MEASUREMENT SETS AND SITES COMMONLY USED FOR CHARACTERIZATIONS

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ABSTRACT:

Scientists with NASA's Earth Science Applications Directorate are creating a well-characterized Verification &Validation (V&V) site at the Stennis Space Center (SSC). This site enables the in-flight characterization of remote sensing systems and the data that they acquire. The data are predominantly acquired by commercial, high-spatial resolution satellite systems, such as IKONOS and QuickBird 2, and airborne systems. The smaller scale of these newer high-resolution remote sensing systems allows scientists to characterize the geometric, spatial, and radiometric data properties using a single V&V site. The targets and techniques used to characterize data from these newer systems can differ significantly from the techniques used to characterize data from the earlier, coarser spatial resolution systems. Scientists are also using the SSC V&V site to characterize thermal infrared systems and active Light Detection and Ranging (LIDAR) systems. SSC employs geodetic targets, edge targets, radiometric tarps, and thermal calibration ponds to characterize remote sensing data products. This paper presents a proposed set of required measurements for visible-through-longwave infrared remote sensing systems, and a description of the Stennis characterization. Other topics discussed include 1) use of ancillary atmospheric and solar measurements taken at SSC that support various characterizations, 2) other sites used for radiometric, geometric, and spatial characterization in the continental United States, and 3) the need for a standardized technique to be adopted by the Committee on Earth Observation Satellites (CEOS) and other organizations.

1. INTRODUCTION

NASA scientists and others who use remote sensing data to make policy, economic or scientific decisions should have confidence in and an understanding of its characteristics in order to make informed decisions about its use. Confidence in the data is gained by performing characterizations or data assessments. These assessments can be broken down into three categories: geometric, spatial and radiometric characterizations. The importance of each characterization depends on how the data will be used. Geometric characterization includes both relative and absolute location assessments as well as elevation assessments. Spatial characterization involves Ground Sample Distance (GSD) and a measure of image sharpness such as edge response (edge slope), line spread function or Modulation Transfer Function (MTF). Radiometric characterization includes both relative and absolute measurements. Understanding remote sensing data characteristics becomes particularly important to scientists at NASA as they begin to incorporate commercially obtained high-spatial resolution data from systems designed and operated outside of the NASA scientific community into their research.

The NASA Stennis Space Center (SSC) in Mississippi is being developed as a remote sensing Verification & Validation (V&V) site. The site, also referred to as the Stennis Fee Area, is relatively square and encompasses approximately 55 sq km of Government-owned land. Land cover is predominately forested, but also contains a significant number of natural and man-made features including grasslands, marshes, canals, ponds, buildings, rocket motor test stands, roads, etc.

Targets, ground truthing measurement and analysis techniques required to characterize the different aspects of a remote sensing system are being put in place at SSC. The techniques being developed at this site are examples of standardized measurement techniques. Because the spatial resolution of remote sensing systems continues to increase and the swath of these systems is often decreasing, it is now possible to measure the geometric, spatial and radiometric properties of a remote sensing system at a single site within a single acquisition. Although much of the literature focuses on radiometry, geometric and spatial characterizations are often more important in high-spatial resolution systems. SSC has a heritage of working with commercially acquired remote sensing data (NASA, 2002) and has already begun to evaluate IKONOS and QuickBird 2 imagery taken over the Stennis site (NASA/NIMA/USGS, 2002).

This paper begins with a discussion of geometric and spatial characterizations and then follows with a discussion on the more traditional radiometric characterization methods.

2. GEOMETRIC CHARACTERIZATION

2.1 Geometric Characterization Site Requirements

Geometric characterizations are performed with an array of "photo-identifiable" known points or targets located at the V&V site. For the errors associated with defining the location of the points to become insignificant to the characterization process, their position must be known to an order of magnitude

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better than the spatial resolution of the system (Federal Geographic Data Committee, 1998). For example, to characterize a 1-m GSD system, the known points must be surveyed to within 10 cm. At this level of precision, unbiased errors are a few percent for a single measurement. The points must also be unambiguously identifiable in the remotely sensed imagery. To do this, the targets must have a significant contrast against their surrounding.

To meet these requirements, an array of geodetic targets has been deployed at the SSC. These white-painted targets are 8 ft, or 2.44 m, in diameter and are shown in Figure 1 (left section). The centers of these targets are painted red and have a diameter of 2 ft, or 0.61 m. A red center was chosen to better identify the targets on film-based systems, and plays no role in the characterization of digital sensing systems being discussed.

In addition to the geodetic targets, targets of opportunity such as manhole covers are being used to perform geometric characterizations. One such target is shown in Figure 1 (right section). Currently, 136 manhole covers, ranging from 0.637 m to 2.9 m in diameter have been painted and surveyed at Stennis. White paint with nominally a 60 percent reflectance value in the visible spectrum was selected.

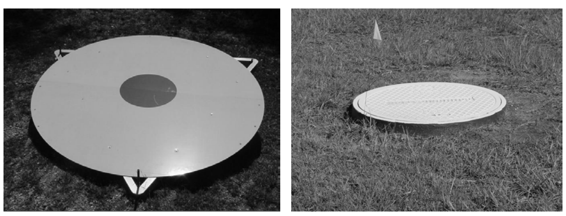

Figure 1. Geodetic target and painted manhole cover target at SSC

The geodetic targets have been deployed evenly throughout SSC as shown in Figure 2. There are 44 geodetic targets deployed and plans are in place to deploy an additional 45 targets during the coming year. Figure 2 also highlights the location of the manhole cover targets. These targets are found along roads within the site, and predominately generate long target arrays in the E-W and N-S directions.

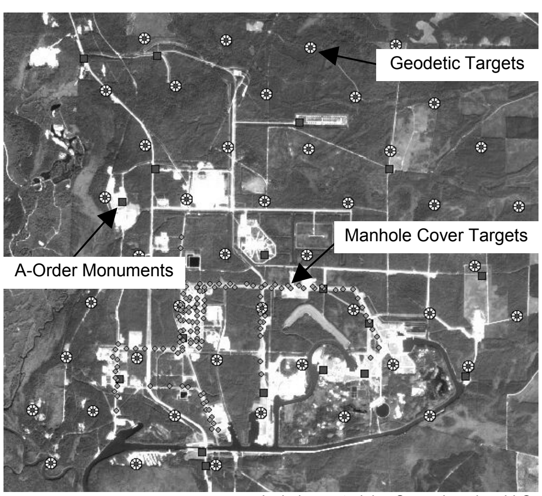

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Figure 2. Target positions throughout SSC fee area

All of the targets discussed have been surveyed using standard static surveying techniques. The center of each target is known to within 6 cm horizontal and 9 cm vertical accuracy. Periodic checks are made to ensure that these known point locations remain stable over time. To assist in the surveying of these targets, 17 A-order monuments exist within the SSC Fee Area and are also shown in Figure 2. A National Geodetic Survey (NGS) Continuously Operated Reference (COR) site, maintained by the National Oceanic and Atmospheric Administration National Data Buoy Center (NOAA NDBC), provides carrier phases and code range measurements and is also within the SSC Fee Area.

2.2 Geometric Characterization Techniques

An automated process has been developed at SSC to evaluate the position of the targets on remotely sensed imagery as compared to known surveyed target locations. Commercially available software that displays the location of the georeferenced imagery is utilized.

2.3 Other Geometric Characterization Sites

SSC maintains a target-rich environment from which to characterize the geometric properties of remotely sensed data. The site however, has a fairly constant elevation. Sites such as Morrison Quad in Colorado and Kaintuck Hollow Quad in Missouri are characterized sites that offer more Earth surface relief. They are maintained and used extensively by the U.S. Geological Survey (USGS).

3. SPATIAL CHARACTERIZATION

3.1 Spatial Characterization Site Requirements

One way to perform spatial characterizations at a V&V site is to measure a sensor's ability to image an edge. Edge targets, which are high contrast areas that form a sharp edge from a uniform dark area to a uniform bright area, are used in this type of characterization. The contrast between the dark and bright areas should strive to maximize the Digital Number (DN) range of the sensor being evaluated to maximize the sensor's signal-to-noise ratio (SNR). When imaged, at least 30 pixels should lie on the target: 10 on the bright area, 10 on the dark area and 10 along the transition or edge (Shea, 1999; Reichenbach et al., 1991). Edges should also be formed in two planes perpendicular with each other so that edge analysis in two directions can be performed simultaneously.

At the SSC there are two different types of edge targets that are currently being employed to evaluate the spatial properties of an image product. The first type of edge target consists of an edge pattern painted on a concrete slab. The pattern and dimensions are highlighted in Figure 3. The same pattern is painted twice, rotated 3.7 degrees apart, to enable digital imagery having different image coordinate systems, the ability to provide the appropriate number of pixels across an edge. Each pattern contains edges in both a northerly and easterly direction. The targets are large enough to evaluate imagery having GSDs up to 1 meter. The dark areas were painted with paint that is nominally 5 percent reflective in the visible spectrum, and the bight areas were painted with paint nominally 50 percent reflective.

The second type of edge target employed at SSC is formed using two contrasting radiometric tarps, manufactured by MTL

Systems, Inc., as shown in Figure 4. The advantage these tarps have over the painted concrete targets is that they can be deployed at alternate sites. Each contrasting color of the radiometric tarps is 20 m by 20 m in size. Two different contrast edges can be formed with the tarps: 3.5 to 52 percent reflectance and 22 to 34 percent reflectance. These tarps are large enough to characterize the spatial characteristics of 1-m GSD class imagery.

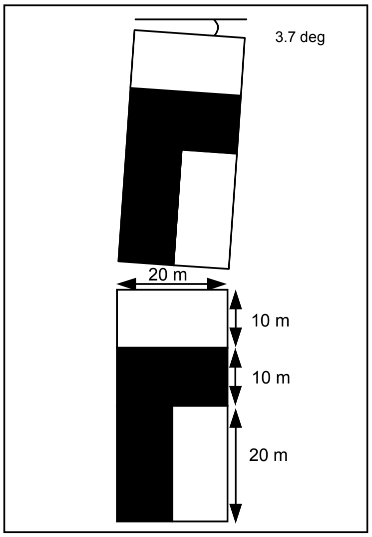

Figure 3. SSC concrete edge target layout

Figure 4. Tarp edge target

The tarps were manufactured under very strict specifications. Each seam is straight to within 6 cm along a 20-m length. The standard deviation about the average reflectance does not vary by more than 1 percent spatially. Peak to peak variation in reflectance is less than 10 percent within any 100-nm spectral band and there is less than 10 percent variation in reflectance values when measuring the tarps from 10 to 60 degrees off axis.

3.2 Spatial Characterization Techniques

The technique used at SSC to evaluate the spatial performance of edges in imagery begins with deploying the target edge such that it is tilted between 4 and 8 degrees from the image pixel frame of reference. This enables the analyst to generate an appropriately sampled edge with at least 10 pixels defining the edge.

Once the edge, properly oriented in the imagery is obtained, the edge response, measured in Digital Numbers (DN), is plotted as a function of distance from the known edge. A best fit through these points is then generated. The resulting plot is known as the system edge response and is shown in Figure 5 (top section). The derivative of this plot, called the line-spread function, is then calculated. Quite often the analysis ends with calculating the Full Width at Half Maximum (FWHM) of the line-spread function as shown in Figure 5 (center section). This parameter gives a measure of how sharp an edge appears in the image; the smaller the value, the steeper the edge response, and the sharper the image appears.

Often scientists quantify an image's spatial characteristics with a single parameter known as the MTF at Nyquist frequency. This parameter is generated by looking at the value of the Fourier Transform of the line-spread function at half the sampling frequency (1/(2*GSD)), shown in Figure 5 (bottom section). The higher the value, the sharper the image, but the greater the aliasing effects.

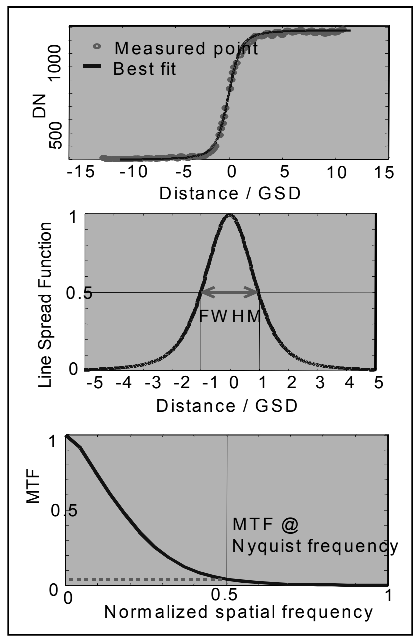

Figure 5. MTF calculation

It should be noted that this edge response technique is highly dependent on how accurate the edge response is defined. Small errors induced by curve fitting the edge response can lead to FWHM errors in excess of 10 percent. The errors are carried over into the MTF at Nyquist calculation. This method is also highly sensitive to the uniformity of the bright and dark areas of the edge target. Error analyses are currently underway at SSC.

3.3 Other Spatial Characterization Sites

Historically, spatial characterization of relatively large GSD (≥ 30 m) imagery has been accomplished by imaging very large man-made edges such as bridges or buildings. South Dakota State University (SDSU) generates edges by deploying tarps in a similar fashion as currently described at their university site.

In addition, commercial vendors of high spatial resolution imagery have constructed and maintain their own proprietary edge targets within the U.S.

4. RADIOMETRIC CHARACTERIZATION - REFLECTIVE REGION

4.1 Reflective Radiometric Characterization Site Requirements

A vicarious radiometric characterization, in the context of this paper, predicts at-sensor radiance by measuring the reflectance of a ground target, modeling the atmosphere using a radiative transport code and measured atmospheric properties, and then propagating the ground target radiance through the modeled atmosphere. To perform these characterizations, a V&V site must possess the ability to accurately measure the reflectance of a ground target and appropriate properties of the atmosphere between the target and the sensor at the time a scene is imaged. The target can be either man made or a naturally occurring feature such as sand or grass. The target must have a relatively uniform reflectance such that the pixels describing the target do not vary considerably from one to another. Atmospheric properties that control radiative transport in the reflective spectral region must be measured as well. This includes down-welling solar irradiance, aerosols, water vapor and atmospheric pressure.

Several ground targets are used to make radiometric characterizations at the SSC V&V site. The 20-m x 20-m radiometric tarps discussed above are the primary targets used to evaluate imagery having GSDs that are 4 m or less. These tarp targets can be deployed individually, in pairs to form edges, or all together in a checkerboard pattern. In addition to the tarps, a relatively uniform grass field and a portion of a concrete parking lot are often used as radiometric targets. An image generated by the Space Imaging IKONOS sensor shows a typical target layout at SSC (Figure 6). Two of the tarps have been aligned to form an edge, so that they can be used in both spatial and radiometric characterizations. A third radiometric tarp is to the left. Two smaller tarps, which act as fiducial markers, mark the grass target area further to the left. A closer inspection of the image reveals two additional small black fiducial markers, identifying a 20-m x 30-m concrete area in the lower left-center portion of the scene.

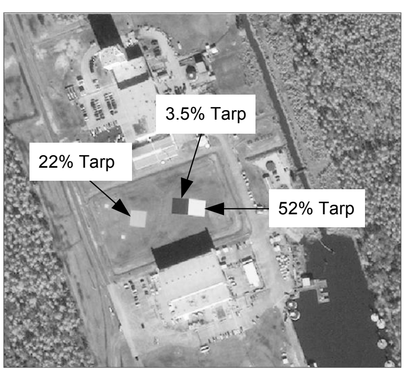

Figure 6. IKONOS image of tarp layout at SSC

The SSC V&V site maintains several Analytical Spectral Devices (ASD) spectroradiometers for measuring the reflectance of ground targets. A sensor calibration lab at SSC calibrates the spectroradiometers and much of the ancillary equipment necessary to make these measurements.

Several instruments are used at the SSC to measure atmospheric properties. Stennis maintains two different solar radiometers as shown in Figure 7. The Automated Solar Radiometers (ASRs, left side), are manufactured by the University of Arizona (UofA) (University of Arizona, 2002) and the Multifilter Rotating Shadowband Radiometers (MFRSRs, right section), are manufactured by Yankee Environmental Systems (Yankee Environmental Systems, 2000). During a typical ground truthing campaign, several solar radiometers are deployed to measure downwelling solar irradiance in select narrow bandwidths, and data from each instrument is compared. In addition, a Radiosonde weather balloon is launched within a half hour of when the sensor acquisition takes place. A Radiosonde launch provides temperature, pressure and relative humidity measurement profiles of the atmosphere.

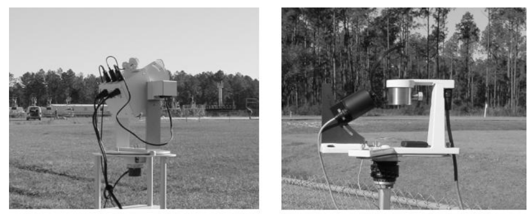

Figure 7. Solar radiometers at SSC

4.2 Reflective Radiometric Characterization Techniques

At the time of the sensor acquisition, radiometric target reflectance values and atmospheric properties are measured. Typical reflectance measurements from a radiometric characterization are shown in Figure 8. Thousands of spectra, taken by more than one instrument to reduce the risk of instrument bias or failure, are typically obtained.

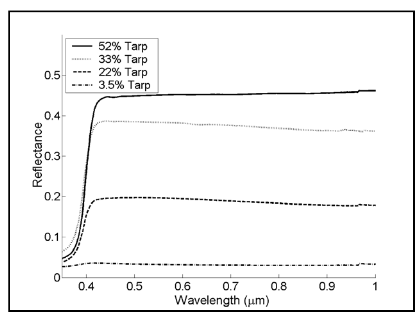

Figure 8. Measured tarp reflectance values

Atmospheric transmission values in several bands are calculated based on the solar radiometer measurements. The values, along with other key parameters such as measured atmospheric water vapor content, barometric pressure, position on Earth, and time of image acquisition are used to formulate a model atmosphere. NASA Stennis scientists use the MODTRAN radiative transport code (Berk et al., 1999) to establish this model atmosphere. A typical model atmosphere, with its comparison to measured values, is shown in Figure 9.

The model atmosphere is then coupled with the measured target reflectance values to predict at-sensor radiance values. These predictions are compared to image-acquired values to evaluate the radiometric performance of a sensing system.

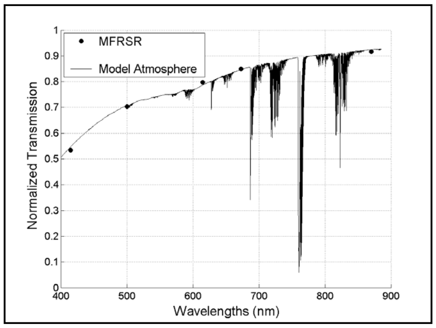

Figure 9. Atmospheric transmission

4.3 Other Reflective Radiometric Characterization Sites

The SSC is unique in that this site is capable of providing several different radiance values spanning a significant portion of a sensor's DN range. It should be noted however, that weather constraints hinder the year round utilization of this site. There are several playas in the western United States that have been used by NASA and the UofA to make comparable measurements. These include Lunar Lake playa in Nevada, Railroad Valley playa in Nevada, Ivanpah playa in California and the White Sands Missile Range in New Mexico. These sites are highly desirable because of their high reflectance, high elevations and relatively benign weather, even though they are fairly remote and difficult to access. Other more challenging sites include the SDSU V&V site, whereby grass fields are used as radiometric targets.

5. RADIOMETRIC CHARACTERIZATION - THERMAL REGION

5.1 Thermal Radiometric Characterization Site Requirements

Thermal characterizations are often performed using large uniform water bodies. These water bodies typically need to be at least 20-30 ft deep to ensure uniformity and encompass at least 10 pixels spatially. Using water bodies allows one to take advantage of the high emissivity of water. Approximately 99 percent of the radiation in the thermal region is absorbed in the first 100 μm of water. Therefore, only the very thin layer of water at the water-air interface, commonly referred to as the skin, radiates. In this way, the most accurate way to measure the temperature of a water body is to make radiant temperature measurements.

Just as in reflective region radiometric characterizations, the atmosphere at the time of a sensor acquisition must be measured. Aerosol concentrations are not as significant in this part of the spectral region. Atmospheric water vapor concentration, temperature and pressure, however, become critical.

At SSC a man made High Pressure Industrial Water Reservoir (HPIWR), primarily used to provide a water source to cool the rocket engine test stands also on site, is used as a water body source. This reservoir is shown in Figure 10.

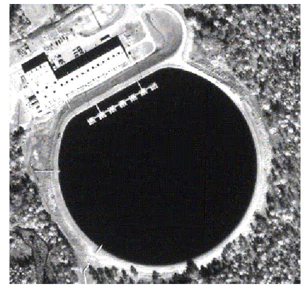

Figure 10. HPIWR at SSC

5.2 Thermal Radiometric Characterization Techniques

At the time of the sensor acquisition, water body radiant temperature measurements and atmospheric properties are measured. To measure the radiant temperature of a body of water, NASA Stennis scientists designed and built a thermal measurement float, which is shown in Figure 11 (Pagnutti, 2002). The float takes radiant temperature measurements with Heimann radiometers pointed at both the water body and the sky. In addition, physical temperature measurements are made with a thermocouple probe at several depths below the water surface. Atmospheric information such as wind speed, wind direction and air temperature are measured as well.

Figure 11. SSC Measurement Float

The SSC V&V site maintains several radiometers and black bodies for measuring the radiant temperature of ground targets. The sensor calibration lab at Stennis calibrates these and other ancillary equipment necessary to make these measurements.

A Radiosonde is also launched within a half hour of when the sensor acquisition occurs to generate atmospheric profiles of temperature, pressure and water vapor content. Just as in the reflective radiometric characterization technique, NASA Stennis scientists use the MODTRAN radiative transport code to establish a model atmosphere, based on the radiosonde data collected.

The model atmosphere is then coupled with the measured water body temperature to predict at-sensor radiance values of the water body. These predictions are compared to image-acquired values to evaluate the radiometric performance of a sensing system.

5.3 Other Thermal Radiometric Characterization Sites

Thermal radiometric characterization sites are typically centered on large, deep-water bodies. A site used by many NASA scientists is at Lake Tahoe. The NASA Jet Propulsion Laboratory (JPL) maintains four thermal measurement floats there. (Hook, 2000).

6. ACTIVE LIDAR CHARACTERIZATION

To perform LIDAR characterizations, a well known, surveyed site must exist. Not only must features be identified, but their relative and absolute positions must be known. As with the geometric characterizations, these features must be located to an order of magnitude better than the resolution of the LIDAR product. In addition, if intensity based LIDARs are to be characterized, edge responses and biases with reflectance will be characterized.

To meet these requirements, SSC scientists have generated an accurate digital elevation model (DEM) of the site. This model is based on aerial photography flown over the site and scanned at 6-in resolution. The imagery was georectified using 26 ground control points surveyed to an accuracy equal to or better than 16 cm. The model was generated using the commercially available Socet Set software (BAE Systems, 2001).

6.1 LIDAR Characterization Techniques

An automated process to evaluate LIDAR data is currently planned at SSC. This process will evaluate the positions of known features and compare them to LIDAR data products. In the case of LIDAR intensity images, locations of known contrast will be incorporated. Of particular value will be the edge targets described above.

6.2 Other LIDAR Characterization Sites

Manufacturers of LIDAR systems quite often characterize them at their own test sites. Other groups such as the University of Florida along with NOAA and the Federal Aviation Administration (FAA) have done extensive LIDAR evaluations (Woolard, 2001).

7. CONCLUSIONS

The NASA Stennis Space Center in Mississippi is being developed as a remote sensing V&V site. Several different targets as well as the ground truthing measurement and analysis techniques required to characterize the performance of a remote sensing system are being put in place. This site is unique in that it is capable of simultaneously characterizing the geometric, spatial and radiometric performance of high-spatial resolution remote sensing systems. It is also being developed as a LIDAR characterization site. The site is currently being used to characterize commercially acquired imagery from IKONOS and QuickBird 2.

The CEOS and other organizations need to adopt a standardized technique to characterize remotely sensed data of all scales. The V&V site at SSC begins to address that need.

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