

AirMSPI Data Quality Statement

9 April 2014

This statement applies to AirMSPI Level 1B2 Products (Ellipsoid and Terrain) with a version number of 004, and updates the Quality Statement released on 28 January 2014.

Radiometric Calibration

Laboratory radiometric calibration of the AirMSPI instrument was conducted by observing the output port of a 1.65 m integrating sphere. The sphere illuminates the entire field of view of the instrument. Data were collected at multiple light levels and the sphere output was monitored with an Analytical Spectral Devices (ASD) FieldSpec Pro spectrometer in order to generate a DN vs. radiance regression for each pixel. The AirMSPI line arrays have 1536 pixels in each channel. Offset levels are determined from observations in 100 pixels at the end of each array that are shielded from illumination; hence only 1436 pixels in each line collect image data. The 13 channels of the instrument measure incident radiance, L , at wavelengths close to 355, 380, 445, 470, 555, 660, 865, and 935 nm (8 channels). In keeping with Stokes parameter nomenclature, the polarization channels report I , Q , and U , where I is again the total measured incident radiance. Thus, I and Stokes parameter Q are reported at 470, 660, and 865 nm (3 channels); and I and Stokes parameter U at 470, 660, and 865 nm (3 channels). These data are used to generate the radiance and polarization data reported in the 8 spectral bands of the L1B2 product. Linear gain factors on a per-pixel basis for each channel were derived from the integrating sphere observations and applied to the data.

On October 24, 2013 AirMSPI overflew Ivanpah Playa in Nevada and a field team was deployed to acquire surface reflectance and sunphotometer data. The resulting “vicarious calibration” was used to adjust the laboratory calibration gain coefficients, retaining the pixel-to-pixel gain variations determined from the laboratory results. At 935 nm, the vicarious calibration was uncertain due to the sensitivity of this channel to atmospheric vapor. In this band, simultaneous Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data, collocated with AirMSPI on a previous flight, were used to define the AirMSPI radiometric scale.

Although gain factors are derived on a per-pixel basis, residual striping can appear in Earth images as a result of imperfect gain determination in certain pixels in the line array, particularly in the UV bands. It is believed that this striping is the result of out-of-band spectral leakage due to physical imperfections in the focal plane filter (see discussion in next section).

Radiometric Data Quality Indicators

Following MISR practice, each pixel is assigned a Radiometric Data Quality Indicator (RDQI). The RDQI definitions are as follows:

RDQI = 0: No radiometric issues are identified.

RDQI = 1: The radiometric quality does not meet an identified threshold but is deemed usable for scientific analysis purposes.

RDQI = 2: The radiometric quality does not meet a secondary threshold and the data from this pixel should not be used scientific analysis purposes.

RDQI = 3: The quality of the pixel is scientifically and cosmetically unusable. In addition, the shielded pixels at the end of each line array are marked with RDQI of 3.

During calibration, a “gain ratio” is calculated for each pixel in each band, based on illumination of the camera with a quartz halogen lamp, and also with a combination of quartz halogen and Luxim light emitting plasma lamps. The output of these two types of lamps have different spectral output, making this strategy useful for characterizing the ratio of out-of-band to in-band light. Pixels with out-of-band spectral leakage show a different slope of digital number vs. calculated in-band radiance for the two light sources as a result of not accounting for out-of-band radiance. Pixels for which the gain ratio is between 0.95 and 1.05 are assigned an RDQI value of 0 indicating that out-of-band light is a small contributor to the measured radiance. Pixels for which the gain ratio is outside of this range, but between 0.90 and 1.10 are assigned an RDQI value of 1. Pixels with gain ratios outside both these ranges, but between 0.80 and 1.20 are assigned an RDQI value of 2. All other pixels are assigned an RDQI value of 3. This out-of-band leakage is believed to be the cause of striping, which is particularly noticeable in the UV channels. A correction algorithm is under development.

Occasionally, scene elements (e.g., deep clouds or sunglint) are so bright as to cause saturation in some pixels. Future versions of the AirMSPI product will flag these situations, but this has not been done for the current version of the publicly available data. Isolated pixels that experienced saturation in one or more bands are readily identifiable in the imagery due to their anomalous appearance. In some scenes, saturation affected a significant portion of the imagery at a particular view angle, and release of those data is delayed pending implementation of the saturation flag. For some other scenes, users may notice that the files corresponding to the aftmost angles are shorter than normal, or missing. This can occur, for instance, when the step-and-stare observing sequence was terminated early by the ER-2 pilot.

For the 470 nm band, two channels are used to generate the image data reported in the L1B2 product: a channel measuring I and Q , and a channel measuring I and U . The RDQI values reported for the band represent the maximum value between these two channels. For the 660 and 865 nm bands, three channels are used to generate the image data reported in the L1B2 product: a channel measuring I only, a channel measuring I and Q , and a channel measuring I and U . The RDQI values reported for these bands represent the values in the non-polarimetric I channel, and are typically 0. There are 4 pixels in the 865 nm I, Q channel and 8 pixels in the 865 nm I, U channel that have RDQI = 1. The current RDQI reporting does not reflect this. In future versions of the product, RDQI's will be separately reported for intensity and polarimetric quantities.

Other than the radiometric calibration procedures discussed above, independent calibration verification and traceability to *Système international* (SI) Units, via National Institute of Standards and Technology (NIST) standards, has not yet been performed. For this initial data release, pixels marked with RDQI = 0 are expected to have an absolute radiometric uncertainty of better than 5%. This radiometric uncertainty is mainly attributed to the change of the response over several flight seasons. Reduced uncertainty in the calibration will be possible once the response change from one flight to another is determined. Currently we are investigating the use of the LED illumination system in AirMSPI’s on-board “validator” in conjunction with vicarious calibration data collected on several flight dates to serve this purpose.

Spectral Calibration

Determination of the detailed spectral response function of each AirMSPI channel has been made. A monochromator was used for this purpose. The spectral response function is equal to the camera response to monochromatic light, as normalized by a silicon diode response. The monochromator provided wavelength scans from 300 to 2500 nm. Two sources were used in separate spectral scans of all channels — a Luxim Light Emitting Plasma lamp for ultraviolet-blue and a quartz-halogen lamp for the remaining visible and near-infrared channels. The results of this calibration are shown in Table 1 and Figure 1.

Table 1. Wavelength, effective bandwidth, full width at half maximum (FWHM) [nm] Solar irradiance E_0 [$W\ m^{-2}\ sr^{-1}\ nm^{-1}$]

| Band name | Center wavelength | Effective bandwidth | FWHM | Band-weighted E_0 from spectral calibration | E_0 currently reported in the product | Fractional difference in E_0 |
|-----------|-------------------|---------------------|------|---|---|--------------------------------|
| 355I | 354.8 | 37.244 | 28.4 | 1.002 | 1.009 | 0.007 |
| 380I | 377.1 | 39.358 | 30.3 | 1.079 | 1.068 | -0.010 |
| 445I | 443.2 | 44.441 | 37.1 | 1.86 | 1.868 | 0.004 |
| 470Q | 469.4 | 44.045 | 37.8 | 1.997 | 2.000 | 0.002 |
| 470U | 468.7 | 44.308 | 37.9 | 1.998 | 2.000 | 0.002 |
| 555I | 553.4 | 34.663 | 29.3 | 1.856 | 1.853 | -0.002 |
| 660I | 659.3 | 44.441 | 37.8 | 1.554 | 1.553 | 0.002 |
| 660Q | 659.1 | 43.337 | 38.7 | 1.555 | 1.553 | 0.002 |
| 660U | 659.1 | 43.272 | 38.7 | 1.555 | 1.553 | 0.002 |
| 865I | 863.3 | 42.262 | 37 | 0.976 | 0.972 | -0.004 |
| 865Q | 863.8 | 42.746 | 37.7 | 0.976 | 0.972 | -0.004 |
| 865U | 864.3 | 42.613 | 37.5 | 0.975 | 0.972 | -0.004 |
| 935I | 931.4 | 51.519 | 45.8 | 0.823 | 0.814 | -0.011 |

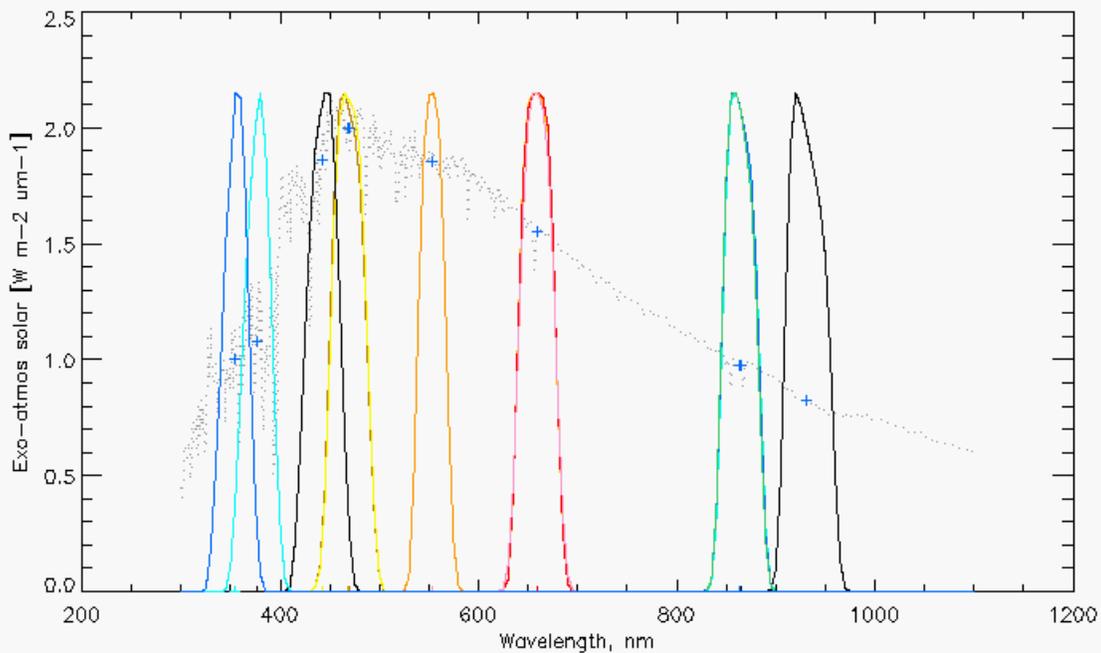


Figure 1. MISR spectral response functions (SRF), colored lines, and the Wehrli exoatmospheric irradiance values, dotted line. E_0 values are shown using a "+" symbol.

In general, radiometric response at wavelengths beyond the “in-band” spectral region is estimated at $< 10^{-4}$ of the peak response, though as noted above, a larger amount of out-of-band leakage is present in a small subset of pixels in the UV bands, leading to striping in a portion of the UV images. In most bands and detector array locations, pixel-to-pixel gain variations are removed when these SRFs are used to process the radiometric calibration data. Currently uncorrected striping in the 355 and 380 nm bands is attributed to filter blemishes that create a scene-dependent scattered light response. As noted above, an algorithm to correct for this spectral leakage is under development.

In the current product release, spectral bands are reported at the nominal band center wavelengths, and the solar irradiance values (E_0) correspond to averages over the nominal full width at half maximum in-band region. The Wehrli (1985) extraterrestrial solar spectrum was used for this purpose. Table 1 shows a comparison of solar irradiance values computed per this algorithm, and as compared to the full band-weighted values. Agreement is typically to within less than 1%.

Polarimetric Calibration

AirMSPI uses a time-varying retardance in the optical path to modulate the orientation of the linearly polarized component of the incoming light, described by the Stokes components Q (excess of horizontally over vertically polarized light) and U (excess of 45° over 135° polarized light) (Diner et al., 2007, 2010; Mahler et al., 2011). As a result, the ratios of these parameters to intensity I , given by $q = Q/I$ and $u = U/I$ are to first order

insensitive to the absolute radiometric calibration of a given pixel because both the numerator and denominator are determined from signals acquired by the same detector element. The degree of linear polarization (DOLP) and angle of linear polarization (AOLP) derived from these ratios, equal to $\sqrt{q^2 + u^2}$ and $0.5 \tan^{-1}(u/q)$, respectively, are likewise insensitive to absolute radiometric calibration, based on similar considerations. To compensate for instrumental polarization aberrations (e.g., mirror diattenuation, imperfect retardance), a set of 10 polarimetric calibration coefficients is established for every pixel (Diner et al., 2010). Results from a ground-based version of the instrument, GroundMSPI (Diner et al., 2012), show DOLP uncertainties, determined as the root-mean-square residual in DOLP as a polarizer is rotated in front of the camera, of ± 0.003 or better. Results for AirMSPI, using the rotating polarizer methodology described in Diner et al. (2010), show similar residuals.

Georectification and Co-registration

As a part of the ground data processing, AirMSPI data from all spectral bands and all viewing angles are georectified and co-registered to a common Earth-based map (UTM) projection grid. Distortions that can be associated with this type of pushbroom remote sensing imaging are taken into account by properly defining instantaneous pixel projection rays using ancillary data such as estimates of camera internal viewing geometry and ER-2 navigation data, which provide dynamic measures of the platform altitude and attitude variations. There are two types of AirMSPI georectified data products: 1) terrain projected and 2) ellipsoid projected. Terrain-projected data use a digital elevation model (DEM) for the projection surface so that cloud-free imagery is truly orthorectified with reference to that surface. Ellipsoid-projected data use the Earth reference ellipsoid (i.e., WGS 84) for the projection surface. One purpose of the ellipsoid projection is to provide input to stereoscopic height retrievals for predominantly cloudy imagery. Stereoscopic retrieval software is currently in development.

Factors affecting geospatial accuracy of AirMSPI products include: 1) relative band-to-band co-registration within a single viewing angle, 2) multi-angle co-registration, and 3) absolute georectification. The uncertainty depends on the magnitude of the errors in the supplied ancillary data and errors in the projection surface defined by the DEM. In the case of the PODEX campaign, the USGS-provided National Elevation Dataset (NED) with 10 m horizontal posting and 2.44 m rms error in elevation is used. Errors in the ancillary data defining viewing geometry are handled as static and dynamic pointing errors in order to characterize them using available ground control points (GCPs) in a procedure based on simultaneous bundle adjustment (Jovanovic et al., 2012). For targets where there is an optimum number of GCPs available, both static and dynamic pointing errors are recovered simultaneously prior to georectification and co-registration. These data are denoted as having full geometric calibration “directly” applied with expected co-registration and georectification uncertainty of around 15 m rms across all viewing angles and all bands. For other targets, (i.e., those without available GCPs, which are mostly fully ocean or cloudy imagery), an estimate of static pointing errors made on separate flight lines within the same campaign is utilized. These products are denoted as having geometric calibration “indirectly” applied with a current estimate of georectification and



co-registration uncertainty of less than one hundred meters. The type of geometric calibration is recorded in the file metadata list under the field name “Geolocation stage”. Analysis and implementation efforts are still in progress with an objective to fully optimize the camera viewing model so that uncertainties of indirectly calibrated data are minimized.

Band-to-band relative co-registration uncertainty within the same viewing angle is well within 10 m, which is the pixel size of the map projection grid in the terrain-projected data. In the case of ellipsoid-projected data there will be some offsets in the relative band-to-band registration due to the parallax caused by the true height of the viewing surface and physical band separation in the focal plane. Additionally, slight errors in registration can cause a slight displacement (on the order of a degree or two) of polarimetric features such as the backscatter glory from their expected location.

Occasional gaps of isolated lines in AirMSPI pushbroom imagery are present in an extremely small number of scenes. These are due to changes in ER-2 pitch attitude that occurred too abruptly (e.g., as the result of turbulence) to be captured accurately in the ER-2 navigation data.



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