A Light Aircraft Radiometric Package for MODLAND Quick Airborne Looks (MQUALS

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The ‘MODLAND Quick Airborne Looks’ (MQUALS) is an airborne radiometric system (instruments and protocol) for rapid and low-cost land product validation over a range of terrestrial biome types. The package can be flown ‘below the atmosphere’ at altitudes of 150 to 300 m AGL for accurate and independent characterization of surface reflectances. The package can be flown at higher altitudes (500-1000 m AGL) for scaling or large area studies. In this article we describe the MQUALS system and its application in characterizing the wide range of vegetation canopies represented by the Earth Observing System (EOS) Land Validation Core Sites. The basic package consists of calibrated and traceable "transfer radiometers," digital spectral cameras, an infrared thermometer and a set of albedometers, all connected to a laptop computer for synchronized measurements. The package is easily shipped and mounted on a variety of light airplanes. The flying costs for a 3-5 day deployment with transect measurements at various sun angles would be approximately $5 K. A key feature of MQUALS is the rapid processing "turn-around" of the measured results to within 7 - 10 days.

Background

The MODIS Land (MODLAND) group has the task of validating a series of Geophysical and Radiometric products over a diverse range of terrestrial biomes. As a result of the wide array of lifeforms (species, physiology, and structure) found over land surfaces, with their spatial heterogeneity and temporal dynamics, we have found it desirable to deploy a light, aircraft-based radiometric/imaging package with simple instrumentation for rapid and extensive ‘ground truth’ data collection to aid *in situ* comparisons with MODIS sensor products. This mobile package will be utilized at various validation sites, especially the EOS Land Validation Core Sites (http://modarch. gsfc.nasa.gov/MODIS/LAND/VAL/core_sites.html). Through MQUALS, these sites will be characterized and geolocated with GPS in a consistent manner with an identical and ‘traceable’ radiometric package. In conjunction with simultaneous field sampling, MQUALS will allow us to collect a self-contained set of biophysical and radiometric data from the same ground pixels, which can be correlated and compared with ASTER, Landsat ETM+, and MODIS/MISR pixel values.

Objectives

The main goal is to provide a ‘ground truth’ characterization of land-cover surface types to aid in EOS product validation, support linkages between radiometric accuracies and scientific goals, and accurately tie satellite products to measurements on the ground. MQUALS has the following primary objectives in support of land-product validation:

- a land surface optical characterization, including measurement of multispectral radiances, spectral vegetation indexes, and albedo over transects up to 10 - 20 kilometers,
- a consistent, well-calibrated and "traceable" instrument package, coupled to EOS vicarious calibration activities, for radiometric accuracy analysis,
- analysis of dependencies of MODIS data on sampling geometry, target scene, sun angle, and atmosphere,
- extension, correlation and scaling of ground-based vegetation biophysical (leaf area index, %cover, biomass) and radiometric (fraction of absorbed photosynthetically active radiation) measurements to MODIS pixel sizes (250 m, 500 m and 1 km),
- documentation of surface conditions and sampling of landscape variability with high resolution, spectral-digital camera imagery, providing qualitative and semi-quantitative checks of MODIS data.

In addition, MQUALS can provide quality assessments, uncertainty analyses, and generation of error bars with respect to product performance. MQUALS can also provide feedback on calibrated radiance (Level 1B) processing differences and their impacts on land products and provide for systematic assessments of long-term stability for monitoring studies.

System Design

The basic sensor package consists of a digital, multi-camera array, a nadir-looking Exotech radiometer with MODIS filters, two albedometers, an infrared thermometer (optional), and a laptop computer with Labview software for programmed and coordinated data acquisition. The sensor package can be mounted on a variety of small aircraft. The mounted setup is illustrated in Fig. 1. The ground component of MQUALS consists of a Spectralon reference panel with a second Exotech mounted for continuous measurements of site irradiance.

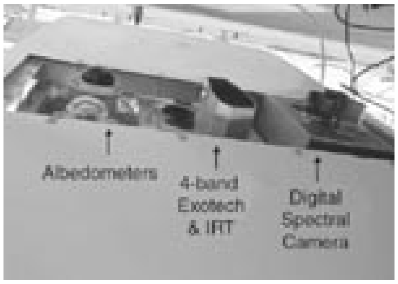

Figure 1. Mounted setup of the MQUALS radiometric package.

Exotech Radiometer (Model 100 BX) with 4 Filter Set

The Exotech radiometer is a stable, durable, and calibrated radiometer with four spectral MODIS bands (Table 1). The four channels are co-aligned to within ±0.5°.

Table 1. Spectral characteristics of MQUALS components.

Filter/Sensor	MODIS Sensor	Exotech Radiometer	Digital Camera
Channel 1, red	620 - 670 nm	623 - 670 nm	635 - 667 nm
Channel 2, NIR	841 - 876	838 - 876	835 - 870
Channel 3, blue	459 - 479	456 - 475	455 - 465
Channel 4, green	545 - 565	544 - 564	- - - -

The field-of-view can be varied from 1° square field, 15° circular field and 2 ¼ steradians. We currently are conducting flights with 15° field-of-view lenses, although this differs substantially from the very narrow IFOVs of satellite sensors. However, this setting is an unavoidable compromise between the need to sample representative areas and approximating the IFOV of the satellite. With a 1° field of view, the ground pixel size of the Exotech is approximately 2 m (at 100 m AGL) resulting in highly variable, narrow swath measurements. Table 2 shows the swaths of the Exotech radiometer as a function of aircraft altitude.

Table 2. Measurement swaths for the Exotech radiometer and digital camera system at different aircraft altitudes.

Aircraft AGL	Exotech 1° FOV	Exotech 15° FOV	Camera HFOV	Camera VFOV	Camera pixel resolution
100 m	1.7 m	26 m	60 m	45 m	0.10 m
150	2.6	39	90	67	0.15
300	5.2	78	180	135	0.29
500	8.7	132	300	225	0.50
1000	17.5	264	600	450	1.0

We will fly the aircraft on multiple transects (3-to-10 km in length) over a selected site. The flight lines are designed on a case-by-case basis but will generally: (1) traverse uniform areas of the dominant land-cover type, and (2) span the land-cover heterogeneity, including land cover subtypes and gradients to encompass the range of variability in site parameters. Typical flight transects would occur at an altitude (150 m AGL) corresponding to Exotech 'pixel' resolutions of 40 m. Pixel size could be increased to 100 m or more by flying at higher altitudes. At a speed of 150 km/hr, the aircraft can traverse a 10 km length transect in approximately 4 minutes, collecting approximately 240 Exotech samples at a nearly constant sun angle-target-sensor geometry (Fig. 2).

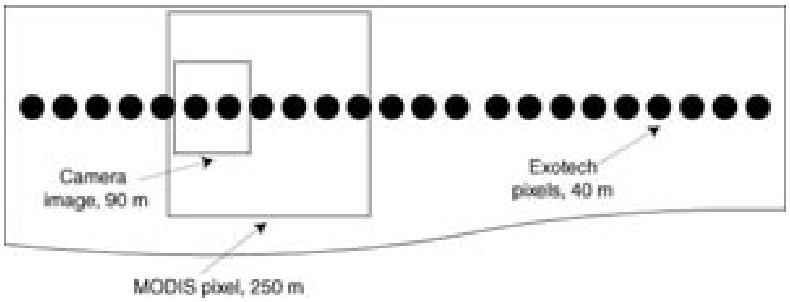

Figure 2. Diagram of Exotech and camera airborne data acquisitions in relation to a MODIS pixel for 150 m AGL and 15° field-of-view Exotech.

Dycam ADC Modular 4 Camera System

This multi-camera array consists of three cameras, upgradable to a fourth camera, with an optical mount and parallel port software. The spectral characteristics of the cameras are summarized in Table 1. The total field-of-view for the 1/4 inch detector array (640 x 480 pixels) in combination with a 6 mm focal-length lens is 33° (horizontal) by 25° (vertical). The swath width and dimensions of the imagery are presented in Table 2. At 150 m AGL, a 90 m swath is imaged while at 1000 m AGL a 600 m swath is imaged. The camera system and software are also designed to be able to measure 'reference' panels for derivation of reflectance-based imagery and computation of vegetation indexes. Figure 3 is an example of a 3-band composite image acquired at 250 m AGL.

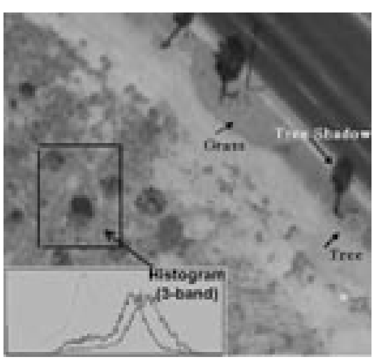

Figure 3. Example of 3-band (blue, red, and near-infrared) airborne image acquired at 250 m AGL over a desert shrubland (bottom) adjacent to a well-watered roadside planted with trees and grass (top). The image is approximately 120 m by 90 m with a pixel resolution of 0.20 m.

Spectralon Diffuse Reflectance Target

Field and low-altitude airborne measurements of radiance reflected from a surface require an assessment of the irradiance in order to derive the reflectance factor (RF). One can approximate irradiance by sampling radiance reflected from a Spectralon panel that is calibrated to account for its inherent nonlambertian properties. A commercially produced Spectralon diffuse reference panel (Labsphere) is utilized on the ground in combination with a second Exotech radiometer to measure irradiance conditions at the site continuously. They have an anodized aluminum frame covered with a specially formulated white reflectance coating (Spectraflect) with a reflectivity of 99% over an effective spectral range of 300 to 2400 nm and a thermal stability of 100° C. An 18-inch-by-18-inch panel constructed from four, 9-inch panels is used for MQUALS. These plates are weather-resistant and washable.

Kipp and Zonen albedometers

MQUALS will use two airborne and one ground-based pyranometers/albedometers from Kipp and Zonen. The clear-dome albedometer provides shortwave broadband albedo in the range of 305 - 2800 nm and the red dome albedometer provides NIR broadband albedo in the range of 695 - 2800 nm. An upward looking, clear-dome pyranometer is mounted on top of the airplane for irradiance measurements. Another set of albedometers is mounted on the ground.

Laptop computer for data logging

A Gateway 233 MHz laptop computer is used as a data-logger and instrument controller. Data logging frequency for all of the on-board instruments and start and stop times are programmed prior to the flight transects. The computer logs the data from all instruments simultaneously. Special purpose software (LabView) is used to synchronize these activities.

LabVIEW Instrument Control Software with PC cards (Version 4.0)

This software is an icon-based graphical programming and data acquisition tool with front-panel user interface for control and data visualization. Complex acquisition, analysis, and presentation applications can be generated in real time using a graphical methodology. Different data acquisition systems such as the Exotech, digital camera, and albedometers can be controlled using this software, and data acquired from these instruments can be checked visually for problems. PC cards, including those for signal conditioning, voltage modulation accessories, and data acquisition, are used to connect the computer with the instruments.

GPS system (from aircraft):

Geo-positioning of the air transects is accomplished using the GPS receiver onboard the aircraft. Plans are being made to acquire a differential GPS and connect it directly to the laptop computer.

Calibration and Traceability

The Exotech radiometers are stable and durable optical instruments that are easily calibrated in the laboratory and can be cross-calibrated with similar instrumentation used in the field as well as on other airborne platforms. These "transfer radiometers" can also be cross-calibrated with the radiometric equipment utilized by MODIS Calibration Support Team (MCST) activities, including simultaneous on-site measurements at vicarious calibration field sites. The MQUALS package is currently being calibrated by the Remote Sensing Group within the Optical Sciences (OSC) Department at the University of Arizona. There are three aspects to the calibration of the Exotech radiometers used as part of MQUALS. One aspect is to calibrate radiometers in flight using "vicarious calibration" techniques similar to those used for Landsat-5 Thematic Mapper. These methods rely heavily upon collecting ground-based data from a well-understood radiometer (an ASD FieldSpec FR in this case) with reference to a field reflectance standard (Spectralon in this case). The field reference is calibrated in the Optical Sciences laboratory prior to the field experiment to determine its bi-directional reflectance with reference to a NIST-traceable standard of reflectance. Differences in the spectral response of the Exotech radiometer relative to MODIS are taken into account by measuring the Exotech spectral response using the Optical Sciences monochromator. An additional tool for the vicarious calibration of the Exotech radiometer, and the digital cameras as well, are a set of calibrated tarps (7 m on a side) that are setup at the calibration sites to be viewed by the airborne camera. This enables characterization of the spectral response and linearity of the camera array system.

A similar technique to the vicarious calibration approach is to cross-calibrate the Exotech radiometer to the ground-based radiometer using the field reflectance standard to transfer the calibration from one instrument to the other. Since the ASD spectroradiometer is hyperspectral, effects due to band differences in the two radiometers are minimized. This method can either rely on an absolute calibration of the ASD spectroradiometer to obtain the absolute calibration of the Exotech, or one can simply do the cross-calibration in terms of reflectance. The latter has the advantage of "reducing" the uncertainty by not relying on the absolute calibration of one of the radiometers but a relative calibration of the reflectance standard. A similar calibration can be done in the lab, but the field-based approach has the advantage of using the same spectral source that the MQUALS data set uses.

The third aspect of the MQUALS calibration is to provide a "traceable" link to the MODIS Instrument (Fig. 4). This is accomplished through the use of ultrastable laboratory radiometers that took part in a calibration round-robin to characterize the Santa Barbara Remote Sensing (SBRS) primary standard source (a large spherical integrating source) used in the pre-launch calibration of the MODIS instrument. These radiometers have also been used to calibrate the Optical Science's sources and reference panels. Thus, any instrument calibrated using Optical Science's laboratory will have traceability to the MODIS sensor.

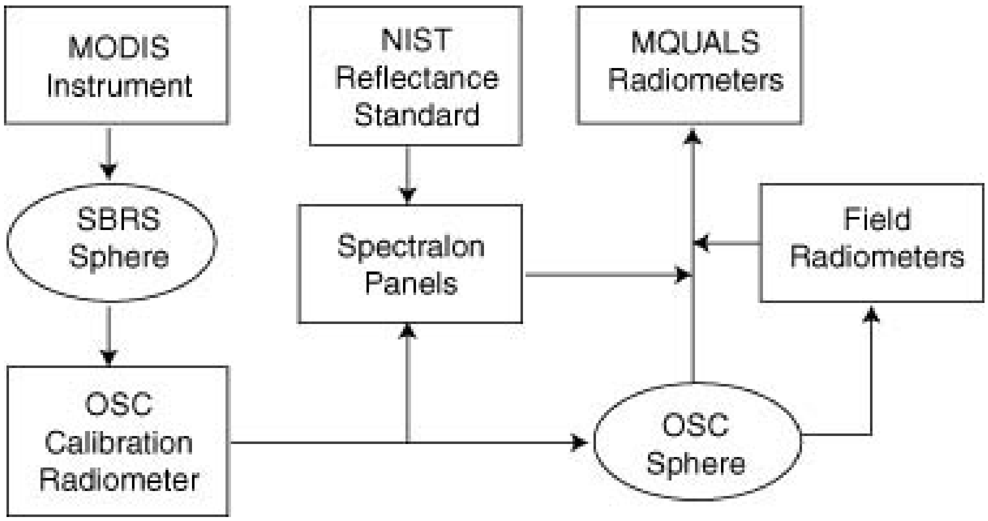

Figure 4. Diagram of the traceability of field validation measurements to the MODIS instrument.

Note that at this point, we do not know of the radiometric stability of the multispectral digital camera system, however we will make efforts to calibrate this instrument if possible. If not, this instrument will primarily be used for characterization of scene heterogeneity and qualitative variability of component optical properties.

MQUALS Schedule for 1999

Site	Dates	Land Cover	Other
Railroad Playa, NV	Late April-early May	Barren, vicarious calibration	Landsat ETM+
La Jornada, NM	Late May & September	Semi-arid grass/shrub	LTER site
*Bondville, IL	July - August	Cropland	BigFoot site
ARM-CART or Konza	July - August	Grassland/agriculture	Possible MAS/ AirMISR overflight
BOREAS NSA	August - September	Boreal Forest	BigFoot site

* tentative

Testing of the MQUALS package is ongoing and has occurred mostly in the vicinity of the Semi-Arid Land-Surface-Atmosphere (SALSA) area in southeast Arizona (http://www.tucson.ars.ag.gov/salsa/salsahome.html), over a fairly uniform dry grassland. We also are testing and calibrating the system in a barren uniform area near the Tucson International Airport. The current schedule for 1999 MQUALS deployments is listed in the table above.

The Railroad Playa calibration experiment is expected in late April — early May, following the April 15 launch of Landsat ETM+. In this experiment we aim to: (1) cross calibrate the MQUALS package with the MODIS vicarious calibration team; (2) register MQUALS data with Landsat ETM+ for a homogeneous site with no vegetation; and (3) establish a zero baseline condition for vegetation indexes. The Jornada Experimental Range (La Jornada) near Las Cruces, New Mexico will be flown in late May (dry season) and September (wet season) time frames. This is a semi-arid validation Core Site with desert shrub, grassland, and mixed grass/ shrub subsites located in a protected area which is part of the NSF's Long Term Ecological Research (LTER) site network. The Bondville, IL and BOREAS NSA (Canada) overflights will occur in conjunction with BigFoot vegetation validation work in the July-September time frame. The objective of the BigFoot program is to provide ground validation of MODIS land cover, LAI, and FPAR, with special consideration of multiple scaling issues (http://www.fsl.orst.edu/larse/bigfoot/plan.html). The MQUALS data will provide insight for scaling from field data to 250 m spatial resolution. Finally, we would like to underfly the ER-2, with MAS/ AirMISR, over some of the ARM-CART or Konza grassland sites.

Product Validation Issues

We propose to characterize the optical properties of the validation sites and at various times of the season. These validation, 'ground truth' sites will be both optically and biophysically characterized, and atmospheric effects will be simultaneously measured with sunphotometers. Precise measurements will include both the heterogeneity and uniformity of the sites and measurements will be conducted at high resolution as well as scales equivalent to that of the MODIS pixel (250 m to 1km). We will initially focus on the surface reflectance, vegetation indexes, albedo, LAI, FPAR and landcover products from MODIS. MQUALS could also be useful for the snow and land surface temperature products.

The Level 3 and 4, composited products result in cloud-free maps at 16-day intervals. These products possess a wide range of view and sun angles and 'residual' atmospheric and cloud effects. Ground truth measurements are necessary to assess how well the composited, as well as daily, MODIS products represent actual surface conditions. For example, with an independent determination of nadir-based, 'true' surface reflectance, we can analyze where the uncertainties in the MODIS products lie and identify systematic errors. Errors associated with MODIS sensor calibration, instrument noise, atmosphere correction, BRDF correction, and the cloud mask algorithm will propagate into the final product. However, MQUALS measurements will similarly be affected by calibration, bidirectional reflectance, spectral sensitivity, and diffuse/direct irradiance effects. Thus, independent measures acquired for product validation will always differ somewhat from MODIS. Surface heterogeneity also presents difficulties in the measurement of biophysical parameters over MODIS pixel sizes. The error and lack of reproducibility in field measurements may exceed those from the satellite.

We are currently drafting field validation methods and protocol documentation as a guide in the standardization of EOS field-collected validation data. MQUALS flights, for example, will generally be made at multiple times of the day in order to bracket a range of sun angles and allow for extrapolation of the radiometric data to specific solar zenith angles for standardization purposes. A single MODIS scene or composited product may contain solar zenith angles that vary by 20°, along with sensor view angles that vary ±55°. End-to-end validation examples involving MQUALS prior to the launch of the Terra EOS satellite will be the subject of a forthcoming article. The URL address for MQUALS is http://gaia.fcr.arizona.edu/newmqual.html..