SEMI-ANNUAL REPORT

NASA CONTRACT NAS5-31368

For
MODIS Team Member: Steven W. Running
Assoc. Team Member: Ramakrishna R. Nemani
Software Engineer: Joseph Glassy

July 15, 1998

PRE-LAUNCH TASKS PROPOSED IN OUR CONTRACT OF DECEMBER 1991:

We propose, during the pre-EOS phase to: (1) develop, with other MODIS Team Members, a means of discriminating different major biome types with NDVI and other AVHRR-based data. (2) develop a simple ecosystem process model for each of these biomes, BIOME-BGC (3) relate the seasonal trend of weekly composite NDVI to vegetation phenology and temperature limits to develop a satellite defined growing season for vegetation; and (4) define physiologically based energy to mass conversion factors for carbon and water for each biome.

Our final core at-launch product will be simplified, completely satellite driven biome specific models for net primary production. We will build these biome specific satellite driven algorithms using a family of simple ecosystem process models as calibration models, collectively called BIOME-BGC, and establish coordination with an existing network of ecological study sites in order to test and validate these products. Field datasets will then be available for both BIOME-BGC development and testing, use for algorithm developments of other MODIS Team Members, and ultimately be our first test point for MODIS land vegetation products upon launch. We will use field sites from the National Science Foundation Long-Term Ecological Research network, and develop Glacier National Park as a major site for intensive validation.

OBJECTIVES:

We have defined the following near-term objectives for our MODIS contract based on the long term objectives stated above.

- Organization of an EOS ground monitoring network with collaborating U.S. and international science agencies.
- Develop improved algorithms for estimating LAI and FPAR for different biome types from AVHRR data.

- Test of a generalized ecosystem process model, BIOME-BGC, for the simulation of the carbon, water and nitrogen cycles for different biomes.
- Implementation of the Global Ecological Simulation System (GESSys) to estimate continental net primary production (NPP) for the globe.
- Deliver formal software engineering of our MODIS products, #15 Leaf Area Index and Fraction Absorbed Photosynthetically Active Radiation, and Daily Photosynthesis - Annual Net Primary Production, #17.

The NTSG lab currently employs:

Dr. Steven Running, Director and Professor,
Dr. Ramakrishna Nemani, Research Assoc. Professor
Dr. Lloyd Queen, Associate Professor
Dr. John Kimball, Postdoctoral Research Associate
Dr. Soizik Laguette, Postdoctoral Research Associate
Dr. Peter Thornton, Postdoctoral Research Associate
Mr. Joseph Glassy, Software Engineer
Mr. Petr Voltava, Programmer
Mr. Saxon Holbrook, Computer Systems engineer
Ms. Galina Churkina, PhD student
Mr. Mike White, PhD student
Mr. Geoff Poole, PhD student
Ms. Alisa Keyser, PhD student
Mr. Carl Seilstad, PhD student
Mr. Jim Plummer, PhD student
Ms. Youngee Cho, Office Manager

All of these members contribute to certain aspects of our MODIS work.

ACTIVITIES OF SWRunning - Team Member, January 1998 – July 15, 1998

WORK ACCOMPLISHED:

EOS-IWG

I participate in a number of projects to develop both MODLAND, and more generally EOS Land product validation. These projects are in many ways interrelated, and their efficiency is maximized by regular coordination. Following are brief exerts of meeting summaries occurring during the January – July 1998 period of:

BIGFOOT = a field ecological measurement program in the US
GTOS-NPP = a global program related to BIGFOOT for GTOS
FLUXNET = a global array of CO2 and H20 flux towers
PIK-NPP = a global NPP model intercomparison
VEMAP = a US based ecological model intercomparison

BIGFOOT -- Characterizing Land Cover, LAI and NPP at the Landscape Scale for EOS/MODIS Validation:

Research Plan (October 1, 1998 - September 30, 2001)

A. Background and Summary

The MODLERS project was initially organized as a collaboration among 15 Long Term Ecological Research (LTER) sites with the goal of providing ground and related measurements for validation of MODLAND (MODIS Land Science Team) land cover, leaf area index (LAI), and net primary production (NPP) products. A workshop was held in 1996 and 9 papers have subsequently been prepared for a special issue of *Remote Sensing of Environment* on topics related to the theory and methods to be employed by both MODLAND and MODLERS. A set of 3 linked proposals was submitted to TECO, the NASA EOS Validation program, and the NASA Terrestrial Ecology Program (TEP) in 1997 but the size of the project made funding difficult. In spring 1998, NASA TEP sponsored a meeting to scale down the size of the project, and this revised research plan reflects the outcome of that meeting. Because the new research plan is less integrated with LTER than was originally planned, the name of the project has been change to BIGFOOT (in reference to the goal of characterizing not just the relatively small footprint of eddy covariance flux towers, but also the larger surrounding landscape).

The revised plan covers measurement, mapping, and modeling activities at 5 sites, 4 of which have associated eddy covariance flux towers. The core BIGFOOT products will be 100 km^2 surfaces at the 25 m spatial resolution for land cover, leaf area index (LAI) and net primary production (NPP). Land cover and LAI will be based on TM or ETM+ imagery, and NPP will be based on spatially-distributed, process-based biogeochemistry models. The models will be initialized with the land cover and LAI surfaces and driven by time-series meteorological data from the flux towers. Validation of BIGFOOT land cover and LAI surfaces will be based on ground sampling of land cover and LAI which is not used in development of the original surfaces. Validation of BIGFOOT carbon and water flux estimates will be made over the flux tower footprints at a daily time step, based on flux tower measurements, and over each site based on new aboveground NPP measurements. Belowground NPP will be measured at each flux tower site.

For comparisons to MODLAND products, the BIGFOOT 25 m grid will be overlain with the 1 km^2 MODLAND grid that is spatially consistent with the MODIS imagery. The NPP models will be run for calendar years 1999 and 2000, and comparisons to MODLAND NPP products will be made at 8 day and annual time steps. Differences between BIGFOOT and MODLAND NPP products will be evaluated in terms of the differences in spatial resolution of the analysis, the differences in vegetation classification system, and the differences in epsilon, the light use efficiency factor, as used in the MODLAND NPP algorithm and as derived from BIGFOOT NPP simulations.

In cooperation with the ORNL DAAC for Biogeochemical Dynamics, the BIGFOOT project will develop a data and information management system (IMS) to facilitate standardization and documentation of methods and products generated. The IMS will enable efficient flow of data among project personnel, and assure data and products are available to the general scientific community as soon as possible but at the latest upon completion of the project. Key features of the BIGFOOT IMS are that data will be available to both internal project users and outside users in a timely manner, appropriate credit will be given to the data originators, data will undergo quality assurance and enhancements into formats easily usable by scientists, documentation and metadata essential to the understanding and use of the data will be provided, and data from all the sites will be compiled into standardized datasets or data products.

B. Sites

Five sites were selected for the BIGFOOT study on the basis of covering a wide range of vegetation types and a wide range of LAIs and NPPs. The boreal conifer forest is represented by the NSA-BS site in Manitoba Canada, originally a BOREAS site. A flux tower is still maintained there by the S. Wofsy group. The Harvard Forest site is representative of the northern hardwoods biome and the flux tower there is also maintained by Wofsy. The temperate coniferous forest is represented by the H.J. Andrews Experimental Forest in the Oregon Cascade Mountains. There is not currently a flux tower there, but the site is desirable from the perspective of extending the range of LAIs out to 10 or so, nearly the highest in N. America, and the range of NPPs out to ~ 2000 $g/m^2/yr$, considerably higher that the other forest sites in this study. There are flux towers in temperate coniferous forest sites at the Wind River, WA and Metolius River, OR but the NPP at theses sites are relatively low. The grassland biome is represented by the Osage Prairie site in Oklahoma where a flux tower is maintained by Shasi Verma. The temperate crop site is alternate crops of corn and soybean in central Illinois with a flux tower maintained by Tilden Meyer.

Global Climate and Terrestrial Observing Systems (GCOS/GTOS)

Exerpts from the TOPC meeting in Corvallis Oregon, on planning for GTOS-NPP project.

6.0 DEMONSTRATION PROJECTS: PRESENTATION AND DISCUSSION TOPC ACTIONS

6.1 Global Net Primary Productivity

The NPP demonstration project was initially proposed at the meeting of Experts of Ecological Networks in Guernica, Spain, 1997. The NPP project has two primary goals, first to distribute a global standard NPP product to regional networks for evaluation, and to translate this standard product into regionally specific crop, range and forest yield maps for land management applications. The project will demonstrate the potential of a

relatively sparse surface network of sites to generate a reliable, useful product with global coverage and local relevance, rapidly and efficiently, by adopting the GHOST hierarchical sampling approach and by using models to combine *in situ* and remotely sensed data. The project is designed so that any network or site, regardless of its level of sophistication, can make a useful contribution to the project. The goal is to complete a demonstration project that would be of value to the participating GT-Net regional or national networks/sites, and to allow the development of the process for contributing site data to a central archive and utilizing site capabilities to validate satellite imagery. The primary source of satellite data will be the AM-1 satellite of the Earth Observing System (EOS), to be launched in 1999 by the NASA.

It is envisaged that site data would be provided to the U.S. LTER Network Office for incorporation into the TEMS database and land cover and Leaf Area Index (LAI) validation data would be provided to the U.S. LTER Network Office for archival. Satellite imagery of land cover and LAI would be provided to sites by the U.S. LTER Network Office. In addition, the project will use the FLUXNET global network of eddy covariance flux towers to translate the EOS NPP product into net ecosystem productivity (NEP), or total net ecosystem CO_2 flux, for use in global climate and carbon cycle models. In this context, the NPP project will inaugurate a globally distributed tracking of NPP and NEP which is critical to global change monitoring. As the network achieves global coverage, it will quantify the significant trends in biospheric productivity, including NPP responses to desertification and land degradation trends, interannual climate variability, CO_2 fertilization, pollution effects, etc. This plan also incorporates the principles of GHOST, the global hierarchical observing strategy, in that the regional NPP drivers will be done as a Tier 4 activity, regional NPP validation a Tier 3 activity, and the FLUXNET towers function as Tier 2 intensive continuous NEP study sites. Finally, the plan offers two end products, one of high practical utility at the local level, the other of high significance at the scientific level.

The project will extract the global 8-day NPP product from the U.S. NASA EOS Data Information System for dissemination to participating surface networks. The U.S. LTER Network Office will lead this effort, including archiving site data and extracting appropriate satellite coverage for individual sites. Specifically, EOS is computing a NPP product at 1 km for the entire global vegetated land surface every 8 days from the MODIS sensor and ancillary data. The initial EOS NPP algorithm is based on the relationship between time integrated absorbed PAR and NPP.

Each participating site should aim to collect the following input variables. Failure to collect the full set does not render the site useless, since the data, that are available, can be used for independent validation of the EOS-derived global data sets. The data must be collected to be representative of a minimum area of 3 km x 3 km. This is because the calculated NPP product will initially have a resolution of 1 km by 1 km, with a positional error of up to 1 km. Future products will have a resolution of 250 m x 250 m.

Implementation Procedures

The anticipated implementation steps are:

1. The U.S. LTER Network Office would initiate a request to potential sites/networks for latitude and longitude data (to the nearest second) for a minimum area of 3 km x 3 km that best represents the research site and local vegetation type. A more ideal area would be 10 km x 10 km and sites would be encouraged to develop this larger area of research in subsequent phases of this demonstration project. The site location coordinates would be used by the U.S. LTER Network Office to develop extraction software for the MODIS satellite imagery. Requests for coordinate data will be initiated August 1, 1998. These data will also be added to the TEMS database. Dr. John Vande Castle from the U.S. LTER Network Office will lead this effort.
2. The U.S. LTER Network Office will request additional information on site descriptions, associated research projects, and site facilities. This information will be added to the TEMS database and archived as companion information to the satellite and validation data sets . James Brunt will lead this effort.
3. The U.S. LTER Network Office will develop an automated extraction routine to be used for each site. The extracted imagery will be archived by the LTER Network Office and distributed or made available to sites by the most appropriate method (e.g., ftp, diskettes, hard copy). Imagery will be extracted every 8 days from the EROS DAAC for MODIS Land products. Implementation will begin at the AM-1 launch date plus 4 months. Dr. Vande Castle will lead this effort.
4. Participating sites will receive AVHRR derived global 1 km land cover data that is the at-launch EOS standard for their defined area. Landsat Thematic Mapper (TM) or SPOT imagery will be provided to complement AVHRR data for high resolution land cover validation for sites that do not have this imagery. The U.S. LTER Network Office will be responsible for providing this imagery by the most appropriate procedures after sites provide site coordinates and associated site information. Dr. Vande Castle will lead this effort.
5. Participating sites will be requested to validate the land cover map for their study region during the summer of 1999. The methods and classification logic used for the land cover maps can be located on the web site at the EOS Distributed Active Archive Center (DAAC) of the EROS Data Center that accompanies these data sets. The U.S. LTER Network Office will provide this information for sites that cannot access this information. Validation data will be sent to the U.S. LTER Network Office by October 1, 1999 or made accessible on a site/network server for retrieval by the U.S. LTER Network Office. Dr. Vande Castle will lead this effort.
6. Participating sites will be required to validate LAI imagery with a sampling design and methodology appropriate to their site (i.e., relative to vegetation type and site heterogeneity). These sampling protocols will be developed by a small group of experts in geostatistical sampling and LAI measurements at a workshop in the winter of 1998-99. The frequency of LAI sampling will be determined by seasonal dynamics of the vegetation type. Sampling protocols will be made available through

web sites or mailings as appropriate. Training in methodology and sampling protocols will be ascertained on a case by case basis. LAI sampling and validation will commence after the AM-1 launch plus 4 months. Dr. Gosz and Dr. Running will lead the workshop effort on sampling and methodology protocols. John Vande Castle will lead the acquisition of the LAI validation data that will be archived in the U.S. LTER Network Office as companion data sets to the LAI imagery.

7. The MODIS Land Team will access site validation data sets from the U.S. LTER Network Office archive to provide the direct validation of the imagery.

Recommendation 6.1: The TOPC recommends that the NPP project should be executed in accordance with the above plans. The TOPC should maintain contacts with the projects as it progresses, and should use the lessons learned to refine plans for other observing networks and for the compilation of global data sets.

FLUXNET

A Report from the Polson FLUXNET WORKSHOP

Prepared by Dennis Baldocchi and Eva Falge, Atmospheric Turbulence and Diffusion Division, NOAA, Oak Ridge, TN

Introduction

The Second International FLUXNET workshop was held in Polson, MT, June 3 to 5, 1998. About 70 scientists from across the world (United States, Canada, Japan, Australia, Italy, United Kingdom, France, Netherlands, Germany, Belgium, Sweden, Finland, and Denmark) attended. These scientists represented the EUROFLUX, AmeriFlux, OzFlux, JapanNet and the Amazonian LBA projects, the remote sensing, biogeochemical and eco-physiological modeling communities and supporting government agencies.

About 80 scientific teams are now measuring continuous and long-term fluxes of carbon, water and energy over a variety of biomes, across the globe. Table 1 lists a breakdown of sites by regional network

Regional Network	Number of Sites
AmeriFlux	35
EUROFLUX	18
JapanNet	5
LBA	2
MedeFlu	7
OzFlux	1
Other	11
FLUXNET	80

Prior to the workshop, the break down of sites, by functional type, is shown in Table 2.

FUNCTIONAL TYPE	Percent
Mixed Forest	3
Temperate Broad-leaved Forest	21
Temperate Conifer Forest	22
Boreal Broad-leaved Forest	1
Boreal Conifer	7
Semi-Arid Woodland	16
Alpine	6
Arctic	4
Grassland	7
Crop	6
Tropical Forest	3
Wetland	1

Most of the research sites are associated with regional networks and are funded by federal governments. The major objectives of the individual studies are to assess the annual net uptake of carbon dioxide from particular biomes, to quantify year to year differences in canopy carbon exchange and to understand the environmental and biological factors controlling trace gas fluxes.

To identify temporal and spatial patterns of carbon, water and energy fluxes on the global scale, quantities that may not be detectable by individual sites or regional networks, there is a need to construct and operate a global flux network. The objectives of the Polson FLUXNET workshop were multifaceted, and concerned scientific, programmatic and societal issues. The scientific objectives of this workshop included:
1) reporting current results;
2) identifying data types and collecting data into a common data-base; and
3) to use acquired data to study how carbon, water and energy fluxes are affected by latitudinal and climatic gradients, differences in species and year to year variability in weather and climate.

The programmatic objectives of the workshop included organizing the regional networks into a global network, promoting communication and cooperation among the regional networks and discussing future experimental and modeling plans. There was also a societal/educational aspect of the meeting. This aspect was to inform the field scientists about how their data may play a role in implementing the Kyoto Protocol, an agreement among nations of the United Nations Framework Convention on Climate Change. If the signatory nations are to reduce the loading of carbon dioxide in the atmosphere they must either increase the strength of carbon sinks or reduce the strength carbon sources. The regional and global flux networks can play a role by assessing regional and global carbon fluxes, and provide guidance to government agencies, which need this information.

Straw-Man Mission Statement:

There was a desire to clarify the distinct roles of the global FLUXNET project and its constituent regional networks, such as EUROFLUX and AmeriFlux. Below a mission statement for FLUXNET is proposed:

> *FLUXNET is an umbrella organization that facilitates the interaction, coordination, cooperation and organization of regional flux measurement networks to form a global network for measuring and assessing carbon, water and energy exchange between ecosystems and the atmosphere.*
>
> *One mission of FLUXNET is to identify and quantify temporal and spatial patterns of carbon, water and energy fluxes on the global and inter-continental scale. A second mission is to produce value-added products on stand-scale CO_2, water and energy fluxes. Value-added products will be derived by synthesizing data at the biome, cross-biome, continental and global scales, by developing empirical algorithms to predict CO_2, water and energy fluxes and by comparing eddy covariance flux measurements with other measures of ecosystem carbon fluxes (such as with carbon stocks and through the inversion of CO_2 concentration measurements). The third mission of FLUXNET is to sponsor a central data-base for the archiving, documenting, and disseminating of flux data. The data base will also collect and archive meta data on climate, site, vegetation and soil characteristics to the global ecological and biogeochemical research community.*

THE GAIM-NPP model intercomparison study

Other projects, like the ongoing IGBP sponsored 1995 Potsdam (PIK)-NPP model intercomparison can likewise use FLUXNET derived validated NPP data to test global NPP model estimates.. The 1995 Potsdam NPP model intercomparison project was an international collaboration that produced single-year global NPP simulations (Cramer et al. 1998). The intent of the Potsdam NPP project was to assess the current state of global NPP models with minimal constraints on model input datasets. For these larger scale modeling projects, the FLUXNET measurements must be scaled properly to represent land surface cells on the order of 0.5x0.5deg, or roughly 10<4> km2. It is then critical to quantify how representative the flux tower area is to the entire landscape cell. This same principal applies when using flux tower data as validation points for land surface models LSMs with GCMs.

Highlights of the subsequent analyses revealed several dissimilarities between NPP:

(1) There were large discrepencies between modelled NPP in northern boreal forests and seasonally dry tropics

(2) Although light use efficiency (LUE) formulations widely differed and produced dissimilar seasonal NPP trajectories, simulated annual NPP was comparable, suggesting either explicit or unconcious calibration towards 'accepted' values.
(3) The sensitivity of modelled NPP for one or more average climatic variables may not be detectable, particularly when averaged across a zonal or global domain and over an entire year, however, simulated differences in global and zonal NPP may emerge when climatic conditions deviate from average conditions, i.e. interannual time scales.
(4) Over much of the global land surface, water availability may strongly influence estimates of NPP, however, the interaction of water with other multiple limiting resources may influence simulated NPP in a non-predictible fashion.
(5) Assumptions of homogeneous land cover within a simulated cell may influence seasonal NPP as much as ecophysiological assumptions with respect to model paramaterization or calibration.
(6) Seasonality of NEP in southern latitudes was strongly influenced by soil hydrology formulations.

Although many of the models simulated global NPP in a reasonable fashion for a single year, the original experimental design precluded an analysis of model sensitivity to interannual variability, constituent components of the carbon budget (NEP, Rh, etc.), or the consequences of unique model formulations with respect to resource-use efficiency. To improve upon model abstractions of processes controlling carbon fluxes from the terrestrial biosphere, GAIM is proposing as a follow-up excersise to the global Potsdam 1995; a two-fold project that includes both regional and global simulations for multiple years.

The objectives of the regional simulations are to improve our global simulations through an understanding of how ecosystems function over broad environmental gradients (e.g. climate, soils) that have been characterized with respect to driving ecological variables (e.g. climate, soils, vegetation type(s), measured NPP) over multiple years. Input datasets will incorporate those regions identified by the Global Primary Producitivity Data Initiative's (GPPDI) (Fig). The addition of FLUXNET tower sites to the regional simulations provides a unique opportunity to simultaneously constrain modeled carbon and water fluxes as well as provide FLUXNET scientists with translations from measured NEP to other ecosystem variables (e.g. Rh, evaporation, transpiration), and those processes that are intimately linked to the carbon budget, such as nitrogen mineralization.

We have submitted the following papers for the GAIM-NPP project:

Galina Churkina and Steven W. Running; Contrasting climatic controls on the estimated productivity of global terrestrial biomes; Ecosystems (1998) 1: 206-215.

Abstract:
Net primary productivity (NPP) represents the greatest annual carbon flux from the atmosphere to the biosphere, is an important component of seasonal fluctuations in atmospheric CO2 concentrations, and is the most critical biotic component of the global

carbon cycle. NPP measures products of major economic and social importance such as crop yield and forest production. Given that global NPP can not be measured directly, model simulations must provide understanding of its global spatial and temporal dynamics. In this study, we used the biogeochemical model BIOME-BGC to simulate global terrestrial NPP and assessed relative importance of climatic controls (temperature, water availability, and radiation) in limiting NPP in the array of climatic combinations found globally. The degree of limitation on NPP by climatic controls was defined using an empirical membership function. Results showed that temperature or water availability limited NPP over larger land areas (31% and 52% respectively) than did radiation limitation (5%). Climatic controls appeared to be important in limiting productivity in most vegetation biomes, except for evergreen broadleaf forests. Nevertheless, there were areas of the globe (12%) where none of the climatic factors appeared to limit NPP. Our research has suggested that other environmental controls such as nutrient availability or biological constraints should then be considered. The wide distribution of NPP between zero and the upper boundary values in the correlation plots indicated that multivariate environmental balances, not single limiting factors, controlledbiospheric productivity.

Galina Churkina, Steven W. Running, Annette L. Schloss
and the participants of "Potsdam '95"; Comparing global models of terrestrial net primary productivity (NPP): The importance of water availability; revised and submitted to Global Change Biology.

Given that neither absolute measures nor direct model validations of global terrestrial net primary productivity (NPP) are feasible, intercomparison of global NPP models provides an effective tool to check model consistency. For this study, we have tested the assumption that water availability is the primary limiting factor of NPP in global terrestrial biospheric models. A water balance coefficient (WBC), calculated as the difference of mean annual precipitation and potential evapotranspiration, has been compared to NPP for each grid cell (0.5° x 0.5° longitude/latitude) in each of fourteen model.We have also evaluated different approaches used for introducing water budget limitations on NPP. Three methods to restrict NPP by water availability were distinguished; 1) direct physiological control on evapotranspiration through canopy conductance; 2) climatological computation of supply/demand constraints on ecosystem productivity; 3) water limitation inferred from satellite data alone. The NPP versus the WBC correlation plots showed comparable patterns for the models using the same method for water balance limitation on NPP. While correlation plots revealed similar boundary lines for most global models, there was high variability in these distributions related to other environmental controls on NPP, as they are captured by the current generation of the global models. Models differed in the amount of variation in NPP, because they used different methods to simulate the interactions among various environmental controls.

Wolfgang Cramer, David W. Kicklighter, Alberte Bondeau, Berrien Moore III, Galina Churkina, Bernard Nemry, Anne Ruimy, Annette L. Schloss and the participants of "Potsdam '95", Comparing global models of terrestrial net primary productivity (NPP): Global Change Biology.

Abstract:

Seventeen global models of terrestrial biogeochemistry have been compared with respect to total, regional, annual and seasonal fluxes of net primary productivity (NPP). The comparison, sponsored by IGBP-GAIM/DIS/GCTE, used standardized input variables wherever possible and was carried out through two international workshops and over the internet. The models differed widely in complexity and original purpose, but could be grouped in three major categories: Satellite-based models that use data from the NOAA/AVHRR sensor as their major input stream (CASA, GLO-PEM, SDBM, SIB2 and TURC), models for (seasonal) carbon fluxes that use a prescribed vegetation structure (BIOME-BGC, CARAIB 2.1, CENTURY 4.0, FBM 2.2, HRBM 3.0, KGBM, PLAI 0.2, SILVAN 2.2 and TEM 4.0), and models that simulate both vegetation structure and carbon fluxes (BIOME3, DOLY and HYBRID 3.0). The simulations resulted in a range of total NPP values (44.4 - 66.3 Pg C yr-1), after two outliers (which produced extreme results as artefacts due to the comparison) had been removed. The broad global pattern of NPP and the relationship of annual NPP to the major climatic variables coincided in most areas. Differences could not be attributed to the fundamental modeling strategies, with the exception that nutrient constraints generally produced lower NPP. The regional and global sensitivity of NPP against the simulation method for the water balance was clearly illustrated. Seasonal variation among models was high, both globally and locally, providing several indications for specific deficiencies in some models. A negative correlation between total absorbed photosynthetically active radiation (APAR) and light use efficiency (LUE) across the majority of models was found after decomposition of annual NPP for those models that do not use remote sensing data into APAR and LUE, and subsequent comparison of these values against those used by the remote sensing models. This may indicate that the models are (consciously or unconsciously) calibrated to achieve 'commonly accepted values' of total NPP, despite widely differing spatial and seasonal patterns. An analysis of the resulting net ecosystem productivities (NEP), using a three-dimensional atmospheric transport model and observed seasonal CO2 observations from the flask sampling network indicates that the uncertainties are larger in water limited systems of the tropics than elsewhere.

Galina Churkina and Steven W. Running, Investigating the balance betweentimber extraction and the productivity of global coniferous forests, GCTE-LUCC Open Science Conference on Global Change. Abstracts; March 1998.

Abstract:

Measurements of extracted timber and modeled forest productivity are used to investigate relationship between forest harvested by people and forest natural productivity. At this stage, we confine our analysis to coniferous forests and countries that have coniferous forest on their territories. Annual roundwood (unprocessed primary wood) production from the database ofFood and Agriculture Organization (FAO) is used as an approximation of annual timber harvest by country. Annual stem primary productivity of coniferous forests is estimated using the BIOME-BGC model. Based on the current rates,

we extrapolate annual timber extraction for each country for the next 15 years. Then, on a country basis, we relate the amount of extracted timber to the estimated forest stem productivity assuming that coniferous forest area would stay unchanged for the next 15 years. We discuss the natural capacity of coniferous forests to sustain increasing wood extraction by people and identify countries where wood shortages may occur in the future if the timber products continue to be consumed at the current rates.

VEMAP - Vegetation ecosystem modeling and analysis project

VEMAP is a project to intercompare leading biogeography and biogeochemistry models in the US for global change and EOS research programs. VEMAP has a homepage at:

http://www.cgd.ucar.edu:80/vemap/

The BIOME-BGC model that is part of our MODIS algorithm development for the EOS NPP product is one of the three biogeochemistry models being tested. Currently VEMAP is building transitory climate and CO2 datasets for the next generation of simulations. The next models will be prototypes of what now are called DGVMs Dynamic Global Vegetation Models incorporating interacting biogeography and biogeochemistry models. We are teaming with Ron Nielson and his MAPPS biogeography model. Test simulations will occur in Summer 1998.

GLOBE

The University of Montana has been selected as a GLOBE regional Training Center. We hosted a GLOBE training workshop in May 1998. Additionally, we have written protocol for a new GLOBE variable (vegetation phenology) to be measured by all participating GLOBE schools world-wide. The text can be found at:

http://www.globe.gov/fsl/html/templ.cgi?butler_budburst&lang=en&nav=1

NASA EOS and Related MEETINGS ATTENDED (SWR)

EOS-SEC Meetings, January, 1998
Dahlem Workshop, Berlin, Germany January 1998
EUROFLUX Workshop, Italy January, 1998
National Space Agency, Bangalore, India February 1998
MODIS Science Team Meeting June 1998
EOS Hydrology planning meeting, Princeton Univ.
EOS Request for Information panels June 1998.

WORK ACCOMPLISHED (the following are journal articles with abstracts for papers related to our MODIS activity written in the last 6 months

Hasenauer, H., R. **Nemani**, K. Schadauer and S. Running. 1998. Forest growth response to change climate between 1960-1990 in Austria. Forest Ecology and Management (revised).

The purpose of this study is to explore if changes in climate could have caused the increased increment rates reported for European forests, specifically in Austria. Using 30 years of climate records from 20 weather stations in Austria, we investigated the magnitudes of temperature changes and the change in length of the growing season between 1961-1990. Special attention was paid to the period between 1981-90 over which forestry observations were available. In order to understand the significance of changes in climate on forest growth, we used the ecosystem model, FOREST-BGC, to predict annual net primary production. The results indicate: (1) no change in precipitation over the period; (2) an average temperature increase of 0.7 C between 1981-90 vs. 0.2 between 1961- 1980; (3) length of growing season increased by 21 days between 1981-1990; (4) net primary production increased by 11% between 1981-90 and only 0.6% between 1961-1980. The trends in NPP are consistent with observed diameter increment rates determined from 614 increment cores of Norway Spruce distributed all over Austria.

Measuring Fractional Cover and Leaf Area Index in Arid Ecosystems: Digital Camera, Radiation Transmittance, and Laser Altimetry Methods Michael A. White[1*], Greg P. Asner[2], Ramakrishna R. Nemani[1], Jeff L. Privette[3], Steven W. Running[1]

Remote Sensing of Environment (submitted)

Field measurement of shrubland ecological properties is important for both site monitoring and validation of remote sensing information. During the May 1997 NASA EOS Prototype Validation Exercise (PROVE), we calculated plot-level plant area index, leaf area index, total fractional cover, and green fractional cover with data from four instruments: 1) a Dycam Agricultural Digital Camera (ADC), 2) a LI-COR LAI-2000 plant canopy analyzer, 3) a Decagon sunfleck Ceptometer, and 4) a laser altimeter. Estimates from the LAI-2000 and Ceptometer were very similar (plant area index 0.3, leaf area index 0.22, total fractional cover 0.19, green fractional cover 0.14) while the ADC produced values 5-10% higher. Laser altimeter values, depending on the height cutoff used to establish FT, were either higher or lower than the other instruments' values: a 10cm cutoff produced values ~ 80% higher while a 20 cm cutoff produced values ~30% lower. Violation of LAI-2000 and Ceptometer assumptions by Jornada's sparsely vegetated ecosystem made these instruments primarily useful for relative within-site plant area index monitoring. Calculation of some parameters required destructive sampling, a relatively slow and labor intensive activity that limits spatial and temporal applicability. Thus, validation/monitoring campaigns should be guided by consideration of the amount of time and resources required to obtain measurements of the desired

variables. Our results suggest that the ADC is both efficient and accurate for long-term or large-scale monitoring of arid ecosystems.

The impact of growing season length variability on carbon assimilation and evapotranspiration over 88 years in the eastern U.S. deciduous forest

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Int. J. Biometeorology (in press)

Abstract

Recent research has suggested that increases in growing season length (GSL) in mid-northern latitudes could be partially responsible for increased forest growth and carbon sequestration. We used the BIOME-BGC ecosystem model to investigate the impacts of including a dynamically-regulated GSL on simulated carbon and water balance over a historical 88-year record (1900-1987) for 12 sites in the eastern U.S. deciduous broadleaf forest. For individual sites, the predicted GSL regularly varied by more than 15 days. When grouped into three climatic zones, GSL variability was still large and rapid. Colder, northern sites showed a recent trend toward longer GSL, but moderate and warm climates did not. Results showed that, for all sites, prediction of a long (short) GSL versus using the mean GSL increased (decreased) net ecosystem production (NEP), gross primary production (GPP), and evapotranspiration (ET). On an absolute basis, GPP differences between the dynamic and mean GSL simulations were larger than NEP differences. As a percent difference, though, NEP was much more sensitive to GSL changes than were either GPP or ET. On average, a one day change in GSL changed NEP by 1.6%, GPP by 0.5%, and ET by 0.2%. Predictions of NEP and GPP in cold climates were more sensitive to changes in GSL than were warm climates. ET showed no similar sensitivity. Our results: 1) strongly agreed with field measurements showing a high NEP correlation with dates of spring growth, and 2) suggested that persistent increases in GSL could lead to long-term increases in carbon storage.

Keywords: Growing Season Length, Net Ecosystem Production, Gross Ecosystem Production, Evapotranspiration, BIOME-BGC

North American high latitude climate change and simulated forest response

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(in preparation for submission to Global Change Biology)

The northern high latitudes are an area of intense interest in the questions surrounding global warming and climate change. The global land area covered by and mass of carbon stored in the vegetation and soils of this zone, currently a carbon sink, provide a large potential feedback to atmospheric CO_2 concentrations. As the greatest magnitude of warming is predicted to occur in the high latitudes, elucidating the consequences of such change becomes increasingly important. Much indirect evidence of warming and vegetation response in the high latitudes exists. In this study, we made a further inquiry into the questions surrounding high latitude climate change and boreal forest response. Our first objective was to analyse the absolute magnitude of climate change in the latitudinal band 50-70°N from long-term daily climate records. Second, we used these long- term records to drive and ecosystem process model, BIOME_BGC, to determine the potential effects that the climate change has induced on the carbon balance of boreal forest ecosystems.

Daily climate records of maximum and minimum temperature and precipitation were obtained for areas of Alaska (NOAA) and Canada (AES). We chose sites for this study which met the general criteria of latitude greater than 50° N and record length greater than 40 years; from the group that met these criteria, those meeting continuity and completeness guidelines were chosen for further analysis. The final set of 14 station records range in length from 44-61 years; all records are through 1997. Once selected, the records were manually examined for discontinuous or missing data and corrected using linear interpolation methods.

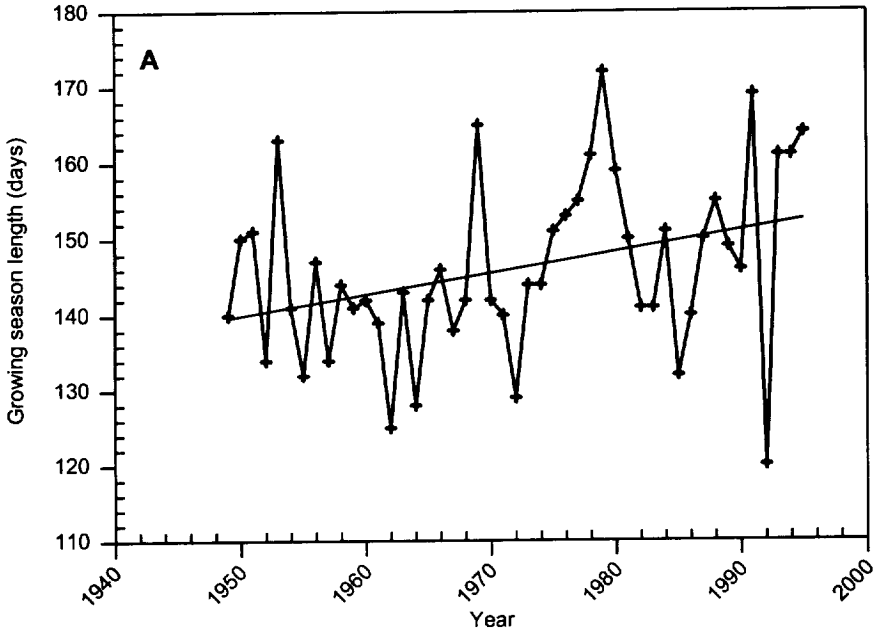
The goal of this climate analysis was to evaluate and determine any long-term changes from an ecological viewpoint. For this reason, before performing any analysis, we seasonalized the climate records according to realized vegetation seasons for the boreal forest--winter, spring, growing season--based on an ecological water year. We used a temperature proxy to determine growing season length for the period of record at each site. We also obtained an 82 year record of spring break-up dates for the Nenana river in interior Alaska. We performed regression analysis on the records for maximum and minimum temperature, precipitation, average daily temperature, daily temperature range, growing season length, and break-up date to determine if any significant trends were present. The trend analysis was performed for each site individually and for the region as a whole.

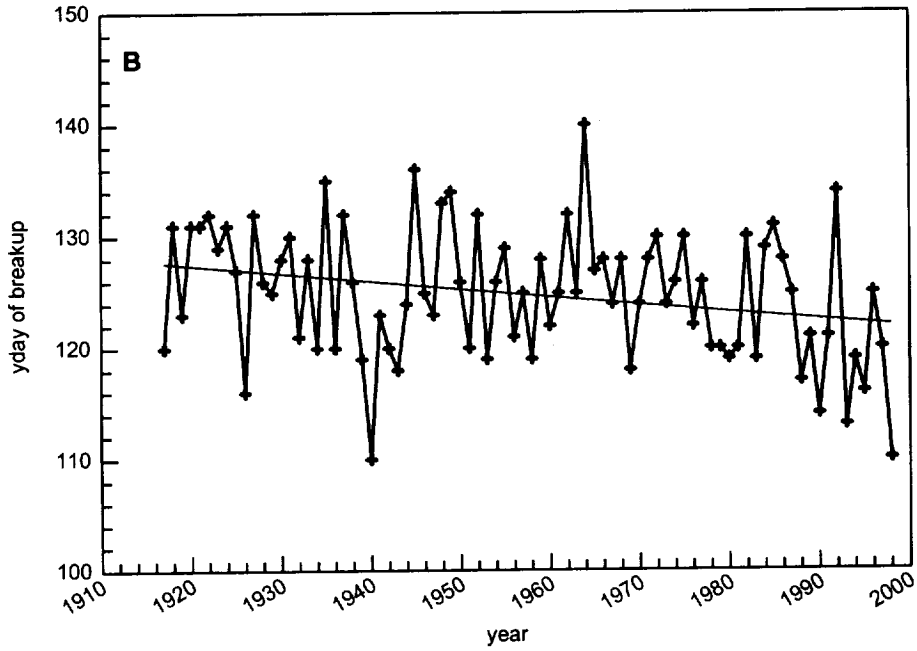
We calculated significant trends for all variables in all seasons. The most pronounced changes in temperature extrema, though, occurred in winter and spring. Absolute increases in spring vary from 1.140°C-9.680°C per 100 yrs. Spring increases in average daily temperature range from 1.280 °C-8.710°C per 100 yrs. All significant spring precipitation trends are positive; the values vary from 0.012cm-0.863cm per 100 yrs. Spring daily temperature range has both positive and negative slope, depending on site;

the values range from -4.300°C-2.020°C per 100 yrs. For all sites the growing season length increased; absolute values range from 2.62-63.6 days per 100 yrs with a mean of 24.2 days per 100 yrs (see Figure 1A for example). The spring break-up of the Nenana river, near Fairbanks, AK, has advanced by 5.8 days over the period 1917-1998 (7.1 days per 100 yrs, Figure 1B).

The climate records indicate that the climate has changed significantly in ecologically sensitive variables since the 1940's. This data on its own, though, does not tell us whether or how these changes have affected the vegetation communities at high latitudes. In order to determine any affect that these changes have manifested in the forest vegetation, we are using the daily long-term climate records to drive the ecosystem process model, BIOME_BGC, for standard deciduous and evergreen tree species. The model output will be evaluated in terms of net changes in the carbon balance (gross primary productivity, net primary productivity, autotrophic respiration) of these systems as a direct result of interannual climate variability.

Figure 1. A) Big Delta growing season, slope = 0.383 days/year. B) Breakup date of Nenana River, AK, slope = -0.071 days/year.





PUBLICATIONS

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MODLAND ACTIVITIES of R. NEMANI

(currently on sabbatical at NASA Ames Res. Ctr.)

ACTIVITIES OF J. M.Glassy, MODIS Software Engineer: July, 1998

OBJECTIVES

My objectives during the time period February 1998 to July 1998 were to:

1) Complete delivery of the MOD_PR15A1 and MOD_PR15A2 V.2.1 codes
2) Complete delivery of the MOD_PR17A1, MOD_PR17A2, and MOD_PR17A3 codes
3) Oversee development of a prototype biome properties lookup table (BPLUT) for the MOD17A1 PSN,NPP daily algorithm
4) Refine our SCF Quality Assurance plan and QA software utilities.
5) Refine our local NTSG laboratory MODIS Compute Ring Facility (MCR)

WORK ACCOMPLISHED

Significant progress has been made during this 6 month period, during which we will have delivered a Version 2.1 generation for each at-launch MODLAND software: PGEs 33, 34, 36, 37, and 38. The following table summarizes key software characteristics for

these algorithms. The code re-use fraction is provided to help quantify code maintenance effort over the expected life cycle of the software. This index is obtained as the fraction of the total number of C statements in an algorithm that is shared (e.g. the MUM API code) between all sibling algorithms. Once this code fraction is stable, it is expected to require very minimal maintenance relative to the "active" (e.g. algorithm specific) portions of the code.

UM SCF AM-1 At-launch algorithm software summary			
Algorithm:	MOD15A1	MOD15A2	MOD17A1,A2,A3
Measure:			
C statements	10672	8713	10207
Algorithm Specific Lines of code	4123	1783	3749
Total lines of code	14075	11168	13312
Cyclomatic Path Complexity	1607	1350	1461
Comment Lines	25172	21356	24189
Average per-tile performance (seconds)			
Code Re-use fraction	73.9 %	85.8 %	75.1 %

Note that interested readers can access a complete, cross-referenced set of our SCF MODIS software documentation via the following World Wide Web (WWW) URLs:

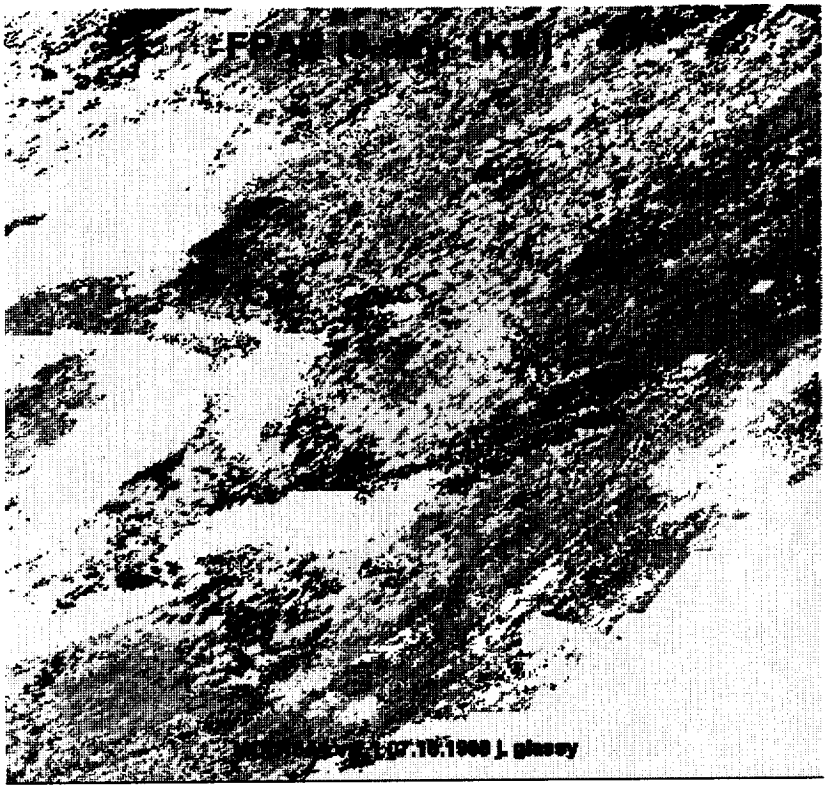
- MOD15A1:
  http://www.forestry.umt.edu/ntsg/projects/global/modis/mod15a1\mod15.htm
- MOD15A2:
  http://www.forestry.umt.edu/ntsg/projects/global/modis/mod15a2\mod15.htm
- MOD17A1,2,3:
  http://www.forestry.umt.edu/ntsg/projects/global/modis/mod17/mod17.htm

MOD_PR15A1, MOD_PR15A2: FPAR/LAI 1KM Product

The MOD_PR15A1 daily FPAR,LAI algorithm software was delivered in April of 1998, followed by a re-delivery in early May, 1998. This delivery represented a complete instance of our two layer algorithm, incorporating both the main lookup table method as well as an empirically based fallback method. The main lookup method, based on an inversion of a 3D radiative transfer solution, was developed at Boston University by Dr. Ranga Myneni, and Yuri Knyazikhin et al. We provided one full MODIS AM-1 Land tile of MOD_PRAGG aggregated 1KM surface reflectance data, projected in the integerized sinuoidal grid (GCTP_ISINUS) with this delivery. The file specification, V.2.1 codeset and now baselined and available for ECS test for this MODLAND AM-1 product.

The MOD_PR15A2 8-day composite FPAR,LAI algorithm software was delivered in late May, 1998. The software shipped in this delivery produces the 8-day composite FPAR and LAI at 1KM on the MODIS Land GCTP_ISINUS 1KM grid. The MOD15A2 file specification, V.2.1 codeset and test data are all currently baselined and available for ECS test. Average per-tile performance is XX sec/tile. The MOD_PR15A2 software consists of a total of XXXX lines of code.

Examples of the V.2.1 1km FPAR and LAI (full 1200x1200 tile) produced from MOD_PR15A2 images are shown below:



MOD17: PSN/NPP Product

The MOD17 gridded Level 4 (PSN, NPP) product is produced using a suite of three (3) PGEs, using a single executable which branches to a different logic path based on which PGE context is in force on a given day. Main inputs for the MOD17 are the at-launch 1km land cover characterization, the most recent 8-day period's FPAR and LAI products, a daily surface climatology, and the incrementally updated daily state variables. The PGE context triggered on a given data-day is associated with the following discrete temporal events recognized within the algorithm. Note that the computational activities performed by the program are organized as nested subsets -- the daily update logic is computed for year days 1..265 regardless of which PGE is triggered, whereas the 8-day composite period boundary logic is triggered once each 8 data-days, and the annual product output logic is triggered just once annually. Note that when the annual period boundary is encountered, it may or may not coincide exactly with the last 8-day composite period boundary, so we recognized this coincidence as a special discrete event.

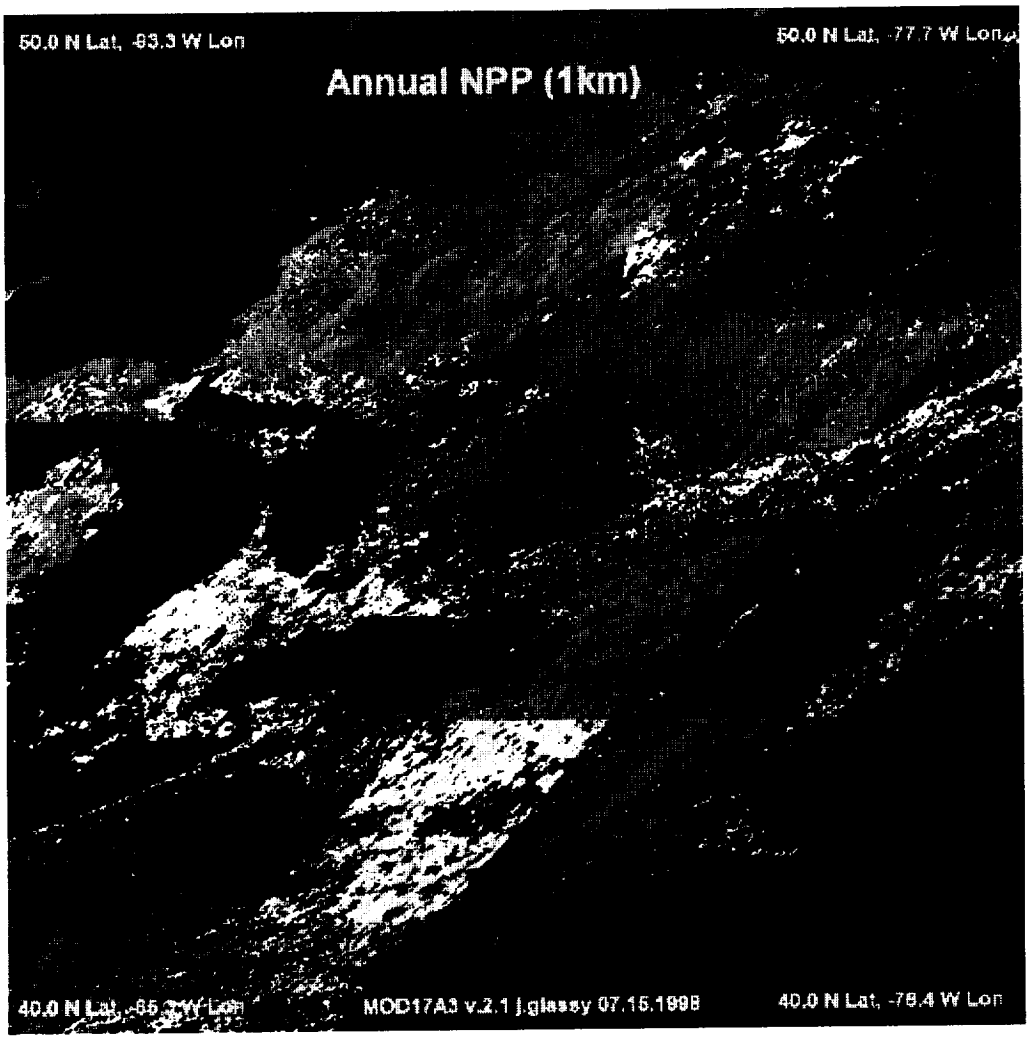
PSN, NPP Algorithm Temporal Events (v.2.1 code)	
Event	***Actions Performed***
First-of-year event	Daily state variable tile-wise files are reset to starting conditions, and the daily portion of the algorithm is fired.
Daily event only	Daily algorithm logic is fired, daily files are updated; no archived products are produced.
8-day Cmposite Period Boundary Event	Daily algorithm logic is fired, daily files are updated, after which the 8-day PSN composite is produced for archive.
Annual Period Boundary Event	Daily algorithm logic is fired, daily files are updated, after which the annual NPP product is generated for archive.
Coincident 8-day and Annual Period Boundary Event	Daily algorithm logic is fired, daily files are updated, an 8-day composite PSN product is generated, followed by generation of the annual NPP product.

The MOD17 (PSN, NPP) v.2.1 algorithm is currently completed. Final delivery documentation is under preparation, so the delivery should be made in a matter of days. This algorithm incorporates several novel characteristics, including a built in global surface climatology pre-processor for DAO data, and an internal compositing method driven from a single set of (326) updatable, daily intermediate HDFEOS state variable files. By staging these daily intermediate variables as updatable tile-wise product files, we obviate the need to read, and then totally re-write an equivalent set of intermediate files with each days processing. The result of this design is that all the science logic required by (3) separate PGE's (PGE 36, 37, and 38) resides in a single executable binary. The differences between these PGEs is then expressed via ECS scheduler generated production rules that spawn a different .pcf and .mcf parameterizaton for each PGE, as well as the different output resulting from each PGE. Two DAO datasets are required for each daily execution of the MOD_PR17A1 process, the "tavg2d" surface climatology 3-hourly timestep data, and the "tsyn2d" energy 3-hourly set. These DAO climatology data are produced by DAS on a daily basis on a global scale geodetic grid of 2.0 latitude by 2.4 degrees longitude. A built in reprojection facility in the MOD_PR17A1 algorithm reprojects these data on the fly to each given integerized sinusoidal grid (IS) tile.

Examples of the PSN and NPP 1km products

The geographic minimum bounding rectangle for the test data 1km tile (1200x1200 pixels) is NW: 50.0 N Lat, -93.33 W Lon, NE: 50.0 N Lat, -77.77 W Lon, SW: 40.0 N Lat, -65.27 W Lon, and SE: 40.0 N Lat, -78.35 W Lon. The PSN product example is shown below:

An example of the annual NPP product is shown next:



Evolution of the MODIS-University of Montana (MUM) API software library

The multi-platform MUM API library is now at version 2.0.7. It is organized into three tightly integrated components; a) a core service layer, b) a standard HDF v.4.1r1 support service layer, and c) an HDFEOS v.2.3 support service layer. Support for HDFEOS data object creation, manipulation and maintenance is limited to the GRID interface. The MUM API consists of a total of XXX lines of code, organized into XXX module files. This API library has been successfully ported to the following UNIX compute environments: IBM AIX 4.1, SGI IRIX v.6.4, DEC Unix v.3.2. On the Intel architecture, the full MUM API library functionality has been ported to Linux v. 2.x. Under Microsoft NT version 4.0, only the core service layer and standard HDF service layer are currently supported. The MUM API's full NASA PGS compatibility mode is only supported for workstation environments the SDPTK is ported to. The more general SCF mode is supported across all port platforms.

QA Environment and Software Tool Development

As part of MODLAND, we continue to work with the existing GSFC LDOPE facility for primary QA feeds and overall QA coordination. We are currently studying ways to further automate and streamline the local QA activities we ancipate occuring at-launch. For planning purposes, QA activities have been divided into two broad categories: a) statistical analysis, and b) interactive visualization; we expect this scheme will be refined with more pre-operational trials and experience. For statistical (tabular, non-spatial) analysis, we have the SPSS and S-Plus packages available both the UNIX workstations as well as on the NT workstations. On the NT platform we also have Mathematica, MathCAD, SigmaPlot, Noesys, Transform, and Stanford graphics software packages. For interactive visualizations, we primarily rely on the French LOA team's Msphinx - Mgraph - HDFLook tool suite, for which we are a beta test site. We also have a limited set of IDL licenses, and plan on also adopting the MODLAND team's standard visualization environment (IDL/ENVY) as our 1999 budget allows. A large number of QA functions are provided by the generic QA toolset provided by the LDOPE. Any key functions identified that are not covered by these utilities will be written as in-house utilities.

Compute Ring (MCR) at the University of Montana SCF

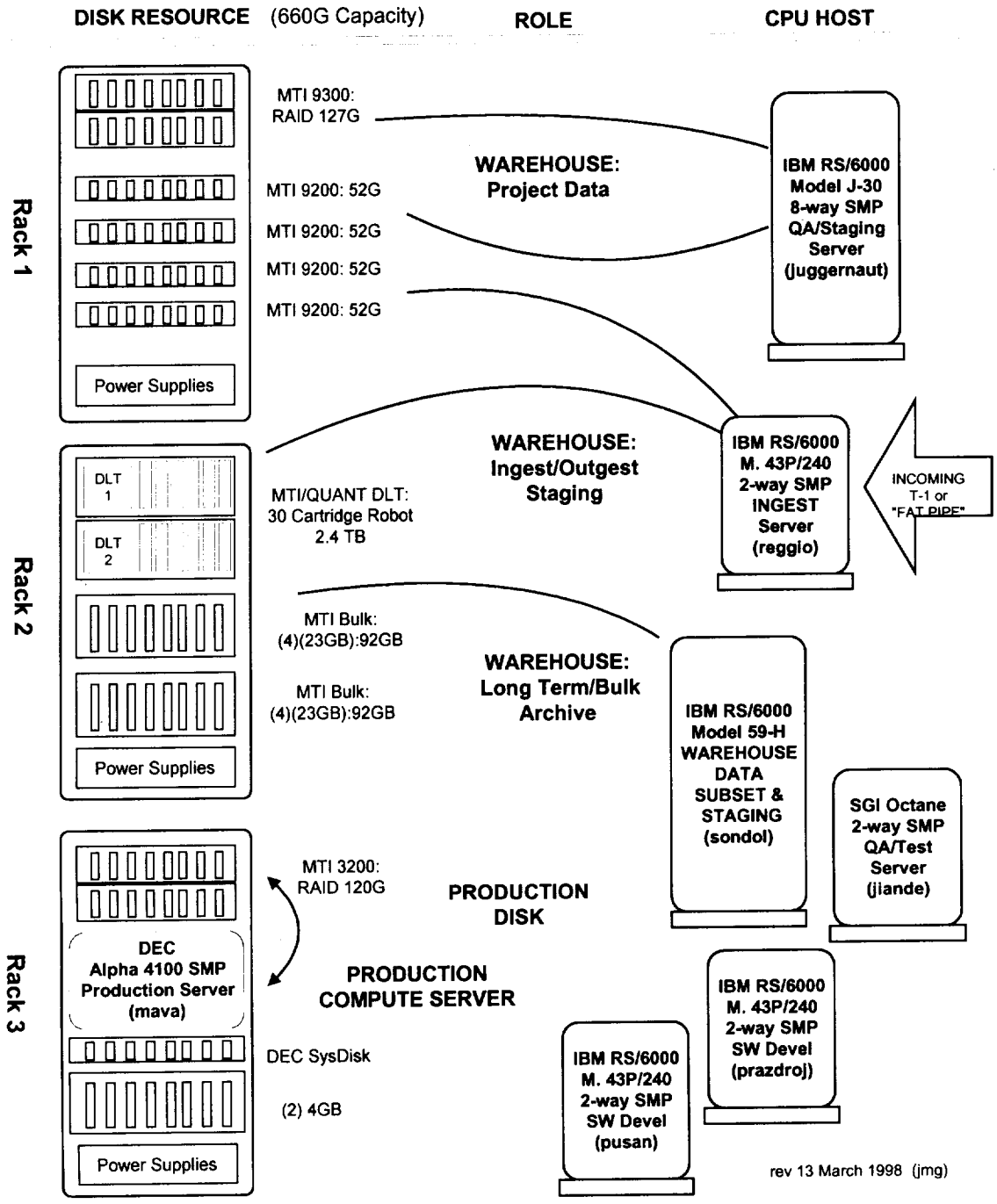
The MODIS SCF at the University of Montana is implemented within a facility we call the MODIS Compute Ring (MCR). The basic design architecture for the MODIS SCF remains stable -- a coordinated cluster of high performance workstations functionally organized by anticipated data flows. Improvements both in the topology as well as the capacity of the MCR will continue to be made as our budget allows, to bring our SCF up to the minimum processing capacity we feel is necessary for efficient at-launch operation. The MODIS validation activities which we expect to carry out during the next 1-2 years are now anticipated to consume additional compute resources above the levels required for routine MODIS operation (QA, test, feedback, etc). We are studying these resource implications and intend to revise our SCF Resource Facility plan accordingly.

At 660Gb of online disk, we are currently at about two thirds of our planned at-launch disk storage capacity, due to unanticipated budget shortfalls project wide. Tape storage provided by our Quantum 30-cartridge Digital Linear Tape (DLT) robot (approximately 2.3Tb) brings our near on-line and HSM capability to within 90% of that required for the at-launch era. The collective performance penalties associated with these compute resource shortfalls are considered significant, and are still being analyzed.

An updated MODIS SCF facility layout diagram appears below:

Montana MCR SCF At-Launch Configuration

Disk to CPU Mapping



MEETINGS ATTENDED

MODLAND/SDST Workshop, February, 1998

ON GOING ACTIVITIES

Algorithm Development

During the next period we will primarily concentrate on a number of testing and quality assurance issues, as well as addressing a number of operational readiness issues involving the evolving DAAC (or TLCF) to SCF interface, network communication protocols, and two directional QA data subscription protocols between the SCF and our data processing partners. In addition, we anticipate much of the next year to be dominated by a series of integrated MODIS validation related activities. These include generation of a set of multi-year global scale (1 degree by 1 degree resolution) ecosystem model runs, for comparing our MODIS algorithm parameterized using historical AVHRR data with Biome-BGC ecosystem model runs. A second set of validation runs are targeted at the U.S. Continent spatial scope at 1KM, also using AVHRR data. Climatology data used to drive these runs will come from the global VEMAP project as well as operational NCEP and DAO data.

Data Development

Test data development activities in the next period will focus on developing and/or assembling:

- ...a higher quality biome properties lookup (BPLUT) table for MOD17A,A2,A3
- ... a longer term global scale climatology database
- ... a more comprehensive MODIS simulated dataset of 1km aggregated surface reflectances

For the BPLUT development we intend to implement a number of ecosystem model runs at various scales and temporal durations. On the climatology requirements, we hope to develop a validation global scale, 1 degree by 1 degree, surface climatology daily dataset including minimum and maximum temperature, incident shortwave solar radiation, humidity and preciptation.

MODIS UM SCF Compute Ring Infrastructure

In the next period, we hope to bring our on-line disk storage capacity closer to the levels originally planned for the at-launch scenario (approximately 1Tb for direct MODIS activities, plus additional disk to dedicate to follow on MODIS instrument validation activities), enhance our near-on-line tape subsystem, as well as performing minor upgrades to our compute server suite.