SEMI-ANNUAL REPORT

NASA CONTRACT NAS 5-31368

For
MODIS Team Member: Steven W. Running
Assoc. Team Member: Ramakrishna R. Nemani
Software Engineer: Petr Votava
Subcontracted Programmer: Joe Glassy

15 January 2002

OBJECTIVES:

We have defined the following near-term objectives for our MODIS contract:

- Test software for our MODIS products, #15 Leaf Area Index and Fraction Absorbed Photosynthetically Active Radiation, #16 Evapotranspiration from land surface, and #17 Daily Photosynthesis Annual Net Primary Production as MODAPS processing delivers global datasets.

- Deliver at launch software for the Aqua MODIS sensor, for MOD 15, MOD 17 and the new MOD 16, Surface Evaporation Index

- Develop MODIS applications products for national natural resource management.

- Organization of a validation effort using AMERIFLUX fluxnet sites to correlate and test the MODIS derived LAI and Net Primary Production.

The NTSG lab currently employs:

Dr. Steven Running, Director and Professor,
Dr. Ramakrishna Nemani, Research Assoc. Professor
Dr. John Kimball, Postdoctoral Research Associate
Dr. Sinkyu Kang, Postdoctoral Research Associate
Dr. Maosheng Zhao, Postdoctoral Research Associate
Dr. Swarna Reddy, Research Associate
Mr. Petr Votava, Software Engineer
Mr. Chad Bowker, Programmer
Mr. Andrew Neuschwander, Programmer/Sys Admin
Mr. Saxon Holbrook, Computer Systems Engineer
Mr. Matt Reeves, PhD student
Mr. W. Matt Jolly, PhD student
Ms. Pat Andrews, PhD student
Ms. Rachel Loehman, PhD student
Ms. Cristina Milesi, PhD student

Ms. Ann Radil, PhD student
Ms. Divya Tipparaju, MS Student
Ms. Alana Oakins, Research Assistant
Ms. Youngee Cho, Office Manager

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

EOS-IWG

I participated 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 summaries of current activity for:

BIGFOOT = a field ecological measurement program in the US
FLUXNET = a global array of CO_2 and H_2O flux towers
GTOS-NPP = a global program related to BIGFOOT for GTOS

BIGFOOT

The BigFoot project grew from a workshop held in 1996, which was attended by ecologists and scientists of related disciplines, primarily from the Long Term Ecological Research (LTER) Network. The purpose was to explore validation protocols and scaling issues that would lead to an improved understanding of several MODLand products. The BigFoot field sites are also EOS Land Validation Core Sites and are part of the FLUXNET program. The sites have active science programs concentrating on CO2, water vapor, and energy exchange using flux tower measurements. The "footprint" over which gas flux data are collected varies, but is roughly 1 km or less. For the BigFoot analysis, this footprint will be extended to 25 km2 to include multiple 1 km MODIS cells, hence the project name. BigFoot investigators will focus on validation of the MODLand land cover, LAI, FPAR, and NPP products. We will develop fine grain (25 m resolution) surfaces of land cover, LAI, FPAR, and NPP, aggregate these to 1 km resolution, then assess the similarities and differences between these surfaces and the MODLand products.

http://www.fsl.orst.edu/larse/bigfoot/overview.html

The BIGFOOT project was just renewed in the recent NASA NRA for Carbon Cycling Research.

FLUXNET

The FLUXNET program is maturing rapidly as the cornerstone of EOS Land validation, website at:

http://daacl.ESD.ORNL.Gov/FLUXNET/.

There are now 120 sites globally, and substantial international coordination. We inaugurated the RealTime flux validation activity with the active participation of ORNL. The following text from the Ameriflux website explains the project, found at:

http://cdiac.esd.ornl.gov/programs/ameriflux/Model_Evaluation/index.html

Model Evaluation Using AmeriFlux Data

One of the ongoing justifications for the AmeriFlux network is the opportunity to use the measurements to test both satellite data and model simulations. Commencing October 2000 the Carbon Dioxide Information Analysis Center (CDIAC) began posting weekly micrometeorological data from participating AmeriFlux sites for an evaluation exercise initiated by Dr. Steve Running (Numerical Terradynamic Simulation Group (NTSG) at the University of Montana). During this exercise participating AmeriFlux sites will provide canopy-top, micrometeorological data every week for use by numerous models including NTSG's BIOME-BGC model. In return, site-specific daily evapotranspiration, GPP, NEE, and NPP model output and weekly MODIS-derived NPP values will be posted weekly for comparison by participating AmeriFlux scientists to their own productivity estimates. Other modeling teams are welcome to participate but must be willing to provide site-specific, daily ET, GPP, NEE, and NEP computations each week to CDIAC for use by participating AmeriFlux groups.

The FLUXNET project was also just renewed in the Carbon Cycle NRA.

Global Climate and Terrestrial Observing Systems (GCOS/GTOS)

The GTOS-NPP project is being initiated to provide coordinated global measurements of landcover, LAI and NPP for EOS validation, and can be found at:

http://www.fao.org/gtos/actthemanpp.html

The following text from the GTOS website explains the current plan.

The launch of NASA's Terra satellite on 18 December 1999 means that the GTOS project on Net Primary Productivity (NPP) can now move towards an operational phase. It will play a key role in strengthening collaboration among its networks and sites.

The **NPP Demonstration Project** will compare global ecological data streams produced by Terra's Moderate Imaging Spectrometer (MODIS) sensor with similar land measurements obtained from participating GTOS ecological sites. After validation, these data will be used to generate regionally specific crop, range and forest yield maps for land management applications.

Measurement of NPP - the amount of new plant growth within a given area over a specified time period and the mechanistic basis of harvest yield for grass, grain or timber production – is a key indicator of ecosystem degradation or improvement.

To determine NPP values, variables such as rainfall, temperature, soil water holding capacity and nitrogen content, as well as basic land cover type and Leaf Area Index (LAI) measurements, will be extracted from the MODIS data stream, then exchanged and compared with similar land measurements obtained from participating sites. Currently, 45 sites in 12 countries have been identified to carry out the initial validation studies required by NASA.

One of the major efforts for start-up of the NPP Demonstration Project was to generate example **global datasets** useful as examples of data that will be available once TERRA/MODIS is operational. A dataset of basic landcover data for Europe is shown in the figure below. It depicts the IGBP scheme of 16 basic land cover types ranging from forest to shrub lands to croplands to barren lands, snow cover and water. The primary land cover types are croplands (red) and a mixture of croplands and natural vegetation types (yellow).

Plans to distribute similar datasets to help sites involved in the NPP Demonstration Project get started with their data comparisons and information exchange are under discussion within GTOS. An important step has been to obtain access to the SPOT IV vegetation dataset on distribution of composite normalized vegetation indices (NDVI).

Datasets are also being developed at the **site level** in order to carry out comparison and validation of the global data sets. The regional meetings of the International Long Term Ecological Research (ILTER) Network in Budapest, Hungary (June, 1999), and Skukuza, South Africa (August, 1999) served to discuss sample datasets developed by research sites in Hungary, Czech Republic, Ukraine and Kruger National Park in South Africa.

GLOBE ACTIVITY

Phenology, the study of recurring biological cycles and their connection to climate, is a critical and growing field of global change research. In particular, scientists now recognize that regular satellite monitoring of the timing and length of the terrestrial growing season is a valuable metric of biospheric responses to short- and long-term climate variability. While many methodologies exist with which to detect growing season dynamics, most have a poorly understood relationship to actual ground vegetation conditions. GLOBE schools, through participation in the budburst protocols, are helping to bridge this gap between satellite observations and ground conditions. In this research we show how GLOBE budburst data can be used to select the optimal satellite compositing length (a technique used to reduce cloud, snow, and atmospheric contamination). One- and two-week compositing lengths produced similar results, both of which were superior to monthly compositing. The longer compositing length, contrary to popular remote sensing lore, tended to predict an earlier initiation of growth due to removal of inflection points in the satellite greenness time series. Overall, the GLOBE budburst data were extremely useful but also contained several troubling artifacts probably relating to infrequent observation, errors in date reporting, and use of exotic species.

ESIP ELECTION

In February NTSG applied and was admitted to the Earth Science Information Partners (ESIP) program. We are working with the ESIP program to enhance the distribution of advanced vegetation biophysical products from MODIS, particularly versions of our MOD 17 algorithm that go beyond the standard global MOD 17 NPP. We now are participating in ESIP telecons, and will attend the ESIP meeting in July in North Dakota.

NASA EOS and Related meetings attended (SWR)

AsiaFlux Workshop, Jeju, Korea, Jan. 2002

MODIS Science Team Meeting, Washington, DC, Dec. 2001
3rd Carbon Cycle Scientific Steering Group Meeting, Washington, DC, Nov. 2001
Information Management Kickoff meeting, NASA Ames Research Center, San Jose, CA, Nov. 2001
NASA/EOS investigator Working Group meeting, San Antonio, TX, Oct. 2001
ESE 2nd Science Review, Video Conference, Missoula, MT, Oct. 2001
US-Japan Workshop on Carbon Cycle Management in Terrestrial Ecosystem, Tokyo, Japan, Oct. 2001
The North American Carbon Cycle Workshop, Boulder, CO, Sept. 2001
National Environmental Trust Energy Tour, Helena, Missoula, MT, Aug 2001
Aqua Science Working Group meeting, Washington, DC, Aug. 2001
ESA 86th Annual Meeting, Madison, WI, Aug. 2001
NASA Terrestrial Ecology Program Workshop, Madison, WI, Aug. 2001
NASA Carbon Cycle Team Kick-off Meeting, Polson, MT, Aug. 2001
The GLOBE Program Annual Conference, Blaine, Washington, July 2001

Publications:

Jackson, R.B., S. R. Carpenter, C. N. Dahm, D. M. McKnight, R. J. Naiman, S. L. Postel, and S. W. Running. (2001) Water in a changing world. Ecological Applications, 11: 1027-1045.

White, M.A., R.R. Nemani, P.E. Thornton, S.W. Running. Satellite evidence of phenological differences between urbanized and rural areas of the eastern United States deciduous broadleaf forest. Ecosystems. Accepted.

White, M.A. and S.W. Running. 2001. Identification of optimal satellite compositing length using GLOBE budburst measurements. Proceedings of the Sixth Annual GLOBE Conference. Blaine, Washington. GLOBE. July, 2001. pp. 270-276.

University of Montana EOS Natural Resource Training Center

A. Overview

The University of Montana, EOS Training Center was initiated February 1, 1999. The EOS Training Center consists of two main components; the EOS Natural Resource Project, which addresses the needs of the scientific and natural resource community and the EOS Education Project, which addresses the needs of the K-16 educational community. The overall objectives of the EOS Training Center are:

OBJECTIVES:

We have identified the following near-term objectives for our University of Montana EOS Training Center contract:

EOS Natural Resource Project

- Work with natural resource managers to produce relevant EOS application products particularly in the fields of fire management and vegetation productivity.
- Develop and provide training to remote sensing, GIS, earth system scientists, and natural resource personnel in the acquisition, interpretation, and application of NASA EOS application products.

EOS Education Project

- Expand national outreach efforts on EOS Education Project products and services.
- Expand development of web-based presence.
- Begin integration of Terra data and imagery into existing EOS Education Project programs.

B. Project Partners

The University of Montana, EOS Training Center is actively participating with a number of project partners. These partners include:

1. USDA Forest Service, Region One Fire Sciences Lab, Rocky Mountain Research Station. Contact - Patricia Andrews

The EOS Training Center is coordinating with the Fire Sciences Lab to include current and future EOS data to support wildland fire decision making. We are developing a link between the EOS Training Center World Wide Web site (http://eostc.umt.edu) and the Wildland Fire Assessment System (WFAS) World Wide Web site (http://www.fs.fed.us/land/wfas). The system is in place to post current Satellite Moisture Index (SMI) and meteorological (see Daymet) data to the WFAS web site. This will become operational as soon as the WFAS web site is updated.

2. University of Alaska - Fairbanks. Contact - Dr. David Verbyla

Dr. Verbyla has conducted a number of workshops in Alaska regarding EOS data; Remote Sensing: An Alaskan Natural Resource Perspective, ArcView Processing of Landsat 7 Imagery.

3. University of Missouri - Columbia. Contact - Dr. David Larsen

Under the direction of Dr. Larsen, an on-line tutorial on change detection based on Landsat imagery is being used by faculty and staff at the University of Missouri to incorporate EOS data into current curriculum and research.

4. University of Idaho

The EOS Education Project is partnering with the University of Idaho and using their expertise in the work they have performed with NASA's GLOBE project.

C. NASA'S EOS and Ancillary Data

The University of Montana EOS Natural Resource Project is focusing on two fields of NASA's EOS Application Products for land natural resource management; fire management and vegetation productivity. In collaboration with the Numerical Terradynamic Simulation Group and the Remote Sensing Lab at the University of Montana, we have been enhancing EOS algorithms within these fields for regional applications.

Fire Management

Remote sensing is becoming more applicable to a number of applications in fire management. The EOS Natural Resource Project, in cooperation with the Remote Sensing Lab and NTSG at the University of Montana operationally tested and produced two UM-EOS application products that will be applied to Terra MODIS data when available.

Surface Moisture Index

The Surface Moisture Index (SMI) estimates vegetation moisture condition over large scales for both fire and drought monitoring. Using both NDVI and surface temperature from the heritage AVHRR instrument, vegetation stress is monitored once a week from composited data. The EOS Natural Resource Project posted the Surface Moisture Index as both a browse image and as a data file in ERDAS Imagine format (.img). An ERDAS Imagine format was selected as a number of popular Remote Sensing/GIS Software packages can read this file format (ERDAS, ARC/Info, ARCView) and it is a reasonable size for ftp download. Departure indexes were established by applying the SMI algorithm to a 10-year historic data base of AVHRR data.

Fire Detection/Monitoring

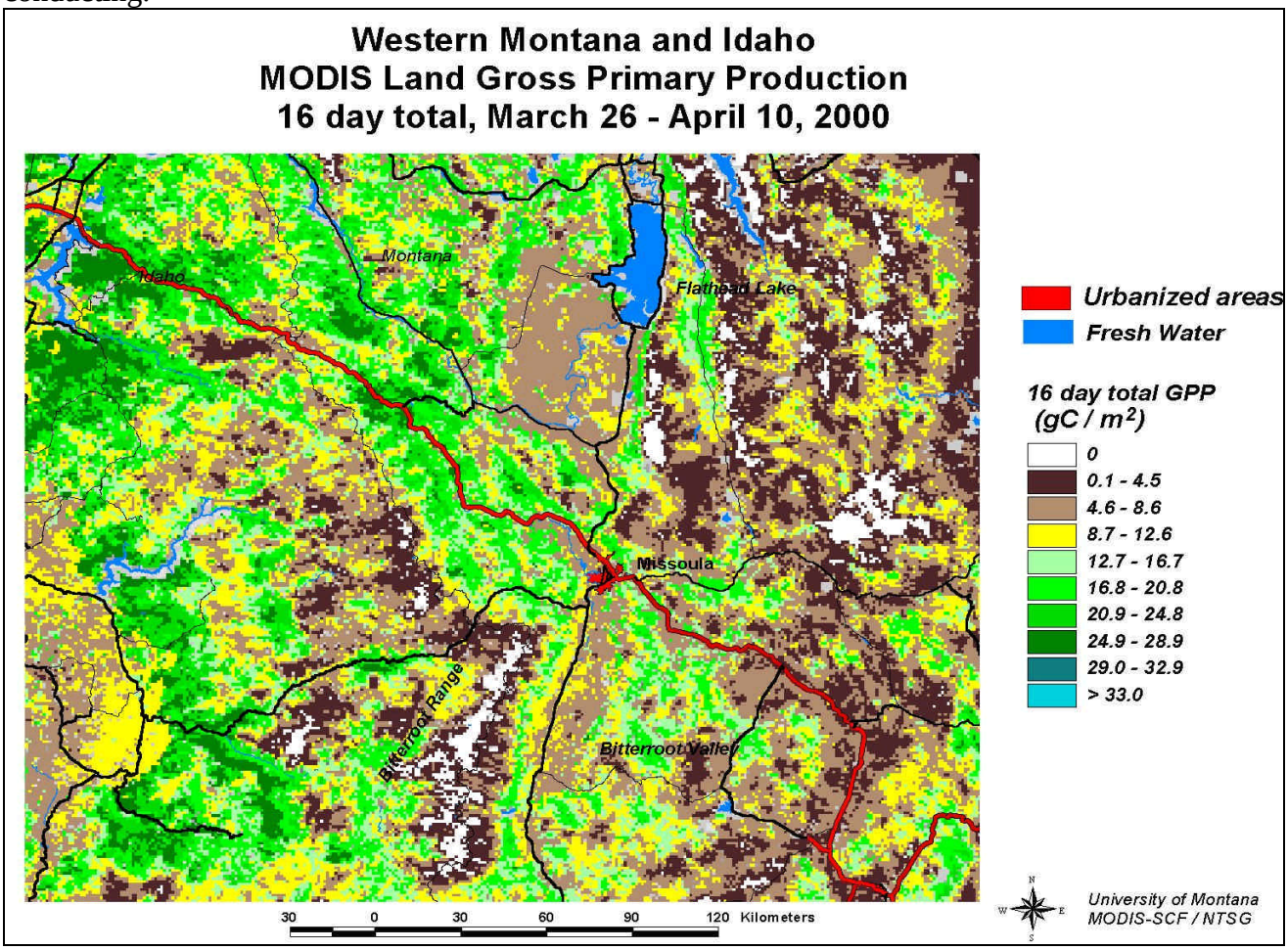
Fire detection and monitoring is a MODIS at launch product (MOD 14). The MODIS active fire detection routine relies on a neighborhood analysis in which brightness temperatures of potential fire pixels are compared to mean background brightness temperature of adjacent pixels. Fire pixels are identified using fixed thresholds in the 4μm and 11μm bands. The EOS Natural Resource Project and the Remote Sensing Lab will provide training on the MODIS fire algorithm and regional applications.

Vegetation Productivity

Global estimates of weekly vegetation productivity and annual net primary productivity will be estimated by the MODIS instrument using algorithms developed by Dr. Steven Running and his lab at the University of Montana (Running *et al.*, 2000). The EOS Natural Resource Project has been working with historic Pathfinder data to simulate MODIS products in order to demonstrate estimates of weekly vegetation productivity and annual NPP to natural resource personnel. In addition, range and forest researchers have been investigating resource applications for MODIS vegetation productivity.

With the recent availability of MODIS vegetation productivity data, we have continued discussions with natural resource personnel to develop regional applications for these and similar data sets. We are working closely with the Idaho Panhandle Forest to test some applications of

these data with the remote sensing, inventory, and forest health monitoring that they are currently conducting.



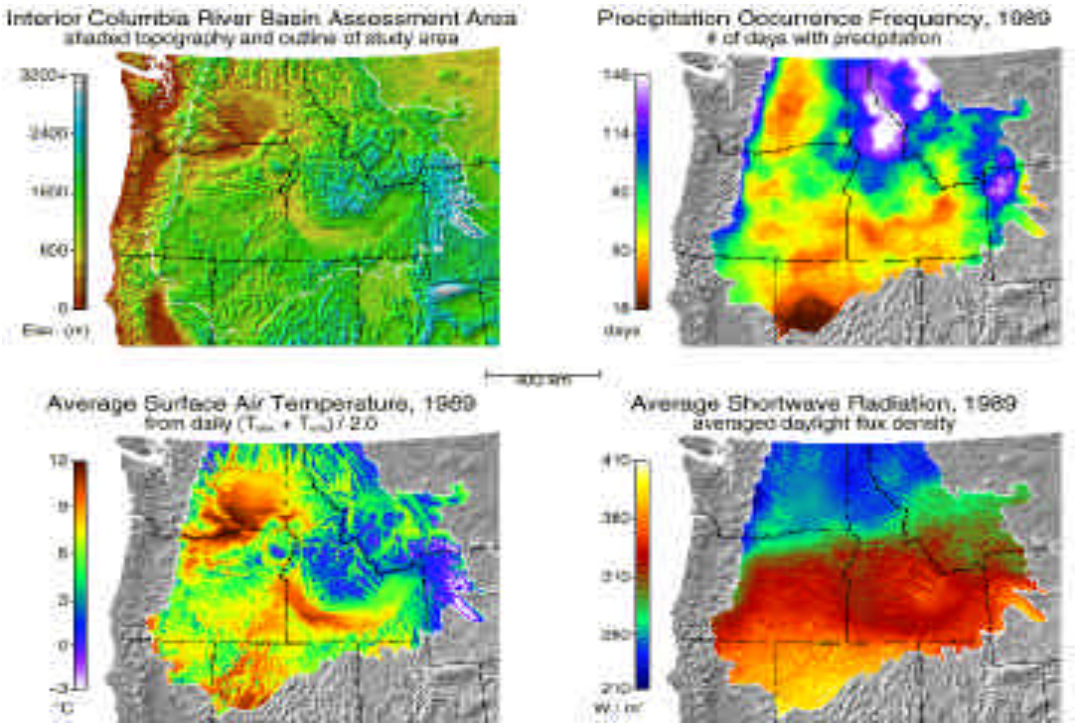
Gross Primary Productivity for western Montana and Idaho as estimated from the MODIS instrument.

DAYMET US DAILY CLIMATOLOGY SERVER

Daymet is a model that generates DAILY surfaces of temperature, precipitation, humidity, and radiation over large regions of complex terrain. Daymet has been developed at the University of Montana, NTSG lab, to fulfill the need for fine resolution,
daily meteorological and climatological data necessary for plant growth model inputs. Using a digital elevation model and daily observations of minimum and maximum temperatures and precipitation from ground-based meteorological stations, an 18-year daily data set (1980 - 1997) of temperature, precipitation, humidity and radiation has been produced as a continuous surface at a 1 km resolution. A wide range of summary and point daily data over the conterminous United States is now available. No other data at this temporal and spatial resolution exists. This data is currently being distributed, free of charge, from the NTSG lab through its outreach component, the EOS Training Center Natural Resource Project.

The Daymet method is based on the spatial convolution of a truncated Gaussian weighting filter with the set of station locations. Sensitivity to the typical heterogeneous distribution of stations in complex terrain is accomplished with an iterative station density algorithm. Spatially and

temporally explicit empirical analyses of the relationships of temperature and precipitation to elevation are performed. A daily precipitation occurrence algorithm is introduced, as a precursor to the prediction of daily precipitation amount. Surfaces of humidity (vapor pressure deficit) are generated as a function of the predicted daily minimum temperature and the predicted daily average daylight temperature. Daily surfaces of incident solar radiation are temperature range.



The website for DAYMET data distribution is at: http://DAYMET.ORG/

RANGE PRODUCTIVITY STUDIES

We have started a two-year study to monitor temporal and spatial patterns of rangeland vegetation dynamics. Ground based measurements of vegetation productivity will be compared with Net Primary Productivity (NPP) estimates derived from MODIS data and associated NPP algorithms. Given that Net Primary Productivity is a measure of both above and below ground productivity, a below ground correction factor will have to be applied to MODIS derived estimates to ensure comparability with field based above ground biomass measures. The rangeland vegetation monitoring system is the first of its kind because it combines MODIS data, meteorological data and fundamental principles of rangeland plant physiology in the NPP algorithm to derive management oriented information for large regions. This has not yet been done using MODIS data and therefore this study serves as a prototype designed to address two questions:

1) Is it possible to sufficiently quantify temporal and spatial dynamics of grassland productivity using MODIS;
2) What spatial resolution is most appropriate for estimating and monitoring grassland productivity?

Study Site

The Little Missouri National Grasslands (LMNG) of western North Dakota were chosen as the study area (Fig. 1). This area provides an excellent opportunity for development of a broad scale vegetation monitor and for accuracy assessment of the satellite derived NPP estimates because the LMNG contains the largest tract of federally owned grasslands in the United States. Ground based field sampling has been confined to rolling prairie landform types, that are federally owned and dominated by green leaf needle grass (*Stipa viridula*)/western wheat grass (*Agropyron smithii*) habitat type.

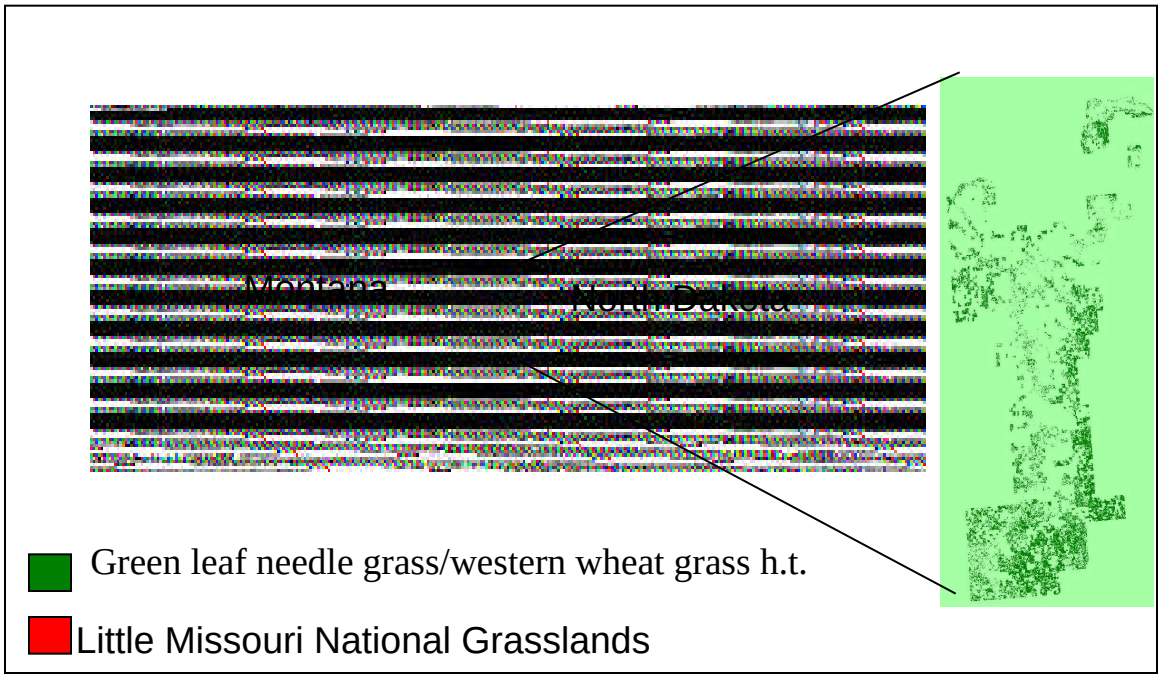


Fig. 1. Location of Little Missouri National Grasslands and the green leaf needle grass/western wheat grass habitat type under federal ownership where biomass measurements are being taken.

Confining biomass sampling to these areas will enable us to avoid problems associated with confounding spectral responses from clay escarpments and woody vegetation that typify the interior portion of the grasslands. To facilitate analysis of temporal and spatial vegetation productivity dynamics, the entire 2.2 million hectare LMNG have been stratified using Landsat Thematic Mapper imagery into four broad classes based on species composition and biomass productivity potential including hi productivity native, low productivity native, high productivity seeded and low productivity seeded grasslands. The native strata are dominated by predominantly native species (e.g. green leaf needle grass and western wheatgrass) whereas the seeded strata are dominated almost exclusively by crested wheat grass (*Agropyron desertorum*). The hypothesis is that there are different patterns of vegetation productivity between these four strata and that MODIS data can sufficiently quantify these differences.

Methods

Biomass measures have been systematically collected for May 10 – 16, May 25 – 31, and June 13 – 19. Two more periods for sampling are scheduled including July 13-19 and August 10-16, 2001. This series of sampling periods should permit broad characterization of growing season dynamics ranging from greenup, maximum productivity and finally ontogenetic decline. All biomass within a 0.5 m^2 plot is clipped and later dried and weighed under controlled conditions in a laboratory. To date 189 transects have been completed, corresponding to roughly 476 m^2 of grass clipped. In addition to biomass measurements, species composition, stubble height and digital camera radiometric measurements are being taken. Stubble height and species composition data will be correlated with both ground measurements of biomass and remote sensing derived estimates of biomass. The digital camera measurements will also be correlated with biomass at each transect to determine the usefulness of hand held digital camera as a new means of biomass sampling in rangeland environments. A similar field campaign will be completed during the 2002-growing season. Once MODIS based leaf area index (lai) and fraction of photosynthetically active radiation (fpar) data are available, NPP model runs will be completed for the strata in the LMNG previously identified in part 1. Part of this experiment will help determine which spatial scale of imagery is most appropriate for characterizing growing season dynamics in shortgrass prairie of the LMNG. Three spatial scales will be tested including 250 meter, 1 Km, and four Km MODIS data. The four Km data will be constructed via aggregation of the 1 Km data. Productivity estimates and spectral properties at each of these resolutions will be compared with ground based biomass measurements. This process should enable determination of which spatial scale is most appropriate for monitoring grassland vegetation dynamics.

COMPARISON OF GRAZED AND UNGRAZED SITES USING MODIS

We are comparing above ground productivity of grazed and ungrazed areas located on the U.L. Bend National Wildlife Refuge and adjacent Bureau of Land Management lands in north-central Montana. Our hypothesis is that the use of the Moderate Resolution Imaging Spectroradiometer (MODIS) will:

(1) Accurately quantify productivity between grazed and ungrazed landscapes; and,

(2) Allow a sound statistical comparison in productivity between grazed and ungrazed sites that is difficult to measure by standard aboveground standing crop measures (clipping small plots) because of the high variability across the landscape.

The study area is classified as the Northern Mixed Prairie, represented here by big sagebrush (*Artemisia tridentata*)/western wheatgrass (*Agropyron smithii*)/blue grama (*Bouteloua gracilis*) association. Soils of the study area are composed of varying densities of shale-derived clays, with many localized deposits of glacial till (Pan Spot range sites), that create a relatively variable landscape. The ungrazed study site is located on the U.L. Bend National Wildlife Refuge and has not been grazed by domestic livestock for 25 years. The grazed study site is on Bureau of Land Management lands and is currently grazed on a rest-rotation system. Aboveground productivity is being determined in the field by using two double-sampling methods. The first method is a weight estimation procedure utilizing 1.0 m^2 plots. Every 10^{th} plot is clipped, above ground herbage separated into current and past year's growth, bagged in individual paper sacks, and dried (65^o C), and weighed. Above ground estimates will be correlated to clipped plots and corrected using a correction factor. The second double sampling method utilizes a herbage meter to measure electronic capacitance and electronic capacitance is correlated to above ground

biomass after clipping current above ground biomass on a subset of plots and drying and weighing as described in the first double sampling method. In addition to aboveground biomass the sites will be characterized as to species composition using a canopy cover estimates (Daubenmire 1959). Field sampling was planned for late May, late June, and late July 2001. The initial sampling date in late May occurred during a severe drought with little or no growth occurring in the study area. The late June sampling period occurred following significant rains and data are currently being analyzed. Aboveground productivity estimates from field estimates will be compared to MODIS derived aboveground productivity estimates using a 250 m resolution. Productivity of grazed and ungrazed sites will be compared using both the field-derived estimates of aboveground and the MODIS derived productivity estimates

ACTIVITIES OF R. Nemani (MODIS Associate Team Member)

MODIS Evaporation Index (MOD16):

Evapotranspiration (ET, or latent heat flux; In this paper, in W m^{-2}) from land surface is an essential factor for climate dynamics and ecosystem productivity, because it is closely related to energy transfer process on the land surface as well as photosynthesis and respiration of terrestrial ecosystem. It also has applications significance within such as water resource managements and wild fire assessments.

As a result of many antecedent studies, accurate estimation of ET is becoming available via a number of methods using surface meteorological observations and radiosonde observations. However, these ground observation networks cover only a portion of global land surface. Therefore, many attempts have been made to minimize use of the ground observations for estimating spatial distribution of ET in a regional and the global scale. Satellite remote sensing is one of the most promising tools for this purpose. Nevertheless, most of the conventional techniques of ET estimation by using satellite remote sensing are not satisfactory for this purpose, because they still require ground observation support. Therefore, consistent observation of up-to-date global ET distribution with satellite remote sensing, which is independent of ground observation, remains a challenging task. One possible approach is utilization of reanalysis data of global circulation model (GCM) as a surrogate for ground observations, but it is still problematic because the accuracy of reanalysis data also strongly depends on ground observation network. In addition, the grid scale of reanalysis data is usually too coarse to be combined with conventional satellite observation of ET.

We developed an algorithm for estimating evaporation fraction (EF), expressed as a ratio of actual evapotranspiration (ET) to available energy, from satellite data. Our algorithm is a simple 2-source model of ET. We characterize a landscape as a mixture of bare soil and vegetation and thus we estimate EF as a mixture of EF of bare soil and EF of vegetation. We use the complementary relationship and canopy conductance model for estimation of EF of vegetation, whereas we use "VI-T_s" (vegetation index – surface temperature) diagram for estimation of EF of bare soil. We applied this algorithm to NOAA/AVHRR 14-day composite data and created prototype EF datasets. We validated results of this prototype with actual observations of EF at AmeriFlux stations (standard error ≅ 0.18 and R^2≅0.69). By using this algorithm, global distribution of EF every 8 days will be operationally produced from the data of MODIS on EOS-PM (Aqua) satellite.

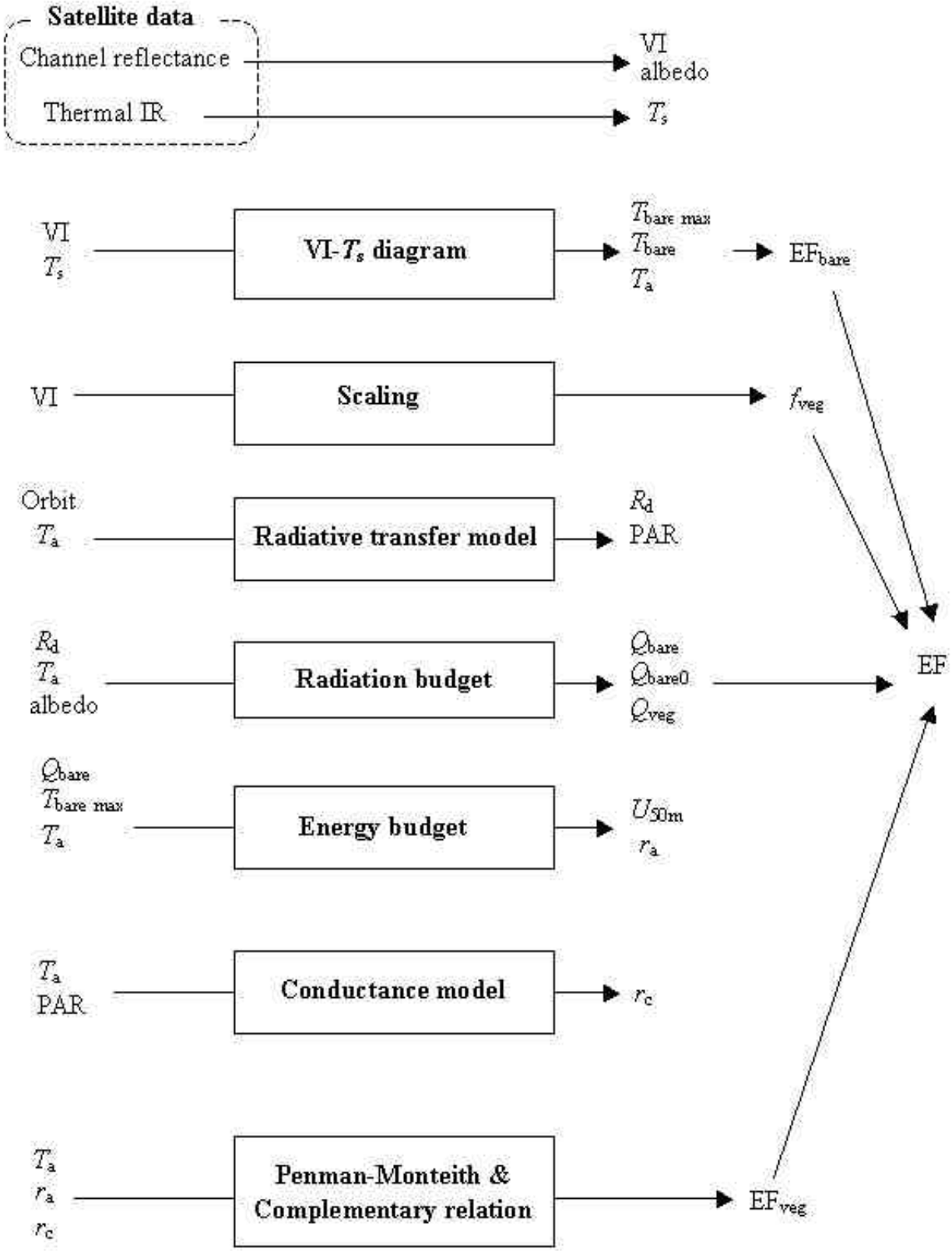


Figure 1: Flowchart for the operational production of EF product from satellite data.

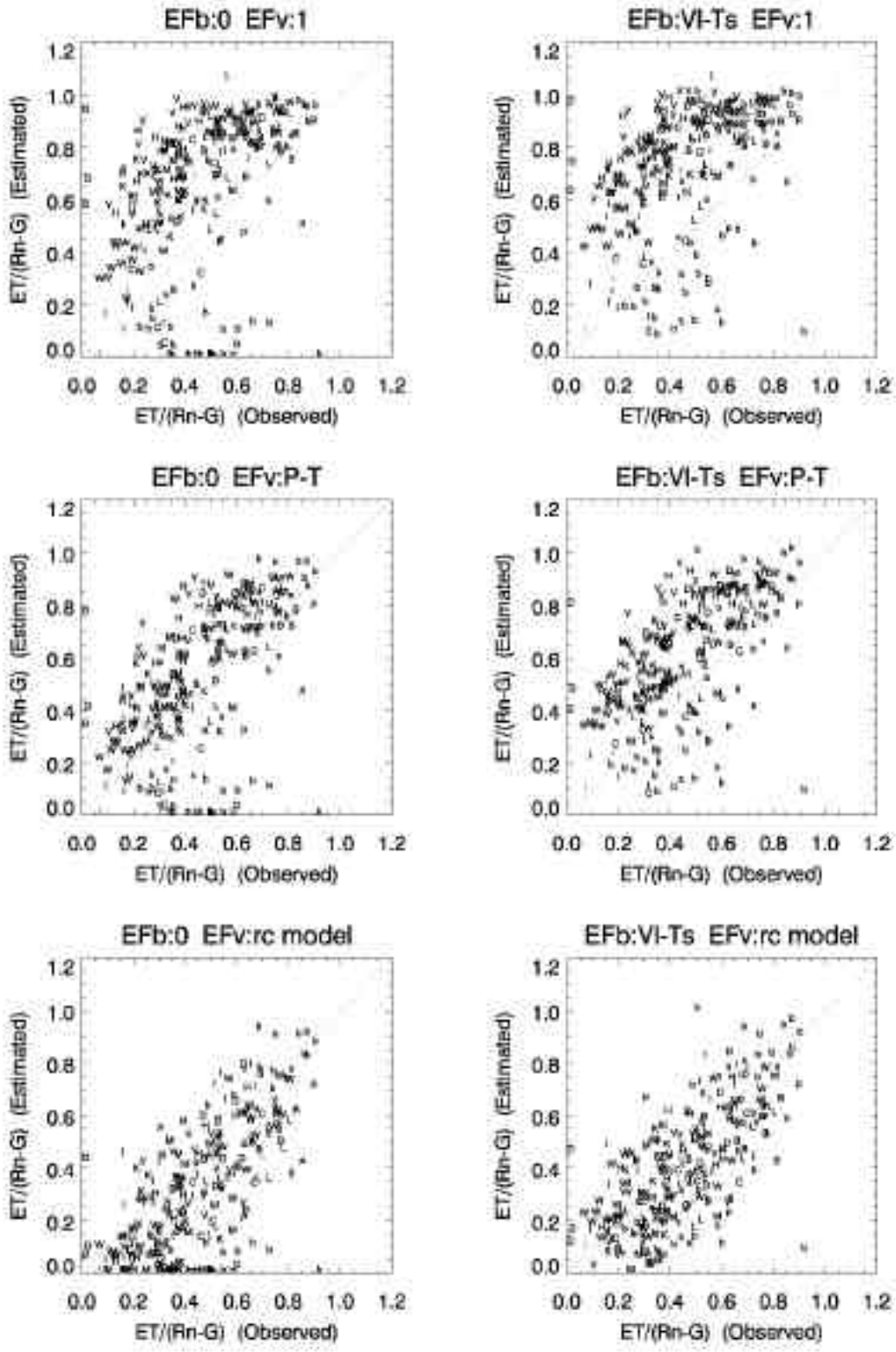
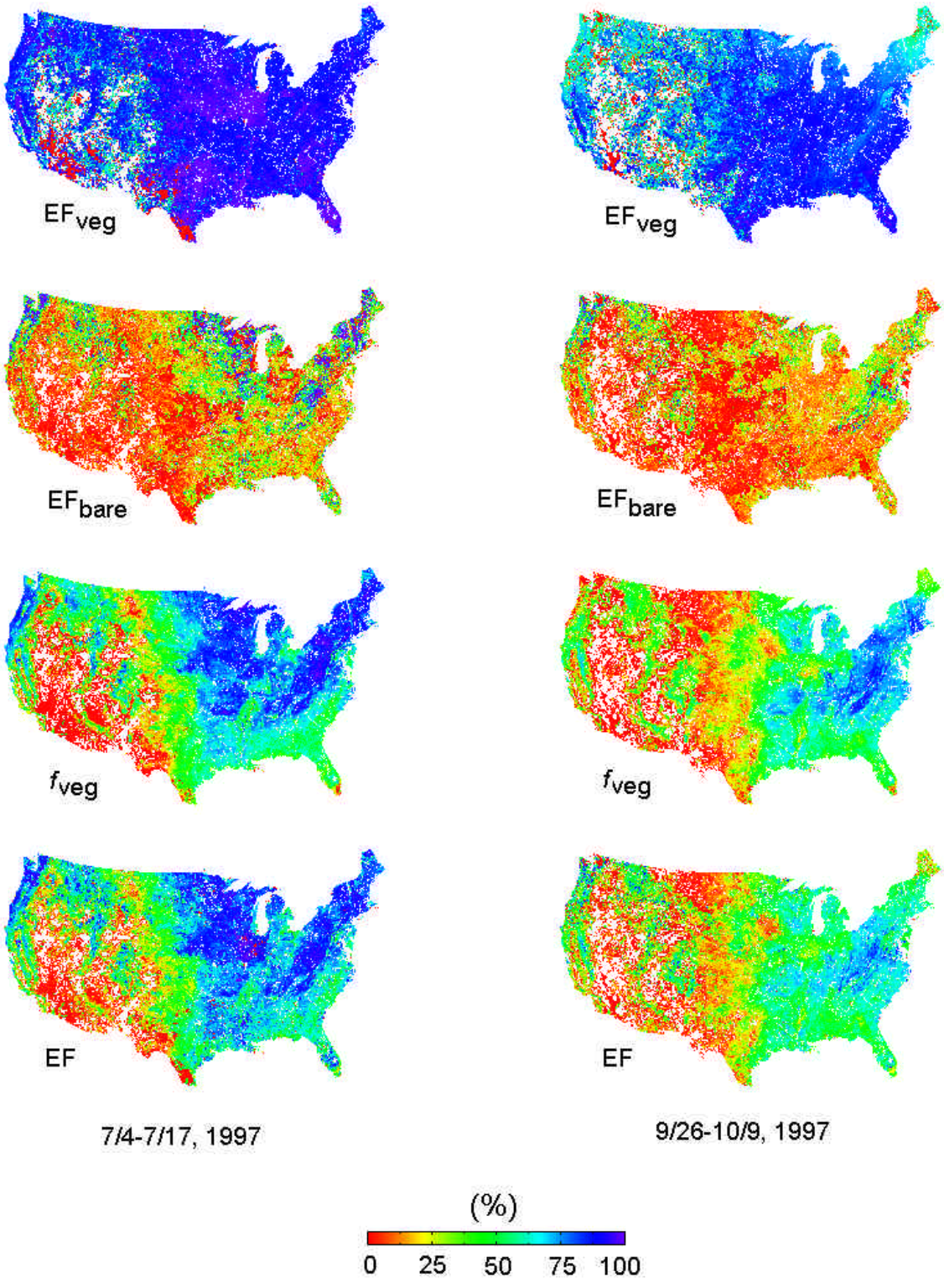


Figure 2: Comparison of EF estimates from satellite data with EF derived from FLUXNET sites across the continental U.S.

Figure 3: Spatial mapping of EF from satellite data, representing the geographic variations over the continental U.S. for two days during 1997.



PRESENTATIONS:

EOS/MODIS products for terrestrial ecosystem monitoring, Trieste, Italy, September, 2001

MEETINGS ATTENDED

EOS/ESIP Federation meeting, Grand Forks, ND,

PUBLICATIONS:

Nemani, R.R., M.A. White, D.R. Cayan, G.V. Jones, S.W. Running, J.C. Coughlan and D.L. Peterson. 2001. Asymmetric climatic warming in coastal California and its impact on the premium wine industry. Climate Research, 19: 25-34.

White, M.A., R. Nemani, P.E. Thornton and S.W. Running. (2002). Satellite evidence of phenological differences between urbanized and rural areas of the eastern United States deciduous broadleaf forest. Ecosystems (in press).

MacKay, S.D., R.R. **Nemani** and L.E. Band. 2002. Corroborating thermal remote sensing data and distributed hydrologic modeling in a mountainous watershed. Journal of Hydrology (in press)

Nishida, K., R.R. Nemani, S.W. Running and J.G. Glassy. 2002. Remote sensing of evaporation: Theoretical basis for an operational algorithm. Journal of Geophysical Research (Atmospheres) (in review)

ACTIVITIES OF P. Votava, Lead MODIS Software Engineer

OBJECTIVES

The objectives during the time period January 2001 to December 2001 are summarized here, with details on each of the indicated activity areas following.

- Patch our existing production code for Collection 3 reprocessing
- Oversee and troubleshoot MODAPS production of our biophysical land product suite.
- Perform ad-hoc Quality Assurance/Quality Control activities on our set of MODIS data products.
- Refine our SCF procedures and architecture using early MODIS product experience.
- Augment the MODAPS production team efforts by implementing selected SCF production scenarios required to supply NASA collaborators with early PR materials
- Submit first version of MODIS AQUA Fpar/Lai code

WORK ACCOMPLISHED

From January 2001 to December 2001 we have focused our efforts mainly at troubleshooting of our at launch algorithms, and at monitoring of the production of our products in the MODIS Adaptive Processing System (MODAPS) located at GSFC, which was pretty much nonexistent. As a part of the troubleshooting, we have implemented number of Quality Control and Quality Assurance procedures.

Key accomplishments for this period is further automation of procedures for PR image production, including reprojection, tiling, and sub-sampling. Additionally, we have developed in-house software for our internal QA procedures with capabilities missing in all externally available tools. Most of this process is now database driven and the overall design uses a set of plug-in filters. Finally, we have produced several global PSN (GPP) images derived from MODIS instrument data in different projections.

ALGORITHM DEVELOPMENT

FPAR, LAI Daily and 8-day Composite (PGE33, PGE34)

The main science logic in the daily and 8-day FPAR, LAI has been stable for quite some time, with the changes effected during this period mostly applying to minor engineering issues pertaining to QA handling and ECS metadata interpretation. Additionally, new version of PGE34 (v2.1.17) has been delivered. This version includes support for generating 5km browse products. Last, two more patch deliveries has been made – both of them deal with MCF and metadata issues which make the code ready for use in the collection 3 reprocessing.

The daily FPAR, LAI algorithm (PGE33) is currently at version v3.0.1, and is built using the SDPTK v5.2, HDFEOS 3.2, HDF 4.1r2, and MUM v.2.5.5 libraries. This algorithm is now at 18,723 LOC (77,095 LOC total includes the MUM API).

The 8-day FPAR, LAI algorithm (PGE34) is currently at version v3.0.1, and is built using the SDPTK v5.2, HDFEOS 3.2, HDF 4.1r2, and MUM v.2.5.5 libraries. This algorithm is now at 10,198 LOC (70,043 LOC total includes the MUM API).

PSN, NPP (PGE36, PGE37, PGE38) Algorithm

The PSN, NPP biophysical algorithm (ESDT: MOD17A1, A2, A3) is unique among the other MODIS Land algorithms in the degree to which it is a model oriented rather than instrument radiometry oriented process. It requires daily availability of the new DAO DAS subset of global surface climatology variables, as well as the FPAR, LAI 8-day composite tiles from the most recent period relative to the day, the MOD12Q1 landcover definition, and its static ancillary data. The single most critical factor that sets the PSN, NPP algorithm apart from the others its temporal sensitivity, driven by the way that cumulative (additive) state variables for GPP, GPP minus maintenance respiration, maximum leaf mass and annual sum of maintenance respiration are carried forward throughout the year. From a production standpoint, delivering a temporally reliable stream of FPAR, LAI data to the daily PSN, NPP algorithm has become one of the most challenging, quality limiting aspects of the MODAPS. In the larger MODIS Land processing stream, persistent production gap problems arising in the EDOS portion of the ground system have propagated tile and time drop-outs of the MODAGAGG to the daily FPAR, LAI processing. These in turn are reflected in drop-outs of 8-day MOD15A2 to the daily PSN algorithm. While corrections to EDOS problems are reportedly on their way, to run our PSN, NPP algorithm reliably, our SCF has had to locally stage up the required inputs, to implement limited processing here. Recently we were able to generate several 8-day period sequences of PSN, NPP daily runs, culminating in the generation of (2) 8-day period PSN data product sets, each approximately 288 tiles globally.

The PSN, NPP algorithm (PGE36, 37, 38) are currently at version v3.0.1, built using the SDPTK v5.2, HDFEOS 3.2, HDF 4.1r2, and MUM v.2.5.8 libraries. The PSN, NPP algorithm is now at 18037 LOC (78,093 LOC total includes the MUM API).

QA AND OPERATIONAL ACTIVITIES

Quality Assurance activities for this period focused mainly on retrieving and visually inspecting frequent samples of golden tile products of FPAR, LAI 8-day composite product, and the outputs of our 8-day PSN. We did update our QA tool environment during this time, as summarized here:

- Our IDL visualization software was upgraded to 5.4. We are still awaiting solid support for the HDFEOS 3.x and HDF data models from the major COTS vendors (RSI, ESRI, etc).
- Our HDFLook visualization and QA software was upgraded to v.8.2
- A number of small, console tools were refined, including the ***eosmt*** tool for quick analysis of FPAR and LAI products.
- W have refined a tile-wise reprojection utility (reprojtool, v1.13 for reprojecting MODIS ISINUS tiles into the Lambert Azimuthal Equal Area, Robinson's, Goodes interrupted homolosine, and Plate Carre rectangular map projections. Tiles thus projected are then mosaiced at in our SCF using several IDL scripts.

- Development of in-house QA tools that provide additional capabilities beyond what is currently available from external sources
- Developed complete system for image production which includes reprojection, mosaicing, subsampling and creating a JPEG or GIF image. This is done with Perl, Java, C, and IDL. An efforts are currently under way to refine these components, optimize the algorithms used, and integrate with the database system into.

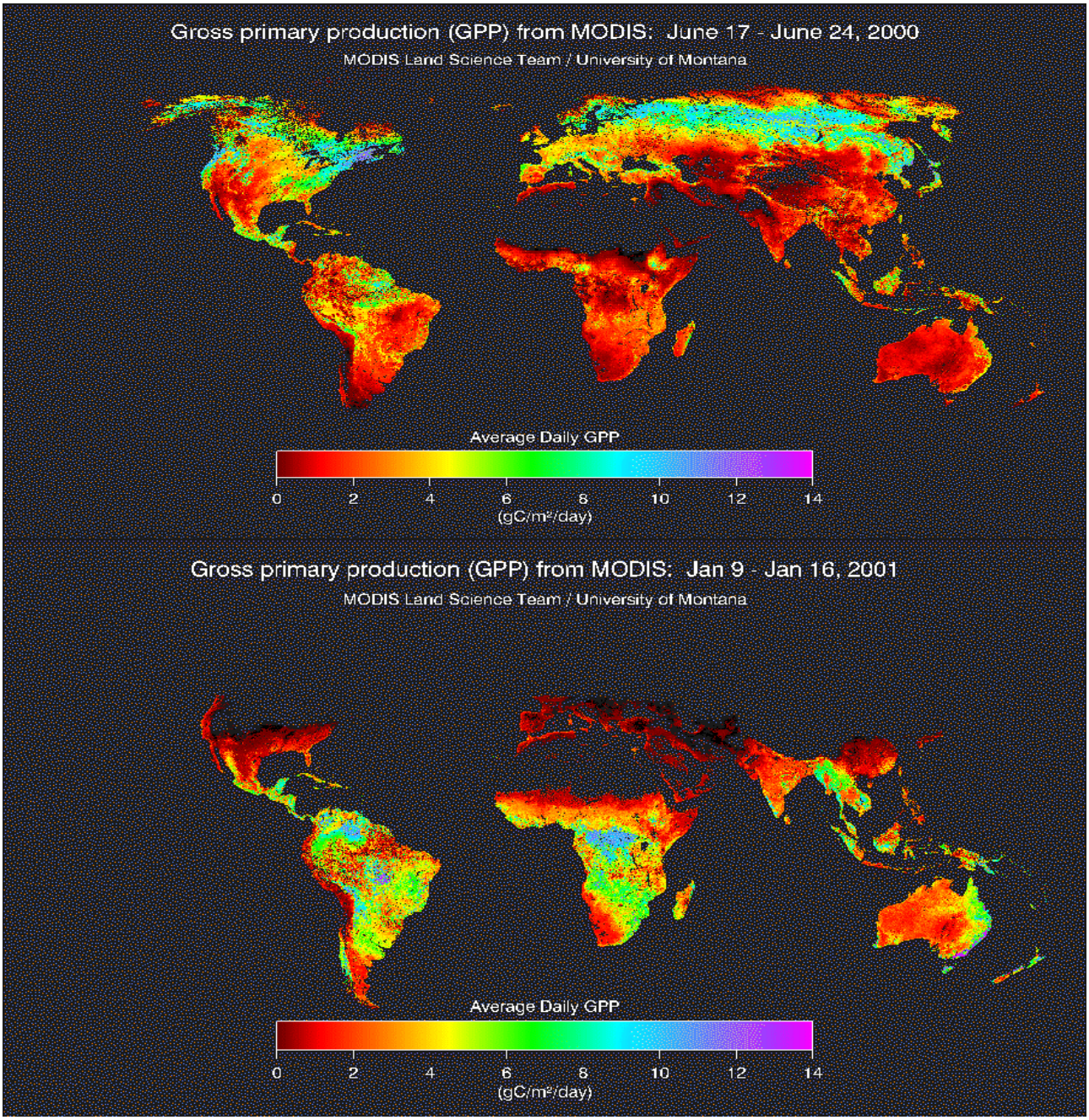


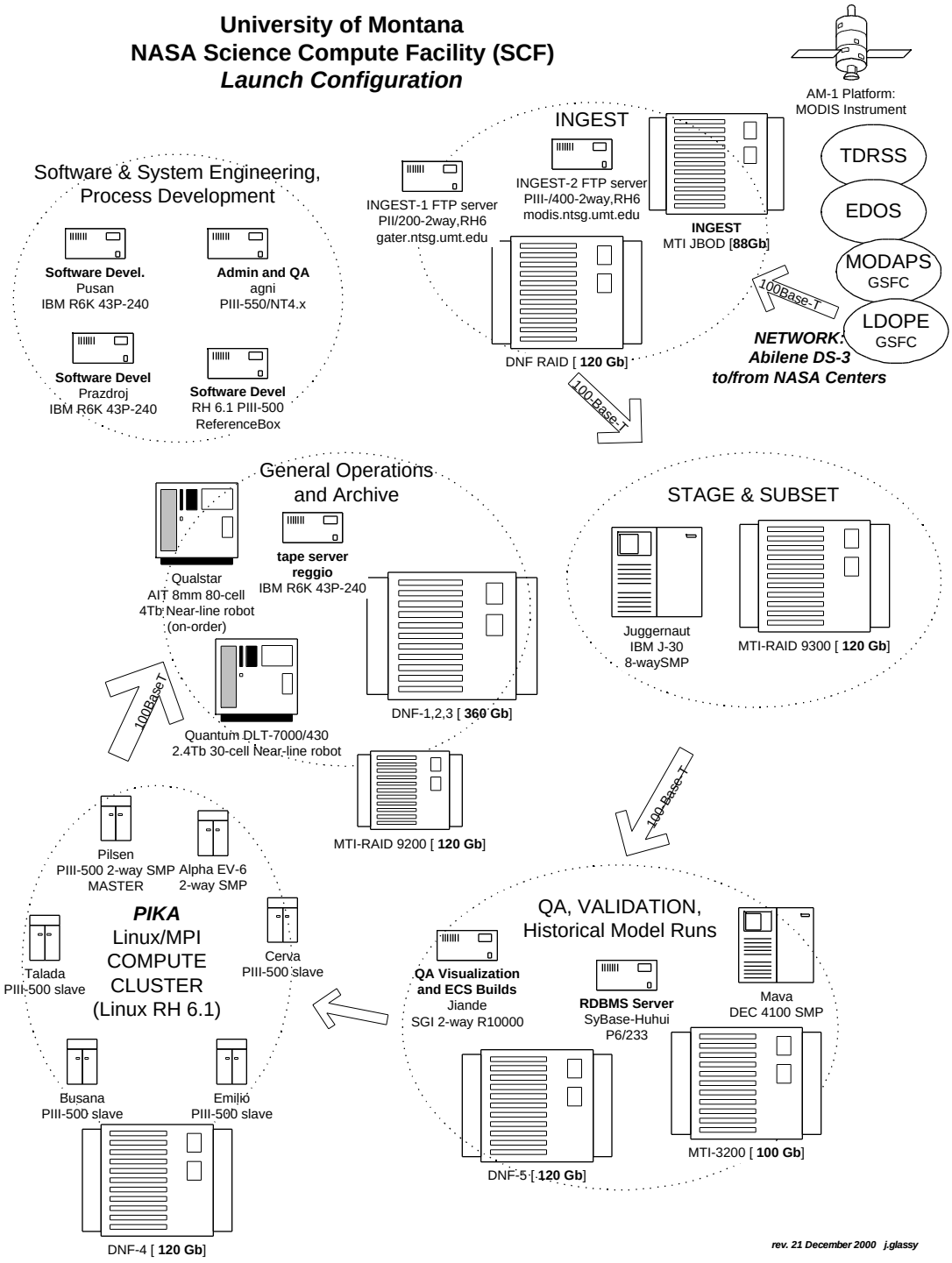
Figure 1 - *Global GPP comparison June 2000 [top] vs January 2001 [bottom]*

SCF DEVELOPMENT

Incremental additions to the Montana SCF were made during this period to increase our ability to perform high volume QA, test, and limited production in support of our global validation

program.

We have added several high-end Linux workstations, and 500 GB of RAID storage.

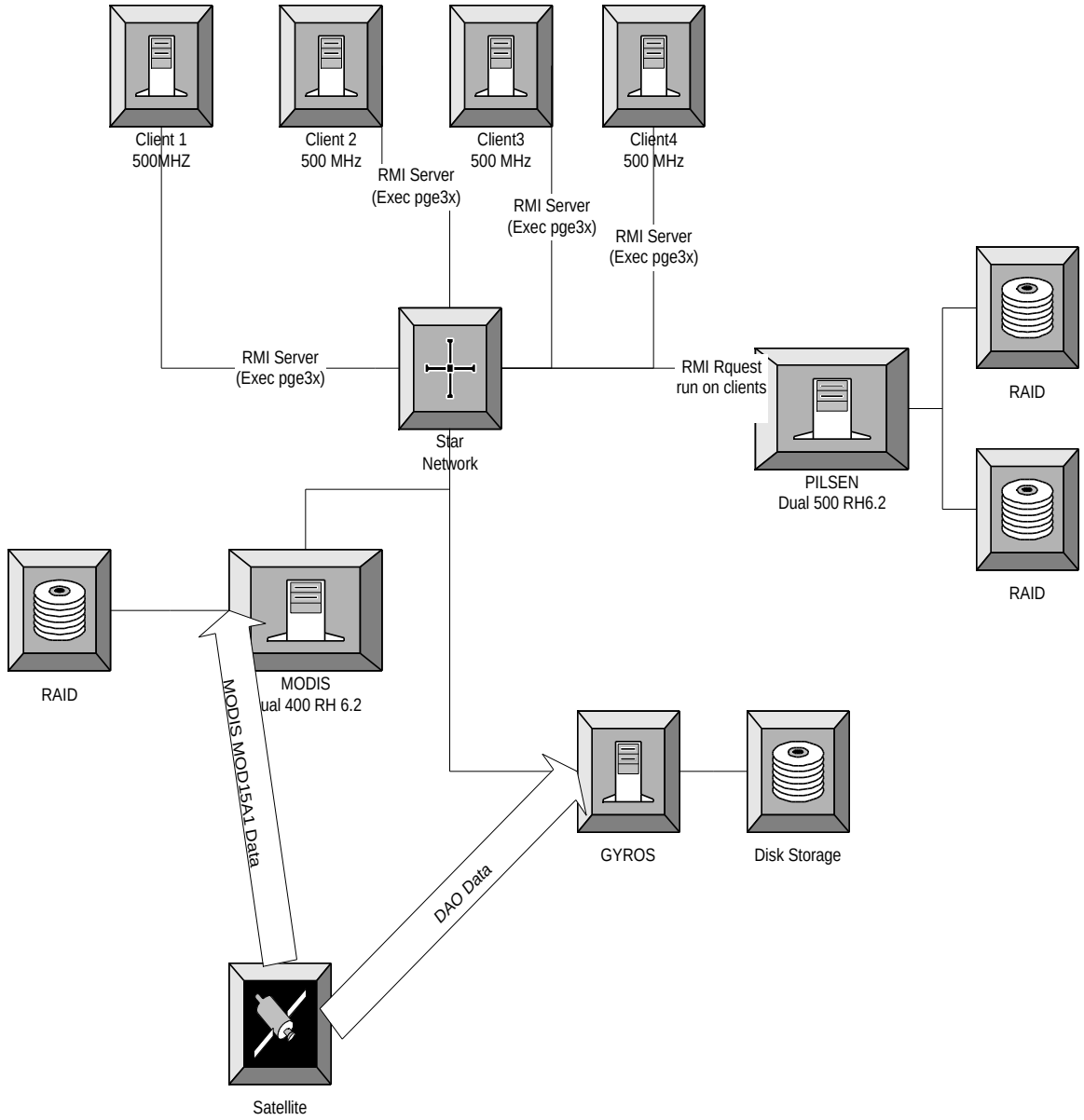


Linux Cluster Development and Implementation

In last several months we have geared up to do several processing campaigns that involved our Linux cluster. The development of the cluster and automation software has spanned several versions. We are moving from collection of Perl and shell scripts towards an integrated Java

environment that would give us more control in the distributed environment. We have refined our Java client/server model to implement the distribution of tasks among the hosts in the cluster. One of the advantages of this approach is that we have removed the limitation of running the distributed environment only on Linux hosts – the Java portability should allow us to operate in truly heterogeneous environment. A diagram of our distributed cluster environment is shown below:

UM SCF Cluster and Processing Development



We have currently implemented distributed cluster servers to run both the FPAR, LAI 8-day (PGE34) and PSN daily (PGE36). On the client side we have a new version of PGE34 client and scheduler that implements a simple load balancing scheme. Additionally, we have added our global PR (reprojection, mosaicing, subsampleing, and imaging) system to run on our distributed environment as well. This system has been used in runs that produced our latest FPAR/LAI

composites. Using 5 hosts we were able to process daily global FPAR/LAI composite in about 25 minutes. A similar system was used to produce our global 8-day PSN composite, which is quite bit more complicated. In the latter case, we needed to perform around 5,000 tile executions using the PGE. On current Linux cluster this required ca 4 hours to complete. In the next version , we plan on implementing a better graphical user interface for our system and to unify the Java/RMI environment. The initial step of each processing campaign starts with a PCF (runtime input command set) generation step, which are currently written in Perl and with a graphical front end written in PerlTk.

COLLABORATIONS: SCIENCE AND DATA SYSTEMS

During this period the following collaborations were pursued for MODIS related activities:

- Continued to collaborate with MODIS Oceanographer Dr. Mark Abbott of Oregon State University on the MODIS Direct Broadcast program progress, involving his satellite dish installation at Corvallis, performing a limited series of network throughput tests using the Abilene DS-3 between Corvallis and Missoula.
- Continued to closely collaborate with the Boston University staff (Yura K, Yu Zhang, Yujie Wang, Ranga Myneni in the refinements to QA procedures and interpretation of MOD15A1 and MOD15A2.
- We initiated an interim scheme to locally archive our daily intermediate data products (MOD15A1 and MOD17A1), in support of our on-going Quality Assurance program, via periodic downloads from the MODAPS production environment.

CONFERENCES/MEETINGS

- MODIS Science Team Meeting, February 2001
- NASA's Intelligent Data Understanding (IDU) Workshop, May 2001
- MODIS Science Team Meeting, December 2001

PRESENTATIONS

- *Terrestrial Observation and Prediction System (TOPS)* at IDU, 2001

PUBLICATIONS

Nemani, R.R., M.A. White, P. Votava, J. Glassy, J. Roads and S. Running. 2000. *Biospheric forecast system for natural resource management*. In.4th Symposium on "GIS and Environmental Modeling", Eds: Brad Parks, M. Goodchild and M. Crane. www.colorado.edu/cires/research/banf.

ACTIVITIES OF J. Glassy (Under EOS/MODIS Subcontract)

Overview

Lupine Logic, Inc. (LLI) has worked under contract to the University of Montana NTSG group (under UM contracts P0000641 and P0000761) to assist the NTSG group in the performance of selected NASA MODIS related projects and activities. LLI's principle, Joe Glassy, previously worked at the NTSG as Director of NASA MODIS software development from July 1994 until February 15, 2001. Lupine Logic, Inc. is a Montana corporation dedicated to providing geo-spatial data and information technology services and products for government, academic and commercial organizations. We hold professional memberships in both the IEEE and ACM.

Summary of Contributed Activities

- NTSG Terra MODIS NTSG land algorithm maintenance
- Terra MODIS Direct Broadcast
- Aqua MODIS algorithm development – MOD16 EF/ET Algorithm

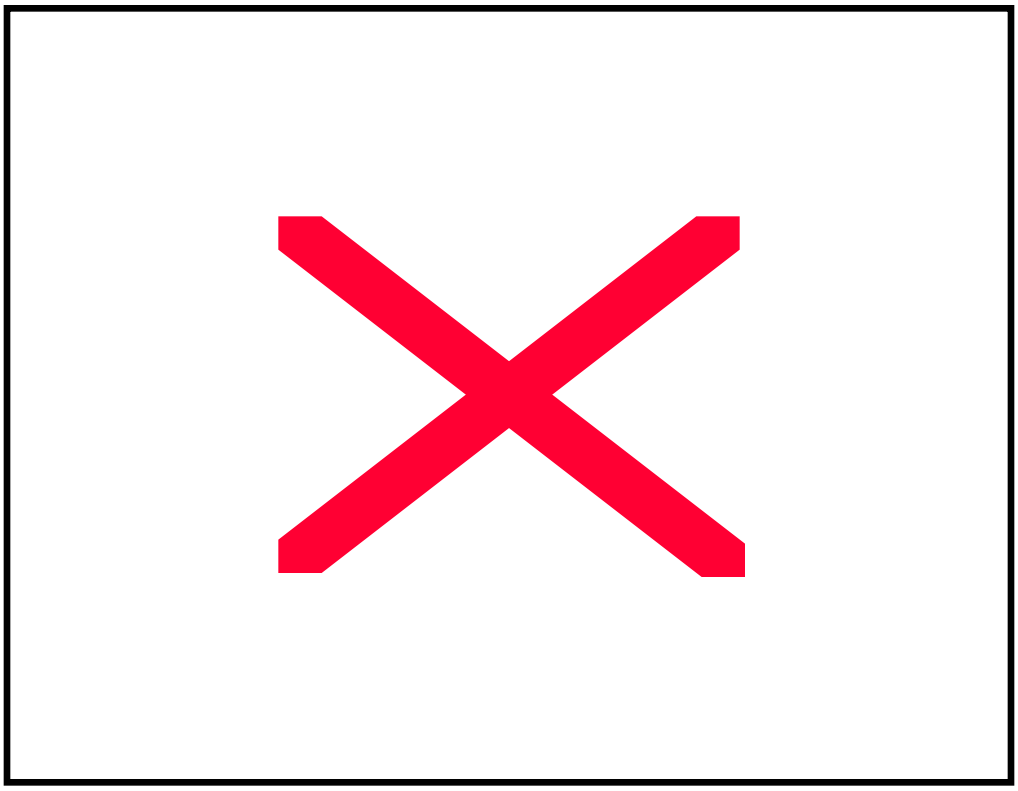
Lupine Logic's contributions for this past year under the EOS project managed by NTSG is outlined in more detail below.

NASA Terra MODIS NTSG land algorithm maintenance

Throughout this year, Mr. Glassy has periodically served as an "on-call" consultant to the current NASA MODIS team at NTSG on issues pertaining to the original suite of land surface products and algorithms originally developed under his tenure. These operational land algorithms included the daily and 8-day composite FPAR and LAI algorithms (PGE33 and PGE34) as well as the daily and 8-day composite PSN, NPP algorithm (PGE36, 37) and annual net primary productivity algorithm (PGE38). The majority of legacy algorithm issues involved ECS metadata, quality assurance, and minor questions clarifying versioning of operational codes. LLI has also contributed to the overall NTSG EOS effort via proposal reviews, editing peer review publications, and developing algorithm documentation products.

NASA Terra Direct Broadcast

As a commercial firm, LLI has actively participated in the NASA Terra direct broadcast community. NASA has expressed an interest in exploring the commercial applications of MODIS data products, and to this end LLI has continued to research the commercial potential of key land products, focusing at this point more on "value added" products potentially may be derived from regional direct broadcast systems. This year LLI has performed a variety of system integration and data system development tasks for several regional MODIS direct broadcast sites now in the process of becoming operational within the USDA Forest Service. LLI is also continuing to explore appropriate ways that DB source "value-added" data products and custom software may benefit a larger commercial audience. LLI has worked within a strategic partnership with the University of Montana NTSG to track the evolving progress of key NASA SCF direct broadcast sites such as Patrick Coronado's GSFC (http://directreadout.gsfc.nasa.gov/) DB site, OSU oceanographer Mark Abbott's site (http://picasso.oce.orst.edu/ORSOO/MODIS/DB), and the SSEC site maintained by Liam Gumley and others at the University of Madison, WI SSEC group (http://eosdb.ssec.wisc.edu/modisdirect/). A representative direct broadcast scene for Eastern taken from Jan 7 ,2002, obtained from the SSEC DB site, is shown below.



In our partnership role with NTSG, LLI was invited to attend the NASA Direct Broadcast meeting sponsored by OSU's Mark Abbott held in the fall of 2001 at Mt. Hood, Oregon. At this meeting a wide variety of both commercial vendors, NASA, and academic members of the MODIS Direct Broadcast community came together to discuss the state of MODIS direct broadcast efforts, developments in DB related algorithm software, and the future context of DB activity within both the EOS Terra and Aqua programs.

NASA Aqua MODIS Algorithm Development

During this past year, the majority of LLI's contribution to the NTSG EOS effort has been to assist in the development of the NASA Aqua Evaporative Fraction (MOD16) algorithm, due to become operational once the NASA Aqua satellite platform with a 1:30pm overpass time is launched later in 2002. On the EF operational algorithm, our primary development contacts at NTSG have been Kenlo Nishida and Dr. Rama Nemani. Algorithm development activities we have participated in include development of a series of AVHRR based stand alone prototype to verify the fundamental modeling science, as well as having begun work on the ECS form of the MOD16 algorithm. The EF MOD16 algorithm is currently organized as two separate process generation executables (PGE), similar to how the FPAR, LAI algorithm appears. The first PGE is a daily process that accumulates a set of (8) daily candidate layers, which are then composited on each 8 day period boundary by the second PGE.

One of the early MOD16 development tasks LLI has contributed to during this past year was the finalization of the inputs for the operational algorithm. As with the FPAR, LAI and PSN, NPP algorithms, we have strived for a practical balance between algorithm reliability/accuracy, performance, and resource requirements. We acknowledge that developing an evaporative fraction algorithm using only satellite derived inputs requires an abbreviation of desired conceptual detail in order for the method to be practical from a computational and archive volume standpoint. Interested readers are referred to the EF algorithm conceptual description section elsewhere in this document for more details.

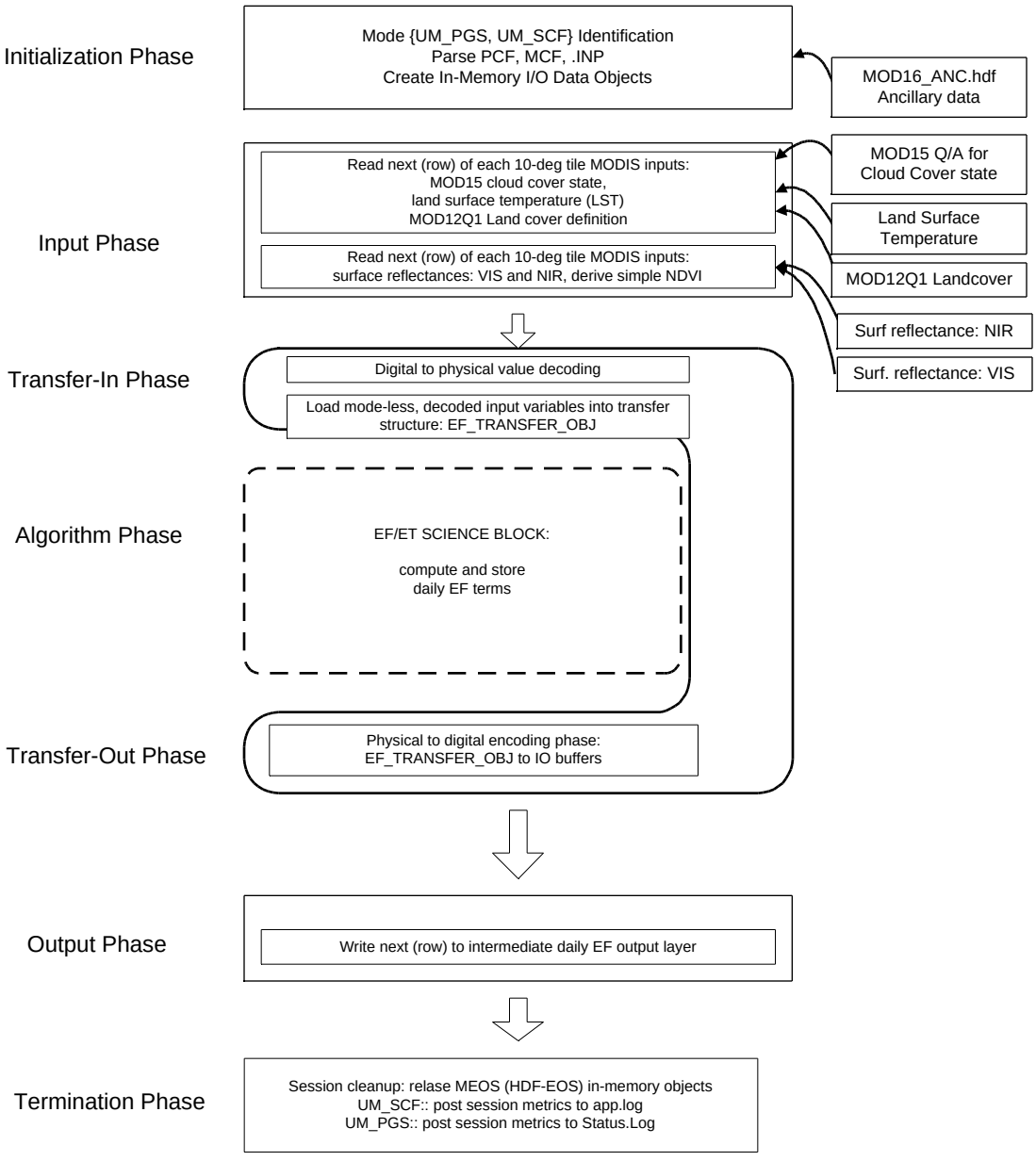
ECS Aqua EF Operational Algorithm Overview

At this time, the Aqua EF daily algorithm code (developmental skeleton) consists of approximately 17,000 LOC distributed across 18 module files. Like the other ECS operational algorithms originating at the NTSG SCF, it is built upon the MODIS-Univ. Montana API, a separate support library consisting of 61 module files and some 56,000 LOC. This operational code set is still in development and is expected to change before the at-launch delivery is performed.

The diagram below provides a high level view of how the MOD16 EF/ET algorithm is organized from a high level topology viewpoint.

MODIS MOD16 Algorithm Component:
Evaporative Fraction (EF)

Software Organization



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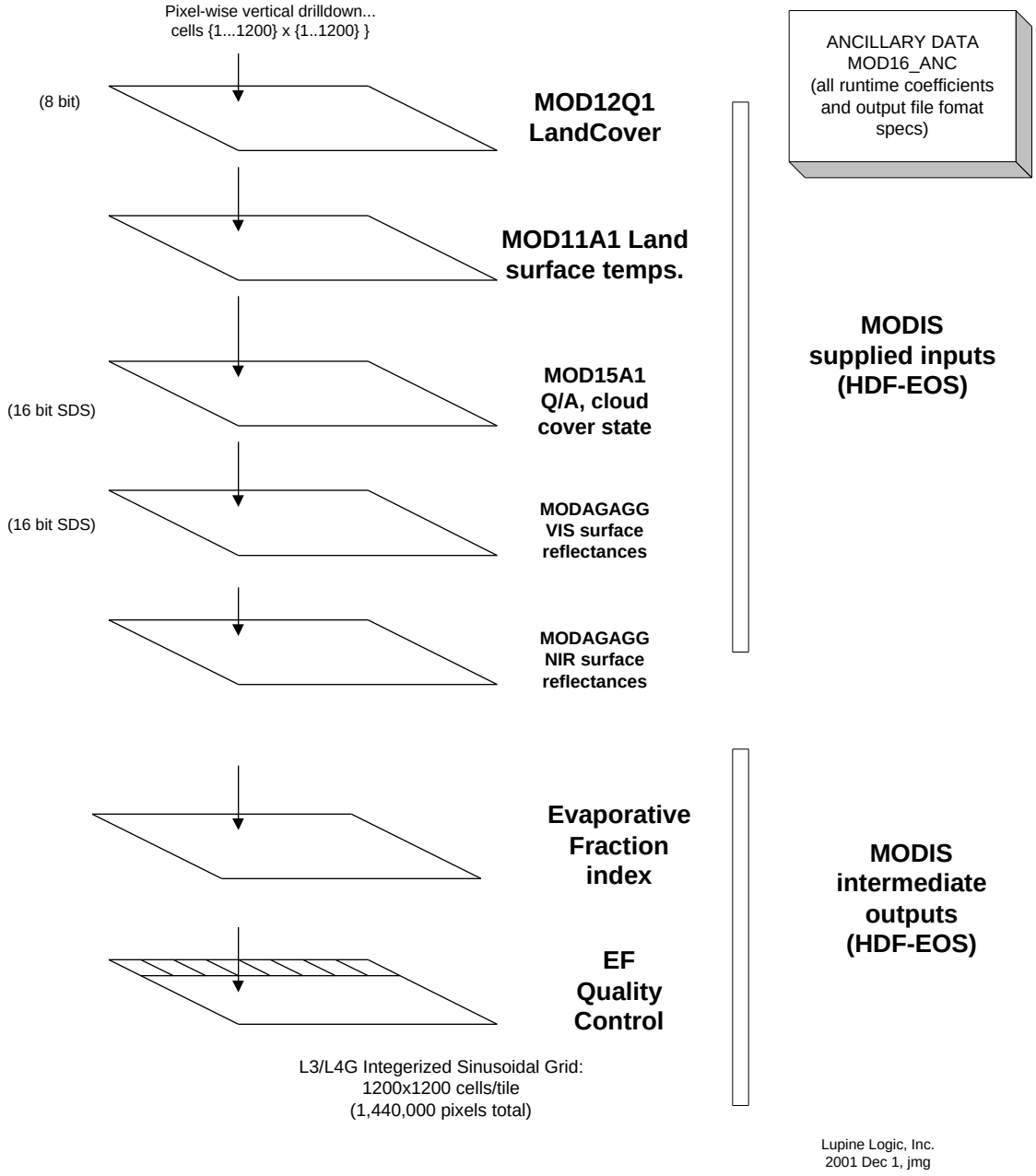
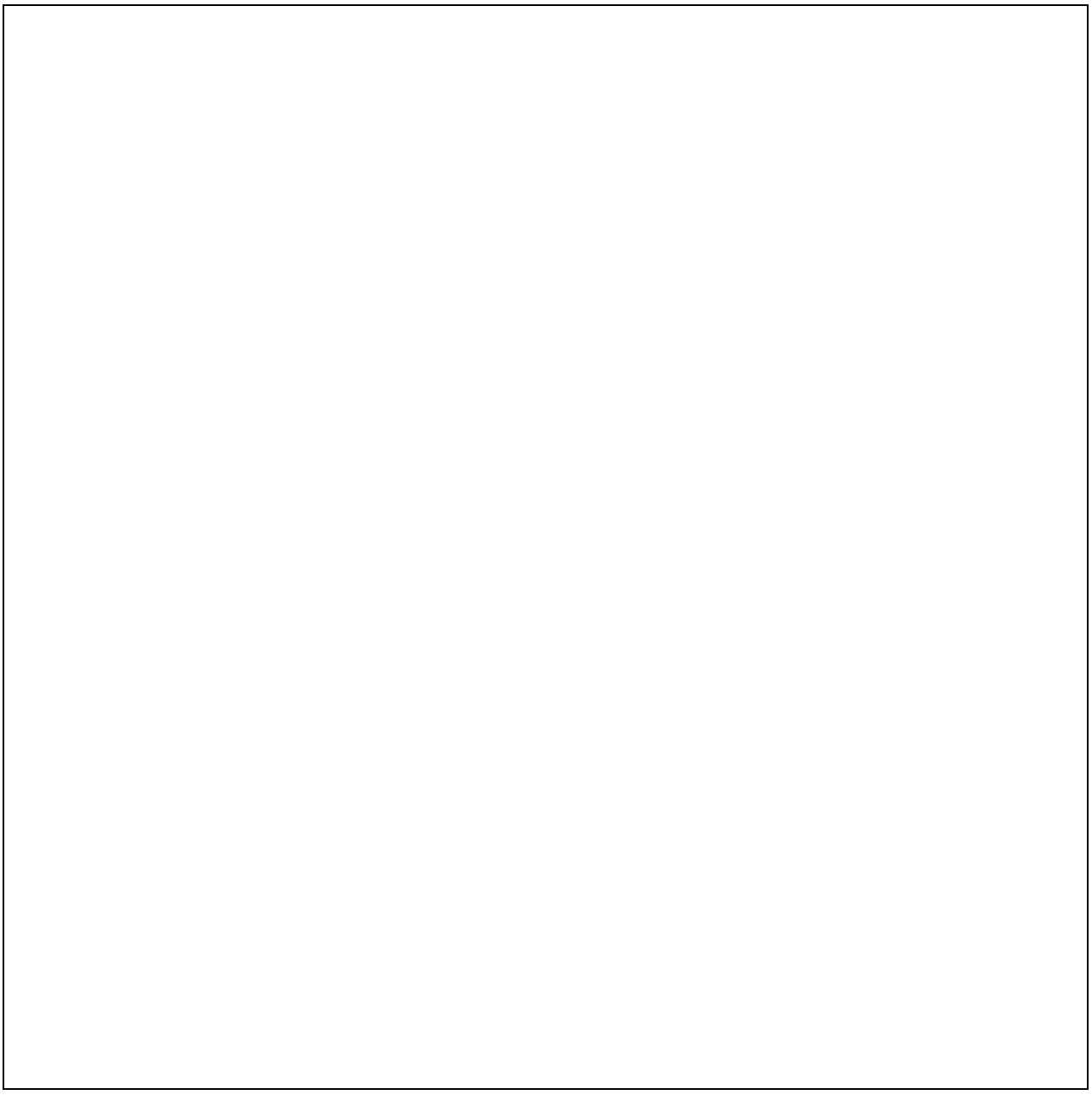


Representative Samples of MOD16A1 MODIS Inputs

The figure below illustrates several of the key spatially defined inputs to the MOD16A1 daily EF algorithm. Not shown are the two surface reflectance layers (VIS, NIR) which are also used at runtime to calculate a trial NDVI measure for each pixel.



Co-authored Publications

Kenlo Nishida, Ramakrishna R. Nemani, Steven W. Running, and Joseph M. Glassy, 2002. Remote Sensing of Land Surface Evaporation (I) Theoretical Basis for an Operational Algorithm (pending). Submitted to Journal of Geophysical Research (JGR) for review January 2002.

Meetings Attended by LLI

1. NASA Direct Broadcast meeting, Sept 2001 at Mt. Hood, Oregon.
2. NASA Direct Broadcast (Fire Algorithm) Planning Meeting, March, 2001, at University of Maryland, College Park, MD.