FINAL TECHNICAL REPORT

Enhanced Land Cover and Land Cover Change Products from MODIS

1996 - 2003

Contract No. NAS596060

Submitted by:

John Townshend, Principal Investigator and MODIS Science Team Member

Ruth DeFries, Associate MODIS Science Team Member

Robert Sohlberg, Researcher
Matthew Hansen, Researcher
Charlene Dimiceli, Scientific Programmer
Mark Carroll, Researcher

SUMMARY

During the performance period of this contract, investigators at the University of Maryland were charged with the development of innovative land cover and land cover change products based upon data from the soon to be launched Moderate Resolution Imaging Spectroradiometer instrument onboard the Terra, and later Aqua, platforms. Two primary products were developed and delivered: Vegetation Continuous Fields (MOD44B) and Vegetative Cover Conversion (MOD44A).

The work also entailed a significant effort developing precursor composited data sets and evaluation of pre-launch MODIS test data as well as early post-launch data.

This document will address each of the two final products as well as the data collection steps which were required. The document will also address other aspects of team membership, specifically training of graduate students and outreach to the MODIS user community. Finally, we will address lessons learned.

PRECURSOR PRODUCTS

Use of polar orbiting remote sensing instruments such as MODIS to produce global land cover products requires a data reduction and compositing step to create input data sets from which to derive the final products. This is required both to reduce the extraordinary amount of data collected by these instruments as well as to select from all candidate observations those of the highest quality.

In the case of land cover dynamics, the observations we require are reflectance in the visible and near and middle infra-red portions of the electromagnetic spectrum as well and brightness temperature in the longer wavelength thermal infra-red spectrum. The intention is to use time-series of these observations to capture the phenologic signal of the earth's vegetated surface.

We developed compositing software which creates 16-day composites known as the MOD44C product. This software, which runs in the MODAPS computing environment at Goddard Space Flight Center, interrogates all daily MODIS observations produced by the MOD09 L2G Surface Reflectance product (Eric Vermote, PI). The L2G input data has previously been calibrated, geolocated, mapped, and corrected for geometric effects and atmospheric attenuation of the signal. L2G also provides a host of quality assurance flags bounding the integrity of the retrieval.

In short, MOD44C selects from all candidate observations those which have the minimum contamination by clouds and aerosols and are nearest to nadir, thus preserving the maximum spatial resolution. L2G quality flags are interrogated as an integral part of this process. The end result is a 16-day composite product with one observation for each 250 m grid cell in a global sinusoidal map. Only the red and near infra-red observations are obtained at 250 m resolution. For the other 500 m observations, that observation which corresponds with the highest quality 250 m observation is retained. The result is a 250 m resolution data set for all land bands. Twenty-three of these 16-day products comprise an annual characterization of the earth's land surface.

Previous work by the investigators had utilized the AVHRR instrument to produce heritage land cover products. The distinct characteristics of MODIS, especially different spectral observations and more robust quality information, required significant adaptations to the new instrument. Much of the early work with MODIS involved examination of the calibration, quality, and information content of the new observations. This work was conducted as part of the MODLAND group, where a team effort was employed to evaluate and improve the initial observations.

Later efforts focused on incremental improvements and involved extensive collaboration with the Surface Reflectance investigators. MOD44C has been through three major code deliveries corresponding with MODIS Collections 1, 3 and 4. The software runs continuously at the MODAPS facility and results are automatically transferred to a tape storage system on the University of Maryland campus via a high-speed internet link.

VEGETATION CONTINUOUS FIELDS

The Vegetation Continuous Fields (MOD44B) product provides sub-pixel estimates of percent cover for woody, herbaceous and bare components of the landscape. Currently available from the Land Processes DAAC are these data sets at a spatial resolution of 500 m. In the second phase of MODIS development, this resolution will increase to 250 m.

The products are derived by using a Landsat-based high resolution training data set in conjunction of annual MODIS time series data from MOD44C. The Landsat training data are resampled to the MODIS resolution and a regression tree model is derived relating the training data cover characteristics with the corresponding MODIS time series observations. This model is then applied to the full data set to produce a continuous estimate of sub-pixel percent cover in one percent increments. An example for tree cover in the Amazon Basin is shown in Figure 1.

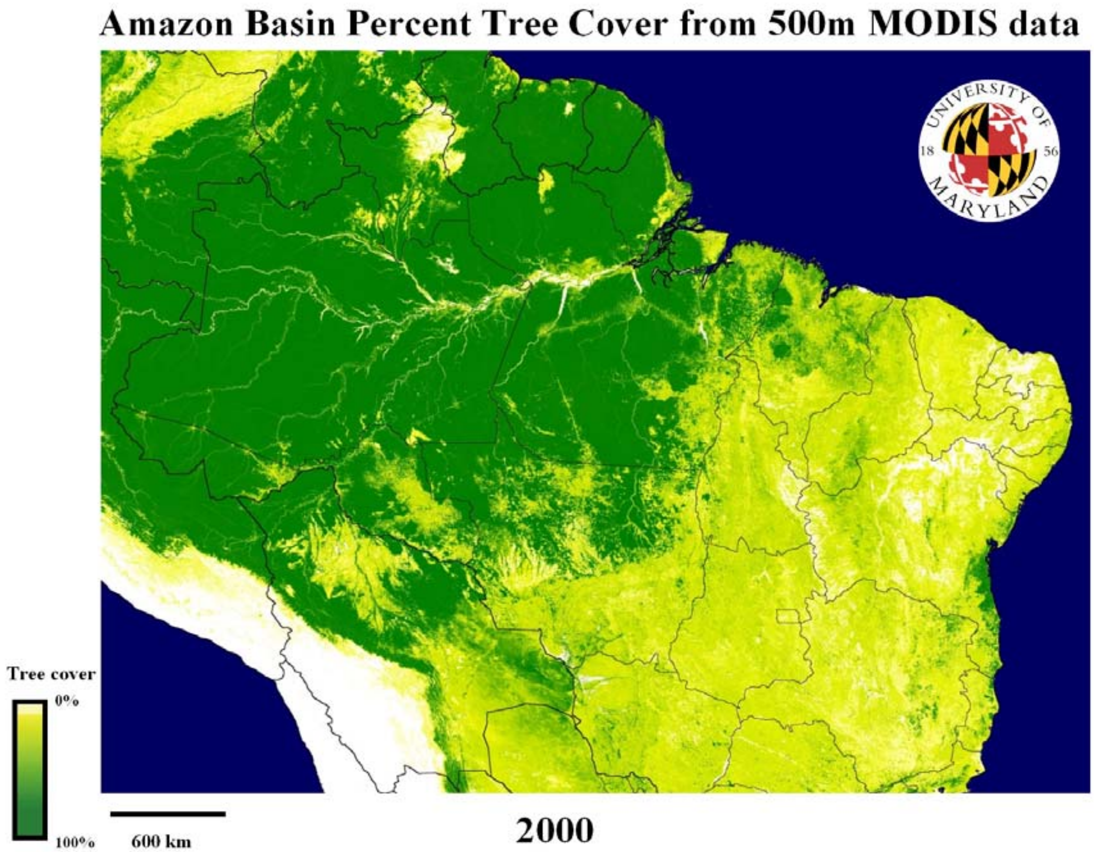

Figure 1. An example of the MODIS Vegetation Continuous Fields percent tree cover product for the Amazon Basin.

Validation has been an integral part of developing the Vegetation Continuous Fields product. A methodology has been developed using a laser instrument to sample under the footprint of multiple Landsat pixels. For each observation, the laser reports that the canopy is either open or closed. By aggregating observations on a grid under the Landsat pixel, it is possible to directly tie the moderate resolution MODIS cover estimate to the fine resolution Landsat estimate and ultimately to the ground. This methodology has been employed thus far in the western United States, Zambia, Brazil and Norway. Future work is planned to complete ground-based validation for a sample comprising the range of the earth's biomes. For full details see Hansen et al, 2003.

VEGETATIVE COVER CONVERSION

Vegetative Cover Conversion (MOD44A) is intended as a global alarm for land cover change. The product is produced at a spatial resolution of 250 m using the MOD44C composite product as an input. Change in land cover is determined by use of a decision tree classifier which determines boundaries in n-dimensional spectral space which partition the landscape into strata of vegetative cover. When the observation for a particular pixel moves from one strata to another, that event is flagged as change. By analyzing the distribution of detected change, hot spots can be located which deserve characterization at a finer resolution. Results for deforestation in the humid tropics are currently available from the Land Processes DAAC. Figure 2 shows an example for Mato Grosso, where new deforestation can be seen along the edges of previous clearings.

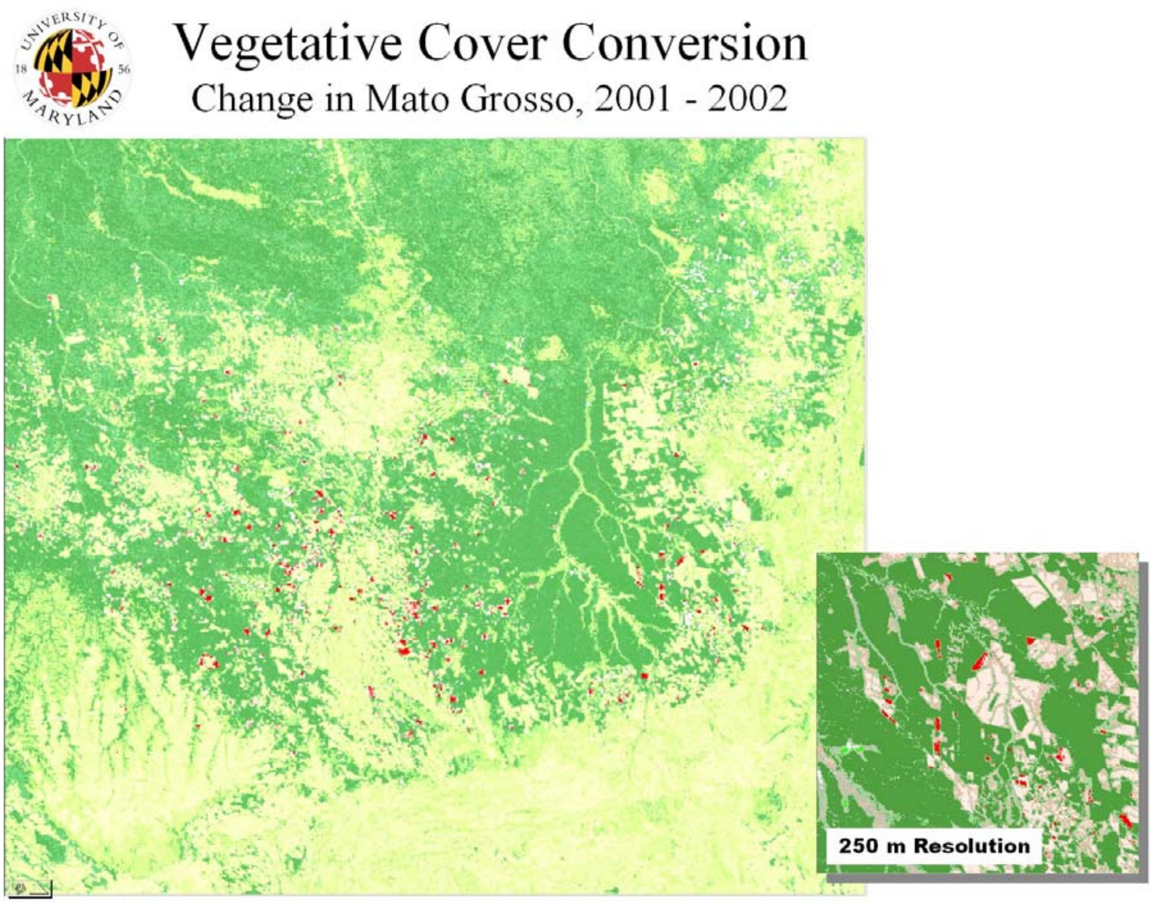

Figure 2. Deforestation in Mato Grosso as detected by the Vegetative Cover Conversion algorithm. Changed areas are shown in red.

During the next phase of MODIS production, new Vegetative Cover Conversion products will be produced for the entire instrument record including a global portrait of flooding. Full details on the MOD44A approach can be found in Zhan et al, 2002.

TRAINING OF GRADUATE STUDENTS

During the course of this funded research, gradate and undergraduate students were intimately involved throughout. This included graduate assistantships as well as hourly employment for undergraduates. A list of those who received degrees is listed below.

PhD: Matthew Hansen, Eric Brown de Coulston, Cheng Huang
MA: Jill Eastman, April Tompkins, Jenny Hewson

In addition, at least a dozen other graduate students benefited from the MODIS research efforts either by interacting with the research team or using MODIS data as part of their academic research. An effort was also made to move MODIS data into the classroom in multiple undergraduate and graduate classes.

COMMUNITY OUTREACH

Outreach to the broader potential user community for MODIS data has been an important part of our efforts. These efforts include multiple presentations at the American Geophysical Union meetings, as well as Multitemp, IGARSS, ASPRS, and multiple international meetings in Europe and Asia.

Dr. Townshend in particular has concentrated on the international community, while Dr. DeFries has spent substantial time working with the community of biogeochemical modelers.

On June 3rd and 4th of 2002, the University of Maryland research team hosted a community outreach workshop for the MODIS land cover product suite in cooperation with our colleagues at Boston University and the Land Processes DAAC. Attendees included over forty scientists from within state and federal government, academia, the private sector, and non-governmental organizations. During 2002 and 2003 we also participated in outreach meetings hosted by the University of Montana.

Led by Mr. Sohlberg, there has been a great deal of collaboration with the USDA Forest Service, especially their Remote Sensing Applications Center in Salt Lake City and the Forest Inventory and Analysis unit at the Northeast Research Station outside Philadelphia. Dr. Hansen has devoted his efforts to collaboration with deforestation investigators, especially in Brazil and Africa.

For the broader community, we have also been involved in print and broadcast media outreach including a television documentary for the Discovery Channel. Mr. Sohlberg has done multiple “live shot” campaigns for NASA-TV. We have made an effort to quickly respond to all inquiries directed to us by the NASA public affairs office. Members of the team have been quoted in several dozen print articles in outlets ranging from the Times of London to the San Jose Mercury News.

DATA SET DISTRIBUTION

As a matter of course, we have made all of our data sets available in user-friendly formats via the Global Land Cover Facility (www.landcover.org) in addition to the traditional DAACs. Value-added content includes familiar map projections, logical geographic subsetting, and common file formats. We will continue to attempt to address user requests in this fashion through partnership of the ESIP / REASON community. Of particular interest in coming years will be compatibility with geographic information systems.

LESSONS LEARNED

The primary lesson learned is that each new generation of instrument has unique characteristics which will not, and cannot, be fully understood until you are working with real data from a real instrument on orbit.

Although test data sets were emphasized in the pre-launch era, these were primarily useful only for exercising software and processing systems. As is to be expected, the actual problems encountered with calibration, striping, crosstalk, and differences in radiometric response were not those problems that were anticipated in pre-launch testing. In the end, all issues were resolved to meet specifications, but this process was not without pain.

A note about map projections and file formats: Just because it is considered “the best” by the engineering community, does not mean that it is the most useful. As we are all now aware, the Integerized Sinusoidal map projection and the HDF-EOS file format caused real headaches for both investigators and the user community. These issues had to be worked off, and sometimes got in the way of promoting MODIS to the broader user community. Data ordering systems, especially the EOS Data Gateway, were also an issue and unlike the data format and map projection issues, these have never been fully dealt with. Enough said.

On a more positive note, precise geolocation is a huge success and provides unprecedented opportunities for land cover research and applications. The instrument itself is much better than AVHRR, which was a great workhorse in its own right. The radiometric fidelity, narrower bands, and depth in the shortwave infra-red are making it possible to characterize land cover conditions not previously possible on a global basis and recurring time step.

PUBLICATIONS & PRESENTATIONS

2003:

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., Carroll, M., DiMiceli, C., and Sohlberg, R. 2003. Global percent tree cover at a spatial resolution of 500 meters: first results of the MODIS Vegetation Continuous Fields algorithm, Earth Interactions, 7, 1-15.

Descloitres, J., Justice, C., Sohlberg, R., Giglio, L., Schmaltz, J., Seaton, J., Davies, D., Anyamba, A., Hansen, M., Carroll, M., and Sullivan, M., 2003. The MODIS Rapid Response Project: Near-Real-Time Processing for Fire Monitoring and Other Applications. American Geophysical Union Fall Meeting, San Francisco.

Hansen, M.C., DeFries, R.S., Townshend, J.R., and Sohlberg, R.A., 2003. Using Vegetation Continuous Fields to Monitor Change in Forest Cover. American Geophysical Union Fall Meeting, San Francisco.

Sohlberg, R., 2003 (invited). Use of NASA Earth Observing System data to monitor active fires and to develop sensorweb decision support systems. Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Fore Meteorology, Orlando.

Finco, M., Quayle, B., Sohlberg, R., and Descloitres, J., 2003. Satellite to the public in near real-time: providing active wildfire information with MODIS Rapid Response. Interface 2003: Security and Infrastructure Protection, Salt Lake City.

2002:

Bobbe, T., Descloitres, J., Finco, M., Giglio, L., Justice, C., Sohlberg, R., and Townshend, J. (2002). MODIS Land Rapid Response System: implementation with USDA Forest Service and implications for active fire detection and land cover change products from future moderate resolution sensors. NPOESS MAXI Review 2002, Silver Spring, MD.

Carroll, M., Descloitres, J., Giglio, L., Sohlberg, R., Finco, M, Quayle, B., Owens, J., Townshend, J., and Justice, C. (2002). MODIS Land Rapid Response activities with the USDA Forest Service: time sensitive data acquisition to support wildfire management. Proceedings of 2002 NASA Science Data Processing Workshop, Greenbelt, Md.

DeFries, R., Houghton, R.A., Hansen, M., Field, C., Skole, D., Townshend, J.R.G. (2002). Carbon Emissions from Tropical Land Use Change Based on Satellite Observations for the 1980s and 90s. Proceeding National Academy of Sciences, 99, 14256-14261.

Eastman, J., Townshend, J., Justice, C., and Sohlberg, R. (2002). Roadless areas and

forest fires in the western United States. American Geophysical Union Spring Meeting, Washington, DC, 2002.

Eastman, J.C., Townshend, J.R.G., Justice, C.O., Sohlberg, R., and Tucker, C.J. (2002, submitted). Roadless areas and forest fires in the western United States. EOS Transactions.

Hansen, M., DeFries, R.S., Townshend, J.R.G., and Sohlberg, R. 2002 (invited) (2002). Continuous fields of tree cover for the United States using multi-resolution satellite Data. RS2002: Ninth Biennial Forest Service Remote Sensing Applications Conference, San Diego CA.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., Marufu, L., and Sohlberg, R. (2002). Development of a MODIS tree cover validation data set for Western Province, Zambia. Remote Sensing Environment, 83, 320-335.

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 Environment, 83, 303-319.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., Sohlberg, R., Carroll, M., and DiMiceli, C. (2002). Global percent tree cover from MODIS data. American Geophysical Union Spring Meeting, Washington, DC, 2002.

Huang, C. Townshend, J.R.G., Liang, S. Kalluri, S.N.V. and Defries, R.D. (2002). Impact of sensor’s point spread function on land cover characterization, assessment and deconvolution. Remote Sensing of Environment, 80, 203-212.

Huang, C., Davis, L. S., and Townshend, J.R.G. (2002). An assessment of support vector machines for land cover classification. International Journal of Remote Sensing, 23, 725-749.

Justice, C.O., and Townshend, J. (2002). Special issue on the moderate resolution imaging spectroradiometer (MODIS): a new generation of land surface monitoring. Remote Sensing of Environment, 83(1), 1-2.

Justice, C.O., Townshend, J.R.G., Vermote, E., Wolfe, R. El Saleous, N. and Roy, D (2002). Status of MODIS, its data processing and products for terrestrial science applications. Remote Sensing of Environment, 83, 3-15.

Justice, C.O., Townshend, J.R.G., Vermote, E.F., Masuoka, E., Wolfe R.E., Saleous N., Roy D.P., Morisette J.T. (2002). An overview of MODIS Land data processing and product status. Remote Sensing Of Environment, 83(1-2), 3-15.

Townshend J.R.G. and Justice C.O. (2002). Towards operational monitoring of terrestrial systems by moderate-resolution remote sensing. Remote Sensing of Environment, 83(1-2), 351-359.

Townshend, J.R.G., Justice, C.O., Hansen, M., DeFries, R., Sohlberg, R., Zhan, X., Carroll, M., DiMiceli, C. (2002). The use of EOS data for characterizing and monitoring land cover change in the framework of the program of Global Observations of Landcover Dynamics. Proceedings of Advanced Training Workshop on Land Use and Land Cover Changes Study, December 9-20, 2002, National Taiwan University, Taiwan, 357-398.

Townshend, J.R.G., Sohlberg, R.A., DeFries, R.S., Hansen, M.C., Carroll, M.L., DiMiceli, C., and Semeiks, B.M. (2002). The MODIS vegetative cover and change products: validation and analysis. American Geophysical Union Fall Meeting, San Francisco, CA 2002.

Zhan, X., Sohlberg, R.., Townshend, J.R.G., DiMiceli, C., Carroll, M., Eastman, J.C., Hansen, M., R.S. DeFries, R. S. (2002). Detection of land cover changes using MODIS 250m data. Remote Sensing of Environment, 83, 336-350.

<u>2001:</u>

Descloitres, J., Giglio, L., Sohlberg, R., Owens, J., Justice, C., Townshend, J., Seaton, J., Crisologo, M., Carroll, M., and Finco, M. (2001). The MODIS Land Rapid Response project: a comprehensive suite of products to support U.S.D.A. Forest Service fire management. American Geophysical Union Fall Meeting, San Francisco, CA 2001.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., and Sohlberg, R.A. (2001). Using continuous fields of tree cover maps from satellite data to assess degradation within ecoregions, an example from South America. IGBP Open Science Conference, Amsterdam, The Netherlands, 2001.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., and Sohlberg, R.A. (2001). Using continuous fields of tree cover to assess degradation within ecoregions: An example from South America. American Geophysical Union Spring Meeting, Boston MA 2001.

Huang, C. and Townshend, J.R.G. (2001, in press). A stepwise regression tree for nonlinear approximation: applications to estimating sub-pixel land cover. International Journal of Remote Sensing.

Kalluri, S.N.V., Zhang, Z., JaJa, J., Liang, S. and Townshend, J.R.G. (2001). Characterizing land surface anisotropy from AVHRR data at a global scale using high performance computing. International Journal of Remote Sensing, 22, 2171-2191.

Sohlberg, R., Zhan, X., DiMiceli, C., Carroll, M., Townshend, J., Eastman, J., Hansen, M., and DeFries, R. (2001). Change detection for flood and burning events using MODIS 250m data and the Vegetative Cover Conversion algorithm. American Geophysical Union Spring Meeting, Boston MA 2001.

Townshend, J., Hansen, M., DeFries, R., Sohlberg, R., Desch, A., and White, B. (2001). Monitoring the extent of forests on national to global scales. American Geophysical Union Spring Meeting, Boston MA 2001.

Townshend, J.R.G., DeFries, R.S., Zhan, X., Sohlberg, R.A., DiMiceli, C., Carroll, M.L., Hansen, M.C., and Eastman, J.C. (2001). A global alarm product for land cover change: MODIS 250 meter Vegetative Cover Conversion algorithm. IGBP Open Science Conference, Amsterdam, The Netherlands, 2001.

Townshend, J.R.G., DeFries, R.S., Zhan, X., Sohlberg, R.A., Hansen, M.C., DiMiceli, C., Carroll, M.L., and Eastman, J.C. (2001). MODIS 250m and 500m time series data for change detection and continuous representation of vegetation characteristics. Multitemp 2001, Trento, Italy.

Townshend, J.R.G., Sohlberg, R.A., Hansen, M.C., DeFries, R.S. (2001). MODIS vegetation Cover Products for Estimating Tree Cover and Monitoring Change. American Geophysical Union Fall Meeting, San Francisco, CA 2001.

2000:

Chan, J.C.W., DeFries, R.S., Zhan, X., Huang, C., and Townshend, J.R.G. (2000). Texture Features For Land Cover Change Detection At 250m Resolution-An Application Of Machine Learning Feature Subset Selection . Proceedings of IEEE 2000 International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, July 2000 , 3060-3063.

DeFries, R. Hansen, M., Townshend, J.R.G., Janetos, A.C., and Loveland, T.R. (2000). A new global 1km data set of percent tree cover derived from remote sensing . Global Change Biology, 6, 247-254.

DeFries, R., Hansen, M., and Townshend, J. (2000). Global continuous fields of vegetation characteristics: A linear mixture model applied to multiyear 8km AVHRR data . International Journal of Remote Sensing, 21, 1389-1414.

El Saleous, N., Vermote, E., Justice, C. O., Townshend, J. R.G., Tucker, C.J., and Goward, S.N. (2000). Improvements in the global biospheric record from the Advanced Very High Resolution Radiometer (AVHRR). International Journal of Remote Sensing, 21, 1251-1278.

Hansen M.C., Defries R.S., Townshend J.R.G., Sohlberg R. (2000). Global land cover classification at 1km spatial resolution using a classification tree approach . International Journal of Remote Sensing, 21, 1331-1364.

Hansen, M.C., DeFries, R.S., Zhan, X., Sohlberg, R., and Townshend, J.R.G. (2000). Continuous Fields of Vegetation from MODIS data. American Geophysical Union Fall Meeting, San Francisco CA 2000.

Huang, C., Chan, C.W., Townshend, J.R.G., and DeFries, R. (2000). Impact of data dimension on the comparative performance of classification algorithms. IGARSS2000, Honolulu, Hawaii.

Huang, C., Townshend, J.R.G., Zhan, X., Hansen, M.C., DeFries, R.S., & Sohlberg, R. (2000). Detecting land cover changes based on their trajectories in the spectral space . IGARSS: IEEE International Geoscience and Remote Sensing Symposium Proceedings, Honolulu, Hawaii, 2000.

Justice, C.O., Townshend, J.R.G., Vermote, E.F., Sohlberg, R., Descloitres, J., Roy, D., Hall, D., Salomonson, V., Riggs, G., Huete, A., Didan, K., Miura, T., Wan, Z., Strahler, A., Schaaf, C., Myneni, R., Running, S., Glassy, J., Nemani, R., El Saleous, (2000). Preliminary land surface products from the NASA Moderate Resolution Imaging Spectroradiometer(MODIS) . Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS 00), Honolulu, Hawaii.

Kalluri, S.N.V., Ja Ja, J., Bader, D.A. , Zhang, Z., Townshend, J.R.G and Fallah-Adl, H. (2000). High performance computing algorithms for land cover dynamics using remotely sensed data. International Journal of Remote Sensing, 21, 1513-1536.

Sohlberg, R., Kalluri, S.N.V., DiMiceli, C.M., Vermote, E.F., El Saleous, N.Z., Justice, C.O., Townshend, J.R.G. (2000). Comparative advantages of MODIS 250m data for earth science applications . American Geophysical Union Spring Meeting, Washington, D.C.

Teillet, P.M., El Saleous, N., Hansen, M.C., Eidenshink, J.C., Justice, C.O. and Townshend, J.R.G. (2000). An Evaluation of the Global 1-km AVHRR Land Data Set. International Journal of Remote Sensing, 21(10), 1987-2022.

Townshend, J.R.G., Huang, C., Kalluri, S.N.V., Defries, R.S., Liang, S. and Yang, K. (2000). Beware of Per-Pixel Characterization of Land Cover . International Journal of Remote Sensing, 21, 839-843.

Tucker, C. J. and Townshend, J.R.G. (2000). Strategies for tropical forest deforestation assessment using satellite data. International Journal of Remote Sensing, 21, 1461-1472.

Zhan, X. Jiang, Y. and Townshend, J.R.G. (2000). A simple assessment of the expansion of American urban areas from the 1970s to the 1990s using the North American Landscape Characterization Data Set. IGARSS2000, Honolulu, Hawaii, 3060-3063.

Zhan, X., Defries, R.S., Townshend, J.R.G., DiMiceli, C.M., Hansen, DeFries M.C., Huang, C., Sohlberg, R. (2000). The 250 m global land cover change product from the Moderate Resolution Imaging Spectroradiometers of NASA's Earth Observing System . International Journal of Remote Sensing , 21, 1433-1460.

Zhan, X., Sohlberg, R., Townshend, J.R.G., DeFries, R.S., Dimiceli, C., and Hansen, M.C. (2000). Vegetative Cover Conversion product from MODIS 250m data: Early results. American Geophysical Union Fall Meeting, San Francisco CA 2000.

Zhan, Xiwu, Yongjing Jiang and Townshend, John R.G. (2000). A Simple Assessment Of The Expansion Of American Urban Areas From 1970s To 1990s Using The North American Landscape Characterization Data Set. . Proceedings of IEEE 2000 International Geoscience and Remote Sensing Symposium (IGARSS 2000), Honolulu, Hawaii , 2867-2870.

<u>1999:</u>

DeFries, R. S., Hansen, M., Townshend, J.R.G, Janetos, A. and Loveland, T. (1999). A New Global 1km Data Set of Percent Tree Cover Derived from Remote Sensing. Global Ecology and Biogeography, 8(5), 367-379.

DeFries, R., Townshend, J. R. G. and Hansen, M. (1999). Continuous fields of vegetation characteristics at the global scale. Journal of Geophysical Research, 104, 16911-16923.

El Saleous, N. Z., Vermote, E. F., Justice, C. O., Townshend, J. R., Tucker, C. J., & Goward, S. N., (1999, accepted). Improvements in the global biospheric record from the Advanced Very High Resolution Radiometer (AVHRR). International Journal of Remote Sensing.

Estes, J.E., Belward, A., Loveland, T., Scepan, J., Strahler, A., Townshend, J.R.G. and Justice, C.O. (1999). The IGBP 1 km Land-Cover Data Set: The Way Forward. Photogrammetric Engineering and Remote Sensing, 65(9), 1099-1106.

Zhan, X., Hansen, M., DeFries, R., Townshend, J.R.G, Huang, C., Dimiceli, C., & Sohlberg, R. (1999). MODIS Enhanced Land Cover and Land Cover Change Product, Algorithm Theoretical Basis Documents (ATBD) Version 2.0 . EOS project office document at Goddard Space Flight Center, Greenbelt, MD, 94pp.

<u>1998:</u>

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, 3141-3168.

Hansen, M., DeFries, R., DiMiceli, C., Huang, C., Sohlberg, R., Zhan, X. and Townshend, J.R.G. (1998). Red and infrared space partitioning for detecting land cover change . IGARSS '98: 1998 IEEE International Geoscience and Remote Sensing Symposium Proceedings, Seattle, Washington, 1998 , V, 2512-2514.

Huang, C., Townshend, J.R.G., Zhan, X., Hansen, M., DeFries, R., and Sohlberg, R.

(1998). Developing the spectral trajectories of major land cover change processes . Proceedings of SPIE, Hyperspectral Remote Sensing and Applications, Beijing, China, 155-162.

Justice, C., Vermote, E., Townshend, J. R. G., Defries, R., Roy, D. P., Hall, D. K., Salomonson, V. V., Privette, J., Riggs, G., Strahler, A., Lucht, W., Myneni, R., Knjazihhin, Y., Running, S., Nemani, R., Wan, Z., Huete, A., van Leeuwen, W., Wolfe, R., (1998). The Moderate Resolution Imaging Spectroradiometer (MODIS): Land remote sensing for global change research. IEEE Transactions on Geoscience and Remote Sensing, 36(4), 1228-1249.

Zhan, X., Huang, C., Townshend, J.R.G., DeFries, R., Hansen, M., DiMiceli, C., Sohlberg, R., Hewson-Scardelletti, J. and Tompkins, A., (1998). Land cover change detection with change vector in the red and near-infrared reflectance space. . IGARSS' 98: 1998 IEEE International Geoscience and Remote Sensing Symposium Proceedings. Seattle, Washington , II, 859-861.

Zhang, Z., Kalluri, S., Ja’ Ja’, J., Liang, S., and Townshend, J.R.G. (1998). High Performance Algorithms for Global Bidirectional Reflectance Distribution Function Retrieval. IEEE Transactions in Computational Science and Engineering, 5(4), 16-29.

1997:

DeFries, R., Hansen, M. Steininger, M., Dubayah, R., Sohlberg, R. and Townshend, J.R.G. (1997). Sub-pixel forest cover in Central Africa from multisensor, multitemporal data. Remote Sensing of Environment, 60, 228-246.

DeFries, R., Townshend, J. and Los, S. (1997). Scaling land cover heterogeneity for global atmosphere-biosphere models. Scale in Remote Sensing and GIS, 231-246.

Skole, D.L., Justice, C.O., Townshend, J.R.G. and Janetos, A. C. (1997). A land cover change monitoring program: Strategy for an International effort. Mitigation and Adaptation Strategies for Global Change, 2(2-3), 157-175.