Emissions from Land Use Change due to Increased Biofuel Production

Satellite Imagery and Emissions Factor Analysis

Peer Review Report
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Introduction

Background of Indirect Land Use Emissions Analysis

The United States Environmental Protection Agency (EPA) has undertaken a lifecycle assessment of the greenhouse gas (GHG) emissions associated with increased renewable fuels production as part of the proposed revisions to the National Renewable Fuel Standard (RFS) program. The Energy Independence and Security Act of 2007 (EISA) set the first-ever mandatory lifecycle GHG reduction thresholds for renewable fuel categories. The Act requires EPA to conduct a broad lifecycle analysis of expanded biofuel use, including emissions associated with indirect land use changes.

Several new pieces of analysis were developed to support this lifecycle assessment. Two important parts of this analysis are determining the extent, type and location of land use conversions occurring due to biofuel production and developing emissions factors for land conversion. Work done by Winrock International (referred to as Winrock, hereinafter) for EPA addresses these issues by determining the extent of land use change using MODIS imagery from 2001 and 2004 and estimating emission factors for each type of land use conversion for a number of key agriculturally producing countries around the world.

EPA used the work done by Winrock to estimate emissions associated with indirect land use changes both domestically and internationally. EPA relied on the Food and Agricultural Policy Research Institute (FAPRI) model to project location-specific increases in cropland across the world as the result of increased biofuel production in the United States. The next step of the analysis was to decide which land types would be converted to cropland in each of these countries. EPA based the determination of land use conversion on an analysis of historical land use trends using MODIS satellite imagery from 2001 and 2004. Winrock conducted the satellite imagery change detection analysis and determined which land use types decreased or increased at the country level during this time period. EPA used this trend to assign land use conversion types to new cropland. Winrock also calculated the GHG emissions resulting from this projected land use change by compiling world-wide data on carbon stocks in different land types. The emissions factors used accounted for changes in above and below-ground biomass carbon stocks, changes in soil carbon stocks, lost forest sequestration, land clearing with fire, and emissions from rice cultivation. Winrock followed Intergovernmental Panel on Climate Change (IPCC) (2006) guidelines when calculating the change in carbon stocks resulting from the projected land use changes. The peer review detailed in this report focuses on the satellite imagery and emissions factor sections of the indirect land use changes section of the RFS program review.

Indirect and Direct Emissions in the Lifecycle Analysis

The definition of lifecycle analysis set forth in EISA 2007 includes both direct and indirect emissions related to the full fuel lifecycle. EPA defined direct emissions as those that are emitted from each stage of the full fuel lifecycle, and indirect emissions as those emitted from second-order effects that occur as a consequence of the full fuel lifecycle. For example, direct emissions for a renewable fuel would include net emissions from growing of renewable fuel feedstock, distribution of the feedstock to the renewable fuel producer, production of renewable fuel, distribution of the finished fuel to the consumer, and use of the fuel by the consumer. Similarly, direct emissions associated with the baseline fuel would include net emissions from extraction of the crude oil, distribution of the crude oil to the refinery, production of gasoline and diesel from the crude oil, distribution of the finished fuel to the consumer, and use of the fuel by the consumer. Indirect emissions would include other emissions impacts that result from the effects of fuel production or use, such as changes in livestock emissions resulting from changes in feedstock costs and livestock numbers, or shifts in acreage between different crop types. The definition of indirect emissions specifically includes “land-use changes” such as changes between forest, pasture, savannah, and crop land types. Most of the charge questions in this peer review are concerned with the international indirect land use impacts analysis.

Background of Peer Review and Overview of Results

From May to July 2009, EPA arranged for several peer reviews to be conducted regarding aspects of its revisions to the RFS. Each of these reviews focused on the projection of emissions from indirect land use changes associated with increased fuel production as specified by EISA 2007. ICF International, an independent third-party contractor, coordinated the peer reviews and adhered to EPA's "Peer Review Handbook "(3rd Edition).

The peer review process summarized here focuses on the Winrock analysis of the historic satellite imagery and the calculation of emission factors associated with land use conversion to cropland.

EPA's work assignment requesting the peer review required that peer reviewers be established and published experts with knowledge of the following topics:

- Satellite imagery to track and characterize land use change
- Land use change economics
- Interactions between cropland, forest, pasture and other types of land and how this is impacted by changing prices of commodities
- Determining GHG emission releases for different land use conversions
- Greenhouse gas emissions from land use

Using these criteria, the contractor developed a list of qualified candidates from the public, private, and academic sectors. The contractor compiled candidates from the following sources: (1) contractor experts in this field with knowledge of relevant professional society membership, academia, and other organizations; (2) Internet searches; and (3) suggestions from EPA.

Nearly 30 qualified individuals were initially identified as candidates to participate in the peer review. Each of these individuals was sent an introductory screening email to describe the needs of the peer review and to gauge the candidate's interest and availability. Also, candidates were asked to disclose any real or perceived conflicts of interest (COI) or other matters that would create the appearance of a conflict of impartiality. Candidates also were asked to provide an updated resume or curriculum vitae (CV). The contractor reviewed the responses and COI statements and evaluated the resume/CV of individuals who were interested for relevant experience and demonstrated expertise in the above areas, as demonstrated by educational degrees attained, research and work experience, publications, awards, and participation in relevant professional societies.

A number of candidate reviewers were unable to participate in the peer review due to previous commitments or real or perceived conflicts of interest. The contractor reviewed the remaining qualified candidates with the following concerns in mind. As stated in EPA's Peer Review Handbook, the group of selected peer reviewers should be "sufficiently broad and diverse to fairly represent the relevant scientific and technical perspectives and fields of knowledge; they should represent balanced range of technically legitimate points of view." As such, the contractor selected peer reviewers to provide a balance of complimentary economic, policy, and technical perspectives by including experts with expertise, knowledge, skills, and experience in each of those fields. In addition, balance was sought by including experts from both academic and non-profit backgrounds, as well as individuals with experience working on these issues in the United States and internationally. The contractor submitted the proposed peer reviewers to

EPA. In accordance with the EPA Peer Review Handbook, EPA reviewed the list of the selected reviewers with regard to conformance to the qualification criteria in the contractor's work assignment, which was established prior to the reviewer selection process. EPA concurred that all of the contractor's peer review selections met the qualification criteria.

The contractor contacted the following five peer reviewers who agreed to participate in the peer review:

1. Dr. Holly Gibbs, Stanford University
2. Dr. Richard Houghton, Woods Hole Oceanographic Institution
3. Dr. Rattan Lal, Ohio State University
4. Dr. Jason Tullis, University of Arkansas
5. Dr. Brian Wardlow, University of Nebraska

In addition to the initial COI screen mentioned above, the contractor asked the peer reviewers to complete a conflict of interest disclosure form that addressed in more depth topics such as employment, investments/assets, property interests, research funding, and various other ethical issues. The Peer Review Handbook acknowledges that "experts with a stake in the outcome – and therefore a conflict or an appearance issue – may be some of the most knowledgeable and up-to-date experts because they have concrete reasons to maintain their expertise," and that these experts may be used as peer reviewers if COI or the appearance of the lack of impartiality is disclosed. However, upon review of each form, the contractor and EPA determined that there were no direct and substantial COI or appearance of impartiality issues that would have prevented a peer reviewer's comments from being considered by EPA.

EPA provided reviewers with the October 2008 Winrock Emission Factors Report, the April 2009 Winrock Emission Factors Report, additional materials detailing EPA's lifecycle analysis, and charge questions to guide their evaluation. The charge questions were divided into two sections. The first set of questions concerned Winrock's use of historic MODIS satellite imagery to assign land use conversion types to modeled increases in cropland. The second set of questions focused on the emissions factors that Winrock calculated for the land use conversions.

The peer reviewers generally agreed that the approach taken by EPA and Winrock was scientifically justifiable, especially given existing data and technology constraints. However, the reviewers highlighted several problematic areas of the analysis and recommended possible revisions. In general, these problematic areas were part of the satellite imagery analysis, rather than the emissions factor analysis. The peer reviewers concurred more strongly with EPA's approach in the latter analysis.

The main areas of concern with the satellite imagery analysis as outlined by the peer reviewers are listed below in order of the frequency of comments received from peer reviewers:

- The 3-year time period of the two MODIS data sets chosen and the error associated with each of those data sets.
- The coarse resolution of the satellite imagery.
- The change detection analysis performed on the two MODIS data sets from 2001 and 2004.
- The reclassification analysis performed by Winrock on the satellite data, especially the categories of excluded land and the role of the 'mixed' or 'other' category.

- The methodology for projecting land use change patterns caused specifically by biofuel production.
- Evaluation of error and uncertainty associated with the satellite imagery analysis.

In the emissions factor analysis, the peer reviewers generally felt that Winrock's analysis followed IPCC guidelines and was scientifically justifiable. However, they did make several suggestions of new data sources and recommended areas that could benefit from additional clarification.

The following section includes summaries of the peer reviewer responses to each charge question. The set of charge questions can be found in Appendix A and the full text of the peer reviewers' written responses can be found in Appendices B-G.[1] The peer reviewers' curricula vitae can be found in Appendix H. Peer reviewers were instructed to work independently and comments made by peer reviewers are individual opinions and do not represent the views of their affiliated organizations.

[1] Typographical errors in original peer review responses were corrected where noticed.

Peer Reviewer Responses to Charge Questions

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

All five peer reviewers agreed that it is scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change. However, each peer reviewer mentioned a unique set of concerns related to this question. Dr. Wardlow stipulated that using a higher resolution of MODIS data would be useful in categorizing highly fragmented landscapes more accurately. Dr. Gibbs noted that the remote sensing approach assumes that the conditions determining land use patterns will be the same in the historic and future time periods. She recommended combining the historic remote sensing analysis with information on the drivers and causes of land use changes as one way to account for dynamic conditions.

Dr. Tullis commented that while few studies have attempted to quantitatively project future land use based on historical land cover data, the ones that have done so usually, "attempt to model a stochastic (rather than deterministic) process so as to arrive at the most probable scenario." He added that, "this activity is most scientifically justifiable when its probability of success (or failure) can be tested; as new remote sensing-assisted observations become available it is possible to test the accuracy of projection methodologies used in the past."

Dr. Lal noted that using historic remote sensing data in this manner is appropriate as long as it is "validated against change in future population increase and the associated demand." Dr. Houghton commented that while it is scientifically justifiable to use remote sensing data to evaluate and project the pattern of future land use in the near future, the justification becomes weaker for longer-term projects.

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

All five peer reviewers agreed that it is scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production. However, each peer reviewer qualified that statement by describing relevant uncertainties and existing gaps in knowledge. Dr. Tullis noted that inherent discontinuities in spatial and temporal scales constrain the "ability to assess the value of combined in situ, remote sensor and ancillary data and models." As an example, he noted that country-scale estimates may not take into account the spatial patterns of within-country biofuel production and indirectly related land use changes.[2] He stated further that the most scientifically justifiable approach to combining these disparate models would continually minimize and

[2] Dr. Tullis was asked to revise several of his responses in order to clarify distinctions between indirect and direct land use change. This report notes areas in the text, such as the one indicated by the placement of this footnote, where revisions occurred in Dr. Tullis' response. The full text of his initial responses and his revised responses can be found in the appendices.

monitor the uncertainties in discontinuities over time as the modeling process evolves. Dr. Wardlow commented that estimates of land use change emissions associated with biofuel production will be dependent on the level of resolution employed in the analysis. Dr. Gibbs mentioned that future techniques will provide improved results. Dr. Lal opined that the approach is scientifically justifiable, but only assuming that projections of future needs for biofuel production are reliable and credible. Finally, Dr. Houghton agreed with the statement, but noted that the models determine the rate of cropland expansion, not the remote sensing data.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Four of the five peer reviewers highlighted potential problems with using remote sensing data to project the pattern of land use change caused specifically by biofuel production. As Dr. Houghton stated in his answer, "while it is theoretically possible that the changes in land use resulting from biofuel production occur in ecosystems or regions that would not be the ones affected by other drivers, this doesn't appear very likely." He continued by commenting that while changes in land use driven by biofuel production will likely involve large parcels of land, other land use changes will likely involve small parcels of land and may not be readily characterized by remote sensing data, especially MODIS 1 km. He recommended that this point be further investigated. Dr. Gibbs focused on a similar issue and commented that biofuels are a driver of land use requiring special consideration. She recommended that, "combining remote sensing data with other empirical information on land use change drivers. . .could provide an improved means of projecting future land use."

Dr. Tullis stated that the proper use of agricultural sector models may require that the remote sensor data itself be used to monitor specific types of biofuel production and not simply agricultural expansion. In addition, he was not convinced that the relationship between direct biofuel production and agricultural expansion should be simply assumed as highly correlated in their spatial distributions. He commented that this assumption in turn affects the reliability of modeled estimates of indirect land use change that depend on direct biofuel production monitoring.[3] However, if the approach included efforts to mitigate this source of uncertainty, Dr. Tullis would agree that the overall strategy seems reasonable. Dr. Lal agreed that the existing analysis was reasonable, but added that using other models for validation would be essential.

Dr. Wardlow did not address the issue of projecting the pattern of land use change caused specifically by biofuel production. He commented that remote sensing does not detect local-scale changes, changes with less distinct spectral signatures, and other possibly relevant details.

[3] Dr. Tullis revised his initial response to this charge question with regard to the details specified in footnote one.

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

Three of the five peer reviewers agreed that it is scientifically justifiable to use remote sensing data to estimate a specific land use change value that would be applied to a biofuel's overall lifecycle GHG impact. Dr. Wardlow agreed without any qualifications. As he mentioned previously, Dr. Tullis commented that agricultural sector models combined with remote sensor products that do not take specific types of biofuel changes into account will be more susceptible to uncertainties in spatial scale. He continued by noting that even if agricultural sector models robustly take into account the aggregate human decision making process through the biofuel lifecycle, historical type-specific biofuel production will still be a critical observable (i.e., it will be difficult to replicate without a remote sensing-assisted spatial decision support system[SDSS]). Dr. Tullis stated that the overall strategy seems reasonable if this uncertainty is minimized in the future.[4] Similarly, Dr. Lal commented that validation is essential.

Dr. Gibbs was the reviewer who most strongly disagreed with the statement in this charge question. She noted that, "in many cases, remote sensing data alone is unlikely to estimate a specific land use change value for biofuels LCA." Instead, she recommended developing crop and location specific pathways using remote sensing data. She also suggested determining whether a specific pathway is related to biofuel production by combining top-down satellite data with bottom-up information.[5] Dr. Houghton noted that future changes in the value of carbon might "encourage nations to manage wood products differently from the way they are managed currently. . .To the extent that such changes occur, it would not be justifiable to assume the same overall lifecycle GHG impact."

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

The peer reviewers disagreed over whether other methods would be more scientifically justifiable than the existing analysis of remote sensing data. However, four of the five reviewers agreed that any approach must use remote sensing data. Dr. Lal recommended using "empirical models relating land use change to the demands of changing demography" and then extrapolating into the future based on future demographic variables and demands.

Dr. Gibbs and Dr. Tullis strongly recommended using additional methods or data to supplement the existing analysis. Dr. Gibbs commented that remote sensing data must form the basis of any study done on land cover changes occurring over large areas. However, she repeated her comment that other types of data should be integrated with the remote sensing measurements. Similarly, Dr. Tullis provided a thorough response that recommended using an SDSS to supplement the existing remote sensing analysis.

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[4] Dr. Tullis revised his initial response to this charge question with regard to the details specified in footnote one.

[5] It appears that Dr. Gibbs may have focused on direct land use change, rather than indirect land use change, in her response to this question. However, this has not yet been confirmed by Dr. Gibbs' because she has been inaccessible due to foreign field work.

Dr. Tullis noted that when combining remote sensing data with agricultural sector models it is vital to manage the origin of any given decision support product so that assumptions can be more clearly identified and expert decisions made. For example, he pointed out that the traditional remote sensing process cannot be used to identify indirect land use changes associated with biofuel production. He noted that the underlying assumption is that the agricultural sector model is able to predict those indirect changes based on detailed land use (and other information) in conjunction with remote sensing. Dr. Tullis commented that the role of the remote sensing-assisted SDSS is to construct better linkages between the model and remote sensing data by drawing on expert knowledge in a systematic way. He detailed an example where an SDSS built within a single computing environment could assemble expert rules to spatially model the suitability of new agriculture for biofuel production. Finally, Dr. Tullis suggested that if agricultural sector models for estimating indirect land use changes begin to rely more heavily on spatial data, then the SDSS could additionally be used to assess the suitability of those indirect changes. [6]

Dr. Wardlow stated that “remotely sensed data products. . .provide the best, globally consistent information that is currently available for documenting land use land cover (LULC) change worldwide.” He added that while national and subnational datasets may exist, they present “several potential issues that would limit their utility for this study.” Dr. Houghton commented that remote sensing data are the best choice for land use change and monitoring, reporting and verifying changes in carbon storage and commitments.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

Four of the five peer reviewers stated that there are other sources of data that can be used to supplement the remote sensing data. Dr. Tullis expanded upon his SDSS concept as outlined in his response to Question 5. He commented that the SDSS could help to identify which types of spatial data would be most appropriate to use. For example, he suggested that data which incorporated topographic effects such as a digital elevation model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) would be relevant to an analysis using SDSS. He stipulated that use of the DEM would depend on whether the SDSS is being used in reference to indirect or direct data on biofuel production. Dr. Tullis also suggested that the deployment of fully-automated GPS receivers on selected trucks involved in biofuel activities would provide new data on direct biofuel production. He stated that these data could also have implications for better understanding indirect activities and that such data would dramatically reduce spatial uncertainties identified in this analysis, particularly in regard to direct biofuel production. Dr. Gibbs responded to the charge question by listing several sources of additional data, including spatial datasets of transportation infrastructure, land ownership, protected areas, human settlements, soils, land suitability and agricultural production. Dr. Lal suggested data sets such as those with the USDA, FAO, ISRIC and WRI. Dr. Houghton stressed the importance of using ancillary data to help constrain findings based on remote sensing data. Dr. Wardlow stated that he is unaware of other data sources beyond remote sensing that could be used.

[6] Dr. Tullis revised his initial response to this charge question with regard to the details specified in footnote one.

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

All five peer reviewers agreed that the remote sensing data set selected was appropriate for the analysis, given the goals of the study at the time. Dr. Wardlow and Dr. Lal did not make any qualifying statements. However, Dr. Tullis commented that while the MOD12Q1 version 4 dataset was the most appropriate dataset to choose when this work was begun, he would now recommend using MCD12Q1 version 5 with a spatial resolution of 500 m x 500 m. Dr. Gibbs commented that MODIS data is an appropriate choice for large-scale land cover mapping because it is the "only dataset available in already processed land cover maps covered more than one year for this decade." However, she felt that it may not be the "best option for tracking the detailed changes in land use needed for this study." Dr. Houghton commented that "identifying the (3-year) difference between two land-cover maps, each of which has been collapsed from 17 to 6 cover types, and each one of which has considerable error, is of questionable merit."

Charge Question 1a: What other different data set or sets do you recommend be used?

All five reviewers specified a different data set to be used in the analysis. Three recommended using a remote sensing dataset with a higher resolution. Dr. Tullis recommended that MODIS version 5 with a 500 m x 500 m resolution be used instead of the MODIS version 4 with a 1 km x 1 km resolution. He noted that in the literature, 1 km x 1 km is not recommended for monitoring land use changes. In addition, he commented that because the 500 m x 500 m data relies on both the Terra and Aqua satellites, there is a significant benefit to using this data in areas where cloud cover is ubiquitous. Dr. Wardlow agreed with Dr. Tullis that the spatial resolution was too low for the analysis. He added that the 500 m x 500 m MODIS land cover data also would contain less area of the 'mixed class.' Dr. Gibbs agreed with Drs. Tullis and Wardlow that the spatial resolution was too coarse for the analysis. She added that "subtracting the MODIS land cover maps is not a suitable method for change detection so it will be important to either conduct a proper change detection or use available products for the 1980s and 1990s from the FAO." Dr. Houghton agreed with the cloud cover issue that Dr. Tullis noted in his comments, but highlighted the ALOS/PALSAR data which have been available since 2006-2007 are able to "see through" cloud cover. Dr. Lal reiterated the data sets he mentioned in response to charge question A-6.

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

All five reviewers agreed that the MODIS data set was properly reclassified. However, Drs. Tullis, Wardlow and Gibbs commented that documentation surrounding the decision to reclassify the 17 IGBP categories into those 6 categories was insufficient. Dr. Wardlow commented further that the 'Mixed' class needs better clarification. He noted an inconsistency between the reclassified map legends and the written text for the 'Mixed' class. Dr. Gibbs disagreed with excluding the "cropland/natural vegetation mosaic," "barren or sparsely vegetated" and "permanent wetland" categories from the reclassification. She also noted that no clear reason for this exclusion was given in the report. However, Dr. Houghton commented that the exclusion of the "cropland/natural vegetation mosaic" was justifiable because it is likely that most conversion of land for biofuel production will be large parcels of land.

Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

Both Dr. Tullis and Dr. Gibbs suggested possible changes in the existing classification scheme. Dr. Tullis noted that many other studies doing this type of analysis use the IPCC (2003) categories of forest, grassland, cropland, water, settlement and other. Since the Winrock categories are similar, but not identical to these IPCC categories, Dr. Tullis felt it would be important to have a justification for the Winrock categories. Dr. Gibbs recommended including a secondary forest category. She also stressed the need for all land cover classes, including cropland mosaic, barren land and wetlands, to be included in the analysis. Dr. Wardlow did not recommend using a new classification scheme, and Drs. Houghton and Lal did not respond to this question.

Charge Question 3: Is the accuracy of the MODIS product accurately characterized?

Three of the five reviewers agreed without reservations that the accuracy of the MODIS product had been accurately characterized in the report. Of the remaining two, Dr. Wardlow agreed with the other three reviewers, but recommended some "spot checking" of the accuracy for specific LULC changes in order to supplement the MODIS Science team's accuracy values. He noted that some LULC types and locations are more difficult to classify, leading to misclassification in one or both maps and "false LULC change detections in the change product derived for this study." Dr. Wardlow also commented that "any supporting evidence whether it is ground truth observations, reports, and/or high resolution imagery to highlight potential errors either regionally or thematically would be helpful in understanding the possible uncertainty they could introduce into the GHG emissions estimates and change projections." Dr. Houghton disagreed with the statement in the charge question. He noted that the accuracy is characterized in a general way. However, he questioned how the calculated change between the two datasets over 3 years compared to the errors within one classification. He also commented that the comparison of forest areas with those reported by FAO's FRA2005 was "an inadequate attempt at evaluation of errors."

Charge Question 3a: If not, how can the characterization be improved?

Two peer reviewers, Drs. Tullis and Lal, did not respond to this question. Dr. Wardlow recommended a spot checking approach as detailed in his answer to Charge Question 3. Dr. Gibbs recommended additional comparison with other studies tracking expanding croplands, particularly Morton et al. (2006), Pin Koh and Wilcove (2008), Brink and Eva (2009) and Gibbs et al. (submitted). Dr. Houghton strongly recommended that the calculated change be compared to a map of the error. He commented that if the 3-year change is small when compared to the error, there may be little confidence in the results. Dr. Houghton also noted that it would be interesting to investigate how changes in forest cover obtained in the study compare to rates of change reported by Hansen et al.

(2008). He felt that such a comparison would suggest a spatial dimension to where the 1 km data is or is not sufficient for analysis.

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

Three of the five reviewers (Drs. Gibbs, Wardlow, and Houghton) agreed that the expanded geographic coverage in the Winrock April 2009 report adequately addressed the need to extrapolate land use changes. Dr. Lal commented that other options for extrapolated land use changes include extrapolation based on soil type and moisture regime. Dr. Tullis disagreed with the statement in the charge question and noted that the MODIS data at a spatial resolution of 1 km x 1 km would be less suitable for very small countries. He noted that this issue could be mitigated if future studies could transition to the 500 m x 500 m measurement scale. Dr. Tullis also commented that he could not find a discussion on the influence of clouds, particularly in the tropical regions.

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

Three of the five peer reviewers agreed with the statement in the charge question. For example, Dr. Tullis noted that the analysis used “is the best choice given the limitations of today’s remote sensing at the geographic scale.” He also approved of the fact that the Winrock team focused on “developing percentages of change in different categories rather than trying to make a direct observation of absolute change.” However, Drs. Houghton and Gibbs disagreed with the statement in the charge question. Dr. Houghton noted that the “changes over 3 years may be too small relative to the errors in a single year’s classification to get a reliable estimate of what has changed.” Dr. Gibbs reiterated her objections in her response to Charge Question B-5a.

Charge Question 5a: If not, how can the characterization be improved?

Drs. Tullis, Wardlow, and Lal did not recommend any improvement in characterization. Dr. Gibbs commented that comparing two classified land cover products directly is not an accurate way to assess change. She recommended that a true change assessment be conducted by a remote sensing laboratory that routinely processes MODIS imagery. She cited a recent study by Hansen et al. (2008) that used a combination of MODIS and Landsat imagery to estimate rates of deforestation during 2000-2005. Dr. Gibbs also stated that the Winrock analysis may be underestimating the amount of forest cleared for new croplands. In support of this statement, she cited Gibbs et al. (submitted), which found that more cropland is usually associated with more deforestation and that 80% of new cropland replaced some type of forest. Dr. Gibbs also mentioned two other studies which found similar types of results. Finally, Dr. Gibbs noted a discrepancy between the Winrock analysis of Brazil’s forest cover and the Landsat-based analysis by the Brazilian space agency. Dr. Houghton noted that a 5-10-year change should be instead of 3 years.

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

Four of the five reviewers agreed with some qualifications that EPA applied the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change. For example, Dr. Tullis disagreed with the underlying assumption that land use changes directly related to biofuel production are highly correlated with agricultural expansion throughout the study areas. He suggested that a more robust approach would attempt to predict the suitability of sites for direct biofuel production. He also suggested that, while remote sensing alone cannot be used to estimate land use change indirectly related to biofuel production, it could potentially be used to refine those estimates within an SDSS framework. However, since the cost and effort of this approach would be substantial, Dr. Tullis agreed that the current EPA approach is currently the best option.[7] Dr. Wardlow also agreed with the statement in the charge question, but noted that if more time and resources were available, improvements might be gained by "mapping specific crop types and/or rotations for specific areas of interest using MODIS 250-meter data or other high resolution imagery." Dr. Houghton disagreed with the statement in the charge question, commenting that it was unclear why a change detection evaluation was not possible. His second point was that 1 km data misses smaller parcels of land, noting that the examples described in the EPA report concern Brazil, where land use change tends to involve large parcels. He added that in Africa, such as assumption may not be valid.

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

Dr. Houghton was the only reviewer who responded to Charge Question B-6.a with information not mentioned in his response to Charge Question 6. He recommended two specific changes to EPA's application of the data. First, he recommended using a 5-10 year difference (instead of three) between the two sets of spatial data. Secondly, he recommended using a change detection rather than differencing method for the two MODIS images.

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

Each peer reviewer responded to this charge question by suggesting at least two major changes to improve the use of remote sensing data. Two of the peer reviewers, Drs. Tullis and Wardlow, recommended changing to higher resolution satellite imagery. Drs. Wardlow, Gibbs, and Houghton agreed that the land cover change analysis should be conducted over a longer period of time. Both Dr. Gibbs and Dr. Houghton commented that the existing method of detecting change was inadequate. Dr. Tullis further recommended finding a way to test the sensitivity of observed distributions of direct biofuel production in future scenarios. He continued by noting that future estimates should be compatible with the most recent changes in the landscape and not simply land use changes from several years ago. He added that this would require an SDSS

[7] Dr. Tullis revised his initial response to this charge question with regard to the details specified in footnote one.

framework, which he described previously.[8] Dr. Lal recommended ground truthing and validation.

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

All five peer reviewers recommended augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense.

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

The reviewers suggested several different data sets and methods for higher-resolution analyses. Dr. Tullis recommended using ASTER because it is the highest spatial resolution sensor on Terra and could be easily compared to MODIS. In terms of methodology, Dr. Tullis noted that it would not be necessary to generate land cover maps. Instead, he commented that, "simple unsupervised clusters could be used to analyze these effects to make sure they are not dramatically limiting the ability of EPA to monitor activities related to biofuel production at the 500 x 500 m measurement scale." Dr. Wardlow recommended using MODIS 250 m data because they are the most widely available and cost effective data. He also commented that Landsat ETM+ imagery "would also be helpful to supplement the coarse MODIS 250-meter observations." Dr. Wardlow recommended a "simple differencing between the two independently derived maps" from the MODIS 25-meter data. Dr. Houghton recommended the use of multi-temporal Landsat TM data in selected sites to supplement the coarser resolution analyses. Dr. Gibbs recommended using Landsat data either as a stratified random sample as provided by FAO or in conjunction with MODIS. She included additional details of possible data sources in her response. Finally, Dr. Lal recommended obtaining data from national institutions.

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

Reviewers supplied a different suggestion regarding how EPA should integrate regional analyses into a globally consistent evaluation of land use change. Dr. Tullis noted that this question is an important one for any organization serious about multi-scale remote sensing. He recommended that the issue be taken seriously and that those working to integrate EPA's data should be given sufficient resources to address the emerging problem of scale management. He emphasized that "questions about spatial scale need to be tightly integrated in the computational aspects of the remote sensing process." Dr. Tullis also predicted that emerging GIS modeling capabilities that are supported by cloud computing environments may be extremely promising for this type of application. He commented that EPA may want to consider "coordinating with other agencies on trying to solve this problem in remote sensing." Dr. Wardlow suggested a different approach focusing on integrating higher resolution LULC change products into coarser LULC information by aggregating the 250-m resolution to the 1-km resolution. Dr. Lal suggested yet a third approach of involving regional and international institutions in providing the soil specific information to validate the data. Finally, Dr. Houghton

[8] Dr. Tullis revised his initial response to this charge question with regard to the details specified in footnote one.

commented that regional analyses should be tailored to yield globally consistent results, meaning “similar accuracies in evaluating the type of ecosystems (including size of parcels) converted directly or indirectly as a result of biofuel production.”

II. Estimation of Land Conversion GHG Emissions Factors

Dr. Tullis did not believe that his expertise was sufficient to address the questions in this section. Therefore, only four peer reviewers responded to the charge questions in Section II.

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

All four peer reviewers agreed that IPCC guidelines were followed appropriately.

Charge Question 1a: If not, please detail how the analysis can be improved.

None of the peer reviewers had any suggestions for improvement of the analysis.

Charge Question 1b: What other guidelines should EPA consider in its estimate of land conversion emission factors?

Three of the four reviewers felt that considering the IPCC guidelines is sufficient. However, Dr. Lal suggested validating the guidelines against site-specific data published in the literature.

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

Three of the four peer reviewers agreed with the statement in this charge question. However, Dr. Houghton commented that, in reference to the weighted emissions factors, it was “not clear what was ‘weighted’ in the weighted average for all other countries.”

Charge Question 2a: If not, what data sources do you recommend?

Dr. Houghton was the only reviewer who suggested a new data source in response to this charge question. He commented that EPA might consider “estimating emissions factors for regions rather than one estimate for global application.”

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

All four peer reviewer agreed with the statement in this charge question.

B. Forest Carbon Stocks

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Three out of the four reviewers agreed to the statement in this charge question. Dr. Gibbs added that the analysis could be updated with improved maps of forest biomass as they become available. Dr. Houghton commented that while these carbon stock estimates were likely the best available, they may not be correct and may be updated with future work.

Charge Question 1a: If not, how do you suggest improving these estimates?

The only reviewer who suggested improvements in response to this charge question was Dr. Lal. He commented that forest carbon stocks consist of both above and below ground components and wondered if the soil carbon component was included in the estimates.

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

All four peer reviewers agreed with the statement in this charge question. There were no additional concerns.

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

Three of the four peer reviewers agreed that the scaling procedure that was used provided accurate results. However, Dr. Lal, did not state specifically whether he agreed or disagreed. He recommended comparing the scaling procedure results with the data sources listed in a new book published by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA).

Charge Question 1a(i): What different approach do you recommend?

Dr. Wardlow was the only reviewer who responded to this charge question. Dr. Wardlow outlined an option to introduce more realistic intra-class variation in the carbon stock numbers. He recommended using “historical 1-km normalized different vegetation index (NDVI) data” as a proxy for green vegetation biomass. The lower end of the NDVI data range would indicate lower carbon stock values and vice versa.

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

Three of the four reviewers agreed that grassland carbon stocks were appropriately estimated and did not suggest any new sources. Dr. Lal did not state agreement or disagreement with the charge question, but suggested comparing the approach to a new source recently published by EMBRAPA.

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

All four reviewers agreed that the IPCC guidelines and data sources were appropriately utilized to estimate biomass carbon stocks for annual and perennial crops.

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

Two of the peer reviewers, Drs. Houghton and Wardlow, agreed that it is scientifically justifiable to use the default factor for all annual crops. Dr. Houghton noted that the variation in cropland biomass does not justify a more elaborate procedure for estimation. Dr. Lal did not directly address the question, but commented that the C stock of cropland estimated at 5 tC/ha seemed too low. He added that if it was a value for biomass only, it would be appropriate, but that this should be specified in the text. Dr. Gibbs did not agree that it was scientifically justifiable to use the default factor in this manner and stated that the IPCC AFOLU value for croplands is "quite limited in that it only provides a single value for all crops and is likely not appropriate for this analysis."

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

All four reviewers gave varying responses to this question. Dr. Gibbs suggested using crop yield maps such as those produced by Ramankutty et al. (2008) and Monfreda et al. (2008) to scale the IPCC crop biomass estimates. While Dr. Wardlow agreed that it is scientifically justifiable to use the default factor, he added that it might be possible to provide more refined estimates by crop type and region using a mapping approach. Dr. Lal suggested that the IPCC (2000) LULUCF report might have more data sets available. Dr. Houghton commented that there would be little to gain by trying to assign specific carbon stocks to different crop types.

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Three of the four peer reviewers agreed that the biomass carbon stocks were appropriately estimated for oil palm and rubber. The fourth reviewer, Dr. Lal, did not directly answer the question.

Charge Question 3a: If not, how do you suggest improving these estimates?

Drs. Lal and Gibbs suggested two methods of improving these estimates. Dr. Lal recommended validating the estimates against data from Malaysia, Nigeria, and Australia. He noted that data from the Oil Palm Research Institute in Nigeria is a good source for comparison. Dr. Gibbs recommended scaling the estimates according to yield.

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

All four peer reviewers agreed that soil carbon stocks were appropriately estimated with the best available data and application of IPCC guidelines. Dr. Lal commented that more explanation is needed on how the average annual change in carbon stock in the top 30 cm of soil and the reference are calculated.

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

Three of the four reviewers agreed that GHG emissions from peat drainage were appropriately estimated with the best available data and IPCC guidelines. While Dr. Gibbs agreed that GHG emissions from peat drainage had been appropriately estimated, she said she was not clear on how the MODIS data would be able to identify clearance of peat swamp forests in the Winrock analysis. Dr. Lal did not directly answer the question, but commented that the estimates were based on one reference and that there are numerous other sources of emissions from drained peatlands. He also asked whether the subsidence rate of peat should be another technique to assess peatland emissions.

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

Three of the four peer reviewers (all except Dr. Gibbs) did not think that the timing of the soil carbon emissions was appropriately evaluated. Dr. Wardlow commented that the assumption of an even spread of soil carbon emissions over 20 years after a land cover conversion seems to generalize the variability in emissions over time. Similarly, Dr. Houghton questioned whether carbon emissions from cultivation of soils occurred more rapidly than the 20-year value used in the study. Dr. Lal commented that justification is needed for choosing a 20-year time period because most peatlands are used for longer periods following drainage and development.

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

All reviewers except Dr. Wardlow suggested improvements for the estimates of soil carbon stocks and emissions. Both Dr. Gibbs and Dr. Lal suggested improving estimates of soil carbon stocks and emissions by improving estimates of peatlands. Dr. Gibbs commented that emissions from peat swamp clearing and other wetlands should be better accounted for. Dr. Lal noted that reliance on a single reference may not be sufficient for peatlands. He suggested comparing the analysis used with the subsidence and bulk density data published in the literature for specific peatlands.

Dr. Gibbs and Dr. Houghton also both commented on possible weaknesses in the soil carbon map. Dr. Gibbs noted that the soil carbon stocks should be updated as new soil carbon maps become available. Dr. Houghton commented that the weakest part of the soil carbon analysis is the map of soil carbon distribution. He noted that the map could be improved where data exist.

F. Lost Forest Sequestration

Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

All four peer reviewers agreed that foregone forest sequestration was appropriately estimated with the best available data and IPCC guidelines. Dr. Houghton stated that it would be instructive to see how much foregone forest sequestration adds to the emissions from conversion, noting that foregone sequestration may be small relative to direct emissions.

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

All four reviewers agreed with some qualifications that the default factors in IPCC Table 4.9 were used appropriately.

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

Drs. Wardlow and Lal questioned whether the assumption of a steady state reached after 20 years was scientifically justifiable. Dr. Wardlow stated that "the application of default factors beyond 20 years (particularly those at 40 or 50+ years) may overestimate the carbon sequestration potential lost from the deforested areas since the sequestration rate may decline with age of tree." Dr. Houghton felt that it was scientifically justifiable to use the default factors in this instance, particularly because if the MODIS analysis did not distinguish between >20 year-old forests and <20-year-old forests, there was no way to assign true age to the forests converted.

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

Both Dr. Wardlow and Dr. Houghton agreed that IPCC Table 4.9 is the best source of data for these estimates. However, Dr. Lal commented that these data sources can be complemented with the data from the literature and national institutes. In addition, he wondered whether the loss in the soil carbon pool following clearing is also considered in the analysis on page 14 of the report. If not, he warned that it might cause an error. Dr. Gibbs added that Table 4.9 could be improved upon by looking to peer reviewed literature where extensive monitoring systems are examined.

Charge Question 2c: If not, what data sources would you recommend?

Dr. Lal suggested that a thorough literature search be done to complement the IPCC data. In particular, he recommended a book called “Carbon Sequestration in Soils of Latin America.” Dr. Gibbs listed several sources of possibly useful information in her answer.

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing. Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

Drs. Lal and Houghton felt that this assumption was reasonable and scientifically justifiable. Dr Houghton added that it would depend on the annual uptake assumed and queried whether the annual uptake multiplied by 80 years added up to a reasonable forest biomass. However, Drs. Gibbs and Wardlow did not believe that this assumption was scientifically justifiable. Dr. Wardlow commented that while foregone forest sequestration likely continues for 80 years after forest clearing, an average rate would not likely be maintained over that long of a period of time. He suggested that a better assumption would be a gradually changing rate over time, which would depend on the forest type replaced, the land cover type that replaced the forest, and the general environmental conditions. Dr. Gibbs commented that the foregone forest sequestration is likely an underestimate and that a longer time period should be included here as described by Harris et al.

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

Three of the four peer reviewers agreed that the IPCC guidelines were appropriately utilized to estimate non-CO_2 emissions from clearing with fire. The fourth reviewer, Dr. Lal, commented that the data sources for fire from Australia, Africa, and Brazil are available to compare and supplement the IPCC guidelines.

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

Drs. Wardlow and Lal concurred that the assumptions were appropriately made for which countries use fire to clear land for crop production. Dr. Houghton expressed concern over the way in which fire was used to estimate the emissions of non-GHGs. He commented that the more worrisome aspect of the analysis was that all of the change in carbon stocks as a result of land use change was assumed to occur immediately.

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

Both Dr. Gibbs and Dr. Wardlow suggested MODIS Fire Products as data sources that would help to determine which regions and land transitions were most likely to involve clearing with fire. Dr. Wardlow noted that these data would provide an approximation of where fire is most frequently used by a country and which locations converted to cropland experienced a period of fire during the period between the two study years. Dr. Gibbs also suggested AVHRR fire data in order to help identify the regions and land transitions likely to use fire. She also commented that the work by Doug Morton and Ruth DeFries on distinguishing between fire use in clearing pastures versus forest could be helpful. Dr. Lal suggested comparing the existing analysis to land clearing experiments done in the 1970s and 1980s in Indonesia (the Sumatra Transmigration Scheme), Amazon and West Africa (ORSTOM and IITA).

Charge Question 2b: Please discuss whether any such data sources and assumptions on current fire clearance are reasonable to project to the future time period used in the analysis.

Dr. Lal confirmed that his suggested data sources and assumption on current fire clearance would be reasonable to project to the future time period used in the analysis. Dr. Wardlow suggested that a historical summary of fire occurrence observations in the MODIS 1-km fire data could provide information on the future use of fire. However, he did warn that future rates and projections based on fire could be problematic because of the effect that climate change could have on fire frequency. Dr. Gibbs did not anticipate large changes through time in the use of fire for clearing in the tropics. However, she commented that if the woody biomass from cleared trees and vegetation was being used as a fuel source, the result would be different. Dr. Houghton said he was not aware of studies in addition to those cited by the Winrock study.

H. Timing of Emissions from Land Clearing

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

Drs. Wardlow, Gibbs and Lal agreed that the timing of emissions from land clearing was appropriately estimated. However, Dr. Lal noted that fire-induced emissions continue for a long time. Dr. Houghton disagreed, stating that it was unreasonable to assume that all of the change in carbon stocks as a result of land use change occurs immediately. He did agree the assumption of immediate emissions seemed reasonable for lands cleared for biofuels because it is very difficult to estimate whether and for how long boles will decay before they are burned.

Charge Question 1a: If not, how do you suggest improving these estimates?

All reviewers except Dr. Wardlow suggested improvements. Dr. Gibbs stated that while she agreed that the timing of emissions from land clearing was appropriately estimated, she felt that the 100-year time period was not an appropriate benchmark for assessing the LCA of biofuels. She suggested that the 30-year time frame would be more appropriate. Both Dr. Lal and Dr. Houghton suggested conducting a literature review. Dr. Lal suggested researching fire-induced emissions and Dr. Houghton suggested researching the relative fractions of woody material that are burned or allowed to decay.

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

All four peer reviewers agreed with the statement in this charge question. Dr. Houghton noted that forests converted to croplands are generally driven by interests unrelated to timber, and thus the trees are simply burned and exceptions are probably of minor importance.

Charge Question 1a: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

None of the peer reviewers made any suggestions for improvement.

Appendix A

Full Text of Charge Questions

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

> Charge Question 1a: What other different data set or sets do you recommend be used?

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

> Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

Charge Question 3: Is the accuracy of the MODIS data product accurately characterized?

> Charge Question 3a: If not, how can the characterization be improved?

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

Charge Question 5a: If not, how can the characterization be improved?

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

II. Estimation of Land Conversion Greenhouse Gas Emissions Factors

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

Charge Question 1a: If not, please detail how the analysis can be improved.

Charge Question 1b: What other guidelines should EPA consider in its estimate of land conversion emission factors?

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

Charge Question 2a: If not, what data sources do you recommend?

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

B. Forest Carbon Stocks

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Charge Question 1a: If not, how do you suggest improving these estimates?

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

Charge Question 1ai: What different approach do you recommend?

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Charge Question 3a: If not, how do you suggest improving these estimates?

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

F. Lost Forest Sequestration

Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

Charge Question 2c: If not, what data sources would you recommend?

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing? Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

Charge Question 2b: Please discuss whether any such data sources and assumptions on current fire clearance are reasonable to project to the future time period used in the analysis.

H*. Timing of Emissions from Land Clearing*

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

Charge Question 1a: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Charge Question 1a: If not, how do you suggest improving these estimates?

Appendix B

Dr. Gibbs Response to Charge Questions

General Comments:

I applaud the efforts of the EPA to consider the complexity of indirect land use change (iLUC) and am honored to have reviewed these emerging standards. Including the carbon emissions from direct and indirect land use change will be critical to ensure that the benefits of biofuels can come to fruition. Neglecting these emissions could lead to unintentional increases rather than decreases in net GHG emissions to the atmosphere. The EPA successfully synthesized several key pieces of information to develop this framework, and I appreciate the scientific quality and clear presentation of the work presented here. Similarly, Winrock International has provided an excellent service by taking the lead on answering these questions using available data sets and under a short time period, and provided a highly transparent and reflective report describing the methods and results.

However, I do have concerns regarding the details of the land use analysis and posit that it substantially underestimates the amount of forest cleared for crop expansion (all crops, not just biofuels). Alternative data sources and approaches should be considered.

Suggestions for future improvements:

- The analysis should not exclude the cropland / natural vegetation mosaic, barren land or wetlands categories as these all could be cultivated in response to cropland expansion.

- No secondary or degraded forest category is included in this analysis leading to an overestimation of emissions if these forests are lumped with intact forest categories and an underestimation of emissions if lumped with savanna.

- The time period and source of satellite data is not appropriate. The 3-year time period is too short to capture the often gradual or sequential cropland expansion that often occurs in the tropics. In Brazil for example, clearing forest for soybeans or other mechanized agriculture may take two years and be part of a larger sequence (forest → pasture / small-holder ag → soy) thus would be missed by the short time period examined here. The short time period may also show unusual or temporary trends in land use caused by short-term policy changes or market influences. The 500m-1km spatial resolution of MODIS imagery may be too coarse to capture some land transitions.

- For all the reasons listed above, this analysis likely underestimates the amount of forest clearing that occurred and will continue to make room for new croplands in the tropics. Other longer-term studies, including the Gibbs et al. (submitted) analysis of the FAO's intensive Landsat database, indicate much higher rates of forest clearing from agricultural expansion. In fact, we find that more than 55% of new agricultural land came at the expense of forests between 1980 and 2000, with another 28%

coming from disturbed forests across the tropics. These results are echoed by the work of Brink and Eva (2008) across sub-Saharan Africa.

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Yes, using historic remote sensing data is a justifiable approach to project future land use changes particularly considering that there are few other options. It is important to note that this approach assumes that the conditions determining land use patterns will be the same during the historic and future time periods and may require adjustments if major changes occur. Combining the historic remote sensing analysis with information on the drivers and causes of land use changes to allow for modified rates and locations of change would be one way to account for dynamic conditions.

These historic reference periods should be measured using remote sensing observations over 5-10 to reduce the impact of anomalous years, and should be as recent as possible to help improve the chances of similar land use change drivers and patterns (i.e. same political systems in place, infrastructure, protected areas etc.).

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Yes, this is the best approach given our available tools. As we move forward, improved and more integrated modeling and observation systems will be available that will provide improved results.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Remote sensing imagery provides our only means to observe large-scale land use patterns and as such is needed to measure past changes and monitor those happening today. Analysis of satellite data collected over previous time periods allows us to identify the biophysical and socioeconomic conditions leading to different types of land use changes or lack thereof. This ground-based information can be combined with satellite data to identify the biomes likely to be affected by biofuel expansion.

Pan-tropical remote sensing analyses conducted over the last three decades have already established those areas most affected by land use change (e.g., Achard et al. 2003, DeFries et al. 2002, Hansen et al. 2007, Lepers et al. 2005). Biofuels clearly presents a more recent driver of change that requires special consideration. Generally speaking however, we can expect direct and indirect expansion of biofuel crops to occur similarly to food and feed crops.

Agricultural census data also provides insights into where the likely agricultural expansion will occur. For example, we know definitively that most net expansion in global agricultural land during the 1980s and 1990s occurred in tropical countries (FAOSTAT 2009). Mollicone et al. (2007) estimate that the area of cultivation decreased by 2.8% in developed countries between 1990 and 2004, while developing countries saw the area of cultivation increase by 13.8% during the same period. The lower production costs and fewer environmental constraints have helped forest-rich tropical countries such as Brazil, Indonesia, and Malaysia quickly responded to increased demand for crops such as sugarcane, soybeans and oil palm (Dufey 2006, Johnston and Holloway 2007, FAOSTAT 2008). For example, soybeans now cover more than 20 million ha of land in the Brazilian Amazon alone, up from just 13 million ha at the turn of the century (FAOSTAT 2009). Similarly, Indonesia's oil palm production tripled during the 1990s, increasing from 0.6 million ha in 1990 up to 4.6 million ha in 2007 (FAOSTAT 2009). Demands for biofuels and animal feed alone are expected to drive increases in soy and sugarcane acreage in Brazil from 28 million ha today to 88-128 million ha by 2020 (RRI 2008). Oil palm estates in Indonesia are expected to grow from 6.5 million ha today to 16.5 to 26 million ha in this same time period (RRI 2008).

Combining remote sensing data with other empirical information on land use change drivers (transportation infrastructure, poverty rates, opportunity costs, markets etc.) could provide an improved means of projecting future land use (e.g., Soares-Filho et al. 2006).

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

No, in many cases remote sensing data alone is unlikely to estimate a specific land use change value for biofuels LCA. Perhaps under some specific circumstances where we know that a crop such as sugarcane is being grown to expand biofuel production we could use remote sensing to track that expansion pathways and use that to provide insights into the cane-ethanol LCA but in many cases it would be difficult to distinguish a specific land use change (on a pixel by pixel basis) due to biofuel crop expansion from those for food or feed.

However, crop- and location-specific pathways can be identified using remote sensing data. We could also determine if the specific expansion pathway was for biofuel production if we combined the top-down satellite view with bottom-up information. For example, we could monitor the corn expansion in the U.S. if we know which farmers or areas are expanded for biofuel production or in response to higher price signals stemming from biofuel mandates. But this would likely require additional ground-based or census information to be considered with the remote sensing analysis.

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

No, land cover changes occurring over large areas must be assessed using remote sensing measurements. Field data collection would not be accurate or feasible and there are no other ways to measure land use change over such large scales. Even models used to predict land use change would be parameterized with remote sensing measurements if they were reality based (vs theoretical). However, as mentioned above, it would be helpful to integrate other types of data with the remote sensing measurements.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

Yes, detailed spatial datasets of transportation infrastructure, land ownership, protected areas, human settlements, soils, land suitability, agricultural production and so on could be used to supplement the remote sensing data. These supplementary datasets would help better constrain the causes of land use change and help ensure that land use changes rather than just land cover changes were being identified (i.e. plantation as cropland vs forest).

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

MODIS data is an appropriate choice for large-scale land cover mapping but may not be the best option for tracking the detailed changes in land use needed for this study. MODIS data are likely inadequate for accurate change area estimation because most land use clearing in the tropics occurs at a smaller scale than a MODIS pixel so is likely to be missed (Hansen et al. 2008). That said, MODIS is the only dataset available in already processed land cover maps covering more than one year for this decade so it does make sense that Winrock chose to use it given the time constraints of the analysis.

Charge Question 1a: What other different data set or sets do you recommend be used?

Remote sensing data with a higher spatial resolution such as Landsat would be much preferred to MODIS for this type of analysis. Most importantly, subtracting the MODIS land cover maps is not a suitable method for change detection so it will be important to either conduct a proper change detection or use available products for the 1980s and 1990s from the FAO discussed below and used to estimate land sources for new croplands by Gibbs et al (submitted).

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

Yes, Winrock properly reclassified the IGBP land cover classes. However, I disagree with excluding the “cropland / natural vegetation mosaic”, “barren or sparsely vegetated” and “permanent wetland” categories. No clear reasoning for this exclusion is given.

The cropland mosaic category is particularly important to include for the following reasons:

- It is often the source for new cultivated land area as it is clearly in close proximity to existing agricultural land.

- It is one of the only categories that could include degraded or secondary forests within the IGBP classification scheme that have been impacted by fuelwood collection, logging, or small-scale or shifting agriculture. Note that the savanna category may also include these lower biomass forests.

The permanent wetland category defined as "lands with a permanent mixture of salt, brackish or fresh water and herbaceous or woody vegetation" should also be included in the analysis. These areas could include peat swamp forests that would lead to very large carbon emissions if cleared for oil palm or other plantations.

The barren / sparsely vegetated category is also important to include to help identify if cropland is expanding into degraded areas. It is unlikely that expansion would occur in this category due to lower profitability as compared to more fertile areas but excluding it could make the results appear biased away from the use of degraded lands for crop production.

Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

The IGBP classification scheme is appropriate but not necessarily preferred over other schemes. It would be ideal to include a secondary forest category; as it stands now the only way for a degraded (logging, partially cleared, etc.) forest is accounted for is when it is lumped into the savanna or shrubland categories. It should also be pointed out that in Table 2.6-2.3 the definitions of savanna and woody savanna are missing the word "forest" in front of canopy, which gives the incorrect impression that these areas do not include woody species. Lastly, as mentioned above, all land cover classes should be included in this analysis (cropland mosaic, barren and wetlands).

Charge Question 3: Is the accuracy of the MODIS data product accurately characterized?

Yes, the discussion of MODIS data product accuracy is complete. Harris et al. provide a solid discussion of ambiguities in the MODIS change analysis (compare to FRA, point out inconsistencies in transition matrices). There is not a formal accuracy assessment of the change detection analysis provided, but that would not be feasible given the large spatial extent and timing of the project.

Charge Question 3a: If not, how can the characterization be improved?

Additional comparison with other studies tracking expanding croplands would be helpful (e.g., Morton et al. 2006, Pin Koh and Wilcove 2008, Brink and Eva 2009, Gibbs et al submitted).

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

Yes, most likely.

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

Charge Question 5a: If not, how can the characterization be improved?

As described by Harris et al., comparing two classified land cover products directly is not an accurate way to assess change and can lead to spurious change results as shown in Table 7 of the Winrock April report. A true change assessment is needed to accurately identify the land use changes occurring during the 2001-2004 time period. A remote sensing laboratory at a University or corporation that routinely processes MODIS imagery would likely be able conduct a thorough change assessment using MODIS over several months. For example, Hansen et al. 2008 recently used a combination of MODIS and Landsat imagery to estimate rates of deforestation during 2000-2005. MODIS data was used to identify those areas undergoing rapid change and then Landsat was used within these regions to estimate the specific rate of change. Contracting the work with this or a similarly experienced lab could enable a timely turnaround with improved accuracy.

Moreover comparison with other studies indicates that the <u>Winrock analysis may be underestimating the amount of forest cleared for new croplands.</u>

- Gibbs et al. (submitted) analyzed a very detailed library of Landsat satellite collected over the 1980s and 1990s processed and archived by the United Nations FAO. This database is exceptional in that the FAO used a detailed land cover classification scheme that accounted for major human-induced land cover types and used interdependent, visual interpretation of two satellite images acquired at different dates within a single interpretation process when estimating land cover change. This approach secures a high level of consistency and reduces the error associated with change detection, and allowed Gibbs and colleagues to directly track the land sources for expanding agricultural land in each scene.
    - The results definitively confirm that more cropland means more deforestation. In the 1990s for example, more than half of new croplands came at the expense of mature, intact forests. Another third came from forests that had been disturbed by logging or small-scale agriculture. So in total roughly 80% of new cropland replaced some type of forest.

- A detailed study employing field and remote-sensing observations by Morton et al. (2006) identified roughly equal shares of forests, pasture and grassland as the sources for expanding soy fields in Mato Grosso between 2000 and 2004.

- A recent analysis of national agricultural and deforestation statistics from 1990-2005 by Pin Koh and Wilcove (2008) found that more than half of new plantations were carved from forests.

- Lastly, the Winrock analysis shows a net increase in Brazil's forest cover of 1.6 Mha while Landsat-based analysis by the Brazilian space agency, INPE, clearly shows increasing deforestation rates between 2001-2004. These discrepancies may indicate a problem with the MODIS analysis.

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

I believe that EPA's use of the Winrock analysis is correct. However, as mentioned above I think that we need to improve the land use change input data to the EPA analysis.

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

The EPA is on the correct path with the land use change analysis but additional work will be needed to improve the results. I do not believe the Winrock analysis can be used as is due to the short time period considered and the lack of a true change detection procedure. However, I think that it would be possible to quickly update this analysis working with Winrock for the emissions factor / carbon mapping work but collaborating with larger remote-sensing laboratories for the change detection portion of the work.

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

YES, I strongly recommend using Landsat data either as a stratified random sample as provided by the FAO or in conjunction with MODIS or other coarse resolution satellite imagery as demonstrated by Hansen et al. (2008).

Specific data sources:

- FAO Landsat analysis for the 1980s and 1990s; see Gibbs et al (submitted) for analysis of land sources for expanding agricultural lands
- The FAO Landsat database for the current decade is now being archived and distributed by South Dakota State University. This would be an excellent data source. http://globalmonitoring.sdstate.edu/projects/fao/pages.land/w063s10.html
- Here is a description of this data that could be used for the RFS2 and other efforts:

"The FAO FRA Remote Sensing Survey (copied from website above)
As part of the Global Forest Resources Assessment 2010 (FRA 2010), the UNFAO and its member countries and partners will undertake a global remote sensing survey of forests. This survey will substantially improve knowledge on forest dynamics, including deforestation, afforestation and natural expansion of forests. The primary aims of the new global survey are to obtain information on the distribution of forests and on changes in forest area over time at regional, biome and global levels. The survey has two main components:

- Generating a new, validated global tree-cover map using time-series imagery from MODIS satellites at 250m resolution. This will be done in cooperation with South Dakota State University.

- Gathering and analyzing the best existing global imagery (Landsat images at 30 m resolution) from 1975, 1990, 2000 and 2005 for improved estimates of forest area and forest area change. This will be done by FAO, the Joint Research Centre of the European Commission in close collaboration with countries.

Selection of archival Landsat satellite images (at 30 m resolution) at more than 10,000 locations across the planet will provide a comprehensive sample of the world's land surface for 1975, 1990, 2000 and 2005. Each sample tile will cover a 10 km by 10 km square at each junction of one degree of latitude and longitude (approximately 100 km apart). Images will be processed to provide statistically reliable estimates of forest extent and change at regional, biome and global levels. The results will enable an internally consistent global assessment of forest change dynamics."

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

II. Estimation of Land Conversion Greenhouse Gas Emissions Factors

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

Yes, the IPCC guidelines were appropriately followed throughout.

Charge Question 1a: If not, please detail how the analysis can be improved.

Charge Question 1b: What other guidelines should EPA consider in its estimate of land conversion emission factors?

The IPCC guidance is ideal for this use. Other guidelines could be considered but for simplicity and political acceptance I suggest using only the IPCC.

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

Yes.

Charge Question 2a: If not, what data sources do you recommend?

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

Yes.

__B. Forest Carbon Stocks__

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Yes. This analysis could be updated with improved maps of forest biomass as they become available.

A point of clarification: In the text, the global carbon map by Ruesch and Gibbs (2008; referred to as Ruesch et al in the text) is described as being based on only 20 values. While it is correct that the IPCC default values from Table 4.12 of the Good Practice Guidance (2006) form the backbone of the map we actually mapped 124 unique carbon values after accounting for variation in root:shoot ratios, carbon fraction, and disturbance history around the world.
Here's a brief description of the methods: We created the vegetation biomass carbon database following two main steps: 1) estimate carbon stocks, and 2) map values using a range of spatially-explicit climate and vegetation datasets. We followed the IPCC GPG Tier-1 method for estimating vegetation carbon stocks using the globally consistent default values provided for aboveground biomass (IPCC 2006). We added belowground biomass (root) carbon stocks using the IPCC root to shoot ratios for each vegetation type, and then converted total living vegetation biomass to carbon stocks using the carbon fraction for each vegetation type (varies between forests, shrublands and grasslands). All estimates and conversions were specific to each continent, ecoregion and vegetation type (stratified by age of forest). Thus, we compiled a total of 124 carbon zones or regions with unique carbon stock values based on the IPCC Tier-1 methods.

* This spatial database is likely the best available, globally consistent map depicting vegetation carbon stocks, circa 2000, and follows the widely accepted IPCC methods for estimating carbon stocks at the national level. **That said, this dataset is highly uncertain and the methods employed here are not directly linked to ground-based measures of carbon stocks. We essentially applied a sophisticated paint-by-numbers approach, which consequently masks variations within classes and may lead to unnatural, abrupt gradients between vegetation classes as defined by the GLC 2000 and FAO ecoregions (Gibbs et al. 2007).
For example, our approach does not account for different vegetation conditions that could lead to lower or higher carbon stocks, such as logged, regrowing, or virgin ecosystems. Similarly, croplands received the same carbon stock value regardless of the type of crop that might be growing, which is clearly a simplification. The same IPCC default carbon value was applied to all vegetation within each broad class regardless of condition. This means that the actual carbon storage in a given location could be more or less than indicated by our map.

Charge Question 1a: If not, how do you suggest improving these estimates?

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Yes, Harris et al. managed the uncertainty and data paucity very well. No recommendations.

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

Charge Question 1ai: What different approach do you recommend?

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

Harris et al appropriately estimated grassland stocks. No recommendations.

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

Yes.

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

The IPCC AFOLU for croplands is quite limited in that it only provides a single value for all crops and likely not appropriate for this analysis. I would suggest at a minimum using crop yield maps such as those produced by Ramankutty et al. (2008) and Monfreda et al. (2008) to scale the IPCC or other crop biomass estimates. For example, Gibbs et al. (2008) followed the IPCC AFOLU guidelines in combination with Monfreda et al. (2008) crop yield maps to allow for crop biomass to vary across broad tropical regions. Although, this variation in crop carbon stocks will be minor compared the carbon dynamics from the initial land clearing.

TABLE from Gibbs et al. (2008)

Table S1. Estimates of carbon stocks for tropical landscapes.

All values include carbon stored in aboveground and belowground living plant biomass (t C / ha)[1, 2]

Biomass Carbon of Tropical Land Cover Types (t C / ha)												
	Americas			Sub-Saharan Africa			Southeast Asia			Pan-Tropical		
Crop Type	Humid	Seasonal	Dry	Humid	Seasonal	Dry	Humid	Seasonal	Dry	Humid	Seasonal	Dry
Forests	197	132	130	204	156	76	229	109	82	210	132	96
Disturbed Forests[3]	100	68	67	104	80	40	116	56	43	107	68	50
Shrubland / Savanna	64	43	42	67	51	24	75	35	26	69	43	31
Grassland	8	8	4	8	8	4	8	8	4	8	8	4
Degraded Land[4]	1	1	1	1	1	1	1	1	1	1	1	1
Annual Cropland[5]	6	7	7	4	3	5	5	5	5	5	5	5
Sugarcane	10	14	10	10	10	14	14	14	14	11	13	13
Oil Palm[6]	71	81	69	17	24	53	88	78	82	58	61	68
Coconut[7]	96	112	108	68	50	39	67	80	83	77	81	77

1. Humid, seasonal and dry ecoregions were defined according to the FAO Global Ecoflorisitic zones. The dry ecoregions includes both dry tropical forests and shrublands. Mountain ecoregions were included as humid tropics in Southeast Asia and dry tropics in Africa and Latin America. All biomass carbon values estimated using IPCC Tier-1 methods (Eggelston *et al* 2006, Gibbs *et al* 2007). Estimates include litter and dead wood carbon stocks for forests (Eggelston *et al* 2006).
2. Used insular Southeast Asia value for humid forests and continental Southeast Asia values for seasonal and dry forests based on patterns of forest distribution.
3. Forest carbon values were reduced by 50% to estimate disturbed forest biomass (i.e. affected by shifting cultivation, logging, fragmentation, fire etc.)
4. Assumed that degraded lands have very little living biomass.
5. To estimate biomass for annual crops, we assigned 5 t C / ha to the mean tropical yield for annual crops and then scaled according to regional yields. Ratios of average pan-tropical yield / regional yields (0.85, 0.73, 0.76 for Americas, 1.41, 1.45, 1.11 for Africa, and 1.01, 0.99, 1.10 for Asia)
6. Oil palm value based on average IPCC GPG (Eggelston *et al* 2006) value for humid Southeast Asia, we used 0.47 for C fraction and then added in root biomass according to IPCC. Scaled across tropics using ratios of SE Asia / Africa and Americas yield data (5.3, 3.3, 1.54 for Africa and 1.23, 0.96 and 1.18 for Americas)
7. Coconut value based on average IPCC value for humid SE Asia, we used 0.47 for C fraction and then added in root biomass according to IPCC (Eggelston *et al* 2006). Scaled using ratios of SE Asia / Africa and Americas yield data (0.99, 1.61, 2.11 for Africa and 0.71, 0.71, 0.76 for Americas)

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Charge Question 3a: If not, how do you suggest improving these estimates?

Yes. However, I would also recommend scaling them according to yield as in Gibbs et al. (2007).

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

Yes.

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

Yes. However, I'm not clear as to how the MODIS land use change would be able to identify clearance of peat swamp forests in the Winrock analysis? This could be a major omission for oil palm expansion in Southeast Asia.

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

Yes.

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

The emissions from peat swamp clearing and other wetlands should be better accounted for but that will fall under the land use change analysis rather than the soil carbon stocks and emissions.

The soil carbon stocks should be updated as new soil carbon maps become available in coming years.

F. Lost Forest Sequestration

Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

Yes.

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

The default factors were used according to the IPCC guidance. However, Table 4.9 could be improved upon by looking to peer reviewed literature where extensive monitoring systems are examined. The most recent reference cited by the IPCC in Table 4.9 is 2004, so more recent information could be useful. For example:

Lewis et al. 2009. Increasing carbon storage in intact African tropical forests. Nature 457:19.

Baker, T. R. et al. Increasing biomass in Amazonian forest plots. Phil. Trans. R. Soc. Lond. B 359, 353–365 (2004).

Lewis, S. L. Tropical forests and the changing Earth system. Phil. Trans. R. Soc. Lond. B 261, 195–210 (2006).

Malhi, Y. & Grace, J. Tropical forests and atmospheric carbon dioxide. Trends Ecol.Evol. 15, 332–337 (2000).

Phillips, O. L. et al. Changes in the carbon balance of tropical forests: Evidence from long-term plots. Science 282, 439–442 (1998).

Phillips, O., Lewis, S. L., Baker, T. R., Chao, K.-J. & Higuchi, N. The changing Amazon forest. Phil. Trans. R. Soc. B 363, 1819–1827 (2008).

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

Charge Question 2c: If not, what data sources would you recommend?

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing? Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

I believe this is likely an underestimation of foregone forest sequestration and a longer time period should be included here as described by Harris et al.

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

Yes.

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

MODIS and AVHRR fire products could be used to help identify the regions and land transitions like to use fire. The work by Doug Morton and Ruth DeFries distinguishing between fire use in clearing pastures versus forest could provide helpful insights for the land transition issue.

Charge Question 2b: Please discuss whether any such data sources and assumptions on current fire clearance are reasonable to project to the future time period used in the analysis.

I would not anticipate large changes in the use of fire for clearing in the tropics so in that sense it seems appropriate to project current fire clearance into the future. However, if the woody biomass from cleared trees and vegetation is used as a fuel source then the picture would be different.

H*. Timing of Emissions from Land Clearing*

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

Charge Question 1a: If not, how do you suggest improving these estimates?

Yes, I think the timing of emissions was properly estimated. However, the 100 year time period is not an appropriate benchmark for assessing LCA of biofuels when we are attempting to reduce emissions over the near term. I think the 30 year time frame is much more appropriate.

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Yes.

Charge Question 1a: If not, how do you suggest improving these estimates?

Appendix C

Dr. Houghton Response to Charge Questions

General Comments:

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Yes, it is scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change for the *near* future, meaning 5-10 years. Obviously, the justification becomes weaker for longer-term projections, such as 25, or more, years. It is possible, for example, that, if carbon becomes a commodity through UNFCCC agreements such as REDD, there will be a greater incentive to keep forests as carbon stocks and thus use non-forest lands to expand bio-energy production.

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Yes. It is important to note that in these EPA analyses the remote sensing data are being used to identify the types of ecosystems (i.e., carbon stocks) converted and the location of the conversion (again, for carbon stocks). The remote sensing data are *not* being used to determine rates of deforestation, for example. Rates of cropland expansion are obtained from models.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Changes in land use result from a number of drivers, only one of which is biofuel production. While it is theoretically possible that the changes in land use resulting from biofuel production occur in ecosystems or regions that would not be the ones affected by other drivers, this doesn't appear very likely. Croplands are expanding, some portion of which is for biofuels, and the point of this exercise is to document where these expansions are (for whatever reasons).

My guess is that changes in land use caused specifically by biofuel production will involve agri-businesses and large parcels of land-use change that are readily observed by remote sensing. Other, more subsistence-based changes in land use, which are more likely to involve small parcels of land, may *not* be readily characterized by remote sensing data, or by MODIS data (1 km) especially. This is just a guess, however, and should be investigated.

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

I suppose it's possible that future changes in the value of carbon could encourage nations to manage wood products differently from the way they are managed currently. Thus, while forests cleared for soybeans today might be burned, with different incentives they might be harvested and turned into long-term products in the future. To the extent that such changes occur, it would not be justifiable to assume the same overall lifecycle GHG impact.

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

No. I think remote sensing data are the best choice for identifying where, and which ecosystems, are being converted to other land uses and land covers. Furthermore, remote sensing data explicitly bring spatial data to the table. Spatial changes in cover and carbon will be essential for monitoring, reporting, and verifying changes in carbon storage and commitments.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

I think it will always be important to use ancillary data to help constrain findings based on remote sensing data. For example, this analysis referred to data on the number of cattle to indicate that stocking densities had changed. Such information, or information on fertilizer use, for example, might be useful to help interpret changes in management intensity, which might not be apparent from remote sensing data.

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

Given that the question was "what types of ecosystems are being converted?" and not "what are current rates of deforestation?", I think that the 1 km MODIS data were most appropriate. On the other hand, identifying the (3-year) difference between two land-cover maps, each of which has been collapsed from 17 to 6 cover types, and each one of which has considerable error, is of questionable merit. How does that calculated change compare with the errors of one map? Aren't the errors for one year greater than the change over 3 years?

Charge Question 1a: What other different data set or sets do you recommend be used?

ALOS/PALSAR data have been available since 2006-2007, and they have the advantage of 'seeing' through clouds, which MODIS data cannot do. Clouds are a serious impediment to this type of monitoring in tropical regions.

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

I think the reclassification was reasonable. I'm guessing that excluding the cropland/natural vegetation mosaic was justifiable because most conversion for biofuels will be large parcels of land. If small parcels are also used, then some of this conversion may be within the cropland mosaics and more difficult to observe.

Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

Charge Question 3: Is the accuracy of the MODIS data product accurately characterized?

The accuracy is characterized (not quantified) in a general way. The proof of the pudding, however, is in how well the data capture what they are being used to capture. As above, how does the calculated change over 3 years compare with the errors of one classification? Aren't the errors greater than the change over 3 years? I don't see an evaluation of the specific errors in this context, and, thus, in this sense, the data product has *not* been accurately characterized.

The comparison of forest areas with those reported by FAO's FRA2005 (Table 2.6-24) was an inadequate attempt at evaluation of errors. Differences were explained by 'hand waving' at best (woody savannas and shrublands on the one hand, and plantations on the other were used to justify differences from average) and by selective explanations. China and India have large areas of plantations, as well, yet the MODIS approach yielded lower estimates of forest areas there.

Charge Question 3a: If not, how can the characterization be improved?

The calculated change should be compared to a map of error. If the 3-year change is small relative to the error, there may be little confidence in the results. Scientists on the MODIS team (e.g., Mark Friedl at Boston University) are working on this type of analysis. Why weren't they involved in the analysis?

It might also be interesting to investigate how the changes in forest cover obtained here with MODIS (2001-2004) compare with the rates of change reported by Hansen et al. (2008). The 1 km resolution is coarse relative to many changes in land use, and thus misses some change, but a comparison might reveal a spatial dimension to differences, suggesting where and where not the approach might be working. The assumption in this work is that the large, observable changes correspond to the changes driven by conversion for biofuels. This assumption might be tested in more detail in a few case studies.

Hansen, M.C., S.V. Stehman, P.V. Potapov, T.R. Loveland, J.R.G. Townshend, R.S. DeFries, K.W. Pittman, B. Arunarwati, F. Stolle, M.K. Steininger, M. Carroll, and C. DiMiceli. 2008. Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. Proceedings of the National Academy of Sciences 105, 9439-9444, 2008.

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

Yes. The MODIS coverage is global and, to the extent it works at all, it can be expected to work anywhere. There should be no need to extrapolate land-use changes to areas without coverage.

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

As noted above, the changes over 3 years may be too small relative to the errors in a single year's classification to get a reliable estimate of what has changed. Furthermore, the assumption in this work is that the large changes observable with 1 km MODIS data correspond to the changes driven by conversion for biofuels. This assumption might be tested in more detail in a few case studies using higher spatial resolution or ground data.

Charge Question 5a: If not, how can the characterization be improved?

I would use a 5-10-year change rather than 3 years.

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

First, it is not clear to me why doing a change detection was not possible. As the Report states, that would have been the best way to evaluate the ecosystems changed. Second, I think another weakness of the approach is use of 1 km data, and the possibility that conversions include a number of smaller parcels of land that would be missed by MODIS data. The examples described in the EPA summary focus on Brazil, where changes in land use involve large parcels. In Africa this may not be the case.

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

i) a 5-10-year difference (instead of 3); ii) change detection rather than differencing two independent MODIS images

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

The EPA study noted that the comparison of two LU/LC maps to obtain change is not the most desirable approach, but that it was the only approach available given the products that exist. I would suspect that somewhere in the MODIS data products chain there exist the data for doing change detection directly (the preferred approach). Only those pixels identified as having changed need identification, and the accuracy is likely to be much higher because a greater number of land cover types could be considered. Further, I suggest that a period of five years (not three) be used to determine changes in land cover. A single year (and by extrapolation 3 years) is a narrow window for documenting change. There are likely to be environmentally-induced 'changes' that are incorrectly attributed to land-use change. A period of 5, or more, years gets away from this year-to-year 'noise'.

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

Yes. Besides the possibility that much land-use change is missed with the 1 km MODIS data, there is also the concern that some of the changes identified are not really conversions but a change from one agricultural crop to another (or some other source of error). This shouldn't happen if the classes are accurately identified, but there is some error.

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

I recommend use of multi-temporal Landsat TM data in selected sites to serve as checks to the coarser resolution analyses.

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

What does 'globally consistent' mean if there are systematic differences in the way land-use changes occur in different regions? Brazilian changes in land use are likely to be spatially different from African changes. Regional analyses may have to be tailored to yield 'globally consistent' results, meaning similar accuracies in evaluating the types of ecosystems (including size of parcels) converted directly or indirectly as a result of biofuel production.

II. Estimation of Land Conversion Greenhouse Gas Emissions Factors

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

The EPA report claims to have used the 2006 IPCC guidelines. As far as I can tell it has.

Charge Question 1a: If not, please detail how the analysis can be improved.

Charge Question 1b: What other guidelines should EPA consider in its estimate of land conversion emission factors?

I can suggest no other guidelines.

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

The EPA calculated weighted average emissions factors for 10 countries/regions and then used a weighted average for other countries. Emissions factors varied with biofuel type, but it is not clear what was 'weighted' in the weighted average for all other countries: area converted, share of crop expansion covered, or something else.

Charge Question 2a: If not, what data sources do you recommend?

The EPA might consider estimating emissions factors for regions rather than one estimate for global application. For example, the Southeast Asia countries all have high factors. Perhaps a weighted value for Southeast Asian countries should be higher than, and other regions lower than, the global average.

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

Yes, as far as I can tell.

B. Forest Carbon Stocks

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

The Winrock approach used regional estimates where they exist, with a default of IPCC Tier-1 values in other regions (from Ruesch and Gibbs, 2008). These may be the best available, recognizing, first, that they may not be correct and, second, that the estimates may be updated with subsequent work.

Charge Question 1a: If not, how do you suggest improving these estimates?

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

The estimates for grasslands, savannas, and shrublands seem reasonable and appropriate.

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

As far as this reviewer can tell, the results appear reasonably accurate.

Charge Question 1ai: What different approach do you recommend?

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

There seems to be so little variation in grassland carbon stocks; the approach is totally appropriate.

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

As far as I can tell, yes.

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

Yes. The variation in cropland biomass does not justify a more elaborate procedure for estimation.

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

I am sure there are estimates from case studies scattered throughout the published literature, but there would be little to gain by trying to assign specific carbon stocks to different crop types.

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Yes. The approach appears reasonable and appropriate.

Charge Question 3a: If not, how do you suggest improving these estimates?

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

Yes, for Tier-1 types of accuracy.

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

Yes, for Tier-1 types of accuracy.

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

My understanding is the carbon emissions from cultivation of soil occur more rapidly, for example, over ~5 years, rather than 20.

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

The weakest part of the analysis seems to be the map of soil carbon distribution. The FAO-UNESCO Soil Map of the World shows little variation in soil carbon in throughout the tropics (40-80 tC/ha). Such a map could be improved where data exist, much as the forest biomass maps were improved with recent estimates from the literature. Such a map exists for China, for example, but I am not sure for many other countries.

F. Lost Forest Sequestration

Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

As far as I can tell. It would be instructive to see how much foregone forest sequestration adds to the emissions from conversion. How do the two processes contribute to the total? My guess is that the foregone sequestration is small relative to direct emissions.

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

They seem to have been, as shown in the EPA's Table 2.6-35.

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

Yes, I think it is justifiable. Some forests are re-cleared before they have reached 20 years, but overall, forests are giving way to croplands. I suppose it is possible that biofuels are being converted from young forests, originally cleared and abandoned from some other activity, but, again, this seems unlikely. Besides, if the MODIS analysis doesn't distinguish between >20-year-old forests and <20-year-old forests, there is no way to assign true age to the forests converted. I think the approach is justifiable.

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

Yes, for a Tier-1 (i.e., consistent global) approach.

Charge Question 2c: If not, what data sources would you recommend?

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing. Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

80 years seems reasonable. It depends on the annual uptake assumed. Does the annual uptake x 80 years add up to a reasonable forest biomass?

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

The EPA study reports that IPCC defaults were used for the forest combustion factor. Values for clearing other cover types (grassland, savanna, shrubland) were from de Castro and Kaufmann (1998). These estimates seem appropriate.

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

The EPA study says that fire was assumed to occur in all of the ten countries they considered in detail except for China and Argentina. The application of global average emissions factors to other countries means that their emissions included those from fire.

Appendix 2 of the Winrock 2009 report lists the countries assumed to use fire to clear for agriculture. No details are given.

Fire seems to be used to estimate the emissions of non-greenhouse gases. The more worrisome aspect to the analysis is that all of the change in carbon stocks as a result of land use change is assumed to occur immediately.

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

I am not aware of studies in addition to those cited by the Winrock study.

Charge Question 2b: Please discuss whether any such data sources and assumptions on current fire clearance are reasonable to project to the future time period used in the analysis.

Projections based on current estimates seem reasonable.

H*. Timing of Emissions from Land Clearing*

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

As mentioned above, it is unreasonable to assume that all of the change in carbon stocks as a result of land use change occurs immediately. Morton et al. show that this is more likely when forests are cleared for soy cultivation than when they are cleared for pasture. Nevertheless, the assumption of immediate emissions seems reasonable for lands cleared for biofuels, not necessarily because it is correct, but because it is very difficult to estimate whether, and for how long, boles will decay before they are burned. There are few data on this topic. The carbon accounting becomes much more complicated if one has to keep track of the stocks of carbon in decaying trees. The effect of such calculations delays immediate emissions from fires but builds up a pool of debris that may become a long-term, but annually significant carbon source after the year of conversion.

Charge Question 1a: If not, how do you suggest improving these estimates?

There are few studies I know of that have documented the relative fractions of woody material that are burned or allowed to decay. Such studies should be carried out in the field, and perhaps a literature review of the topic would suggest patterns.

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Harvested wood products, including long-term storage and retirement, were not considered in the EPA analysis, and this seems reasonable to me. Forests converted to croplands are generally driven by interests unrelated to timber, and thus the trees are simply burned. Exceptions are probably of minor importance.

Charge Question 1a: If not, how do you suggest improving these estimates?

Appendix D

Dr. Lal Response to Charge Questions

General Comments:

In general, it is a very well done report. My main concerns are with regards to:

1. Validation against ground truth.
2. More emphasis on soil carbon.
3. Check data on emission from rice paddies from Japan, Korea, and China (in addition to IRRI).
4. Complement with new literature since IPCC of 2007 was compiled in 2005 and is not all inclusive.

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Yes, as long as it is validated against change in the future population increase and the associated demand.

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Yes, if the future needs for biofuel production are reliable and credible.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Yes, but using other models for validation would be essential.

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

Validation is essential.

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

Yes, some empirical models relating land use change to demands of changing demography, and then extrapolation on the future demographic variables and the demands.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

There are other data sets such as with USDA, FAO, ISRIC, WRI, etc.

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

Yes

Charge Question 1a: What other different data set or sets do you recommend be used?

The other data set is listed in A-6.

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

Yes.

Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

Charge Question 3: Is the accuracy of the MODIS data product accurately characterized?

Yes.

Charge Question 3a: If not, how can the characterization be improved?

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

Other options are extrapolation on the basis of soil type and moisture regime.

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

Yes.

Charge Question 5a: If not, how can the characterization be improved?

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

Yes.

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

Ground truthing and validation.

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

Yes

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

Obtain data from the national institutions.

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

Involve regional and international institutions in providing the soil specific information to validate the data.

II. Estimation of Land Conversion Greenhouse Gas Emissions Factors

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

Yes.

Charge Question 1a: If not, please detail how the analysis can be improved.

Charge Question 1b: What other guidelines should EPA consider in its estimate of land conversion emission factors?

Validate against site-specific data published in the literature.

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

Yes.

Charge Question 2a: If not, what data sources do you recommend?

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

Yes.

B. Forest Carbon Stocks

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Charge Question 1a: If not, how do you suggest improving these estimates?

Forest carbon stocks consist of both above and below ground components. The below ground component also includes soil carbon. It is not clear if the soil carbon component is also included?

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Yes.

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

EMBRAPA has published a book in 2008 by Fabio Gelape Faleiro and Lopes de Farias Neto(Eds) “Savannas” EMBRAPA, Brasilia. Check the data sources listed in it from the world‘s grasslands and savannas.

Charge Question 1ai: What different approach do you recommend?

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

See comments under C-1a.

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

Yes.

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

The C stock of cropland estimated at 5 tC/ha (page 11 para 2) seems to be low. What does it include? If this is biomass only, it is OK. Specify.

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

LULUCF Report by IPCC (2000) has more data sets.

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Charge Question 3a: If not, how do you suggest improving these estimates?

Validate against data from Malaysia, Nigeria, Australia. The data from the Oil Palm Research Institute in Nigeria is a good source to compare with.

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

Yes, but provide more explanation of how the average annual change in carbon stock in top 30cm of soil and the reference are calculated (Eq on the bottom of page 12 and the top of page 13)

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

These estimates are based on one reference (Hoojier et al.,2006). There are numerous other sources of emission from drained peatland. Expand the data base. Should the subsidence rate of peat, corrected for change in bulk density, be another technique to assess peatland emissions?

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

Is the assumption of 20 years valid, because most peatlands are used for much longer periods following drainage and development. The justification for choosing 20 years is needed.

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

Compare with subsidence and bulk density data published in the literature for specific peatlands. The reliance on one reference alone may not suffice.

F. Lost Forest Sequestration

Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

Yes.

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

The justification that a steady state is reached after 20 years is questionable in view of many factors.

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

These data sources can be complemented with the data from the literature and national institutes. In the last but one paragraph on page 14, is the loss in soil carbon pool following clearing also considered? If not, it can cause an error.

Charge Question 2c: If not, what data sources would you recommend?

A thorough literature search to complement the IPCC data. See a book “Carbon Sequestration in Soils of Latin America” 2006, Haworth Press.

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing. Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

Yes

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

The data sources for fire (from Australia, Africa, Brazil) are available to compare and supplement.

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

Yes.

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

Numerous land clearing experiments were done in 1970s and 1980 s in Indonesia (Sumatra Transmigration Scheme), in the Amazon and in West Africa (ORSTOM,and IITA). Comparing these data would be useful.

Charge Question 2b: Please discuss whether any such data sources and assumptions on current fire clearance are reasonable to project to the future time period used in the analysis.

Yes.

H*. Timing of Emissions from Land Clearing*

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

Yes, however, the fire-induced emissions continue for a long time.

Charge Question 1a: If not, how do you suggest improving these estimates?

Review the current literature on fire-induced emissions.

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Yes.

Charge Question 1a: If not, how do you suggest improving these estimates?

Appendix E

Dr. Tullis Response to Charge Questions (Original)

General Comments:

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Yes. Multi-temporal remote sensor data is commonly used by scientists to observe anthropogenic changes to the surface of the earth. Most of these so called remote sensing-assisted land use change detection studies have at least an implied interest in projecting future land use. While few have attempted to do so quantitatively, those that project future land use changes from historical data usually attempt to model a stochastic (rather than deterministic) process so as to arrive at the most *probable* scenario. Many details of the remote sensing process must be carefully considered with the goal to observe spatiotemporal patterns in the developmental cycle of land use change. This activity is most scientifically justifiable when its probability of success (or failure) can be tested; as new remote sensing-assisted observations become available it is possible to test the accuracy of projection methodologies used in the past. This is obviously an ongoing art and science; it is subject to refinements as more is learned about the relationships between the human developmental cycle of land use, scales in space and time, and the application of geographic information science and technology (GIS).

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Yes. However, it is important to note that the ability to quantitatively assess the value of combined *in situ*, remote sensor and ancillary data and models is constrained by discontinuities in spatial and temporal scales. Insufficient knowledge about how these scales affect combined model predictions is available. For example, country-scale estimates may not easily take into account the spatial patterns of within-country biofuel production; this could be considered an "ecological fallacy" since biofuel production is likely affected by soils, minerals, geomorphology, and climate – all which often vary at the sub-country scale. In the most scientifically justifiable approach to combining these disparate models, uncertainties in spatial and temporal scale discontinuities should be minimized and monitored over time as the modeling process evolves.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Unfortunately, the kind of remote sensor data for providing the most reasonable basis of projected changes in biofuel production may be cost ineffective at the international scale. The reason is that the remote sensor data itself might need to be used to monitor specific types of biofuel production and not simply agricultural expansion. In short, I am not convinced that the relationship between the biofuel production and agricultural expansion should be simply assumed (e.g. as highly correlated in their spatial distributions). If plans include efforts to mitigate this uncertainty then the overall strategy seems reasonable.

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

This answer is closely related to that of Question 3 above. The difference is that the decision making process about where to expand agriculture specifically for biofuel may change significantly over the biofuel lifecycle; again, if this uncertainty can be minimized then the overall strategy seems reasonable.

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

I feel the analysis could significantly benefit from the development of a spatial decision support system (SDSS); there are many varieties of these and EPA has certainly built some of them. It is clear that most of the data being analyzed in this specific study can be indexed in time and space (managed using GIS). However, the goal of minimizing all of the assumptions underlying the predicted emissions may be difficult or costly to achieve, especially within the timeframe of interest to EPA. Spatial and temporal scales are a major factor in these assumptions. As described in the SDSS literature, the unstructured nature of the problem is accepted while at the same time a focus is given to the support of the immediate decision maker.

This strategy is not new to EPA (and perhaps one or more SDSSs are related to this current investigation). I only mention it here since I didn't find it highlighted in the materials provided, and SDSS approaches seem to be most successful when they tightly integrate any remote sensor or GIS data processing. The only way to integrate such processing (that I know of) is through a single scalable computing environment. Costly as this may be, it could be more costly keep the models loosely coupled since the data to decision making path is easier to manage when it is tightly integrated.

For example an SDSS built within a single computing environment could assemble expert rules to spatially model the *suitability* of new agriculture for biofuel. The uncertainty about the transportability of such a "suitability model" from one country or region to the next requires decisions that collaborating experts familiar with the data could make. They would have to have access to the data and not simply to a description of that data; that is where the multi-user SDSS can provide more powerful feedback from experts so that the final decision (e.g. a threshold set by the EPA Administrator) more robustly addresses the inevitable uncertainties that cannot be mathematically modeled. In a complete circle, individual countries may find the *suitability* model of decision making value when attempting to stimulate biofuel production.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

In the SDSS strategy (outlined above in the answer to Question 5), all spatial data that can be legally accessed is potentially available. This leads to an overwhelming set of choices and so the question is well founded. However, the SDSS itself can help to identify which datasets will be most valuable and suggest new ones that may be needed. I imagine topographic effects would come into play (slope, aspect, elevation) and so datasets such as a 90 x 90 m DEM derived from the Shuttle Radar Topography Mission (SRTM) would likely be useful (e.g. for the suitability model mentioned previously).

Transportation network data is already part of the world's emerging spatial data infrastructure. Therefore, as far as new data collection, I would imagine that the deployment of GPS receivers on trucks involved in biofuel activities is not out of the question as long as the data were used ethically. Such data would dramatically reduce uncertainties identified in this analysis even if only a representative sample of trucks could be sampled. The cost of these sensors has dropped significantly.

As far as the use of land use change data, I would continue to rely on global products such as those derived from MODIS due to its high level of calibration and consistency. I don't see the need to increase nominal spatial resolution beyond the 500 x 500 m scale for the overall assessment of land conversion. The main reason is that frequent observations are necessary in the tropics where cloud cover is ubiquitous. A secondary reason is that higher spatial resolutions allow more complex schemas but not necessarily greater spatial accuracy at the country / regional scale of analysis. I would make sure to continue to monitor the effects of spatial scale using the SDSS framework suggested.

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

Yes. At the time the research was begun, I would have to agree with Winrock that the MOD12Q1 version 4 dataset was the best choice even though it had a nominal spatial resolution of only 1 x 1 km. I would now recommend using the MCD12Q1 version 5 with a nominal spatial resolution of 500 x 500 m.

Charge Question 1a: What other different data set or sets do you recommend be used?

According to the Summary of EPA use of the Winrock results (excerpted from Draft Regulatory Impact Analysis, Chapter 2), the MODIS-derived land cover dataset selected was the MOD12Q1 version 4 with a nominal spatial resolution of 1 x 1 km. According to the April 2009 Report to EPA, Winrock also examined [MCD12Q1] version 5 which has a nominal spatial resolution of 500 x 500 m and found that most of the percentages changed very little with some notable exceptions. These included shrubland conversion to savanna and grassland.

Given that there were some notable differences, how does one determine whether to use version 4 or version 5 (for years when both are available)? This is not an easy question to answer since "accuracy" assessed at both these measurement scales may be difficult to compare. The most frequent spatial resolution for land cover analysis in the literature is based on the nominal 30 x 30 m specification associated with the Landsat program. Jensen's (2007) text *Remote Sensing of the Environment: An Earth Resource Perspective* indicates that the MODIS 500 x 500 m data is a candidate for land cover monitoring but doesn't mention using 1 x 1 km data for the same process. As of March 13, 2009, the USGS is apparently no longer providing access to the earlier version 4 (1 x 1 km) dataset through their Land Processes Distributed Active Archive Center:

https://lpdaac.usgs.gov/lpdaac/about/news_archive/friday_march_13_2009_lp_daac_retires_modis_version_004_data_collections

Increased temporal resolution is available for some year in the 500 x 500 m product because it is developed using both the Terra and Aqua satellites (instead of just Terra). This provides significant benefit in areas where cloud cover is ubiquitous. Higher spatial resolutions (e.g. 30 x 30 m) are most frequently cited in the literature in cases where *in situ* data were compared to remote sensing-derived products. Future changes in the spatial resolution of MODIS-derived land cover products is not likely since the 250 x 250 m data collected by MODIS only covers two spectral bands.

Given these considerations, I feel that the version 5 would be a better option going forward. This is not a major change in direction since Winrock has already taken steps to test the sensitivity of the analysis to version 5 (instead of version 4). I would recommend using MCD12Q1 version 5 (see discussion above):

https://lpdaac.usgs.gov/lpdaac/products/modis_products_table/land_cover/yearly_l3_global_500m/v5/combined

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

The Summary of EPA use of the Winrock results indicates that the 17 IGBP land cover classes were reclassified into 5 (not 6) general classes, including cropland, forest, grassland, savanna, and shrubland (pp. 4-5). I didn't find a justification for the classes that were selected although they are very similar to general categories recommended by IPCC (2003). As far as the mechanical details of the reclassification that was performed, it seems to me that this was done correctly.

Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

Other studies interested in assessing land cover change for greenhouse gas monitoring purposes using MODIS (e.g. Tullis et al., 2007) have used a 6 category schema recommended by IPCC (2003). It is very similar to the general categories used by Winrock and includes forest, grassland, cropland, water, settlement, and other. It would be useful to have a justification for the five categories Winrock used since there is a difference.

Charge Question 3: Is the accuracy of the MODIS data product accurately characterized?

Yes. I had difficulty accessing the website reported in the summary document but found one with similar numbers here:

http://www-modis.bu.edu/landcover/userguidelc/consistent.htm

Charge Question 3a: If not, how can the characterization be improved?

n/a

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

The Winrock team used global MODIS imagery at nominal spatial resolution of 1 x 1 km; this data would be less suitable for very small countries; some of this could be mitigated if future studies could transition to the 500 x 500 m measurement scale. Also, I didn't find a discussion on the influence of clouds, particularly in tropical regions. I am not aware of other "missing data" issues (besides those related to atmospheric attenuation) that need to be addressed with global MODIS imagery.

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

Essentially the Winrock team analyzed change detection matrices (also known in the literature as post classification change detection). This is the best choice given the limitations of today's remote sensing at the geographic scale. Also, I was pleased to see that the team focused on developing percentages of change in different categories rather than trying to make a direct observation of absolute change.

Charge Question 5a: If not, how can the characterization be improved?

n/a

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

It appears that Winrock used regional-scale averages in various categories of percent land use change to spatially distribute biofuel changes predicted by FAPRI. The underlying assumption here is that changes in biofuel production are highly correlated with agricultural expansion throughout the study area, and this may not be the case. A more robust approach would additionally attempt to predict the suitability of sites for biofuel production. However, the cost of this approach would be substantial using current technology. Therefore I agree with the strategy Winrock used at this time as long as efforts to improve the remote sensing-assisted monitoring of biofuel production continue.

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

n/a

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

If not already considered, I recommend finding a way to test the sensitivity of observed distributions of biofuel production in future scenarios and, if necessary, to account for that distribution in future estimates.

I recommend changing to the 500 x 500 m MODIS-derived land cover product (version 5 in the same series). While it is difficult to prove that this dataset is more accurate without further research, it will be more comparable to other remote sensor data going forward in terms of its measurement scale.

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

Yes.

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

I would recommend that selected areas where significant expansion of biofuel production is occurring be scrutinized with higher spatial resolution remote sensor data. If possible I would choose ASTER since it is the highest spatial resolution sensor on Terra and would allow easy comparison with MODIS. The goal would be to test the effects of spatial resolution in remote sensing derivatives related to biofuel production. How much of an effect does it have? It is not necessary for land cover maps to be generated. Simple unsupervised clusters could be used to analyze these effects to make sure they are not dramatically limiting the ability of EPA to monitor activities related to biofuel production at the 500 x 500 m measurement scale.

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

This is a major challenge for any organization that is serious about multi-scale remote sensing. The remote sensing process is too sensitive to loosely couple disparate methodologies. Those who work to integrate EPA's data should be given the resources to address the emerging problem of spatial scale (and temporal scale) management. This is an area of research directly applicable to moving between local, regional, and global analyses. Tullis and Defibaugh y Chavez (2009) detail a research agenda for spatial scale management in forest monitoring. Essentially, questions about spatial scale need to be tightly integrated in the computational aspects of the remote sensing process. Efforts to coordinate this type of work using emerging GIS modeling capabilities that are supported by cloud computing environments hold significant promise. The goal is to computationally find the cheapest way to integrate sensors at various spatial (and temporal) resolutions so that the necessary decisions are best supported. This is a dramatic departure from desktop-based GIS analysis. EPA may want to consider coordinating with other agencies on trying to solve this scale problem in remote sensing.

II. Estimation of Land Conversion Greenhouse Gas Emissions Factors

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

B. Forest Carbon Stocks

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Charge Question 1a: If not, how do you suggest improving these estimates?

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

Charge Question 1ai: What different approach do you recommend?

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Charge Question 3a: If not, how do you suggest improving these estimates?

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

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Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

Charge Question 2c: If not, what data sources would you recommend?

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing? Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

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H*. Timing of Emissions from Land Clearing*

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Charge Question 1a: If not, how do you suggest improving these estimates?

Appendix F

Dr. Tullis Response to Charge Questions (Revised)

General Comments:

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Yes. Multi-temporal remote sensor data is commonly used by scientists to observe anthropogenic changes to the surface of the earth. Most of these so called remote sensing-assisted land use change detection studies have at least an implied interest in projecting future land use. While few have attempted to do so quantitatively, those that project future land use changes from historical data usually attempt to model a stochastic (rather than deterministic) process so as to arrive at the most *probable* scenario. Many details of the remote sensing process must be carefully considered with the goal to observe spatiotemporal patterns in the developmental cycle of land use change. This activity is most scientifically justifiable when its probability of success (or failure) can be tested; as new remote sensing-assisted observations become available it is possible to test the accuracy of projection methodologies used in the past. This is obviously an ongoing art and science; it is subject to refinements as more is learned about the relationships between the human developmental cycle of land use, scales in space and time, and the application of geographic information science and technology (GIS).

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Yes. However, it is important to note that the ability to quantitatively assess the value of combined *in situ*, remote sensor and ancillary data and models is constrained by discontinuities in spatial and temporal scales. Insufficient knowledge about how these scales affect combined model predictions is available. For example, country-scale estimates may not easily take into account the spatial patterns of within-country biofuel production and indirectly related land use changes; this could be considered an "ecological fallacy" since these activities are likely affected by such factors as soils, minerals, geomorphology, climate, and socioeconomics – all which often vary at the sub-country scale. In the most scientifically justifiable approach to combining these disparate models, uncertainties in spatial and temporal scale discontinuities should be minimized and monitored over time as the modeling process evolves.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Unfortunately, the kind of remote sensor data for providing the most reasonable basis of projected changes in biofuel production may be cost ineffective at the international scale. The reason is that the proper use of agricultural sector models may require that the remote sensor data itself be used to monitor specific types of biofuel production and not simply agricultural expansion. In short, I am not convinced that the relationship between direct biofuel production and agricultural expansion should be simply assumed (e.g. as highly correlated in their spatial distributions). This in turn affects the reliability of modeled estimates of indirect land use change that depend on direct biofuel production monitoring. If plans include efforts to mitigate this uncertainty then the overall strategy seems reasonable.

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

This answer is closely related to that of Question 2 and 3 above. Agricultural sector models combined with remote sensor products that don't take into account specific types of biofuel changes will me more susceptible to uncertainties in spatial scale as mentioned previously. Even if agricultural sector models robustly take into account the aggregate human decision making process throughout the biofuel lifecycle, it seems to me that historical type-specific biofuel production will still be a critical observable (one that would be difficult to replicate without a remote sensing-assisted spatial decision support system or SDSS). If this uncertainty can be minimized in the future then the overall strategy seems reasonable.

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

I feel the analysis could significantly benefit from the development of an SDSS; there are many varieties of these and EPA has certainly built some of them. It is clear that most of the data being analyzed in this specific study can be indexed in time and space (managed using GIS). However, the goal of minimizing all of the assumptions underlying the predicted emissions may be difficult or costly to achieve, especially within the timeframe of interest to EPA. Spatial and temporal scales are a major factor in these assumptions. As described in the SDSS literature, the unstructured nature of the problem is accepted while at the same time a focus is given to the support of the immediate decision maker.

This strategy is not new to EPA (and perhaps one or more SDSSs are related to this current investigation). I only mention it here since I didn't find it highlighted in the materials provided, and SDSS approaches seem to be most successful when they tightly integrate any remote sensor or GIS data processing. The only way to integrate such processing (that I know of) is through a single scalable computing environment. Costly as this may be, it could be more costly keep the models loosely coupled since the data to decision making path is easier to manage when it is tightly integrated.

When combining remote sensing with agricultural sector models it is vital to manage the provenance of any given decision support product so that assumptions can be more clearly identified and expert decisions made. For example, it is clear that the traditional remote sensing process cannot be used to identify indirect land use changes associated with biofuel production. The assumption is that the agricultural sector model will be able to predict those indirect changes based on detailed land use (and other information) in conjunction with remote sensing. The role of the remote sensing-assisted SDSS is to construct better linkages between the two by drawing on expert knowledge in a systematic way.

For example an SDSS built within a single computing environment could assemble expert rules to spatially model the *suitability* of new agriculture for biofuel production. If agricultural sector models (for estimating indirect land use changes) begin to rely more heavily on spatial data, then the SDSS could additionally be used to assess the *suitability* of those indirect changes. In either case, the uncertainty about the transportability of such a "suitability model" from one country or region to the next requires decisions that only collaborating experts familiar with the data could make. They would have to have access to the data and not simply to a description of that data; that is where the multi-user SDSS can provide more powerful feedback from experts so that the final decision (e.g. a threshold set by the EPA Administrator) more robustly addresses the inevitable uncertainties that cannot be mathematically modeled. In a complete circle, individual countries may find the *suitability* model of decision making value when attempting to stimulate biofuel production.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

In the SDSS strategy (outlined above in the answer to Question 5), all spatial data that can be legally accessed is potentially available. This leads to an overwhelming set of choices and so the question is well founded. However, the SDSS itself can help to identify which datasets will be most valuable and suggest new ones that may be needed. For example, I imagine topographic effects would come into play (slope, aspect, elevation) and so datasets such as a 90 x 90 m DEM derived from the Shuttle Radar Topography Mission (SRTM) would likely be useful (e.g. for the suitability model mentioned previously). Actually how to use the DEM would depend on whether the SDSS is being used to garner direct or indirect data on biofuel production.

Transportation network data is already part of the world's emerging spatial data infrastructure. As an example of new data collection on direct biofuel production which could also have implications for better understanding indirect activities, I would imagine that the deployment of fully-automated GPS receivers on selected trucks involved in biofuel activities is not out of the question as long as the data are used ethically. Such data would dramatically reduce spatial uncertainties identified in this analysis (particularly in direct biofuel production) even if only a random subset of trucks could be sampled within a country. The cost of these sensors has dropped significantly. I am approaching this suggestion from a technical angle. Obviously this sort of monitoring would require political support in any country where it is implemented, and this may not be very likely in some countries.

As far as the use of land use change data, I would continue to rely on global products such as those derived from MODIS due to its high level of calibration and consistency. I don't see the need to increase nominal spatial resolution beyond the 500 x 500 m scale for the overall assessment of land conversion. The main reason is that frequent observations are necessary in the tropics where cloud cover is ubiquitous. A secondary reason is that higher spatial resolutions allow more complex schemas but not necessarily greater spatial accuracy at the country / regional scale of analysis. I would make sure to continue to monitor the effects of spatial scale using the SDSS framework suggested.

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

Yes. At the time the research was begun, I would have to agree with Winrock that the MOD12Q1 version 4 dataset was the best choice even though it had a nominal spatial resolution of only 1 x 1 km. I would now recommend using the MCD12Q1 version 5 with a nominal spatial resolution of 500 x 500 m.

Charge Question 1a: What other different data set or sets do you recommend be used?

According to the Summary of EPA use of the Winrock results (excerpted from Draft Regulatory Impact Analysis, Chapter 2), the MODIS-derived land cover dataset selected was the MOD12Q1 version 4 with a nominal spatial resolution of 1 x 1 km. According to the April 2009 Report to EPA, Winrock also examined [MCD12Q1] version 5 which has a nominal spatial resolution of 500 x 500 m and found that most of the percentages changed very little with some notable exceptions. These included shrubland conversion to savanna and grassland.

Given that there were some notable differences, how does one determine whether to use version 4 or version 5 (for years when both are available)? This is not an easy question to answer since "accuracy" assessed at both these measurement scales may be difficult to compare. The most frequent spatial resolution for land cover analysis in the literature is based on the nominal 30 x 30 m specification associated with the Landsat program. Jensen's (2007) text *Remote Sensing of the Environment: An Earth Resource Perspective* indicates that the MODIS 500 x 500 m data is a candidate for land cover monitoring but doesn't mention using 1 x 1 km data for the same process. As of March 13, 2009, the USGS is apparently no longer providing access to the earlier version 4 (1 x 1 km) dataset through their Land Processes Distributed Active Archive Center:

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This provides significant benefit in areas where cloud cover is ubiquitous. Higher spatial resolutions (e.g. 30 x 30 m) are most frequently cited in the literature in cases where *in situ* data were compared to remote sensing-derived products. Future changes in the spatial resolution of MODIS-derived land cover products is not likely since the 250 x 250 m data collected by MODIS only covers two spectral bands.

Given these considerations, I feel that the version 5 would be a better option going forward. This is not a major change in direction since Winrock has already taken steps to test the sensitivity of the analysis to version 5 (instead of version 4). I would recommend using MCD12Q1 version 5 (see discussion above):

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Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

Other studies interested in assessing land cover change for greenhouse gas monitoring purposes using MODIS (e.g. Tullis et al., 2007) have used a 6 category schema recommended by IPCC (2003). It is very similar to the general categories used by Winrock and includes forest, grassland, cropland, water, settlement, and other. It would be useful to have a justification for the five categories Winrock used since there is a difference.

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Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

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C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

If not already considered, I recommend finding a way to test the sensitivity of observed distributions of direct biofuel production in future scenarios and, if necessary, to account for that distribution in future estimates. In other words, future estimates should be compatible with the most recent changes in the landscape (now in 2009) and not simply land use changes from several years ago. This probably requires an SDSS framework as described above. By following this path, a greater burden is placed on remote sensing-derived products. As all observed land use changes across the globe continue to be monitored in this way, the reliability of methods for measuring both direct and indirect effects of biofuel production will benefit from ongoing comparison with real observations

I recommend changing to the 500 x 500 m MODIS-derived land cover product (version 5 in the same series). While it is difficult to prove that this dataset is more accurate without further research, it will be more comparable to other remote sensor data going forward in terms of its measurement scale.

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I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Charge Question 1a: If not, how do you suggest improving these estimates?

Appendix G

Dr. Wardlow Response to Charge Questions

General Comments:

None.

I. Use of Remote Sensing Data to Evaluate Land Use Change

A. General Application of Remote Sensing Data

Charge Question 1: Is it scientifically justifiable to use historic remote sensing data to evaluate and project the pattern of future land use change?

Yes, the use of satellite-based remotely sensed data from a global imager such as the Moderate Resolution Imaging Spectroradiometer (MODIS) is scientifically justifiable given the synoptic, spatially continuous coverage of the Earth's land surface it provides. The MODIS instrument is the appropriate data source for detecting broad-scale land use/land cover (LULC) changes over large geographic areas in the recent past (2001 to present). LULC changes occurring at a localized scale will often not be resolvable at the 1-km spatial resolution used in this study. The MODIS 250-meter spectral bands were added to the instrument to assist in detecting human-induced LULC changes, which were found to occur at or near this spatial scale (Townshend and Justice, 1988). The appropriate spatial resolution is highly dependent on the objective of a specific study and the 1-km resolution is likely adequate for estimating large-scale changes in LULC patterns and greenhouse gas (GHG) emissions. The 1-km MODIS land cover product provides sufficient resolution for most major LULC changes that would have the greatest influence on GHG emissions, but higher resolution data such as the MODIS 500-m or 250-meter observations would provide an improved spatial representation of these changes across the landscape. The MODIS 500-meter land cover product (MCD12Q1) that was tested by Winrock (April 2009 report) and found to provide the same overall trends in land use patterns as those obtained from the 1-km data. Although this may be true, the 500-m data set many contained much less area of the 'mixed' class, which could be problematic in GHG emission estimates because the class represents a composite of multiple land cover types. This consideration was not reported in the documentation, but might be worthwhile revisiting particularly for regions that have large areal extents of the 'cropland/natural vegetation mosaic' class in the original IGBP classification. A real gain may be achieved using the MODIS 250-meter observations if crop-specific or more thematic detailed land cover conversions (beyond the 6 class map used in this study) are needed for future modeling scenarios. The 250-meter data would also be useful in areas with highly fragmented landscapes where multiple land cover types are contained within the 1-km footprint of each MODIS pixel. The detection of LULC changes occurring before 2001 would require the application of the Advanced Very High Resolution Radiometer (AVHRR) data, which provides observations dating back to the late-1980s.

The use of such data is scientifically justifiable to project the pattern of future land use change if the observed trend in changes between the 2001 and 2004 study years is assumed to be representative of future LULC change trends globally. If a more recent MODIS global land cover map is available (circa 2008 or 2009) in the near future, applying the same LULC change detection technique might be helpful to ensure the trends observed between 2001 and 2004 are representative on those occurring over a longer 8 or 9 year period. Currently, the most recent MODIS land cover product (MCD12Q1) available is for 2005.

Charge Question 2: Is it scientifically justifiable to use the remote sensing data in conjunction with projected land use change from agricultural sector models to estimate land use change emissions associated with biofuel production?

Yes, it is scientifically justifiable to use the remote sensing data for this purpose. However, the estimates of land use change emissions associated with biofuel production will be dependent of the thematic detail of the LULC maps derived from the remote sensing information. The six class map used in this study provides very general information about cropland areas, which are treated as a single homogeneous area (i.e., cropland), when in reality they are comprised of a mosaic of different crop types and management practices. This could generalize some of the GHG estimates in certain parts of the world. The development of a crop type classification for certain countries or regions is possible using MODIS data and observations from other instruments (e.g., Landsat Enhanced Thematic Mapper (ETM+), SPOT, and) Advanced Wide Field Sensor (AWiFS)), but would require a substantial commitment in terms of time and resources that may not be justifiable for this specific study.

Charge Question 3: Given the range of factors that affect land use decisions, does remote sensing data provide a reasonable basis for projecting the pattern of land use change (e.g., the biomes affected by agricultural expansion) caused specifically by biofuel production?

Remote sensing provides the best available means for acquiring global-scale, geographically explicit information related to LULC patterns and changes given the synoptic and spatially-continuous spectral observations provided by sensors such as MODIS. However, like any other data source, remote sensing has its limitations in characterizing specific land use practices and/or changes if they do not result in a detectable change in the spectral-temporal signature that is observed by space-borne sensor. In general, moderate-resolution remote sensing is appropriate for detecting changes associated with broad-scale land use decisions but is limited or not applicable for very localized-scale changes. In addition, certain land use changes such as conversion from forest to cropland are easier to discern than changes such as shrubland to grassland conversion, which has a less distinct spectral change. Overall, remote sensing does provide a reasonable, globally-consistent basis for providing initial information for projecting land use change but the specific changes that can be projected will be dependent on the thematic detail of the 1-km land cover classification scheme used in this study. For example, projections of forest to cropland conversion will be possible based on this data set but a projection for forest to corn (maize) will not.

Charge Question 4: Given the range of factors involved with land use change, is it scientifically justifiable to use the remote sensing data to estimate a specific land use change value that would be applied to a biofuels overall lifecycle GHG impact?

Yes, it is scientifically justifiable to use remote sensing data to estimate certain types of land use change values depending on what those values represent. For example, if the values only reflect the change from land cover class 1 to class 2, then remote sensing is sufficient for providing this general information. Remote sensing can also be used to get global estimates of specific aboveground biophysical measures of vegetation (e.g., leaf area index and gross primary productivity) that are relevant to GHG lifecycles. Several of these parameters are available as gridded, 1-km MODIS global data products.

Charge Question 5: Are there other methods, besides or in addition to the use of remote sensing data, which would be more scientifically justifiable for this analysis?

Remotely sensed data products such as the MODIS Land Cover Type product (MCD12Q1) provide the best, globally consistent information that is currently available for documenting LULC change worldwide. Better national and/or sub-national land cover data sets derived from other high resolution remote sensing data may exist, but present several potential issues that would limit their utility for this study, which include:

1) Lack of multiple land cover classifications over the targeted study period,
2) Lack of a consistent LULC classification scheme, such as the IGBP scheme used in the MODIS products, which would make it difficult to aggregate these numerous data sets into a consistent classification scheme that could be implemented globally,
3) Different data inputs and classification algorithms would likely be used to generate each nation's and/or region's LULC maps, which could lead to inconsistencies from location to location in the LULC change information when different LULC data sets are used.

Charge Question 6: If EPA continues to use remote sensing data, are there any other sources of data, besides remote sensing data, or analysis of land use change patterns that could be used to supplement the remote sensing data?

To the best of my knowledge, there are no other data sources beyond remote sensing that could be used. If data sets do exist, they should be globally available or comparable data sets should be available throughout the world in order to provide consistent inputs for land use change detection.

Simple thematic differencing between land cover maps generated for two specific dates, as conducted in this study, provides the best approach for detecting and analyzing land use pattern changes globally. Other change detection techniques exist (e.g., spectral change analysis and principal component analysis), but are not well suited for global applications given the immense spectral-temporal variability in a specific LULC type throughout the world and the requirement to identify the specific LULC types after a change has been detected, which can be problematic even over a small geographic area.

B. Selection and Application of Remote Sensing Data

Charge Question 1: Given the goals of this analysis, was the most scientifically justifiable remote sensing data set selected?

Yes, the most scientifically justifiable global land cover maps were selected for this study. The MODIS 1-km land cover products (MCD12Q1) representative data sets that have been produced globally using a consistent set of data inputs, algorithms, and classification scheme that allow the maps for the two study years to be directly compared.

Charge Question 1a: What other different data set or sets do you recommend be used?

Although, as reported in the Winrock document, the 500-meter MODIS land cover product was tested against the 1-km product and similar overall trends in land use patterns were found, the higher resolution maps may be appropriate for certain parts of the world with more highly fragmented landscapes. Also, the 500-meter land cover data should contain less area of the 'mixed' class (e.g., 'cropland/natural vegetation mosaic'), which would provide more thematically accurate LULC change information for modeling purposes.

If the classification of specific crop types and/or cropping practices would be of interest to this study, then the use of time-series MODIS 250-meter data is recommended over targeted areas of importance. The development of a seamless, crop type map over all global cropland areas would be difficult and resource intensive, but the development of maps over selected regions or countries to better refine GHG emission estimates and LULC change projections may be feasible. Many authors have demonstrated the potential of MODIS 250-meter data for classifying crops such as corn (maize), soybeans, sorghum, and rice (Lobell and Anser, 2004; Chang et al., 2007; Wardlow and Egbert, 2008), as well as, crop rotation mapping (Morton et al., 2006; Sakamoto et al., 2006; Brown et al., 2007; Galford et al., 2008). The ability to capture 'vertical' intensification (i.e., multiple crops planted on field in same year) should be considered in addition to 'vertical' crop intensification (i.e., land cover conversion to add new cropland areas) in countries such as Brazil that can double and sometimes triple crop the same field with corn and/or soybeans in a single year. MODIS 250-meter data holds the potential to identifying such cropping sequences in some parts of the world (Morton et al., 2006; Sakamoto et al., 2006; Brown et al., 2007; Galford et al., 2008).

References:

Brown, J.C., W.E. Jepson, J.H. Kastens, B.D. Wardlow, J. Lomas and K.P. Price, 2007, Multi-temporal, moderate spatial resolution remote sensing of modern agricultural production and land modification in the Brazilian Amazon, *GIScience and Remote Sensing* **44** (2) pp. 117–148.

Chang, J., M.C. Hansen, K. Pittman, M. Carroll, and C. DiMiceli, 2007. Corn and soybean mapping in the United States using MODIS time-series data sets. *Agronomy Journal*, 99:1654-1664.

Galford G.L., Mustard J.F., Melillo J., Gendrin A., Cerri C.C., Cerri C.E.P., 2008, Wavelet analysis of MODIS time series to detect expansion and intensification of row-crop agriculture in Brazil. *Remote Sensing of Environment*, 112 (2), pp. 576-587.

Lobell, D. B. and G. P. Asner, 2004, "Cropland Distributions from Temporal Unmixing of MODIS Data," Remote Sensing of Environment, 93:412-422.

Morton, D. C., DeFries, R. S., Shimabukuro, Y. E., Anderson, L. O., Arai, E., del Bon Espirito-Santo, F., Freitas, R., and Morisette, J., 2006, "Cropland Expansion Changes Deforestation Dynamics in the Southern Brazilian Amazon," *Proceedings of the National Academy of Sciences of the USA*103:39, 14,637-14,641.

Sakamoto, T., N.V. Nguyen, H. Ohno, N. Ishitsuka and M. Yokozawa, Spatio-temporal distribution of rice phenology and cropping systems in the Mekong Delta with special reference to the seasonal water flow of the Mekong and Bassac rivers, *Remote Sensing of Environment* **100** (2006), pp. 1–16.

Wardlow B.D., Egbert S.L., 2008, Large-area crop mapping using time-series MODIS 250 m NDVI data: An assessment for the U.S. Central Great Plains. *Remote Sensing of Environment*, 112 (3), pp. 1096-1116.

Charge Question 2: Was the MODIS data set properly reclassified from 17 IGBP land cover classes into 6 general land cover classes for use in land cover change analysis?

Yes, the generalized IGBP classification was properly reclassified for this study in the 6 class map. However, the ‘Mixed’ class needs better clarification in the written documentation. What original IGBP classes comprise this class? Is it just the ‘cropland/natural vegetation mosaic’ or does it also include wetlands? Also, there is an inconsistency between the reclassified map legends and the written text for the ‘Mixed’ class. The maps show an ‘Other’ class, which I assume is actually the ‘Mixed’ class that was referenced.

Charge Question 2a: If not, what different classification scheme or schemes do you recommend?

A different classification scheme is not recommended.

Charge Question 3: Is the accuracy of the MODIS data product accurately characterized?

Yes, the MODIS land cover data product is accurately characterized based on the validation information the MODIS Land Science team has provided for this data set. However, some ‘spot checking’ of the accuracy for specific LULC changes might be helpful to supplement the MODIS Science teams accuracy values. Inherently, some LULC types (e.g., grassland vs. shrubland) and certain locations (e.g., highly fragmented landscapes) are more difficult to classify for various reasons, which can lead to misclassification in one or both maps and false LULC change detections in the change product derived for this study. A cursory check of potentially problematic areas using high resolution satellite imagery (e.g., MODIS 250-meter data, Landsat ETM+, and/or SPOT) to verify specific LULC changes and/or trends would be helpful in further characterizing the strengths and limitations of the LULC change data that forms the basis of the GHG emission estimates and future LULC change projections. Any supporting evidence whether it is ground truth observations, reports, and/or high resolution imagery to highlight potential errors either regionally or thematically would be helpful in understanding the possible uncertainty they could introduce into the GHG emission estimates and change projections.

Charge Question 3a: If not, how can the characterization be improved?

Suggestions for addition characterizations listed in previous paragraph.

Charge Question 4: Does the expanded geographic coverage in the Winrock April, 2009 report adequately address / eliminate the need to extrapolate land use changes from similar geographic areas to areas missing coverage?

The expansion of the geographic coverage of the Winrock analysis did address the need to extrapolate land use changes from similar geographic areas to areas with missing coverage.

Charge Question 5: Was the reclassified MODIS data set used in a scientifically objective and justifiable manner to assess the pattern of land use changes during the 2001-2004 time period?

Yes, the reclassified MODIS data set was used in a scientifically objective and justifiable manner to assess the pattern of land use changes from 2001 to 2004. The aggregation of original IGBP classes was logical and typical of other studies that have generalized global land cover data sets for various applications.

Charge Question 5a: If not, how can the characterization be improved?

No improvements are suggested.

Charge Question 6: Did EPA apply the MODIS data in the best possible way to evaluate the pattern of biofuel-induced land use change?

The EPA evaluated the pattern of biofuel-induced land use changes in the best possible way given the data resources available globally. However, given more time and resources, improvements might be gained by mapping specific crop types and/or rotations for specific areas of interest using MODIS 250-meter data or other high resolution imagery to gain information about both 'where' cropland is expanding and 'what' is being grown there. With the emphasis on biofuels and land cover conversion to cropland, the addition of this information could improve insights into future GHG emissions and land use changes.

Charge Question 6a: What specific changes to EPA's application of the data do you recommend?

No recommendations for specific changes to the EPA's application of the data are made. A few suggestions for possible additions, given adequate time resources, have been discussed above.

C. Recommendations for Further Analysis

Charge Question 1: Going forward, what major changes, if any, do you recommend to improve the use of remote sensing data in this analysis?

Three recommendations (as discussed earlier) that might augment the existing LULC change products, would include:

1. Crop type or crop rotation mapping using higher resolution satellite imagery for targeted areas of interest.
2. Use of higher resolution satellite imagery and other geospatial information to further assess the accuracy of specific LULC conversions and trends revealed in the 2001 to 2004 analysis.
3. Conduct the land cover change analysis using a more recent MODIS Land Cover data set (such as 2008, if one becomes available) and the 2001 product to check the rates of change between the current 2001 to 2004 study period are maintained over a longer period of time (i.e., 8 or 9 years).

Charge Question 2: Do you recommend augmenting the current global analysis with higher resolution analyses of regions where agricultural expansion is likely to be most intense?

Yes, the use of higher resolution imagery over these regions would be recommended as discussed earlier.

Charge Question 2a: If so, what data sets and methods for higher-resolution analyses do you recommend?

Time series MODIS 250-meter data are the most widely available and cost effective data source available for additional national and/or regional scale work. Landsat ETM+ imagery would also be helpful to supplement the coarse MODIS 250-meter observations. A simple differencing between two independently derived maps (for 2001 and 2004, respectively) from the MODIS 250-meter data would be recommended.

Charge Question 2b: How should EPA integrate regional analyses into a globally consistent evaluation of land use change?

A consistent, classification and change detection methodology should be implemented globally over the targeted areas and the higher resolution LULC change results can be directly integrated with the coarser LULC change information (by aggregating the 250-meter information to the 1-km resolution) for the surrounding areas. The contribution of higher resolution LULC change products should can serve one of three roles: 1) resolve LULC change patterns that could not be identified at the 1-km resolution, 2) reduce the spatial extent of the ‘mixed’ class in the 1-km product, and 3) enable the identification of specific land cover types (e.g., crop types) and conversions that were not part of the IGBP classification scheme.

II. Estimation of Land Conversion Greenhouse Gas Emissions Factors

A. Overall Methods and Application of Data Sources

Charge Question 1: Were IPCC guidelines followed appropriately for estimation of land conversion emissions factors?

To the best of my knowledge, the IPCC guidelines were appropriately followed for the estimation of land conversion emission factors.

Charge Question 1a: If not, please detail how the analysis can be improved.

No recommendation for this point.

Charge Question 1b: What other guidelines should EPA consider in its estimate of land conversion emission factors?

No other guidelines are recommended.

Charge Question 2: Were emissions factors estimated using the best available data sources given the geographical scale and scope of the study?

Based on the data sets that I am aware of, the best available data sources that are either global, regional, or national in coverage were used to estimate emission factors in this study.

Charge Question 2a: If not, what data sources do you recommend?

No new data sources recommended.

Charge Question 3: Overall, were the data sources and works cited appropriately applied?

Yes, the data sources and works were appropriately applied for the objectives of this study.

B. Forest Carbon Stocks

Charge Question 1: Were forest carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Yes, to the best of my knowledge, the forest carbon stocks were estimated appropriately with the best available data and the IPCC guidelines were appropriately applied for the study's purposes.

Charge Question 1a: If not, how do you suggest improving these estimates?

No suggested improvements.

C. Grassland, Savanna and Shrubland Biomass Carbon Stocks

Charge Question 1: Were grassland, savanna and shrubland carbon stocks in each region estimated appropriately with the best available data and application of IPCC guidelines?

Yes, to the best of my knowledge, the savanna and shrubland carbon stocks were estimated appropriately with the best available data for different areas of the world. The IPCC guidelines also appear to be correctly applied for this objective.

Charge Question 1a: Given the paucity of data for biomass carbon stocks for lands classified as shrubland and savanna outside of Brazil, did the scaling procedure that was used provide accurate results?

Yes, the scaling procedure of increasing the carbon stocks from grassland to savanna to shrubland seems logical and should provide reasonable results. The accuracy of the results will be dependent on how universal these numbers are globally. Awareness of specific regions/locations that may substantially deviate from the carbon stock numbers for any of the three land cover types is important because this would introduce increased error into the estimates for a specific country or region. A general understanding of where these static carbon stock values may be less representative would be useful in understanding the potential bias and/or error rate of a specific calculation for a specific area(s).

Charge Question 1ai: What different approach do you recommend?

A possible option to introduce more realistic intra-class variations in the carbon stock numbers spatially would be to use historical 1-km normalized difference vegetation index (NDVI) data, which has been shown to be a good proxy for green vegetation biomass. Lower carbon stock values (within a specific stock range for each land cover type) could be assigned to locations at the lower end of the NDVI value range for each land cover type and the highest stock values to locations with the highest NDVI values. A metric such as average annual accumulated NDVI (greenness) over a historical period (e.g., 4+ years with MODIS NDVI data and 20+ years with AVHRR NDVI data) would be recommended because it would reflect historical vegetation performance for each 1-km pixel globally over locations comprised of each of these three land cover types. Refer to the "time-integrated NDVI" in Reed et al., (1994) for an example of the accumulated NDVI metric that would be recommended. There are several different analytical techniques that can be used to generate the necessary information to calculate an accumulated NDVI measure from time-series NDVI data.

Reference:

Bradley C. Reed, Jesslyn F. Brown, Darrel VanderZee, Thomas R. Loveland, James W. Merchant, Donald O. Ohlen. Measuring Phenological Variability from Satellite Imagery. *Journal of Vegetation Science*, Vol. 5, No. 5, Applications of Remote Sensing and Geographic Information Systems in Vegetation Science (Nov., 1994), pp. 703-714 URL: http://www.jstor.org/stable/323588.

Charge Question 2: Were grassland carbon stocks appropriately estimated using Table 6.4 of the IPCC AFOLU? What better sources than Table 6.4 either globally or on a regional basis do you recommend?

Yes, to the best of my knowledge the grassland carbon stocks were appropriately estimated using this table in the IPCC AFOLU.

D. Cropland Biomass Carbon Stocks

Charge Question 1: Were IPCC guidelines and data sources appropriately utilized to estimate biomass carbon stocks for annual and perennial crops?

Yes, the IPCC guidelines and data sources (currently available at a global scale) appeared to be appropriately applied to estimate biomass carbon stocks for annual and perennial crops.

Charge Question 2: Is it scientifically justifiable to use the default factor in Table 5.9 of the IPCC AFOLU for all annual crops?

Yes, to the best of my knowledge it was justifiable to use the default factor in this Table of the IPCC AFOLU all annual crops.

Charge Question 2a: What data sources and methods provide more refined estimates by crop type and region?

A recommendation to provide more refined estimates by crop type and region would be to map the distribution of the major crop types (e.g., corn (maize) and soybeans or summer crops in general) in areas that experienced land cover conversions between 2001 and 2004 using MODIS 250-meter data or other high resolution data sets. Several researchers (referenced) earlier have been working on large-area crop mapping strategies that could greatly benefit these estimates. The ability and feasibility to produce these data sets would be highly dependent on the time and resources (both financial and personnel) available for such an undertaking. The generation of global crop type maps is likely not feasible without major resources, so a targeted assessment for key locations and crop types might be a preferred option.

Charge Question 3: Were biomass carbon stocks appropriately estimated for oil palm and rubber?

Yes, to the best of my knowledge the biomass carbon stocks were appropriately estimated for oil palm and rubber in this study.

Charge Question 3a: If not, how do you suggest improving these estimates?

No improvements are suggested.

E. Soil Carbon

Charge Question 1: Were soil carbon stocks appropriately estimated with the best available data and application of IPCC guidelines?

Yes, to the best of my knowledge the soil carbon stocks were appropriately estimated with the best available data globally and the IPCC guidelines appeared to be correctly applied.

Charge Question 2: Were GHG emissions from peat drainage appropriately estimated with the best available data and IPCC guidelines?

Yes, to the best of my knowledge the GHG emissions from peat drainage were appropriately estimated with the best available data globally and the IPCC guidelines appeared to be correctly applied.

Charge Question 3: Was the timing of soil carbon emissions (i.e., spread evenly over 20 years) appropriately evaluated?

Although this is not my area of expertise, the assumption of an even spread of soil carbon emissions over 20 years after a specific land cover conversion seems to generalize the temporal variability in these type of emissions that may exist over that long of time period. I would assume over the 20 year period that the rate of emissions would be higher for certain periods (e.g., first few years after a conversion) than others after a LULC change has occurred. I do not have a recommendation on alternatives to further evaluate this issue, but it might warrant some additional study by experts in this field.

Charge Question 4: How do you suggest improving the estimates of soil carbon stocks and emissions?

No specific suggestions for improvements are made.

F. Lost Forest Sequestration

Charge Question 1: Was foregone forest sequestration appropriately estimated with the best available data and IPCC guidelines?

Yes, to the best of my knowledge the foregone forest sequestration was appropriately estimated using the best available data and IPCC guidelines.

Charge Question 2: Were the default factors in IPCC Table 4.9 used appropriately?

Yes, to the best of my knowledge the default factors in the IPCC table were used appropriately.

Charge Question 2a: Is it scientifically justifiable to use the default factors for forests greater than 20 years old to estimate average foregone forest sequestration from forest lands cleared as a result of biofuel induced land use change?

Again, I am not an expert in this specific field, but I would assume that the factors would change as you transition from a young to old growth forest. The application of the default factors beyond 20 years (particularly those at 40 or 50+ years) may overestimate the carbon sequestration potential lost from the deforested areas since the sequestration rate may decline with age of the tree. This may require further analysis and recommendations from experts working in this scientific area.

Charge Question 2b: Is IPCC Table 4.9 the best source of data for these estimates given the geographic scope and scale of this study?

Yes, to the best of my knowledge, the IPCC Table is best source of data globally for these estimates. Better regional, national, and/or sub-national data sets may exist that I am unaware of though.

Charge Question 2c: If not, what data sources would you recommend?

No specific recommendation of alternative data sources is made.

Charge Question 3: Winrock assumed that, on average, foregone forest sequestration continues for 80 years after forest clearing. Is this a scientifically justifiable assumption, and if not, what do you believe would be a better average assumption?

Foregone forest sequestration likely continues for 80 years after forest clearing, but I don't think an average rate is maintained over that long of period of time. I believe a better assumption would be a gradually changing rate over time, which would depend on the forest type replaced, the land cover type that replaced the forest, and the general environmental conditions (soils and climate).

G. Non-CO2 Emissions from Clearing with Fire

Charge Question 1: Were IPCC guidelines appropriately utilized to estimate non-CO2 emissions from clearing with fire?

Yes, to the best of my knowledge the IPCC guidelines were appropriately used to estimate non-CO2 emissions from clearing with fire.

Charge Question 2: Were the assumptions appropriately made for which countries use fire to clear land for crop production?

Yes, proper assumptions were made for which countries in general use fire to clear land for crop production.

Charge Question 2a: Please recommend any data sources or studies that would help to determine which regions and land transitions are most likely to involve clearing with fire.

MODIS Thermal Anomalies and Fire 8-Day L3 Global 1-km Product (MOD14A2, https://lpdaac.usgs.gov/lpdaac/products/modis_products_table/thermal_anomalies_fire/8_day_l3_global_1km/v5/terra) provides 8-day composited observations of fire locations globally that could be used to determine the relative timing, duration, and frequency of fires (during the 2001 and 2004 study years interval) for locations that have been identified as being converted to cropland between 2001 and 2004. This would provide an approximation of where fire is most frequently used by country and which locations converted to cropland experienced a period of fire during the period between the two study years.

Charge Question 2b: Please discuss whether any such data sources and assumptions on current fire clearance are reasonable to project to the future time period used in the analysis.

A historical summary of fire occurrence observations in the MODIS 1-km Fire data (referenced above) could provide information on the frequency of fires used throughout the world in areas that have been cleared to provide some general information about the future rate of fire usage for future periods. However, the future rates and projections based on fire could be problematic because of the role climate change could play (e.g., increased or decreased fire frequency), which is not being accounted for in this study.

H*. Timing of Emissions from Land Clearing*

Charge Question 1: Were the timing of emissions from land clearing appropriately estimated?

Yes, to the best of my knowledge the timing of emissions from land clearing were appropriately estimated.

Charge Question 1a: If not, how do you suggest improving these estimates?

No improvements for these estimates are suggested.

I. Harvested Wood Products and Other Considerations

Charge Question 1: Was credit for harvested wood products, and other factors that could delay or prevent emissions from land clearing (e.g., land filling), appropriately accounted for?

Yes, to the best of my knowledge the credit for harvested wood products and other factors that could delay or prevent emissions from land clearing were appropriately accounted for in this study.

Charge Question 1a: If not, how do you suggest improving these estimates?

No suggestions for improving these estimates are made

Appendix H

Curricula Vitae of Selected Peer Reviewers

CURRICULUM VITAE

Holly K. Gibbs

David H. Smith Conservation Research Fellow
The Woods Institute for the Environment
Program on Food Security and the Environment
Energy and Environment Building - Rm 350
473 Via Ortega
Stanford University
Stanford, CA 94305

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Research Interests

Land-use / land-cover change, tropical ecosystems, integrated studies of human-environment systems, global carbon cycle, remote sensing, ecosystem modeling, food security, international climate policy, economic incentives for conservation, energy systems, macroeconomics

Education

Ph.D. Environment and Resources, University of Wisconsin-Madison*,* October 2008
Dissertation: Shifting Pathways of Tropical Land Use and their Implications for Carbon Emissions. Advisor: Jonathan Foley, Center for Sustainability and the Global Environment

M.S. Natural Resources, The Ohio State University, March 2001
Thesis: Human-induced changes in global vegetation and climatic parameters
Specialization: Remote sensing, geographic information systems, and spatial modeling

B.S. Natural Resources (Degree of Distinction), The Ohio State University Mar. 1999, *cum laude*
Thesis: Obstacle avoidance by hand-raised, captive-born, and wild-caught big brown bats
Specialization: Environmental science, wildlife biology and natural resources

Honors and Awards

- National Academies of Science Kavli Frontiers of Science Fellow (2008)
- David H. Smith Conservation Post-Doctoral Research Fellowship (2008-2010)
- Papers selected as “Best of 2007” and “of 2008” by Env Res. Letters (2007, 2008)
- Selected as International Young Scholar by IGBP – START program (2006)
- Department of Energy’s Graduate Environmental Research Fellowship (2005-2008)
- Outstanding Student Paper Award, American Geophysical Union, Fall Meeting (2004)
- OSU School of Natural Resources Competitive Graduate Student Research Grant (2000)
- Student Alumni Society’s Outstanding Student Leadership Award (1999)
- Awarded “Outreach Project of The Year” by the College of Food, Agriculture, and Environmental Science for “Increasing Diversity in the Environmental Field” (1999)
- The Ohio State University’s Honors Summer Research Fellowship (1998)
- The Pressey Honors Endowment for direct research funding (1998)
- Research Award, the U.S. Fish and Wildlife Service Endangered Species Division (1998)
- Highest rank in the School of Natural Resources’ Honors Proposal Competition (1997)

Professional Experience

David H. Smith Conservation Research Fellow, Stanford University, October 2008 - current
Leading research on the impacts of U.S. climate and biofuels policies on tropical forest conservation, climate change, and food security.

Conservation Research Consultant, Various NGOs and companies, January 2006 - current
Assess and map forest carbon and other ecosystem services provided by the world's protected areas and potential forest conservation projects.

Graduate Research Fellow, University of Wisconsin - Madison, August 2003 – Sept. 2008
Developed statistical models to reconcile and hybridize estimates of tropical deforestation during the 1980s and 1990s. Tracked land use dynamics and C emissions across Tropics.

Post-Masters Research Associate, Oak Ridge National Laboratory, May 2001 – Sept. 2003
Remote-sensing scientist for DOE Global Water Cycle Pilot Project focused on coupled land-atmospheric-hydrologic modeling at the basin-scale. Developed satellite algorithms and led field campaigns related to carbon cycle and bioenergy research.

Graduate Teaching Associate, The Ohio State University, Sept. 1999 - Dec. 2000
Taught introductory ecology and social science courses by lecturing and leading discussion sections. Advised individual students on academics and potential career paths.

Graduate Research Associate, The Ohio State University, May 1999 - Sept. 2000
Utilized laboratory and field techniques for isotopic soil and precipitation analysis. Developed meta-analysis framework for landscape-level soil ecology hypothesis.

Graduate Research Associate, The Ohio State University, Mar. 1999 - Sept. 1999
Integral part of science education initiative support team. Identified and solicited potential funding sources, co-authored successful grant, and led community workshops.

Summer Research Fellow, The Ohio State University, June 1999 - Sept. 1999
Designed, funded, and conducted research investigating the mother-young relationship in big brown bats (*Eptesicus fuscus*). Constructed outdoor flight cage and flight-obstacle course.

International Science Service

- Co-organized AAAS symposium "Biofuels, Tropical Deforestation and Climate Policy: Key Challenges and Opportunities (February 12-16, 2009)
- Guest Co-Editor for special issue of Environmental Research Letters "Tropical Deforestation and Carbon Emissions"
- Reviewer for *Journal of Geophysical Research, Environmental Management, Ecological Applications, Earth Interactions, Environmental Research Letters, Biomass and Bioenergy, Biological Conservation, Ecology Letters, Tropical Conservation Science Journal, Environmental Science & Technology*
- Science support for policy initiatives led by the Coalition for Rainforest Nations, Tropical Forest Group and Conservation International's Center for Applied Biodiversity (2006-08)
- American Geophysical Union, Biogeosciences Student Representative (2006)

Leadership & Communication Experience

- Interviews and recent research results have appeared in print and radio media including: Science Magazine's ScienceNOW, NOVA Science NOW, KQED Public Television, Canadian Broadcast Company "As it Happens", Environmental Research Web, Reuters, Associated Press, Santa Barbara Independent, Yahoo News, MongaBay, University NewsWire, U.S. News and World Reports, Wisconsin State Journal, and Cap Times, Jakarta Post, Santa Barbara Independent, DevNet among others.

- Co-Developer (along with Jon Foley) of the "Earth Collaboratory" website – an Internet-based system that integrates multiple kinds information (bridging scales, disciplines, perspectives) and serves as an interface between global environmental scientists and local experts and citizens drawn from all over the world.

- Conflict Management and Group Facilitation: Practiced resolving conflicts with diverse stakeholders groups in international settings, Jersey Island, May 2005. Facilitated Transdisciplinary Workshop on Coupled Human-Environment Systems" and several faculty aiming to transdisciplinary curriculum for graduate programs, May – Sept. 2005.

- Strategic Management Experience: Project Associate on the Nelson Institute for Environmental Studies Mission Review Team; Developed, facilitated and analyzed self-assessments of faculty and student to evaluate mission statement, April-June, 2005.

University Leadership Positions and Committees

- The Nelson Institute New Director Search and Screen Committee (2007)
- The Nelson Institute Research Committee, Student Representative (2006-2008)
- Madison Ecology Group (MEG) Graduate Student Representative (2003-05)
- Nelson Institute for Environmental Studies Land Resources Student Rep. (2003-04)
- Undergraduate Honors Thesis Reading Group Mentor (2003-04)
- Graduate Student Council Mentor Awards Selection Committee (2003-04)
- Member of the School of Natural Resources' Seminar Committee (2000-01)
- Executive member of The Graduate Student Organization (Gradroots) (2000-01)
- Member of the School of Natural Resources' Director Search Committee (2000-01)
- Vice-president of the School of Natural Resources' Honor Society (1998-99)
- School of Natural Resources' Student Leadership Forum Representative (1997-99)

Commissioned Review Papers

Miles, L., Kapos, V., Gibbs, H.K., Lysenko, I., Campbell, A. 2008. Mapping Vulnerability of Tropical Forest to Conversion and Resulting Potential CO_2 Emissions: A Rapid Assessment for the Eliasch Review. UNEP World Conservation Monitoring Centre.

Campbell A., Kapos V., Lysenko I., Scharlemann J.P.W., Dickson B., Gibbs H.K., Hansen M., Miles L. 2008. Carbon emissions from forest loss in protected areas. UNEP World Conservation Monitoring Centre. A report commissioned by The Nature Conservancy as part of the PACT 2020 Innovation Initiative in collaboration with UNEP-WCMC and the IUCN World Commission on Protected Areas.

H. K. Gibbs. 2007. Estimating National Level Tropical Forest Carbon Stocks and Emissions. Commissioned Paper for the Coalition for Rainforest Nations in support of the UNFCCC Agenda Item #6, Reducing Emissions from Deforestation and Degradation.

Olander, L. P., B. C. Murray, H. K. Gibbs, M. Steininger. 2007. Establishing Credible National Baselines for Efforts to Reduce Emissions from Degradation and Deforestation. Commissioned Paper for the Coalition for Rainforest Nations in support of the UNFCCC Agenda Item #6, Reducing Emissions from Deforestation and Degradation.

Published Peer-Reviewed Journal Manuscripts

G. P. Robertson, V. H. Dale, O. C. Doering, S. P. Hamburg, J. M. Melillo, M. M. Wander, W. J. Parton, R. Pouyat, P. R. Adler, J Barney, R. M. Cruse, C. S. Duke, P. M. Fearnside, R. F. Follett, H. K. Gibbs, J. Goldemberg, D. J. Mladenhoff, D. Ojima, M. W. Palmer, A. Sharpley, L. Wallace, K. C. Weathers, J. A. Wiens, W. W. Wilhelm. Sustainable Biofuels Redux. Science 322: 49-50.

J. A. Patz, S. H. Olson, C. Uejio, and H. K. Gibbs. Disease emergence from global climate and land use change. Medical Clinics of North America. 92(6): 1473-1491.

Gibbs, H.K., M. Johnston, J. A. Foley, T. Holloway. C. Monfreda, N. Ramankutty, and D. Zaks. 2008. Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. Environmental Research Letters 3 034001

Olander, L. P., H. K. Gibbs, M, Steininger, J. J. Swenson, and B. C. Murray. Reference scenarios for deforestation and forest degradation in support of REDD: a review of data and methods. Environmental Research Letters 3 025011

Gibbs, H.K., S. Brown, J. O. Niles. J.A. Foley. 2007. Monitoring and measuring tropical forest carbon stocks: Making REDD a reality. Environmental Research Letters 2(4): 045023.

Gibbs, H. K. and M. Herold. 2007. Tropical deforestation and carbon emissions: Introduction to special issue. Environmental Research Letters 2: 045021.

Patz, J., H. K. Gibbs, J. A. Foley, and K. Smith. 2007. Climate change and global health: Quantifying a growing ethical crisis. EcoHealth 4(4):1612-1910.

Patz, J., D. Campbell-Lendrum, H. K. Gibbs, and R. Woodruff. 2008. Health Impact Assessment of Global Climate Change: Expanding upon Comparative Risk Assessment approaches for Policy Making. Annual Reviews of Public Health 29: 27-39.

Ramankutty, N., H. K. Gibbs, F. Achard, R. DeFries, J.A. Foley, and R.A. Houghton. 2007. Challenges in estimating carbon emissions from tropical deforestation. Global Change Biology 13(1):51-66.

Foley, J.A., G.P. Asner, M.H. Costa, M.T. Coe, R. DeFries, H.K. Gibbs, et al. 2007. Amazonian revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin, Frontiers in Ecology and Environment 5(1): 25-32.

Foley, J.A., R. S. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. Stuart Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, et al.. 2006. Land-Use Practices Have Negative, Global-Scale Effects on Ecosystem Services and Human Welfare. Science 309 (5734): 570-574.

Miller, N.L., A.W. King, M.A. Miller, E.P. Springer, M.L. Wesely, K.E. Bashford, M.E. Conrad, K. Costigan, P.N. Foster, H.K. Gibbs, J.Jin, J. Klazura, B.M. Lesht, M.V. Machavaram, F. Pan, J. Song, D.Troyan, R.A. Washington-Allen. 2005. The DOE Water Cycle Pilot Study. Bulletin of the American Meteorological Society 86(3):359-374.

Wali, M.K., F. Evrendilek, T.O. West, S. Watts, D. Pant, H. K. Gibbs, B. McClead. 1999. Assessing terrestrial ecosystem sustainability: Usefulness of modeling regional carbon and nitrogen budgets. Nature and Resources 35: 21-33.

Gibbs, H. K. and D. L. Johnson. 1999. Obstacle avoidance by hand-raised, captive-born, and wild-caught big brown bats. Olentangy River Wetlands Research Park Review. 10(20): 201-06.

Journal Manuscripts – In review or preparation

C. M. Stickler, D. C. Nepstad, M. T. Coe, H. K. Gibbs, and G. J. Fiske. Tropical forests in the pathway of agricultural expansion. (Submitted to Science as Brevia, July 4, 2008)

Gibbs, H, K., N. Ramankutty, J. A. Foley, R. S. DeFries, F. Achard, and R. A. Houghton. A new spatially-explicit hybrid estimate of tropical deforestation rates in the 1980s and 1990s (in prep).

Gibbs, H. K., J. A. Foley, N, Ramankutty, F. Achard, and P. Holmgren. Shifting patterns and causes of tropical deforestation across the tropics during the 1980s and 1990s (in prep).

Gibbs, H. K., J. A. Foley, N, Ramankutty, F. Achard, and P. Holmgren. The changing source of agricultural land across the tropics (in prep).

Data Set Publications

Ruesch, A.S. and H,K. Gibbs. 2008. New global biomass carbon map for the year 2000 based on IPCC Tier Methodology. ORNL-CDIAC.

Gibbs, H.K. and S. Brown. 2007. Carbon pools in the forests of tropical Africa: An updated database using the GLC2000 Land Cover Product. NDP-017b. ORNL-CDIAC.

Gibbs, H.K. and S. Brown. 2007. Carbon pools in the forests of tropical Southeast Asia: An updated database using the GLC2000 Land Cover Product. NDP-017b. ORNL-CDIAC.

Gibbs, H. K. 2006. Major World Ecosystem Complexes Ranked by Carbon in Live Vegetation: An Updated Database Using the GLC2000 Land Cover Product. NDP-017b. ORNL-CDIAC.

Gibbs, H. K., R. L. Graham, and R. B. Cook. 2002. The Oak Ridge Reservation Geographic Information System. Available on-line [http://mercury.ornl.gov/EDORA/] from the Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Other Publications – Technical reports, book chapters

Campbell, A., Miles. L., Lysenko, I., Hughes, A., Gibbs, H. 2008. Carbon storage in protected areas: Technical report. UNEP World Conservation Monitoring Centre.

Selected Presentations

H.K. Gibbs. The Biofuels Boom: Ripple Effects on Tropical Forests and Global Climate. The Field Museum of Natural History, February 11, 2009, Chicago, IL ***(Invited)***

H.K. Gibbs. Mapping Land Sources for Expanding Biofuel Croplands Across the Tropics. American Association for the Advancement of Science Annual Meeting, February 14, 2009, Chicago IL. ***(Session Organizer)***

H.K. Gibbs. The Biofuels Boom: Promise or Peril for Food, Forests and Climate? National Academies of Science Kavli Frontiers of Science Symposium, November 7, 2008, Irvine, CA ***(Invited)***

H.K. Gibbs. Carbon Payback Times for Tropical Biofuel Expansion. The Kathryn Fuller Science for Nature Fund 2008 Science for Nature Symposium: Biofuels – Which are More Sustainable?, November 19, 2008, World Wildlife Fund, Washington D.C. ***(Invited)***

H. K. Gibbs. The Changing Fate of Cleared Land Across the Tropics: Critical New Inputs for Ecosystem Service Evaluation. Land Tenure Center Symposium on Pro-Poor Rewards for Ecosystem Services, April 7-8, University of Wisconsin-Madison. **(*Invited*)**

H.K. Gibbs. Navigating the Biofuels Debate. Union of Concerned Scientists Lunchtime Seminar. March 13. 2008, Washington D.C. **(*Invited*)**

H.K. Gibbs. Tropical Ecosystems and the Biofuels Boom: Navigating a Sustainable Path Forward? Conference on the Ecological Dimensions of Biofuels. March 10. 2008, Washington D.C.

H. K. Gibbs. New National-Level Estimates of Tropical Forest Carbon Stocks. United Nations Framework Convention on Climate Change COP-13, Forest Day. December 8, 2008, Bali, Indonesia.

H. K. Gibbs. Biofuel Expansion in the Tropics May Increase Global Warming. United Nations Framework Convention on Climate Change COP-13, Forest Day. December 8, 2008, Bali, Indonesia.

H. K. Gibbs. Sustainable pathways of biofuel crop expansion in the Tropics? Large-Scale Biosphere-Atmosphere ECO Meeting, September 26-29, 2007. Bahia, Brazil.

H. K. Gibbs. Shifting Patterns of Tropical Land Use and Their Implications for Carbon Emissions. Stockholm Resilience Series: Frontiers in Sustainability Science and Policy. Stockholm, Sweden. June 4, 2007. **(*Invited*)**

H. K. Gibbs. Estimating Tropical Forest Carbon Stocks. Coalition for Rainforest Nations Science, Technology, and Methods Workshop. Columbia University Business School, NY. January 22-23, 2007**. (*Invited*)**

H. K. Gibbs. Tracking the fate of cleared land across the Tropics: Critical New Inputs for Ecosystem Service Evaluation. Large-Scale Biosphere-Atmosphere ECO Meeting, October 4-6, 2006. Brasilia, Brazil.

H. K. Gibbs. Estimating National Level Tropical Forest Carbon Stocks and Emissions. Pre-Session for the UNFCCC Workshop on COP11 Agenda Item #6 organized by the Coalition for Rainforest Nations Rome, Italy. August 28-29, 2006. **(*Invited*)**

H. K. Gibbs. Tracking the Fate of Cleared Land Across Africa: Critical New Inputs for Ecosystem Service Evaluation. *Plenary Session* of Conservation International's Annual Symposium, Defying Nature's End: The African Context. Antannarivo, Madagascar. June 20-24, 2006. **(*Invited*)**

H. K. Gibbs. Tracking the Fate of Cleared Land Across the Tropics: Critical New Inputs for Ecosystem Service Evaluation. Conservation International's Center for Applied Biodiversity Brownbag, Washington, D.C. May 24, 2006. **(*Invited*)**

H. K. Gibbs. Estimating Tropical Deforestation and Carbon Emissions: What We Need, What We Have, and How to Make Ends Meet. Coalition for Rainforest Nation's Policy Workshop on the UNFCC COP-11 Agenda Item #6. Columbia University, NY. 13-14 March, 2006. **(*Invited*)**

H. K. Gibbs. An Improved Spatial Data Set of Tropical Deforestation Rates for the 1980s and 1990s. The American Geophysical Union Fall Meeting. San Francisco, CA. 5-9 December, 2005.

H. K. Gibbs. Estimating tropical land cover change dynamics for the 1980s and 1990s. The 6th Open Meeting of the Human Dimensions of the Global Environmental Change Research Community, Bonn, Germany. October 9-13.

H.K. Gibbs. Tracking the fate of deforested land in Central America. NASA Marshall Space Flight Center, Huntsville, AL. 24-25 August 2005. **(*Invited*)**

H.K. Gibbs. Addressing Major Uncertainties in Rates of Tropical Deforestation. Department of Energy Global Change Education Program End of the Summer Meeting, Washington, D.C. 22-24 August 2005.

H.K. Gibbs. Reducing Uncertainty in Rates of Tropical Deforestation and Associated Carbon Emissions. International Earth System Science Postdoctoral Network Meeting. Breckenridge CO. 23-25, June 2005.

H. K. Gibbs. Challenges in Estimating Global Tropical Deforestation in the 1980s and 1990s. Oral Presentation. The American Geophysical Union Fall Meeting. 13-17 December, 2004.

H. K. Gibbs. Challenges in Estimating Tropical Deforestation in the 1980s and 1990s. LUCC Workshop on Impacts of changes in land use and management on carbon stocks and turn-over in the tropics. Institute of Geography, University of Copenhagen, Denmark. 23-25 August, 2004.

H. K. Gibbs, R. A. Washington-Allen, A. W. King, M. A. Sale, and F. Pan. Geographic Portability of the Relationships between LAI, FPAR, and Spectral Vegetation Indices. The American Geophysical Union Spring Meeting, Washington D.C. 28-31 May 2002.

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Education

B. A. in Biology, Hamilton College, 1965
Ph.D. in Ecology, S.U.N.Y., Stony Brook, 1979

Professional Experience

2009-present	Acting Director, The Woods Hole Research Center, Woods Hole, Massachusetts
1989-present	Senior Scientist, The Woods Hole Research Center, Woods Hole, Massachusetts
1993-1994	Visiting Senior Scientist, Office of Mission to Planet Earth, NASA, Washington, D.C.
1987-1989	Associate Scientist, The Woods Hole Research Center, Woods Hole, MA
1984-1987	Assistant Scientist, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA
1975-1984	Research Associate, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA
1967-1974	Research Associate, Biology Department, Brookhaven National Laboratory, Upton, NY

Professional Societies

Member, Ecological Society of America
Member, American Geophysical Union
Member, Sigma Xi

Partial List of Publications in the Last 10 Years

Houghton, R.A. 1999. The annual net flux of carbon to the atmosphere from changes in land use 1850-1990. *Tellus* **51B**:298-313.

Houghton, R.A., and J.L. Hackler. 1999. Emissions of carbon from forestry and land-use change in tropical Asia. *Global Change Biology 5*:481-492.

Houghton, R.A., and K. Ramakrishna. 1999. A review of national emissions inventories from select non-Annex I countries: Implications for counting sources and sinks of carbon. *Annual Review of Energy and the Environment 24*:571-605.

Houghton, R.A., J.L. Hackler, and K.T. Lawrence. 1999. The U.S. carbon budget: contributions from land-use change. *Science 285*:574-578.

Houghton, R.A. 2000. Emissions of carbon from land-use change. Pages 63-76 *in*: *The Carbon Cycle* (T.M.L. Wigley and D.S. Schimel, editors), Cambridge University Press, New York, NY.

Houghton, R.A., and J.L. Hackler. 2000. Changes in terrestrial carbon storage in the United States. 1. The roles of agriculture and forestry. *Global Ecology and Biogeography 9*:125-144.

Houghton, R.A., J.L. Hackler, and K.T. Lawrence. 2000. Changes in terrestrial carbon storage in the United States. 2. The role of fire and fire management. *Global Ecology and Biogeography 9*:145-170.

Houghton, R.A., D.L. Skole, C.A. Nobre, J.L. Hackler, K.T. Lawrence, and W.H. Chomentowski. 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature 403*:301-304.

Noble, I., M. Apps, R. Houghton, D. Lashof, W. Makundi, D. Murdiyarso, B. Murray, W. Sombroek, and R. Valentini. 2000. Implications of different definitions and generic issues. Pages 53-126 in: R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken (editors). *Land Use, Land-Use Change, and Forestry. A Special Report of the IPCC.* Cambridge University Press, New York.

Houghton, R.A. 2001. Counting terrestrial sources and sinks of carbon. *Climatic Change 48*:525-534.

Houghton, R.A., K.T. Lawrence, J.L. Hackler, and S. Brown. 2001. The spatial distribution of forest biomass in the Brazilian Amazon: A comparison of estimates. *Global Change Biology* **7**:731-746.

DeFries, R.S., R.A. Houghton, M.C. Hansen, C.B. Field, D. Skole, J. Townshend. 2002. Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 90s. *Proceedings of the National Academy of Sciences* **99**:14256-14261.

Goodale, C.L., M.J. Apps, R.A. Birdsey, C.B. Field, L.S. Heath, R.A. Houghton, J.C. Jenkins, G. H. Kohlmaier, W. Kurz, S. Liu, G.-J. Nabuurs, S. Nilsson, and A.Z. Shvidenko. 2002. Forest carbon sinks in the northern hemisphere. *Ecological Applications* **12**:891-899.

Houghton, R.A. 2002. Magnitude, distribution and causes of terrestrial carbon sinks and some implications for policy. *Climate Policy* **2**:71-88.

Houghton, R.A., and J.L. Hackler. 2002. Carbon flux to the atmosphere from land-use changes. In *Trends: A Compendium of Data on Global Change,* Carbon Dioxide Information and Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

Hurtt, G.C., S.W. Pacala, P.R. Moorcroft, J. Caspersen, E. Shevliakova, R.A. Houghton, and B. Moore III. 2002. Projecting the future of the U.S. carbon sink. *Proceedings of the National Academy of Sciences* **99**:1389-1394.

Houghton, R.A. 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850-2000. *Tellus* **55B**:378-390.

Houghton, R.A. 2003. Why are estimates of the terrestrial carbon balance so different? *Global Change Biology* **9**:500-509.

Houghton, R.A., and J.L. Hackler. 2003. Sources and sinks of carbon from land-use change in China. *Global Biogeochemical Cycles,* 17(*2*), 1034, doi:10.1029/2002GB001970.

House, J.I., I.C. Prentice, N. Ramankutty, R.A. Houghton and M. Heimann. 2003. Reconciling apparent inconsistencies in estimates of terrestrial CO_2 sources and sinks. *Tellus* 55B: 345-363.

DeFries, R.S., G.P. Asner, and R.A. Houghton (editors). 2004. *Ecosystems and Land Use Change*. American Geophysical Union, Washington, D.C.

Houghton, R.A., and C.L. Goodale. 2004. Effects of land-use change on the carbon balance of terrestrial ecosystems. Pages 85-98 *in*: R.S. DeFries, G.P. Asner, R.A. Houghton (editors), *Ecosystems and Land Use Change*. American Geophysical Union, Washington, D.C.

Houghton, R.A., F. Joos, and G.P. Asner. 2004. The effects of land use and management on the global carbon cycle. Pages 237-256 *in*: G. Gutman, A.C. Janetos, C.O. Justice, E.F. Moran, J.F. Mustard, R.R. Rindfuss, D. Skole, B.L. Turner II, and M.A. Cochrane (editors), *Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Houghton, R.A. 2005. Aboveground forest biomass and the global carbon balance. *Global Change Biology* **11**:945-958.

Houghton, R.A. 2005. Tropical deforestation as a source of greenhouse gas emissions. Pages 13-21 *in*: P. Moutinho and S. Schwartzman, editors. *Tropical Deforestation and Climate Change.* Amazon Institute for Environmental Research, Belém, Pará, Brazil.

Houghton, R.A., and J.L. Hackler. 2006. Emissions of carbon from land use change in sub-Saharan Africa. *Journal of Geophysical Research* **111**, G02003, doi:10.1029/2005JG000076.

Hurtt G.C., S. Frolking, M.G. Fearon, B. Moore, E. Shevliakova, S. Malyshev, S.W. Pacala, and R.A. Houghton. 2006. The underpinnings of land-use history: three centuries of global gridded land-use transitions, wood harvest activity, and resulting secondary lands. *Global Change Biology* **12**:1-22.

Canadell, J.G., C. Le Quéré, M.R. Raupach, C.B. Field, E.T. Buitenhuis, P. Ciais, T.J. Conway, N.P. Gillett, R.A. Houghton, and G. Marland. 2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences* **104**:18866-18870.

Houghton, R.A. 2007. Balancing the global carbon budget. *Annual Review of Earth and Planetary Sciences* **35**:313-347.

Houghton, R.A., 2007: The carbon cycle in land and water systems. In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [King, A.W., L. Dilling, G.P. Zimmerman, D.M. Fairman, R.A. Houghton, G. Marland, A.Z. Rose, and T.J. Wilbanks (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, USA, pp. 103-106.

Houghton, R.A., D. Butman, A.G. Bunn, O.N. Krankina, P. Schlesinger, T.A. Stone. 2007. Mapping Russian forest biomass with data from satellites and forest inventories. *Environmental Research Letters* **2**, 045032 (doi:10.1088/1748-9326/2/4/045032).

Ramankutty, N., H.K. Gibbs, F. Achard, R. DeFries, J.A. Foley, and R.A. Houghton. 2007. Challenges to estimating carbon emissions from tropical deforestation. *Global Change Biology* **13**:51-66.

Saatchi, S.S., R.A. Houghton, R.C. dos Santos Alvala, J.V. Soares, and Y. Yu. 2007. Distribution of aboveground live biomass in the Amazon basin. *Global Change Biology* **13**:816-837.

DeFries, R.S., D.C. Morton, G.R. van der Werf, L. Giglio, G.J. Collatz, J.T. Randerson, R.A. Houghton, P.K. Kasibhatla, and Y. Shimabukuro. 2008. Fire-related carbon emissions from land use transitions in southern Amazonia. *Geophysical Research Letters* **35**, L22705, doi:10.1029/2008GL035689.

Houghton, R.A., and S.J. Goetz. 2008. New satellites help quantify carbon sources and sinks. *Eos* 89(43):417-418.

Ito, A., J.E. Penner, M.J. Prather, C.P. de Campos, R.A. Houghton, T. Kato, A.K. Jain, X. Yang, G.C. Hurtt, S. Frolking, M.G. Fearon, L.P. Chini, A. Wang, and D.T. Price. 2008. Can we reconcile differences in estimates of carbon fluxes from land-use change and forestry for the 1990s? *Atmospheric Chemistry & Physics* **8**:3291-3310.

Searchinger, T.D., and R.A. Houghton. 2008. Biofuels: Clarifying assumptions. *Science* **322**:371-374.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. Use of U.S. croplands for biofuels increases greenhouse gasses through emissions from land use change. *Science* **319**:1238-1240.

Canadell, J.G., M.R. Raupach, and R.A. Houghton. 2009. Anthropogenic CO_2 emissions in Africa. *Biogeosciences* **6**:463-468.

Curriculum Vitae of Prof. Rattan Lal

Name

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Biographical Information

Date/Place of Birth: September 5, 1944, Karyal, Punjab, India (what is now Pakistan)

Education:

1959 Matriculation, Government High School, Rajaund, District Jind, Haryana, India

1963 B.Sc. (Agriculture) Punjab Agricultural University, Ludhiana, Punjab, India

1965 M.Sc. (Soils), Indian Agricultural Research Institute, New Delhi, India

1968 Ph.D. (Soils), The Ohio State University, Columbus, Ohio, USA

Positions Held:

1963-1965	Research Assistant, The Rockefeller Foundation, New Delhi, India
1966-1968	Research Assistant, OARDC, Wooster, Ohio, U.S.A.
1968-1969	Senior Research Fellow, University of Sydney, NSW, Australia
1970-1984	Soil Physicist, International Institute of tropical Agriculture (IITA), Ibadan, Nigeria
1978	Visiting Professor, University of Maracay, Venezuela (taught soil conservation 1 month
1984-1987	Coordinator, Upland Production Systems, Farming Systems Program, IITA, Ibadan
1987-1989	Associate Professor, Dept. of Agronomy, The Ohio State University, Columbus, Ohio
1989-1994	Professor of Agronomy, The Ohio State University, Columbus, Ohio
1994-	Professor, School of Natural Resources, The Ohio State University, Columbus, Ohio
1997	Visiting Professor, Ayub Agric. Res. Institute, Faisalabad, Pakistan (taught soil management for 1 month)
2000-	Director, South Asia Program, FAES, The Ohio State University, Columbus, Ohio
2000-2001	Director, Carbon Management & Sequestration Program, FAES/OARDC, The Ohio State University, Columbus, Ohio
2001-	Director, Carbon Management. & Sequestration Center, FAES/OARDC, The Ohio State University, Columbus, Ohio

Professional Affiliations:

American Society of Agronomy (1966 - present)
Soil Science Society of America (1966 - present)
International Union of Soil Science (1971 - present)
International Soil and Tillage Research Organization (1976 - present)
Society for Promotion of Wasteland Development in India (1980 - present; Founding member)
World Association of Soil and Water Conservation (1982 - present)
Soil and Water Conservation Society (1987- present)
American Society for Advancement of Science (1992 - present)
American Geophysical Union (1999 - present)

Honors and Awards

University Student Awards

- Highest GPA in Government High School Rajaund, District Jind, Haryana, India, 1959.
- Gold Medal, for highest GPA, Punjab Agricultural University, Ludhiana, India, 1963.
- Academic Roll of Honor, Punjab Agricultural University, Ludhiana, India, 1963.
- Biswas-Desai Gold Medal, and IARI Gold Medal for the highest GPA, IARI, New Delhi, India, 1965.
- Member, Sigma Xi, Ohio Chapter, Columbus, Ohio, USA, 1968.

Professional Awards

- Fellow, American Society of Agronomy, 1985.
- Fellow, Soil Science Society of America, 1986.
- International Soil Science Award, Soil Science Society of America, 1988.
- Member, Phi Beta Delta, Honor Society for International Scholars, 1990.
- Distinguished Scientist, Association of Scientists of Indian Origin, 1990.
- Member, The Honor Society of Phi Kappa Phi, 1991.
- Soil Science Applied Research Award, Soil Science Society of America, 1992.
- Fellow, Third World Academy of Sciences, Trieste, Italy, 1992.
- Distinguished Scholar Award, OSU, 1994.
- International Agronomy Award, American Society Agronomy, 1995.
- Fellow, American Association For The Advancement of Science, 1996.
- The President's Citation, Soil and Water Conservation Society, 1996.
- Fellow, Soil and Water Conservation Society, 1997.
- The President's Citation, Soil and Water Conservation Society, 1997.
- Fellow, National Academy of Agricultural Sciences, India, 1998.
- Hugh Hammond Bennett Award, Soil and Water Conservation Society, 1998.
- Distinguished Alumni Award, Punjab Agricultural University, Ludhiana, India, 1999.
- Outstanding Publication Award, Soil and Water Conservation Society-Ohio Chapter, 2000.
- Honorary Member, World Association of Soil and Water Conservation, 2000.
- Doctor of Science, *Honoris Causa*, Punjab Agricultural University, Ludhiana, India, 2001.
- Scroll of Honor, Haryana Agricultural University, Hissar, India, 2001.
- Soil Science Research Award, Soil Science Society of America, 2002.
- William E. Larson and Ray R. Allmaras Inaugural Lecture, Univ. of Minnesota, 2003.
- Environment Quality Research Award, American Society of Agronomy, 2004.
- Borlaug Award, IARI, New Delhi, India, 2005.
- Certificate of Appreciation, Los Alamos National Lab, Los Alamos, NM, 2005.
- Doctor of Science, Honoris Causa, Norwegian Univ. of Biological Sciences, Åas, Norway, 2005.
- Carl Sprengel Agronomic Research Award, American Society of Agronomy, 2005.
- Zayed Intl. Prize for the Environment, Millennium Ecosystem Assessment, Author Award, 2005.
- Liebig Award, Int. Union of Soil Sciences, IUSS, 2006.
- Presidential Lecture, 10 May 2006, Reykavijk, Iceland.
- 2007 Nobel Peace Prize Certificate from IPCC, 2007.
- Cordban Award, University of Cordoba, Spain, 2008.
- COMLAND Award, Commission on Land Degradation & Desertification, Helmhotlz Center for Env. Research, Leipzig, Germany, 2009.

Institutional/Employment Awards

- IITA Dedicated Service Award, 1987.
- Distinguished Scholar Award, The Ohio State University, Columbus, Ohio, 1994.
- Member, Gamma Sigma Delta, Ohio Chapter, 1995.

- Research Award of Merit, Gamma Sigma Delta, Ohio Chapter, 1995.
- Department Research Award, Ohio Agricultural Research & Development Center, 1996.
- Department Research Award, Ohio Agricultural Research & Development Center, 1997.
- Outstanding International Award, Gamma Sigma Delta, Ohio Chapter, 1998.
- Department Research Award, Ohio Agricultural Research & Development Center, 1999.
- Certificate of Appreciation, USDA-NRCS, Washington, DC, 1999.
- University Distinguished Lecturer, The Ohio State University, 2000.
- Certificate of Appreciation, College of Food, Agricultural & Environmental Sciences, 2000.
- Distinguished Senior Faculty Research Award, Ohio Agricultural Research & Development Center, 2001.
- Certificate of Appreciation for 10 years of distinguished service, Ohio Agricultural Research & Development Center, 2001.
- Certificate of Appreciation, College of Food, Agricultural & Environmental Sciences, The Ohio State University, Columbus, Ohio, 2002.

Biographical Listings

- Citation, American Men and Women of Science, 1991.
- Citation, Who's Who in Science and Engineering, 1991.
- Who's Who in the World, 1998.
- Distinguished Leadership, 1998.

Offices Held in Professional and Honorary Societies

- Vice President, International Commission for Continental Erosion, Int'l Assoc. Hydrol. Sciences, 1982-1987.
- Vice President, World Association of Soil and Water Conservation (WASWC), 1983-1987.
- Board Member, International Soil Tillage Research Organization (ISTRO), 1984-1988.
- Chairman, Working Group on Soil Erosion Research Methodology of ISSS, Vienna, Austria (1983-1988).
- Network coordinator, Land Clearing & Development, International Board of Soil Research and Management, Thailand (1982-86).
- Member, Working Group on World Soil Erosion, International Union for Conservation of Nature & Natural Resources (1987-89).
- President, International Soil Tillage Research Organization (ISTRO) (1988-1991).
- President, World Association of Soil and Water Conservation (WASWC) (1987-1991).
- Member, SSSA Committee on International Soil Science Award (1990-1991).
- Chairman, SSSA Committee on International Soil Science Award (1991-1992).
- Member, working Group of ASA (A-6) on "Methodologies for Sustainable Agriculture in the Tropics": 1990-1991.
- Member, NRC's Committee on "Sustainable Agriculture and Environment," National Research Council, Washington D.C.
- National Academy of Sciences, Washington, D.C. (1990-93).
- Member, NRC Panel on "Vetiveria" 1990-1992, Washington, D.C.
- Board Member, Organization for Tropical Studies (OTS), Durham, N.C./San Pedro de Montes de Oca, Costa Rica: 1989-1994.
- Cooperating Scientist: USAID-PL480 Cooperative Project in India, 1988-90.
- Advisor to "Committee on Agricultural Sustainability for Developing Countries," World Resources Institute, Washington, DC: 1990-2000.
- Scientific liaison officer for USAID to International Agric. Res. Centers on Natural Resources Management (1991-1997).
- Member, ASA Committee on Agronomic Service Award (1994-1995).
- Member, Task Force on "Collaboration between U.S. Universities and CGIAR system" (1993-1994).
- SSSA Liaison to Consortium of Affiliates for International Program of AAAS, 1993-2005.
- Member, Program Committee, 50th Anniversary Meeting Soil Water Conservation Society, Ankeny, Iowa, 1995, Organizing Committee of special symposia in Keystone, Co. (1996) and Toronto, Canada (1997), Calgary, Canada (1998).
- Chair, Working Group "Methods of Assessment of Soil Degradation", ISSS, Vienna, Austria, 1995-1997.
- Chair, Working Group "Techniques of Characterizing Physical Properties of Clayey Soils", ISTRO, 1995-to date.
- Member, Search Committee, Director General, UNU-Natural Resources Program in Africa, Accra, Ghana, 1997.
- Task Force, GREAN Consortium Team Visit to India, 1996.

- Coordinator, GREAN-India Program 1996-1997.
- Rapporteur, Commission For Agric. Met., WMO, Geneva, Switzerland, 1995-1998.
- IPCC/OECD Member of Workgroup Inter-Governmental Panel on Climate Change, 1993-1996.
- Member, International Affairs Committee, Soil and Water Conservation Society, 1996-1997.
- Vice Chair, Global Activities Committee, Soil and Water Conservation Society, 1997-2000.
- Vice Chair, Committee on "International Network for Soil and Water Conservation", SWCS, 1998-2000.
- Member, ISCO-1999 (International Soil Conservation Organization) Task Force, SWCS, (1999).
- Vice Chair, ISTRO-2000 Organizing Committee (1997-2000).
- Member, U.S. National Committee for Soil Science, National Academy of Sciences, Washington, D.C., 1998 – 2002.
- IPCC, Lead author, Special Report on LULUCF, 1998-2000.
- IPCC 2001, Planning Meeting, Revised Guidelines for Practice Guidance, Geneva, Switzerland, March 2001.
- IPCC 2001, Reviewer of IPCC 2000 Report (Working Group II).
- Millennium Ecosystem Assessment, Lead Author, Condition Working Group Assessment (2003-to date).
- Member, Task Force of CAST on "Agricultural Mitigation of Greenhouse Gases," 2000-2004.
- Member, SSSA Committee to develop position paper on C sequestration, 2000-2001.
- Advisor, Chicago Climate Exchange, Carbon Trading, 2002-to date.
- Member, NRC Steering Committee on Direct and Indirect Human Contributions to Terrestrial Greenhouse Gas Fluxes, 2003.
- Coordinator, Latin American Soil Carbon Network (LASCANet), 2004-to date.
- Leader, International Year of the Planet Earth Team on "Desertification", International Geo Unions (2004).
- President, Soil Science Society of America (2006- 2007).

Member Editorial Board of International Scientific Journals

- Field Crops Research, Elsevier, Holland, 1978-1990.
- Soil & Tillage Research, Elsevier, Holland, 1980-to date.
- International J. Tropical Agriculture, Hissar, India, 1982- to date.
- Advances in Soil Science, Springer Verlag, N.Y., 1986-1992.
- J. of Agroethics, Taylor & Francis, N.Y., 1987-to date.
- Land Degradation and Rehabilitation, Wiley, U.K., 1989-todate.
- Journal of Sustainable Agriculture, The Haworth Press, Inc., New York, 1989-to date.
- The Encyclopedia of Soil Science & Technology, Von Nostrand Reinhold, New York, N.Y., 1992-1994.
- Advances in Soil Science, CRC/ Lewis Publishers, Boca Raton, 1992-1998.
- Editorial Board on Sustainable Agriculture, The Oxford University Press, 1994-to date .
- Soil Science, Williams and Wilkins, Baltimore, MD, 1996-to date.
- Environment, Development and Sustainability, Kluwer Press, Holland, 1998-2001.
- Progress in Environmental Science, Arnold, London, 1998-to date.
- Pedosphere, Science Press, Beijing, China, 1998-to date.
- The West African J. Applied Ecology, Accra, Ghana, 1999-to date.
- Geoderma, Elsevier, Holland, 2001-2004.
- Critical Reviews in Plant Sciences, CRC, 2001- to date.
- Environmental International, Elsevier Science, U.K. 2001-to date.
- Soil Systems: The Scientific World, U.K., 2001-to date.
- Soil Science Reviews, Elsevier, Holland, 2002-to date.
- Editor-In-Chief, Encyclopedia of Soil Science, Marcel Dekker/Taylor and Francis 2nd Edition, Dec. 2005 (1998–to date).
- Editor-In-Chief, Soil & Tillage Research, Elsevier, Holland (2004–to date).
- J. Land and Water, Sakia.org, 2005.
- Pakistan J. Soil Science, SSSP, Lahore, Pakistan, 2005.
- Associate Editor, J. Arid Environment, Academic Press, London; New York, 2005.
- Editor for the Americas, Land Degradation & Development, J. Wiley & Sons, U.K. (2006-to date).
- Editorial Advisory Board, J. Sci. of Food & Agric., SCI Publications, London, U.K (2006-to date).
- Regional Editor for Americas, Land Degradation & Development, Wiley, U.K. (2006-to date).
- Member of the Advisory and Editorial Boards, Int. J. Food Security, Springer, Germany (2009-to date).

Grant Proposal Reviewer Since 1990

- National Oceanic and Atmospheric Administration
- National Science Foundation
- US-DOE
- USDA-CSRES
- USDA-NRI
- National Geographic Society
- The Royal Society, London, U.K.
- Natural Environmental Research Council, Swindon, U.K.
- The Rockefeller Foundation, East Africa Program
- Third World Academy of Sciences, Trieste, Italy
- Sustainable Agricultural Research & Education (SARE), Lincoln, NE
- National Aeronautics and Space Administration, Washington, D.C.
- International Foundation for Science, Stockholm, Sweden
- National Science Foundation
- BARD, Israel

International Conferences Organized

1. Soil and Water Conservation and Management in the Humid Tropics, Ibadan, Nigeria, 1975.
2. Soil Physics and Crop Production in the Tropics, Ibadan, Nigeria, 1977.
3. Tropical Agricultural Hydrology, Ibadan, Nigeria, 1979.
4. Land Clearing and Development in the Tropics, Ibadan, Nigeria, 1982.
5. Tropical Deforestation, IBSRAM (Bangkok), Sumatra, Indonesia, 1986.
6. Sustainable Agriculture, Columbus, Ohio, 1988.
7. Myths and Sci. of Soils of the Tropics, ASA, Las Vegas, Nevada, 1989.
8. Soil Management for Sustainability, WASWC, Edmonton, Canada, 1989.
9. Twelfth Conference of ISTRO, Ibadan, Nigeria, 1991.
10. Soil Processes and Greenhouse Gas Emission, USDA/EPA, Columbus, Ohio, 1993.
11. Soil Management and Agric. Sustainability, USAID, Columbus, Ohio, 1993.
12. Managing Acid Soils In Latin America, CIAT, Colombia (Chairperson), 1993.
13. Conservation Tillage For Agricultural Sustainability And Water Quality, Hungarian Acad. Budapest, Hungary, 1994.
14. Carbon Sequestration In Soils, NRCS/FS, Columbus, Ohio, 22-26 July 1996.
15. Soil Quality and Erosion Interaction, SWCS, Keystone, CO, 7-8 July 1996.
16. Soil Quality and Agricultural Sustainability, Columbus, OH, 26-27 July 1996.
17. Global Challenges in Ecosystem Mgt. in Watershed Context, SWCS, Toronto, Canada, 25-26 July 1997.
18. Global Climate Change and Pedogenic Carbonates, 13-17 October 1997, Tunis, Tunisia.
19. Carbon Pools and Dynamics in Tropical Ecosystems, 1-5 December 1997, Belem, Brazil.
20. Carbon Pools and Dynamics in Tundra and Boreal Ecosystems, March 1998, Columbus, OH.
21. World soils and the greenhouse effect, SSSA, October 1998, Baltimore, USA.
22. Methods of Assessment of Soil Carbon, November 1998, Columbus, OH.
23. Rangeland Management for Carbon Sequestration, 17-19 Sept. 1998, NMSU, NM.
24. Carbon Sequestration in Soils: Science, Monitoring and Beyond, 3-5 Dec. 1998, St. Michaels, Baltimore, Pacific Northwest National Lab., Washington, D.C.
25. Agricultural Practices and Policies for C Sequestration in Soils: 19-23 July 1999, Columbus, OH.
26. Reconciling Food Security and Environment Quality in Industrializing India, 7-8 March, 2001, Columbus, OH.
27. The Potential of U.S. Forest Lands to Sequester Carbon and Mitigate the Greenhouse Effect, 17-19 April 2001, Charleston, SC, USA.
28. No-till Farming in South Asia's Rice-Wheat System, 20-21 February 2002, Columbus, OH.
29. Effect of Land Use and Management on Erosion and Carbon Sequestration, 23-28 September 2002, Montpellier, France.
30. Climate Change and Global Food Security, 9-10 June 2003, Columbus, OH.
31. The Potential of Soils of Latin America to Sequester Carbon and Mitigate the Climate Change.
32. OSU/USP/IRD, Piracicaba, São Paulo, 2-5 June 2004, Brazil.
33. Soil Carbon Sequestration in Central Asia, 2-4 November 2005, Columbus, OH.

34. Regional Symposium on Climate Change, Food Security, Sea Level Rise and Environment in South Asia, 25-29 August, Dhaka, Bangladesh.

Research Grants Since 1982 (Total to date $10.7 million)

1. United Nations University, Tokyo, Japan ($1.1 million) 1983-1988
2. GTZ, Germany, ($50,000/yr.) 1982-1987
3. United Nations University, Tokyo, Japan ($30,000) 1988-1991
4. Proctor and Gamble
   • Support grant ($15,000) 1987
   • Soil Physical properties ($50,000), 1992 (Co-PI)
5. USAID Funding for three conferences
   • Sustainable Agric. ($30,000) 1988
   • ISTRO ($30,000) 1991
   • Soil Management ($22,500) 1993
6. Rockefeller Foundation ($50,000) 1992-1993
7. US-EPA ($50,000) 1991-1993
8. USDA:
   • Technical Brochure ($50,000) 1993-1994
   • N-use efficiency ($50,000) 1991-1993
9. Sustainable Agriculture-NC Region ($38,000/yr.) 1988-1989
10. Sustainable Agriculture-NC Region ($40,000/yr.) 1989-1990
11. Special grant from IITA, ($50,000) 1991-1992
12. Participants in Principal Multidisciplinary Grant Proposals
    • MSEA ($350,000) 1991-1992, ($360,000) 1992-1993
    • FGD ($217,371) 1991-1995
13. Conference grants
    • UNDP ($30,000) 1991
    • Soil Sci. Soc. Am. ($5,000) 1991
    • CTA-Holland ($5,000) 1991
    • USDA-USEPA ($100,000) 1993
14. SANREM Planning Grant ($150,000) 1991-1992
15. SCS, Soil Erosion And Global Change, ($100,000), 1994-96
16. Research Council of Norway, $60,000/yr for 3 years (1993-95)
17. U.S.-Hungary Fund $20,000, 1994
18. USDA, Carbon Sequestration in Soils, $30,000, 1996-97
19. USDA, ARS/FS international symposium, $35,000, 1995-96
20. SSSA international symposium, $6,000, 1996
21. FGD Grant (Co-PI), $265,507, 1996-98
22. Lockhead Martin Energy System Inc. 1997-2000 ($148,000)
23. USDA-NRCS: Land use and C dynamic 1997-98 ($48,000)
24. GTZ conference grant, Tunisia 1997 ($8,200)
25. USDA-NRCS conference grant, 1997 ($60,000)
26. USDA-NRCS Research Bulletin, 1997 ($26,328)
27. USDA-NRCS: Soil Erosion and C Dynamics 1997-98 ($40,000)
28. USDA-NRCS: Soil Management for C Sequestration, 1998-99 ($250,000)
29. USDA-ERS: Soil degradation assessment, 1998-99 ($40,000)
30. USDA-NRCS: Soils and Greenhouse Effect, 1999-2000 ($120,000)
31. USDA-SMSS: Conference grant for “Land Degradation” Thailand, 1998-1999 ($12,000)
32. USDA-NRCS: State of Soil Degradation, 1999 ($25,000)
33. USDA-ERS: Soil Degradation, 1999 ($25,000)
34. Lockhead Martin Energy System Inc., 1999 ($28,000)

35. DOE, Center for Global Change Cooperator, 1999 ($29,500)
36. USDA-NRCS: Soils and Greenhouse Effect, 2000-2001 ($120,000)
37. USDA-NRCS: Land Use and Carbon Dynamics, 2000 ($25,000)
38. The Nature Conservancy, Soil C Dynamics in Fish Creek Watershed, Phase I, 2000 ($37,000)
39. DOE, Soil Carbon on Disturbed Lands, 2000 ($20,000)
40. CAS MGS, 2000 ($23,000)
41. Congressional appropriation to CASMGS group of 12 universities ($15 million) with OSU share of $0.8 million/yr
42. JRD Tata Trust, India Program, $467,000 for 3 years (2000-2003)
43. OARDC-Multidisciplinary Research Award, 2001 ($100,000)
44. USDA-NRCS funds for Soils and Greenhouse Effect 2001-2002 ($120,000)
45. Los Alamos National Laboratory, 2001 ($50,000)
46. Ohio Coal Development Office, 2002-2004 ($600,000)
47. USDA-NRCS, Soils and Greenhouse Effect, 2002-2003 ($80,000)
48. Office of Research, OSU, 2001-2002 ($50,000)
49. The Mershon Center, 2002-2003 ($37,000)
50. American Electric Power in collaboration with LANL, 2003-2005 ($220,000 for three years, Co-PI)
51. Center for Development of Agriculture and Forestry, D.R., $594,000 (Co-PI)
52. Los Alamos National Lab, 2002-2003 ($60,000)
53. Office of Research, OSU, 2002-2003 ($50,000)
54. Office of International Affairs, OSU, 2001-2004 ($40,000/yr)
55. National Energy Tech Lab, 2003-2006 ($600,000)
56. DOE, Midwestern Regional Carbon Sequestration Partnership, 2003-2005 ($2.4 million for two years; co-PI with Battelle as PI)
57. C-Site grant with PNNL, 2002-2003 ($60,000)
58. C-Site grant with ORNL, 2004-2006 ($56,000/yr for 3 yrs)
59. LANL grant, 2003-2004 ($70,000)
60. CASMGS 2-year grant, 2002-2004 ($800,000)
61. USDA-NRCS, 2002-2004 ($20,000)
62. U.S. Army Corp of Engineers, 2004 ($20,000)
63. C-Site grant with PNNL, 2004-2005 ($32,000/yr for 3 years)
64. DOE, Midwestern Regional Carbon Sequestration Partnership, 2005-2009 ($14 million for four years, co-PI with Battelle for OSU share of $1.2 million)
65. Targeted Investment in Excellence (TIE), Climate, Water and Carbon Project, OSU, $10 million over 5 years (2006-2010)
66. OCDO, Carbon sequestration in minesoils, $405,000 over 3 years (2008-2010)

Teaching Experience

- Soil and Water Conservation, Ibadan, Nigeria, 1976-1986.
- Soil and Water Conservation, Univ. of Maracay, Venezuela, 1978.
- Soil Management (Agron 442, 5 Cr.), 1988.
- Soil Physics (Agron, Soil Sci. 671, 5 Cr.), 1988-to date.
- Advanced Soil Physics (Agron 871, 3 Cr.), 1989-to date.
- Soil and Water Conservation, Training Course, India, 1994.
- Tropical Soils (Agron 643, 3 Cr.), 1993.
- Soil Degradation and Conservation In The Tropics, Ohio State/Univ. Hohenheim, Germany, 1994-1996.
- Soil Physics course (Pakistan Agric. Res. Board, Faisalabad, March-April, 1997).
- Global Land Degradation (NR797, 3 cr), 1999-to date.
- Soils and the Greenhouse Effect (Soil Sci 871, 3 cr), 1999-2003 (alternate years).
- Environmental Hot Spots: Middle East & Africa (NR693, 3 cr), 1999-2000.
- Climate Change, Science, Policy and Human Dimension (Intl. Studies, 3 cr), 2002-2003.
- Soils and Climate Change ENR 871, since 2008 and jointly with School of Earth Sciences, beginning Winter 2009.

Consultancies with International Organizations

1. FAO/UNDP, Rome, Italy (1977, 1991, 1994, 1997; 2001; India)

2. World Bank, Washington (1988, 1989, 1997, 1998,2008, India; 1986, 1996, Brazil; 1997, Pakistan; 1988, 1993 Washington; 2001, Morocco,)
3. GTZ, Germany (1992, Colombia)
4. USAID, Morocco (1990)
5. CIAT, Colombia (1992, 1996)
6. United Nations University (1983, 1990)
7. EMBRAPA - Brazil (1985, 1996)
8. UNEP, Nairobi, Kenya (1991)
9. USAID, member of the CRSP review team (l994)
10. NORAD (1992, 1993, 1994, 1995, Tanzania)
11. NATP-ICAR, India (1997-1998)
12. DOE, Washington (1998)
13. Asian Development Bank, Mania, Philippines (1998)
14. Los Alamos National Laboratory, Member of the Review Panel (2001-2004)
15. Winrock International, Uzbekistan 14-23 October 2002
16. CIMMYT Review, Team Leader, for Resource Management Program, 2008.
17. UNCCD position paper "Inter-Government Panel on Soil Sustainability" (IPSS) (2009)

Countries Visited on Official Missions

(a) Africa
Algeria, Benin, Burundi, Burkina Faso, Cameroon, Congo, Egypt, Ethiopia, Ghana, Ivory Coast, Kenya, Liberia, Libya, Madagascar, Malawi, Mali, Morocco, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Tunisia, Uganda, Zaire, Zambia, Zimbabwe

(b) Asia
Bangladesh, China, Dubai, India, Indonesia, Israel, Japan, Kuwait, Kajkastan, Lebanon, Malaysia, Pakistan, Philippines, South Korea, Sri Lanka, Syria, Taiwan, Thailand, Turkey, UAE, Uzbekistan

(c) South America
Argentina, Brazil, Colombia, Ecuador, Peru, Venezuela

(d) Central America
Costa Rica, Guatemala, Honduras, Nicaragua

(e) Caribbean
Dominican Republic, Haiti, Puerto Rico, Trinidad & Tobago

(f) North America
Canada, Mexico, USA

(g) Europe
Austria, Belgium, Denmark, France, Georgia, Germany, Greece, Holland, Hungary, Iceland, Italy, Norway, Poland, Portugal, Russia, Slovakia, Spain, Sweden, Switzerland, Turkey, U.K., USSR

(h) Pacific
Australia, Fiji, New Zealand

Service to The Ohio State University Community

- Member Int'l Advisory Committee, College of Food, Agric. & Env. Science, 1988-90.
- Member, Int'l Committee on Project Reinvent, 1996-98.
- Member, Graduate Studies Committee of Soil Science (1988-89; 1991-92; 1996-97; 1998-99); Environmental Science (1996-98) and Natural Resources (1996-98).

- Member, Faculty Council, College of Food, Agric. & Env. Science (1996-98).
- Graduate Associates and Fellowship Committee of the University (1996-98,2004-2006).
- Member, Univ. Postdoctoral Fellowship Committee (1989-90; 1994-95).
- University Distinguished Scholar Award Committee (1998-2000).
- Honorary Doctorate Degrees in Soil Science and Natural Resources (12 nominees processed and awarded from (1989-2004).
- Member, Policy and Standard Committee, Faculty Council (1997-2000).
- Member, India Cooperative Program Steering Committee (Visited India with President Kirwan and have since developed collaborative programs with PAU and ICAR) (1998-to date).
- Member, Screening Committee, Associate Provost International Affairs (2000).
- Member, Selection Committee, Anderson Chair, FAES, (2000, 2004).
- Member, South Asia committee, OIA (2001-2003).
- Member, Advisory Committee, Center for African Studies (2002-2003).
- Coordinator, OSU-CASMGS program (2000-2004).
- Coordinator, CCERI (Office of Research): 2001-2003.
- Faculty Coordinator, Climate Change CIRIT (OIA) (2002-2006).
- Coordinator, OSU/Battelle Project on MRCSP (2003-2009).
- Member, OSU Honorary Degree Committee (2004-2007).
- Member, Research and Graduate Council (2004- 2006).
- Member, University Senate (2007-2009).
- Member, Senate Steering Committee (2007-2009).
- Member Faculty Cabinet (2007-2009).
- Member Faculty Council (2007-2009).
- Member University Research Committee (2007-2009).
- Chair, Honorary Degree Committee (2007-2009).
- Member, Graduate Council (2008-2010).

Cooperation With Overseas Universities

(a) Europe

1. Agricultural University of Norway, As, Norway (program on agricultural sustainability in Africa, 1993-to date).
2. University of Hohenheim, Stuttgart, Germany (program on soil erosion in the Andes, Colombia, 1992-1997).
3. Ministry of Environment and Regional Policy, and The Hungarian Academy of Sciences, Budapest, Hungary, (cooperative program on conservation tillage, 1994-1996).
4. Univ. of Ghent, Belgium, Assoc. Expert Program (1976-87).
5. Univ. of Munich and Gottingen, Assoc. Expert Program (1983-87).
6. Univ. of Reading, U.K. (1976-86).
7. Institute of Land Reclamation and Grassland Farming, Falenty, Poland (2000-to date).
8. IRD/CIRAD France (2002-to date)
9. Soil Conservation Service of Iceland (2002-to date)
10. University of Iceland (2007-to date).

(b) Africa

1. Sokoine Univ. of Agric., Morogoro, Tanzania (1980-85, 1994-97).
2. Univ. of Ibadan, Nigeria (1970-87).
3. Univ. of Ghana, Legon (1974-80; 1996-97).

(c) Asia

1. Univ. Putra. Malaysia, Kuala Lampur (external faculty reviewer, 1995- to date).
2. Tamil Nadu Agric. Univ., Coimbatore, India (1998- to date).
3. ANGR Agric. Univ., Hyderabad, India (1998- to date).
4. Indian Institute of Technology, Kharagpur, India (1997- to date).
5. Punjab Agricultural University, Ludhiana, India (1998 - to date).
6. Haryana Agricultural University, Hisar, India (1998 - to date).
7. JLNKVV, Jabalpur, India (2001 - to date).
8. M.S. Swaminathan Res. Foundation (2000 - to date).

9. University of Agriculture, Faisalabad, Pakistan (1997 - to date).
10. Indian Council of Agricultural Research (1995- to date).
11. Tashkent Institute of Irrigation & Agricultural Mechanics, Uzbekistan (2002- to date).

(d) South America
1. Univ. of Palmira, Colombia (1997- to date).
2. Univ. of Piracicaba, Brazil (1997- to date).
3. Univ. of Bahia Blanca, Argentina (1995).
4. Universidad de Buenos Aires, Argentina (2000).
5. Univ. Of Audonoma de Santo Domingo, D.R. (2002-2005).
6. Center Para El Desaprollo Agropecuario y Forestal, Inc., D.R. (2002-2005).

Major Interests

(a) Research
Climate change and land use, soil processes and greenhouse effect, soil erosion and greenhouse gas emissions, soil C sequestration, sustainable management of soil and water resources, restoration and rehabilitation of degraded lands and mine lands, soil and water conservation, soil structure and compaction, conservation tillage, natural resources management with particular emphasis on food security in relation to environment quality, soil degradation and food security.

(b) International agriculture
Agriculture development in the third world, particularly through research on sustainable management of natural resources, soil productivity and environmental quality, and institutional building.

Graduate Student Research Supervision

M.Sc..…	40 (from 17 countries)
Ph.D..	40 (from 17 countries)
Special trainees (non-degree)…………………	18 (from India/ NATP/ World Bank)

Postdoctoral Research Supervision and Visiting Scientists

Postdoctoral..	41 (from 24 countries)
Visiting Scientists and Special Trainer..............	46 (from 17 countries)

Testimony to U.S. Congressional Briefings and Senate Hearings

1. Lal, R, 1999. Policy implications for soil carbon sequestration. Congressional Briefing, 3 August 1999, Hart Senate Office Building, Washington, D.C.
2. Lal, R. 1999. Soil management for achieving global food security and mitigating the greenhouse effect. Cannon House Office Building, 18 October 1999, Washington, D.C.
3. Lal, R. 2001. Importance of soil carbon in mitigating global warming. Senate Hearing, EPW Committee. Senate Office Building, 30 April 2001, Washington, D.C.
4. Lal, R. 2000. Senate Agricultural Sub-Committee, 4 May, 2000, Washington, D.C.
5. Lal, R. 2001. Soil Carbon sequestration and climate change. Senate Hearing. Science and Technical Sub-Committee, 24, May, 2001, Washington, D.C.
6. Lal, R. 2003. Potential of agricultural sequestration to address climate change. Senate Committee on Environments and Public Works. 8 July 2003, Dirksen Senate Office Building, Washington, D.C.
7. Lal, R. 2006. House Soil Caucus,8 December, Cannon House Office Building, Washington, D.C.

Soils Resolution

As President of the Soil Science Society of America (2007), Prof. Lal spearheaded the “Soils Resolution” for adoption by the U.S. Senate. The Resolution “Recognizing Soils As An Essential Natural Resource” (S.R. 401) was adopted unanimously by the U.S. Senate on 23 June, 2008. This Resolution is the first of its kind adopted by any government.

Some Notable Publications Books

1. Lal, R. 1987. Tropical Ecology and Physical Edaphology. J. Wiley & Sons, Chicker, U.K., 732pp.
2. Lal, R. 1994. Methods and Guidelines for Assessing Sustainable Use of Soil and Water resources in the tropics. USDA/SMSS Soil Bull. 21, Washington, D.C.
3. Portuguese Edition (2000): Metodos para a Availicao do Uso Sustentavel dos Agua nos Tropicos." ISSN 15164691, EMBRAPA, Brazil.
4. Spanish Edition (2004) "Metodos y Normas Para Evaluar El Uso Sostenible De Los Recursos Suelo y Agua En El Tropico." CORPOSCA, Columbia.
5. Lal, R. 2002 (Ed) Encyclopedia of Soil Science. Marcel Dekker, New York, 1476 pp (2nd edition, Dec. 2005).
6. Lal, R. and M.K. Shukla. 2004. Principles of Soil Physics. Marcel Dekker, New York, 716 pp.
7. H. Blanco-Canqui and R. Lal. 2008. Principles of Soil Conservation and Management. Springer Verlaag, Germany.

Journal Articles

8. Lal, R. 1986. Soil surface management in the tropics for intensive land use and high and sustained production. Adv. In Soil. Sci. 5: 1-105.
9. Lal, R. 1987. Managing soils of sub-Saharan Africa. Science 236: 1069-1076.
10. Lal, R. 1989. Conservation tillage for sustainable agriculture. Adv in Agron. 2:85-197.
11. Lal, R. 1997. Degradation and resilience of soils. Phil. Tans. Royal Soc. Lond B. 352: 987-1010.
12. Lal, R. 1995. Erosion Crop productivity relationships for soils of Africa. Soil Sci. Soc. Am. J. 59: 661-667.
13. Lal, R. 2001. Managing World Soils for food security and environmental quality. Adv in Agron. 74: 155-192.
14. Lal, R., M. Griffin, J. Apt., L. Lave and M. Granger. 2004. Managing soil carbon. Science 304, 393.
15. Lal, R.2004. Soil carbon sequestration impacts on global climate change and food security. Science 304: 1623-1627.
16. Lal, R. 2008. Carbon sequestration. Phil. Trans. Royal Soc. (B) 363: 815-830.
17. Lal, R. 2008. Sequestration of Atmospheric CO2 in global C pools. Energy & Env. Sci. 1: 86-100.

Some Invited/Keynote Presentations Since 1990

- Soil research for agricultural sustainability in the tropics, NRC/NAS, November 13-15, 1990, Washington, D.C.
- Sustainable management of soils of sub-Saharan Africa, UNU/NUEP, August 27-28, 1991, Nairobi, Kenya.
- Food production and environmental concerns regarding agricultural development in the tropics. 27th Annual conf., Intl. Agric. And Rural Dev. (AIARD), USAID, 9-11 June, 1991, Washington, D.C.
- Soil Conservation and Biodiversity. CAB International/Intl Council of Scientific Union, Third World Acad. of Sciences, 26-27 July 1990, London, U.K.
- Degradation and resilience of soils, The Royal Society, December 4-6, 1996, London, U.K.
- Managing tropical soil resources for food security and environmental quality, Brazilian Academy of Sciences Third World Acad. Sciences, September 6-10, 1997, Rio, Brazil.
- Agronomic consequences of soil erosion. IBSRAM, Bogar, 17-20 Nov. 1997, Indonesia.
- Soil management and the greenhouse effect, The Keystone Center, Arlie House, March 10-13, 1997, Warrentown, VA.
- Soils and the greenhouse effect, Summit on Food, Fiber and Environment, July 26-28, 1998, St. Louis, MO.
- Agricultural intensification for food security and environment quality. 90th Annual meeting of ASA, 18-22 October 1998, Baltimore, MD.
- Sustainability of agriculture in Asia, in "Rural Asia: Beyond the Green Revolution," The Asian Development Bank, 29 April, 1999, Manila, Philippines.
- Soil management for food security and environment quality, in "Feeding the World, Past, Present and Future," XVI International Botanical Congress, August 1-7, 1999, St. Louis, MO.
- Soils and nutrient balances: Raising agricultural productivity in the tropics, Harvard University, JFK School of Government, October 16-17, 2000, Boston, MA.
- Sustainable management of natural resources in India for food security and environment quality, 88th Session of India Science Congress, January 3-7, 2001, New Delhi, India.
- Soils: Challenges and research needs, NRC Workshop on "Opportunities in Agriculture: A vision for USDA

Food and Agricultural Research in the 21st Century, " May 22-23, 2001, NRC/NSA, Washington, D.C.

- Soil degradation: a serious problem or a storm in the tea cup. USDA-ERS, 16 April 2001, Washington, D.C.
- Conservation tillage in tropical agro-ecosystems, American Society of Agronomy, November 10-14, 2002, Indianapolis, IN.
- Agriculture, land use and sustainability, Carnegie Melon/World Bank, June 26-27, 2003, Washington, D.C.
- Linking global food security with climate change, Inaugural William Larson/Ray Allmaras Lecture, Department of soils, University of Minnesota, April 4, 2003, St Paul, MN.
- Soil carbon and climate change, Willie Woltz Lecture, March 29-30, 2004, NCSU, Raleigh, NC.
- Terrestrial carbon and climate change, 25th Anniversary Sigma Xi Lecture, Univ. of Toledo, April 23, 2004, Toledo, OH.
- Climate change and global food security, University of Florida, 2004, Gainesville, FL.
- Global food security and soil management, Pierre Soil Science Lecture, Iowa State University, November 16, 2004, Ames, IA.
- Soil conservation for global food security and mitigating climate change. "Strategies, Science and Laws of the Conservation of World Soil Resource", 14-18 Sept. 2005, Reykjavik, Iceland.
- Potential of degraded soils as source of feedstock for biofuel production. Scientific and Technical Advisory Panel of the Global Environment Facility (STAP/FEF) "Liquid Biofuels", 29 August- 1 Sept., 2005, IIT/UNDB, New Delhi, India.
- Sustainable horticulture and natural resource management. Intl. Hort. Conf., 13-19 August 2006, Seoul, Korea.
- Soil restoration to mitigate global climate change and advance food security, Presidential Lecture Series (Current Trends), 19 May 2006.
- Desertification control to sequester carbon and enhance productivity. GEF Third General Assembly, 28-30 August 2006, Cape Town, South Africa.
- Interactive effects of desertification on global climate change and food security. UNU Desertification Conference, 17-19 December 2006, Algiers, Algeria.
- Reasons for lack of adoption of improved technology in Sub-Saharan Africa, World Agric. Forum, 8-10 May 2007, St. Louis, MO.
- The impact on soil organic matter and carbon cycles of land use changes. European Commission, 15 June 2007, Brussels, Belgium.
- Biofuels, is all gold that glitters. Green Week, European Commission, 13-16 June 2007, Brussels, Belgium.
- Soil science in the 21st century. 60th Anniversary of the Brazilian Soc. of Soil Sci., 5-10 August, 2007, Granada, RS, Brazil.
- Mitigating climate change through combating soil degradation and desertification. Soils, Society and Global Change. 31 August-4 Sept. 2007, Selfos, Iceland.
- Managing soil quality to mitigate climate change and advance food security. IACA, 12-4 November, Vienna, Austria.
- Carbon sequestration in world soils, European Sci. Foundation, 20-22 Nov., 2007, Pont-a'-Moussem, France
- Organic residues management and tropical soil functioning. IAD, 3-8 Dec. 2007, Antananarivo, Madagascar.
- Managing soils for climate change mitigation and adaptation, 3-4 March 2008, FAO, Rome, Italy.
- Sustaining soil quality in a warming planet, NAS, 18 July 2008, Washington, D.C.
- World agricultural production and climate change. Royal Swedish Academy of Sciences, Stockholm, Sweden.
- Restoring degraded soils for advancing food security and mitigating climate change. 11th Natl. Soil Sci. Cong., 24-27 Sept., Beijing, China.
- Role of soils and fertilizers in managing climate change, AAPRI, Tsukuba, 21-22 October 2008, Japan.

Grants Received by Prof. Rattan Lal Since 1982 ($25 million)

Year	Sponsoring Organization	Duration (yrs)	Amount US $
1982	GTZ, Germany	1982-1987 (5)	250,000
1983	UNU, Tokyo, Japan	1983-1988 (5)	1,100,000
1987	Proctor & Gamble	1987 (1)	15,000
1988	UNU, Tokyo, Japan	1988-1991 (3)	30,000
1988	ASAID, Washington, D.C.	1988-1993 (5)	88,500
1988	SAREC, Sustainable Agric.	1988-1991 (3)	78,000
1991	USDA/NRCS, Washington, D.C.	1991-1994 (3)	100,000
1991	OCDO, Columbus, OH (a collaborator)	1991-1995 (5)	271,371
1991	ISTRO Conference Grant	1991(1)	40,000
1991	USAID - SANREM CRSP	1994-1992 (1)	150,000
1992	MSEA, USDA (a collaborator)	1992-1993 (2)	360,000
1992	The Rockefeller Foundation	1992-1993 (1)	50,000
1993	US-EPA, Washington, D.C.	1993 (1)	50,000
1993	NORAD - Norway	1993-1995 (3)	180,000
1993	USDA - NRCS/FS	1995-1997 (2)	65,000
1993	USDA - NRCS/USEPA	1993 (1)	100,000
1996	SSSA, Madison, WI	1996 (1)	5,000
1996	OCDO, Columbus, OH (a collaborator)	1996-1998 (3)	265,507
1997	Lockhead Martin Energy Inc.	1997-2000 (3)	176,000
1997	GTZ, Germany	1997 (1)	8,200
1997	USDA - NRCS, Washington, D.C.	1997-2004 (7)	938,328
1999	USDA - ERS, Washington, D.C.	1999 (1)	29,500
1999	DOE/PNNL	1999-2004 (5)	145,500
2000	CASMGS (CSREES)	2000-2005 (5)	823,000
2000	JRD Tata Trust (India Program)	2000-2005 (5)	467,000
2001	OARDC/OSU Grants/Mershon Center	2001-2005 (4)	327,000
2001	LANL, New Mexico	2001-2004 (3)	180,000
2002	OCDO, Columbus, OH	2002-2004 (3)	600,000
2003	DOE/MRCSP (Co-PI with Battelle)	2003-2005 (2)	2,400,000
2003	DOE/NETL, Pittsburgh	2003-2006 (3)	600,000
2003	D.R. Center for Agriculture & Forestry (Co-PI)	2003-2006 (3)	594,000
2004	DOE/NETL, Pittsburgh	2004-2006 (2)	551,719
2004	U.S. Army Corps of Engineers	2004-2005 (2)	20,000
2005	DOE/MRCSP (Co-PI with Battelle)	2005-2009 (4)	14,000,000
2007	CWC-TIE		12,000,000
2008	OCDO, Columbus, OH		405,000
	Total		**$37,463,625**

International Thermatic Conferences Organized by Prof. Rattan Lal

	Theme	Period	Venue	Number
1	**Soil degradation, erosion**	**1975-1987**	**Nigeria, Indonesia, Thailand**	**5**
2	**Sustainable agriculture**	**1988-1993**	**USA, Nigeria**	**6**
3	**Tropical Soils**	**1989-1993**	**USA, Columbia**	**4**

4	**Soil and water quality**	**1995-1996**	**USA, Canada**	**2**
5	**Soil carbon dynamics and climate change**	**1995-2008**	**USA, Brazil, Morocco, France, C. Asia, Bangladesh, India**	**13**
6	**Global food security**	**1995-2004**	**USA**	**4**
		Total		**34**

Year	Books Written	Books Edited	Refereed Journal Articles	Chapters in Multi-authored books	Invited Keynote presentations	Contributory Papers	Miscellaneous Publications	Total
2009	1	2	51	5	6	-	-	65
2008	1	1	30	8	23	13	9	85
2007	0	2	43	9	11	9	15	89
2006	0	2	25	25	15	2	0	69
2005	0	3	31	12	12	0	1	59
2004	1	1	22	8	9	7	5	53
2003	1	0	18	5	6	1	0	31
2002	0	4	10	28	6	5	2	55
2001	0	3	19	15	9	1	5	52
2000	0	3	16	20	18	3	6	66
1999	0	2	16	13	21	4	1	57
1998	1	4	16	29	14	5	5	74
1997	0	1	21	3	6	5	0	36
1996	0	0	12	3	8	3	1	27
1995	1	4	16	17	2	1	0	41
1994	2	2	6	10	10	1	0	31
1993	0	1	9	11	7	1	3	32
1992	0	2	9	2	2	2	2	19
1991	0	1	11	10	7	8	3	40
1990	1	1	11	3	10	1	4	31
1989	0	1	25	2	1	3	0	32
1988	1	0	5	12	4	12	1	35
1987	1	1	12	4	6	0	5	29
1986	0	1	16	6	8	0	0	31
1985	0	0	7	0	12	3	0	22
1984	0	0	14	2	8	4	0	28
1983	0	0	11	0	5	5	1	22
1982	0	0	7	0	4	5	0	16
1981	1	1	7	6	1	0	0	16
1980	0	0	6	12	1	7	0	26
1979	0	2	8	10	2	1	3	26
1978	0	0	7	4	2	1	0	14
1977	1	0	1	6	3	1	0	12
1976	0	0	8	2	2	2	1	15
1975	0	0	1	0	1	3	2	7
1974	0	0	5	1	2	2	0	10
1973	0	0	1	0	0	0	0	1
1972	0	0	1	0	0	0	0	1
1971	0	0	2	0	0	0	0	2
1970	0	0	4	0	0	0	0	4
1969	0	0	1	0	0	0	0	1
1967	0	0	1	0	0	0	0	1
Total	13	43	542	303	265	121	75	1362

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Education

B.S. Brigham Young Univ., Provo, UT, 1992-1999 (Geography: GIS, Physical; Minor Botany). Senior thesis title: "Distribution of Terrestrial Impact Craters: Correlation with Geologic Structure". Advisor: Perry J. Hardin.

M.S. Univ. of South Carolina, Columbia, SC, 1999-2001 (Geography: GIS/Remote Sensing, Machine Learning, Urban Ecology). Thesis title: "Artificial Intelligence for Automated Housing Enumeration from Pan-Sharpened IKONOS Imagery". Advisor: John R. Jensen. Other committee members: David J. Cowen and Robert E. Lloyd, Dept. of Geography.

Ph.D. Univ. of South Carolina, Columbia, SC, 2001-2003 (Geography: GIS/Remote Sensing, Geocomputation, Biogeography). Dissertation title: "Data Mining to Identify Optimal Spatial Aggregation Scales and Input Features: Digital Image Classification with Topographic LIDAR and LIDAR Intensity Returns". Advisor: John R. Jensen. Other committee members: David J. Cowen and Michael E. Hodgson, Dept. of Geography; Ronald D. Bonnell, Dept. of Computer Science and Computer Engineering.

Academic Positions

Assistant Professor, Dept. of Geosciences, Univ. of Arkansas (Aug 2004 to present).

NASA ARC Program Manager, Dept. of Geography, Univ. of South Carolina (Jun 2001 to Aug 2004).

Instructor, Dept. of Geography, Univ. of South Carolina (Aug 2001 to Dec 2003).

Research Assistant, Dept. of Geography, Univ. of South Carolina (Aug 1999 to May 2001).

PUBLICATIONS

A. Refereed Journal Articles

1. Hodgson, M.E., J.R. Jensen, J.A. Tullis, K.D. Riordan and C.M. Archer, 2003, "Synergistic Use of LIDAR and Color Aerial Photography for Mapping Urban Parcel Imperviousness", *Photogrammetric Engineering and Remote Sensing* 69(9):973-980.

2. Tullis, J.A. and J.R. Jensen, 2003, "Expert System House Detection in High Spatial Resolution Imagery Using Size, Shape, and Context", *Geocarto International* 18(1):5-15.

3. Hodgson, M.E., J.R. Jensen, G.T. Raber, J.A. Tullis, B.A. Davis, G. Thompson and K. Schuckman, 2005, "An Evaluation of LIDAR-derived Elevation and Terrain Slope in Leaf-off Conditions", *Photogrammetric Engineering and Remote Sensing* 71(7):817-823.

4. Hadley, B.C., M. García-Quijano, J.R. Jensen and J.A. Tullis, 2005, "Empirical versus Model-based Atmospheric Correction of Digital Airborne Imaging Spectrometer Hyperspectral Data", *Geocarto International* 20(4):21-28.

5. Raber, G.T., J.R. Jensen, M.E. Hodgson, J.A. Tullis, B.A. Davis and J. Berglund, 2007, "Impact of Lidar Nominal Post-spacing on DEM Accuracy and Flood Zone Delineation", *Photogrammetric Engineering and Remote Sensing* 73(7):793-804.

6. Raber, G.T. and J.A. Tullis, 2007, "Rapid Assessment of Storm-Surge Inundation after Hurricane Katrina Utilizing a Modified Distance Interpolation Approach", *GIScience and Remote Sensing* 44(3):220-236.

7. Tullis, J.A., J.D. Cothren, D.E. Irwin, C. Yeager, W.F. Limp, J.M. Wilson, B.E. Gorham and S. Ogle, 2007, "Yearly Extraction of Central America's Land Cover for Carbon Flux Monitoring", *GIScience and Remote Sensing* 44(4):334-355.

8. Im, J., J.R. Jensen and J.A. Tullis, 2008, "Object-based Change Detection Using Correlation Image Analysis and Image Segmentation Techniques", *International Journal of Remote Sensing* 29(2):399-423.

9. Aquino, L.D., J.A. Tullis and F.M. Stephen, 2008, "Modeling Red Oak Borer (*Enaphalodes rufulus* Haldeman) Damage Using *In Situ* and Ancillary Landscape Data", *Forest Ecology and Management* 255:931-939.

10. Jensen, J.R., M.E. Hodgson, M. García-Quijano, J. Im and J.A. Tullis, 2009, "A Remote Sensing and GIS-assisted Spatial Decision Support System for Hazardous Waste Site Monitoring", *Photogrammetric Engineering and Remote Sensing* 75(2):169-177.

B. Refereed Journal Articles in Review or in Press

1. Tullis, J.A. and J.M. Defibaugh y Chávez, 2009, "Scale Management and Remote Sensor Synergy in Forest Monitoring", *Geography Compass* 3(1):154-170.

2. Riggins, J.J., J.A. Tullis and F.M. Stephen, 2009, "Per-segment Aboveground Forest Biomass Estimation Using LIDAR-derived Height Percentile Statistics", *GIScience and Remote Sensing*, in review.

3. Riggins, J.J., J.M. Defibaugh y Chávez, J.A. Tullis and F.M. Stephen, 2009, "Spectral Identification of Pre-visual Norther Red Oak (*Quercus rubra*) Foliar Symptoms Related to Oak Decline", *Southern Journal of Applied Forestry*, in review.

C. Book Chapters

1. Jensen, J.R., J.A. Tullis and Xueqiao Huang, 2005, "Information Extraction Using Artificial Intelligence", *Introductory Digital Image Processing* (J.R. Jensen), 3rd Ed., Upper Saddle River, NJ: Prentice Hall, 526 pages.

2. Jensen, J.R., M.E. Hodgson, J.A. Tullis and G.T. Raber, 2005 "Remote Sensing of Impervious Surfaces and Building Infrastructure", in *Geo-Spatial Technologies in Urban Environments* (R.R. Jensen, J.D. Gatrell and D. McLean, editors), New York, NY: Springer-Verlag, Inc., 176 pages.

3. Schill, S.R., D. Rundquist, A. Filippi, K. Kvamme, J. Cothren and J.A. Tullis, 2008, "In Situ Sensors and Field Methods", in *Manual of Remote Sensing: Platforms and Sensors* (M.W. Jackson, editor), Silver Springs, MD: American Society of Photogrammetry and Remote Sensing, in press.

D. Presentations at Meetings of Professional Societies (speaker underlined)

1. Tullis, J. A., 2001, "Expert System Identification of Houses in Satellite Imagery", *Bulletin of the South Carolina Academy of Science* LXIII:102.

2. Tullis, J. A., 2001, "IKONOS House Detection Using an Expert System", *ASPRS 2001 Annual Convention*, 23-27 April, St. Louis, Missouri (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

3. Hodgson, M.E., J.R. Jensen, G.T. Raber, J.A. Tullis, B.A. Davis, G. Thompson, L. Schmidt, and K. Schuckman, 2001, "An Evaluation of LIDAR- and IFSAR- derived Digital Elevation Models in Leaf-on Conditions with USGS Level 1 and Level 2 DEMs," *ASPRS/MAPPS Fall 2001 Terrain Mapping Conference*, 31 October-2 November, St. Petersburg, Florida (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), poster presentation.

4. Cowen, D.J., J.R. Jensen, W.L. Shirley and J.A. Tullis, 2002, "Use of IKONOS Data to Measure Housing Density", *Proceedings of the AAG 98th Annual Meeting*, 19-23 March, 2002, Los Angeles, California (Association of American Geographers, Washington, D.C.), unpaginated CD-ROM.

5. Tullis, J.A., D.J. Cowen, J.R. Jensen, W.L. Shirley and D.R. Morgan, 2002 "GIS and Remote Sensing for Smart Growth Research", *Proceedings of the ASPRS 2002 Annual Convention*, 19-26 April, Washington, D.C. (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM.

6. Raber, G.T., M.E. Hodgson, J.R. Jensen, J.A. Tullis, G. Thompson, B.A. Davis and K. Schuckman, 2002, "Comparison of LIDAR Data Collected Leaf-on vs. Leaf-off for the Creation of Digital Elevation Models", *Proceedings of the ASPRS 2002 Annual Convention*, 20-26 April (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM.

7. Hodgson, M.E., J.R. Jensen, J.A. Tullis, B.C. Hadley, C. Robinson, K.D. Riordan, G.T. Raber, and C.M. Archer, 2002, "The Use of LIDAR and Optical Remotely Sensed Data for Mapping Parcel Level Permeability", *ASPRS 2002 Annual Convention*, 20-26 April, Washington, D.C. (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

8. Jensen, J.R., M.E. Hodgson, G.T. Raber, J.A. Tullis and B.A. Davis, 2003, "LIDAR-Derived Elevation and Slope Accuracy in Leaf-on and Leaf-off Conditions", *Proceedings of the AAG 99th Annual Meeting*, 5-8 March, 2003, New Orleans, Louisiana (Association of American Geographers, Washington, D.C.), unpaginated CD-ROM.

9. Raber, G.T., M.E. Hodgson, J.A. Tullis, B.A. Davis, J. Dorman, 2003, "Effects of LIDAR Posting Density and Physiography on DEM Accuracy and Flood Risk", American Society for Photogrammetry and Remote Sensing, *ASPRS 2003 Annual Convention*, 5-9 May, Anchorage, Alaska (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

10. Tullis, J.A., J.R. Jensen, K.D. Riordan, G.T. Raber, A.M. Browne, J. Backman and D.R. Morgan, 2003, "Measurement of Impervious Surfaces for Stormwater Management Applications Using Digital Aerial Imagery, Topographic LIDAR, and LIDAR Intensity Returns", *Proceedings of the ASPRS 2003 Annual Convention*, 5-9 May, Anchorage, Alaska (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM.

11. Davis, B.A., J. Berglund, L. Estep, M.E. Hodgson, G.T. Raber, J.A. Tullis, D. Maidment, P. Gueudet, V. Fischer, D. Box, G. Thompson and J. Dorman, 2003, "The Relationship Between Optimal Post Density Spacing and Flood Model Performance", *ASPRS/MAPPS Fall 2003 Terrain Mapping Conference*, 27-30 October, Charleston, SC (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

12. Tullis, J.A., J.R. Jensen, M.E. Hodgson and G.T. Raber, 2004, "LIDAR Digital Elevation Model Accuracy as a Function of Posting Density and Land Cover Category", *Proceedings of the AAG 100th Annual Meeting*, 14-19 March, 2004, Philadelphia, Pennsylvania (Association of American Geographers, Washington, D.C.), unpaginated CD-ROM.

13. Raber, G.T., J.A. Tullis, and J.R. Jensen, 2004, "LIDAR Statistical Image Fusion with IKONOS Data for Land Cover Classification", *Proceedings of the AAG 100th Annual Meeting*, 14-19 March, 2004, Philadelphia, Pennsylvania (Association of American Geographers, Washington, D.C.), unpaginated CD-ROM.

14. Raber, G.T., J.R. Jensen, M.E. Hodgson, M.E. Meadows, J.A. Tullis, B.A. Davis, J. Berglund, and J. Dorman, 2004, "The Impact of Varied Nominal Posting Density Topographic LIDAR Data on DEM Accuracy, Hydraulic Modeling and Flood Mapping", *AWRA 2004 Spring Specialty Conference*: *Geographic Information Systems (GIS) and Water Resources III*, 17-19 May, Nashville, Tennessee (American Water Resources Association, Middleburg, Virginia).

15. Tullis, J.A., J.R. Jensen and G.T. Raber, 2004, "LIDAR Data Mining to Enhance Aerial Image Classification", *Proceedings of the ASPRS 2004 Annual Convention*, 23-28 May, 2004, Denver, Colorado (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM.

16. Vaughan, D., J.R. Jensen, D. Porter, S. Walker, B.C. Hadley and J.A. Tullis, 2004, "Hyperspectral Change Detection of Spartina alterniflora in Murrells Inlet, SC 1997-2003", *ASPRS 2004 Annual Convention*, 23-28 May, 2004, Denver, Colorado (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

17. Raber, G.T., M.E. Hodgson, J.R. Jensen and J.A. Tullis, 2004, "A Sensitivity Analysis Using Varied Nominal Posting Density LIDAR Data for Hydraulic Modeling and Flood Zone Delineation", *ASPRS 2004 Annual Convention*, 23-28 May, 2004, Denver, Colorado (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

18. Hodgson, M.E., J.R. Jensen, G.T. Raber, J.A. Tullis, B.A. Davis, J. Dorman and G. Thompson, 2004, "Parcel-level Zoning Decisions and LIDAR Collection Parameters", *ASPRS 2004 Annual Convention*, 23-28 May, 2004, Denver, Colorado (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

19. Hadley, B.C., J.R. Jensen, J.A. Tullis and J.B. Gladden, 2004, "Hyperspectral Turf Grass Biomass Predictions as a Function of Atmospheric Correction Technique", *ASPRS 2004 Annual Convention*, 23-28 May, 2004, Denver, Colorado (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

20. Tullis, J.A., J.R. Jensen, M.E. Hodgson, 2004, "A Local-to-national Partnership for Comparing USGS and LIDAR-derived Elevation Models as Inputs for Hurricane Storm Surge Prediction", *Proceedings of AmericaView 2004*, 20-22 September, 2004, Sioux Falls, South Dakota (AmericaView Program, USGS, Reston, Virginia).

21. Gorham, B., J.A. Tullis and L. Farley, 2005, "Mapping Arkansas' Ever-changing Landscape; Arkansas LULC Program: 1992-2004", *ASPRS 2005 Central Region Technical Session*, 11 February, 2005, Fayetteville, Arkansas (Central Region of the American Society for Photogrammetry and Remote Sensing, Rolla, Missouri).

22. Tullis, J.A., B. Gorham and L. Farley, 2005, "Arkansas' 2004 Land-use / Land-cover Mapping Using Decision Trees", *ASPRS 2005 Central Region Technical Session*, 11 February, 2005, Fayetteville, Arkansas (Central Region of the American Society for Photogrammetry and Remote Sensing, Rolla, Missouri).

23. Tullis, J.A., J.R. Jensen and M.E. Hodgson, 2005, "Sensitivity of Hurricane Storm Surge Predictions to DEM Input: LIDAR versus USGS", *ASPRS 2005 Annual Convention*, 7-11 March, 2005, Baltimore, Maryland (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

24. Raber, G.T. and J.A. Tullis, 2005, "The Combination of Multi-spectral and LIDAR Statistical Image Data for Mapping Surface Roughness Coefficients", *ASPRS 2005 Annual Convention*, 7-11 March, 2005, Baltimore, Maryland (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

25. Jensen, J.R., J.A. Tullis and J. Im, 2005, "Urban Remote Sensing", *Third International Symposium on Remote Sensing and Data Fusion Over Urban Areas* and *Fifth International Symposium on Remote Sensing of Urban Areas*, 15 March, 2005, Phoenix, Arizona.

26. Cowen, D.J., J.R. Jensen, M.E. Hodgson, E.T. Bramble, A. Goyal and J.A. Tullis, 2005, "Development and Calibration of a Cellular Automata Urban Growth Model", *Auto-Carto 2005 Research Symposium*, 21-23 March, Las Vegas, Nevada (Cartography and Geographic Information Society).

27. Im, J., J.R. Jensen and J.A. Tullis, 2005, "Development of a Remote Sensing Change Detection System Based on Neighborhood Correlation Image Analysis and Intelligent Knowledge-based Systems", *IEEE International Geoscience and Remote Sensing Symposium*, 27 July, 2005, Seoul, Korea.

28. Tullis, J.A., B.E. Gorham, J. Cothren and W.F. Limp, 2005, "Per-segment Decision Tree Classification in the Arkansas 2004 Land Cover Project", *GIS For Local Government Conference 2005*, 17-19 October, 2005, University Park, Pennsylvania (Penn State Cooperative Extension, Geospatial Technology Program).

29. Tullis, J.A., J.D. Cothren, W.F. Limp, J. Im and J.R. Jensen, 2005, "GIS Implementation of Machine Learning Decision Trees", *Proceedings of Arkansas GIS Users Forum Conference and Symposium 2005*, 2-4 November, 2005, Hot Springs, Arkansas (Arkansas GIS Users Forum, Arkansas).

30. Gorham, B. and J.A. Tullis, 2005, "Monitoring Changes on the Arkansas Landscape: Land-use and Land-cover Dynamics 1992-2004", *Proceedings of Arkansas GIS Users Forum Conference and Symposium 2005*, 2-4 November, 2005, Hot Springs, Arkansas (Arkansas GIS Users Forum, Arkansas).

31. Im, J., J.R. Jensen and J.A. Tullis, 2006, "Object-oriented Change Detection Based on Correlation Analysis and Image Segmentation", *Proceedings of the AAG 2006 Annual Meeting*, 7-11 March, 2006, Chicago, Illinois (Association of American Geographers, Washington, D.C.), unpaginated CD-ROM.

32. Smith, Z.D., J.A. Tullis, K.F. Steele, L. Malfavon, 2006, "Martian Sinkholes: Implications for Large Scale Evaporite Deposits", *Proceedings of the Lunar and Planetary Sciences XXXVII*, 13-17 March, 2006, Houston, Texas (Lunar and Planetary Institute).

33. Tullis, J.A., J.D. Cothren, J.R. Jensen, M.E. Hodgson, B.C. Hadley and M. García-Quijano, 2006, "Hurricane Storm Surge Prediction as a Function of DEM Input: Exploring a LIDAR-derived Alternate in Beaufort County, SC", *ASPRS 2006 Annual Convention*, 1-5 May, 2006, Reno, Nevada (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

34. Riggins, J.J., J.A. Tullis and F.M. Stephen, 2006, "Assessing Forest Health at the Speed of Light: Applying Remote Sensing Technology to a Destructive Forest Insect", *ESA Annual Meeting*, 10-13 December, 2006, Indianapolis, Indiana (Entomological Society of America).

35. Stephen, F.M., M. Fierke and J.A. Tullis, 2006, "Red Oak Borer in Ozark Forests: Tracking the Rise and Fall of a Native Tree-killing Cerambycid", *ESA Annual Meeting*, 10-13 December, 2006, Indianapolis, Indiana (Entomological Society of America).

36. Coleman, K.S.A. and J.A. Tullis, 2007, "Classification of Depression Types on Mars", *Proceedings of the Lunar and Planetary Sciences XXXVIII*, 12-16 March, 2007, League City, Texas (Lunar and Planetary Institute).

37. Gorham, B.E. and J.A. Tullis, 2007, "Landsat Legacy and the Arkansas Land-use, Land-cover Mapping Project", *AAG 103rd Annual Meeting*, 17-21 April, 2007, San Francisco, California (Association of American Geographers).

38. Knapp, J.P., J.J. Riggins, J. Defibaugh y Chávez, J.A. Tullis and F.M. Stephen, 2007, "Examination of Spectral Leaf Signature Collection Methods in a Complex Upland Oak Ecosystem", *AAG 103rd Annual Meeting*, 17-21 April, 2007, San Francisco, California (Association of American Geographers).

39. Tullis, J.A., J. Wilson, J. Defibaugh y Chávez, F.M. Stephen, M. Fierke and J. Riggins, 2007, "Remote Sensing-assisted Decision Support for Red Oak Borer Hazard Response in Upland Oak-hickory Forests", *ASPRS 2007 Annual Convention*, 7-11 May, 2007, Tampa, Florida (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

40. Riggins, J. J., F. M. Stephen and J. A. Tullis, 2007, "Seeing the Forest AND the Trees: High Resolution Remote Sensor Technology and a Destructive Forest Insect Pest", *50th Southern Forest Insect Work Conference*, 23-26 July, 2007, Jekyll Island, Georgia (University of Georgia, Athens, Georgia).

41. Riggins, J. J., F. M. Stephen and J. A. Tullis, 2007, "Estimation of Upland Oak Forest Biomass from LIDAR-derived Statistics", *Proceedings of AmericaView 2007*, 19-20 September, 2007, Fayetteville, Arkansas (AmericaView Program, USGS, Reston, Virginia).

42. Tullis, J.A., B. Culpepper, J. Defibaugh y Chávez, J.S. Jones, F.M. Stephen, J. Riggins, 2008, "Forest LIDAR-derived Statistical Enhancement of Oak Hazard Models", *ASPRS 2008 Annual Convention*, 28 April-2 May, 2008, Portland, Oregon (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland).

43. Stephen, F.M., M. Fierke, J. Guldin, L. Haavik, J. Riggins, J.A. Tullis, 2008, "Red Oak Borer as an Agent of Change in Arkansas Forests: an Historical Perspective", *International Congress of Entomology (ICE) XXIII*, 6-12 July, 2008, Durban, South Africa (Entomological Society of Southern Africa).

44. Tullis, J.A., J.S. Jones, J.M. Guldin, F.M. Stephen, B. Culpepper, P. Smith, 2009, "Integrated Remote Sensing-assisted Decision Support for Red Oak Borer Hazard Response", *AAG 2009 Annual Meeting*, 22-27 March, 2009, Las Vegas, Nevada (Association of American Geographers, Washington, D.C.).

E. Articles in Trade Periodicals

1. Ata, H.A., J.C. Cothren and J.A. Tullis, 2005, "QT Modeler 3.0", a review of a LIDAR visualization and analysis package developed by Johns Hopkins University Applied Physics Laboratory, *GeoWorld Magazine* (Mar).

2. Raber, G.T., J.A. Tullis and J.R. Jensen, 2005, "Remote Sensing Data Acquisition and Initial Processing", *Earth Observation Magazine* 14(5).

3. Limp, W.F., J.C. Cothren and J.A. Tullis, 2007, "New Analysis Tools – Expanded LIDAR Information Content Drives New Application Opportunities", *Earth Imaging Journal* (Jan/Feb).

TECHNICAL REPORTS

Tullis, J.A., W.L. Shirley and S. Vehige, 2001, "Evaluation of High Resolution Imagery as Part of an Automated Classification System to Assess Market Potential for Future Investment Brokerage Branch Offices", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 63 pages.

Raber, G.T., M.E. Hodgson and J.A. Tullis, 2002, "A Comparison of LIDAR-derived Elevation Accuracy in Leaf-on and Leaf-off Conditions", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 15 pages.

Tullis, J.A., B.C. Hadley, K.D. Riordan and C.M. Archer, 2002, "The Use of LIDAR and Remotely Sensed Imagery for Mapping Parcel Level Permeability", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 64 pages.

Cowen, D.J., W.L. Shirley and J.A. Tullis, 2002, "GIS and Remote Sensing in Support of Smart Growth Research", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 52 pages.

Jensen, J.R., B.C. Hadley, J.A. Tullis, J. Gladden, E. Nelson, S. Riley, T. Filippi, M. Pendergast, 2003, "2002 Hyperspectral Analysis of Hazardous Waste Sites on the Savannah River Site", *DOE Office of Science and Technology, Westinghouse Savannah River Company* Technical Report 2003-00275, Westinghouse Savannah River Company: Aiken, SC, 52 pages.

Goyal, A. and J.A. Tullis, 2003, "GIS and Remote Sensing in Support of Smart Growth Research – Phase II", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 36 pages.

Raber, G.T. and J.A. Tullis, 2003, "Effects of LIDAR Posting Density and Physiography on DTM Accuracy", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 7 pages.

Tullis, J.A., K.D. Riordan and A.M. Browne, 2003, "Measurement of Impervious Surfaces for Stormwater Management Applications Using Digital Aerial Imagery, Topographic LIDAR, and LIDAR Intensity Returns", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 74 pages.

Jensen, J.R., J.A. Tullis, M.J. García-Quijano, B.C. Hadley and J. Im, 2004, "Improved Management of Technological Hazards Focusing on the Development of a Remote Sensing-assisted Hazardous Waste Site Monitoring Decision Support System", *NASA Earth Science Enterprise, University of South Carolina Research, Education, and Application Solutions Network (REASoN)* Report, 28 pages.

Bramble, E.T. and J.A. Tullis, 2004, "GIS and Remote Sensing in Support of Smart Growth – Phase III", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 34 pages.

Tullis, J.A., 2004, "Predicted Storm Surge Inundation Boundaries: SLOSH Modeling with LIDAR-derived DEMs", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 17 pages.

Raber, G.T. and J.A. Tullis, 2004, "LIDAR Posting Density and Physiography: Effects on DTM Accuracy and Flood Zoning", *NASA Earth Science Enterprise, Earth Science Applications Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 57 pages.

Gorham, B.E. and J.A. Tullis, 2005, "ArkansasView Semiannual Report (January-June 2005)", *AmericaView* Progress Report, USGS: EROS Data Center, SD, 7 pages.

Tullis, J.A. and B.E. Gorham, 2005, "Arkansas LULC Mapping – Phases I – II", *Arkansas Soil and Water Conservation Commission* Final Report, Arkansas Soil and Water Conservation Commission: Little Rock, AR, 4 pages.

Bramble, E.T., K.C. Remington and J.A. Tullis, 2005, "GIS and Remote Sensing in Support of Smart Growth – Phase IV", *NASA Earth Science Enterprise, Applied Sciences Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 19 pages.

Tullis, J.A., B.C. Hadley, M. García-Quijano and Y. Greene, 2005, "Predicted Storm Surge Inundation Boundaries: SLOSH Modeling with LIDAR-derived DEMs – Phase II", *NASA Earth Science Enterprise, Applied Sciences Directorate, University of South Carolina Affiliated Research Center* Final Report, NASA: Stennis Space Center, MS, 29 pages.

Stephen, F.M., *et al.* and J.A. Tullis, 2005, "Development of Geospatial Techniques for the Prediction and Assessment of Red Oak Decline Due to Red Oak Borer", *USDA Forest Service Forest Health Monitoring Program, Evaluation Monitoring Project* Technical Report, USDA Forest Service: Atlanta, GA, 5 pages.

Stephen, F.M., *et al.* and J.A. Tullis, 2005, “Assessment, Analysis, and Monitoring of Red Oak Borer Populations”, *USDA Forest Service Special Technology Development Program* Technical Report, USDA Forest Service: Asheville, NC, 6 pages.

Tullis, J.A. and B.E. Gorham, 2006, “ArkansasView Semiannual Report (July-December 2005)”, *AmericaView* Progress Report, USGS: EROS Data Center, SD, 6 pages.

Tullis, J.A., 2006, “Intelligent Knowledge-based Systems for Data Integration” in “New Approaches to the Use and Integration of Multi-sensor Remote Sensing for Historic Resource Identification and Evaluation”, *Strategic Environmental Research and Development Program* (SERDP) Final Report by K.L. Kvamme, E. Ernenwein, M. Hargrave, T. Sever, D. Harmon, W.F. Limp, B. Howell, M. Koons and J.A. Tullis (2006), DOD, 13 pages.

Stephen, F.M., *et al.* and J.A. Tullis, 2006, “Development of Geospatial Techniques for the Prediction and Assessment of Red Oak Decline Due to Red Oak Borer”, *USDA Forest Service Forest Health Monitoring Program, Evaluation Monitoring Project* Technical Report, USDA Forest Service: Atlanta, GA, 8 pages.

Stephen, F.M., *et al.* and J.A. Tullis, 2006, “Assessment, Analysis, and Monitoring of Red Oak Borer Populations”, *USDA Forest Service Special Technology Development Program* Technical Report, USDA Forest Service: Asheville, NC, 9 pages.

Tullis, J.A. and B.E. Gorham, 2007, “ArkansasView Semiannual Report (July-December 2006)”, *AmericaView* Progress Report, USGS: EROS Data Center, SD, 11 pages.

Gorham, B.E. and J.A. Tullis, 2007, “Arkansas Land Use and Land Cover (LULC) 2006”, *Arkansas Natural Resource Commission* Final Report, Arkansas Natural Resource Commission: Little Rock, AR, 5 pages.

Tullis, J.A. and B.E. Gorham, 2008, “ArkansasView Semiannual Report (July-December 2007)”, *AmericaView* Progress Report, USGS: EROS Data Center, SD, 13 pages.

Gorham, B.E. and J.A. Tullis, 2008, “ArkansasView Semiannual Report (July-December 2008)”, *AmericaView* Progress Report, USGS: EROS Data Center, SD, 19 pages.

TEACHING

University of South Carolina

Digital Techniques of Remote Sensing Laboratory (GEOG 751 Lab; Fall 2001, Spring 2003).

Principles of Remote Sensing (GEOG 551; Spring 2002).

Principles of Remote Sensing Laboratory (GEOG 551 Lab; Spring 2002, Fall 2003).

University of Arkansas

Introduction to Raster GIS (ANTH/GEOG 4553; Fall 2004).

GIScience in Biogeography (GEOG 510V; Spring 2009).

Remote Sensing of Natural Resources (GEOL 5423; Spring 2005, 2007).

Principles of Remote Sensing (GEOL/GEOS 4413; Fall 2005; Fall 2006, 2007, 2008).

Vector GIS (ANTH 4563/GEOS 4583; Spring 2006, 2008, 2009).

[*Individual Studies in GIScience*] (ENDY/GEOS variable; Summer 2006, Fall 2006, Spring 2008).

GRADUATE STUDENT MENTORING

Advisees who Completed their Degree

Katherine S. Auld Coleman (M.S. Geology), "A Classification of Closed Depression Types on Mars", Department of Geosciences, University of Arkansas, Fayetteville, AR (Aug 2006).

Committee Service Completed

Michael S. Sarhan (M.A. Geography), "A Comparative Assessment of the Flooding Caused by Tropical Storm Jeanne in Haiti and the Dominican Republic" (Aug 2006).

Philip D. Tonimoto (Ph.D. Environmental Dynamics), "Advances in Biogeographic Modeling of Montane-obligate Avifauna in Mesoamerica" (Dec 2006).

Mark D. Spond (M.A. Geography), "Ancient Cypress-Tupelo Forest at the Dagmar Wildlife Management Area, Arkansas" (May 2007).

John V. Ward (Ph.D. Environmental Dynamics), "Changing Patterns of Land-use and Basin Morphometry: Impacts on Stream Geomorphology in the Illinois River Basin, Northwest Arkansas, 1941-2004" (Jul 2007).

Aaron D. Jensen (M.A. Geography), "Remote Sensing Analysis of Surface Temperature and Landscape Feature Dynamics" (Aug 2007).

Rana N. Al-Jawarneh (M.A. Geography), "Spatial Analysis of Land Cover and Land Use in Evaluating Land Degradation in Northwestern Al-Mafraq City, Jordan" (May 2008).

John J. Riggins (Ph.D. Entomology), "Remote Sensing of Forest Decline and *Enaphalodes Rufulus* Outbreak in the Arkansas Ozarks, U.S.A." (Jul 2008).

Jason Patton (Ph.D. Environmental Dynamics), "Comparative Sedimentation and Geochemistry of Three Coves, Beaver Reservoir, Northwest Arkansas" (Aug 2008).

Advisement

Jason Defibaugh y Chávez (Ph.D. Environmental Dynamics – Fall 2005 to Spring 2009).

Karl A. Lintvedt (M.A. Geography – Spring 2008 to Spring 2009).

Joshua S. Jones (M.A. Geography – Fall 2008 to Spring 2010).

Committee Service

Zola Moon (Ph.D. Environmental Dynamics).

John Dennis (Ph.D. Environmental Dynamics).

Dawn Farver (Ph.D. Environmental Engineering).

Katherine Coleman (Ph.D. Space and Planetary Sciences).

David McFee (M.A. Geography).

Chris Cerney (M.A. Geography).

Obadiah Kegege (Ph.D. Space and Planetary Sciences).

Chris W. Rogers (M.S. Crop, Soil, and Environmental Sciences).

Kwasi Asante (M.A. Geography).

Patricia Gavin (Ph.D. Space and Planetary Sciences).

Kelly Howe (Ph.D. Space and Planetary Sciences).

Carrie A. Davis (M.A. Geography).

Katie M. Simon (M.A. Anthropology).

OTHER MENTORING

Julia Danz (Department of Geosciences; *National Science Foundation Research Experience for Undergraduate* participant), analyzed a variety of Central American land cover maps, Summer 2005.

Zack D. Smith (Arkansas Center for Space and Planetary Sciences; *National Science Foundation Research Experience for Undergraduate* participant), investigated Martian geology, Summer 2005.

Luis Malfavon (University of Arkansas; *U.S. Department of Education Upward Bound* participant), investigated planetary remote sensing and GIS, Summer 2005.

Jonathan P. Knapp (Department of Geosciences; *National Science Foundation Research Experience for Undergraduate* participant), "Applying Remote Sensing to Northern Red Oak Decline in the Ozark National Forest: Preliminary Methods Evaluation", Summer 2006.

Adam W. Rollins (Department of Biological Sciences; *Arkansas Space Grant Consortium* participant), "Spatial and Temporal Dynamics of Red Spruce Population in the Central Appalachians", Apr 2007 to Apr 2008.

Daniel Sundara (University of Arkansas; *U.S. Department of Education Upward Bound* participant), investigated the geoweb and geospatial visualization, Summer 2007.

CONTRACTS & GRANTS

- Tullis, J.A. (*principal investigator*) and B. Gorham, "Arkansas Land-use / Land-cover Mapping with Machine Learning Decision Trees", *Arkansas Soil and Water Conservation Commission*, 1 Nov 2004 to 31 May 2005, **$46,411**.
- Limp, W.F., B.E. Gorham, and J.A. Tullis (*senior investigator beginning Sep 2004*), "ArkansasView", *US Geological Survey* & *AmericaView*, 1 Jul 2004 to 5 Jun 2005, **$89,496**.
- Stephen, F.M., W.F. Limp, J.A. Tullis (*senior investigator beginning Sep 2004*) and J. Wilson, "Development of Geospatial Techniques for the Prediction and Assessment of Red Oak Decline Due to Red Oak Borer", *US Forest Service*, 30 Jun 2004 to 30 Sep 2008, **$35,000**.
- Stahle, D.W. and J.A. Tullis (*co-principal investigator*), "The Distribution of Cross Timbers in Western Arkansas", *USDA Forest Service*, 1 Apr 2004 to 31 Dec 2010, **$11,019**.
- Limp, W.F., J.C. Cothren, J.A. Tullis (*senior investigator beginning Oct 2004*), *et al.*, "An Enterprise Geospatial Architecture and Development of Automated Analysis Methodologies for Central American Carbon Sequestration Analysis", *NASA*, 1 Oct 2004 to 30 Sep 2006, **$193,257**.
- Tullis, J.A. (*principal investigator*), K.F. Steele and G.T. Raber, "Search for Martian Sinkholes", *NASA* and *Arkansas Center for Space and Planetary Sciences*, 1 May 2005 to 30 Apr 2006, **$29,290**.

- Stephen, F.M., *et al.* and J.A. Tullis (*senior investigator beginning May 2005*), "Applied Silvicultural Assessment of Upland Oak-Hickory Forests and the Red Oak Borer in the Ozark and Ouachita Mountains of Arkansas", *USDA Forest Service*, 2005 to 2006, **$16,875** (subset of $249,042).

- Kvamme, K., *et al*. and J.A. Tullis (*senior investigator beginning Jul 2005*), "New Approaches to Use of Integration of Multi-sensor Remote Sensing", *US Department of Defense*, 18 Jun 2002 to 15 Dec 2005, **$5,000** (subset of total).

- Limp, W.F., J.A. Tullis (*co-principal investigator*) and B.E. Gorham, "ArkansasView Program Development and Operations", *US Geological Survey* & *AmericaView*, 1 Jul 2005 to 30 Jun 2006, **$89,500**.

- Tullis, J.A. (*principal investigator*), B.E. Gorham, W.F. Limp and R.K. Davis, "Arkansas Land Use and Land Cover 2006", *Arkansas Natural Resource Commission*, 1 Oct 2005 to 31 May 2007, **$62,188**.

- Stephen, F.M., M.K. Fierke and J.A. Tullis (*co-principal investigator*), "Applied Silvicultural Assessment (II) of Upland Oak-Hickory Forests and the Red Oak Borer in the Ozark and Ouachita Mountains of Arkansas", *USDA Forest Service*, 1 Oct 2006 to 30 Sep 2011, **$220,000**.

- Rollins, A.W., Stephenson, S.L. and J.A. Tullis (*faculty mentor*), "Spatial and Temporal Dynamics of Red Spruce Populations in the Central Appalachians", *NASA*, 15 Apr 2007 to 14 Apr 2008, **$2,382**.

- Inlander, E.M., Slay, M.E., Brahana, J.V., Tullis, J.A. (*participant*), *et al.*, "The Karst Conservation Toolbox: Advancing the Protection of Karst Species and Habitats Globally", *The Nature Conservancy*, 1 Jul 2007 to 30 Jun 2009, **$50,000**.

- Stephen, F.M. and J.A. Tullis (*co-principal investigator*), "Applied Silvicultural Assessment (III) of Upland Oak-Hickory Forests and the Red Oak Borer in the Ozark and Ouachita Mountains of Arkansas", *USDA Forest Service*, 18 Sep 2007 to 15 Sep 2012, **$115,000**.

- Tullis, J.A. (*principal investigator*), B.E. Gorham and W.F. Limp, "ArkansasView: Expanding the Use and Value of Remote Sensing through Education, Research, and Outreach", *US Geological Survey & AmericaView*, 1 Jul 2006 to 29 Sep 2009, **$158,989**.

AWARDS & HONORS

- Awarded the *U.S. Department of Agriculture Certificate of Merit* twice for initiative and success in conducting the Uinta Oak Fuels Analysis fire ecology project, U.S. Forest Service, Pleasant Grove, UT (1996 – 1997).

- Invited to discuss forestry applications of remote sensing with Teddy Reynolds and Jackson Cothren on *Timber Talk*, a 30 minute live radio interview broadcast over 59 counties or parishes in Arkansas, Louisiana, Oklahoma, and Texas, from 100.5 FM KZHE, Magnolia, AR (Jan 2005).

- Received *commendation from USAID and NASA officials* for success in leading the Spanish language "Land Use / Land Cover Change Detection for Central American Carbon Management" workshop for eighteen representatives from across Central America, City of Knowledge, Panama (Oct 2005).

- Invited to discuss LIDAR-assisted forestry assessment related to the red oak borer with Jacqueline Froelich and Fred Stephen on *Ozarks at Large*, a weekly radio broadcast from 91.3 FM KUAF *National Public Radio*, Fayetteville, AR (Mar 2007).

PROFESSIONAL SERVICE & ACTIVITIES

Refereed Journal Service

- Reviewed a manuscript for *Computers, Environment and Urban Systems* published by Elsevier (Dec 2003).
- Reviewed ten manuscripts for *GIScience and Remote Sensing* published by Bellwether (Mar 2004, Apr 2004, Nov 2004, Sep 2005, Jan 2006, Jun 2006, Oct 2006, May 2008, Jul 2008, Jan 2009).
- Served on the editorial board for the Earth Observation section of *Geography Compass* published by Blackwell (Jun 2007 to present).
- Reviewed three manuscripts for *Geography Compass* published by Blackwell (Dec 2007, Feb 2008, Nov 2008).
- Reviewed two manuscripts for *Photogrammetric Engineering & Remote Sensing* published by the American Society for Photogrammetry & Remote Sensing (Feb 2008, Oct 2008).
- Reviewed a manuscript for *Physical Geography* published by V.H. Winston & Sons (Jan 2009).

Program Review and Development

- Reviewed National Sea Grant College Program proposal for consideration by the *University of Puerto Rico Sea Grant* (Sep 2005).
- Served on two internal grant proposal review panels for NASA and NSF proposals prepared by the *Arkansas Center for Space and Planetary Sciences* (Jun 2006; Nov 2007).
- Raber, G.T., J.A. Tullis and J.R. Jensen, 2006, "Geospatial Primer", an online course from *The Institute for Advanced Education in Geospatial Sciences,* University of Mississippi, Oxford, MS.
- Served on the *Learning Outcomes* (Aug 2006 to present) and *Curriculum* (Jan 2007 to present) committees in the *Department of Geosciences* at University of Arkansas.
- Reviewed proposal for consideration by the *National Science Foundation* program in *Geomorphology and Land-Use Dynamics* (Oct 2006).
- Reviewed proposal for consideration by the *USGS Northern Prairie Wildlife Research Center* (Nov 2007).
- Worked with *Organization of American States* and *Inter American Biodiversity Information Network* to investigate and review "Machine Learning-assisted Terrestrial Ecosystem Classification Schema 'Cross-walks' for Central and South America" (Oct 2007 to Mar 2009).
- Worked with *U.S. EPA* and *ICF International* to review and advise *in situ* and geomatics-based efforts to improve land use / land cover maps for greenhouse gas monitoring in Guatemala, Honduras, El Salvador, Nicaragua, and Costa Rica (Apr 2008 to Sep 2009).
- Reviewed two proposals for consideration by the *National Science Foundation* program in *Geography and Regional Science* (May 2008, Nov 2008).
- Reviewed proposal for an advanced environmental remote sensing textbook being considered by *Springer* (Aug 2008).
- Developed "RefCruz 2009", a Python-based terrestrial ecosystem GIS interoperability tool for *Organization of American States* and *Inter American Biodiversity Information Network* (Sep 2008 to Mar 2009).

Professional Society Service

- Served as moderator for the "DEM Technologies and Applications: Modeling Surface Roughness, Coastal Movements, and Hurricane Storm Surge" session for the *American Society for Photogrammetry and Remote Sensing* 2005 Annual Convention, Baltimore, MD (Mar 2005).

- Served as a *Central Region Director* within the *American Society for Photogrammetry and Remote Sensing* (Apr 2005 to Mar 2008).

- Served as moderator for the "Hurricane Katrina" session for the *Southwest Division* of the *Association of American Geographers* Annual Convention, Fayetteville, AR (Nov 2005).

- Served as moderator for the *American Society for Photogrammetry and Remote Sensing* Central Region Technical Meeting, Fayetteville, AR (Apr 2006).

- Served as moderator for the "Monitoring Natural Hazards" session for the *American Society for Photogrammetry and Remote Sensing* 2006 Annual Convention, Reno, NV (May 2006).

- Served as *Central Region Membership Subcommittee Chair* for the *American Society for Photogrammetry and Remote Sensing* (Aug 2006 to Mar 2008).

- Served as a *Faculty Mentor* for the inaugural *University of Arkansas Student Chapter of the American Society for Photogrammetry and Remote Sensing* (Feb 2007 to Aug 2008).

- Served as moderator for the "Applications of Lidar to Forestry" session for the *American Society for Photogrammetry and Remote Sensing* 2007 Annual Convention, Tampa, FL (May 2007).

- Served as moderator for the "Lidar – Forestry Applications" session for the *American Society for Photogrammetry and Remote Sensing* 2008 Annual Convention, Portland, OR (May 2008).

Invited Papers, Lectures, Presentations, Workshops & Media Interviews

- Presented "The Use of LIDAR and Remotely Sensed Imagery for Mapping Parcel Level Permeability" to NASA officials from *Earth Science Enterprise* (*ESE*), Stennis Space Center, MS (Feb 2002).

- Presented "Measurement of Impervious Surfaces for Stormwater Management Applications Using Digital Aerial Imagery, Topographic LIDAR, and LIDAR Intensity Returns" to NASA officials from *Earth Science Enterprise* (*ESE*), Stennis Space Center, MS (Feb 2003).

- Presented workshops and a seminar on remote sensor and digital terrain modeling, GIS databases, data mining, and visualization for researchers in the *Mathematics Department*, Univ. of South Carolina, Columbia, SC (Dec 2002, May 2003, Nov 2003).

- Presented workshops on "Principles of Remote Sensing" and "Remote Sensing Information Extraction with Decision Trees" at the *State Mapping Advisory Committee* (*SMAC*) Biennial Conference, Columbia, SC (Jan 2004).

- Presented "GIS and Remote Sensing for Smart Growth Research – Phase III" and "Predicted Storm Surge Inundation Boundaries: SLOSH Modeling with LIDAR-derived DEMs" to NASA officials from *Earth Science Enterprise* (*ESE*), Stennis Space Center, MS (Feb 2004).

- Presented "GIScience for Industry, Government, and the People: Examples in Urban Analysis and Floodplain Modeling" to faculty and students in the *Geography Department*, Ohio University, Athens, OH (Feb 2004).

- Presented "GIS Data Mining and Decision Trees" to faculty and students in the *Geography & Earth Sciences Department*, University of North Carolina, Charlotte, NC (Feb 2004).

- Presented "LIDAR Data Mining and Scale Optimized Decision Tree Classification" to faculty and students in the *Geography Department*, University of Iowa, Iowa City, IA (Feb 2004).

- Presented "LIDAR Assisted Land Cover Analysis" to faculty and students in the *Geosciences Department*, University of Arkansas, Fayetteville, AR (May 2004).

- Presented "CAST and Forestry Applications: From LIDAR to SDSS" with Jackson Cothren and W. Fredrick Limp to foresters at the *Arkansas Forestry Association* (AFA) 2004 meeting, University of Arkansas, Fayetteville, AR (Oct 2004).

- Presented "Expert and Machine Learning Decision Trees" to *Arkansas Soil and Water Conservation Commission* officials, University of Arkansas, Fayetteville, AR (Oct 2004).

- Presented "Hurricane Storm Surge Prediction as a Function of DEM Input: Exploring a LIDAR-derived Alternate" to faculty and students in the *Geosciences Department*, University of Arkansas, Fayetteville, AR (Oct 2004).

- Presented "On the Road to Generic Remote Sensing-assisted Spatial Decision Support Systems" to faculty and students in the *Environmental Dynamics PhD Program*, University of Arkansas, Fayetteville, AR (Nov 2004).

- Presented a workshop on 3D visualization of orthophotography and LIDAR-derived elevation data to students, faculty, and government officials at the *Mullins Library GIS Day Open House*, University of Arkansas, Fayetteville, AR (Nov 2004).

- Discussed forestry applications of remote sensing with Teddy Reynolds and Jackson Cothren on *Timber Talk*, a 30 minute live radio interview broadcast over 59 counties or parishes in Arkansas, Louisiana, Oklahoma, and Texas, from 100.5 FM KZHE, Magnolia, AR; the program is available at http://www.timbertalk.com/ (4 Jan 2005).

- Presented "Exploring LIDAR-derived Inputs for Hurricane Storm Surge Models" to faculty and students in the *Department of Geography*, University of Southern Mississippi, Hattiesburg, MS (Feb 2005).

- Presented "Predicted Storm Surge Inundation Boundaries: SLOSH Modeling with LIDAR-derived DEMs – Phase II" to NASA officials from *Applied Sciences Directorate*, Stennis Space Center, MS (Feb 2005).

- Presented "Potential Remote Sensing-assisted Terrain, Land Cover, and Decision Support Models within a Grid Computing Environment" to Dr. Pat Brezonik from NSF and Central U.S. hydrology researchers at the *Great Plains Network Cyberinfrastructure Workshop*, University of Kansas, Lawrence, KS (Feb 2005).

- Presented "Per-segment Classification and Machine Learning Decision Trees" to geospatial community professionals at the *eCognition 2005 International User Meeting*, Baltimore, MD (Mar 2005).

- Presented "Automating & Optimizing Intelligent Knowledge-based Extraction of Land Cover Change" to students and faculty in the *Department of Biological Sciences*, University of Arkansas, Fayetteville, AR (Apr 2005).

- Presented "Optimizing Arkansas' 2004 Land Use / Land Cover Map" to students and faculty in the *Environmental Dynamics PhD Program*, University of Arkansas, Fayetteville, AR (Apr 2005).

- Presented "Automating & Optimizing Intelligent Knowledge-based Extraction of Land Cover Change" to students and faculty in the *Program in Environmental Science and Regional Planning*, Washington State University, Pullman, WA (Apr 2005).

- Presented "Overview of Remote Sensing Activities", posters and graphics featuring remote sensor data processing, and a 3D fly-through over Northwest Arkansas to the chief executives of Leica Geosystems, faculty and students, local officials, and local media as part of the inaugural *Leica Geosystems Center of Excellence* press conference at University of Arkansas (May 2005); a related article by Jeff Smith of *The Morning News* can be viewed at http://www.nwaonline.net/articles/2005/05/03/front/03fzuagis.txt.

- Submitted "Remote Sensor Data Processing Applications in Dire Need of Supercomputing at the Center for Advanced Spatial Technologies (CAST)" white paper to Dr. Kenneth Bishop at *University of Kansas* as a collaborative effort toward acquiring new supercomputing capabilities at University of Arkansas (May 2005).

- Presented "Space and Planetary Science: An Earth Remote Sensing Perspective" to visiting undergraduate students, graduate students, and faculty in the *Arkansas Center for Space and Planetary Sciences* as part of the Center's summer undergraduate research program, University of Arkansas, Fayetteville, AR (May 2005).

- Presented "The Search for Martian Sinkholes" with Kenneth F. Steele, Zackery E. Smith, and Luis Malfavon to students and faculty in the *Arkansas Center for Space and Planetary Sciences*, University of Arkansas, Fayetteville, AR (Jul 2005).

- Presented a workshop on LIDAR-assisted hydrologic modeling to staff and affiliated high school students of *Audubon Arkansas* as part of their efforts to raise public awareness on issues surrounding the College Branch watershed, University of Arkansas, Fayetteville, AR (Jul 2005).

- Presented "A Cellular Automata Model for ArcMap" with David J. Cowen, E. Thomas Bramble, Kevin Remington, John R. Jensen, Michael E. Hodgson, W. Lynn Shirley, and Apurva Goyal to geospatial community professionals at the *ESRI 2005 International User Conference*, San Diego, CA (Jul 2005).

- Presented "Overview of Remote Sensing Activities" to *Computer Science and Computer Engineering (CSCE)* faculty at two workshops aimed at developing collaboration between the Center for Advanced Spatial Technologies (CAST) and CSCE, University of Arkansas, Fayetteville, AR (Sep 2005).

- Presented colloquium on "Intelligent Knowledge-based Extraction of Remotely Sensed Variables" to students at the *Arkansas Center for Space and Planetary Science*, University of Arkansas, Fayetteville, AR (Sep 2005).

- Presented with Jack Cothren and John Wilson the five-day Spanish language "Land Use / Land Cover Change Detection for Central American Carbon Management" *USAID-funded NASA SERVIR workshop* for eighteen representatives from across Central America, City of Knowledge, Panama (Oct 2005).

- Presented with John Wilson "Extraction of Polygonal Ridgetop Areas in the Ozark Mountains" to students, faculty, and government officials at the *Mullins Library GIS Day Open House*, University of Arkansas, Fayetteville, AR (Nov 2005).

- Presented with Fred Stephen *et al.* "Monitoring and Predicting Populations of Red Oak Borer in the Ozark Mountains" in the *2006 National Forest Health Monitoring (FHM) Working Group Meeting*, Charleston, SC (Jan-Feb 2006).

- Presented "Extraction of Polygonal Ridgetop Areas in the Ozark Mountains" and "Integration of *In Situ*, Ancillary, and Remote Sensor Databases" to Jim Guldin of *USDA Forest Service Southern Research Station* and ecologists from *University of Missouri* and *University of Kansas*, Lawrence, KS (Mar 2006).

- Assisted members of the *University Wellness Committee*, Tom Paradise, and geomatics students in a workshop and data preparation for maps delineating walking and jogging routes on campus, *University of Arkansas*, Fayetteville, AR (Spring 2006).

- Recognized with Jackson Cothren and Bruce Gorham for geomatics research and development with *NASA*, *USAID*, and *Central American countries*; a news release from University of Arkansas *Daily Headlines* is available at http://dailyheadlines.uark.edu/text/8579.htm, Fayetteville, AR (Apr 2006).

- Presented, with George T. Raber, "Rapid Assessment of Hurricane Katrina Storm Surge Inundation in Mississippi Utilizing a Cost Weighted Interpolation Approach", a multimedia map exhibition at the *26th ESRI International User Conference*, San Diego, CA (Aug 2006).

- Presented "Remote Sensing-assisted Decision Support for Red Oak Borer Hazard Response" to *USDA Forest Service* officials and forest entomologists from around the United States at the *East Texas Forest Entomology Seminar*, Nacogdoches, TX (Oct 2006).

- Presented a workshop on "LIDAR applications for High Throughput Computing (HTC)" to students enrolled in *Computer Science and Computer Engineering Senior Design*, University of Arkansas, Fayetteville, AR (Oct 2006).

- Presented "Automated Processing of 2006 Pictometry Neighborhood Orthogonal Images" and "High Throughput Computation (HTC) of a LIDAR-derived Digital Elevation Model (DEM)" to students, faculty, and government officials at the *Mullins Library GIS Day Open House*, University of Arkansas, Fayetteville, AR (Nov 2006).

- Presented "High Throughput Computation (HTC) of Light Detection and Ranging (LIDAR) Derivatives" poster for the Governor's reception in conjunction with a press conference on the *AREON high speed network initiative*, University of Arkansas, Fayetteville, AR (Dec 2006).

- Discussed LIDAR-assisted forestry assessment related to the red oak borer with Jacqueline Froelich and Fred Stephen on *Ozarks at Large*, a weekly radio broadcast from 91.3 FM KUAF *National Public Radio* (program aired 23 Mar 2007 and 25 Mar 2007 and is available at http://www.kuaf.org/); a previous news release on 14 Mar 2007 from University of Arkansas *Daily Headlines* is found at http://dailyheadlines.uark.edu/10367.htm; a short summary was also posted by *USA Today* on 15 Mar 2007.

- Presented "Scalable Remote Sensing-assisted Decision Support" with a focus on a LIDAR in forestry and high throughput computing to the *Geosciences External Advisory Board*, Fayetteville, AR (May 2007).

- Forest LIDAR research was highlighted by Joe M. Smith of the *Society of American Foresters* in an article entitled "Researchers Use Spatial Technology to Gain Insights into Insect's Role in Oak Decline" published in *The Forestry Source* (May 2007).

- Presented "The Fourth R: Remote Sensing" to Arkansas and Oklahoma high school students in the 8th-10th grade *Gifted and Talented Program*, Fayetteville, AR (Jul 2007).

- Presented "Buscando Referencias Cruzadas Entre Ecosystemas de América Latina" or "Search for Latin American Ecosystem Crosswalks" in Spanish to Central and South American scientists at a terrestrial ecosystem workshop sponsored by the *Inter-American Biodiversity Information Network (IABIN)*, Panama City, Panama (Dec 2007).

- Presented options on Central American land cover monitoring to Tom Wirth from *EPA Climate Change Division* and geomatics researchers at the *Centro de Estudios Ambientales*, Universidad del Valle de Guatemala, Guatemala City, Guatemala and at the *Centro Agronómico Tropical de Investigación y Enseñanza* or *CATIE*, Turrialba, Costa Rica (Apr 2008).

- Presented "Central American Carbon Analysis" and "Remote Measurement of Deciduous Forest Biomass in the Ozark Mountains" to Emil Peña, Executive Director of *Energy & Environmental Systems Institute* at *Rice University*, Fayetteville, AR (Jun 2008).

- Forest monitoring research was highlighted by Barbara Shields of *Environmental Systems Research Institute* (*ESRI*) in an article entitled "Rx for Forest Health: Scientists Use GIS to Battle Red Oak Borer in Ozark Woodlands" published in *National Woodlands Magazine 31(2):11-12* and available at http://www.woodlandowners.org/ (Spring 2008).

- Presented "Integrated Spatial Decision Support for Red Oak Borer Hazard Response" including an interactive red oak borer hazard map and website (http://asa.cast.uark.edu/) to *USDA Forest Service* officials and forest entomologists from around the United States at a workshop and at the *East Texas Forest Entomology Seminar*, Nacogdoches, TX (Oct 2008).

- Presented, with Joshua S. Jones, Fred M. Stephen *et al.*, poster entitled "Satellite and LIDAR-derived GIS Inputs for Forest Inventory and Analysis in the Ozark Mountains" to students, faculty, and visiting public at the *GIS Day Open House*, University of Arkansas, Fayetteville, AR (Nov 2008).

- Presented with Jeffrey R. Jones, Fabrice DeClerk, Tom Wirth, Zac Andereck, Kevin Wright, and Stephen Ogle "Central America Regional Approach to REDD [Reduced Emissions from Deforestation and Degredation] Monitoring" at a *REDD Capacity Development Workshop* on "Forest Area Change Assessment: the Experience of Existing Operational Systems", *National Institute for Space Research* (*INPE*), Sao Jose dos Campos, Brazil (Feb 2009).

- Presented "Observing Forests, Landscapes, and Beyond" as part of the *Arkansas Public Lectures in Space and Planetary Sciences*, Fayetteville, AR (Feb 2009).

BRIAN D. WARDLOW

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EDUCATION

Ph.D. Geography (honors), University of Kansas, Lawrence, Kansas, December 2005.
Dissertation: *The Development of a Crop-Related Land Use/Land Cover (LULC) Modeling Protocol in the U.S. Central Great Plains Using Time-Series MODIS 250-Meter Vegetation Index (VI) Data.* Dissertation advisor: Dr. Stephen L. Egbert

M.A. Geography (honors), Kansas State University, Manhattan, Kansas, May 1996.
Thesis title: *Temporal Monitoring of Suspended Sediment Patterns Using Landsat Thematic Mapper Imagery – A Study of Tuttle Creek Reservoir, Kansas.* Thesis advisor: Dr. John A. Harrington, Jr.

B.S. Geography (Geology minor) (***Magna Cum Laude***), Northwest Missouri State University, Maryville, Missouri, May 1994. Academic advisor: Dr. Don Hagan

RESEARCH INTERESTS

Remote Sensing	Land Use/Land Cover Characterization	Drought Monitoring
Geographic Information Systems	Human Impacts on the Environment	Biogeography
Environmental/Physical Geography	Natural Hazards	Plant Ecology

PRESENT POSITION

Assistant Professor, 3/2006 – Present, National Drought Mitigation Center, School of Natural Resources (SNR), University of Nebraska-Lincoln, Lincoln, NE.
Current appointment: 60% research and 40% outreach/service. Serve as the GIScience Program Area Leader an overview the remote sensing and GIS-related projects and staff at the NDMC. Conduct research on the use of remote sensing, geographic information systems (GIS), and geospatial modeling techniques for drought monitoring and vegetation characterization, develop integrated decision support systems for drought planning, conduct workshops related to drought monitoring assessment tools. Other academic duties include advisement and mentoring of graduate students in the SNR involving the application of remote sensing and GIS for environmental monitoring and natural resource management.

WORK EXPERIENCE

NASA Earth System Science Graduate Research Fellow, 9/2002 - 3/2006, Kansas Applied Remote Sensing Program, University of Kansas, Lawrence, KS

Graduate Research Assistant, 9/1999 - 8/2002, Kansas Applied Remote Sensing Program, University of Kansas, Lawrence, KS

Remote Sensing Scientist, 10/1996 - 8/1999, USGS EROS Data Center, Sioux Falls, SD

Graduate Research Assistant, 5/1996 - 9/1996, Kansas Geological Survey, University of Kansas, Lawrence, KS

Graduate Research Assistant, 5/1995 - 9/1995, Department of Geography, Kansas State University, Manhattan, KS

Community and Regional Planning Intern, 5/1993 - 9/1994, Southeast Nebraska Development District (SENDD), Humboldt, NE

TEACHING EXPERIENCE

Guest Lecturer, Spring 2006, GEOG 980 Remote Sensing Graduate Seminar, Department of Geography, University of Kansas, Lawrence, KS.
Lecture topics include time-series analysis of remotely sensed data for land cover characterization and environmental modeling and data mining techniques (i.e., classification and regression trees).

Guest Lecturer, Fall 2004, GEOG 526 Remote Sensing I, Department of Geography, University of Kansas, Lawrence, KS.
Lecture topics included vegetation indices (theory, historical development, and applications), time-series VI data and temporal compositing techniques, the AVHRR and MODIS sensors, and examples of specific application of time-series VI data (land cover classification, vegetation monitoring, and biophysical modeling).

Graduate Teaching Assistant, 8/1994 - 5/1996, Department of Geography, Kansas State University, Manhattan, KS
Instructor for Remote Sensing of the Environment Lab (GEOG 705) for four semesters. Course content included air photo interpretation, photogrammetry, digital imagery, digital image processing methods, and selected remote sensing applications (e.g., land cover classification). Duties included the instruction of 30-40 undergraduate and graduate students per semester, the development of lab exams and exercises, and guest lectures in the lecture portion of the course.

PUBLICATIONS

Journal Articles (refereed)

Wardlow, B.D., M.J. Hayes, M.D. Svoboda, T. Tadesse, and K.H. Smith, 2009. Sharpening the Focus on Drought – New Monitoring and Assessment Tools at the National Drought Mitigation Center. *Earthzine*, In press.

Wardlow, B.D. and S.L. Egbert, 2009. A comparison of MODIS 250-m evi and ndvi data for crop mapping in the U.S. Central Great Plains. *International Journal of Remote Sensing,* In press.

Albright, T., A. Pidgeon, C. Rittenhouse, M. Clayton, C. Flather, P. Culbert, **B. Wardlow**, and V. Radeloff, 2009.. Effects of drought on avian community structure. *Global Change Biology,* In review.

Gu, Y., E. Hunt, **B.D. Wardlow**, J.B. Basara, J.F. Brown, and J.P. Verdin, 2008. Evaluation and validation of modis ndvi and ndwi for vegetation drought monitoring using Oklahoma mesonet soil moisture data. *Geophysical Research Letters,* doi:10.1029/2008GL035772.

Tadesse, T., M. Haile, G. Senay, C. Knutson, and **B.D. Wardlow**, 2008. Building integrated drought monitoring and food security systems in sub-Saharan Africa. *Natural Resources Forum,* 32, 265-279.

Brown, J.F., **B.D. Wardlow**, T. Tadesse, M.J. Hayes, and B.C. Reed, 2008. The vegetation drought response index (VegDRI): a new integrated approach for monitoring drought stress in vegetation. *GIScience and Remote Sensing*, 45(1):16-46.

Wardlow, B.D. and S.L. Egbert, 2008. Large-area crop mapping using time-series MODIS 250 m ndvi data: an assessment for the U.S. Central Great Plains. *Remote Sensing of* Environment, 112:1096-1116.

Gitelson, A.A., **B.D. Wardlow**, G.P. Keydan, and B. Leavitt, 2007. Green leaf area index estimation in crops using MODIS 250 meter data. *Geophysical Research Letters*, 34, L20403, doi:10.1029/2007GL031620*.*

Wardlow, B.D., S.L. Egbert, and J.H. Kastens, 2007. Analysis of time-series MODIS 250-meter vegetation index data for crop discrimination in the U.S. Central Great Plains. *Remote Sensing of Environment*, 108, 290-310.

Gu, Y., J.F. Brown, J.P. Verdin, and **B.D. Wardlow**, 2007. A five-year analysis of MODIS ndvi and ndwi for grassland drought assessment over the central great plains of the United States. *Geophysical Research Letters*, 34, L06407, doi:10.1029/2006GL029127.

Brown, J.C., W. Jepson, J. Kastens, **B. Wardlow**, J. Lomas, and K. Price, 2007. Multi-temporal, moderate spatial resolution remote sensing of modern agricultural production and land modification in the Brazilian Amazon. *GIScience and Remote Sensing*, 44(2), 1-32.

Wardlow, B.D., J.H. Kastens, and S.L. Egbert. 2006. Using USDA crop progress data for the evaluation of greenup onset date calculated from MODIS 250-meter data. *Photogrammetric Engineering and Remote Sensing*, 72(11):1225-1234.

Wardlow, B.D. and S.L. Egbert, 2003. A state-level comparative analysis of the GAP and NLCD and cover data sets. *Photogrammetric Engineering and Remote Sensing*, 69(12):1387-1397.

Book Chapters (refereed)

Tadesse, T., **B. Wardlow**, and M. Hayes, 2008. The application of data mining for drought monitoring and prediction. *Data Mining Applications for Empowering Knowledge Societies*, Idea Group Publishers, New York, NY, pp. 280-291.

Ph.D. Dissertation

Wardlow, B.D., 2005. *An Evaluation of Time-Series MODIS 250-Meter Vegetation Index Data for Crop Mapping in the U.S. Central Great Plains*. Ph.D. Dissertation, University of Kansas, Lawrence, KS.

Conference Proceedings (refereed)

Wardlow, B.D., T. Tadesse, J.F. Brown, and Y. Gu, 2008. The vegetation drought response index (vegdri): a new drought monitoring approach for vegetation. *National Integrated Drought Information System (NIDIS) Knowledge Assessment Workshop – Contributions of Satellite Remote Sensing to Drought Monitoring*, Boulder, CO, February 6-7.

Tadesse, T. and **B Wardlow**, 2007. The vegetation outlook (vegout): a new tool for providing outlooks of general vegetation conditions using data mining techniques. *Seventh IEEE International Conference on Data Mining*, Omaha, NE, October 28-31

Conference Proceedings (non-refereed)

Brown, J.F., S. Pervez, **B. Wardlow**, T. Tadesse, and K. Callahan, 2008. Assessment of 2006 and 2007 drought patterns in the vegetation drought response index across Nebraska. *Proceedings, Percora 17*, Denver, CO, November 18-20.

Tadesse, T., **B.D. Wardlow**, and J.H. Ryu, 2008. Identifying time-lag relationships between vegetation condition and climate to produce vegetation outlook maps and monitor drought. 88th *American Meteorological Society Annual Meeting*, New Orleans, LA, January 20-24.

Brown, J.F., S. Maxwell, S. Pervez, **B. Wardlow**, and K. Callahan, 2008. National irrigated lands mapping via an automated remote sensing based methodology. 88th *American Meteorological Society Annual Meeting*, New Orleans, LA, January 20-24.

Brown, J. Christopher, J.H. Kastens, **B.D. Wardlow**, W. Jepson, A.C. Coutinho, A. Venturieri, J. Lomas, K. Price, 2007. Using MODIS to detect cropping frequency variation in mechanized agriculture in Amazonia. *XIII Brazilian Symposium of Remote Sensing*, Florianópolis, Santa Catarina, Brazil. April 21-26.

Wardlow, B.D. and S.L. Egbert, 2005. State-level crop mapping in the U.S. Central Great Plains agroecosystem using MODIS 250-meter NDVI data. *Proceedings, Pecora 16*. Sioux Falls, SD, October 23-27.

Wardlow, B.D. and S.L. Egbert. 2002. Discriminating cropping patterns in the U.S. Central Great Plains region using time-series MODIS 250-meter NDVI data – Preliminary Results. *Proceedings, Pecora 15 and Land Satellite Information IV Conference.* Denver, CO, November 10-15.

Wardlow, B.D. and S.L. Egbert. 2001. A comparison of the GAP and USGS NLCD land cover data sets for the state of Kansas – Classification Systems, Methods, and Results. *Proceedings, 2001 American Society of Photogrammetry and Remote Sensing.* St. Louis, MO, April 23-27.

PRESENTATIONS AND POSTERS AT PROFESSIONAL MEETINGS (with published abstracts)

Wardlow, B.D. and T. Tadesse, 2009. A hybrid-based remote sensing approach for predicting vegetation conditions – results from the central U.S. *Association of American Geographers' Annual Meeting*, Las Vegas, NV, March 22-27.

Brown, J., **B. Wardlow**, T. Tadesse, K. Callahan, and S. Pervez, 2009. Monitoring recent drought effects on corn yields across the corn belt with the vegetation drought response index. *Association of American Geographers' Annual Meeting*, Las Vegas, NV, March 22-27.

Swain, S., S. Narumalani, **B. Wardlow**, and T. Tadesse, 2009. An integrated approach for drought induced vegetation stress assessment in Nebraska using remote sensing and GIS. *Association of American Geographers' Annual Meeting*, Las Vegas, NV, March 22-27.

Albright, T.P., C.D. Rittenhouse, A.M. Pidgeon, C.D. Flather, P.D. Culbert, M.K. Clayton, **B.D. Wardlow**, and V.C. Radeloff, 2009. Diverse responses of avian communities to heat waves. *Association of American Geographers' Annual Meeting*, Las Vegas, NV, March 22-27.

Tadesse, T., **B.D. Wardlow**, and J.H. Ryu, 2009. Discovering the spatial and temporal relationships between vegetation condition and climate in monitoring drought. *Climate Prediction Applications Science Workshop*, Norman, OK, March 23-25.

Brown, J.F. and **B.D. Wardlow**, 2008. Improving decision support for drought using new geospatial models and online tools. *A Conference on Ecosystem Services (ACES)* Naples, FL, December 8-11.

Swain, S., S. Narumalani, **B. Wardlow**, and T. Tadesse, 2008. An assessment of vegetation response to drought in Nebraska using Terra-MODIS land surface temperature and normalized difference vegetation index. *AAG Great Plains-Rocky Mountain Regional Meeting*. Grand Forks, ND, September 12-13.

Gu, Y., E. Hunt, **B. Wardlow**, J.B. Basara, J.F. Brown, and J.P. Verdin, 2008. Evaluation and validation of MODIS NDVI and NDWI for vegetation drought monitoring over the central Great Plains of the United States. *XXI Congress for the International Society for Photogrammetry and Remote Sensing (ISPRS)*, Beijing, China, July 3-11.

Wardlow, B.D., T. Tadesse, J.F. Brown, Y. Gu, and K. Callahan, 2008. The vegetation drought response index (VegDRI) – Zooming in to a Local Scale to Meet the Needs of the Drought Monitoring Community. *Association of American Geographers Annual Meeting*, Boston, MA, April 15-19.

Albright, T.P., A.M. Pidgeon, M.K. Clayton, C.H. Flather, C.D. Rittenhouse, **B.D. Wardlow**, and V.C. Radeloff, 2008. Characterization and influence of drought on avian abundance and diversity in the Great Plains, USA. *US Regional Association of the International Association of Landscape Ecology Annual Meeting*, Madison, WI, April 6-10.

Tadesse, T., **B.D. Wardlow**, and J.H. Ryu, 2008. Monitoring and predicting general vegetation condition using climatic, satellite, oceanic, and biophysical data. *Climate Prediction Applications Science Workshop (CPASW)*, Chapel Hill, NC, March 4-7.

Gitelson, A.A., D.C. Rundquist, J.G. Masek, **B.D. Wardlow** and G.P. Keydan, 2007. Quantitative Remote Estimation of Land Surface Biophysical Characteristics Using ETM+ Landsat and 250-m MODIS Data, *AGU Fall Meeting*, San Francisco, CA, December 10-14.

Wardlow, B.D., 2007. The vegetation drought response index (VegDRI) – an update on progress and future research activities. *U.S. Drought Monitor Forum*, Portland, OR, October 10-11.

Gu, Y., J.F. Brown, J.P. Verdin, and **B. Wardlow**, 2006. A five-year analysis of MODIS ndvi and ndwi for rangeland drought assessment: preliminary results. *EOS Transactions AGU Fall Meeting Supplement*, 87(52), Abstract GC41A-1038, San Francisco, CA, December 11-15.

Brown, J., J. Verdin, T. Tadesse, and **B. Wardlow**, 2006. Remote sensing tools for improving drought decision support. *Managing Drought and Water Scarcity in Vulnerable Environments – Creating a Roadmap for Change in the United States Meeting*, The Geological Society of America, Longmont, CO, September 18-20.

Wardlow, B.D., T. Tadesse, J. Brown, M. Hayes, D. Wilhite, and M. Svoboda, 2006. The vegetation drought response index: a new drought monitoring tool integrating climate, satellite, and biophysical data. *Global Vegetation Workshop*, University of Montana, Missoula, MT, August 8-10.

Wardlow, B.D., and S.L. Egbert, 2006. An evaluation of multi-temporal MODIS 250-meter vegetation index data for crop mapping in the U.S. Central Great Plains. *Global Vegetation Workshop*, University of Montana, Missoula, MT, August 8-10.

Gu, Y. J.F. Brown, and **B.D. Wardlow**. 2006. A 5-year analysis of MODIS NDWI/NDVI for rangeland drought assessment. *Global Vegetation Workshop*, University of Montana, Missoula, MT, August 8-10.

Wardlow, B.D. and S.L. Egbert. 2004. Regional scale crop mapping using a decision tree classifier. *Association of American Geographers 100th Annual Meeting*, Philadelphia, PA, March 14-19.

Wardlow, B.D. and S.L. Egbert. 2003. A state-level crop mapping prototype using intermediate resolution EOS data – early results. *Annual Meeting of the Great Plains/Rocky Mountain Division of the American Association of Geographers*, Manhattan, KS, October 2-4.

Wardlow, B.D. and S.L. Egbert. 2003. Crop mapping in the U.S. Central Great Plains region using time-series MODIS 250-meter data: a case study of Southwest Kansas. *30th International Symposium on Remote Sensing of Environment*, Honolulu, HI, November 10-14.

Wardlow, B.D. and S.L. Egbert. 2003. An agricultural land use/land cover (lulc) mapping protocol for the U.S. Central Great Plains region. *Association of American Geographers 99th Annual Meeting*, New Orleans, LA, March 5-8.

Wardlow, B.D. and S.L. Egbert. 2002. Discrimination of cropping patterns in Kansas using time-series MODIS 250-meter NDVI data. *MODIS Vegetation Workshop*, University of Montana, Missoula, MT, August 16-18.

INVITED PRESENTATIONS

10/28/08 VegDRI – A New Hybrid Drought Index for Monitoring Vegetation in the U.S., U.S.-Canada GEO Bilateral Workshop on Ice and Water, National Science Foundation (NSF), Arlington, VA.

10/16/08 Vegetation Drought Response Index (VegDRI): A Hybrid-Based Approach for Vegetation Drought Monitoring, North American Drought Monitor Workshop, Ottawa, Canada.

10/25/07 Geospatial Tools for Environmental Monitoring in a Changing World. Presentation at the USGS and UNL Workshop on Climate Change – Partnerships in Climate Change Science, University of Nebraska-Lincoln, Lincoln, NE.

10/23/07 Remote Sensing Activities at the NDMC – Bridging the Drought Monitoring Gaps. Presentation at the School of Natural Resources Research Colloquium, University of Nebraska-Lincoln, Lincoln, NE.

10/11/07 New NDMC Tool Development Update: Working to Meet the Needs of Drought Monitor, RMA, and NIDIS End Users, U.S. Drought Monitor Forum, Portland, OR.

10/16/06 Evaluation of MODIS 250-Meter Vegetation Index Data for Regional-Scale Crop Mapping – Results from the State of Kansas. Presentation to Geographic Information Science Center of Excellence, South Dakota State University, Brookings, SD.

12/22/05 Regional-Scale Crop Mapping in the U.S. Central Great Plains Using MODIS 250-Meter NDVI Data – Results and Future Directions for Drought Monitoring. Presentation to the National Drought Mitigation Center, School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE.

12/16/05 An Evaluation of MODIS 250-Meter Vegetation Index Data for Regional-Scale Crop Characterization in the U.S. Central Great Plains. Presentation to the Science and Application Branch, USGS EROS Data Center, Sioux Falls, SD.

12/08/05 Regional-Scale Crop Mapping in the U.S. Central Great Plains Using MODIS 250-Meter Vegetation Index Data: Results and Future Research Directions. Presentation to the Department of Geography, Oklahoma State University, Stillwater, OK.

10/24/03 An Overview of Crop Mapping Activities Using Time Series MODIS 250 Meter Data. Presentation to the Science and Applications Branch, USGS EROS Data Center, Sioux Falls, SD.

05/16/03 A State-Level Crop Mapping and Monitoring Prototype for Kansas. Presentation to the KansasView State and Local Government (SLG) Remote Sensing Applications Workshop, University of Kansas, Lawrence, KS.

0/24/02 Proposal Strategies for the NASA Earth System Science (ESS) Graduate Research Fellowship. Presentation at the Mt. O'Read Geospatial Technologies Club Scholarship/Grant Writing Workshop, University of Kansas, Lawrence, KS.

10/12/98 USGS EROS Data Center: Remote Sensing Science for a Changing World and the Multi Resolution Land Cover Characterization Land Cover Mapping Project. Presentation to Department of Geography, Kansas State University, Manhattan, KS.

10/14/96 Temporal Monitoring of Suspended Sediment Patterns Using Landsat Thematic Mapper Imagery, Presentation to the Science and Applications Branch, USGS EROS Data Center, Sioux Falls, SD.

GRANTS

Funded Grant Proposals

Rodell, M., J. Lawrimore, J.S. Famiglietti, R. Heim, R. Reichle, M. Svoboda, **B. Wardlow**, B. Zaitchik, and A. Pinheiro. Integrating Enhanced GRACE Water Storage Data into the U.S. and North American Drought Monitors, NASA ROSES Decision Support through Earth Science Research Results $597,000 2008-2010)

Svoboda, M., **B. Wardlow**, T. Tadesse, and D. Wilhite. Incorporating Remote Sensing Information into the U.S. Drought Monitor. U.S Geological Survey Unsolicited Proposal Award, $152,598 (2007-2009).

Wardlow, B., The Development of a Near Real-Time Mapping and Monitoring Protocol for the U.S. Great Plains Agro-ecosystem Using Time-Series MODIS 250-Meter Data. NASA Earth System Science Graduate Research Fellowship, $72,000 (2002-2005).

Other Funded Grants

Kansas EPSCoR Graduate Student Travel Grant, $500, 2003.
University of Kansas Graduate School Conference Travel Grant, $500, 2002.

PROFESSIONAL SERVICE

School and University

Faculty Advisor, 2008-present, Geography Student Organization (GSO), University of Nebraska-Lincoln
Graduate Curriculum Committee, Geography Program, University of Nebraska-Lincoln, 2008-present
Faculty Fellow, 2007-present, Center for Advanced Land Management and Information Technologies (CALMIT), University of Nebraska-Lincoln
Graduate Faculty, 2006-present, Department of Anthropology and Geography, University of Nebraska-Lincoln
Courtesy Graduate Faculty, 2007-present, Department of Geography, University of Kansas

Graduate Committees

Ph.D. Completed

Iwake Masialeti. Fulbright student in the Department of Geography, University of Kansas. Completed in July 2008.

Ph.D. in Progress

Eric Hunt, 2008 – present. Student in School of Natural Resources, University of Nebraska-Lincoln. Course work in progress. (Chair)
Sharmistha Swain. 2008 – present. Student in Geography, University of Nebraska-Lincoln. Course work in progress. (Co-advise with Sunil Narmulani.)
Nicole Wall, 2009 – present. Student in School of Natural Resources with emphasis in forensic science, University of Nebraska-Lincoln. Course work in progress.
Jane Okalebo, 2009-present. Student in School of Natural Resources, University of Nebraska-Lincoln. Course work in progress.

M.A. Completed

Jeff Nothwehr. Completed Summer 2007.

M.A. in Progress

Sandra Jones, 2007 - present. Thesis in progress.

Professional Working Group Membership

National Phenology Network (NPN) Land Surface Phenology and Remote Sensing Working Group
NASA Soil Moisture Active Passive (SMAP) Satellite Applications Working Group

Reviewer for Professional Journals

Photogrammetric Engineering and Remote Sensing (6 manuscripts), 2003-2008
Remote Sensing of Environment (8 manuscripts), 2004, 2006-2009
IEEE Geoscience and Remote Sensing (1 manuscript), 2006
Journal of Agronomy (1 manuscript), 2006
Natural Hazards (1 manuscript) 2007
Journal of Environmental Management (2 manuscripts) 2008
IEEE International Geoscience and Remote Sensing Symposium (multiple abstracts) 2008, 2009
Canadian Journal of Remote Sensing (1 manuscript) 2008
Journal of Applied Remote Sensing (1 manuscript) 2008
GeoCarto International (2 manuscripts) 2008
Landscape and Urban Planning (1 manuscript) 2008
ISPRS Journal of Photogrammetry and Remote Sensing (1 manuscript) 2008
Sensors (1 manuscript) 2009

Invited Reviewer for Proposals

NOAA Coastal Restoration and Enhancement through Science and Technology (CREST) Program, 2009

U.S.-Central Asian Research Travel Grant Competition, U.S. Civilian Research and Development Foundation, 2008

Professional Societies

Session Chair, Remote Sensing, Annual Meeting, Great Plains-Rocky Mountain Division / West Lakes Division, American Association of Geographers, Lincoln, NE, 2006

Session Chair, Land Cover Change, Pecora 16 Symposium, Sioux Falls, SD, 2005

Session Chair, Remote Sensing: Agriculture and Fractals, Annual Meeting, Association of American Geographers, Philadelphia, PA, 2004

Session Chair, Macro Land Cover Mapping, Annual Meeting, American Society of Photogrammetry and Remote Sensing, St. Louis, MO, 2001

Judge (invited), Remote Sensing Specialty Group Student Paper Competition, Annual Meeting, Association of American Geographers, New Orleans, LA, 2003

Vice-President, Mount O'Read Geospatial Technologies Club and American Society of Photogrammetry and Remote Sensing Student Chapter, University of Kansas, Lawrence, KS, 2002-2006

Liaison, 2001-2006, AmericaView MODIS Database Representative for the State of Kansas

ACADEMIC/PROFESSIONAL AWARDS

2007, John I. Davidson President's Award for Best Practical Paper presented by the American Association of Photogrammetry and Remote Sensing

2007, Leica Geosystems Award for Best Scientific Paper in Remote Sensing presented by the American Association of Photogrammetry and Remote Sensing

2003, GIS/Remote Sensing Specialty Group Illustrated Paper Award (1st place), Association of American Geographers 99th Annual Meeting, New Orleans, LA.

2000, USGS EROS Data Center Group Achievement Award for the National Land Cover Data Set Mapping Team

1996, Distinguished Graduate Assistantship Award, Department of Geography, Kansas State University.

1994, Mark Jefferson Outstanding Geography Student Award, Department of Geography, Northwest Missouri State University.

1994, Scholar Athlete Award, Northwest Missouri State University

1992-1994, Academic All-Conference Team, Mid-America Intercollegiate Athletic Association

1990-1994, Regents' Scholarship, Northwest Missouri State University

1990-1994, Athletic Department Scholarship, Northwest Missouri State University

MEMBERSHIPS

Association of American Geographers

American Society of Photogrammetry and Remote Sensing

Gamma Theta Upsilon International Geographic Honor Society

Sigma Gamma Epsilon National Honor Society for the Earth Sciences