MODIS Land Team

Validation update

for Terra and Aqua

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1 Abstract / Executive Summary

The MODIS Land Discipline Team (MODLAND) will use several validation techniques to develop estimates for the uncertainty of its products. The methods include comparisons with *in situ* data collected over a distributed set of validation sites, comparisons with data and products from other airborne and spaceborne sensors, analysis of trends in MODLAND products, and analysis of process model results (including EOS Interdisciplinary Science, IDS, models), which are driven or constrained by MODLAND products. Primary validation activities are based on the collection of a suite of data that can be compared to MODIS land products. In general, this will include field and tower measurements, *fine*-resolution imagery (less than 10m Instantaneous Field of View, IFOV), and *high*-resolution imagery (from 10 – 30m IFOV) imagery from airborne and satellite sensors. The validation activities can be broken down by:

1) Primary validation data sources
2) Validation data storage, distribution, and archive
3) Product specific validation procedures
4) Communicating validation results and
5) Integrating validation activities into the global community

This validation update provides the status and plans for each of these.

Based on existing activities and the desire to continuously improve validation results, this plans concludes with recommendation for future activities, which are:

- Advancing work on scaling and correlative procedures
- Utilizing the global network approach for validation data collection
- Stress operational collection and correlative analysis
- Integrate validation activities with scientific application of global land products

The activities outlined in this updated plan provide the foundation for operational product validation in the near-term for Terra and Aqua while the recommendations promote rigorous validation science to contribute to the establishment of science quality climate data records.

MODLAND Validation information is available via the Internet at:
http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/

> ***When one admits that nothing is certain one must, I think, also add that some things are more nearly certain than others.***
>
> ***Bertrand Russell***

2 Introduction

This document provides an update on the activities the MODLAND team will use to evaluate and validate its systematic data products and algorithms. It is meant as a supplement to update the 1998 MODIS Land Validation Plan (Morisette et al., 1998) and serve as a validation plan for MODLAND products produced from the sensors on board both the Terra and Aqua platforms. Much of what is described in the 1998 document as "being developed" (e.g., the EOS Land Validation Core Sites, the MQUALS system, FLUXNET, Oak Ridge National Laboratory's (ORNL's) Mercury tool,) is now established. The current activities will build on what has been accomplished with continued efforts to test and validate MODLAND products and share the validation results with the user community.

2.1 Science Objectives

The Terra satellite was launched in December 1999 and first Earth views from MODIS were taken in February 2000. For approximately the first six months after launch the MODIS calibration support team was working to stabilize the MODIS level 1 products. During this time, the MODLAND team was working with the MODIS Production System to refine MODLAND algorithms. Now, as MODLAND data start to become publicly available through the EROS Data Center DAAC (EDC DAAC), EOS-funded and other validation investigations relevant to MODLAND are starting to yield real results, and an internet-based infrastructure is in place to support validation data. The primary objective for MODLAND Validation activities is to provide the user community with measures of uncertainty for its level 2-4 products. These include:

- **Radiation Budget Variables**: Surface Reflectance, Land Surface Temperature (LST) and Emissivity, Snow and Ice Cover, Bi-directional Reflection Distribution function (BRDF)/Albedo,
- **Ecosystem Variables**: Vegetation Indices, Leaf Area Index (LAI) and Fractional Photosynthetically Active Radiation (FPAR), Vegetation Production, Daily Photosynthesis (PSN) and Annual Net Primary Production (NPP)
- **Land Cover Characteristics**: Fire and Thermal Anomalies and Burned Area, Land Cover, Vegetative Cover Conversion, and Vegetation Continuous Fields

Because each of these is a global product, MODLAND plans to develop uncertainty information over each of the major surface-atmosphere systems.

MODLAND validation is based on the collection of independent data that can be compared to MODIS land products. In general, the suite of validation data will include field and tower measurements, *fine*-resolution imagery (less than 10m Instantaneous Field of View, IFOV), and *high*-resolution imagery (from 10 – 30m IFOV) imagery from airborne and satellite sensors. The validation activities can be broken down by:

1. Primary validation data sources
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The following validation update provides the status and plans for each of these activities.

The Committee on Earth Observing Satellites (CEOS) Working Group on Calibration and Validation (WGCV) defines validation as "the process of assessing by independent means the quality of the data products derived from the system outputs" (*http://wgcv.ceos.org/*). In this context, the MODLAND Validation activities are the means by which we will assess the quality of the MODLAND products.

3 Primary validation data sources

The general approach for collecting data to validation MODLAND products involves either airborne or higher resolution satellite data, or both, coupled with ground based measurements. The particular protocol for the ground based measurement and the processing of the higher resolution imagery will depend on the product being validated. In this section we review background information on several key data sets.

3.1 NASA's Airborne Science Program

NASA's Airborne Science Program (http://www.dfrc.nasa.gov/airsci/) provides airborne platforms to carry NASA sensors such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS), and Earth Observing System (EOS) sensor simulators, such as The MODIS Airborne Simulator (MAS), MODIS/ASTER Airborne Simulator (MASTER), and the Airborne Multi-angle Imaging SpectroRadiometer (AirMISR).

NASA's Airborne Science program sensor URLs:

- AVIRIS *http://makalu.jpl.nasa.gov/*
- MAS *http://ltpwww.gsfc.nasa.gov/MAS/*
- MASTER *http://masterweb.jpl.nasa.gov/*
- AirMISR *http://www-misr.jpl.nasa.gov/mission/air.html*

Due to the usual very high altitude of these flights, the image data from the NASA Airborne program have ~50m resolution. Funding for validation-related NASA airborne data has, to date, come from a combination of EOS project office and individual team member budgets.

3.2 MQUALS System

The MODIS Quick Airborne Looks (MQUALS) is an aircraft mounted system that houses an array of 3 digital cameras, a calibrated Exotech 4-channel radiometer, and an albedometer. The typical MQUALs flight covers roughly a 10 x 10 km area. The Exotech will use custom filters to match the first four bands from the MODIS[1]. While the spectral digital camera array matches MODIS bands 1, 2, and 3. Off-nadir and thermal sensing capability may be added if it can be readily implemented with one or two fixed-mount radiometers. The package is housed on a versatile mount usable by most aerial photo-based light aircraft with nadir-viewing ports. Information on MQUALS can be found at *http://gaea.fcr.arizona.edu/projects/validation/index.htm*

3.3 Scientific Data Purchase program

The Scientific Data Purchase (SDP) is

> a demonstration program developed in response to the President's Space Policy, directing NASA to purchase remote sensing data from the private sector. Initiated in fiscal year 1997, the SDP was funded under the Earth Science Enterprise (ESE) Program to provide scientific data to the ESE science community. (*http://www.crsp.ssc.nasa.gov/databuy/dbmain.htm*)

This provides a source of high-resolution data to validate some of the MODIS land products. The MODLAND team will utilize several of the image data sets available through the SDP program. For example, MODLAND will use the precision geocoded 1990 era Landsat 5 data supplied by Earth Satellite Corporation as a baseline, geocoded high-resolution data set. MODLAND will also use the SDP program for the fine resolution imagery of the Ikonos sensor (1m panchromatic and 4m multi-spectral) supplied by Space Imaging, and the 1m multi-spectral airborne imagery supplied by Positive Systems. The SDP has allocated resources specifically to the MODLAND team to support its validation efforts.

3.4 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

The Advanced Spaceborne Thermal Emission and Reflection Radiometer obtains high-resolution (15 to 90 meter pixels) images of the Earth in 14 different wavelengths of the electromagnetic spectrum, ranging from visible to thermal infrared light. All three ASTER telescopes (VNIR, SWIR, and TIR) are pointable in the cross-track direction. ASTER's high resolution and its ability to change viewing angles, allow for the derivation of stereoscopic images and detailed terrain-height models. Unlike the other instruments

[1] band 1= 620- 670nm, band 2= 841- 876, band 3 = 459- 479nm, band 4= 545- 565nm

aboard Terra, ASTER will not collect data continuously; rather, it will collect an average of 8 minutes of data per orbit. Because of this discontinuity, it has been necessary for the MODLAND team to request ASTER data be collected over validation sites. These requests have been submitted to the ASTER team and continued dialog will help ensure acquisition. ASTER is the only high spatial resolution instrument on the Terra platform and so offers the best opportunity for high-resolution imagery coincident with MODIS data. The detailed terrain-height models will also provide useful information in characterizing the landscape. More information on ASTER can be found at *http://asterweb.jpl.nasa.gov/*. Currently these data are available free of charge through the EOS data gateway connection to EDC DAAC.

3.5 Landsat 7: Enhanced Thematic Mapper Plus

LANDSAT 7 with its Enhanced Thematic Mapper Plus (EMT+) instrument was successfully launched on April 15, 1999. Since that time it has shown to be a stable instrument, both radiometrically and geometrically (Barker et al., 1999) and continues the heritage of previous Landsat data. The ETM+ instrument is an eight-band multi-spectral scanning radiometer capable of providing high-resolution image information of the Earth's surface. It detects spectrally filtered radiation at visible, near-infrared, short-wave, and thermal infrared frequency bands from the sun-lit Earth. Nominal resolution is 15 m IFOV in the panchromatic band; 30m IFOV in the 6 visible, near and short-wave infrared bands; and 60m IFOV in the thermal infrared band. The ETM+ imagery will provide high-resolution imagery in visible and near-infrared bands similar to MODIS. An account has been set up at EDC DAAC to purchase ETM+ data for MODLAND validation needs.

3.6 Surface Science Networks

Data from several surface networks have been and will continue to be used for MODLAND validation. Primarily, these include the AERONET sunphotometer network and FLUXNET CO_2/H_20 flux network. In addition, MODLAND plans to investigate the usefulness of the BSRN and SurfRad networks for albedo validation.

3.6.1 AERONET

The AERONET (AErosol RObotic NETwork) program is an inclusive federation of over 100 ground-based remote sensing aerosol networks. AERONET provides hourly transmission of CIMEL sunphotometer data to the GOES (or METEOSAT) geosynchronous satellites, which in turn relay the data to Goddard Space Flight Center (GSFC) for daily processing and archiving. By teaming with AERONET, MODLAND scientists have access to validation data from a global network of CIMELs in near real-time. The

AERONET network will be the main source of atmospheric characterization for MODLAND Validation activities. AERONET data are available on-line at *http://aeronet.gsfc.nasa.gov:8080.*

3.6.2 FLUXNET

The FLUXNET network is dedicated to long-term measurements of carbon dioxide, water vapor, and energy exchange from a variety of worldwide ecosystems, integrated into consistent, quality assured, documented datasets. FLUXNET is a network of networks, which integrates worldwide CO_2/H_20 flux measurements through the ASIAFLUX, AmeriFlux, CARBOEROFLUX, and Oznet networks. There are currently over 140 towers registered with FLUXNET and over 60 of these have submitted data or defined a start date for doing so. The Oak Ridge DAAC will be the point of contact for FLUXNET data archive and distribution. Details on FLUXNET can be found at *http://daacl.esd.ornl.gov/FLUXNET/.*

4 Validation data storage, distribution, and archive

The primary mechanisms for data storage, distribution, and archive for MODLAND validation-related data are the EOS Land Validation Core Site infrastructure and the Mercury system.

4.1 EOS Land Validation Core Sites

Following a number of years of consensus building among the EOS instrument teams, the Science Working group for the AM-1 Platform (SWAMP) decided at its meeting in December 1997 to focus much of its land validation activity on a set of "Core" sites (Justice et al., 1998b). This focus will allow collaboration within and among science teams and reduce the duplicated effort that would result from validation efforts at disparate sites. This decision resulted in an EOS community effort to establish the ***EOS Land Validation Core Sites***. The data collected at these sites will provide an important resource for the broader science community. Although their development has been led by MODLAND, the sites are intended for use by all satellite sensors (Justice et al, 2000).

The EOS Land Validation Core Sites will provide the user community with timely ground, aircraft, and satellite data for EOS science and validation investigations. The sites, currently 24 distributed worldwide, represent a consensus among the instrument teams and validation investigators and represent a range of global biome types (see Figure 1; Table 1; Morisette et al., 1999; Justice et al., 1998). The sites typically have a history of *in situ* and remote observations and can expect continued monitoring and land cover research activities. In many cases, a Core Site will have a tower equipped with above-canopy instrumentation for near-continuous sampling of landscape radiometric, energy and CO_2 flux,

meteorological variables, and atmospheric aerosol and water vapor data. These will be complemented by intensive field measurement campaigns.

The CEOS WGCV Land Product Validation (LPV) is currently considering the EOS Land Validation Core Sites as an example of focused validation activity. An objective of the LPV is to utilize the established data, infrastructure, and lessons learned from the EOS Land Validation Core Sites as a model for global validation activities/sites organized through CEOS WGCV. In light of this and other related LPV activities, the MODLAND team will continue to interact with the LPV sub-group.

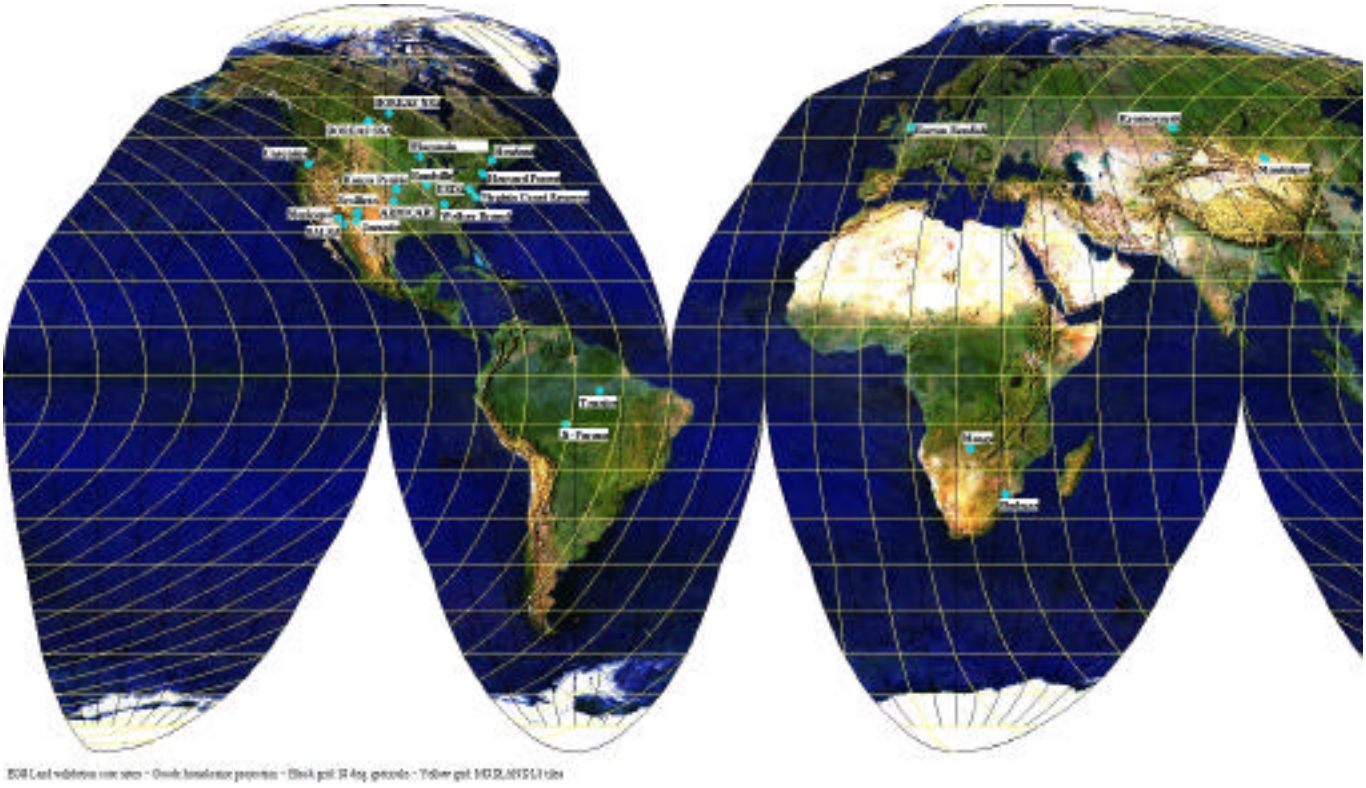

Figure 1: EOS Land Validation Core Sites

Table 1: EOS Land Validation Core Site information

(an up-to-date list can be found at *http://modis-land.gsfc.nasa.gov/val/coresite_gen.asp*)

SiteName	Country	Latitude	Longitude	ActiveNetworks	Airborne data
ARM/CART, SGP	OK, USA	36.640	-97.500	AERONET, FLUXNET	
BARC, USDA ARS	MD, USA	39.030	-76.850	AERONET, FLUXNET	AVIRIS, 5/11/00
Barton Bendish, UK	UK	52.618	0.524	AERONET (planned)	
Bondville	IL, USA	40.007	-88.291	AERONET	AVIRIS, 6/22/00
BOREAS NSA	Canada	55.880	-98.481	FLUXNET	
BERMS/BOREAS SSA	Canada	53.656	-105.323	AERONET, FLUXNET	AVIRIS, 7/10/00
Cascades	OR, USA	44.249	-122.180	AERONET	
Harvard Forest LTER	MA, USA	42.538	-72.171	FLUXNET	AVIRIS, 5/7/00
Howland	ME, USA	45.200	-68.733	AERONET, FLUXNET	
Ji-Parana (LBA: "Jaru Tower")	Brazil	-10.083	-61.931	AERONET	
Jornada LTER	NM, USA	32.607	-106.869	AERONET (planned)	MQUALs, 5/10 & 9/30/00 AVIRIS, 6/10/00 MQUALS planned for '01
Konza Prairie LTER	KS, USA	39.082	-96.560	AERONET, FLUXNET	AVIRIS, 6/22/00
Krasnoyarsk	Russia	57.270	91.600	AERONET (planned)	
Mandalgobi	Mongolia	45.995	106.327	AERONET (nearby)	
Maricopa Ag. Cnt.	AZ, USA	33.070	-111.970	AERONET	
Mongu	Zambia	-15.438	23.253	AERONET	
SALSA San Pedro	AZ, USA Mexico	31.740	-109.850	-	MQUALs, 3/31/00
Sevilleta LTER	NM, USA	34.344	-106.671	AERONET	AVIRIS, 6/10/00
Skukuza, Kruger NP	RSA	-25.020	31.497	AERONET	
Tapajos (LBA: Santarem)	Brazil	-2.857	-54.959	AERONET	MQUALs, 7/9/00 - 7/13/00
Uardry/NSW	Australia	-34.390	145.300	-	
Virginia Coast Reserve	VA, USA	37.500	-75.670	-	
Walker Branch	TN, USA	35.958	-84.288	AERONET, FLUXNET	
Wisconsin: Park Falls	WI, USA	45.946	-90.272	AERONET, FLUXNET	

The Core Site Internet-based infrastructure is now and place. The suite of data being compiled for the Core Sites includes each data set listed in Section 3. In addition, the SeaWiFS project at GSFC (*http://seawifs.gsfc.nasa.gov/SEAWIFS.html*) has supplied SeaWiFS data subset over the Core Sites. Considerations are underway to provide MISR data (*http://www-misr.jpl.nasa.gov/*) through the Langley DAAC. To help facilitate quick access to MODIS products, once the level 3 and 4 MODLAND products are available through EDC DAAC these products will also be subsetted over the Core Sites.

The current plan is to acquire from one to five ETM+ and ASTER scenes per year for each Core Site, depending on the activity related to each site, selected to coincide with field campaigns and/or vegetation phenology. With the assistance of EDC, the MODIS Land Discipline team will query and order ETM+ and ASTER data needed for validation investigations. Due to their high cost, NASA Airborne data and/or Ikonos imagery are limited to only one or two acquisitions through the MODIS Terra/Aqua validation activities and, therefore, have been or will be acquired to coincide with intensive field campaigns. The SeaWiFS coverage is at an approximate frequency of every four days. MISR data is also planned to be available every two days. The MODIS data available for the Core Sites will be 200 km x 200 km subsets from the original MODIS Level L3 and L4, 1200 km x 1200 km, MODIS Tiles. The subsetted data sets will contain daily and multi-day composites. The decision to produce MODIS subsets over the validation sites was based on the need for rapid and convenient access to high temporal resolution data. Spatial subsetting over the sites will help reduce the data volume and permit ftp access and on-line storage of MODIS data for all of the Core Sites.

Ancillary date for the Core Sites is also available. The University of Maryland's Commercial Remote Sensing for Earth System Science (CRESS, *http://www.geog.umd.edu/landcover/cress/*) program has extracted several data layers from global sources. Extracting the subsets from global dataset allows for comparability of these products across sites.

The data layers that have been generated for the Core Sites include:

- U.S. Geological Survey's EROS Data Center (EDC) 1km land cover map
- University of Maryland 1 km land cover product
- Percent Tree Cover
- United Nations Food and Agricultural Org. (FAO) Soils data
- U.S. Geological Survey's EROS Data Center (EDC) "GTOPO 30" Elevation, and
- a reference layer with airports, municipal boundaries, major cites, rivers, and ETM+ footprints.

These ancillary data layers, and more information pertaining to them, are available through the University Maryland's Global Land Cover Facility (*http://glcf.umiacs.umd.edu/*).

The entire data suite being compiled for the Core Sites is depicted in Figure 2.

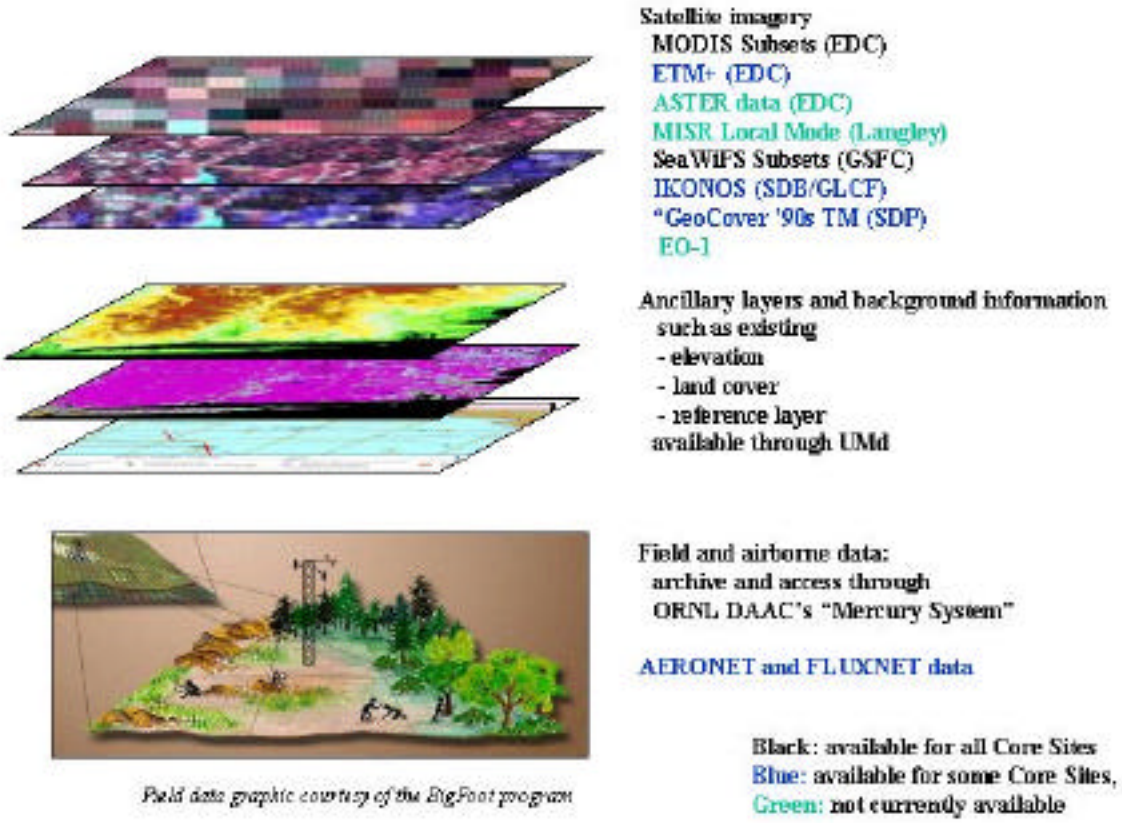

Figure 2: Data Suite available for the EOS Land Validation Core Sites

All of the data available for the Core Sites will be accessible through the Internet. A map, detailed information on the Core Sites, and links to data for each site are available at

http://modis-land.gsfc.nasa.gov/val/coresite_gen.asp

4.2 Mercury

Mercury will facilitate the availability of field data sets collected by EOS and other Land Validation investigations. It provides a realistic system by which EOS Validation Investigators can allow public access to their data within six months of data collection, as required by the EOS Validation Program.

Perhaps the most unique characteristic for *validation* sites is the fieldwork, either ongoing measurements or short-term intensive observational periods. Traditionally, data from multiple field campaigns at various sites have not been available through one centralized database. Individually, the NASA-sponsored

campaigns such as FIFE (*http://www-eosdis.ornl.gov/FIFE/FIFE_Home.html*) and BOREAS (*http://boreas.gsfc.nasa.gov/BOREAS/BOREAS_Home.html*) have made significant steps toward this goal. For EOS Land Validation, the ORNL DAAC will perform a key role in centralizing the distribution and archiving of field data. To facilitate this effort, ORNL DAAC has developed the Mercury system (Cook et al., 1999). Mercury is a Web-based system that allows searching distributed metadata files to identify data sets of interest and direct the user to them.

The Mercury system provides both the team collecting the data and the data users significant advantages relative to traditional data management systems. Data sets remain with those responsible for the data collection, thus allowing them to maintain full control of the quality, version, and availability of their data. The ORNL DAAC provides these collectors with a metadata editor tool that can be used to help organize their field data. Once the URL of the data's location is registered through the metadata tool, the Mercury system harvests the metadata and creates a pointer to the data. The scientist maintains full control of his/her site. The scientist has the option of temporarily removing the data or restricting access by requiring a password from users. This allows for the metadata to be created and registered as soon as possible, yet provides some time for initial quality checks on the data before making it available to the general public.

Mercury related URLs:

Front page	http://mercury.ornl.gov/
Search Page	http://mercury.ornl.gov/ornldaac/
Metadata Editor	http://www-eosdis.ornl.gov/cgi-bin/MDE/MERCURY/access.pl

5 Product specific validation procedures

The land validation efforts for EOS will follow the approach adopted by other major intensive field campaigns; such as FIFE, BOREAS and the MODIS Prototype Validation Experiments (PROVEs, Privette et al., 2000) and utilize recent findings of the EOS funded and other validation investigators working with MODLAND Products. Given below are the developments and plans specific to the individual MODLAND products.

5.1 Surface Reflectance

The University of Maryland is responsible for the Land Surface Reflectance products (PI: E. Vermote, *http://modis-land.gsfc.nasa.gov/mod09/*). The primary data used to validate the surface reflectance products are CIMEL sunphotometers (AERONET data) for atmospheric characterization, surface

characterization through hand held radiometers, and airborne MQUALS, MAS, AirMISR and/or AVIRIS data.

The surface reflectance validation activities build on experience of previous validation campaigns that used sunphotometers, such as BOREAS, PROVE, HAPEX (*http://www.orstom.fr/hapex/*), and SCAR-A and –B, *http://climate.gsfc.nasa.gov/Projects.htm - SCAR*) and will link closely with MODIS Calibration Support Team and MODIS Atmospheric Team. Current (and planned) *surface* reflectance validation efforts are being (will be) conducted at those EOS Land Validation Core Sites where field spectral data have been or will be collected, Airborne and/or Ikonos data have been acquired, and are part of the AERONET Network.

Validation of the surface reflectance product is coordinated with the EOS Investigation "Validation MODIS/MISR Land Surface Reflectance and Albedo Products" (PI: S. Liang, *http://eospso.gsfc.nasa.gov/validation/nra/liang.html* and *http://www.glue.umd.edu/~sliang/validation/*).

5.2 Land Surface Temperature

The University of California, Santa Barbara is responsible for the Land Surface Temperature (LST) product (PI: Z. Wan, *http://www.icess.ucsb.edu/modis/modis-lst.html*). The primary data used to validate LST include Thermal Infrared spectrometers, the UCSB Spectral Infrared Bidirectional Reflectance and Emmissivity instrument, Heimann thermometers, MAS and MASTER Airborne data, and ETM+ and ASTER imagery (Wan, 1999).

The absolute radiometric accuracy of MODIS Thermal Infrared (TIR) channel data was evaluated with *in-situ* data collected in a vicarious calibration field campaign conducted in Lake Titicaca, Bolivia, during May 26 and June 17, 2000. The specified absolute radiometric accuracy is reached or nearly reached in MODIS bands 21 and 29-32. It is difficult to obtain a definitive estimate in other bands because of the polarization effect, and large effects of variations and uncertainties in atmospheric temperature and water vapor profiles. An error in the difference of brightness temperatures in bands 31 and 32 is estimated as 0.3K. A related correction was made starting in version 2.2.21 of the LST product algorithm (the product generation executable or "PGE") found at *http://modland.nascom.nasa.gov/prod/PGE_HISTORY_FILES/PGE16/COMB/HISTORY.txt*. The accuracy of MODIS LST product was validated through in-situ measurement data collected in four field campaigns. The MODIS LST accuracy is better than 0.7K over Lake Titicaca and Bolivia, Mono Lake, California (in two daytime and one nighttime cases); over grassland in Bridgeport, California (in two nighttime cases); and over a rice field in Chico, California (in two nighttime cases). It is difficult to validate the daytime LST product over land sites (other than lakes) because of the high spatial variations in land-surface

temperature during daytime. Validation activities for 2001 include Railroad Valley, Nevada and Mono Lake and Lake Tahoe, California as well as the Jornada Core site.

In addition, the EOS Validation Investigation: "Validation of Thermal Infrared Data and Products from MODIS and ASTER over Land" (PI: S. Hook, *http://eospso.gsfc.nasa.gov/validation/nra/hook.html*) has the objective of validating the thermal infrared (TIR) data products acquired over land from ASTER and MODIS using a set of automated validation sites. These sites include: Lake Tahoe, CA, USA and Thangoo, WA, Amburla NT, and Uardry[2], NSW, Australia. This investigation is making progress in the automatic collection of data needed for validating TIR products as well as validation analysis that incorporates MASTER and ETM+ data.

5.3 Snow and Sea Ice

The Goddard Space Flight Center (GSFC) is responsible for the Snow and Sea Ice products (PI: D. Hall, http://snowmelt.gsfc.nasa.gov/MODIS_Snow/modis.html). The primary data used to validate these products are field surveys of snow cover and snow characteristics, and airborne and high-resolution satellite imagery. Validation investigations will also include comparison with the National Operational Hydrologic Remote Sensing Center (NOHRSC) 1-km resolution snow-cover product (Hall, et al., 1999).

A Snow and Ice field experiment was conducted at Keene, New Hampshire, in March 2000. Concomitant with NASA ER-2 and MODIS overpasses, snow cover, snow depth, air temperature and canopy density were measured at various sites in the field. Preliminary results show a good correspondence among the NOHRSC 1-km, the 500-m resolution MODIS snow maps and the MAS-derived 50-m resolution snow map (Hall et al., 2000). Sites in New Hampshire and central New York will be studied again in January and February of 2001 both using field measurements and ETM+ data to validate the MODIS snow map products. Current and future validation work is developing through three EOS Validations investigations: "Validation Of MODIS Snow and Sea Ice Products in the Southern Ocean (PI S. Li, *http://eospso.gsfc.nasa.gov/validation/nra/li.html*), "Validation Studies and Sensitivity Analyses for Retrievals of Snow Albedo from EOS AM-1 Instruments" (PI: A. Nolin, *http://eospso.gsfc.nasa.gov/validation/nra/nolin.html*), and "Investigation of Snow Properties Using MODIS and ASTER Data" (PI: J. Shi, *http://eospso.gsfc.nasa.gov/validation/nra/shi.html*). Together with these investigations, current and future Snow and Sea Ice validation sites include:

[2]an EOS Land Validation Core Site

- Southern Ocean Experiment (Li)
- New Hamsphire (Hall)
- Mid-west U.S. (Hall, Nolin)
- King's River, Sierra Nevada, California (Shi)
- Turquoise Lake, Colorado (Nolin)
- Greenland ice sheet (Nolin)
- SURFRAD site near Fort Peck, MT (Nolin)
- Possibly EOS Land Validation Core Sites with some snow cover (Shi)

5.4 Bidirectional Reflection Distribution function (BRDF)/Albedo

Boston University (BU) is responsible for the BRDF/Albedo product (PI: A. Strahler and J. P. Muller, University College London, *http://geography.bu.edu/brdf/index.html*). The primary data used to validate BRDF/Albedo products include: field albedometers, fine- and high-resolution airborne and satellite imagery, albedo products derived from the MISR & VEGETATION (*http://sirius-ci.cst.cnes.fr:8080/*) sensor, and Baseline Surface Radiation Network (BSRN, *http://bsrn.ethz.ch/*) albedos. Initial validation for the BRDF/Albedo product compared ground transects of total shortwave and near-infrared broadband albedo with AVHRR- and POLDER-derived spectral albedos using the MODIS algorithm. Ground transects were used to construct spatial models of the area. AVIRIS spectra were used to do spectral-to-broadband conversions. Albedometers used were Kipp+Zonen CM21 with filtered domes (Lucht et al., 2000; Barnsley et al., 2000)

Current and planned BRDF/Albedo validation efforts are being (will be) conducted at those EOS Land Validation Core Sites where: field albedometer measurements are being made, airborne and/or Ikonos data have been acquired, and AERONET Network data are being acquired. In particular, validation activities continue through the associated validation scientist, S. Liang of the University of Maryland (see section 5.1 for related URL) whose work is ongoing at the Beltsville Agricultural Research Center (BARC) Core Site. The EOS Validation Investigation: "Southern Africa Validation of EOS (SAVE): Coordinated Augmentation of Existing Networks" (PI: J. Privette, *http://eospso.gsfc.nasa.gov/validation/nra/privette.html*) will contribute to validation through collection of field albedo measurements at the Mongu and Skukuza Core Sites. BRDF/Albedo validation plans also include collaboration with M. Barnsley and P. Lewis at the Barton Bendish Core Site, R. Pinker at the Jornada Core Site, and through BU's activity at the Harvard Forest LTER Core Site. Additional exploration includes the use of the Baseline Surface Radiation Network (BSRN) through collaborative work with BSRN, led by J. Peter Muller. BU is also collaborating with Xiaowen Li on albedo validation in Luancheng, China.

5.5 Vegetation Indices

The University of Arizona (UAz) is responsible for the Vegetation Indices (VIs) products (PI: A. Huete, *http://gaea.fcr.arizona.edu/projects/modis/index.html*). The primary data used to validate the VI products are field spectrometers, airborne data (primarily MQUALs: Huete, 1999), and high-resolution satellite imagery.

Current and planned VI validation efforts are being/will be conducted at sites where the MQUALS system is deployed. An MQUALs deployment includes acquisition of the airborne data, as described in section 3.2, as well as field spectrometer measurements coincident with the flight and acquisition of an associated high resolution image. Preliminary results from the San Pedro/Walnut Gulch site, and other flights from 2000, are being used to develop scaling and correlative procedures for combining the field spectral measurements, MQUALs, ETM+, and MODIS VI data (Gao and Huete, 2000). MQUALs flights for 2000 were:

- SALSA, San Pedro Core Site, March 31, 2000.
- Jornada Core Site, May 10
- Jornada Core Site, Sept. 30
- Brasilia National Park, April 16 - May 5
- Brasilia National Park, July 17-19
- Tapajos Core Site, July 9 – 13

Plans are underway to make these data publicly available to serve additional validation needs. Also, approximately 3-5 MQUALS flight will occur in 2001, tentative plans are to fly the system again at Jornada and one of the forested Core Sites, as well as 1-3 more sites depending on collaboration opportunities.

In addition, the UAz team has been working with Y. Honda from the Center for Environmental Remote Sensing, Chiba University, Japan, on validation activities at the Mandalgobi Mongolia, Core site. Team members from UAz participated in the campaigns in Mongolia in 1999. In June of 2000 Dr. Honda and his team, hosted by A. Huete and S. Running, led a U.S. Campaign over several sites in the western U.S., including the Konza Prairie and Jornada Core Sites. Data from this campaign will be publicly available on CD and through Mercury. Details are given at *http://earthobservatory.nasa.gov/Newsroom/Campaigns/HueteHelicopter.html*.

Also, the EOS Validation investigation “Validation and Correction for the MODIS Spatial Response” (PI: R. Schowengerdt, *http://eospso.gsfc.nasa.gov/validation/nra/schowengerdt.html*) is conducting an error analysis of the MODIS adjacency effect on the Normalized Difference VI (NDVI) and the Enhanced VI (EVI) products.

5.6 Leaf Area Index/Fraction of Photosynthetically Active Radiation

Boston University is responsible for the Leaf Area Index (LAI)/Fraction of Photosynthetically Active Radiation (FPAR) products (PI: R. Myneni, *http://cybele.bu.edu/*). The primary data used to validate the LAI/FPAR products are the "LAI-2000 Plant Canopy Analyzer (*http://env.licor.com/products/lai2000/2000.htm*), the "Trac" instrument (*http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/rd/apps/em/beps/trac_e.html*), field ceptometers, field spectrometers measuring both leaf and background spectral reflectance, and fine and high resolution imagery. Secondary, but useful, data include: fraction of area vegetation cover, vegetation crown allometry (height, width, gap), phenology (green-up, mature, senescent stage), vegetation composition (either by species or structural type), wet or dry status, and a minimum set of meteorological data. Issues involved with the Global Validation of EOS LAI and FPAR products were discussed at an international meeting held at Boston University, October 1998 (Privette et al., 1998). Results from that meeting were used to frame the MODLAND LAI/FPAR validation activities.

Validation work on the LAI/FPAR products will come from BU's LAI team as well as collaborations with the "BigFoot" project, the EOS Validation Investigation: "Validation of ASTER and MODIS Surface-Temperature and Vegetation Products with Surface-Flux Applications" (PI: S. Gower, *http://eospso.gsfc.nasa.gov/validation/nra/gower.html*), the Privette/SAVE EOS Investigation (see section 5.4 for related URL), and the joint NASA/Sukachev Institute project in Krasnoyarsk Russia (PI: D. Deering, *http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/vrr_workshop/krasnoyarsk.pdf*). These investigations will provide validation data, detailed spatial analysis, and comparison of field measurements with the MODIS LAI/FPAR products.

The BigFoot program will examine the landscape characteristic over four CO_2 flux tower sites – scaling from the relatively small flux tower "footprint" to the larger satellite footprint over the towers. The goals of the BigFoot program are to:

- Explore the errors and information losses that accrue when extrapolating field data to coarse grain (1 km) surfaces
- Determine if there is a fundamental grain size at each site, above which error rates accelerate when modeling land cover, LAI, FPAR, and NPP
- Develop a better understanding of the climatic and ecological controls on net primary production and carbon allocation within and among biomes
- Learn how flux tower measurements of net ecosystem exchange (NEE) and field measurements of NPP co-vary, and how to translate between them using ecological models.

Detailed information on the BigFoot program is available at *http://www.fsl.orst.edu/larse/bigfoot/*.

Current and planned LAI/FPAR validation efforts are being or will be conducted at those Core Sites where LAI and spectral measurements are being collected:

- BOREAS NSA (BigFoot)
- Bondville, IL (BigFoot)
- Harvard Forest, MA (BU, BigFoot)
- Konza Prairie LTER (BU, BigFoot)
- Krasnoyarsk (NASA/Sukachev Institute)
- Mongu, Zambia (BU, Privette/SAVE)
- Wisconsin: Park Falls (Gower)

As well as several additional sites:

- Kalahari transect (four sites in Botswana) (BU, Privette/SAVE)
- Nova Scotia, Canada (BU)
- Ruokolahti Forest in Finland (*http://cybele.bu.edu/modismisr/validation/ruokolahti/ruokolahti.html*) (BU)

5.7 Daily Photosynthesis and Annual Net Primary Production

The University of Montana (UMt) is responsible for the Daily Photosynthesis (PSN) and Annual Net Primary Production (NPP) products (PI: S. Running, *http://www.forestry.umt.edu/ntsg/RemoteSensing/modis/*). The primary data used to validate these products will be the data from CO_2 flux towers – as part of the FLUXNET Network listed in Section 3.6.2.

The validation protocol will be based on the work of Running et al. (1999) and will involve:

- Comparing MODIS product with the MODIS algorithm run with site specific FLUXNET micro meteorological data in lieu of Data Assimilation Office (DAO) climate data
- Comparing MODIS product with site specific BIOME-BGC output (Bio-Geo-Chemical modeling, *http://www.forestry.umt.edu/ntsg/EcosystemModeling/BiomeBGC/*)
- Computing site specific PSN/NPP using MODIS LAI/FPAR products

Currently 11km by 11km subsets of MODLAND product are being extracted over the FLUXNET sites and operationally sent to UMt. The infrastructure for collecting and utilizing the field data from FLUXNET has been established through two EOS Validation Investigations: "FLUXNET: Flux networks for Validating EOS Terrestrial Carbon, Water and Energy Budgets (PI: D. Baldocchi, *http://eospso.gsfc.nasa.gov/validation/nra/baldocchi.html*) and "A Global Flux Data and Information System to Support EOS Product Validation (PI: R. Olson, *http://eospso.gsfc.nasa.gov/validation/nra/olson.html*). These investigations, through collaborative work with UMt and MODLAND, will continue to define the procedures needed to utilize the FLUXNET network for MODLAND validation of the PSN and NPP products. Flux towers measure both water and

carbon fluxes. The carbon fluxes will be used to validate PSN/NPP and water fluxes will be used to validate surface resistance and evapotranspiration product. Therefore, validating this product does not involve additional data collection.

5.8 Fire and Burn Scar

The University of Virginia is responsible for the Fire products (PI: C. Justice, *http://modis-fire.gsfc.nasa.gov/*). The primary data used to validate the Fire products include field surveys, airborne imagery and high-resolution satellite imagery.

The MODIS active fire data are being compared to data from the AVHRR, DMSP, AVHRR and ASTER instruments. Initial Fire and Burn Scar validation efforts are being conducted in the context of the SAFARI 2000 initiative (*http://safari.gecp.virginia.edu/*) using a network of regional collaborators. This network will involve field surveys and image interpretation over 13 regionally distributed ETM+ scenes, which will be compared to MODIS fire and burn scar products. Subsequent emphasis will be on examining algorithm performance in the Boreal ecosystem and in Southeast Asia through the Global Observation of Forest Cover (GOFC) regional network. In addition, the EOS Validation Investigation: "Biomass Burning and Emissions of Trace Gases and Aerosols; Validation of EOS Biomass Burning Products (PI: W. M. Hao, *http://eospso.gsfc.nasa.gov/validation/nra/hao.html*), will analyze prescribed fires in Zambia as part of the SAFARI 2000 initiative and will work with the USDA Forest Service and Canadian Forest Service to analyze fires in Alaska and the western U.S. The MODIS Fire Product validation is being undertaken in the context of the Global Observation of Forest Cover Project (*http://www.gofc.org/gofc/index.html*) and the CEOS LPV subgroup.

5.9 Land Cover

The Boston University is responsible for the Land Cover products (PI: A. Strahler, *http://geography.bu.edu/landcover/index.html*). The primary data used to validate the Land Cover product are field surveys, airborne imagery, and fine and high-resolution satellite imagery.

Boston University conducted a New England field campaign during June-July 1998 and participated in the IGBP DISCover Validation project (Muchoney et al., 1999). Through these efforts, BU has developed a test site database for Land Cover algorithm training, testing, and validation. This global landcover/TM/ETM+ database includes over 900 sites. The work from the IGBP DIScover Validation project will provide the protocol for validating the MODIS land cover product, based on independent training and testing, and contingency table analysis to quantify classification accuracies using BU's global test site database. In addition, detailed land cover maps will be created for several EOS Land Validation

Core Sites for land cover validation over these sites. BU is investigating informal collaborations with international groups who have compiled data sets that might serve as a sound basis for land cover validation (e.g. TREES, *http://europa.eu.int/comm/research/rtdinf14/14e06.html*).

5.10 Vegetative Cover Conversion/Vegetation Continuous Fields

The University of Maryland is responsible for the Vegetative Cover Conversion (VCC) and Vegetation Continuous Fields (VCF) products (PI: J. Townshend, *http://www.geog.umd.edu/landcover/modis*). The primary data used to validate the VCC and VCF products are field surveys, airborne imagery, and fine resolution airborne and satellite imagery (*http://www.geog.umd.edu/landcover/modis/MOD44_valplan.pdf*).

In the case of the VCC product prototyping, changes were traced as bitmaps using high-resolution image pairs. These bitmaps of change are then degraded to 250m MODIS resolution and are compared to the VCC product to determine errors of commission and omission. For post-launch validation activities these methods are being automated. For the VCF product, fractional cover proportions are derived using high-resolution data for transects representing a vegetation gradient. These proportions are then compared with the VCF product. In the case of both VCC and VCF validation, field observations will be collected for comparison with both the high-resolution validation images and the MODIS products. In the case of VCF this is done using a laser instrument that reports canopy closure.

For Vegetative Cover Conversion validation activities, UMd is partnered with US Forest Service RSAC (Remote Sensing Applications Center, Salt Lake City) to validate results for western U.S., using GIS field data and comparison with Landsat 7 for selected sites. One of these sites from the year 2000 is the Cerro Grande fire where IKONOS data were also collected.

Vegetation Continuous Fields validation will utilize field data collected for Kalahari woodlands and eastern U.S. during 2000, and a Miombo follow-on planned for 2001. In addition, two airborne campaigns over the "Appalachian Transect" (AT) will be flown during leaf–on and leaf-off conditions, covering a gradient of vegetation cover densities (*http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/vrr_workshop/Sohlberg_app_trans.pdf*). The transect traverses from the Beltsville Core Site to Columbus, Ohio. The leaf-on flight was completed in July, 2000 and the leaf-off flight is currently scheduled for March 2001. The AT campaign involves collaboration with S. Liang's EOS Validation investigation (see section 5.4 for URL) at the USDA Beltsville Core Site and an EO-1 Validation investigation over the Appalachian Laboratory Tower, Frostburg, MD (PI: P. Townsend).

6 Communicating validation results

One of the ultimate objectives of the MODLAND Validation activities is to communicate validation results, in terms of product uncertainty, to the user community. This will help users understand the reliability, as well as the limitations of the MODLAND products. Current validation activity is posted on the Internet, with the guiding principle of making as much data freely available as possible, as soon as possible. There have also been several peer-review papers on the pre-launch activities and several conference papers on initial post-launch activities, as referenced throughout this report. Validation activities will be included in the planned MODIS Land Team special issue of Remote Sensing of Environment (expected in 2001). Additional peer-review publication on MODIS products and related validation activities are forthcoming from the MODLAND team as well as EOS and other validation investigations.

MODLAND, in conjunction with the ORNL and EDC DAACs, hosted the "Land Validation Readiness Review" workshop (*http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/vrr_workshop.html*) at GSFC, in November 1999, to encourage collaboration between the MODLAND team and the EOS Validation Investigators and other validation-related programs. MODLAND plans to hold similar workshops annually, at a time and location adjacent to a MODIS science team meeting. Current plans are for a two-day validation workshop, January 22 and 23, 2001 (*http://modis-land.gsfc.nasa.gov/val/modland_val_mtg_2001.html*).

The MODLAND team will also continue to interact with users, to consider their use and how validation results can properly temper that use. This type of "user driven" validation activity is just now starting to occur; possible focus projects include the Global Observation of Forest Cover (GOFC, *http://www.gofc.org/gofc/index.html*) project, the Millennium Ecosystem Assessment project (*http://www.ma-secretariat.org/*), and current and future International Satellite Land Surface Climatology Projects (ISLSCP-II&III, *http://islscp2.gsfc.nasa.gov/*).

7 Integrating validation activities into the global community

Currently, the MODLAND validation activities are serving as a model for the Committee on Earth Observing Satellites (CEOS) Working Group on Calibration and Validation (WGCV) Land Product Validation (LPV) subgroup. The validation efforts of MODLAND and EOS will continue to provide contributions to the working group on LPV. Plans for the next 5+ years include:

- Transitioning measurement protocol from pilot projects to standardized techniques
- Combining EOS Land Validation Core Sites with other networks to create a set of CEOS Land Validation Sites and
- Contributing to validation activities of the CEOS Pilot project: Global Observation of Forest Cover (GOFC)

These and other, continued interaction with CEOS WGCV will allow the MODLAND validation activities to make more significant contributions to the global change research community.

8 Conclusions and future considerations

In general, there has been significant progress on MODLAND validation activities. MODLAND's investment in validation activities has resulted in major accomplishments in the infrastructure for collection, archive, and distribution of the necessary validation data. The MODLAND team, together with EOS and other validation investigators have made progress on instrument development and establishing measurement protocols. At this point, attention should focus on correlative analysis procedures that make the most of data that have been and will continue to be collected, specifically:

- Advancing work on scaling and correlative procedures
- Utilizing the network approach to validation data, building on the EOS Core Sites
- Undertaking product validation in the context of the use of the product to meet scientific goals.
- Securing continuous or periodic independent data collection and correlative analysis to determine the accuracy of time-series data
- Developing long-term MODIS 'climate' land data records of science quality and known accuracy and establishing the relationship of those products to those provided by operational sensing systems e.g. NOAA AVHRR, NPP/NPOESS VIIRS (http://www.ipo.noaa.gov/)
- Strengthening international cooperation with respect to land product validation with emphasis on shared validation sites, protocols, and data.

As more actual MODIS data become available, it is anticipated that the MODLAND team and validation investigators will continue to make progress in correlative and scaling procedures. The FLUXNET and AERONET networks, and their utilization by the MODLAND team, provide a good example of how existing networks can contribute to global validation. Attention should be given to advancing the utilization of these networks. Other networks that can provide validation data should be considered as well. Future work will have to address not just the collection of validation-related data provided by a given network, but methods to conduct continuous correlative analysis of those data. Work with automated procedures and integrated database management could help with this effort.

As stated in section 6, communicating results is and will continue as an important component of land product validation. Current activities should continue but new efforts are needed to communicate and integrate validation results into the science applications of the products. The projects introduced at the end

of section 6 can provide pilot activities where validation results can contribute to the most appropriate use of the global land products.

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