ASSESSMENT OF BIOMASS CONSUMPTION VARIABILITY IN FOREST FIRES USING SATELLITE REMOTE SENSING

Year 1 Progress Report for Grant #NNG04GR24G

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Introduction and Summary of Project Goals

Carbon emissions from wildland fire is a topic of current interest because of concerns about increases in atmospheric carbon. The basic model used for estimating fire carbon emissions was presented in (French et al. 2002) and is based on the standard equation of (Seiler and Crutzen 1980). Models used in estimating carbon and carbon-based gases released to the atmosphere during biomass burning need to account for variations in forest structure, soil organic carbon, weather, fuel moisture, and fire behavior, either by directly including the variable in the model or by acknowledging the inherent variation within each model parameter. Previous work by French et al. (French et al. 2000, French et al. 2002) provided the methodology for making spatially-defined estimates of carbon released from fires. In a subsequent study (French et al. 2004) a Monte Carlo simulation technique was employed to propagate the uncertainty attached to the different parameters of the basic equation to yield a distribution of possible values for total carbon released during burning (output uncertainty). The relative impact of each input parameter on the output uncertainty was also quantified (sensitivity analysis) to identify priorities in terms of data collection and information accuracy.

Under the NASA New Investigator Program in Earth Science (NASA-NIP), Dr. French and her assistants are performing further research to better quantify the variability in the amount of biomass consumed during forest fires. Based on results of previous research, it is hypothesized that the variability in biomass consumption during burning is the main driver of uncertainty in the emission of carbon-based greenhouse gases from wildland fires in temperate and boreal forest regions (French et al. 2004). The uncertainty analysis presented in this earlier work highlighted the fact that variability in consumption is not well documented; in particular, the range of values and the shape of the uncertainty distribution have not been described well enough to properly account for the impact of consumption variation on fire emissions.

For this Earth System Science research project, biomass consumption levels in forested regions of northern and western North America are being documented with a goal of learning how variable consumption can be within a given ecoregion. The result will be a more complete view of the amount of biomass consumed during burning so that estimates of carbon emissions can be better quantified. The questions to be explored under this NASA-NIP research project are:

- How much spectral variability is there within and between fire-disturbed sites in boreal and western forest regions of North America?
- Is spectral variation directly related to burn severity or biomass consumption? How do these relationships vary regionally?
- What is the range of biomass consumption levels found in burns within each ecoregion, and what is the shape of the distribution of consumption values in a single burn and within each ecoregion?
- What are the gaps in information needed to fully quantify biomass consumption and, therefore, fire emissions?

Both field data and remote sensing are being used to sample fire-disturbed sites. Field measurements help quantify the levels of consumption while the remotely sensed information is used to extend these measurements to broad spatial scales so that the full range of fire's impact can be assessed. Previous research on the spectral characteristics of fire-disturbed sites as well as current U.S. and Canadian-based research programs have found that the variability in spectral signatures is related to burn severity and biomass consumption. The intent of the project is to sample a statistically meaningful number of sites using satellite-based measurements, augmented with field data, so that consumption can be described for each forested ecoregion. This will result in a more complete view of the amount of biomass consumed during burning so that estimates of carbon emissions can be better quantified.

The overall goal of the project is to quantify the variability in biomass consumption for forested ecosystems in northern and western North America (Figure 1). The specific objectives outlined in the proposal are:

A. Develop a procedure for estimating biomass consumption with multi-spectral remote sensing imagery in a variety of forest types.

B. Using the relationships developed under Objective A and additional remote sensing data, determine the uncertainty in biomass consumption estimates by assessing its variability at sites across each ecoregion.

To achieve these objectives the following tasks were proposed and further described in the methods section of the proposal:

1. Investigate the connection between spectral signature and biomass consumption by comparing field and image data.
2. Compile existing image and field data and identify vital data gaps for quantifying the range of consumption levels in each ecoregion.
3. Obtain imagery and perform field data collections at appropriate sites to fill in gaps and fully capture the variability in biomass consumption in each ecoregion.
4. Obtain and process images from Landsat, ASTER, and possibly MODIS and SPOT-Vegetation sensors to sample many sites across each ecoregion to obtain the range of values possible.
5. Assess coverage of consumption estimates across site type and fire scenarios to identify remaining gaps and evaluate project contribution.

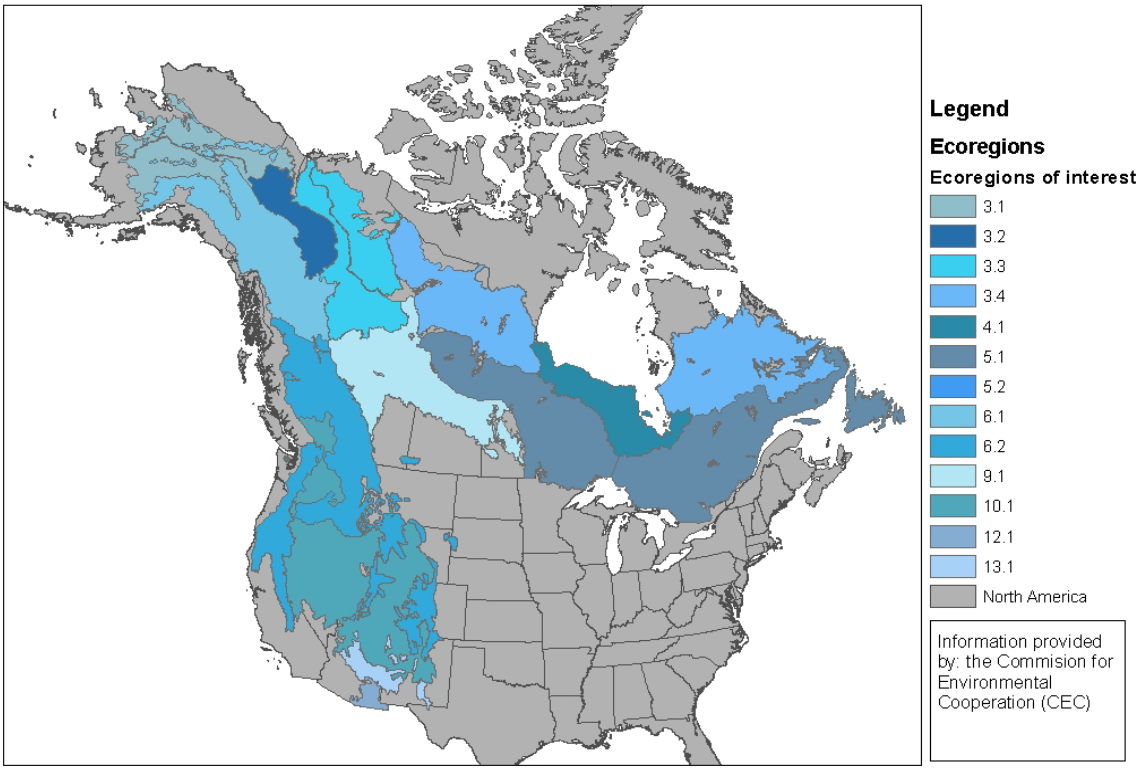

Figure 1. Ecoregions in NASA-NIP study.

For the Education part of the project, student interns are being recruited to work as research assistants. The summer internship program at the Altarum Institute, a small and growing program, is being reviewed and augmented using resources and motivations provided by the NASA-NIP research project. In addition, opportunities to promote high school and college-level internships at institutes where scientific research is happening will be pursued.

Technical Activity and Progress in Year 1

Technical activity on the grant began in September of 2004. Work was performed by the PI, Dr. French, and several research assistants and interns. Progress on Objective A was made with an eye towards making progress on Objective B in subsequent years. In addition to making progress related to the technical objectives outlined in the proposal, Dr. French attended several meetings of collaborators and contributed to symposium papers and journal articles. Interaction with collaborators is essential for this project because the grant does not cover full data collection, and there are many funded activities right now aimed at understanding and quantifying burn severity in North America. Much of the work completed this year was the result of an effort to work with these alternatively funded collaborators. Activities and achievements related to the technical portion of the grant include the following and are further described below.

1. Obtained and processed data for development if GIS-based map of North American ecoregions with attributes for fuel consumption study.
2. Completed literature review and initial assessment of fuel consumption for ecoregions in Boreal North America and Western US forestlands.

3. Contributed to discussions on the utility of the Composite Burn Index for assessment of fuel consumption and fire emissions and the development of procedures to modify protocols for measuring burn severity in Alaska.
4. Participated in field data collection of fuel consumption in recent burn areas in Alaska.
5. Obtained and processed Landsat imagery for use in land cover map of Alaska and derivation of burn severity indexes for several fire-disturbed areas.
6. Met in Edmonton, Alberta with Canadian Forest Service researchers doing assessment of burn severity for carbon emissions assessments.
7. Attended meeting at Glacier National Park with National Park Service researchers who developed remote sensing methods for assessment of burn severity.
8. Hosted a successful meeting of collaborators doing research on wildfire and fuel consumption for carbon cycle studies including researchers from Canada and three US Universities.
9. Presented proposal of NASA-NIP research project at meeting of the Earth System Scholars Network (ESSN), 27-29 September, 2004, College Park, Maryland.
10. Contributed to an analysis and co-authored a symposium paper comparing MODIS-derived fire radiative power to burn severity as mapped using Landsat imagery.
11. Contributed to a paper on the impacts of climate change in Boreal regions.

Progress on technical objectives:

Obtained and processed data for development if GIS-based map of North American ecoregions with attributes for fuel consumption study.

The initial work that was required for task 2 was to process GIS-based maps and information for estimating the fuel consumption by ecoregion. Intern Luz Silverio worked on this task using available datasets. A single map with the ecoregions being studied in this project was created using the North American Ecoregions map created by the Commission for Environmental Cooperation (Commission for Environmental Cooperation 1997). For this activity, some CEC ecoregions sections were merged, naming conventions were changed to correlate with Canadian naming conventions, areas outside of our research area were removed (Figure 1). The map database was populated with information on vegetation type. This map will serve as the base map for integration of field data on fuel consumption collected from the literature and through collaborations with other researchers.

Completed literature review and initial assessment of fuel consumption for ecoregions in Boreal North America and Western US forestlands.

In previous research projects, Dr. French had worked on assessing fuel consumption in Boreal regions using a combination of field data and remote sensing data sources (Michalek et al. 2000, Isaev et al. 2002). For the current project, a review of the literature was performed to gather together this type of information for areas outside of the Boreal region, where Dr. French's expertise mainly lies. Intern L. Silverio assisted in this task by doing literature searches and compiling published data on fuel consumption. In all, 29 journal articles and reports were found to have some relevance to this study. The

locations of each study or measurements were overlaid on the ecoregion map to determine for which ecoregion the work was applicable. The task was approached by quantifying fuel consumption by ecosystem/forest type (i.e. Douglas Fir forest). Using the gathered data and data collected in previous research studies in Alaska, a first-order estimate of fuel consumption was determined for each ecoregion in the study based on the amount of area of each forest/ecosystem type in the ecoregion.

Appendix A provides the results of this study. An abstract will be submitted to the Fall AGU meeting to present these results. The results will also be included in collaborative journal articles and to move forward in the final objectives of the NASA-NIP project. This activity falls under task 2, as listed above.

Contributed to discussions on the utility of the Composite Burn Index for assessment of fuel consumption and fire emissions and the development of procedures to modify protocols for measuring burn severity in Alaska.

One of the salient details that has come out of the research project is the issue of how to define and then measure fuel consumption in the field. Many efforts are underway to understand, map, and quantify burn severity. However, burn severity, most often defined as an ecologically-based term centered on assessment of the impact of fire on the ecology of the site, is not analogous to fuel consumption, which is the measure of the amount of fuel that is converted to carbon gas during burning. Efforts to assess burn severity, therefore, may not benefit the work being done to quantify fuel consumption for the purposes of quantifying fire emissions, as is the goal of this NIP study. Many groups are actively obtaining burn severity measurements for a variety of purposes, including fire and land management as well as post-fire ecological assessment. The National Park Service (NPS) has adopted a procedure to assess burn severity in the field using an assessment called the Composite Burn Index (CBI). The protocol was developed in conjunction with burn severity mapping protocols developed for use with Landsat TM/ETM+ imagery. Since CBI has been adopted by many management and research teams studying fire effects, and the data is designed to fit a remote sensing-based approach to landscape-scale fire assessments, this methodology is being scrutinized for this NIP project. If acceptable, it will mean a large set of field data and complementary Landsat imagery would be available for the assessment of fire carbon emissions.

In addition to assessing the overall CBI methodology, Dr. French has been involved in discussions on how CBI can be adapted to conditions in Alaska. The final decision was to make only small modifications to the procedure, because consistency between ecosystem types and ecoregions was one of the purposes of using a system such as CBI. The final CBI field data sheet was decided on by NPS and other Department of Interior personnel who work in Alaska (Appendix B). This activity fits under task 3.

Participated in field data collection of fuel consumption in recent burn areas in Alaska.

Figure 2: Field data collection of burn severity and fuel consumption in the 2004 Taylor Highway burn in July of 2005

During the month of July, Dr. French and intern L. Silverio spent several weeks measuring burn severity and fuel consumption in burn sites in Alaska (Figure 2). The sites visited were predominantly places that had burned in the 2004 fire season, the largest fire season on record for Alaska. Field measurements collected included ocular assessment of aboveground fuel consumption, measures of ground fuel consumption, and CBI. These data will be processed over the winter to derive fuel consumption for the sites sampled and to assess the comparability of CBI to these more direct measures which have been developed over the years to quantify fuel consumption (Dyrness et al. 1986, Kasischke et al. 2000). This activity fits under task 3.

Obtained and processed Landsat imagery for use in land cover map of Alaska and derivation of burn severity indexes for several fire-disturbed areas.

Land cover maps of Alaska at adequate spatial resolutions are not complete, making an assessment of vegetation/ecosystem types disturbed by fire difficult. Under the NIP project and with additional funds from Alaska Bureau of Land Management (AK-BLM), Altarum helped fill in some of the unmapped regions using Landsat. Approximately 20 million hectares of land was mapped under this project. Intern J. Melwiki assisted in pre-processing of the Landsat imagery.

Landsat imagery was also obtained for burn areas in Alaska and the western US to assess burn severity using procedures developed by the National Burn Severity Mapping Project (see http://burnseverity.cr.usgs.gov/fire_main.asp). With the help of intern T. Hockenberry, burn severity maps were obtained and studied. The maps provided by the Burn Severity Mapping Project are derived from a process known as the differenced Nornalized Burn Ratio (dNBR) using the difference between pre-burn and post-burn Landsat imagery and a formula similar to the Normalized Difference Vegetation Index (NDVI), but with bands in the near infrared and mid-infrared regions of the spectrum (Landsat TM/ETM+ bands 4 & 7) (Appendix C). The data were reviewed to assess its utility for the NIP project. This activity is being done under task 1 and will be valuable for completion of task 4.

Meetings:

Met in Edmonton, Alberta with Canadian Forest Service researchers doing assessment of burn severity for carbon emissions assessments.

A meeting between Dr. French and researchers at the Canadian Forest Service took place on October 20, 2005. The CFS team is working to quantify fire emissions to provide information to a total carbon accounting for Canada. Fire emissions are known

to be a large source of carbon gases to the atmosphere in the heavily forested and fire effected landscape of Canada. The goals of the CFS effort are very similar to that of the team working under this NASA-NIP and other NASA carbon cycle initiatives. Connecting with the CFS team was essential to getting data and results that can help make the estimates planned under this NASA-NIP grant. A list of meeting participants and notes is attached (Appendix D).

Attended meeting at Glacier National Park with National Park Service researchers who developed remote sensing methods for assessment of burn severity.

A key part of developing a proper set of data for the NIP project is collecting data sets from others working on fire severity. Cark Key of the USGS and Nate Benson of the National Park Service. Drs Key and Benson were developers of the CBI and dNBR methodologies being implemented under the National Burn Severity Project and implemented by the National Park Service. The meeting with them and CFS researchers was intended to be a hands-on discussion and demonstration of the CBI and dNBR so those of us working on carbon emissions work could fully appreciate the results of these procedures. A list of attendees and the presentation given on the NASA-NIP project are attached (Appendix E).

Hosted a successful meeting of collaborators doing research on wildfire and fuel consumption for carbon cycle studies including researchers from Canada and three US Universities.

Directly following the meeting at Glacier NP, Dr. French hosted a meeting of several researchers looking at issues of fuel consumption. The meeting was intended to pull together several groups of researchers who were collecting similar field and remote sensing data sets so duplication could be avoided and all could benefit from each others work. At the conclusion of the meeting we agreed to keep in touch, share information and data as appropriate, work on joint papers, and set up a second meeting after summer field data are in order. The meeting Agenda, participants and the notes used and collected during the meeting are attached (Appendix F).

Presentations and Papers:

Presented proposal of NASA-NIP research project at meeting of the Earth System Scholars Network (ESSN), 27-29 September, 2004, College Park, Maryland.

At the very start of this NASA-NIP grant, Dr. French attended and participated in the first meeting of the Earth Systems Scholars Network (ESSN) in College Park, Maryland. The ESSN is comprised of current and former recipients of the NASA Earth Systems Science Fellowship and New Investigators Programs. A copy of the poster presented is attached (Appendix G).

Contributed to an analysis and co-authored a symposium paper comparing MODIS-derived fire radiative power to burn severity as mapped using Landsat imagery.

Recent work has shown that fire radiative power (FRP), the total integrated instantaneous radiative energy emitted by all fires within a satellite pixel (Wooster et al. 2003), correlates with instantaneous biomass consumption rate (Wooster 2002). To test

this conclusion, Dr. French teamed with researchers at the University of Maryland (UMd) to compare FRP measured with the MODIS sensor to burn severity, as defined using the dNBR approach (see above). Intern T. Hockenberry helped process imagery to dNBR and obtained additional processed products from the NPS/USGS web site. This was then provided to Dr. Ivan Czsisar at UMd who located the MODIS pixel that corresponded with a particular burn severity level. The results were written up in a symposium paper and presented as a poster at the 31st International Symposium on Remote Sensing of Environment in St. Petersburg, Russia in June 2005. The paper and poster are attached (Appendix H).

Contributed to a paper on the impacts of climate change in Boreal regions.

Dr. French provided her expertise in Boreal ecology and climate change to contribute as a co-author to a paper authored by Dr. A.J. Soja of NASA Langley Research Center entitled "Current Evidence of Climate-induced Boreal Forest Change". It has been submitted and conditionally accepted to a special issue of *Global and Planetary Change*. A copy of the abstract is attached (Appendix I).

Activity and Progress on Education Goals

The intention of the education portion of the NASA-NIP grant project is to employ interns to work on the project itself, and to help promote and grow the Altarum Institute summer internship program. The project employed three interns this past year. Two worked nearly full-time on the project while one contributed only a small amount of her time to the NASA-NIP project.

Todd Hockenberry began his internship in January. He was just completing an undergraduate degree in Geography from Eastern Michigan University during this time. He worked on the Landsat dNBR activity reported on above (item 5). Results of his work are reported on in the attached description of how dNBR is derived (Appendix C) and the poster and paper presented in St Petersburg, also attached (Appendix H). He completed his internship in May.

Luz Silverio was brought into Altarum's summer internship program and fully funded through the NASA-NIP grant. She had completed her second year of undergraduate schooling at Washington University when she started in May. Her contributions were many. She provided extensive work on the ecoregions map (item 1), did most of the work on the first-order estimation of fuel consumption by ecoregion (item 2), and help collect field data in Alaska (item 4). Her contributions were summarized in her final presentation required under the Institute's summer internship program (Appendix J). She completed her internship in mid-August.

Finally, Jenna Melwiki was hired as a summer intern through the summer internship program with the intention of having her help with the NASA-NIP grant project. She made only a few contributions to this project, however, concentrating her time on other projects within the Environment and Emerging Technologies Group within Altarum Institute. She was called on to help with GIS metadata work for the NASA-NIP. Her main contribution to the NASA-NIP project was in providing help with pre-processing of Landsat imagery for the land cover map of Alaska (item 5).

The summer internship program is an established program within the Institute to encourage young scientists and engineers in learning about real-world research. Through the program , Altarum recruits and hires interns for a 3 to 4-month period in the summer to work full time with a sponsor. The program has requirements and review procedures. Appendix K includes a copy of the internship program description from Altarum's web site and the forms used to evaluate the interns' progress and experience. Under the NASA-NIP grant, these procedures will be reviewed in detail in the next year of funding to assess areas of improvement to enhance this program for future participants.

Planned Activities in Year 2

For year 2, the project will continue to proceed with investigators gathering information from the literature and through collaborations with other researches pursuing similar studies. Field data collections may take place in Alaska, but more effort will be focused on obtaining additional data for fires in the Lower 48. It is expected that Dr. French will travel to western states to meet with other researchers and visit fire-disturbed sites in regions less familiar. This will help in the understanding of the gaps in knowledge which exist and that may be filled through further data collection efforts.

Altarum will be hiring an intern to work on the NASA-NIP during the school year, and will likely hire additional summer interns in May. Ideas formulated through talks with the Human Resources Department in the winter will help move the program. In particular, Dr. French hopes to find new and more direct ways of advertising the internship program so a solid field of participants apply for positions. One idea is to connect with other research firms or non-profit educational institutes with similar internship programs for scientists.

References

Commission for Environmental Cooperation. 1997. Ecological Regions of North America. CEC Secretariat, Montreal.

Dyrness, C. T., L. A. Viereck, and K. Van Cleve. 1986. Fire in taiga communities of interior Alaska. Pages 74-86 *in* K. Van Cleve, F. S. Chapin, III, P. W. Flanagan, L. A. Viereck, and C. T. Dyrness, editors. Forest Ecosystems in the Alaskan Taiga. Springer-Verlag, New York, USA.

French, N. H. F., P. Goovaerts, and E. S. Kasischke. 2004. Uncertainty in estimating carbon emissions from boreal forest fires. Journal of Geophysical Research **109**:D14S08.

French, N. H. F., E. S. Kasischke, B. J. Stocks, J. P. Mudd, D. L. Martell, and B. S. Lee. 2000. Carbon release from fires in the North American boreal forest. Pages 377-388 *in* E. S. Kasischke and B. J. Stocks, editors. Fire, Climate Change, and Carbon Cycling in the Boreal Forest. Springer-Verlag, New York.

French, N. H. F., E. S. Kasischke, and D. G. Williams. 2002. Variability in the emission of carbon-based trace gases from wildfire in the Alaska boreal forest. Journal of Geophysical Research **107**:8151.

Isaev, A. S., G. N. Korovin, S. A. Bartalev, D. V. Ershov, A. Janetos, E. S. Kasischke, H. H. Shugart, N. H. F. French, B. E. Orlick, and T. L. Murphy. 2002. Using remote sensing to assess Russian forest fire carbon emissions. Climatic Change **55**:235-249.

Kasischke, E. S., K. P. O'Neill, N. H. F. French, and L. L. Bourgeau-Chavez. 2000. Controls on patterns of biomass burning in Alaskan boreal forests. Pages 173-196 *in* E. S. Kasischke and B. J. Stocks, editors. Fire, Climate Change, and Carbon Cycling in the North American Boreal Forest. Springer-Verlag, New York.

Michalek, J. L., N. H. F. French, E. S. Kasischke, R. D. Johnson, and J. E. Colwell. 2000. Using Landsat TM data to estimate carbon release from burned biomass in an Alaskan spruce complex. International Journal of Remote Sensing **21**:323-338.

Seiler, W., and P. J. Crutzen. 1980. Estimates of gross and net fluxes of carbon between the biosphere and atmosphere. Climatic Change **2**:207-247.

Wooster, M. J. 2002. Small-scale experimental testing of fire radiative energy fro quantifying mass combusted in natural vegetation fires. Geophysical Research Letters **29**.

Wooster, M. J., B. Zhukov, and D. Oertel. 2003. Fire radiative energy for quantitative study of biomass burning: derivation from the BIRF experimental satellite and comparison to MODIS fire products. Remote Sensing of the Environment **86**:83-107.

Appendices

A. Table of fuel consumption values by ecoregion computed from data collected through literature review.
B. Modified CBI form and instruction “cheat sheet” for use in Alaska.
C. Description of the process to derive dNBR from Landsat.
D. List of participants and notes from meeting at Canadian Forest Service, Edmonton, October 20, 2004 to discuss collaboration.
E. List of participants and notes from May 2-3, 2005 meeting in Glacier National Park to discuss CBI and dNBR.
F. List of participants, agenda, and notes from meeting on May 5-6, 2005 in Ann Arbor to discuss collaborations.
G. Poster presented at the first Symposium for Earth Systems Scholars (ESSN) on Sept. 27-29, 2004.
H. Poster and paper presented at the 31st International Symposium on Remote Sensing of Environment in St. Petersburg, Russia, June 20-24, 2005.
I. Abstract of paper prepared and conditionally accepted for publication in a special issue of *Global and Planetary Change.*
J. Presentation prepared and presented by intern L. Silverio at the conclusion of her internship.
K. Description of Altarum Inst. internship program and evaluation process.