MTI Ground Truth Collection

Ivanpah Dry Lake Bed, California

May, July, and August 2002

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Abstract

A multi-agency collaboration successfully completed a series of ground truth measurements at the Ivanpah Dry Lake bed during FY 2002. Four collection attempts were made: two in May, one in July, and one in August. The objective was to collect ground-based measurements and airborne data during Multispectral Thermal Imager satellite overpasses. The measurements were to aid in the calibration of the satellite data and in algorithm validation. The Remote Sensing Laboratory, Las Vegas, Nevada; the National Aeronautics and Space Administration; Los Alamos National Laboratory; and the University of Arizona participated in the effort. Field instrumentation included a sun photometer on loan from the University of Arizona and the Remote Sensing Laboratory's radiosonde weather balloon, weather station, thermal infrared radiometers, and spectral radiometer. In addition, three reflectance panels were deployed; certain tests used water baths set at two different temperatures. Local weather data as well as sky photography were collected. May presented several excellent days; however, it was later learned that tasking for the satellite was not available. A combination of cloud cover, wind, and dusty conditions limited useful data collections to two days, August 28 and 29. Despite less-than-ideal weather conditions, the data for the Multispectral Thermal Imager calibration were obtained. A unique set of circumstances also allowed data collection during overpasses of the LANDSAT7 and ASTER satellites.

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Acronyms

ADAS	Atmospheric Data Acquisition System
AFB	Air Force Base
ASD	Analytical Spectral Device
DOE	U.S. Department of Energy
LANL	Los Alamos National Laboratory
LWIR	longwave infrared
MTI	Multispectral Thermal Imager
MUG	MTI Users Group
MWIR	midwave infrared
NASA	National Aeronautics and Space Administration
NNSA	U.S. DOE National Nuclear Security Administration
PC	personal computer
PDT	Pacific Daylight Time
PIR	pyrgeometer
PSP	pyranometer
R&D	research and development
R&E	research and engineering
RH	relative humidity
RSL	Remote Sensing Laboratory
SWIR	shortwave infrared
TIR	infrared thermometer
U of A	University of Arizona
WMD	Weapons of Mass Destruction

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Weekly Summaries

Introduction

The U.S. Department of Energy (DOE), National Nuclear Security Administration (NNSA), Office of Nonproliferation Research and Engineering, NA-22, requested the support of the Remote Sensing Laboratory (RSL) –Nellis of Las Vegas, Nevada, in collecting ground truth measurements for the Multispectral Thermal Imager (MTI) satellite program. Los Alamos National Laboratory (LANL) leads the scientific portion of the project and will provide all necessary guidance with NA-22 approval. This report will describe the MTI program and the collection location, requirements, and daily summaries of the RSL Field Team.

RSL Operations Plan

Ground Truth - Objectives

The Remote Sensing Laboratory will provide environmental measurements to aid in the calibration of MTI satellite data and algorithm validation. This may include atmospheric, meteorological, and radiometric measurements in the field or in the laboratory. Additionally, ground and airborne data will be collected, as required, to assess system performance and site variability. Data will be provided to the appropriate users. Data collection may include collaboration with other NNSA laboratories, government agencies, and universities, depending on the objectives of the experiment. Assessment of collection techniques, calibration procedures, and new equipment and instrument designs will be ongoing to ensure accurate, reliable, and repeatable measurements.

Site Selection - Reflectance

The Ivanpah Dry Lake bed in California is the primary site for the reflectance section of the satellite calibration. RSL-Nellis is working with the University of Arizona (U of A) to use the site at the Ivanpah Dry Lake bed. Ivanpah is located about 50 miles southwest of Las Vegas, at the intersection of Interstate 15 and the California/Nevada border, near the town of Primm, Nevada, Figure 1.

Figure 1. Ivanpah Dry Lake bed location.

Site Selection - Thermal

The Ivanpah Dry Lake bed is a secondary thermal calibration site. The surface variability of the site must be measured for the site to be useful for thermal calibrations. RSL will participate in thermal calibration as required.

Instrument Requirements

RSL owns and maintains the following instruments and equipment:

- Truck, trailer, and vans for transport and collection of personnel and instruments
- Weather station
- Spectroradiometer
- Radiometers
- Sky camera
- Radiosonde system
- In-scene calibration panels
- In-scene water baths

RSL proposes a Monday-to-Friday collection week with Monday and Friday scheduled for travel, setup, and teardown. Collection days will be Tuesday, Wednesday, and Thursday. During the weeks of satellite coverage, the schedule may be modified to accommodate the overpass. RSL will prepare and deploy for the collection site on Monday of the collection week. The setup of instruments will begin and data will be logged for the weather station. The sampling grid will be laid out to acquire point measurements over a large area to ensure that the data from the radiometers and spectral radiometers are representative of the satellite resolution. The importance of the sampling grid should not be underestimated. The data will be recorded from the radiometers and the spectral radiometers over time to span the satellite overpass. A typical week will use Friday as a travel day back to RSL at Nellis Air Force Base, Las Vegas, Nevada.

The typical collection scenario will take place from Tuesday to Thursday. A radiosonde will be released approximately 15 minutes before overpass. This will overlap with the time of overpass, as it usually requires 60 minutes for the radiosonde to reach maximum altitude. A 35mm fisheye sky camera with an intervalometer and 36-exposure roll will be started 15 minutes before an overpass. The intervalometer will be set for one-minute exposures and will provide visual documentation of the sky conditions during the overpass.

A sun photometer on loan from the U of A will be used in the atmospheric correction section of the experiment. Ground control and in-scene reflectance targets will be provided by the placement of reflectance panels in the area. Water baths will be deployed in the scene when conditions permit. The layout of the calibration site is shown in Figures 2 and 3. Data that will be useful for calibration from the four collection periods are presented on CD in Appendix A.

Figure 2. Layout of calibration site at the Ivanpah Dry Lake bed.

Figure 3. Aerial view of the calibration layout.

Weekly Collection Summaries

13 – 17 May 2002

The RSL Field Team departed for the Ivanpah Dry Lake bed on Monday, May 13. The tasking was for daytime satellite passes at about 1130 PDT (Pacific Daylight Time) for Wednesday, Thursday, and Friday, 15-17 May.

Monday was a relocation and a setup day, as seen in Figure 4. Tuesday was scheduled to finish the setup and begin checking the instruments. Checkout was completed on Wednesday before the overpass. The satellite tasking for MTI was cancelled due to poor weather. The main problem was high clouds in the area. The satellite tasking for Thursday was also scrubbed due to weather. Friday, a backup day, was also cloudy. The MTI tasking was scrubbed until the following week. On Friday, the equipment and instruments were removed from the lake bed. The weather forecast indicated a good chance of thunderstorms over the weekend. The lake bed would be impassable if it received any significant amount of rain. By permit with the U.S. Bureau of Land Management, all test articles must be removed during inclement weather. May 18-19 were scheduled down days. The customer requested an additional deployment for ground truth collection.

Figure 4. Field Team member sets up the sun photometer.

20 – 25 May 2002

Thunderstorms forecast for earlier in the week did not arrive until Sunday, 19 May. A considerable amount of rain dropped on the lake bed, leaving significant areas of standing water and nearly saturated areas on the lake bed on Monday. Under such conditions, access to the lake bed was not permitted.

The second deployment took place on Tuesday. The site was resurveyed and the equipment and instruments deployed. The instruments were checked on Wednesday.

Weekly Summaries

The first MTI tasking, for Thursday, was scrubbed due to weather (high clouds). Figure 5 shows a cloudy sunrise at Ivanpah. The RSL Field Team collected a complete set of ground truth on Friday. It was learned later that there was no MTI tasking, *i.e.*, no satellite imagery. A NASA-Ames airborne multispectral scanner, MASTER, was flown on Friday in preparation for the satellite pass. Future projects may call for a MASTER underflight in conjunction with the MTI pass. The Saturday backup day was also scrubbed due to weather.

Figure 5. Sunrise over the Ivanpah Dry Lake bed.

The RSL Field Team packed all equipment and instruments and returned to Nellis Air Force Base (AFB) on Saturday.

29 July – 2 August 2002

The RSL Field Team relocated from Nellis AFB to the Ivanpah Dry Lake bed on Monday, 29 July. The Team began site survey and equipment setup for collection on July 31. On Tuesday, the remainder of the equipment was set up and checked. The Team conducted a dry run for the nighttime/daytime collection on July 31.

The Wednesday collection was scrubbed due to poor weather conditions, mainly clouds which restricted the pointing accuracy of the MTI satellite.

The Thursday collection was scrubbed due to tasking conflicts with other MTI satellite users. Collection scheduled for Friday was scrubbed due to tasking conflicts with other MTI satellite users. Equipment was torn down and packed. The Team returned to Nellis AFB. The customer is planning to reschedule in late August and possibly late September.

25 – 30 August 2002

25 August, Sunday

The equipment and trailer pickup were relocated to the Ivanpah Dry Lake bed area; personnel arrived in the evening. The first MTI tasking was planned for daytime on Tuesday. In order to conform to past collections that collected data at least 24 hours prior to an overpass, it was necessary to set up very early on Monday morning.

26 August, Monday

All equipment and personnel were relocated to the experiment site and setup began, as seen in Figure 6. The satellite tasking called for a daytime/nighttime collection series with Tuesday daytime as the first collection. All daylight instruments were put out first; the nighttime instruments were deployed later. The 24-hour period prior to data collection is important for historical records and to document any significant anomalies.

Figure 6. Field Team builds water baths.

The standard field setup was maintained, and atmospheric, meteorological, and radiometric instruments were deployed. Atmospheric instruments included the solar photometer, shadow band (diffuse solar irradiance), direct solar irradiance, and down-welling irradiance. A radiosonde weather balloon was used to record air temperature, relative humidity, and barometric pressure from the surface to about 50,000 feet. Meteorological instruments and measurements include a surface weather station with air temperature, relative humidity, wind speed/direction, and surface temperature. Radiometric measurements include thermal infrared radiometers for surface temperature and spectroradiometers readings for reflectance

Weekly Summaries

in the visible, near, and short-wave infrared, as can be viewed in Figure 7. The Lead on the Los Alamos National Laboratory (LANL) Science Team was kept advised of the RSL Field Team's progress.

Figure 7. RSL/LANL Field Team measures reflectance.

27 August, Tuesday

This first day for MTI satellite tasking began with high, thin clouds with thicker cloud bands in between. These conditions were very poor for data collection due to the large amount of atmosphere between the satellite and the ground. The LANL Science Team notified the RSL Field Team that the tasking was postponed for the daytime collection due to the sky conditions. The nighttime collection was also cancelled due to the atmospheric conditions and the pointing accuracy of the system at night. Data collections were planned for Wednesday, Thursday, and Friday.

28 August, Wednesday

The day started with an almost perfectly clear sky. There were no visible clouds, condensations trails from aircraft, or smoke and haze from forest fires in California. The day continued to be nearly perfect and all data were collected as planned except for the reflectance data from the spectrometer. This instrument had been recently upgraded and calibrated. Unfortunately, an outdated software package left in the instrument created problems with the spectral collection. Correction of the data collected is being evaluated. The software package was updated on site and the instrument functioned properly. Satellite tasking was on schedule and the ground data collected were excellent, except for that noted above. The MTI Science Team was notified of the excellent weather and the equipment problem.

29 August, Thursday

Again the day started with excellent visibility and no clouds, haze, or smoke. The day's collection went well except for the radiosonde. The RSL Field Team discovered a bad transmitter in the first radiosonde; the balloon on the second radiosonde was faulty. By the time the problems were corrected, the satellite window had passed. All other data were collected. The initial assessment of the data was excellent. Friday was scheduled as a backup day. The MTI Science Team left the decision about the ground truth collection to the RSL Field Team. The LANL Science Lead was notified of the excellent weather and the equipment problem. Refer to Figure 8 to view a natural-color composite taken by the MTI at about 360 miles. Figure 9 is a closeup view of Figure 8, in which the calibration site can be seen.

Figure 8. MTI natural-color composite of the Ivanpah Dry Lake bed, August 29, 2002.

Weekly Summaries

30 August, Friday

The final day began with a high thin, overcast. The surface winds and sky conditions were not conducive for collection of good data. The decision was made to scrub. The equipment and instruments were torn down and packed for transit. The MTI Science Team was notified of the scrub and the teardown.

This week proved to be a good one for data collection, as two of the five days were excellent for weather and tasking. Refer to Figures 10-15 for a sampling of sky photos taken with a fish-eye lens from the May, July, and August collection periods. The two minor ground truth problems are being assessed. The spectral data may be retrievable or perhaps the weather conditions were so good that these data may not be needed for calibration. The problem with the radiosonde may be overcome using the atmospheric correction from the sun photometer data. The next set of collections is scheduled for the fall, with one opportunity in October and one in November.

Sky Photo Documentation

Figure 10. May 15, 2002

Figure 13. August 27, 2002

Figure 11. May 24, 2002

Figure 14. August 28, 2002

Figure 12. July 19, 2002

Figure 15. August 29, 2002

An Introduction to the Department of Energy's Multispectral Thermal Imager (MTI) Project Emphasizing the Imaging and Calibration Subsystems¹

Introduction

This paper will introduce readers to the Department of Energy's (DOE's) Multispectral Thermal Imager (MTI) project with emphasis on the payload imaging and calibration subsystems. MTI is a Research and Development (R&D) project, sponsored by DOE's Office of Nonproliferation and National Security and executed by Sandia National Laboratories, Los Alamos National Laboratory and Savannah River Technology Center. Other government participants include the Air Force Research Laboratory, the National Institute of Standards and Technology and the Air Force Space Test Program, which is funding and managing the launch. Major industry participants include Ball Aerospace, Raytheon Optical Systems, Santa Barbara Research Center and TRW. More than fifty government, private and academic organizations are involved in the development. The satellite is scheduled to launch in the fall of 1999 from Vandenberg Air Force Base on an Orbital Sciences Corporation Taurus Launch Vehicle.

DOE's primary objective for MTI is to develop and evaluate advance multispectral and thermal imaging, image processing and associated technologies for detecting and characterizing nuclear and other Weapons of Mass Destruction (WMD) facilities. To achieve this objective, the project will launch and operate a satellite with an advanced multispectral pushbroom imaging payload, capable of imaging sites in 15 spectral bands, ranging from visible to long-wave infrared, with extremely accurate radiometry:

The project combines and advances five technologies:

- 1) Multispectral imaging
- 2) Thermal imaging
- 3) Advanced radiometric calibration
- 4) Atmospheric characterization
- 5) Modeling and analysis

Advances in these technologies, together with the experimental data MTI will provide, are needed to develop more capable treaty monitoring systems.

During its three year mission, the MTI satellite will periodically record images of participating government, industrial and natural sites in fifteen visible and infrared spectral bands. These bands are selected to provide a broad range of data on potential proliferant facilities, including surface temperatures, materials, water quality, and vegetation stress. To achieve thermometric and reflectance accuracies required by the mission, the system also includes bands selected to collect simultaneous information on

¹ R. Rex Kay, Paul G. Weber. *Proceedings*, 12th AIAA/USU Conference on Small Satellites.

the intervening atmosphere, such as column water vapor, aerosol content and subvisual clouds. The combination of spectral bands, very accurate radiometry and good spatial resolution make MTI unique among current and planned space-based imaging systems. Participating sites will be instrumented to record ground truth data to permit investigators to compare, analyze, and validate satellite images against ground truth. MTI is a complex, comprehensive research and engineering (R&E) project that emphasizes up-front modeling and analysis, experimentation and data analysis.

MTI technology has a broad range of national security and civilian applications in addition to treaty monitoring. To ensure the nation realizes maximum benefit from this multi-use potential, DOE has organized an MTI Users Group (MUG) with over 100 members representing over forty national defense and civilian organizations. MUG members advise DOE on multi-use objectives and will conduct their own experiments utilizing MTI images. MUG membership is open to government sponsored investigators who desire to utilize MTI imagery for R&E in the national interest.

System Overview

The system includes a single satellite in a circular, sunsynchronous (1:00 AM/1:00 PM) orbit, initially injected at 575 kilometers, a ground station and operations center located in Albuquerque and a Data Processing and Analysis Center located in Los Alamos.

The satellite will autonomously collect, compress and store six 2-look, 15-band, 12 x 12 kilometer images per day. During each of two daily passes over the ground station, the system will downlink image data and uplink a new target list. Raw image data will be forwarded to the Data Processing and Analysis Center where it will be processed and converted to standard data products and distributed to various experimenters. The satellite has no propulsion system so the orbit will decay as the mission progresses, and the orbit plane will drift about one hour over three years.

The project is also developing advanced computerized site, atmospheric transport and system models, which have been employed in the system design and will be used in the analysis of project data.

Major system performance goals are:

Spectral Bands. Visible, shortwave infrared (SWIR), midwave infrared (MWIR), and longwave infrared (LWIR), as found in Table 1.

Table 1 Spectral bands and band-dependent specifications		
Band	Wavelength Range (microns)	GSD (meters)
A	0.45 – 0.52	5
B	0.52 – 0.60	5
C	0.62 – 0.68	5
D	0.76 – 0.86	5
E	0.86 – 0.90	20
F	0.91 – 0.97	20
G	0.99 – 1.04	20
H	1.36 – 1.39	20
I	1.55 – 1.75	20
J	3.50 – 4.10	20
K	4.87 – 5.07	20
L	8.00 – 8.40	20
M	8.40 – 8.85	20
N	10.20 – 10.70	20
O	2.08 – 2.35	20

Field of View: 12 x 12 km (nominal)
Field of Regard: ± 200 km from ground track
Geographic Coverage: All CONUS sites covered
Pointing Accuracy: ± 0.25 degrees
Temporal coverage: Average site revisit time is 7 days at 1300 or 0100 hours:
 ± 1 hour
View angles: 2-look, one nadir and another at 50-55 degrees off nadir

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Instrumentation

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Weather Station

Manufacturer

Campbell Scientific, Inc.

Models

CR21X Micrologger

SM192 Data Storage Module

Specifications

Configured to measure:

- Air Temperature
- Relative Humidity
- Surface Ground Temperature
- Subsurface Temperature
- Wind Speed
- Wind Direction
- Global Irradiance
- Global Down-Welling Radiance

Description

The Campbell Scientific portable weather station features the CR21X Micrologger precision datalogger. The CR21X is small, self-powered and can operate under extreme weather conditions. Data are collected in the SM192 Data Storage Module and processed in real time for linearization, algebraic functions, unit scaling, averaging, maximum and minimum values, totals, standard deviation, and histograms. Data are normally collected continuously twenty four hours a day, at two-second intervals, and averaged over five minutes.

The weather station may be mounted either on the ground using a seven-foot tripod or mounted on the roof of a towable trailer used for field data reduction and analysis. Data listings and graphs may be generated during data collection, if desired, while operating out of the trailer.

Sample Data

Ground Temp. (Celsius)	Wind Direction (degrees)	Air Temp. (Celsius)	Pyranometer (watts/m ²)	Pyrgeometer (watts/m ²)	Relative Humidity	Wind Speed (meters/sec)	Barometer (millibars)
15.54	347.60	10.34	693.00	289.30	28.23	6.05	931
15.54	345.70	10.34	693.30	289.30	29.23	6.45	931
15.54	346.80	10.34	693.70	289.30	28.63	6.85	931
15.54	353.90	10.41	693.30	289.30	28.70	7.65	931
15.53	356.60	10.41	693.00	289.30	28.83	7.25	931
15.54	359.20	10.41	693.30	288.50	28.10	6.85	932
15.55	356.10	10.47	693.30	287.70	27.43	7.65	932
15.53	357.60	10.41	693.30	287.70	26.24	8.05	931
15.54	355.20	10.41	693.30	286.90	24.97	7.65	931
15.52	0.98	10.41	693.30	286.90	25.17	7.25	931

Air Temperature and Relative Humidity

Manufacturer

Campbell Scientific, Inc.

Model

207

Specifications

	Air Temperature (°C)	Relative Humidity (%)
Resolution:	0.01	0.01 %
Accuracy:	± 0.2	5%
Range:	-30 to +60	10% to 97%

Air Temperature and Relative Humidity

Description

The Model 207 air temperature and relative humidity (RH) combined sensor is normally mounted on the weather station tripod at a height of four feet. The probe contains a Phys-Chemical Research Corp. PCRC-11 RH sensor and a Fenwal Electronics UUT51J1 thermistor. A 41004-5 12-Plate Cell Radiation Shield houses the probe for protection against damage.

Temperature is acquired through a CR21X Micrologger. AC excitation is applied across the probe thermistor and the single-ended voltage is measured. The value is calculated to a fifth-order polynomial; a multiplier and offset then yields temperature in degrees C. RH data are obtained in the same manner; the CR21X performs the required temperature compensation. Temperature and RH data are stored in an SM192 Storage Module.

Air temperature and RH values are normally sampled every two seconds, averaged, and recorded every five minutes. Typically, the data are collected continuously from station setup, usually at least twenty-four hours prior to the overpass or experiment, until mission completion.

The overall accuracy of the probe is typically less than ± 0.4 °C error for normal temperature environments (-33 °C to +48 °C) and a $\pm 5\%$ RH error over a 12% to 100% range.

Sample Data

Ground Temp. (Celsius)	Wind Direction (degrees)	Air Temp. (Celsius)	Pyranometer (watts/m ²)	Pyrgeometer (watts/m ²)	Relative Humidity	Wind Speed (meters/sec)	Barometer (millibars)
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15.54	353.90	10.41	693.30	289.30	28.70	7.65	931
15.53	356.60	10.41	693.00	289.30	28.83	7.25	931
15.54	359.20	10.41	693.30	288.50	28.10	6.85	932
15.55	356.10	10.47	693.30	287.70	27.43	7.65	932

Surface and Subsurface Ground Temperature

Manufacturer

Campbell Scientific, Inc.

Model

107

Specifications

Accuracy:	+0.2 °C
Resolution:	0.10 °C
Range:	-33 C to +48 °C

Surface and Subsurface Ground Temperature

Description

The Model 107 temperature probe for use in air or soil incorporates the Fenwal Electronics UUT51JI Thermister with a standard lead of either ten or twenty-five feet. Different temperature probes are used in low and high-temperature range environments.

Temperature is acquired through a CR21X Micrologger. AC excitation is applied across the probe thermister, and the single-ended voltage is measured and linearized to a fifth order polynomial to output temperature in degrees C. Temperature data are stored in an SM192 Storage Module. The CR21X is powered by a D-cell battery.

Two probes are typically used; one probe lies on the soil surface and the second is inserted about ten millimeters below the soil surface. Soil surface and subsurface temperatures are normally acquired at two-second intervals and averaged every five minutes. Usually the data are collected continuously from station setup, usually at least twenty-four hours prior to the overpass or experiment, until mission completion.

Sample Data

Ground Temp. (Celsius)	Wind Direction (degrees)	Air Temp. (Celsius)	Pyranometer (watts/m⁻²)	Pyrgeometer (watts/m⁻²)	Relative Humidity	Wind Speed (meters/sec)	Barometer (millibars)
15.54	347.60	10.34	693.00	289.30	28.23	6.05	931
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15.53	357.60	10.41	693.30	287.70	26.24	8.05	931
15.54	355.20	10.41	693.30	286.90	24.97	7.65	931

Wind Speed and Wind Direction

Wind Speed

Wind Direction

Manufacturer

Campbell Scientific, Inc.

Models

Met-One 014A Anemometer

Met-One 024A Wind Vane

Specifications

	Anemometer	Wind Vane
Calibrated Range:	0 - 45 m/s	(0-100 mph) 0 - 360
degrees		
Accuracy:	1.5 % or 0.11 m/s	(0.25 mph) ± 5
degrees		
Temperature Range:	-50 °C to +70 °C	-50 °C to +70 °C
Threshold:	0.45 m/s	(1 mph) 0.477 m/s (1.0 mph)

Wind Speed and Wind Direction

Description

The Met-One 014A three-cup anemometer uses a magnet-activated read switch with a frequency proportional to wind speed. As the cup assembly rotates on the shaft, the turning magnet causes the read switch to momentarily close. The number of closures occurring during a given time is measured. A multiplier and offset are entered for automatic calculations and output of wind speed in miles per second (m/s) or miles per hour (m/hr).

The Met-One 024A Wind Vane measures wind direction by using a potentiometer to vary the sensor resistance in relation to wind direction. A multiplier (360/full-scale input voltage) is determined and used in the conversion of the voltage output to wind direction. For orientation, the vane must be physically aligned to true north.

Wind speed and wind direction are acquired through a CR21X Micrologger. Data are typically sampled every two seconds, and averaged and recorded every five minutes. A battery-powered SM192 Storage Module stores the collected data until they can conveniently be downloaded.

The sensors are normally mounted on the weather station tripod at a height of about seven feet. Typically the data are collected continuously from station setup, usually at least twenty-four hours prior to the overpass or experiment, until mission completion.

Sample Data

Ground Temp. (Celsius)	Wind Direction (degrees)	Air Temp. (Celsius)	Pyranometer (watts/m ²)	Pyrgeometer (watts/m ²)	Relative Humidity	Wind Speed (meters/sec)	Barometer (millibars)
15.54	347.60	10.34	693.00	289.30	28.23	6.05	931
15.54	345.70	10.34	693.30	289.30	29.23	6.45	931
15.54	346.80	10.34	693.70	289.30	28.63	6.85	931
15.54	353.90	10.41	693.30	289.30	28.70	7.65	931
15.53	356.60	10.41	693.00	289.30	28.83	7.25	931

Solar Irradiance and Down-Welling Radiance

Manufacturer

The Eppley Laboratory,
Inc.

Model

PSP Precision Pyranometer
PIR Precision Infrared
Radiometer (Pyrgeometer)

Specifications

	PSP	PIR
Wavelength Range:	0.3 μm - 3.0 μm	4.0 μm - 50.0 μm
Sensitivity:	9 μV per Watt/ m^{-2}	4 μV per Watt/ m^{-2}
Linearity:	$\pm 0.5\%$ from 0 to 2800 Watt/ m^{-2}	
Linearity:		$\pm 1\%$ from 0 to 700 W m^{-2}
Temperature Dependence:	$\pm 1\%$, -20 $^{\circ}\text{C}$ to +40 $^{\circ}\text{C}$	$\pm 1\%$, -20 $^{\circ}\text{C}$ to +40 $^{\circ}\text{C}$
Response Time:	1 sec (1/e signal)	2 sec (1/e signal)

Solar Irradiance and Down-Welling Radiance

Description

The Eppley pyranometer (PSP) and pyrgeometer (PIR), when used as elements of the Campbell Scientific weather station, permit precise and continuous measurement and recording of solar radiation components. Both sensors are comprised of wire-wound thermopile detectors under hemispherical glass domes. Incoming radiation is filtered or blocked to pass only the desired wavelengths.

The PSP may be mounted upward-looking for global irradiance, or two PSPs may be mounted back-to-back for net radiance and/or albedo measurements. The PIR measures down-welling atmospheric radiance.

The solar instruments are normally deployed in conjunction with the weather station. The data are sampled every two seconds, averaged, and recorded (in Watts/m²) to a CR21X Micrologger at five-minute intervals throughout the survey period. A PSP pyranometer is also deployed with the shadow-band stand for diffuse solar irradiance measurements.

Sample Data

Ground Temp. (Celsius)	Wind Direction (degrees)	Air Temp. (Celsius)	Pyranometer (watts/m²)	Pyrgeometer (watts/m²)	Relative Humidity	Wind Speed (meters/sec)	Barometer (millibars)
15.54	347.60	10.34	693.00	289.30	28.23	6.05	931
15.54	345.70	10.34	693.30	289.30	29.23	6.45	931
15.54	346.80	10.34	693.70	289.30	28.63	6.85	931
15.54	353.90	10.41	693.30	289.30	28.70	7.65	931
15.53	356.60	10.41	693.00	289.30	28.83	7.25	931
15.54	359.20	10.41	693.30	288.50	28.10	6.85	932
15.55	356.10	10.47	693.30	287.70	27.43	7.65	932
15.53	357.60	10.41	693.30	287.70	26.24	8.05	931

Meteorological Radiosonde Balloon

Manufacturer

Atmospheric Instrumentation Research, Inc.

Model

AS-3A-403 Airsonde Transmitter

Specifications

	Resolution	Accuracy	Range
Air Temperature:	0.01 °C	±0.5 °C	-50 °C - +80 °C
Relative Humidity:	0.01 %	5%	20 % - 100 %
Air Pressure:	0.1 mb	3.0 mb	1,050 mb - 250
mb			
Altitude:	1.0 foot	±2.5%	0 - 50,000 feet

Meteorological Radiosonde Balloon

Description

The sonde consists of a temperature thermistor, carbon hygistor, battery, pressure transducer, data encoder, and radio transmitter encased in a Styrofoam box. The package, as it is carried aloft by the helium-filled balloon, telemeters meteorological data every five to six seconds from each sensor to the ground-based ADAS (Atmospheric Data Acquisition System) where the data are processed and displayed in real-time. The altitude is derived from radiosonde measurements, through the hydrostatic equation, and then stored to a personal computer (PC) or storage module. In addition to the meteorological data, local time, elapsed time, and date are also automatically recorded.

A balloon will usually ascend at about 1000 feet per second and send continuous signals for about one hour.

Sample Data

Sequence Number	MDDYY	HHMMSS	Elapsed Time	Air Temp. (Celsius)	Relative Humidity	Barometer (millibars)	Altitude (meters)
5	31902	100049	2	11.00	17.30	934.00	811
6	31902	100054	7	11.50	17.30	934.00	811
7	31902	100059	11	11.10	17.10	933.80	813
8	31902	100104	16	10.30	17.10	930.40	842
9	31902	100108	21	9.90	17.00	926.90	874
10	31902	100113	26	9.40	17.10	923.50	905
11	31902	100118	30	9.30	17.10	920.60	930
12	31902	100123	35	8.90	17.00	917.20	960
13	31902	100127	40	8.80	17.10	914.40	986
14	31902	100132	45	8.60	17.00	912.10	1007
15	31902	100137	49	8.40	16.70	909.00	1035
16	31902	100142	54	8.20	16.70	905.90	1063
17	31902	100147	59	8.10	16.70	902.80	1091
18	31902	100151	104	7.80	16.70	900.50	1112

Sky and Site Photo Documentation

Manufacturer

Nikon Corporation

Model

F4s 35mm Camera
8-mm (fisheye) lens
MF-23 Multi-Control
Camera Back

Description

The Nikon F4 camera and "fisheye" lens system is a high-quality, automated method for documenting sky conditions during an aerial data acquisition or ground survey. Since clouds and cloud shadows interfere with most types of remotely sensed data collection, a visual account of the cloud status horizon to horizon aids greatly in post-mission data interpretation.

The rate of photo collection is tailored to meet the needs of the particular mission, limited only by the frames per roll of film before reloading. The Nikon F4 can operate with shutter speeds up to 1/8000 of a second and film advance up to 5.7 feet per second. The Nikon MF-23 camera back imprints the frame, time, and data automatically. A typical setup will start 15 minutes before an aircraft/satellite overpass and collect at one-minute intervals. A 36-shot roll of film allows for post-sky coverage during the collection.

Site documentation is generally collected with a second 35mm, 70mm, or digital camera during a relatively slow period of data acquisition. Photos of specific instruments and of the general layout of ground instrumentation are acquired from several angles. Typical ground cover and terrain photos, including areas of soil or radiometric sampling, can be invaluable during subsequent analysis.

Sky and Site Photo Documentation

Sample Data

Reflectance Targets

Manufacturer

General Image Engineering Corporation

Model

DRT-8607/20 Dual-Role Gray Scale

RST-7612 (15' x 25')

RST-7614 Tri-Bar (6' x 9')

Description

The six-step, dual-role gray scale is used to quantify the radiometric qualities of the multispectral scanner. The tri-bar targets are used both to determine and verify spatial resolution for sensor characterization during data acquisition. The resolution of the instrument is defined as the frequency at which the bars are "resolvable" in the image.

The dual-role targets are a series of six, twenty-foot by twenty-foot panels with levels of reflectivity in the visible/near-infrared (IR) spectral region in an arithmetic progression of 2 %, 12 %, 24 %, 36 %, 48 %, and 60 % average reflectance. The 2 %, 12 %, and 24 % panels are also detectable in the 3/ μm - 5/ μm and the 8/ μm - 14/ μm thermal IR spectral regions.

During this collection, the 2 %, 12 %, and 24 % panels were deployed.

Sample Data

Shadow Band Diffuse Irradiance

Manufacturer

The Eppley Laboratory,
Inc.

Model

PSP Pyranometer
SBS Shadow Band Stand

Specifications

Detector	Circular multi-junction thermopile, plated (copper-constantan), wire wound type
Receiver	Circular 1 cm ² coated with Parsons' black optical lacquer, surmounted by a glass hemisphere
Wavelength Range	0.3 μm to 3.02 μm
Temperature Dependence	$\pm 1\%$ over ambient temperature range
Linearity	$\pm 0.5\%$ from 0-2800 Watt/m ⁻²
Power Requirements	8 E-cell batteries
Field of View	180°
Sensitivity	9 mv per Watt/m ⁻²
Impedance	650 ohms
Response Time	1 second

Description

The shadow band pyranometer permits continuous measurement of the diffuse component of solar irradiance in the 0.3 μ m - 3.02 μ m region by shielding the sensing element of the pyranometer from direct solar radiation and correcting for the portion of sky screened by the band. If the diffuse pyranometer measurement is subtracted from the weather station sensor (also a PSP pyranometer), the direct component of solar irradiance may be calculated.

The unit is field portable for operations where precise measurements of sky conditions at the target location are required. The shadow band stand is the standard model for latitudes 0-60 degrees North or South. Constructed for harsh environments, the stand is approximately two feet wide and weighs 75 pounds.

The sky radiation data (in Watts/m²) are usually sampled every two seconds, averaged and recorded at five-minute intervals by a CR21X data logger, and stored to an SM192 Data Storage Module for later, convenient downloading to a PC. A typical data set would begin twenty-four hours prior to an event and continue until the completion of all other data acquisition.

Sample Data

Day of Year	Hour/ Minute	Pyranometer (watts/sq.cm)
78	910	53.45
78	915	53.94
78	920	54.17
78	925	54.22
78	930	54.93
78	935	55.22
78	940	55.68
78	945	55.85
78	950	56.30
78	955	56.77

Thermal Infrared Radiometers

Manufacturer

Everest Interscience, Inc

Model

4000 Series Sensor Heads

Specifications

Output Signal:	-30mV to +1000mV @ 1.0mV/°C or +2000mV@ 1mV/°F
Optical Configuration:	37mm refraction optics
Head Cable Length:	up to 50 feet
Wavelength Range:	3 μ m to 5 μ m
Field of View:	15 degrees
Resolution:	± 0.5 °C or ± 0.5 °F
Response Time:	< than 100msec
Noise Effective Temp.:	less than 0.5 °C
Operational Distance:	2cm to infinity
Accuracy:	$\pm 3\%$ full scale, ± 1 digit
Power Requirements:	12VDC/115VAC
Repeatability:	± 1.0 ° or ± 1.0 °F
Temperature Range:	-30 °C to +100 °C

Description

Thermal infrared thermometers (TIRs) are designed to collect precise, non-contact surface temperature measurements. The sensor operates on the principle of energy flow of net infrared radiation from a hotter to a cooler object, which follows the Stefan-Boltzman law. The fixed position or "staring" system consists of up to eight small, soda can-sized sensor heads attached to a mount for positioning to "stare" at a predetermined target for continuous monitoring of apparent surface temperature. The mid-IR system and the thermal-IR system are both deployable, either separately or coincidentally.

Chopped voltage signals from the sensor heads are recorded through a 21X Micrologger, processed in real time for conversion to temperature in either degrees C or F, and written to an SM192 Data Storage Module. The data are usually collected in two-second intervals and averaged and recorded at five-minute intervals. The averaging and recording rate is adjustable.

Each TIR Staring Radiometer System will record up to eight Series 4000 or Series 4000.4GLIR temperature transducers. The complete system includes a data logger, storage module, power source, and a multiplexer box with leads up to 50 feet long.

Sample Data

Day of Year	Hour/ Minutes	Seconds	Radiometer							
			(RM) 1 (Celsius)	RM 2	RM 3	RM 4	RM 5	RM 6	RM 7	RM 8
78	941	0.1	11.56	14.29	11.70	13.26	12.72	13.24	12.44	13.18
78	941	2.1	11.62	14.34	11.66	13.26	12.75	13.32	12.45	13.18
78	941	4.1	11.59	14.36	11.64	13.21	12.67	13.23	12.49	13.17
78	941	6.1	11.61	14.32	11.67	13.15	12.72	13.24	12.52	13.18
78	941	8.1	11.58	14.38	11.66	13.21	12.80	13.22	12.50	13.22
78	941	10.1	11.55	14.33	11.65	13.17	12.75	13.21	12.49	13.26
78	941	12.1	11.55	14.33	11.68	13.18	12.73	13.21	12.49	13.32
78	941	14.1	11.53	14.34	11.65	13.20	12.72	13.20	12.50	13.29
78	941	16.1	11.56	14.34	11.67	13.22	12.66	13.20	12.50	13.25
78	941	18.1	11.62	14.38	11.68	13.20	12.66	13.20	12.50	13.28
78	941	20.1	11.57	14.38	11.66	13.19	12.69	13.20	12.52	13.22
78	941	22.1	11.60	14.40	11.65	13.17	12.67	13.18	12.53	13.27
78	941	24.1	11.60	14.39	11.70	13.18	12.65	13.23	12.56	13.24
78	941	26.1	11.63	14.36	11.70	13.17	12.73	13.22	12.52	13.23

Spectral Radiometers

Manufacturer

Analytical Spectral Devices

Model

FieldSpec

Specifications

Range	350 nm to 2500 nm
Field of View	5°, 18°, or 25°
Spectral Resolution	3 nm @ 700 nm 10 – 12 nm across the 1000-nm to 2500-nm range
Scan Rate	½-second minimum
Power	Battery pack
Output	Digital counts to PC
Noise Equivalent Radiance	$1.6 \times 10^{-8} \text{ W cm}^{-2} \text{ nm sr}^{-1}$ @ 700 nm $1.2 \times 10^{-8} \text{ W cm}^{-2} \text{ nm sr}^{-1}$ @ 2200 nm
Operating Environment	-10 °C – 50 °C @ 10 – 90% Humidity

Description

In order to make accurate measurements of surface reflectance properties of various vicarious calibration target sites, the Remote Sensing group uses two Analytical Spectral Devices (ASD) FieldSpec spectral radiometers. The ASD radiometers are portable array-based spectrometers consisting of a spectrometer unit, computer interface, and fiber optic probe. The radiometer is a Full Range device employing a silicon photodiode array and two fast-scanning thermoelectrically cooled spectrometers capable of data collection from 350-2500nm (VNIR-SWIR) with a spectral resolution between 3 and 20nm (depending on the detector). This instrument can be operated in the field with 1, 5, or 8-degree field of view foreoptics.

Data collected with these instruments can be viewed in real time through the portable computer interface carried on top of the spectrometer.

Sample Data

Sun Photometer

Manufacturer

University of Arizona
(On loan to RSL)

Model

Automated Solar Radiometer, #980318B
Data Acquisition System

Specifications

10 detector channels (plus 2 housekeeping channels)
8-bit microcontroller with 8 kb of EPROM
16:1 analog multiplexer
16-bit ADC
32 kb RAM Power 12V

Sun Photometer 10-channel filter specifications

Channel	T _P ^a	λ _C ^b	BW ^c
1	0.400	3794	118.31
2	0.399	4003	94.52
3	0.570	4401	95.49
4	0.510	5187	98.69
5	0.465	6106	102.89
6	0.594	6712	109.59
7	0.657	7811	120.23
8	0.751	8697	75.68
9	0.610	9394	119.27
10	0.786	10300	107.16

^a T_P = percent of peak transmission

^b λ_C = center of bandwidth in angstroms

^c BW = total bandwidth of the filter in angstroms

Description

Solar radiometry uses measurements of the sun's energy at the surface of the Earth to determine either the absolute output of the sun or to infer properties of the Earth's atmosphere, such as the number of aerosols (or dust particles), total amount of ozone and water vapor, and the sizes of aerosols. Sun photometer data are used primarily to characterize the atmosphere for vicarious calibrations and atmospheric corrections.

For vicarious calibration, sun photometer data are collected around the time of a satellite overpass. This data are first processed to retrieve total optical thickness (related to total amount of absorbers and scatterers along the solar path), which is used in an inversion scheme to estimate the aerosol size distribution, and columnar amounts of ozone and water vapor. The results are input to a radiative transfer code to predict the radiance at the top of the atmosphere used in the vicarious calibration.

An identical procedure is followed for atmospheric correction, except the radiances at the top of the atmosphere are predicted for several values of surface reflectance. A table of reflectance versus radiance is used to predict the surface reflectance.

Water Baths

Specifications

Size:	3 x 3 meters
Frame:	2 x 8-inch lumber
Ground Cover:	Tarp
Liner:	2 layers of plastic sheeting
Water Amount:	250 gallons
Water Depth:	4 inches

Description

Two 3 x 3-meter water baths provided thermal calibration and characterization sources. The water baths are placed south of the thermal calibration site, and separated from the calibration site and each other by a distance of 50 meters. This separation is useful in subpixel demixing analysis.

The northern water bath is constructed of black plastic sheeting; the southern water bath is built with clear plastic sheeting. The incoming solar energy helps warm the black plastic bath more quickly than the clear plastic bath, providing a thermal gradient from one water bath to the other. Radiometers provide apparent surface temperature measurements of the water.

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