USGS
science for a changing world

System Characterization Report on the Gaofen-6

Chapter M of
System Characterization of Earth Observation Sensors

Open-File Report 2021–1030–M

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

System Characterization Report on the Gaofen-6

By Aparajithan Sampath,[1] Jon Christopherson,[1] Seonkyung Park,[1] Minsu Kim,[1] Gregory L. Stensaas,[2] and Cody Anderson[2]

Chapter M of
System Characterization of Earth Observation Sensors

Compiled by Shankar N. Ramaseri Chandra[1]

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

[2]U.S. Geological Survey.

Open-File Report 2021–1030–M

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

U.S. Geological Survey, Reston, Virginia: 2024

Suggested citation:
Sampath, A., Christopherson, J., Park, S., Kim, M., Stensaas, G.L., and Anderson, C., 2024, System characterization report on the Gaofen-6, chap. M *of* Ramaseri Chandra, S.N., comp., System characterization of Earth observation sensors: U.S. Geological Survey Open-File Report 2021–1030, 9 p., https://doi.org/10.3133/ofr20211030M.

ISSN 2331-1258 (online)

Contents

Figures

Tables

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
USGS	U.S. Geological Survey
WFV	wide field of view

System Characterization Report on the Gaofen-6

By Aparajithan Sampath,[1] Jon Christopherson,[1] Seonkyung Park,[1] Minsu Kim,[1] Gregory L. Stensaas,[2] and Cody Anderson[2]

Executive Summary

Gaofen-6 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 satellites in this series 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 in the "2022 Joint Agency Commercial Imagery Evaluation—Remote Sensing Satellite Compendium" (Ramaseri Chandra and others, 2022).

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 of Gaofen-6. Results of these analyses indicate that Gaofen-6 has an interior geometric performance root mean square error ranging from 2.84 meters (m; 0.18 pixel) to 7.42 m (0.46 pixel) in easting and from 2.84 m (0.18 pixel) to 11.57 m (0.72 pixel) in northing in band-to-band registration, an exterior geometric performance root mean square error ranging from 154.50 m (8.80 pixels) in easting to 14.65 m (0.80 pixel) in northing in comparison to a corresponding Sentinel-2 scene, a radiometric performance ranging from 0.018 to 0.055 (in offset) and from 0.620 to 0.858 (in slope), and a spatial performance ranging from 2.10 to 2.30 pixels at full width at half maximum, with a modulation transfer function at a Nyquist frequency ranging from 0.040 to 0.055.

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

[2]U.S. Geological Survey.

Reference Cited

Ramaseri Chandra, S.N., Christopherson, J.B., Casey, K.A., Lawson, J., and Sampath, A., 2022, 2022 Joint Agency Commercial Imagery Evaluation—Remote sensing satellite compendium: U.S. Geological Survey Circular 1500, 279 p. [Also available at https://doi.org/10.3133/cir1500.] [Supersedes USGS Circular 1468.]

Introduction

This report addresses system characterization of Gaofen-6 and is part of a series of system characterization reports produced and delivered by the U.S. Geological Survey (USGS) Earth Resources Observation and Science Cal/Val Center of Excellence (ECCOE, U.S. Geological Survey, 2020a). 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.

Background

More than 12 satellites have been launched in the Gaofen series, beginning with Gaofen-1 in 2013, which was the first satellite in the China High-resolution Earth Observation System (Ramaseri Chandra and others, 2022). Gaofen-6 is a high-resolution multispectral satellite launched in 2018 by China on a Long March-2D rocket from the Jiuquan Satellite Launch Center (Ramaseri Chandra and others, 2022). 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 (China National Space Administration, 2019, Ramaseri Chandra and others, 2022). Gaofen-6 carries a panchromatic and multispectral camera and a wide field of view (WFV) camera for high-resolution Earth monitoring (Ramaseri Chandra and others, 2022). In this study, only the data captured by the WFV camera are examined.

The data analysis results provided in this report have been derived from approved Joint Agency Commercial Imagery Evaluation (JACIE) processes and procedures. JACIE (U.S. Geological Survey, 2020b) 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.

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-6 sensor is described. The performance of the system is limited to geometric, radiometric, and spatial qualities. The scope of the geometric assessment is limited to testing the interior alignments of spectral bands against each other. The exterior alignment is tested in reference to Sentinel-2.

The USGS ECCOE project (U.S. Geological Survey, 2020b), 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/office-of-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 provides the nominal system characteristics that have a direct bearing on the imaging performance of the sensor. The nominal system characteristics include the satellite information (constellation, expected lifetime, and so on), operational details of the satellite (altitude, local imaging time, and so on), and the sensor characteristics (wavelength bands, ground sample distance [GSD], and so on). An understanding of these relevant system characteristics is useful and informs the parameters of analyses.

Satellite and Operational Information

The nominal characteristics and operational details of Gaofen-6 that are most pertinent to the characterization process are provided in table 1.

Sensor Information

The specific WFV imaging sensor details for Gaofen-6 that are most pertinent to the characterization process are listed in table 2. In this report, we have focused the radiometric comparison on bands 1–4 and band 7 while completing band registration (geometric) assessments and spatial assessments on all bands.

Table 1. Satellite and operational details of the Gaofen-6 sensor.

[kg, kilogram; km, kilometer; °, degree; ±, plus or minus; m, meter]

Product information	Gaofen-6 data
Satellite and operational information	
Product name	Top of Atmosphere reflectance
Satellite name	Gaofen-6
Launch mass	1,080 kg
Sensor name	Wide Field of View
Sensor type	Multispectral
Mission type	Global land-monitoring mission
Launch date	June 2, 2018
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.
Geographic coverage	Global
Temporal resolution	4 days
Nadir repeat	41 days
Temporal coverage	2018 to present
Imaging angles	±35°
Ground sample distance	16 m
Data licensing	Restricted
Data pricing	Free

Table 2. Imaging sensor details for the Gaofen-6 sensor.

[nm, nanometer; m, meter; NIR, near infrared]

Spectral band details	Gaofen-6			
	Lower band (nm)	Upper band (nm)	Radiometric resolution (bits)	Ground sample distance (m)
Band 1—blue	450	520	16	16
Band 2—green	520	590	16	16
Band 3—red	630	690	16	16
Band 4—NIR	770	890	16	16
Band 5—red edge 1	690	730	16	16
Band 6—red edge 2	730	770	16	16
Band 7—coastal	400	450	16	16
Band 8—yellow	590	630	16	16

Standardized 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 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.

[m, meter; RMSE, root mean square error; L8 OLI, Landsat 8 Operational Land Imager; FWHM, full width at half maximum; MTF, modulation transfer function; USGS, U.S. Geological Survey; CNSA, China National Space Administration; MSI, multispectral instrument]

Description of product	Top of Atmosphere reflectance
Geometric performance (easting, northing), in meters (pixels)	
Interior (band to band)	Band 1 (blue) average Mean: 0.34 m (0.02), −1.58 m (−0.09) RMSE: 3.13 m (0.19), 3.93 m (0.25) Band 2 (green) average Mean: 0.30 m (0.02), −0.54 m (−0.03) RMSE: 7.42 m (0.46), 11.57 m (0.72) Band 3 (red) average Mean: 0.22 m (0.01), −1.35 m (-0.08) RMSE: 2.68 m (0.17), 4.00 m (0.25) Band 4 (near infrared) average Mean: 0.93 m (0.06), 2.32 m (0.14) RMSE: 6.03 m (0.38), 8.00 m (0.50) Band 5 (red edge 1) average Mean: −0.02 m (0.00), 0.16 m (0.01) RMSE: 2.32 m (0.15), 2.95 m (0.18) Band 6 (red edge 2) average Mean: 0.26 m (0.02), 2.90 m (0.18) RMSE: 4.08 m (0.26), 6.20 m (0.39) Band 7 (coastal blue) average Mean: −0.67 m (−0.04), −2.63 m (−0.16) RMSE: 5.40 m (0.34), 8.22 m (0.51) Band 8 (yellow) average Mean: −1.05 m (−0.07), 0.61 m (0.04) RMSE: 2.84 m (0.18), 3.35 m (0.21)
Exterior (geometric location accuracy)	Mean: −144.50 m (−8.47 pixels), 10.50 m (0.69 pixel) RMSE: 154.50 m (8.80 pixels), 14.65 m (0.80 pixel)
Radiometric performance (offset, slope)	
Radiometric evaluation (linear regression—Gaofen-6 versus L8 OLI reflectance)	Band 1—blue (offset, slope): 0.019, 0.858 Band 2—green (offset, slope): 0.023, 0.820 Band 3—red (offset, slope): 0.055, 0.620 Band 4—near infrared (offset, slope): 0.043, 0.651 Band 7—coastal blue (offset, slope): 0.018, 0.829
Spatial performance	
Spatial performance measurement	Band 1: FWHM = 2.25 pixels; MTF at Nyquist = 0.040 Band 2: FWHM = 2.30 pixels; MTF at Nyquist = 0.045 Band 3: FWHM = 2.25 pixels; MTF at Nyquist = 0.050 Band 4: FWHM = 2.25 pixels; MTF at Nyquist = 0.045 Band 5: FWHM = 2.30 pixels; MTF at Nyquist = 0.045 Band 6: FWHM = 2.25 pixels; MTF at Nyquist = 0.045 Band 7: FWHM = 2.10 pixels; MTF at Nyquist = 0.055 Band 8: FWHM = 2.15 pixels; MTF at Nyquist = 0.045
Known artifacts and quality issues	
USGS noted artifacts/quality issues	• Although it was announced that Gaofen-6 data are free, most data are not available in the CNSA archive. • The geometric easting shift was substantial when compared with the Sentinel MSI.

Analysis

The following section presents the system characterization analyses for Gaofen-6. The analyses were geometric, radiometric, and spatial performance. Geometric performance included interior (band-to-band) and exterior (geometric location accuracy) performance.

Geometric Performance

The geometric performance of the sensor is analyzed in two stages. In the first stage, the registration quality of bands of the data compared against each other are measured and quantified. In the second stage, the geolocation of the product is validated by comparing against a dataset of higher accuracy.

Interior (Band-to-Band) Performance

For this analysis, each band of the Gaofen-6 was registered against all other bands using the Landsat Image Assessment System software to obtain the results. Results from one image (GF6_WFV_W87.5_N42.5_20201009_L1A1120042103-2) 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 observed with bands 5 and above (higher than near-infrared wavelengths), likely as a result of poorer spatial quality and its spectral distinctness from bands 1–4. Together, the interior and exterior geometric analysis results provide a comprehensive assessment of geometric accuracy.

Exterior (Geometric Location Accuracy) Performance

For this analysis, band 3 (red) of Gaofen-6 was compared against the Sentinel multispectral instrument band 3 panchromatic band, with a control uncertainty of 8 m. The GSD of the Sentinel multispectral instrument dataset (10 m) was resampled to match the Gaofen-6 (16 m) dataset. 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 shift and relative magnitude of the shift, when compared with Sentinel data, is provided in figure 1. Results after removal of the geometric bias (0.35 pixel for easting and 7.21 pixels for northing) are shown in figure 2.

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 at the pixel level with the Landsat 8 (U.S. Geological Survey, 2020c) Operational Land Imager using a near-coincident scene (that is, each pixel was compared to its corresponding Landsat 8 Operational Land Imager pixel). Statistical and graphical representations of the difference between the sensor pair are listed in table 6 and shown in figure 3.

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

[RMSE, root mean square error]

Reference band 1	Mean error (easting)	Mean error (northing)	RMSE error (easting)	RMSE error (northing)
Band 2	−0.04	−0.03	0.12	0.10
Band 3	−0.03	−0.01	0.14	0.14
Band 4	−0.03	0.01	0.31	0.28
Band 5	−0.16	−0.01	0.30	0.20
Band 6	−0.08	0.05	0.37	0.32
Band 7	−0.13	0.07	0.20	0.16
Band 8	−0.20	0.06	0.27	0.16

Table 5. Geometric error of Gaofen-6 relative to Sentinel multispectral instrument band 3.

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

Scene ID	Mean error (easting)	Mean error (northing)	RMSE error (easting)	RMSE error (northing)
GF6_WFV_W87.5_N42.5_20201009_L1A1120042103-2	−8.47 pixels (−144.50 m)	−0.69 pixel (−10.50 m)	8.80 pixels (154.50 m)	0.80 pixel (14.65 m)

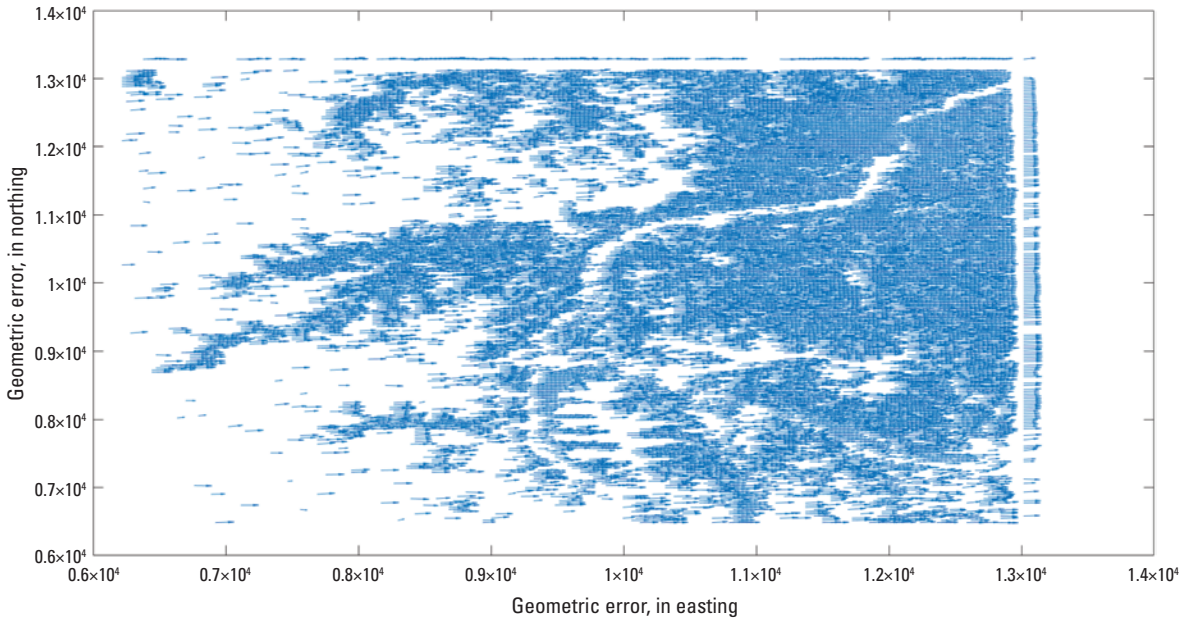

Figure 1. Geometric error comparison for Sentinel multispectral instrument band 3 and Gaofen-6. The comparisons were performed over the Sioux Falls, South Dakota, area.

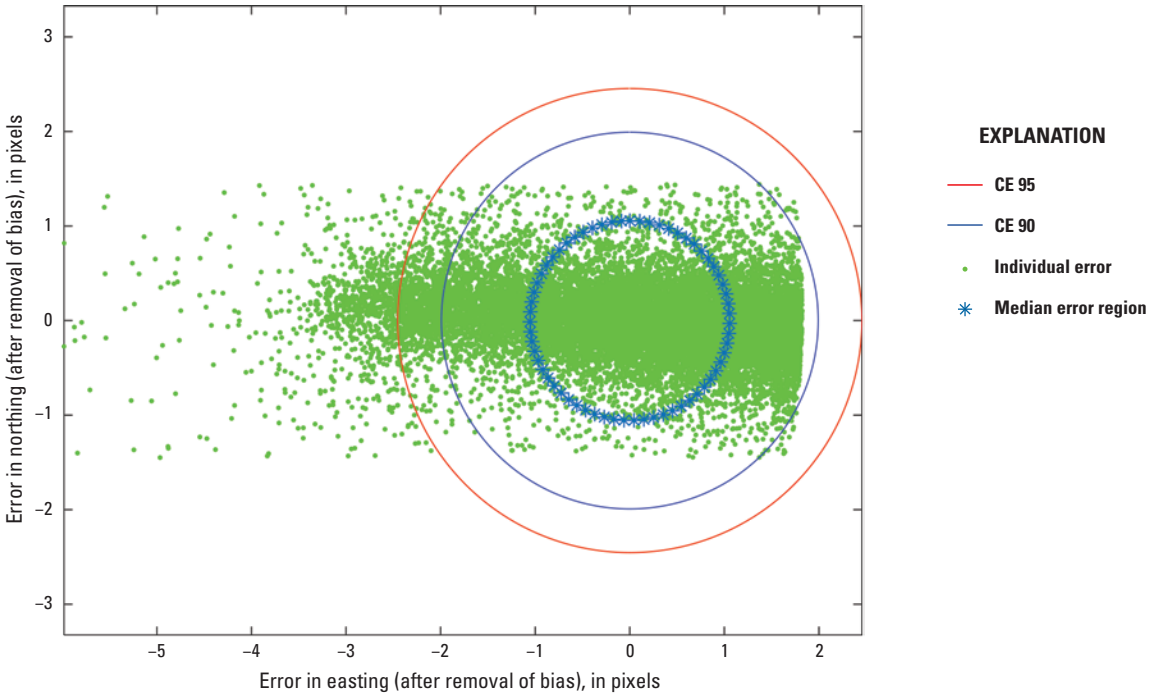

Figure 2. Geometric error for Gaofen-6 image in comparison with Sentinel multispectral instrument band 3 after bias removal (–8.47 pixels in easting and –0.69 pixel in northing). The red circle represents the circular error at 95 percent (CE 95), and the blue circle represents the circular error at 90 percent (CE 90).

Table 6. Top of Atmosphere reflectance comparison of the Gaofen-6 Wide Field of View sensor against the Landsat 8 Operational Land Imager.

[The scene identifier for this dataset is Gaofen: GF6_WFV_W87.5_N42.5_20201009_L1A1120042103-2 (Sioux Falls, South Dakota) and Landsat 8: LC80230302020283LGN00; NIR, near infrared; %, percent; R^2, coefficient of determination]

Statistics	Band 1—Blue	Band 2—Green	Band 3—Red	Band 4—NIR	Band 7—Coastal blue
Uncertainty (%)	3.88	6.60	9.25	2.30	2.54
R^2	0.932	0.946	0.919	0.887	0.927
Radical offset	0.019	0.023	0.055	0.043	0.018
Radical slope	0.858	0.820	0.620	0.651	0.829

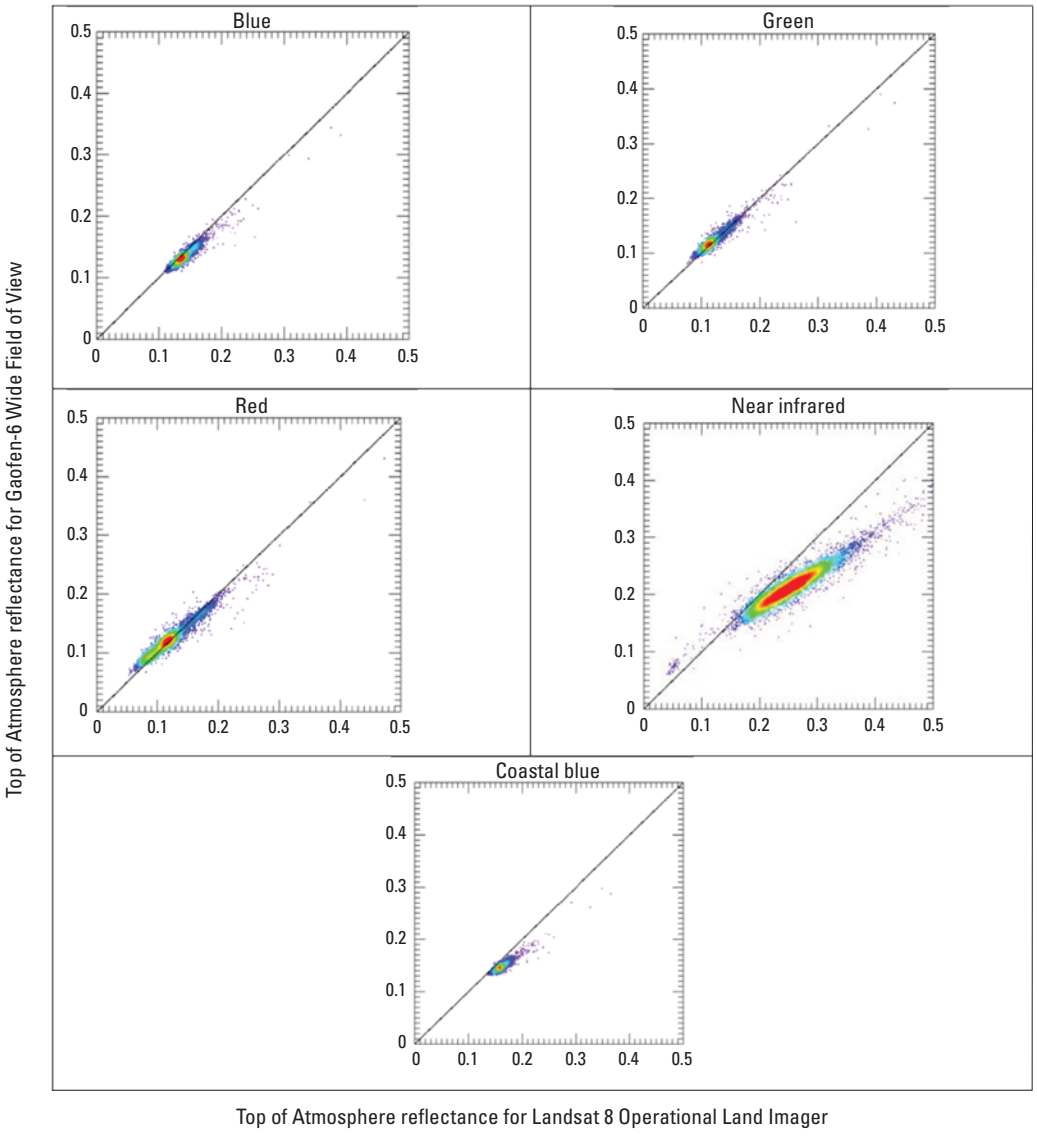

Figure 3. Top of Atmosphere reflectance between the Gaofen-6 Wide Field of View sensor and Landsat 8 Operational Land Imager.

Spatial Performance

For this analysis, the Image Quality Estimation software, designed 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 7. Spatial performance of the Gaofen-6 sensor.

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

Spatial analysis	FWHM	MTF at Nyquist
Band 1—blue	2.25	0.040
Band 2—green	2.30	0.045
Band 3—red	2.25	0.050
Band 4—NIR	2.25	0.045
Band 5—red edge 1	2.30	0.045
Band 6—red edge 2	2.25	0.045
Band 7—coastal	2.10	0.055
Band 8—yellow	2.15	0.045

Summary and Conclusions

This report summarizes the sensor performance of the Gaofen-6 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 root mean square error ranging from 2.84 meters (m; 0.18 pixel) to 7.42 m (0.46 pixel) in easting and from 2.95 m (0.18 pixel) to 11.57 m (0.72 pixel) in northing in band-to-band registration, an exterior geometric performance root mean square error ranging from 154.50 m (8.80 pixels) in easting to 14.65 m (0.80 pixel) in northing in comparison to a corresponding Sentinel-2 scene, a radiometric performance ranging from 0.018 to 0.055 (in offset) and from 0.620 to 0.858 (in slope) in comparison to the corresponding Landsat Operational Land Imager scene, and a spatial performance ranging from 2.10 to 2.30 pixels at full width at half maximum, with a modulation transfer function at a Nyquist frequency ranging from 0.040 to 0.055.

In conclusion, the team has completed an ECCOE standardized system characterization of the Gaofen-6 Wide Field of View 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 Gaofen-6. 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.

Selected References

China National Space Administration, 2019, Standard of China space: China National Space Administration web page, accessed April 4, 2022, at https://www.cnsa.gov.cn/english/n6465684/n6465689/index.html?COLLCC=4074507418.

Helder, D., Choi, T. and Rangaswamy, M., 2004, In-flight characterization of spatial quality using point spread functions, *in* Morain, S.A., and Budge, A.M., Post-launch calibration of satellite sensors: CRC Press, p. 151–170.

Ramaseri Chandra, S.N., Christopherson, J.B., Casey, K.A., Lawson, J., and Sampath, A., 2022, 2022 Joint Agency Commercial Imagery Evaluation—Remote sensing satellite compendium: U.S. Geological Survey Circular 1500, 279 p. [Also available at https://doi.org/10.3133/cir1500.] [Supersedes USGS Circular 1468.]

U.S. Geological Survey, 2020a, EROS CalVal Center of Excellence (ECCOE): U.S. Geological Survey web page, accessed April 9, 2022, at https://www.usgs.gov/calval.

U.S. Geological Survey, 2020b, EROS CalVal Center of Excellence (ECCOE)—JACIE: U.S. Geological Survey web page, accessed April 9, 2022, at https://www.usgs.gov/calval/jacie?qt-science_support_page_related_con=3#qt-science_support_page_related_con.

U.S. Geological Survey, 2020c, Landsat missions—Glossary and acronyms: U.S. Geological Survey web page, accessed April 9, 2022, at https://www.usgs.gov/landsat-missions/glossary-and-acronyms.

For more information about this publication, contact:
Director, USGS Earth Resources Observation and Science Center
47914 252nd Street
Sioux Falls, SD 57198
605–594–6151

For additional information, visit: https://www.usgs.gov/centers/eros

Publishing support provided by the
Rolla Publishing Service Center

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20211030M