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System Characterization Report on the Gaofen-1

Chapter B of

System Characterization of Earth Observation Sensors

Open-File Report 2021–1030–B

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

Cover: A true color image of the Kingdom of Bahrain captured by the Gaofen-1 wide field of view camera. Image courtesy of China National Space Administration Earth Observation and Data Center.

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By Mahesh Shrestha,[1] Aparajithan Sampath,[1] Shankar N. Ramaseri Chandra,[1] Jon B. Christopherson,[1] Jerad Shaw,[1] Gregory L. Stensaas,[1] and Cody Anderson[2]

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[1]KBR, Inc., under contract to the 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)

Abbreviations

ECCOE	Earth Resources Observation and Science Cal/Val Center of Excellence
GSD	ground sample distance
JACIE	Joint Agency Commercial Imagery Evaluation
OLI	Operational Land Imager
USGS	U.S. Geological Survey

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Executive Summary

This report addresses system characterization of Gaofen-1 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 2020. These reports present the detail 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.

Gaofen represents a series of Chinese high-resolution Earth observation satellites. More than 12 satellites have been launched in the Gaofen series, beginning with Gaofen-1 in 2013. Satellites within the series have varying infrared, radar, and optical imaging capabilities. The primary goal for the satellite is to provide near real-time observations for climate change monitoring, geographical mapping, precision agriculture support, environmental and resource surveying, and disaster prevention. More information on Chinese satellites and sensors is available within the "2020 Joint Agency Commercial Imagery Evaluation—Remote Sensing Satellite Compendium" and at http://www.cnsageo.com/#/detailIndex?secondIndex=2&id=3&code=8.

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 Gaofen-1 has an interior geometric performance of −0.48 meter (m) (−0.03 pixel) northing and 0.42 m (0.03 pixel) easting offset for band 1, −0.99 m (−0.06 pixel) northing and −0.38 m (−0.02 pixel) easting offset for band 2, −0.45 m (−0.03) northing and 0.83 m (0.05 pixel) easting offset for band 3, −3.20 m (−0.20 pixel) northing and 1.44 m (0.09 pixel) easting offset for band 4 in band-to-band registration. Similarly, Gaofen-1 has an exterior geometric performance of 7.50 m (0.48 pixel) easting and 109.50 m (7.30 pixels) northing offset in comparison to the Landsat 8 Operational Land Imager; a radiometric performance in the range of −0.014 to 0.149 (absolute reflective difference); and a spatial performance in the range of 1.1 to 2.0 pixels at full width at half maximum, with a modulation transfer function at a Nyquist frequency in the range of 0.040 to 0.250.

Introduction

Gaofen-1 is a high-resolution multispectral satellite launched in 2013 by China on a Long March-2D rocket from the Jiuquan Satellite Launch Center, Ejin Banner, Alxa League, Inner Mongolia, China. Gaofen-1 is the first satellite in the China High-resolution Earth Observation System. The satellite is based on the China Academy of Space Technology-2000 bus built by the Shanghai Academy of Spaceflight Technology for the China National Space Administration. Gaofen-1 carries a panchromatic and multispectral camera-1 and a wide field of view camera for high-resolution Earth monitoring. Gaofen-1 is the first satellite of Gaofen series. Satellites within the series have varying infrared, radar, and optical imaging capabilities. The primary goal for the satellite is to provide near real-time observations for climate change monitoring, geographical mapping, precision agriculture support, environmental and resource surveying, and disaster prevention.

The data analysis results provided within 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.

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 Gaofen-1 sensor is described. The performance of the system is limited to geometric, radiometric, and spatial. The scope of the geometric assessment is limited to testing

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the interior alignments of spectral bands against each other, and the exterior alignment is tested in reference to Landsat 8 Operational Land Imager (OLI).

The U.S. Geological Survey (USGS) Earth Resources Observation and Science 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 and provides information about the Gaofen-1 sensor.

Satellite and Operational Details

Key satellite and operational details of Gaofen-1 are listed in table 1.

Sensor(s) Information

The imaging sensor details for Gaofen-1 are listed in table 2. The relative spectral responses for Gaofen-1 are shown in figure 1.

Table 1. Satellite and operational details for Gaofen-1.

[kg, kilogram; NIR, near infrared; >, greater than; km, kilometer; °, degree; ±, plus or minus; m, meter]

Product information	Gaofen-1 data
Satellite and operational information	
Product name	Top of Atmosphere reflectance
Satellite name	Gaofen-1
Launch mass	1,080 kg
Sensor name(s)	Wide field of view
Sensor type	Multispectral (blue, green, red, and NIR bands)
Mission type	Global land-monitoring mission
Launch date	April 26, 2013
Number of satellites	>12
Expected lifetime	5–8 years
Operator	China National Space Administration
Operational details	
Operating orbit	Sun-synchronous orbit
Orbital altitude range	645 km
Sensor angle altitude	98.05° inclination
Orbit period	97.62 minutes
Imaging time	10:30 a.m.
Transponders	S band, C band, X band
Geographic coverage	Global
Temporal resolution	4 days
Nadir repeat	69 days
Temporal coverage	2013 to present
Imaging angles	±40°
Ground sample distance(s)	16 m
Data licensing	Restricted
Data pricing	Free
Product abstract	http://www.cnsageo.com/#/detailIndex?secondIndex=2&id=3&code=8
Product locator	http://www.cnsageo.com/#/

Table 2. Imaging sensor details for Gaofen-1.

[The wide field of view (WFV) sensor has a swath width of 800 kilometers (using four cameras—WFV1, WFV2, WFV3, and WFV4); µm, micrometer; m, meter; NIR, near infrared]

Spectral band(s) details	Gaofen-1			
	Lower band (µm)	Upper band (µm)	Radiometric resolution (bits)	Ground sample distance (m)
Band 1—Blue	0.45	0.52	10	16
Band 2—Green	0.52	0.59	10	16
Band 3—Red	0.63	0.69	10	16
Band 4—NIR	0.77	0.89	10	16

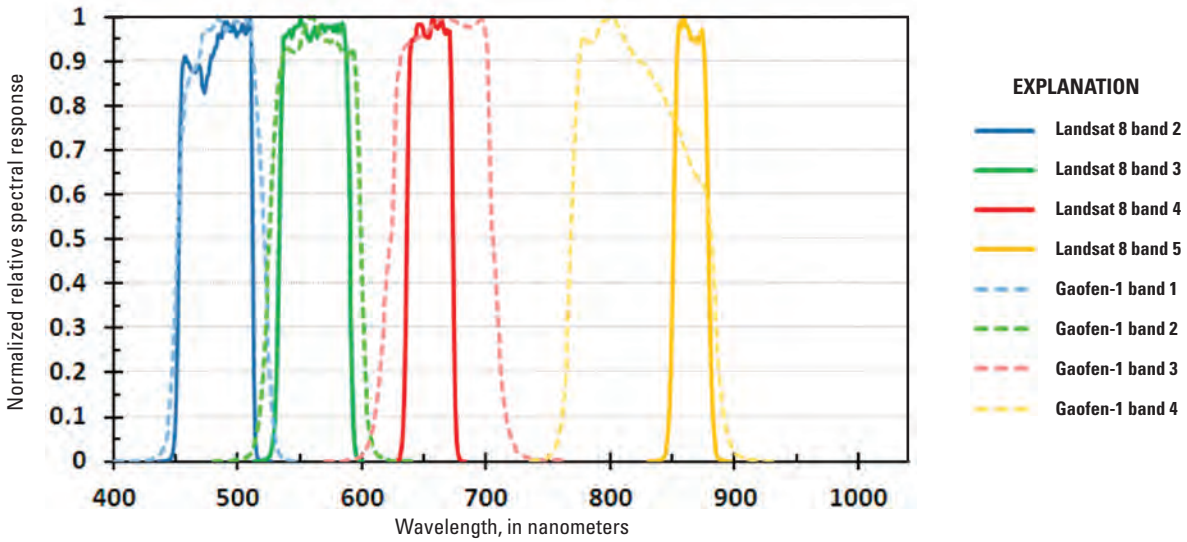

Figure 1. Gaofen-1 relative spectral response (modified from Li and others, 2016).

Procedures

The USGS 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 external 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 Earth Resources Observation and Science Center by the ECCOE project.

Measurements

The observed USGS measurements are listed in table 3. Physical error, in meters, is calculated by the GSD (16 meters [m]) multiplied by the pixel error. Details about the methodologies used are outlined in the "Analysis" section.

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

[USGS, U.S. Geological Survey; m, meter; RMSE, root mean square error; L8 OLI, Landsat 8 Operational Land Imager; WFV, wide field of view sensor; %, percent; FWHM, full width at half maximum; MTF, modulation transfer function; CNSA, China National Space Administration]

Description of product	Top of Atmosphere reflectance
USGS measurement results	
Geometric performance (easting, northing), in meters (pixels)	
Interior (band to band)	Band 1 Mean: −0.48 m (−0.03), 0.42 m (0.03) RMSE: 5.28 m (0.33), 5.31 m (0.33) Band 2 Mean: −0.99 m (−0.06), −0.38 m (−0.02) RMSE: 4.74 m (0.30), 4.58 m (0.29) Band 3 Mean: −0.45 m (−0.03), 0.83 m (0.05) RMSE: 5.47 m (0.34), 4.90 m (0.31) Band 4 Mean: −3.20 m (−0.20), 1.44 m (0.09) RMSE: 20.91 m (1.31), 19.31 m (1.21)
External (geometric location accuracy)	Mean: 7.50 m (0.48), 109.50 m (7.30) RMSE: 16.50 m (1.10), 109.65 m (7.31)
Radiometric performance (offset, slope)	
Radiometric evaluation (absolute and relative reflectance difference—Gaofen-1 versus L8 OLI)	WFV 2 band 1: 0.002, 0.84% WFV 2 band 2: 0.012, 3.75% WFV 2 band 3: 0.086, 19.47% WFV 2 band 4: 0.149, 26.46% WFV 3 band 1: −0.014, −5.79% WFV 3 band 2: 0.007, 2.04% WFV 3 band 3: 0.094, 20.90% WFV 3 band 4: 0.134, 23.36%
Spatial performance	
Spatial performance measurement	Band 1: FWHM = 1.1 pixels; MTF at Nyquist = 0.250 Band 2: FWHM = 1.1 pixels; MTF at Nyquist = 0.250 Band 3: FWHM = 1.4 pixels; MTF at Nyquist = 0.140 Band 4: FWHM = 2.0 pixels; MTF at Nyquist = 0.040
Known artifacts and quality issues	
USGS noted artifacts/quality issues	Although it was announced that Gaofen-1 data are free, most data are not available in the CNSA archive. Substantial geometric northing shift when compared with L8 OLI.

Analysis

This section of the report describes the geometric, radiometric, and spatial performance of Gaofen-1. Gaofen-1 geometric performance was analyzed using one scene whereas radiometric performance was analyzed using two near-coincident scene with Landsat 8 OLI.

Geometric Performance

The geometric performance for Gaofen-1 is characterized in terms of the interior (band-to-band alignment) and exterior (geometric location accuracy) geometric analysis results. Band to band (interior) analysis was performed by choosing one Gaofen-1 band as a reference and analyzed alignment of other bands with respect to the reference band. Geometric location accuracy (exterior) geometric performance was performed by comparing Gaofen-1 band with corresponding Landsat 8 OLI band.

Interior (Band to Band)

For this analysis, each band of the Gaofen-1 image was registered against all other bands using the Landsat Image Assessment System software to obtain the results. Results from one image (scene identifier: GF1_WFV2_W96.5_N42.6_20180809_L1A0003380205) were gathered to determine the mean error and root mean square error as listed in

table 4 with results represented in pixels at a 16-m GSD. Greater misalignment was seen with band 4 (near infrared) of poor spatial quality and its spectral distinctness from bands 1–3. 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 3 (red) of Gaofen-1 was compared against the Landsat 8 OLI panchromatic band, with a control uncertainty of 8 m, because both have about15-m GSD. Additionally, an orthographic image (scene identifier: L1C_T14TPP_A016440_20200429T171636) obtained from aerial photogrammetric means over Sioux Falls, South Dakota, was used to visually verify the results. The Landsat Image Assessment System software was used to complete a mutual information-based correlation assessment, and the mean error and root mean square error results are listed in table 5 with results represented in pixels at a 16-m GSD. A geometric error vector map showing the direction of the shift and relative magnitude of the shift, when compared with the Landsat 8 OLI, is provided in figure 2. Results after removal of the geometric bias (easting, 0.35 pixel; northing, 7.21 pixels) are shown in figure 3.

Radiometric Performance

For this analysis, cloud-free regions of interest were selected from near-coincident scene pairs to determine absolute and relative reflectance differences. Close nadir instruments were cross compared with the Landsat 8 OLI using a near-coincident scene from two Pseudo Invariant Calibration Sites: Egypt 1 (27.41 North, 26.38 East) and Libya 4 (28.55 North, 23.39 East). Pseudo Invariant Calibration Sites are the locations on Earth's surface that are stable over time. Because Egypt 1 and Libya 4 have similar radiometric intensity, and because of the lack of near-coincident scene options, the linear regression offset and slope were not calculated during this analysis. Statistical representations of the differences between the sensor pair are provided in tables 6 and 7, and graphical representations of the differences are shown in figures 4–7.

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

[RMSE, root mean square error]

Band	Mean error (easting)	Mean error (northing)	RMSE (easting)	RMSE (northing)
Reference—Band 1				
Band 2	0.00	−0.02	0.08	0.09
Band 3	0.00	−0.03	0.08	0.09
Band 4	−0.15	0.13	1.33	1.30
Reference—Band 2				
Band 1	0.00	0.02	0.08	0.09
Band 3	0.00	−0.01	0.07	0.07
Band 4	−0.31	−0.12	1.18	1.11
Reference—Band 3				
Band 1	0.00	0.03	0.08	0.09
Band 2	0.00	0.01	0.07	0.07
Band 4	−0.14	0.26	1.41	1.21

Table 5. Geometric error relative to Landsat 8 Operational Land Imager.

[ID, identifier; RMSE, root mean square error; m, meter]

Scene ID	Mean error (easting)	Mean error (northing)	RMSE (easting)	RMSE (northing)
GF1_WFV2_W96.5_N42.6_20180809 _L1A0003380205	0.47 pixel (7.50 m)	6.84 pixels (109.50 m)	1.03 pixels (16.50 m)	6.85 pixels (109.65 m)

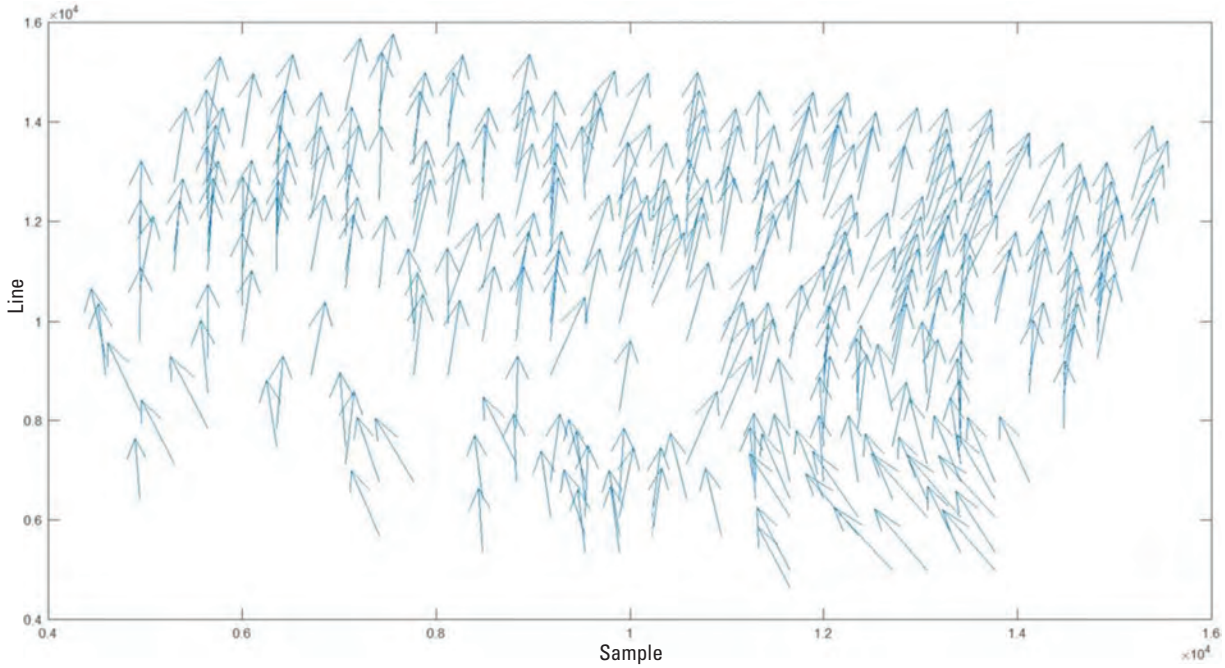

Figure 2. Relative geometric error comparison for Landsat 8 Operational Land Imager and Gaofen-1.

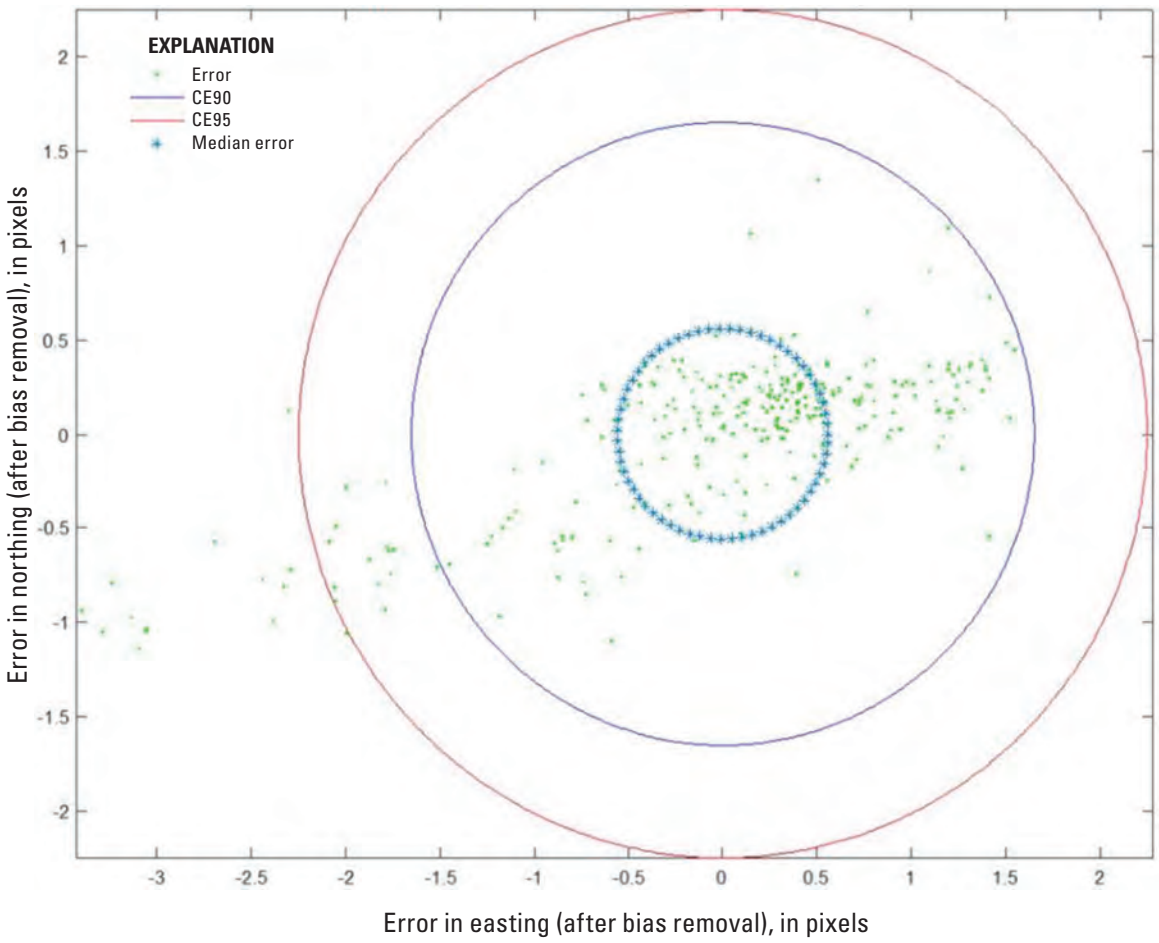

Figure 3. Relative geometric error comparison for Landsat 8 Operational Land Imager and Gaofen-1 after bias removal. CE90 and CE95 represent the radius of the circle such that there is a 90-percent and a 95-percent probability that the error lies within the circle, respectively.

Table 6. Top of Atmosphere reflectance comparison between Gaofen-1 wide field of view camera 2 and Landsat 8 Operational Land Imager over Egypt 1.

[NIR, near infrared; L8, Landsat 8; GF1, Gaofen-1; %, percent]

Reflectance difference	Band 1—Blue	Band 2—Green	Band 3—Red	Band 4—NIR
Absolute difference (L8–GF1)	0.002	0.012	0.086	0.149
Relative difference (%)	0.84	3.76	19.48	26.46

Spatial Performance

For this analysis, the image quality estimation software, designed based on Helder and others (2003), was used to determine the full width at half maximum and modulation transfer function at Nyquist frequency, as listed in table 8.

Table 7. Top of Atmosphere reflectance comparison between Gaofen-1 wide field of view camera 3 and Landsat 8 Operational Land Imager over Libya 4.

[NIR, near infrared; L8, Landsat 8; GF1, Gaofen-1; %, percent]

Reflectance difference	Band 1—Blue	Band 2—Green	Band 3—Red	Band 4—NIR
Absolute difference (L8–GF1)	−0.014	0.007	0.094	0.134
Relative difference (%)	−5.78	2.05	20.90	23.36

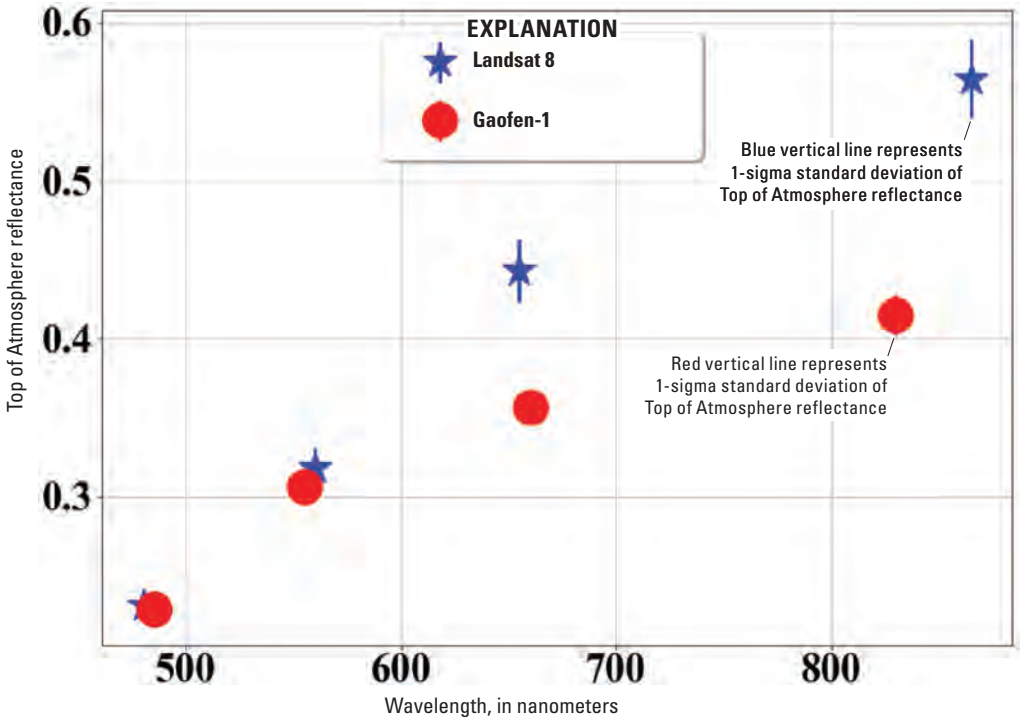

Figure 4. Top of Atmosphere reflectance comparison between Gaofen-1 wide field of view camera 2 and Landsat 8 Operational Land Imager over Egypt 1.

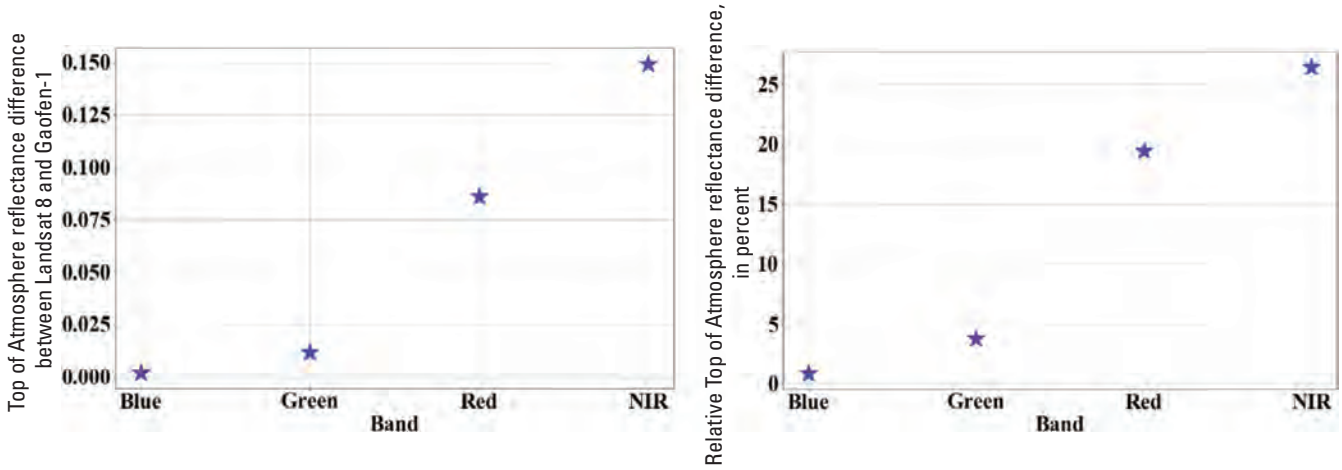

Figure 5. Top of Atmosphere reflectance difference between Gaofen-1 wide field of view camera 2 and Landsat 8 Operational Land Imager over Egypt 1. [NIR, near infrared]

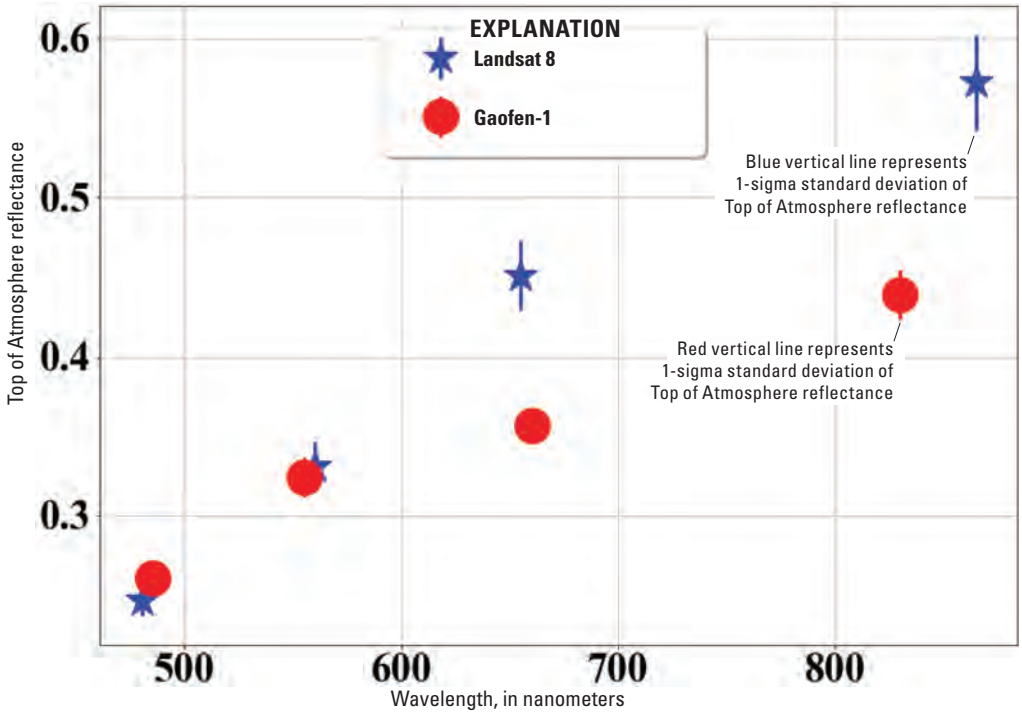

Figure 6. Top of Atmosphere reflectance comparison between Gaofen-1 wide field of view camera 3 and Landsat 8 Operational Land Imager over Libya 4.

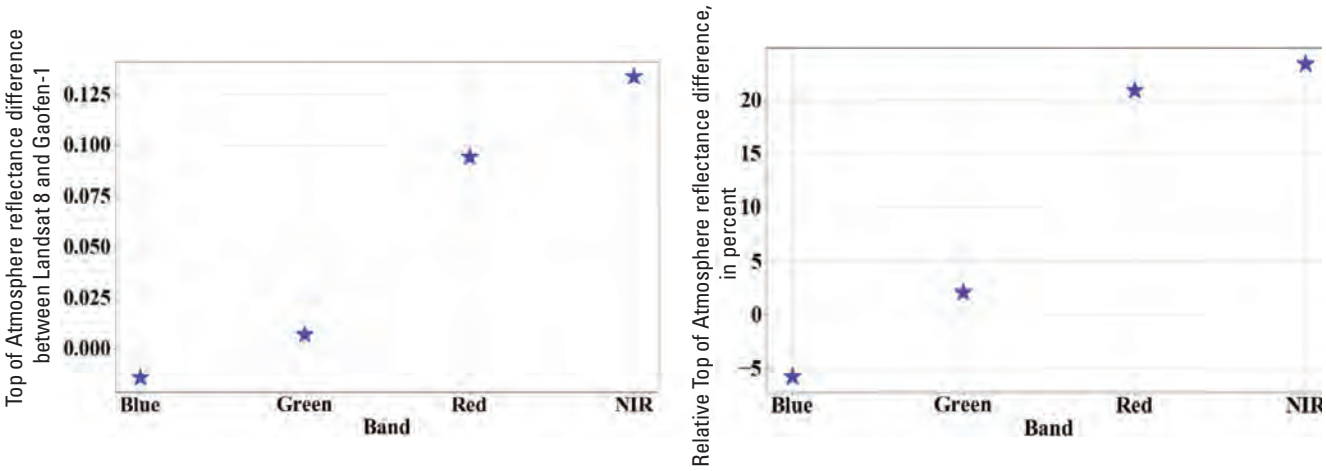

Figure 7. Top of Atmosphere reflectance difference between Gaofen-1 wide field of view camera 3 and Landsat 8 Operational Land Imager over Libya 4. [NIR, near infrared]

Table 8. Spatial performance of Gaofen-1.

[FWHM, full width at half maximum; MTF, modulation transfer function; NIR, near infrared]

Spatial analysis	FWHM	MTF at Nyquist
Band 1—Blue	1.1 pixels	0.250
Band 2—Green	1.1 pixels	0.250
Band 3—Red	1.4 pixels	0.140
Band 4—NIR	2.0 pixels	0.040

Summary and Conclusions

This report summarizes the sensor performance of the Gaofen-1 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 of −0.48 meter (m) (−0.03 pixel) northing and 0.42 m (0.03 pixel) easting offset for band 1, −0.99 m (−0.06 pixel) northing and −0.38 m (−0.02 pixels) easting offset for band 2, −0.45 m (−0.03 pixel) northing and 0.83 m (0.05 pixel) easting offset for band 3, −3.20 m (−0.20 pixel) northing and 1.44 m (0.09 pixel) easting offset for band 4 in band-to-band registration; similarly it has an exterior geometric performance of 7.50 m (0.48 pixel) easting and 109.50 m (7.30 pixels) northing offset, a radiometric performance of −0.014 to 0.149 (absolute reflectance difference), and a spatial performance of 1.1 to 2.0 pixels at full width at half maximum, with a modulation transfer function at a Nyquist frequency of 0.040 to 0.250.

In conclusion, we have completed an ECCOE standardized system characterization of the Gaofen-1 sensing system. Although we follow characterization procedures that are standardized across the many sensors and sensing systems under evaluation, these procedures are customized to fit the individual sensor as we have done with Gaofen-1. Our 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 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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