Megacollect 2004: Hyperspectral Collection Experiment of Terrestrial Targets and Backgrounds of the RIT Megascene and Surrounding Area (Rochester, New York)

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ABSTRACT

This paper describes a collaborative collection campaign to spectrally image and measure a well characterized scene for hyperspectral algorithm development and validation/verification of scene simulation models (DIRSIG). The RIT Megascene, located in the northeast corner of Monroe County near Rochester, New York, has been modeled and characterized under the DIRSIG environment and has been simulated for various hyperspectral and multispectral systems (e.g., HYDICE, LANDSAT, etc.). Until recently, most of the electro-optical imagery of this area has been limited to very high altitude airborne or orbital platforms with low spatial resolutions. Megacollect 2004 addresses this shortcoming by bringing together, in June of 2004, a suite of airborne sensors to image this area in the VNIR, SWIR, MWIR, and LWIR regions. These include the COMPASS (hyperspectral VNIR,SWIR), SEBASS (hyperspectral LWIR), WASP (broadband VIS, SWIR, MWIR, LWIR) and MISI (hyperspectral VNIR, broadband SWIR, MWIR, LWIR). In conjunction with the airborne collections, an extensive ground truth measurement campaign was conducted to characterize atmospheric parameters, select targets, and backgrounds in the field. Laboratory measurements were also made on samples to confirm the field measurements. These spectral measurements spanned the visible and thermal region from 0.4 to 20 microns. These measurements will help identify imaging factors that affect algorithm robustness and areas of improvement in the physical modeling of scene/sensor phenomena. Reflectance panels have also been deployed as control targets to both quantify sensor characteristics and atmospheric effects. A subset of these targets have also been deployed as an independent test suite for target detection algorithms. Details of the planning, coordination, protocols, and execution of the campaign will be discussed with particular emphasis on the ground measurements. The system used to collect the metadata of ground truth measurements and disseminate this data will be described. Lastly, lessons learned in the field will be underscored to highlight additional measurements and changes in protocol to improve future collections of this area.

Keywords: Hyperspectral, Megacollect, Megascene, DIRSIG, SEBASS, COMPASS, MISI, WASP, Spectral Library, Ground Truth

1. INTRODUCTION: BACKGROUND AND HISTORY

The Megacollect represents the experimental component of a larger research scope by the Digital Imaging and Remote Sensing Laboratory (DIRS) to incorporate all the factors that influence information extraction and exploitation from hyperspectral remote sensing imagery whether it be target phenomenology, background influences, environmental effects, or sensor characteristics and limitations. Each of these factors have been key research areas conducted by DIRS in order to encompass all the critical components of the imaging chain as described by Schott[1] to prioritize the level of knowledge necessary to either model or measure these factors and to a determined specified accuracy and precision. The development of DIRSIG has facilitated the modeling of the various target-background-sensor interactions. Parallel development in augmenting the lab's capabilities

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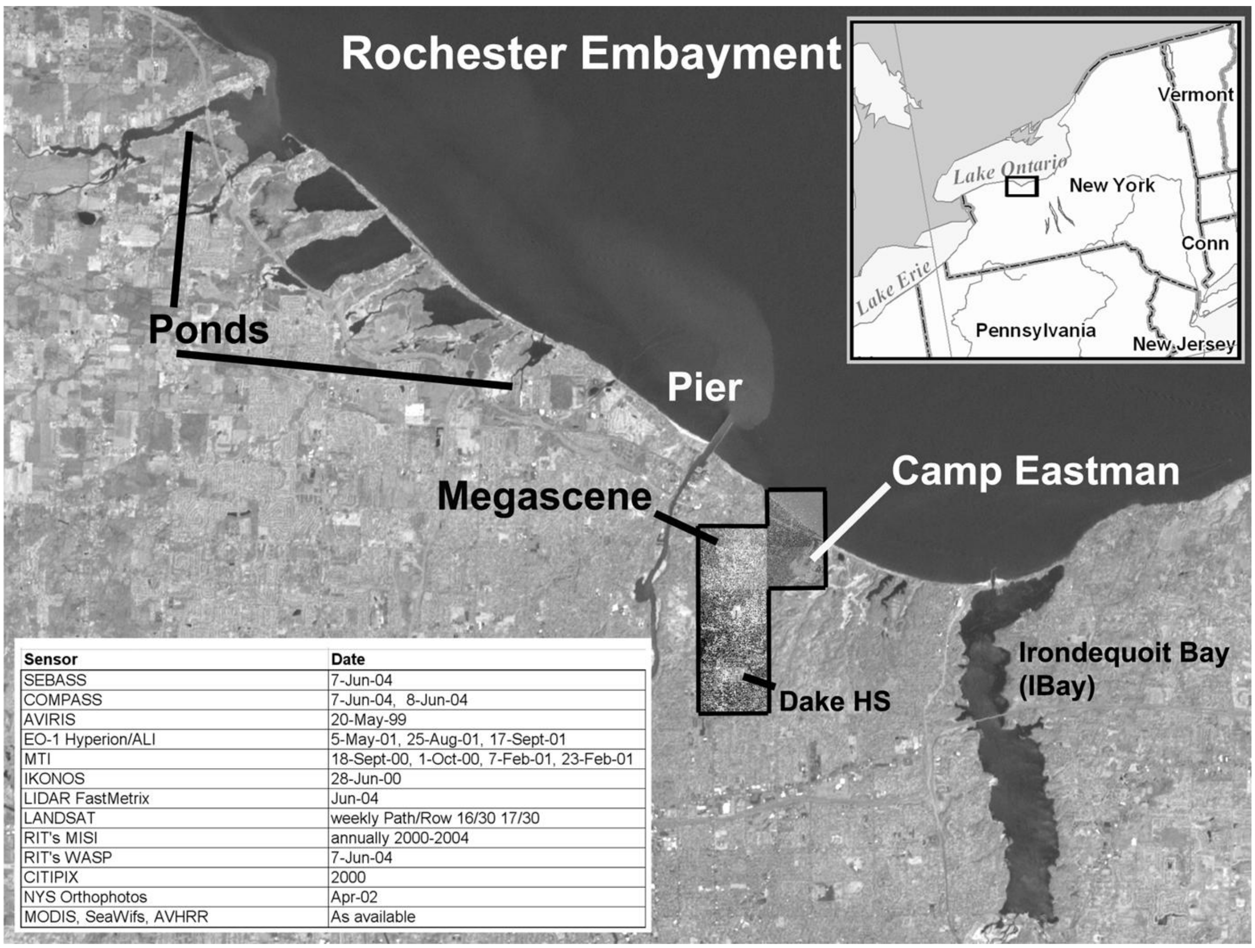
to measure and archive material and environmental properties have also been pursued to supply the necessary inputs to the models. The goal of this measurements database, in addition to being source of model inputs, would be a source for computing representative spatial and spectral statistics for specific materials.

This specific region of Western New York has been under study by DIRS since the lab's inception in the mid-1980's. This interest has accumulated numerous image data sets of the area from various remote sensing instruments spanning the EM spectrum from the visible to the longwave IR region. Figure 1 is a graphic representing an overview of the general region over which various sensors have collected imagery in the past two decades.



Sensor	Date
SEBASS	7-Jun-04
COMPASS	7-Jun-04, 8-Jun-04
AVIRIS	20-May-99
EO-1 Hyperion/ALI	5-May-01, 25-Aug-01, 17-Sept-01
MTI	18-Sept-00, 1-Oct-00, 7-Feb-01, 23-Feb-01
IKONOS	28-Jun-00
LIDAR FastMetrix	Jun-04
LANDSAT	weekly Path/Row 16/30 17/30
RIT's MISI	annually 2000-2004
RIT's WASP	7-Jun-04
CITIPIX	2000
NYS Orthophotos	Apr-02
MODIS, SeaWifs, AVHRR	As available

Figure 1. Overview image showing the historical sensor coverage of the Megacollect area (LANDSAT-7 base image).

Of particular note in this region is the history of modeling efforts of this specific area (Camp Eastman) starting with Ballard and Smith.[2] This was followed by an extensive effort expended to develop tools and build a representative model of the Megascene to provide wide area simulations in support of algorithm testing as described by Ientilucci and Brown.[3] While the spectral and spatial quality of these simulations were significant advances to previous DIRSIG results, no high spatial resolution hyperspectral data sets with well characterized ground truth existed for this area as a basis for assessing the fidelity of the simulations. To date, the tiles highlighted in Figure 2 have been simulated in DIRSIG representing approximately seven square kilometers of real estate representing urban, residential, light industrial, and shoreline regions. The intent is not to generate a simulation that exactly reproduces a specific scene, but rather to create a representative emulation of the spectral character and spectral statistics of scenes acquired by sensors such as those used in this collect.

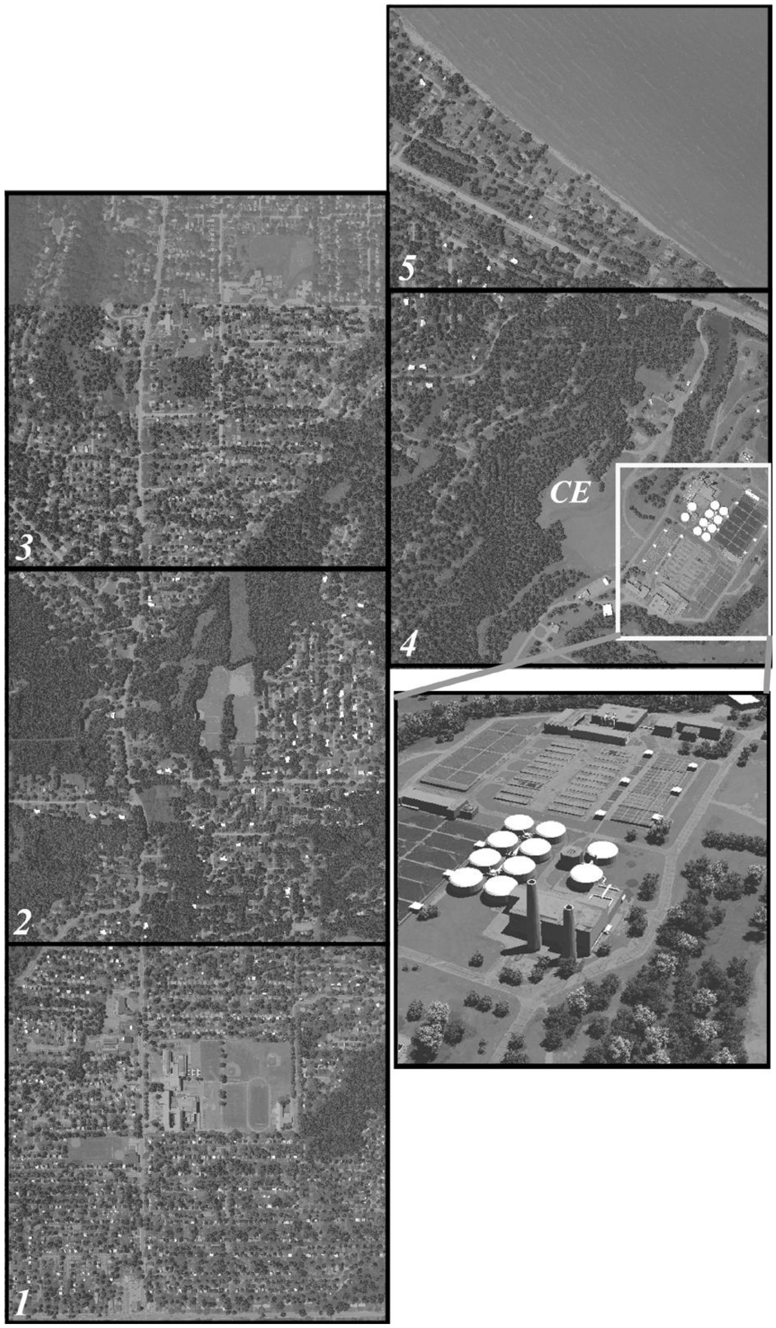


Figure 2. Megascene DIRSIG simulations (Tiles 1-5). Main experiment area is labeled *CE*. The perspective view of the adjacent VanLare water treatment plant shows the level of geometric detail used in modeling the in the entire Megascene.

An opportunity presented itself in late spring of 2004 when a narrow window in the COMPASS and SEBASS collection schedule was identified that allowed the Megascene area to be imaged. Plans were placed into motion to coordinate a simultaneous collection using four airborne imaging systems with contingencies to coincide with a LANDSAT-HYPERION overpass. The Megascene also covers an area near the shores of Lake Ontario so a collateral experiment was organized to collect water samples and ground truth using in-water optical measurements.[4]

2. THE COLLECTION

The opportunity to task four airborne sensors gave DIRS the means to acquire a rich source of both high spectral and high spatial information in the visible and emissive regimes for model validation and algorithm testing. Flight plans were designed to revisit regions that have already been imaged by other sensors as well as areas that have been modeled, but not imaged in a given spectral regime. A total of approximately 65 flight lines for the airborne sensors were planned. The proposed flight lines, parameters, and descriptions are summarized in Figure 3 and Table 1. Ground truth collections were coordinated based on these estimates. As the dates of the first weeks of June drew nearer, the conditions appeared favorable for either a collection on either June 5, 6, or 7th.

Table 1. Planned flight line parameters and descriptions. Similar coverage was planned for RIT's MISI and WASP sensors.

Flight Line Name [C]OMPASS [S]EBASS	**Altitude** $[ft]$ **AGL**	**Length** $[mi]$	**Description**
C1	6250	4.7	Lake Ontario, Camp Eastman, Dake Middle School
C2	6250	1.3	Camp Eastman (Smile Offset)
C3	12500	2.9	Camp Eastman Central to Dake
C4,C5	12500	2.9	Camp Eastman (Smile Offset)
C6	12500	2.9	Camp Eastman West Offset
C7	12500	13.8	Mid-Irondequoit Bay (IBay), Pier, Ponds East-West (North Offset C8)
C8	12500	13.8	Mid-Irondequoit Bay (IBay), Pier, Ponds East-West
C9	12500	6.3	Manitou Pier to Ponds North-South
C10	12500	4.8	Pier to North Irondequoit Bay
S1, S2, S3	3300	1.3	Camp Eastman Smile Offsets
S4	3300, 6600	2.5	Camp Eastman Central
S5	6600	2.5	Camp Eastman West Offset
S6, S7	6600	2.5	Camp Eastman Smile Offsets
S8, S9	6600	2.5	Camp Eastman / VanLare Plant
S10	6600	2.5	Irondequoit Bay (North-South) North of Bridge
S11	6600	2.5	Pier to Lake Ontario
S12	6600	2.5	North Irondequoit Bay to Lake Ontario (East-West)
S13	6600	2.5	Pier to Lake Ontario (East-West)
S14	6600	2.5	Eastern Ponds: Buck, Round, Russell Plant
S15	6600	2.5	Western Ponds: Braddock, Cranberry, Long

2.1. Airborne Sensors

The four airborne sensors brings a complementary mix of spatial and spectral capabilities that allow different features and signatures of the Megascene to be imaged. Table 2 summarizes the general characteristics of the airborne sensors flown for the Megacollect campaign. Specifics regarding the COMPASS and SEBASS sensor are detailed by Simi[5] and Hackwell,[6] respectively. To complement the reflective and thermal spectral data produced by these two sensors, RIT also flew the MISI (Modular Imaging Spectrometer Instrument) and the WASP (Wildfire Airborne Sensor Program). The MISI sensor is a research instrument that has modular focal planes allowing the integration of various sensor groupings.[7] Originally fitted with a LWIR focal plane and a VNIR spectrometer in support of LANDSAT thermal calibration and land/water environmental monitoring, it has recently been upgraded to contain a set of SWIR, MWIR, and LWIR to support a fire phenomenology program. Its detectors range from 1–3 milliradians IFOV which translates to approximately 1–3 meter spot sizes

Table 2. Airborne sensors tasked during during Megacollect 2004 and general characteristics.

Instrument	Type	Wavelength Range	Spectral Bands
COMPASS	Spectral	0.350-2.500 [μm]	256
SEBASS	Spectral	7.6-13.5 [μm]	128
MISI	VNIR Spectral	0.4-1.040 [μm]	70
	SWIR Broadband	1.21-2.35 [μm]	6
	MWIR Broadband	3.2-4.1 [μm]	2
	LWIR Broadband	8.3-14.0 [μm]	6
WASP	VNIR Broadband	0.4-0.7 [μm]	3
	SWIR Broadband	0.9-1.7 [μm]	1
	MWIR Broadband	3.0-5.0 [μm]	1
	LWIR Broadband	8.0-9.2 [μm]	1

at an altitude of 1000 meters AGL. Its primary mission is to provide radiometrically accurate data sets and DIRS will be using this collection to assess how well it meets this goal. MISI's coincident collection of spectral images in conjunction with the different broadband images also brings valuable data sets, with minimal spatial and temporal misregistrations. These will be used as one of the standard to which DIRSIG modeling simulations can be compared.

Where MISI emphasizes radiometric integrity, the strong point of the WASP sensor is its high spatial resolution (in several wavelength regions) and the ability to rapidly geolocate its data. At a flying altitude of 3000 meters AGL, the VIS camera has ground spatial resolution of 0.5 meters while the SWIR, MWIR, and LWIR cameras nominally have 3 meters. Great effort has been expended in determining the various orientations of the WASP cameras in its gimbal assembly and position in the aircraft. Along with the information recorded by an Applanix inertial measurement unit (IMU), image mosaics can be rapidly georectified. Based on estimates from Applanix system specifications and nominal uncertainties in DEM knowledge, geolocation accuracies range between 8 to 11 meters for these image maps. Test flights over known ground control points estimate the geolocation accuracies to be approximately 6 meters. These accuracies can be improved using surveyed control points in the scene. This production of a georectified mosaic simplifies its importation into a GIS to serve as the base image for orienting ground truth and image data from the other sensors. It has proven its value in verifying the identity of different targets of interest marginally resolved by the spectrometers. An added validation of material type was also inferred from the SWIR, MWIR, and LWIR channels. The WASP data set also provides an important source of modeling data for DIRSIG. The spatial resolutions in the VIS, SWIR, MWIR, and LWIR WASP imagery can serve "texture" images to appropriately drive the spatial/spectral correlation of a DIRSIG simulation.[8] Comparisons with ground truth measurements and data collected from the other sensors will allow cross-calibrations to be performed and identify sources of errors in the instruments.

2.2. June 5, 2004 Collection

Weather conditions of Saturday, June 5, 2004 (LANDSAT and HYPERION) overpass were marginal with high clouds present in the near shore area of Camp Eastman. Even in the absence of a concurrent COMPASS and SEBASS collection, the high value of the HYPERION/LANDSAT data set prompted the deployment of the ground truth team and standby of RIT's MISI and WASP instruments. Collateral water collections in the nearby embayment also commenced. Regrettably, the decision was made not to fly the RIT sensors due to weather. The opportunity, however, was taken to exercise the ground truth instruments, collection protocols, and collection timings in preparation for better weather conditions.

2.3. June 7, 2004 Collection

The weather conditions in the early morning of June 7, 2004 were nominal prompting a decision to commence the collection. Approximately fifty ground support individuals were deployed in different sections of the Megacollect area both on land and in the water. As the morning progressed hazy conditions ensued with high clouds developing in the afternoon. Conditions at the flight altitudes also became marginal as the day progressed with one of the flight engineers estimating the visibility to be less than five miles. The coordination of four aircrafts flying in close proximity under these conditions proved to be very challenging. Some flight lines were aborted at the pilot's discretion. Collection with the airborne sensors started at approximately 10:30 AM local time and continued until 2:00 PM. Weather instrument measurements, GPS surveys, and general setup commenced at 7:30 AM with spectral measurements starting at 10:00 AM and continuing until 3:00 PM. Non-time critical spectral measurements continued post-flight.

2.4. Ground Instrumentation Summary

This section summarizes the main instruments used to characterize the key features of the scene. A meteorological station was deployed at the Camp Eastman site to monitor local weather conditions and to provide modifiers to the radiosonde profile for input into MODTRAN. In lieu of a locally launched balloon-borne radiosonde, standard radiosonde data from the Buffalo, New York Airport (approximately 80 miles west of this site) was obtained for both the 8:00 AM and 8:00 PM launch.

The sky illumination conditions were also characterized by measuring spectral downwelling radiance (both direct and diffuse) with a stationary ASD instrument fitted with a remote cosine receiver foreoptic. Measurements were made every 5 minutes. To complement the downwelling information, full sky images were recorded with a video camera to spatially and temporally document the formation and progression of clouds over the scene. In addition to these sky measurements, an Eppley pyranometer was also deployed to provide a broadband verification of the spectral data collected by the ASD.

The location of all targets of interest were recorded by GPS and photographed (*cf.* Figure 4). During the overflight period spectral radiance and emissivity measurements were concentrated on the two large calibration targets and the thermal target. Thermal properties for the two main calibration targets, thermal target, and a generator were measured by eight contact thermocouples and were recorded by a datalogger system. These thermal measurements were complemented by a set of staring radiometers recording the apparent temperature radiance of the calibration targets. Reflectance measurements of all targets of interest and the main background materials were made post-flight with field or laboratory instruments (*cf.* Table 3).

Table 3. Field and laboratory spectral instruments used during Megacollect 2004 and general characteristics.

Instrument	**Measurement**	**Wavelength Range**	**Field/Lab**
ASD	Radiance, Irradiance, Reflectance	0.350-2.500 [μm]	Field
D&P 202F	Reflectance, Emittance	2.0-16.0 [μm]	Field
SOC 400T	Reflectance, Emittance	2.0-25.0 [μm]	Lab and Field
Varian Cary 500	Reflectance, Transmittance	0.35-3.5 [μm]	Lab
SOC 100	Hemispherical Directional Reflectance	2.5-25.0 [μm]	Lab

3. TARGETS OF INTEREST

This section highlights several targets that have been deployed to address and exercise a suite of algorithmic, sensor, and basic phenomenology questions. Several calibration and test targets were deployed in the Camp Eastman area and are depicted in Figure 4. A description of some of the experiments are detailed below.

3.1. Target Variation Scenarios

Several targets were placed in the flight lines for use in target detection experiments. The targets were "generic", nylon tarps and were characterized over the VIS/NIR/SWIR spectrum in laboratory measurements using the Cary 500. Roughly half the tarps were "forest green", termed the "low contrast" targets, while the other half were "tan" and called the "medium contrast" targets. A few tarps were bright "orange", or "high contrast". The tarps were eight feet by ten feet in size - roughly the size of two pixels in the 2 meter GSD flights. All target locations were determined through GPS measurements and photographs were taken from the North, South, East, and West to characterize the target surround. The primary goal of the experiments was to place the targets, or modify the targets in ways, that more closely reflect operational target detection problems. To that end, targets were placed under varying illumination conditions, were contaminated with surface materials, or were located in areas of variable clutter.

In the primary experiment field, pairs of the medium and low contrast tarps were placed on a small berm, or embankment, running along the middle of the primary field of regard for the flight-lines. The angle of the berm slope is estimated to be approximately 30 degrees, thus changing the angle of illumination on the targets. Fortunately, the berm is fully contained in the image and runs roughly north-south. Targets were placed on each of the hillsides. The images thus contain targets angled both toward and away from the solar illumination.

Two tarps, one medium contrast and one low contrast, were placed in the open field, but their surfaces were partially covered with dirt taken from the site. The intent was to create a target with surface contamination similar to a “dirty target” in which the mixing between the surface and contaminate is intimate, at least in some places in the target. Dirt was randomly dispersed onto each target until approximately half the target was covered. The reflectance spectrum of the contaminate material was measured in the field. A similar experiment was conducted on the beach north of Camp Eastman.

Generic camouflage netting was acquired and characterized in the laboratory. The netting was set up on support poles over a medium contrast tarp. Additionally, three tarps (one each of the low, medium, and high contrast) were placed in an area of relatively “sparse” tree canopy cover. Photographs of the sky hemisphere over each target were taken to qualitatively characterize the degree of visibility the target had to the sensor.

A small subset of targets were reserved as part of a single-blind data set to objectively test the performance of target detection algorithms. Targets were placed away from the primary experiment field under significantly different clutter conditions. Several targets were placed in the Megascene Tile 1 collection area (*cf.* Figure 2)- an urban residential area containing roads, houses, trees, multi-story buildings, grass, and a large number of other material types. Other targets were placed near the meeting of the Genesee River and Lake Ontario - an area dominated by housing, marinas, and other urban clutter.

3.2. Sensor MTF and Noise Characterization

Another series of ground measurements were designed to collect information about the MTF and noise of the sensors. All of the information was collected with the goal of simulating a sensor in the DIRSIG environment. The main targets were grey and black canvas tarps placed adjacent to each other and are the large calibration targets in Figure 4. A thermal target of heated black rubber roofing material was also placed in the main target field. To characterize the sensor noise, radiance and temperature measurements were taken of these targets throughout the experiment by the ASD, D&P, Exergen (infrared thermometer), and thermocouples. The sensors flew at various altitudes both in the along and cross-track directions in order to capture to capture the MTF in both directions. In addition to the measurements at the Camp Eastman site, temperature measurements were made at the Charlotte Pier where the warm waters of the Genesee River discharge into Lake Ontario. They provide large thermal targets for sensor noise characterization.

Although these experiments were designed to measure the sensor characteristics of WASP, the same data can be applied to the other sensors to update current sensor specifications. These derived parameters can then update the DIRSIG sensor model with realistic operational values.

3.3. SEBASS Spectral Smile Characterization Targets

A set of highly reflective targets were deployed at Camp Eastman to to characterize spectral smile in the SEBASS imagery. These targets are at the bottom of the WASP imagery in Figure 4. They are spatially resolved in the SEBASS imagery and oriented in the cross-track direction of flight lines to characterize spectral smile using atmospheric absorption features.

3.4. Search/Rescue and Fire Phenomenology Targets

To give the data set operational scenarios for target detection algorithms, a few real life targets were deployed. U.S. Coast Guard exposure suits and personal floatation devices were placed along the Lake Ontario shoreline. Likewise, forest firefighter gear (helmet, jacket, and pants) were deployed near the tree line at the Camp Eastman site. All targets were spectrally characterized with both field and laboratory instruments.

A controlled burn was tended on the Lake Ontario shoreline north of Camp Eastman. The objective of this target was to produce a basic data set that can be used to test fire detection algorithms such as the potassium line emission technique.[9] Limited spectral measurements were captured with the ASD to characterize the spectral radiance of the fire.

4. DATA MANAGEMENT

Significant resources have been invested by DIRS to collect and organize extensive metadata during ground truth measurements. This section describes the systems that have been developed both at the point of measurement acquisition and the archiving process of the ground truth data.

4.1. Data Recording: Mobile GIS

DIRS has long recognized the importance of archiving detailed metadata with any spectral measurement. In 2004, as DIRS spectral measurement capabilities expanded, the measurement protocols and metadata archiving was revisited. A new database structure was developed to efficiently handle multiple instruments measuring the same subject, increase flexibility of data searches, and to deliver spectral data via the web. During this restructuring process the NAIC standards[10] for spectral data were referenced to insure compliance. As a result each material measured has 30 metadata fields to describe its physical characteristics and approximately 70 instrument dependent fields that archive the measurement conditions, images, locations and instrument settings.

In order to manage the growing volume of measurements and metadata, it was recognized that the recording efficiency needed to be improved beyond the use of time consuming paper forms. Experience has shown that while diligence may be exercised during the collection of metadata using paper forms, this crucial information is often backlogged at this stage due to the lack of resources and tedium to enter numerous fields of metadata into a database. This transcription of information is also prone to errors that cause unnecessary confusion and requiring additional resources to verify the provenance of the data. This need was solved by technology and the definition of subject taxonomy. The technological solution came through the use of ESRI's ArcPad mobile GIS platform. This package uses a GPS connected to a Pocket PC running ESRI's ArcPad GIS (*cf.* Figure 5). The ArcPad interface was highly customized to record spectral measurement metadata by adding many drop down fields and custom tool buttons. Operationally, when a subject is measured, the location information is automatically recorded from the GPS and plotted on the mobile GIS base image of Camp Eastman. Then the customized forms step the user through the metadata recording process. In adopting this solution, a taxonomic structure was defined to constrain the naming and categorization of all possible subjects that can be measured. Adoption of this classification scheme into the collection protocols resulted in data consistency and increased search efficiency. This system mitigates the ambiguities previously experienced when using ad-hoc naming conventions and descriptions. The system had been under development and Megacollect was an opportunity to operationally test it. Feedback from the collection team has since been incorporated to improve its performance in subsequent collections. This process has tremendously improved the flow of field data into the overall DIRS Spectral Library.

4.2. Data Delivery: Spectral Library

The DIRS measurement team records thousands of spectra annually. In order to manage and disseminate this information, a spectral library database has been developed. The DIRS Spectral Library (*cf.* Figure 6) is a web searchable database that allows a user to make complex searches on the subject and instrument metadata to locate relevant spectral data for their specific application. The search page generates a results page where the user can further select a specific measurement to view its spectra plot, subject images, and all metadata contents. Once the user determines this spectra is suitable for their particular application they may download the spectral data files.

4.3. Future Directions: Data Integration

The Megacollect campaign proved to be a valuable exercise in planning, multi-agency coordination, measurement protocol review, and execution. A centralized GIS will allow post-collect collaboration to continue through data sharing. Future work includes linking the DIRS Spectral Library to an online GIS for a more comprehensive overview and dissemination of ground truth data from the entire Megacollect campaign. The Megacollect generated roughly 102 gigabytes of overhead imagery and another 1 gigabyte of spectral measurements, metadata, and imagery. Efforts are underway to apply standard hyperspectral algorithms to establish baseline performance metrics. DIRSIG spectral simulations of the Megascene are also being updated with ground truth measurements from this collection to increase the fidelity of the simulations. It is anticipated that the performance of these algorithms on the DIRSIG simulated scenes will better match the algorithm performance observed with real imagery.

5. ACKNOWLEDGEMENTS

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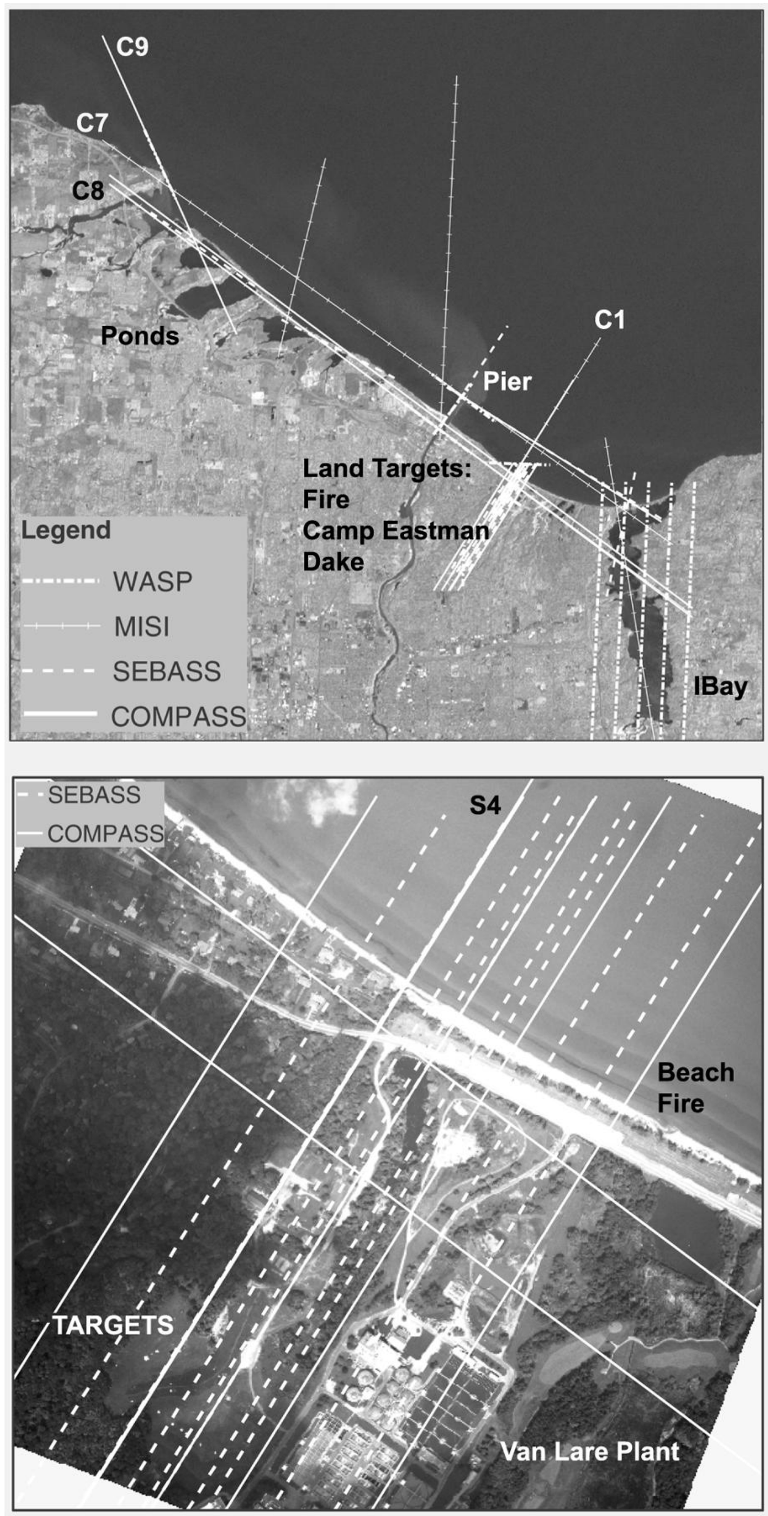

Figure 3. Overview map showing planned flight lines for the Megacollect area. The flight lines in the top figure are overlaid on a LANDSAT-7 base image. Bottom figure shows a zoom of the Camp Eastman area as collected by the WASP sensor on Megacollect.

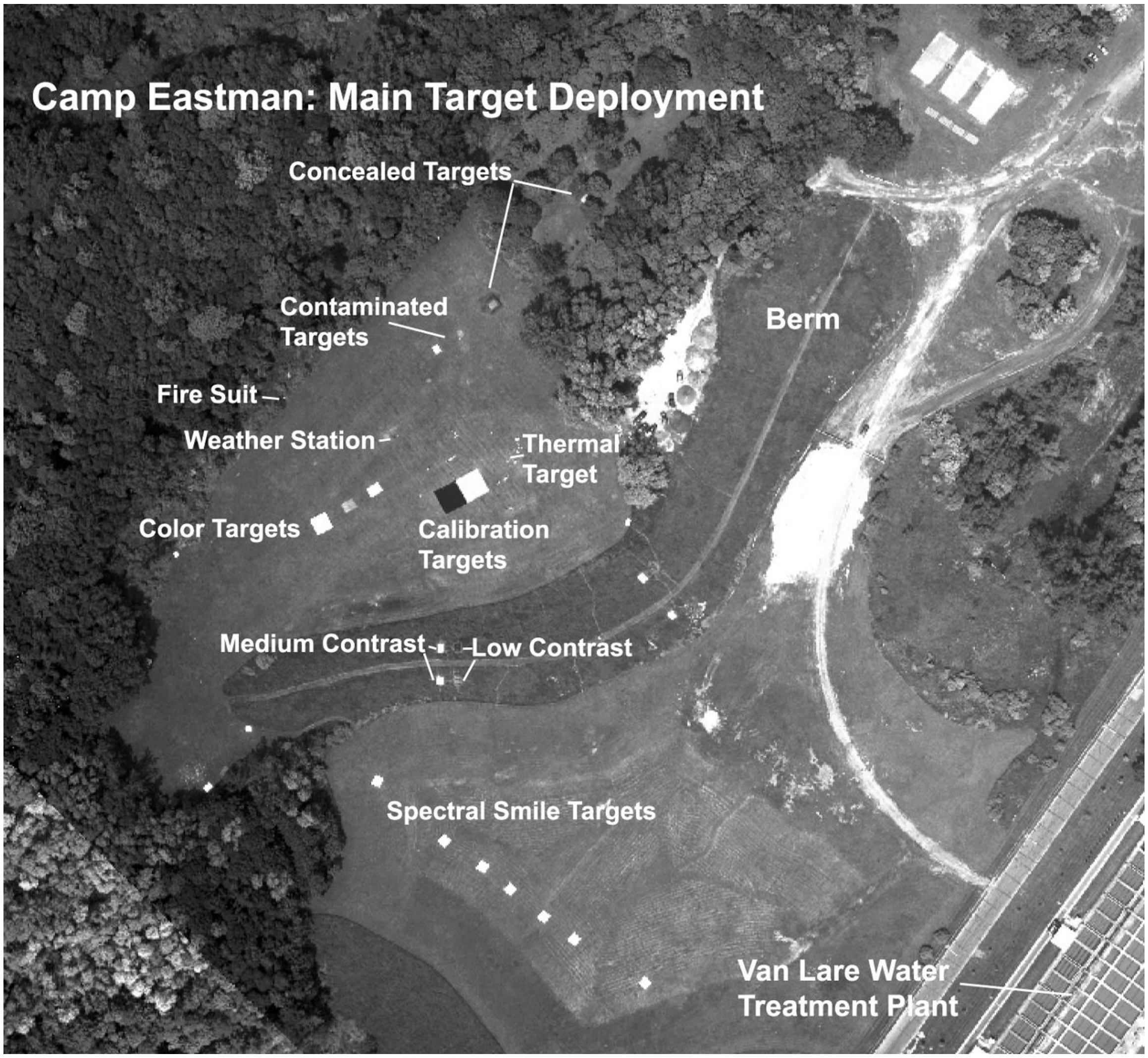

Figure 4. Main Megacollect target deployment area in Camp Eastman as imaged by RIT's WASP Sensor.

Figure 5. ArcPad system used to automatically enter metadata fields to streamline collection process.

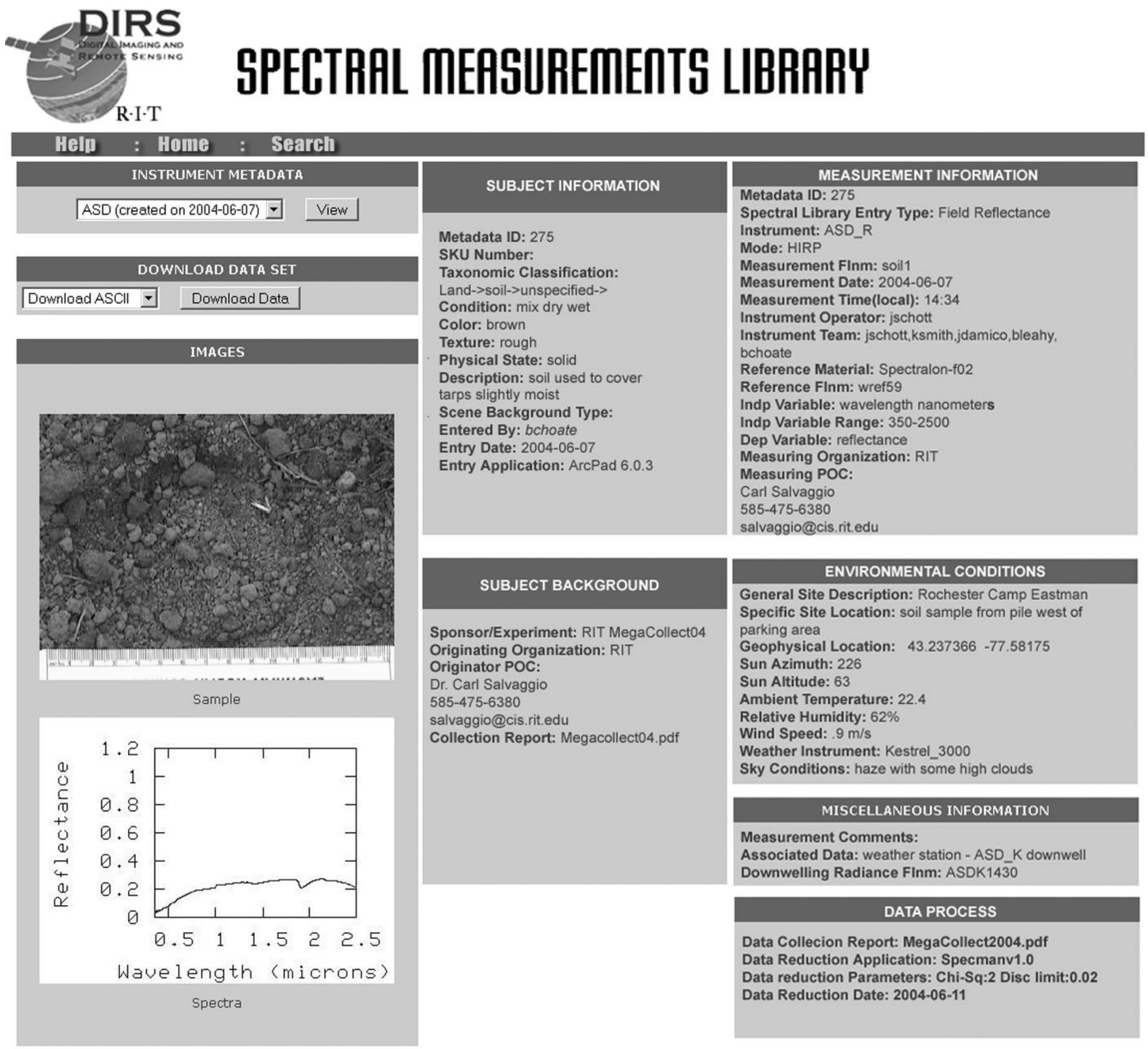

Figure 6. DIRS Spectral Library search results, showing one of the subject images, plot of averaged spectra, and corresponding subject and instrument metadata.