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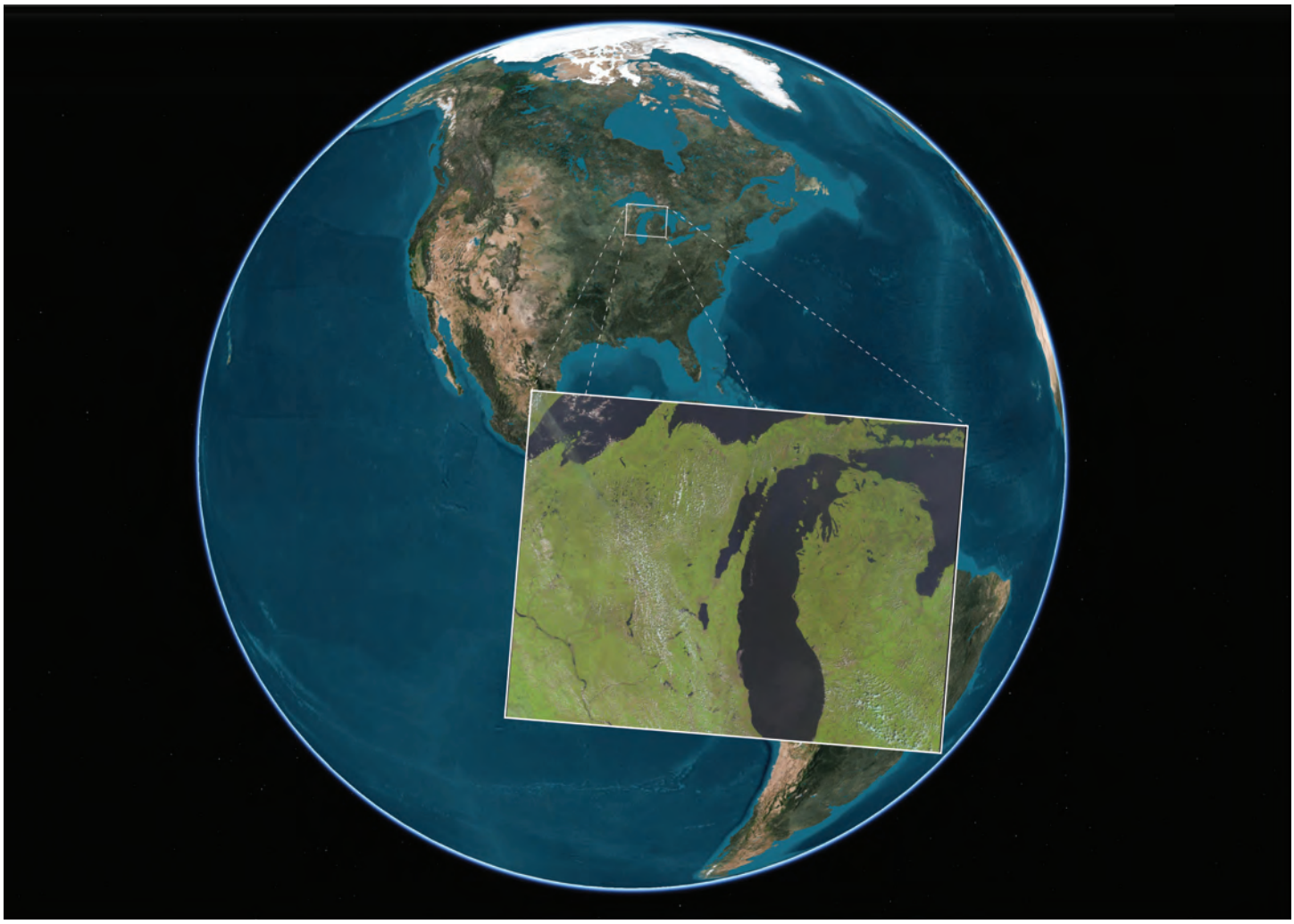
System Characterization Report on Resourcesat-2 Advanced Wide Field Sensor

Chapter G of

System Characterization of Earth Observation Sensors



Open-File Report 2021–1030–G
Version 1.2, August 2024

U.S. Department of the Interior
U.S. Geological Survey

Cover. Image of the Great Lakes captured by the Resourcesat-2 Advanced Wide Field Sensor. Image by the U.S. Geological Survey. Image of Earth from Analytical Graphics, Inc., Systems Tool Kit.

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By Shankar N. Ramaseri Chandra,[1] Minsu Kim,[1] Jon Christopherson,[1] Gregory L. Stensaas,[2] and Cody Anderson[1]

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[1]KBR, Inc., under contract to the U.S. Geological Survey.

[2]U.S. Geological Survey.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)

Abbreviations

AWiFS	Advanced Wide Field Sensor
ECCOE	EROS Cal/Val Center of Excellence
EROS	Earth Resources Observation and Science
EROSSC	EROS System Characterization
GSD	ground sample distance
JACIE	Joint Agency Commercial Imagery Evaluation
OLI	Operational Land Imager
RMSE	root mean square error
STDDEV	standard deviation
USGS	U.S. Geological Survey

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By Shankar N. Ramaseri Chandra,[1] Minsu Kim,[1] Jon Christopherson,[1] Gregory L. Stensaas,[2] and Cody Anderson[2]

Executive Summary

This report addresses system characterization of the Indian Space Research Organisation Resourcesat-2 Advanced Wide Field Sensor (AWiFS) and is part of a series of system characterization reports produced and delivered by the U.S. Geological Survey Earth Resources Observation and Science Cal/Val Center of Excellence in 2021. These reports present and detail the methodology and procedures for characterization; present technical and operational information about the specific sensing system being evaluated; and provide a summary of test measurements, data retention practices, data analysis results, and conclusions.

Resourcesat-2 is a medium-resolution satellite launched in 2011 on the Polar Satellite Launch Vehicle-C16. Resourcesat-2 carries the same sensing elements as Resourcesat-1 (launched in October 2003) and provides continuity for the mission. The objectives of the Resourcesat mission are to provide remote sensing data services to global users, focusing on data for integrated land and water resources management.

Resourcesat-2A is identical to Resourcesat-2 and was launched in 2016 on the Polar Satellite Launch Vehicle-C36 launch vehicle for continuity of data and improved temporal resolution. The two satellites operating in tandem improved the revisit capability from 5 days to 2–3 days. The Resourcesat-2 platform is of Indian Remote Sensing Satellites-1C/1D–P3 heritage and was built by the Indian Space Research Organisation. Resourcesat-2 and Resourcesat-2A carry the AWiFS, Linear Imaging Self Scanning-3, and Linear Imaging Self Scanning-4 sensors for medium-resolution imaging. More information on Indian Space Research Organisation satellites and sensors is available in the "2020 Joint Agency Commercial Imagery Evaluation—Remote Sensing Satellite Compendium" and from the manufacturer at https://www.isro.gov.in/.

The Earth Resources Observation and Science Cal/Val Center of Excellence system characterization team completed data analyses to characterize the geometric (interior and exterior), radiometric, and spatial performances. Results of these analyses indicate that AWiFS has an interior geometric performance in the range of −16.080 (−0.268 pixel) to 35.520 meters (m; 0.592 pixel) in easting and −25.680 (−0.428 pixel) to 23.400 m (0.390 pixel) in northing in band-to-band registration, an exterior geometric error of −64.262 (−1.071 pixels) to −19.059 m (−0.318 pixel) in easting and −29.028 (−0.484 pixel) to 41.249 m (0.687 pixel) in northing offset in comparison to the Landsat 8 Operational Land Imager, a radiometric performance in the range of −0.065–0.083 in offset and 0.652–1.056 in slope, and a spatial performance in the range of 2.29–2.36 pixels for full width at half maximum, with a modulation transfer function at a Nyquist frequency in the range of 0.030–0.035.

Introduction

The Resourcesat-2 Advanced Wide Field Sensor (AWiFS) is a wide-angle medium-resolution camera consisting of four bands: green, red, near infrared, and shortwave infrared. The camera has a swath width of 740 kilometers, which enables AWiFS to provide a 5-day repeat capability. Resourcesat-2 was launched in 2011, and an identical mission, Resourcesat-2A, was launched in 2016. The primary objectives for data acquired by AWiFS include vegetation and crop monitoring, forest mapping, land cover/land use mapping, change detection, and regional resource assessment.

The data analysis results provided in this report have been derived from approved Joint Agency Commercial Imagery Evaluation (JACIE) processes and procedures. JACIE was formed to leverage resources from several Federal agencies for the characterization of remote sensing data and to share those results across the remote sensing community. More information about JACIE is available at https://www.usgs.gov/core-science-systems/eros/calval/jacie?qt-science_support_page_related_con=3#qt-science_support_page_related_con.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

[2]U.S. Geological Survey.

Purpose and Scope

The purpose of this report is to describe the specific sensor or sensing system, test its performance in three categories, complete related data analyses to quantify these performances, and report the results in a standardized document. In this chapter, the AWiFS sensor is described. The performance of the system is limited to geometric, radiometric, and spatial analyses. The scope of the geometric assessment is limited to testing the interior alignments of spectral bands against each other and testing the exterior alignment in reference to the Landsat 8 Operational Land Imager (OLI).

The U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Cal/Val Center of Excellence (ECCOE) project, and the associated system characterization process used for this assessment, follows the USGS Fundamental Science Practices, which include maintaining data, information, and documentation needed to reproduce and validate the scientific analysis documented in this report. Additional information and guidance about Fundamental Science Practices and related resource information of interest to the public are available at https://www.usgs.gov/about/organization/science-support/office-science-quality-and-integrity/fundamental-science-practices. For additional information related to the report, please contact ECCOE at eccoe@usgs.gov.

System Description

This section describes the satellite and operational details for Resourcesat-2 and provides information about the AWiFS.

Satellite and Operational Details

The satellite and operational details of Resourcesat-2 and information about the AWiFS are listed in table 1.

Sensor Information

The spectral characteristics and the relative spectral response of the AWiFS are listed in table 2 and figure 1, respectively.

Procedures

ECCOE has established standard processes to identify Earth observing systems of interest and to assess the geometric, radiometric, and spatial qualities of data products from these systems.

The assessment steps are as follows:

- system identification and investigation to learn the general specifications of the satellite and its sensor(s);
- data receipt and initial inspection to understand the characteristics and any overt flaws in the data product so that it may be further analyzed;
- geometry characterization, including interior geometric orientation measuring the relative alignment of spectral bands and exterior geometric orientation measuring how well the georeferenced pixels within the image are aligned to a known reference;
- radiometry characterization, including assessing how well the data product correlates with a known reference and, when possible, assessing the signal-to-noise ratio; and
- spatial characterization, assessing the two-dimensional fidelity of the image pixels to their projected ground sample distance (GSD).

Data analysis and test results are maintained at the USGS EROS Center by the ECCOE project.

Measurements

The observed USGS measurements are listed in table 3. The mean of interior (band-to-band) and exterior (image-to-image) mean errors, standard deviations (STDDEVs), and root mean square errors (RMSEs) are listed in meters (pixels). Details about the methodologies used are outlined in the "Analysis" section.

Table 1. Satellite and operational details for Resourcesat-2 Advanced Wide Field Sensor.

[kg, kilogram; NIR, near infrared; SWIR, shortwave infrared; W, watt; AH, amp hour; Ni-Cd, nickel-cadmium; Mbps, megabit per second; ~, about; km, kilometer; °, degree; min, minute; ±, plus or minus; lat., latitude; N/A, not applicable; m, meter; USGS, U.S. Geological Survey]

Product information	Resourcesat-2 Advanced Wide Field Sensor data
Satellite and operational information	
Product name	Level 1T
Satellite name	Resourcesat-2
Sensor name(s)	Advanced Wide Field Sensor
Lift-off mass	1,206 kg
Instrument mass	106 kg
Sensor type	Multispectral, visible, and infrared (green, red, NIR, SWIR)
Scanning technique	Pushbroom; 6,000 detectors array
Power	Solar array generating 1,250 W at end of life; two 24 AH Ni-Cd batteries
Data rate	52.5 Mbps
Mission type	Global land-monitoring mission
Launch date	April 20, 2011
Number of satellites	2
Expected lifetime	~10 years
Operator	Indian Space Research Organisation
Operational details	
Operating orbit	Circular polar Sun synchronous
Orbital altitude range	817 km
Sensor angle altitude	98.7° inclination
Altitude and orbit control	Three-axis body stabilized using reaction wheels, magnetic torquers, and hydrazine thrusters
Orbit period	101.35 min
Imaging time	10:30 descending node
Geographic coverage	Land imaging ±81.3° lat.
Temporal resolution	24 days
Temporal coverage	2011 to present
Imaging angles	N/A
Ground sample distance(s)	56 m
Data licensing	Free through USGS for the United States only
Data pricing	Free through USGS for the United States only
Product abstract	https://www.isro.gov.in/Spacecraft/resourcesat-2
Product locator	https://earthexplorer.usgs.gov/

Table 2. Imaging sensor details for Resourcesat-2 Advanced Wide Field Sensor.

[The Resourcesat-2 Advanced Wide Field Sensor (AWiFS) has a swath width of 740 kilometers; µm, micrometer; m, meter; NIR, near infrared; SWIR, shortwave infrared]

Spectral band(s) details	Resourcesat-2 AWiFS			
	Lower band (µm)	Upper band (µm)	Radiometric resolution (bits)	Ground sample distance (m)
Band 2—green	0.52	0.59	10	56
Band 3—red	0.62	0.68	10	56
Band 4—NIR	0.77	0.86	10	56
Band 5—SWIR	1.55	1.70	10	56

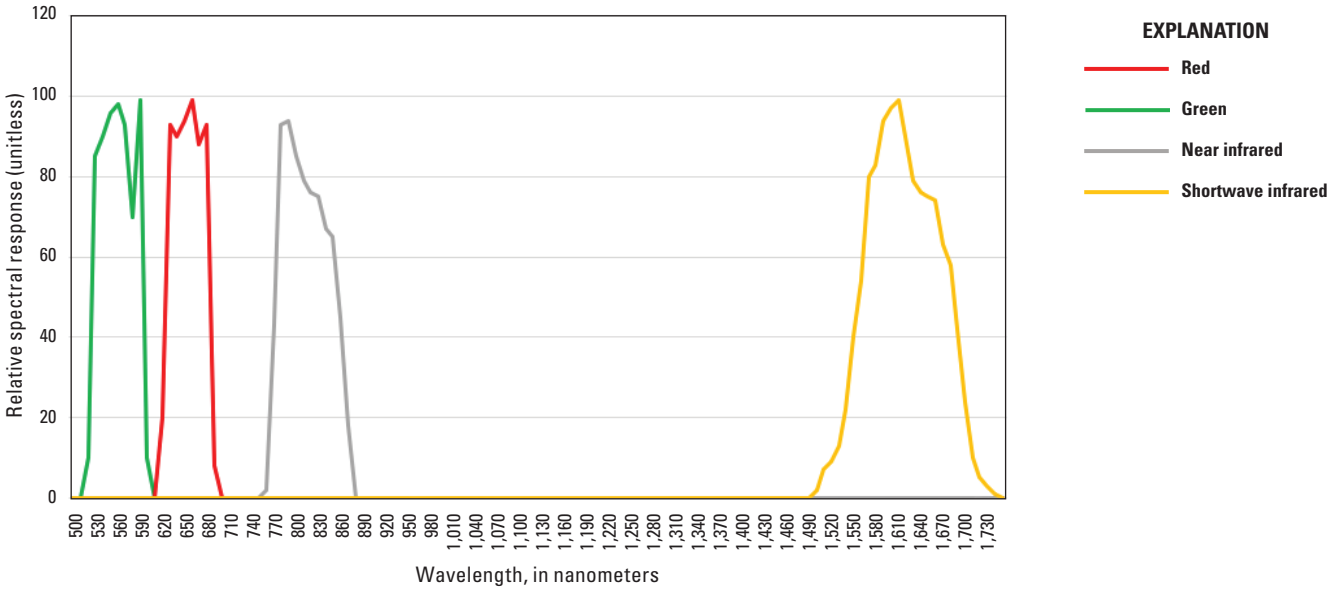

Figure 1. Resourcesat-2 Advanced Wide Field Sensor relative spectral response.

Table 3. U.S. Geological Survey measurement results.

[USGS, U.S. Geological Survey; STDDEV, standard deviation; RMSE, root mean square error; NIR, near infrared; SWIR, shortwave infrared; AWiFS, Advanced Wide Field Sensor; L8 OLI, Landsat 8 Operational Land Imager; FWHM, full width at half maximum; MTF, modulation transfer function]

Description of product	Top of Atmosphere reflectance
USGS measurement results	
Geometric performance (easting, northing), in meters (pixels)	
Interior (band to band)	Band 2 (green) Mean: −9.480 to 35.520 m (−0.158 to 0.592), −25.680 to −1.860 m (−0.428 to −0.031) RMSE: 5.400 to 39.180 m (0.090 to 0.653), 4.980 to 41.460 m (0.083 to 0.691) Band 3 (red) Mean: −12.660 to 25.440 m (−0.211 to 0.424), −17.760 to 11.400 m (−0.296 to 0.190) RMSE: 5.400 to 31.800 m (0.090 to 0.530), 4.980 to 29.040 m (0.083 to 0.484) Band 4 (NIR) Mean: −16.080 to 35.520 m (−0.268 to 0.592), −25.680 to 23.400 m (−0.428 to 0.390) RMSE: 8.400 to 39.180 m (0.140 to 0.653), 10.560 to 41.460 m (0.176 to 0.691) Band 5 (SWIR) Mean: −16.080 to 11.520 m (−0.268 to 0.192), −15.660 to 23.400 m (−0.261 to 0.390) RMSE: 8.340 to 20.340 m (0.139 to 0.339), 9.720 to 32.460 m (0.162 to 0.541)
Exterior (geometric location accuracy)	Mean: −64.262 to −19.059 m (−1.071 to −0.318), −29.028 to 41.249 m (−0.484 to 0.687) RMSE: 0.363 to 1.289 m (21.755 to 77.325), 0.553 to 0.759 m (33.175 to 45.547)
Radiometric performance (offset, slope)	
Radiometric evaluation (linear regression—AWiFS versus L8 OLI reflectance)	Band 2—green (offset, slope): (0.043 to 0.065, 0.746 to 0.907) Band 3—red (offset, slope): (0.031 to 0.065, 0.741 to 0.886) Band 4—NIR (offset, slope): (0.021 to 0.083, 0.708 to 0.912) Band 5—SWIR (offset, slope): (−0.065 to 0.042, 0.652 to 1.056)
Spatial performance	
Spatial performance measurement	Band 2—green: FWHM = 2.32 pixels; MTF at Nyquist = 0.035 Band 3—red: FWHM = 2.32 pixels; MTF at Nyquist = 0.035 Band 4—NIR: FWHM = 2.29 pixels; MTF at Nyquist = 0.034 Band 5—SWIR: FWHM = 2.36 pixels; MTF at Nyquist = 0.030

Analysis

This section describes the geometric, radiometric, and spatial performance of AWiFS.

Geometric Performance

The geometric performance for AWiFS is characterized in terms of the interior (band-to-band alignment) and exterior (geometric location accuracy) geometric analysis results.

Interior (Band to Band)

The band-to-band alignment analysis was completed using the EROS System Characterization (EROSSC) software on three separate images over the United States. Band combinations were registered against each other to determine the mean error, STDDEV, and RMSE as listed in table 4 with results represented in pixels at a 60-meter (m) GSD (the AWiFS image was resampled to 60 m). The geometric error map comparing band 1 to band 2 over the Fargo, North Dakota, image, and the corresponding histogram graphs, are shown in figures 2–5. The geometric error maps indicate the directional shift and relative magnitude of the shift, and the band-to-band error within the image is indicated by the histogram and the error distribution. Together, the interior and exterior geometric analysis results, as reported in the "Interior (Band to Band)" and "Exterior (Geometric Location Accuracy)" sections, provide a comprehensive assessment of geometric accuracy.

Exterior (Geometric Location Accuracy)

For this analysis, band 2 (green) of the AWiFS data was compared against the corresponding band from the Landsat 8 OLI image over two near-coincident images using the EROSSC software. Conjugate points in the reference and search images were identified automatically and refined using similarity measures such as normalized cross-correlation metrics, and the mean error, STDDEV, and RMSE results are listed in table 5 with results represented in pixels and meters at a 60-m GSD (OLI and AWiFS images were resampled to 60 m). A geometric error map showing the directional shift and relative magnitude of the shift, when compared with Landsat 8 OLI, along with the corresponding histogram and error distribution, are provided in figures 6–9. The Landsat 8 OLI imagery had a control uncertainty of about 8 m.

Table 4. Band-to-band registration error (in pixels).

[ID, identifier; STDDEV, standard deviation; RMSE, root mean square error]

Scene ID (location)	Band combination	Mean error (easting)	Mean error (northing)	STDDEV error (easting)	STDDEV error (northing)	RMSE (easting)	RMSE (northing)
R2AWF10212018267035_L1T (Fargo, North Dakota)	Band 2–band 3	0.043	−0.058	0.079	0.060	0.090	0.083
	Band 2–band 4	0.035	−0.265	0.136	0.116	0.140	0.289
	Band 2–band 5	−0.158	−0.261	0.158	0.103	0.223	0.280
	Band 3–band 4	0.01	−0.221	0.148	0.131	0.149	0.257
	Band 3–band 5	−0.211	−0.203	0.143	0.109	0.254	0.230
	Band 4–band 5	−0.183	0.075	0.161	0.159	0.244	0.176
R2AWF10062019264041_L1T (Colorado)	Band 2–band 3	0.185	−0.205	0.152	0.198	0.239	0.285
	Band 2–band 4	0.592	−0.428	0.276	0.543	0.653	0.691
	Band 2–band 5	0.192	−0.031	0.119	0.295	0.226	0.296
	Band 3–band 4	0.424	−0.184	0.318	0.448	0.53	0.484
	Band 3–band 5	0	0.190	0.139	0.146	0.139	0.240
	Band 4–band 5	−0.268	0.39	0.209	0.375	0.339	0.541
R2AWF07062018260042_L1T (New Mexico)	Band 2–band 3	0.057	−0.048	0.104	0.083	0.119	0.096
	Band 2–band 4	0.190	−0.352	0.211	0.363	0.284	0.505
	Band 2–band 5	−0.019	−0.111	0.248	0.177	0.249	0.209
	Band 3–band 4	0.131	−0.296	0.211	0.375	0.248	0.478
	Band 3–band 5	−0.08	−0.067	0.219	0.148	0.233	0.162
	Band 4–band 5	−0.193	0.225	0.192	0.320	0.272	0.391

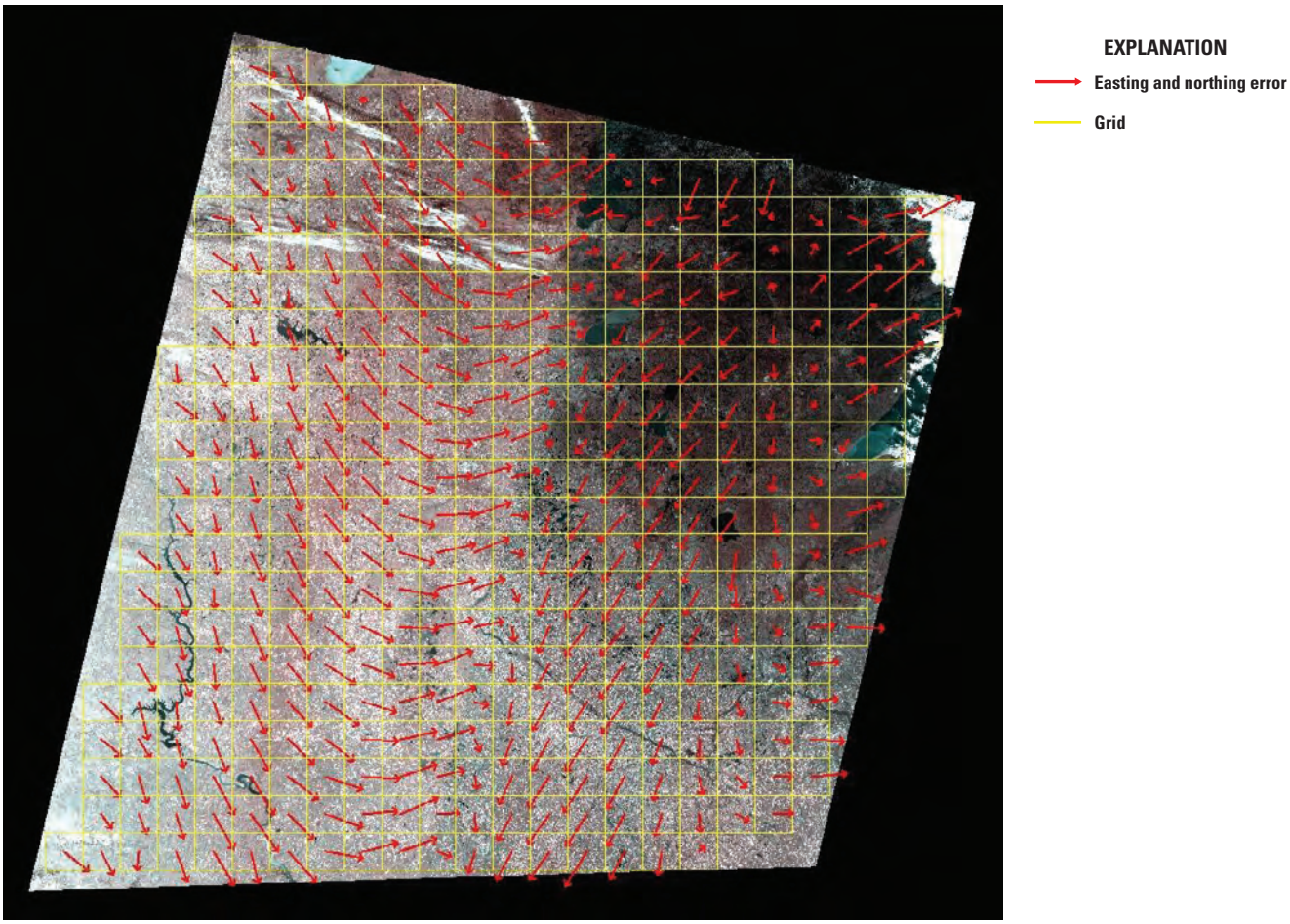

Figure 2. Band 2 (green) to band 3 (red) geometric error map (Fargo, North Dakota).

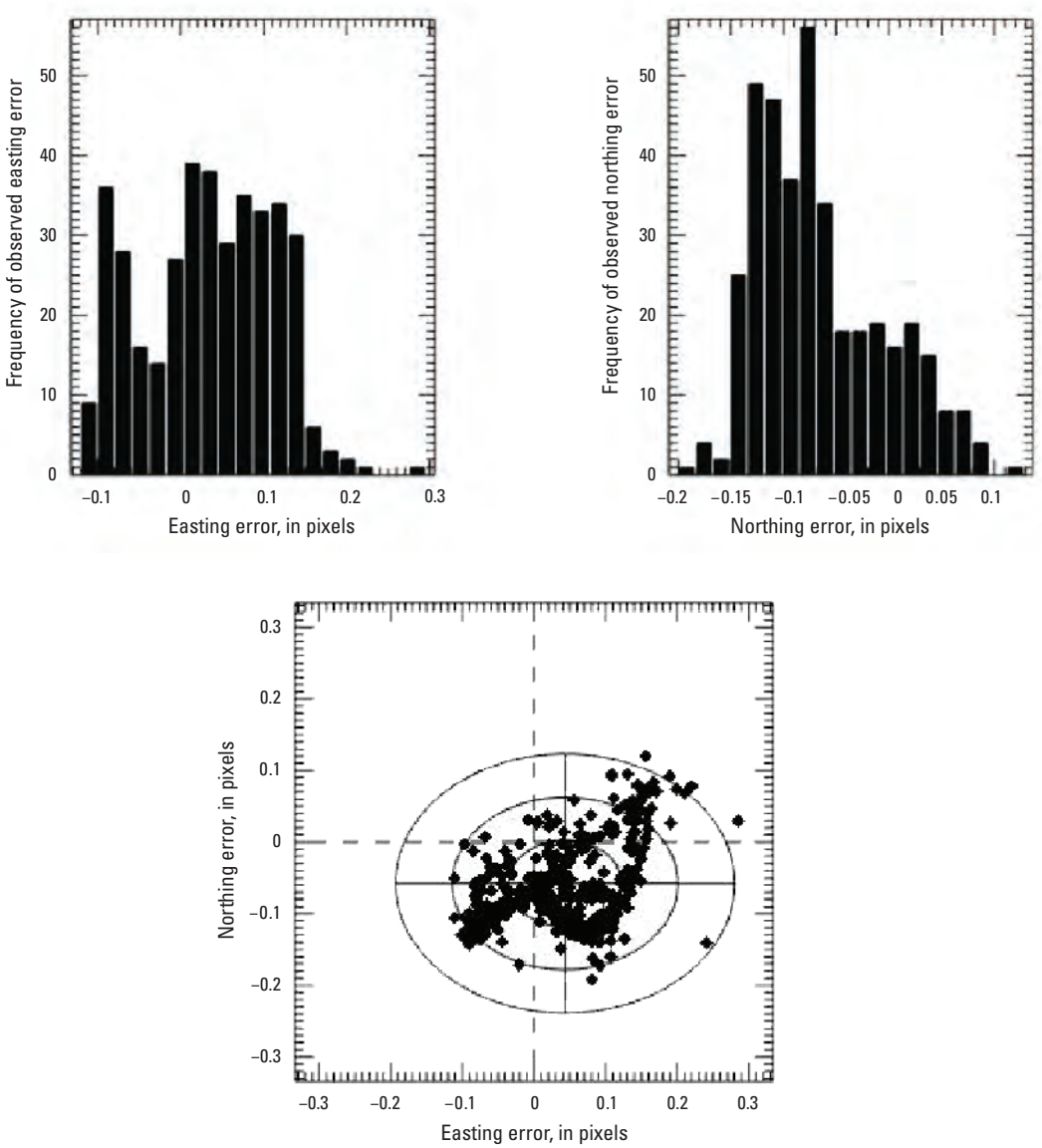

Figure 3. Band 2 (green) to band 3 (red) geometric error histogram (upper) and error distribution (lower) for Fargo, North Dakota.

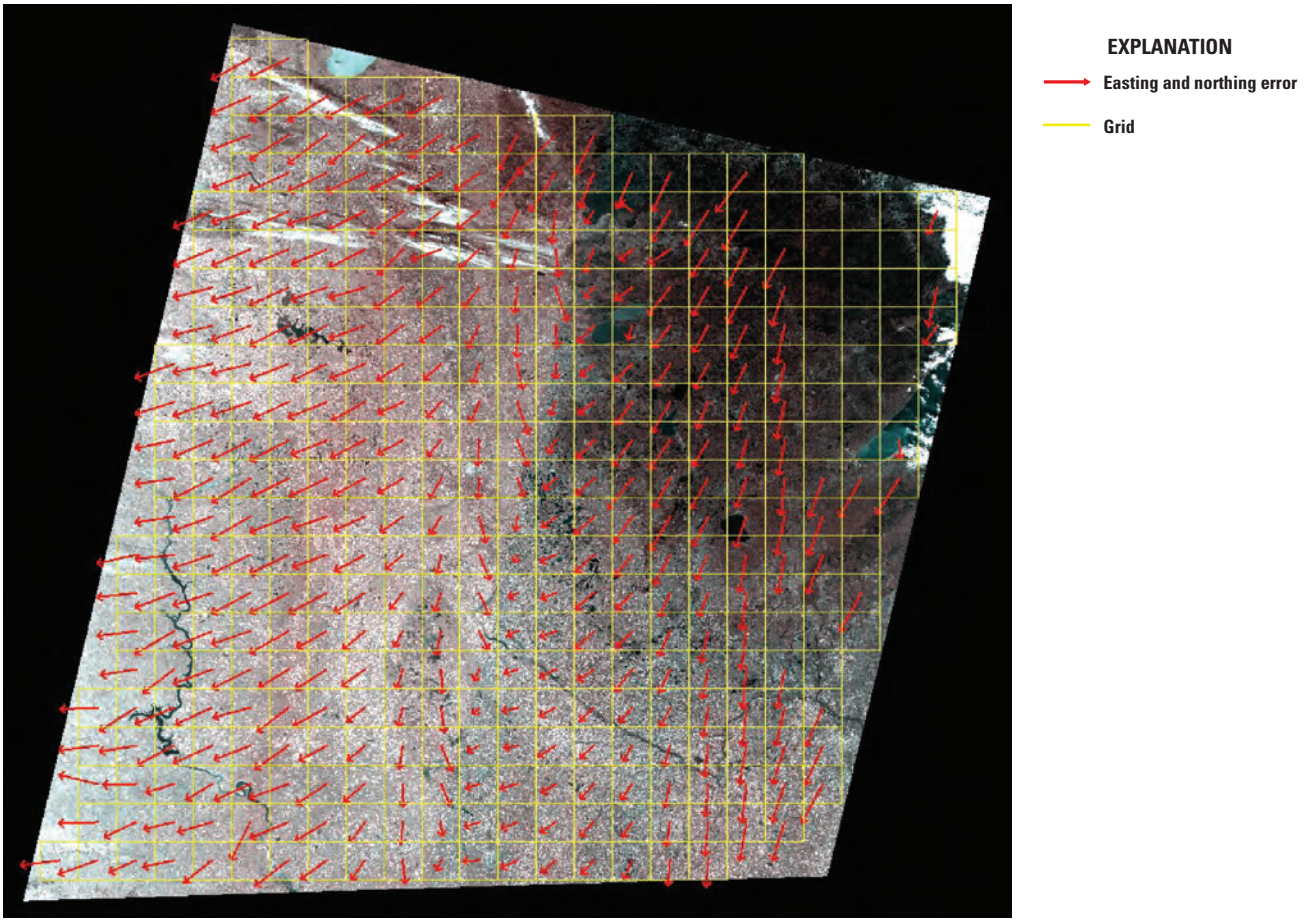

Figure 4. Band 3 (red) to band 5 (shortwave infrared) geometric error map (Fargo, North Dakota).

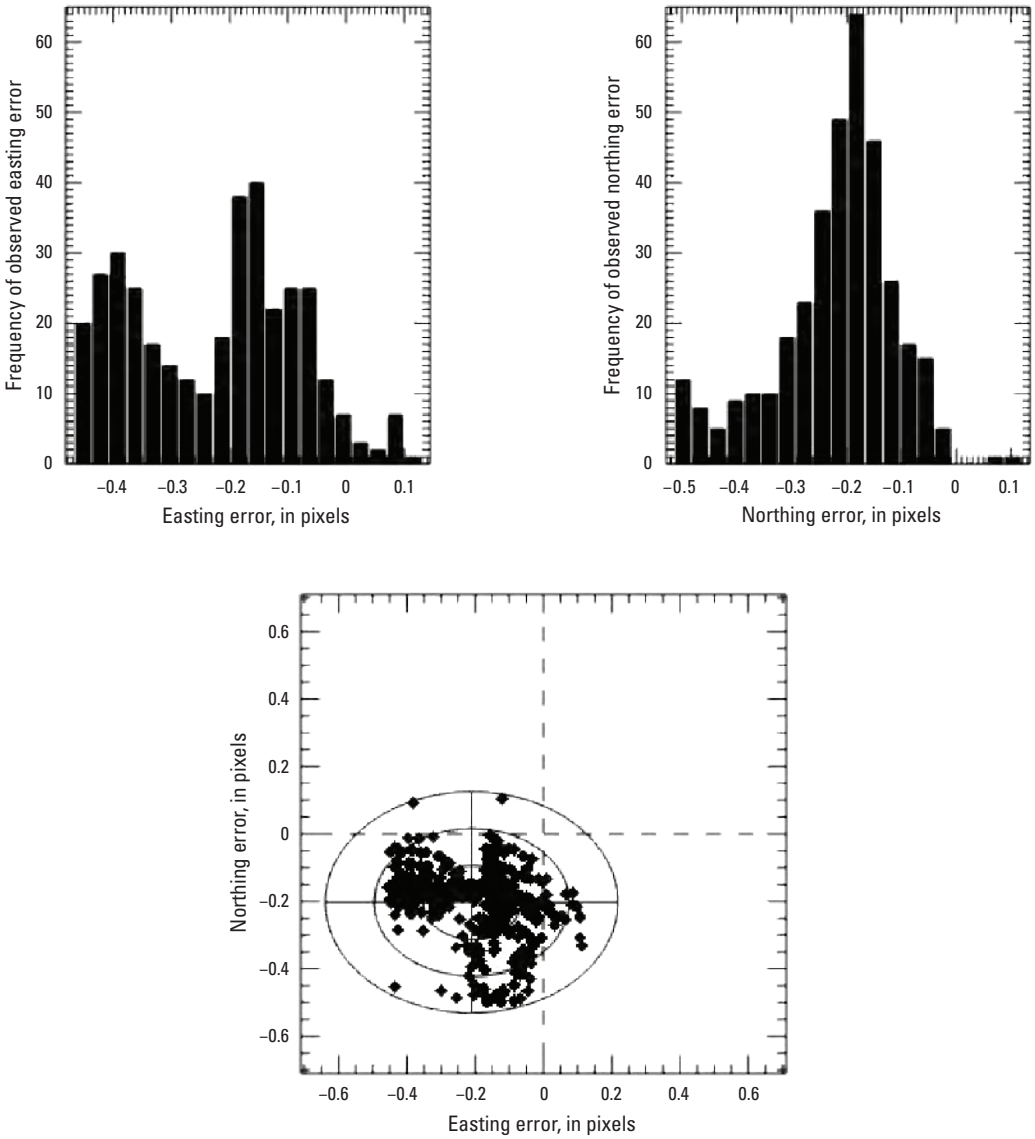

Figure 5. Band 3 (red) to band 5 (shortwave infrared) geometric error histogram (upper) and error distribution (lower) for Fargo, North Dakota.

Table 5. Geometric error of Resourcesat-2 Advanced Wide Field Sensor relative to Landsat 8 Operational Land Imager.

[ID, identifier; STDDEV, standard deviation; RMSE, root mean square error]

Scene ID	Unit	Mean error (easting)	Mean error (northing)	STDDEV error (easting)	STDDEV error (northing)	RMSE error (easting)	RMSE error (northing)
R2AWF102120182670 35_L1T LC08_L1TP_030027_20181021_20200830_02_T1 (Fargo, North Dakota)	Pixels	−0.318	−0.484	0.175	0.268	0.363	0.553
	Meters	−19.059	−29.028	10.514	16.097	21.755	33.175
R2AWF100620192640 41_L1T LC08_L1TP_032034_20191006_20200825_02_T1 (Colorado)	Pixels	−1.071	0.671	0.719	0.289	1.289	0.730
	Meters	−64.262	40.247	43.166	17.355	77.325	43.804
R2AWF070620182600 42_L1T LC08_L1TP_033032_20180706_20200831_02_T1 (New Mexico)	Pixels	−0.596	0.687	0.325	0.323	0.678	0.759
	Meters	−35.744	41.249	19.529	19.409	40.684	45.547

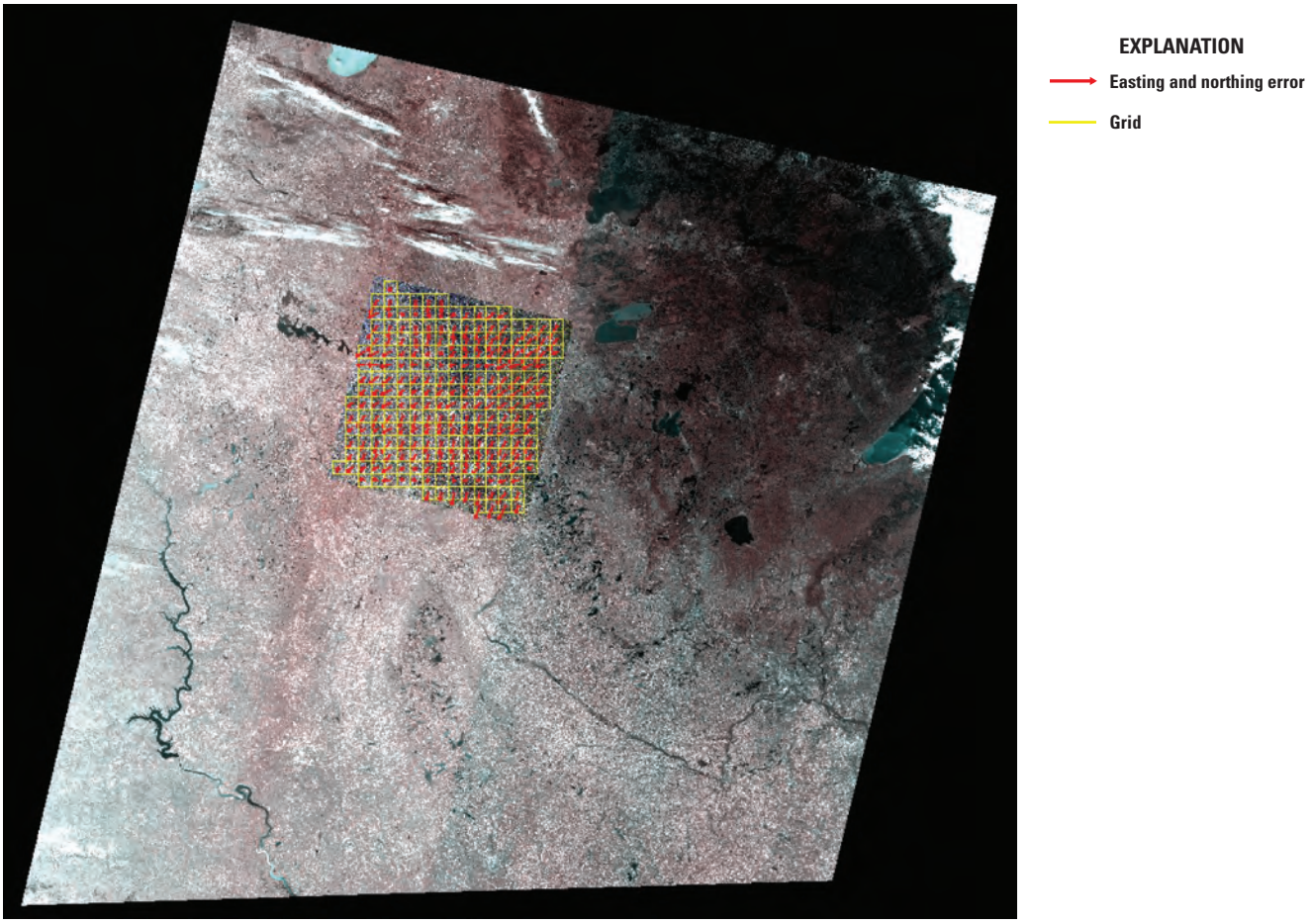

Figure 6. Relative geometric error comparison for Landsat 8 Operational Land Imager and Resourcesat-2 Advanced Wide Field Sensor for Fargo, North Dakota.

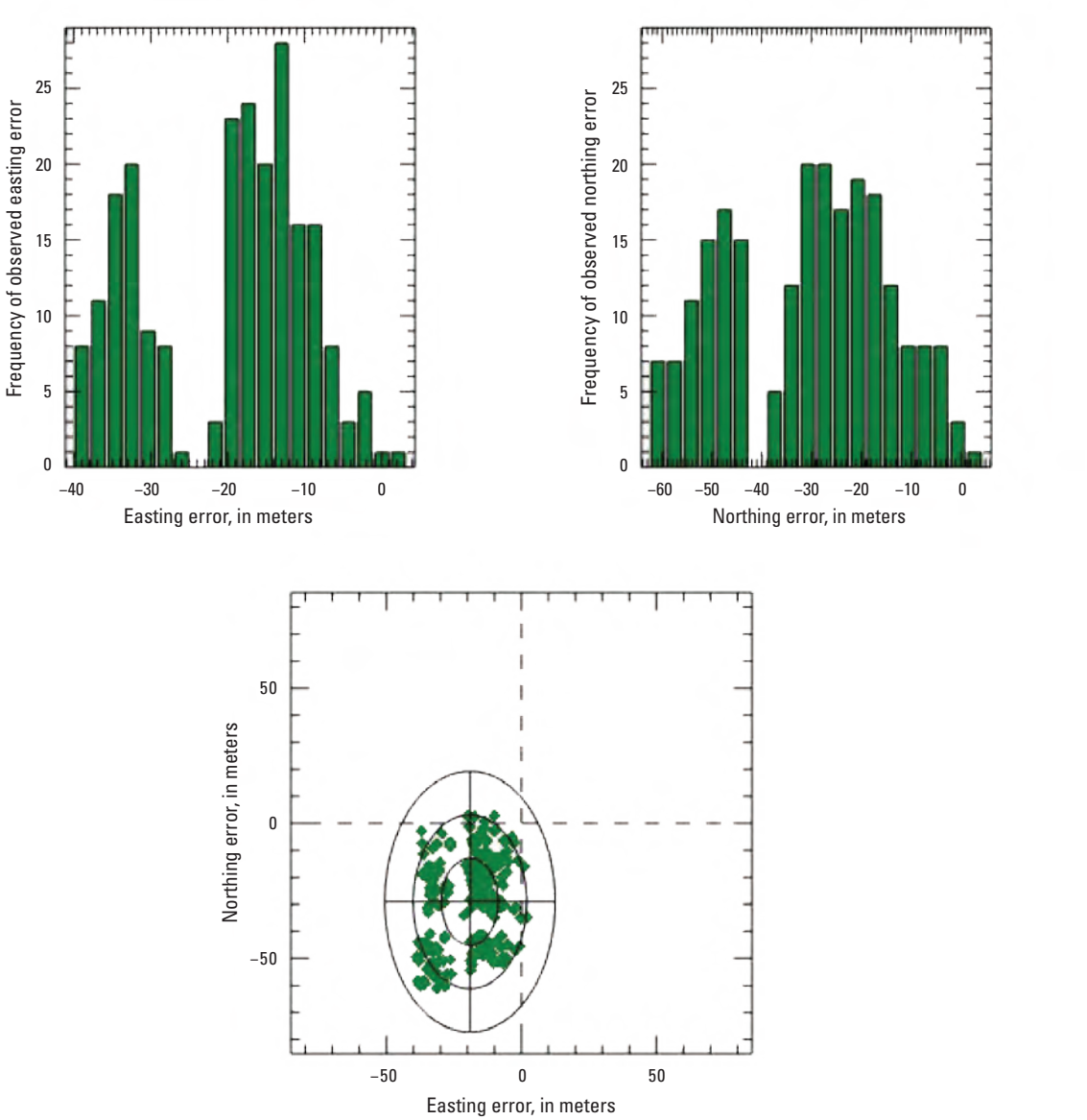

Figure 7. Relative geometric error histogram (upper) and error distribution (lower) for Fargo, North Dakota.

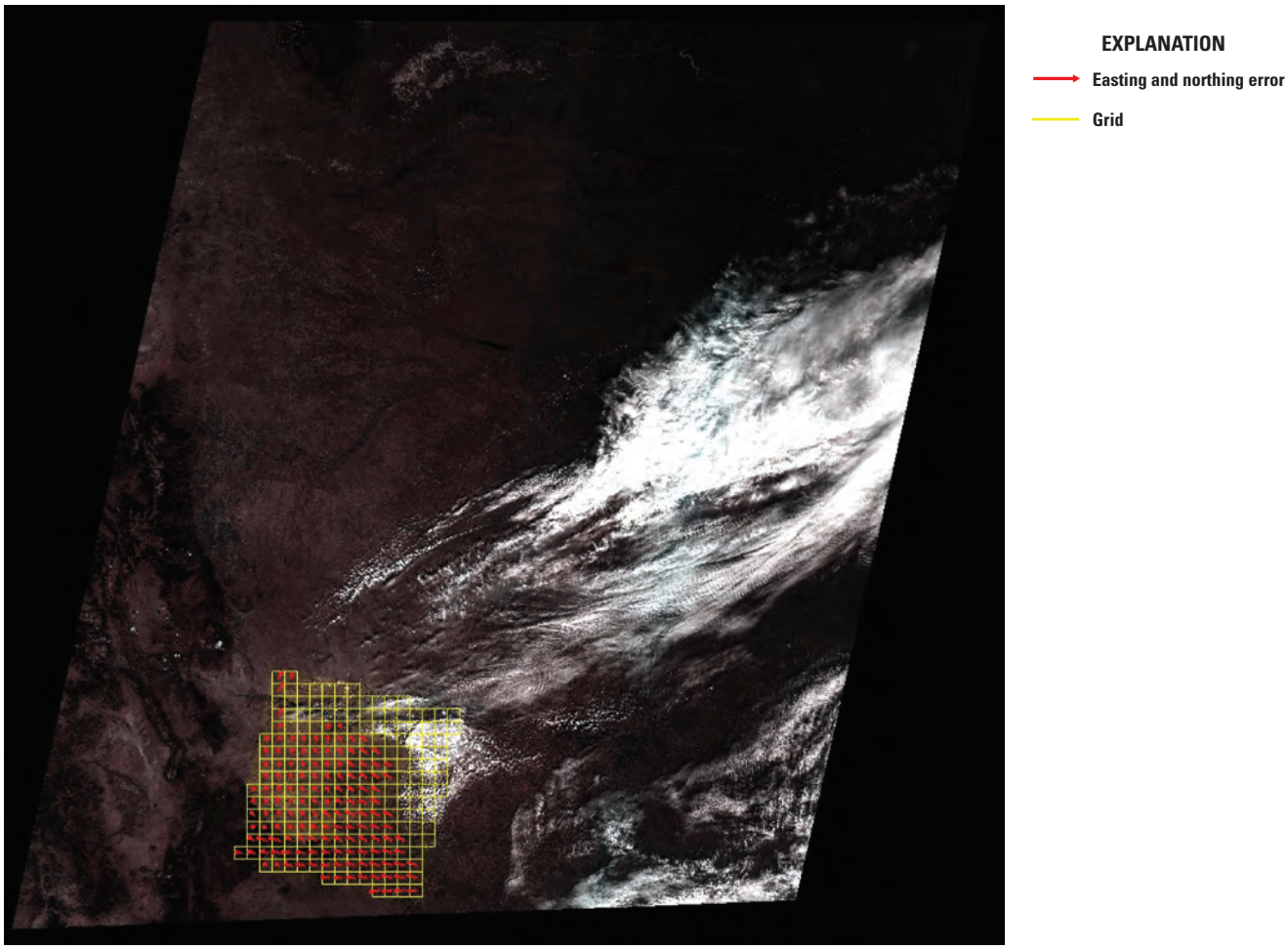

Figure 8. Relative geometric error comparison for Landsat 8 Operational Land Imager and Resourcesat-2 Advanced Wide Field Sensor for Colorado.

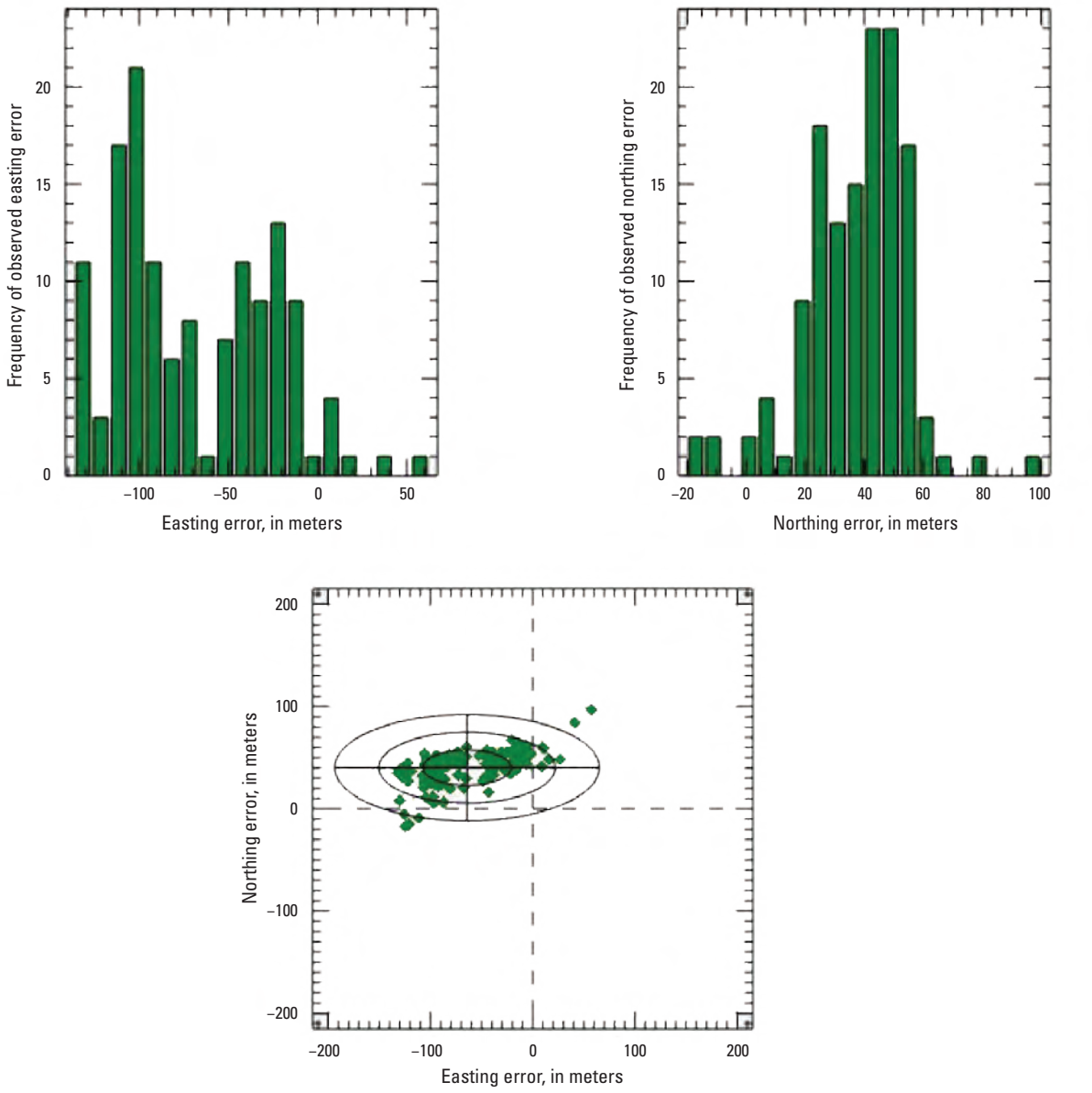

Figure 9. Relative geometric error histogram (upper) and error distribution (lower) for Colorado.

Radiometric Performance

For this analysis, cloud-free regions of interest were analyzed within three AWiFS and Landsat 8 OLI scene pairs using the EROSSC software. Raw digital number-to-radiance conversion coefficients were obtained from the Indian Space Research Organisation. The scatterplot (fig. 10) is drawn in a way that the x-axis is the reference sensor and the y-axis is the comparison sensor. The linear regression, thus, represents Top of Atmosphere reflectance relative to that of the reference sensor. Ideally, slope should be near unity and the offset should be near zero. For instance, if the slope is greater than unity, that means the comparison sensor has a tendency to overestimate Top of Atmosphere reflectance compared to the reference sensor.

Top of Atmosphere reflectance comparison results are listed in table 6. A band-by-band graphical comparison between the AWiFS image over Fargo, N. Dak., when compared against the corresponding Landsat 8 OLI band is shown in figure 10.

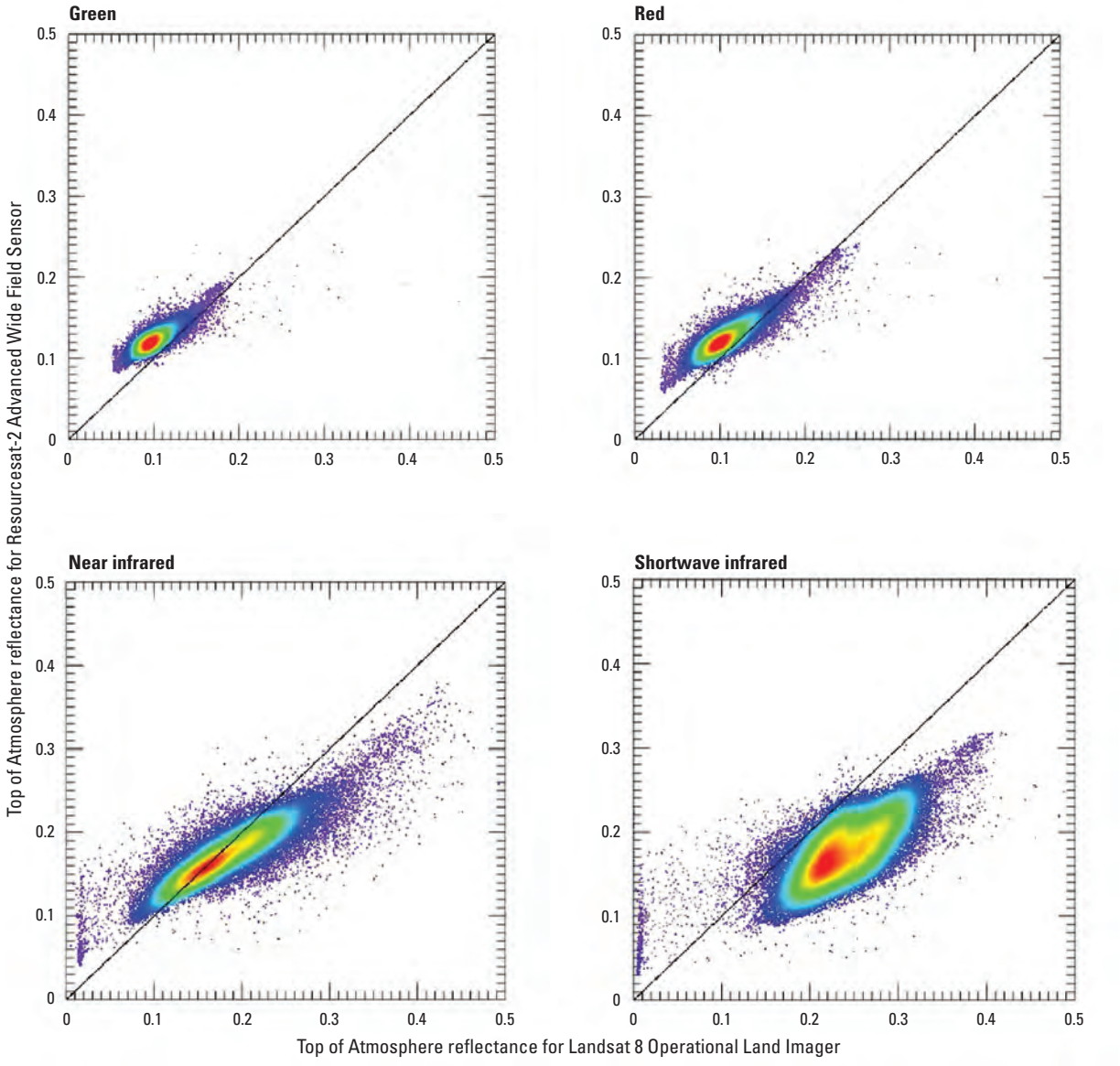

Figure 10. Top of Atmosphere reflectance comparison for Landsat 8 Operational Land Imager and Resourcesat-2 Advanced Wide Field Sensor for Fargo, North Dakota.

Spatial Performance

For this analysis, spatial analysis based on Helder and others (2004), was used to determine the full width at half maximum and modulation transfer function at Nyquist frequency, as listed in table 7.

Table 6. Top of Atmosphere reflectance comparison of Resourcesat-2 Advanced Wide Field Sensor against Landsat 8 Operational Land Imager.

[ID, identifier; B, band; %, percent; R^2, coefficient of determination]

Scene ID	Statistics	B2	B3	B4	B5
R2AWF10212018267035_L1TLC08_ L1TP_030027_20181021_20200830_02_T1 (Fargo, North Dakota)	Uncertainty (%)	8.490	12.050	16.620	14.230
	R^2	0.772	0.789	0.763	0.490
	Radical offset	0.065	0.065	0.083	−0.065
	Radical slope	0.806	0.786	0.712	1.056
R2AWF10062019264041_L1TLC08_ L1TP_032034_20191006_20200825_02_T1 (Colorado)	Uncertainty (%)	7.430	10.460	8.990	11.230
	R^2	0.752	0.727	0.564	0.642
	Radical offset	0.049	0.049	0.021	0.042
	Radical slope	0.907	0.886	0.912	0.761
R2AWF07062018260042_L1TLC08_ L1TP_033032_20180706_20200831_02_T1 (New Mexico)	Uncertainty (%)	10.250	14.330	10.820	15.180
	R^2	0.752	0.796	0.787	0.632
	Radical offset	0.043	0.031	0.040	0.031
	Radical slope	0.746	0.741	0.708	0.652

Table 7. Spatial performance of Resourcesat-2 Advanced Wide Field Sensor.

[RER, relative edge response; FWHM, full width at half maximum; MTF, modulation transfer function; NIR, near infrared; SWIR, shortwave infrared]

Spatial analysis	RER	FWHM (pixels)	MTF at Nyquist
Band 2—green	0.375	2.32	0.025
Band 3—red	0.383	2.32	0.035
Band 4—NIR	0.381	2.29	0.034
Band 5—SWIR	0.358	2.36	0.030

Summary and Conclusions

This report summarizes the sensor performance of the Resourcesat-2 Advanced Wide Field Sensor (AWiFS) system based on the U.S. Geological Survey Earth Resources Observation and Science Cal/Val Center of Excellence (ECCOE) system characterization process. In summary, we have determined that this sensor provides an interior geometric performance in the range of −16.080 (−0.268 pixel) to 35.520 meters (m; 0.592 pixel) in easting and −25.680 (−0.428 pixel) to 23.400 m (0.390 pixel) in northing in band-to-band registration, an exterior geometric error of −64.262 (−1.071 pixels) to −19.059 m (−0.318 pixel) in easting and −29.028 (−0.484 pixel) to 41.249 m (0.687 pixel) in northing offset in comparison to the Landsat 8 Operational Land Imager, a radiometric performance in the range of −0.065 to 0.083 in offset and 0.652 to 1.056 in slope, and a spatial performance in the range of 2.29–2.36 pixels for full width at half maximum, with a modulation transfer function at a Nyquist frequency in the range of 0.030–0.035.

In conclusion, the team has completed an ECCOE standardized system characterization of the Resourcesat-2 AWiFS sensing system. Although the team followed characterization procedures that are standardized across the many sensors and sensing systems under evaluation, these procedures are customized to fit the individual sensor as was done with AWiFS. The team has acquired the data, defined proper testing methodologies, carried out comparative tests against specific references, recorded measurements, completed data analyses, and quantified sensor performance accordingly. The team also endeavored to retain all data, measurements, and methods. This is key to ensure that all data and measurements are archived and accessible and that the performance results are reproducible.

The ECCOE project and associated Joint Agency Commercial Imagery Evaluation partners are always interested in reviewing sensor and remote sensing application assessments and would like to see and discuss information on similar data and product assessments and reviews. If you would like to discuss system characterization with the U.S. Geological Survey ECCOE and (or) the Joint Agency Commercial Imagery Evaluation team, please email us at eccoe@usgs.gov.

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