2001 are specifically designed to meet the needs of the U.S. federal agencies for nationally consistent satellite remote sensing and land cover database. In addition, the MRLC consortium provides the database as public domain information. This paper summarizes the philosophy and scientific and technical issues with regard to design and implementation of the NLCD 1992 and NLCD 2001. Experiences and lessons learned from the intensive efforts to develop the two national land cover datasets are documented, including project design, technical approaches, accuracy assessment strategy, and project implementation.

I. Background

The late 1990s and early 2000s has witnessed several major and formative developments in global- and continental-scale land cover dataset using remotely sensed data (e.g. Townshend et al. 1997; DeFries et al. 1999; Loveland et al. 2000; Vogelmann et al. 2001; Friedl et al. 2002; Hansen et al. 2002; Bartholome et al. 2002; Homer et al. 2004; Liu et al. 2002; Homer et al. 2007). The endeavour is primarily driven by an increasing demand for up-to-date and accurate land cover dataset for study of global change at regional to global scale. The successful completion of those large-area land cover characterization activities are attributable primarily to the improved technological and algorithm development for land cover characterization, and the availability of the high quality remote sensing and geospatial datasets.

Along with development of the continental and global land cover datasets, significant progress has also been made in designing and implementing accuracy assessment for those land cover datasets based on rigorous and statistically defensible design (e.g. Scepan 1999; Yang et al. 2001; Zhu et al. 2001; Stehman et al. 2003). A closer dialogue between the land remote sensing communities and data users is emerging. The continued improvement and availability of remote sensing and geospatial data has provided an excellent opportunity to further improve large-area land cover database development.

One of the major efforts in large area land cover mapping is the development of two-time National Land Cover Datasets in late 1990s and early 2000 under auspices of the Multi-Resolution Land Characteristics Consortium (MRLC) (Loveland and Shaw, 1996). The MRLC was originally formed in early 1990 and consisted of several US federal agencies including: United States Geological Survey (USGS), Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and United States Forest Service (USFS) (Loveland and Shaw 1996). Under the coordination of MRLC 1990, a National Land Cover Data 1992 (NLCD 1992) was developed (Vogelmann et al. 2001). Entering 2000, the need for updated national land-cover data has led to the development of a new initiative under MRLC 2000 to develop a National Land Cover Database 2001 (NLCD 2001) (Homer et al. 2007).

The goals of this paper are two fold: 1) to summarize briefly major experiences learned from the development of NLCD 1992 activities, and 2) to present a new framework under which the NLCD 2001 has been developed. We illustrate the merits of the new framework through discussion of the NLCD 2001 design and implementation. The quality assessment of NLCD 2001 is also discussed.

II. Review of NLCD 1992 project

In early 1990 several federal agencies recognized the need for an up-to-date national land cover dataset of medium spatial resolution to support their national and regional environmental programs. This had let to the formation of the MRLC to pool resources for purchasing and processing Landsat data, and to develop a seamless national land-cover map of the conterminous U.S.

The primary satellite data used for NLCD 1992 land cover mapping project was the Landsat 5 TM data of circa 1992, acquired from both leaf-on and leaf-off seasons. In addition, ancillary geospatial data were compiled for support land cover

---

[*] Information presented in this paper represents the views of the author only. It does not necessarily reflect the views of USGS or any other participating organizations and no official endorsement should be inferred.

mapping, including USGS Digital Terrain Elevation Data and its derivatives (slope, aspect and shaded relief), U.S. Bureau of the Census population density data, USGS land use data analysis of 1970s, the National Wetlands Inventory (NWI) data, and the USDA State Soil Geographic (STATSGO) Database.

The land cover classification scheme designed for NLCD 1992 was a modified Anderson land use/cover classification system with 21 classes (Anderson et al. 1976). Land-cover classification was developed for each of the ten federal regions using either an unsupervised or supervised classification methods (Vogelmann et al., 2001). For unsupervised method, a *k*-mean clustering algorithm was applied to either a leaf-on or leaf-off Landsat image to generate spectral clusters, followed by labelling of clusters by interpreters. In many cases, ancillary data (e.g., census, slope/aspect/elevation) were used to resolve spectral confusion so that each TM pixel can be labelled into one of the 21 classes. A supervised approach was used at the later stage of the project when more training data of the land cover types were available. The main algorithm used for supervised classification was a classification tree algorithm. For details of the mapping procedures employed for NLCD 1991, readers are referred to Vogelmann et al. (1998, 2001).

Following the completion of land cover mapping for each region, an accuracy assessment was conducted using a procedure based on statistical sampling design. The sampling incorporated three layers of stratification and a two-stage cluster sampling protocol (Stehman et al. 2003). Each mapping region constituted a stratum and was sampled independently. The reference data used for assessing land cover data quality were the aerial photographs acquired by the National Aerial Photography Program in 1990 (Zhu et al. 2001; Yang et al., 2001; Stehman et al. 2003; Wickham et al. 2004). The overall agreement between the reference data and the mapping land cover type for the regions range from 38% to 70% at full legend (21 class) and from 70% to 85% for aggregated legend (7 classes) that resembles the Anderson Level I classification scheme (Stehman et al. 2003; Wickham et al. 2004).

The NLCD 1990 has been widely utilized in a wide range of applications, including land use planning, land cover change assessment, wildlife habitat evaluation, urban sprawl development, disease vector study, water quality impact, ecosystem status and health assessment, forest fragmentation study, nutrient and pesticide runoff modeling, spatial patterns of biodiversity, landscape characterization, and land management decision-making. (e.g. Vogelmann et al. 2001). The affiliation of the user community ranges from federal and state agencies, universities and institutes, non-government organizations, and commercial and private companies.

The project design and implantation to produce NLCD 1992 reflect then the philosophy and technological constraints at the time. Several aspects regarding the improvements beyond what have accomplished by the NLCD 1992 development are worth noting, namely: 1) method used to delineate the spatial mapping unit, 2) constraints to select best Landsat scenes for land cover mapping, 3) limit to a single legend land cover product, 4) quality and suitability of ancillary data used for land cover mapping, 5) consistency and efficiency of land cover mapping method, and 6) definition of land cover classes.

III. Strategy for NLCD 2001 Development

The primary goal of the MRLC 2001 initiative was to develop a second generation National Land Cover Database (NLCD 2001). The foundation of the new database is established based on previous experiences in developing global and regional land cover database implementation (Brown et al. 1999; Loveland et al. 2000). Such a database is defined as the multiple interlinked geospatial data sets that are useful either as an individual component, or in synergistic groupings, in order to meet a variety of users needs. In essence, the database consists of all original, and intermediate/derived data product, and all components of the database are standardized and logically linked to each other and are consistent across the United States.

An innovative approach for NLCD 2001 development was developed by following a cohesive and scientifically-based strategy, which consists of: 1) a flexible land cover database approach, 2) an ecologically-based mapping zone delineation, 3) a vegetation phenology-based Landsat scenes selection, 4) a consistent image preprocessing method, 5) a high quality and quantity training dataset, 6) consistent and advanced and efficient classification method, and 7) FGDC compliant metadata for all product. The following sections discuss each of the seven aspects with regard to the improvements made in developing NLCD 2001.

Flexible land cover database design

The NLCD 2001 is a multi-attributes, multi-source database that include a suite of data layers (30 meter resolution) staged as the standardized components intended for many applications – both nationally and locally. Specifically, the NLCD 2001 consists of: 1) calibrated Landsat imagery for three dates per path/row (acquired in early, peak and late growing season), 2) ancillary geospatial data, including 30m DEM and derivatives (slope, aspect and topographic position index), 3) estimates of percent imperviousness and percent tree canopy per-pixel, 4) land-cover classes derived from all images and ancillary data, 5) classification and prediction rules and confidence estimates for land cover and imperviousness and tree canopy data layer, 6) FGDC complaint metadata for the database. Together, such design of the NLCD 2001 provides data users with most flexibility to tailor the database for their specific applications.

Ecologically-based mapping-zone delineation

For large area land cover project, a logically partitioned mapping zones (defined as a mosaic of a few Landsat images) should be made based on landscape and ecological characteristics. Hence, a mapping zone of NLCD 2001 is defined as a relatively homogeneous region with its distinct features. There are five factors that were considered in defining the mapping zones, including physiography, land cover/use characteristics, spectral feature uniformity, edge-matching feasibility among mapping zones, and the size of each mapping zone and the number of Landsat images used to make a mosaic (Homer et al., 2001). For NLCD 2001, there are 66 mapping zones identified for the conterminous US. The mapping zone boundaries were made with reference to ecoregion of the United States, the land cover types (NLCD 1992), and an AVHRR time-series greenness dataset. In combination, the three data layers provided a landscape view of the nation and formed a basis to define mapping zone boundaries.

A Land cover and phenology-based imagery selection

One of the key components of the NLCD 2001 initiative was a plan for acquisition of a nation-wide multi-temporal Landsat 7 ETM+ imagery dataset. In order to establish the image base that can be best suitable for land cover characterization and for other applications, a Landsat image selection strategy was formulated based on knowledge of land cover land use features and the phenology of vegetation within each mapping zone. For each mapping zone, information on land cover type was extracted from the NLCD 1992, and the phenology for each cover type was identified using AVHRR time series greenness data (Reed et al., 1994; Yang et al. 2001). For each mapping zone, a preferred image acquisition time window was selected based on the maximum separation of the major land cover types using NDVI time series greenness data. This strategy provided a consistent framework for Landsat imagery acquisition schedule, and it forms a basis from which three Landsat scenes from a growing season are selected.

Consistent Landsat image preprocessing

Satellite data preprocessing is an important step to obtain good quality data for multi-scene mosaic, spectral transformations and information extraction. The NLCD 2001 data preprocessing follows a standard procedure to ensure consistency of image data preprocessing. Specifically, the key preprocessing steps include: 1) radiometric and geometric calibration, 2) orthorectification of the images through terrain correction with improved accuracy of ground control points and DEM data, 3) conversion of digital number to radiance and at-sensor reflectance/radiant temperature, and 4) a tasseled cap transformation of the original spectral bands into greenness, brightness and wetness components. A new set of tasseled cap transformation coefficients based on Landsat 7 at-satellite reflectance was developed from ten ETM+ scenes representing a variety of landscapes across the United States in both leaf-on and leaf-off season (Huang et al. 2002).

Extensive and high quality training data collection and compilation

To improve consistency and efficiency of classification process, a data mining technique-Classification and Regression Tree (CART) was adopted to develop NLCD 2001. It is recognized that the success of land cover characterization using CART relies greatly on the availability of high quality and quantity training data, hence, a major effort has been devoted to collection of training data for land cover classification and for imperviousness and tree canopy density modeling and mapping. For land cover classification, training data were compiled from several data sources through collaborations with many MRLC consortium members and the state and local organizations. Some of the important sources of training data include the forest plot data collected by USDA Forest Service Forest Inventory and Analysis (FIA) program, the national nature resources data collected by the USDA Nature Resources Conservation Services National Resource Inventory (NRI) program as well as many filed data collected by various agencies and mapping teams/contractors. For modeling imperviousness and tree canopy density, a set of high spatial resolution digital aerial photographs and satellite imagery are assembled from the USGS Digital Ortho-Quads and the Space Imaging IKONOS imagery provided by the NASA's Science Data Purchase Program. When necessary, additional training data were also collected for under-represented land cover types through fieldwork.

Consistent and efficient classification methods

Land cover mapping

As mentioned above, for land cover mapping, a classification tree algorithm was chosen based on previous experiments in large area land cover classification project (e.g. Hansen et al. 2001). The classification tree is a non-parametric statistic technique. It does not require the normality of input variables and can handle both categorical and continuous data. The algorithm provides a robust and efficient way to extract information from a large quantity of satellite and ancillary data, and it yields classification rules that can be readily interpreted and applied spatially. The specific algorithm chosen for NLCD 2001 is called C5[*] and Cubist*. The algorithms provide several advanced options for conducting training and rule-based modeling for classification. Major features include the boosting and cross-validation procedures. With boosting, the algorithm develops a sequence of the classification trees, each subsequent tree intends to reduce the misclassification errors resulted from the previous one. The final prediction is a weighted vote of the predictions of all trees generated. This boosting technique often improves classification accuracy by 5% to 10%. With cross-validation option of the C5*, user can obtain several quantitative estimates regarding classification quality.

Sub-pixel imperviousness and vegetation canopy density modeling and mapping

For NLCD 2001, a new method was developed for estimating percentage of impervious surface and tree canopy density for each 30-meter pixel, a brief description of the method follows. To quantify urban impervious surfaces and tree canopy percentage at Landsat sub-pixel level, a regression tree algorithm (named Cubist*) was utilized. This algorithm generalizes a set of rules based on training data to predict percent imperviousness or tree canopy density for each pixel of an image. Essentially, the algorithm establishes a statistical relationship between known imperviousness (or tree canopy density) at a location and the corresponding Landsat spectral reflectance.

High spatial resolution images (1m or finer) were used to derive reference data of impervious (or tree canopy density). The utility, practicality and affordability of the method for large-area imperviousness and tree canopy mapping were formally evaluated with an acceptable accuracy over several spatial scales (Huang et al. 2001; Yang et al. 2003). Mean absolute error between predicted and actual percent impervious surface (from high resolution data) ranged from 8.8 to 11.4% with correlation coefficients from 0.82 to 0.91 (Yang et al. 2003; Huang et al. 2001). Thus the method was implemented for use in developing a nation wide imperviousness and tree canopy density data set.

Data quality assessment

For NLCD 1992, a rigorous accuracy assessment was conducted for each of the ten federal administrative regions using 1990 vintage NAPP photographs as main reference data. While it is desirable to conduct such designed-based assessment, two major constraints control feasibility and implementation of such assessment for NLCD 2001: the cost and time taken to complete the assessment. For NLCD 2001, an alternative

---

[*] The use of product name is for descriptive purposes only

strategy for data quality assessment was proposed to provide data users with quantitative information on product quality through a two-tired approach. The first tire is to obtain data quality assessment from a cross-validation procedure output from the C5 and Cubist at the classification stage. The second tire of a more rigorous assessment (e.g. a design-based NLCD 1992 accuracy assessment) that are being implemented at the time of this writing by the MRLC consortium partners. The accuracy of the NLCD 2001 at the national level will be reported to data user community once completed.

For the first tire of the data quality assessment, i.e., an N-fold cross-validation, the training/testing data (land cover, imperviousness and canopy density) are divided into N equal-sized subsets. A cross-validation accuracy estimate can be derived by using each subset to evaluate the classification results developed using the remaining training data. The process can be repeated for N times. The average and standard deviation of the N estimates provide an accuracy estimate of the classification. It should be noted that the validity of any accuracy estimate depends primarily on whether the test/reference data are independent from the training data used for mapping and if the data are collected based on a probability sampling. Thus, the reliability of a cross-validation accuracy estimate will depend on how the test data used in each of the N-fold are collected (sampling or ad hoc). The two major training/reference data available to the NLCD 2001 project, FIA plot data and NRI sample points, are collected using probability based sampling designs, cross validation using such data is likely a reasonable approximation of the true accuracy.

Land Cover classification system

The 2001 land cover mapping largely follows 1992 classification scheme with some modifications. The NLCD 2001 maintains the same structure used for NLCD1992 at the Anderson level I classification scheme. However, at a more detailed classification level (at approximately Anderson level II) several classes used in 1992 were merged into other classes, including small grains (merged to cropland), fallow fields (to cropland), recreational grass/park (into open developed), beach and quarry/strip mine classes (to barren/bare). The merges were made because of the difficulty in consistently map those classes due to variation in images dates and separating land cover and land use classes differences. One class excluded from the NLCD 2001 is the transitional class, which was used in 1992 mapping to target area under transition for forest clearing and regrowth. The transitional class was difficult to map because of lack of data to quantify. The two new continuous data layers of NLCD 2001 (canopy density and imperviousness) should provide useful quantitative data if such transitional areas are of major interest. The NLCD 2001 also includes several classes for costal zones (NLCD 2001 coastal classes) and # classes for state of Alaska. Besides, the urban land cover classes of NLCD 2001 are directly determined by the imperviousness estimates rather than using land use classes defined in NLCD 1992 (residential, industrial, and commercial use).

IV. Conclusions

The essence of the NLCD 2001 mapping strategy is the flexible database concept and approach, which is a key to project design and implement. This strategy allows provide users with high quality database not only to meet federal/state agencies but also for multiple usage requirements. The components of database

are appropriate to application needs, are feasible to implement nation-wide, and are cost-effective. Database application potentials demonstrated thus far using prototype data product show that NLCD 2001 is likely a regionally-consistent and locally-relevant flexible database.

Implementation strategy and selection of software are important aspect for NLCD 2001 development. The selection of machine learning algorithm provided potential efficiency for developing data layers and also posed requirements on obtaining high quality and quantity training data. The CART algorithm works well in mapping land cover and two continuous variables. The Boosting option of the algorithm proves to be a useful feature that improves land cover classification.

REFERENCE

Anderson, J.R., Hardy, E.E., Roach J.T., and Witmer R.E., 1976. A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Bartholome, E., A. S. Belward, F. Achard, S. Bartalev, C. Carmonamoreno, H. Eva, S. Fritz, J-M. Gregoire, P. Mayaux, and H-J. Stibig, 2002. GLC 2000; Global Land Cover mapping for the year 2000 Project status. European Communities.

Brown, J.F., Loveland, T.R., Ohlen, D.O., Zhu, Z., 1999. The Global Land-Cover Characteristics Database: The Users' Perspective. Photogrammetric Engineering and Remote Sensing , v. 65, no. 9, p. 1,069-1,074.

DeFries, R. and Townshend, J., 1999. Global land cover characterization from satellite data: From research to Operational implementation?, Global Ecology and Biogeography Letters. 8 (5): 367-379.

DeFries, R., Hansen, M., Townshend, J. R. G. and Sohlberg, R., 1998. Global land cover classifications at 8 km spatial resolution: The use of training data derived from Landsat imagery in decision tree classifiers, International Journal of Remote Sensing; 19 (16): 3141-3168.

Friedl, M. A., McIver, D. K., Hodges, J. C. F., Zhang, X., Muchoney, D., Strahler, A. H., Woodcock, C. E., Gopal, S., Schnieder, A., Cooper, A., Baccini, A., Gao, F., and Schaaf, C., 2002. Global land cover from MODIS: Algorithms and early results, Remote Sens. Environ., vol. 83, pp. 135-148.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., Sohlberg, R., DiMiceli, C. and Carroll, M., 2002. Towards an operational MODIS continuous field of percent tree cover algorithm: Examples using AVHRR and MODIS data. Remote Sensing of Environment, 83(1-2): 303-319.

Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan., 2004. Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing, Vol. 70, No. 7, July 2004, pp. 829-840.

Homer, C., J. Dewitz, J. Fry, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, J.N. VanDriel and J. Wickham., 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States, Photogrammetric Engineering and Remote Sensing, Vol. 73, No. 4, pp 337-341.

Homer, C., and A. Gallant, 2001. Partitioning the Conterminous United States into Mapping Zones for Landsat TM Land Cover Mapping, USGS Draft White Paper.

Huang, C., Wylie, B., Homer, C., Yang, L., and Zylstra, G., 2002. Derivation of a Tasseled cap transformation based on Landsat 7 at-satellite reflectance: International Journal of Remote Sensing, v. 23, no. 8, p. 1741-1748.

Huang, C., L. Yang, B. Wylie and C. Homer, 2001. A Strategy for Estimating Tree Canopy Density Using Landsat & ETM+ and High Resolution Images over Large Areas", The proceedings of the Third International Conference on Geospatial Information in Agriculture and Forestry held in Denver, Colorado, 5-7 November, 2001, 1 disk.

Liu Jiyuan, Liu Mingliang, Deng, Xiangzheng, Zhuang Dafang, Zhang Zengxiang, Luo D., 2002. The land use and land cover change database and its relative studies in China. Journal of Geographical Science, v. 12, no. 3, 275-282.

Loveland, T.R., and Shaw, D.M., 1996. Multi-resolution land characterization--building collaborative partnerships, in Scott, J.M., Tear, T.H., and Davis, F.W., eds., GAP analysis--a landscape approach to biodiversity planning: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 79-85.

Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, J, Yang, L., and Merchant, J.W., 2000. Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data: International Journal of Remote Sensing , v. 21, no. 6/7, p. 1,303-1,330.

Reed, B. C., Brown, J. F., VanderZee, D., Loveland, T. R., Merchant, J. W., and Ohlen, D.O., 1994. Variability of Land Cover Phenology in the United States. Journal of Vegetation Science, 5, 703-714.

Stehman, S., Wickham, J., Smith, J. Yang, L, 2003. Thematic accuracy of the 1992 National Land-Cover Data for the eastern United States: Statistical methodology and regional results. Remote Sensing of Environment 86, 500-516.

Scepan, J., 1999. Thematic Validation of High-Resolution Global Land-Cover Data Sets: Photogrammetric Engineering and Remote Sensing , v. 65, no. 9, p. 1051-1060.

Townshend, J. R.G.. DeFries, R., Dubayah, R. Goward, S.N., Kearney, M., Tucker, C., and Vermote, E. 1997. Land cover characterization at regional and global scales: lessons learnt and prospects. Observations and Interactions, Proceedings Remote Sensing Society Conference, Reading U.K., Remote Sensing Society, Nottingham, U.K., pp. 367-372.

Vogelmann, J.E., Sohl, Terry, and Howard, S.M., 1998. Regional characterization of land cover using multiple sources of data: Photogrammetric Engineering and Remote Sensing, v. 64, no. 1, p. 45-57.

Vogelmann, J.E., S.M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and J. N. Van Driel, 2001, Completion of the 1990's National Land Cover Data Set for the conterminous United States, Photogrammetric Engineering and Remote Sensing 67:650-662.

Wickham, J.D., S.V. Stehman, J.H. Smith, L. Yang. 2004. Thematic Accuracy of the 1992 National Land-Cover Data for the Western United States. Remote Sensing of Environment, Vol. 91, pp. 452-468.

Yang, L., Collin Homer, Kent Hegge, Chengquan Huang, Bruce Wylie and Bradley Reed, 2001. A Landsat 7 Scene Selection Strategy for a National Land Cover Database. Proceedings of the IEEE 2001 International Geoscience and Remote Sensing Symposium, Sydney, Australia, CD-ROM, 1 Disc.

Yang, L., C. Huang, C. Homer, B. Wylie and M. Coan. 2003. An approach for mapping large-area impervious surfaces: Synergistic use of Landsat 7 ETM+ and high spatial resolution imagery. Canadian Journal of Remote Sensing, Vol. 29, No. 2, pp.230-240.

Yang, L., Stehman, S., Smith, J., Wickham, J, 2001. Thematic accuracy of MRLC land cover for the eastern United States. Remote Sensing of Environment 76, 418-422.

Zhu, Z., Yang, L., Stehman, S.V., and Czaplewski, R.L, 2001. Accuracy Assessment for the U.S. Geological Survey Regional Land-Cover Mapping Program: New York and New Jersey Region Photogrammetric Engineering and Remote Sensing 66, No. 12: pg 1425-1435.