USGS
science for a changing world

System Characterization Report on the Amazônia-1 Multispectral Sensor

Chapter N of
System Characterization of Earth Observation Sensors

Open-File Report 2021–1030–N

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

Cover: Satellite image of São Paulo, Brazil, being imaged with the Amazônia-1 multispectral sensor. Images courtesy of the Instituto Nacional de Pesquisas Espaciais, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Image of Earth from Analytical Graphics, Inc., Systems Tool Kit.

System Characterization Report on the Amazônia-1 Multispectral Sensor

By James C. Vrabel,[1] Gregory L. Stensaas,[2] Cody Anderson,[2] Jon Christopherson,[3] Minsu Kim, [3] and Seonkyung Park[3]

Chapter N of

System Characterization of Earth Observation Sensors

Compiled by Shankar N. Ramaseri Chandra[3]

[1]Imaging Technology Consultants, Inc., under contract to the U.S. Geological Survey.

[2]U.S. Geological Survey.

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

Open-File Report 2021–1030–N

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

U.S. Geological Survey, Reston, Virginia: 2022

Suggested citation:
Vrabel, J.C., Stensaas, G.L., Anderson, C., Christopherson, J., Kim, M., and Park, S., 2022, System characterization report on the Amazônia-1 multispectral sensor, chap. N *of* Ramaseri Chandra, S.N., comp., System characterization of Earth observation sensors: U.S. Geological Survey Open-File Report 2021–1030, 33 p., https://doi.org/10.3133/ofr20211030N.

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)
kilometer (km)	0.6214	mile (mi)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)

Abbreviations

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

System Characterization Report on the Amazônia-1 Multispectral Sensor

By James C. Vrabel,[1] Gregory L. Stensaas,[2] Cody Anderson,[2] Jon Christopherson,[3] Minsu Kim,[3] and Seonkyung Park[3]

Executive Summary

This report addresses system characterization of the Instituto Nacional de Pesquisas Espaciais Amazônia-1 satellite 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. 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.

Amazônia-1 is a four-band imager with a 64-meter (m) pixel ground sample distance. Amazônia-1 was launched in February 2021 into a Sun-synchronous orbit of 752 kilometers with an inclination of 98.4 degrees and a swath width of 850 kilometers. The satellite has an expected lifetime of about 4 years. More information on Amazônia-1 is available in the "Land Remote Sensing Satellites Online Compendium" (https://calval.cr.usgs.gov/apps/compendium) and from the Instituto Nacional de Pesquisas Espaciais website (http://www.inpe.br/amazonia1/en/about_satellite/).

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 the Amazônia-1 satellite has an interior geometric performance in the range of −3.584 m (−0.056 pixel) to 0.320 m (0.005 pixel) in easting and −1.984 m (−0.031 pixel) to 2.048 m (0.032 pixel) in northing in band-to-band registration, an exterior geometric performance of −37.256 m (−0.621 pixel) to 54.758 m (0.913 pixel) in easting and −12.684 m (−0.211 pixel) to 54.898 m (0.915 pixel) in northing offset in comparison to the Landsat 8 Operational Land Imager, a radiometric performance in the range of 0.030 to 0.143 in offset and 0.662 to 0.825 in slope, and a spatial performance in the range of 1.62 to 2.06 pixels for full width at half maximum, with a modulation transfer function at a Nyquist frequency in the range of 0.062 to 0.115.

Introduction

The multispectral camera sensor onboard the Amazônia-1 multispectral remote sensing satellite is a medium-resolution land observation instrument consisting of four bands: blue, green, red, and near infrared (bands 1–4, respectively). Amazônia-1 is a medium-resolution multispectral satellite launched in 2021 by the Instituto Nacional de Pesquisas Espaciais (INPE) for the observation and monitoring of deforestation, especially in the Amazon region. Amazônia-1 is the first satellite to be completely designed, integrated, and tested in Brazil. The satellite uses the Multi-Mission Platform designed by the Brazilian Space Agency. Amazônia-1 carries the Wide Field Imager-2 sensor for medium-resolution land imaging. All Amazônia-1 data used in this assessment were downloaded from the INPE Amazônia-1 website (Instituto Nacional de Pesquisas Espaciais, 2019) and are publicly available. More information on the Amazônia-1 satellite and sensor is available in the "Land Remote Sensing Satellites Online Compendium" (https://calval.cr.usgs.gov/apps/compendium) and from the INPE website (http://www.inpe.br/amazonia1/en/about_satellite/).

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/calval/jacie?qt-science_support_page_related_con=3#qt-science_support_page_related_con.

[1]Imaging Technology Consultants, Inc., under contract to the U.S. Geological Survey.

[2]U.S. Geological Survey.

[3]KBR, Inc., under contract to the 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 Amazônia-1 sensor is described. The performance testing 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 the 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/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 describes the satellite and operational details and provides information about the Amazônia-1 Wide Field Imager sensor.

Satellite and Operational Details

The satellite and operational details for Amazônia-1 are listed in table 1.

Table 1. Satellite and operational details for the Amazônia-1 Wide Field Imager multispectral sensor.

[Data from Instituto Nacional de Pesquisas Espaciais (2020); WFI, Wide Field Imager; kg, kilogram; NIR, near infrared; INPE, Instituto Nacional de Pesquisas Espaciais; km, kilometer; °, degree; m, meter]

Product information	NewSat
Satellite and operational information	
Product name	Amazônia-1 WFI L4 DN (Level 4 digital number orthorectified product)
Satellite name	Amazônia-1
Satellite mass	637 kg
Sensor name	Advanced Wide Field Imager (WFI-2)
Sensor type	Multispectral (blue, green, red, NIR)
Mission type	Deforestation monitoring
Launch date	February 28, 2021
Number of satellites	1
Expected lifetime	4 years
Operator	INPE
Operational details	
Operating orbit	Sun-synchronous orbit
Orbital altitude	752 km
Orbital inclination	98.4°
Imaging time	10:30 a.m. (local time) descending node
Temporal resolution	5-day revisit
Temporal coverage	February 2021 to present (2022)
Imaging angles	Nadir
Ground sample distance	64 m
Swath width	850 km
Data licensing	Free
Data pricing	Free
Website	http://www2.dgi.inpe.br/catalogo/explore

Sensor Information

The imaging sensor details for Amazônia-1 are listed in table 2. The relative spectral responses for both cameras (left and right) on Amazônia-1 are shown in figures 1*A* and *B*.

Table 2. Imaging sensor details for Amazônia-1.

[µm, micrometer; m, meter; NIR, near infrared]

Spectral band details	Amazônia-1			
	Lower band (µm)	Upper band (µm)	Radiometric resolution (bits)	Ground sample distance (m)
Band 1—blue	0.45	0.52	10	64
Band 2—green	0.52	0.59	10	64
Band 3—red	0.63	0.69	10	64
Band 4—NIR	0.77	0.89	10	64

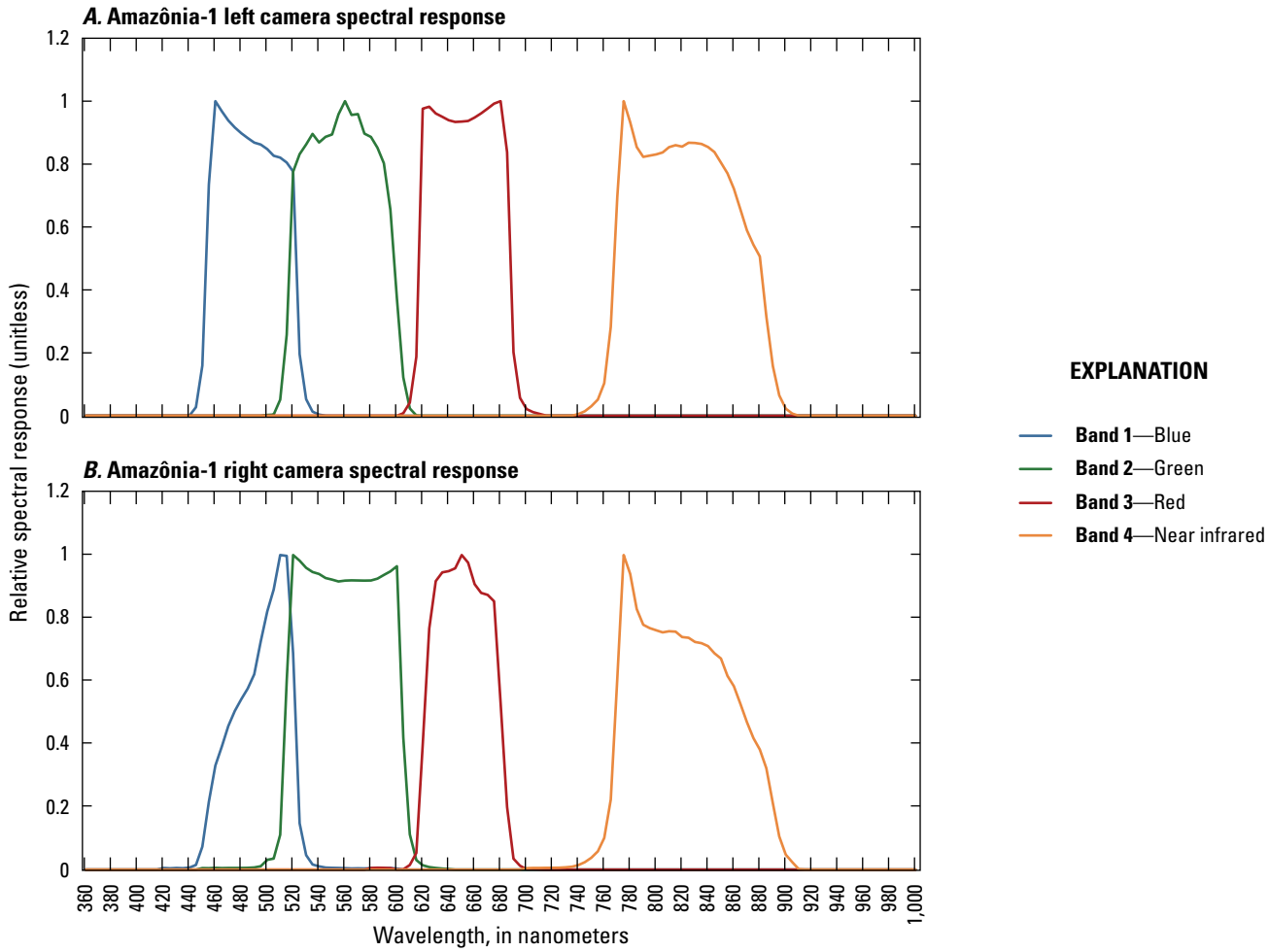


Figure 1. Amazônia-1 relative spectral response. *A*, left camera spectral response; *B*, right camera spectral response.

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 Earth Resources Observation and Science Center by the ECCOE project.

Measurements

The observed USGS measurements are listed in table 3. Details about the methodologies used are outlined in the "Analysis" section.

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

[m, meter; GSD, ground sample distance; RMSE, root mean square error; NIR, near infrared; FWHM, full width at half maximum; RER, relative edge response; MTF, modulation transfer function; USGS, U.S. Geological Survey]

Description of product	Top of Atmosphere reflectance
Geometric performance ranges (easting, northing), in meters (pixels)[1]	
Interior (band to band)	All bands combined to reference band 2 (green) Mean: −3.584 to 0.320 m (−0.056 to 0.005), −1.984 to 2.048 m (−0.031 to 0.032) RMSE: 1.856 to 9.088 m (0.029 to 0.142), 1.344 to 7.168 m (0.021 to 0.112)
Exterior (geometric location accuracy compared to Landsat 8)	Mean: −37.256 to 54.758 m (−0.621 to 0.913), −12.684 to 54.898 m (−0.211 to 0.915) RMSE: 16.569 to 56.725 m (0.276 to 0.945), 16.048 to 59.535 m (0.267 to 0.992)
Radiometric performance ranges	
Radiometric evaluation (linear regression—Amazônia-1 versus Landsat 8 reflectance)	Band 1—blue (offset, slope): (0.030 to 0.043, 0.720 to 0.775) Band 2—green (offset, slope): (0.041 to 0.064, 0.742 to 0.774) Band 3—red (offset, slope): (0.034 to 0.066, 0.768 to 0.825) Band 4—NIR (offset, slope): (0.081 to 0.143, 0.662 to 0.819)
Spatial performance (FWHM, RER, MTF at Nyquist)	
Spatial performance measurement	Band 1: 1.97 pixels, 0.47, 0.067 Band 2: 1.62 pixels, 0.59, 0.115 Band 3: 1.69 pixels, 0.58, 0.089 Band 4: 2.06 pixels, 0.45, 0.062
Known artifacts and quality issues	
USGS noted artifacts/quality issues	Amazônia-1 scenes consist of a left half and right half because of the use of two cameras. We examined several scenes looking for the seam between the left and right cameras. The two halves are well balanced overall. Only an extreme stretch allowed us to easily locate the seam.

[1]Pixel values are provided at a 64-m GSD for the interior assessment and a 60-m GSD for the exterior geometric assessment.

Analysis

This section of the report describes the geometric, radiometric, and spatial performance of Amazônia-1.

Geometric Performance

The geometric performance for Amazônia-1 is characterized in terms of the interior (band-to-band alignment) and exterior (geometric location accuracy) geometric analysis results. Interior accuracy measures how well the various bands of Amazônia-1 are aligned to each other. Exterior accuracy measures the geometric location accuracy of Amazônia-1 compared to Landsat 8 OLI imagery.

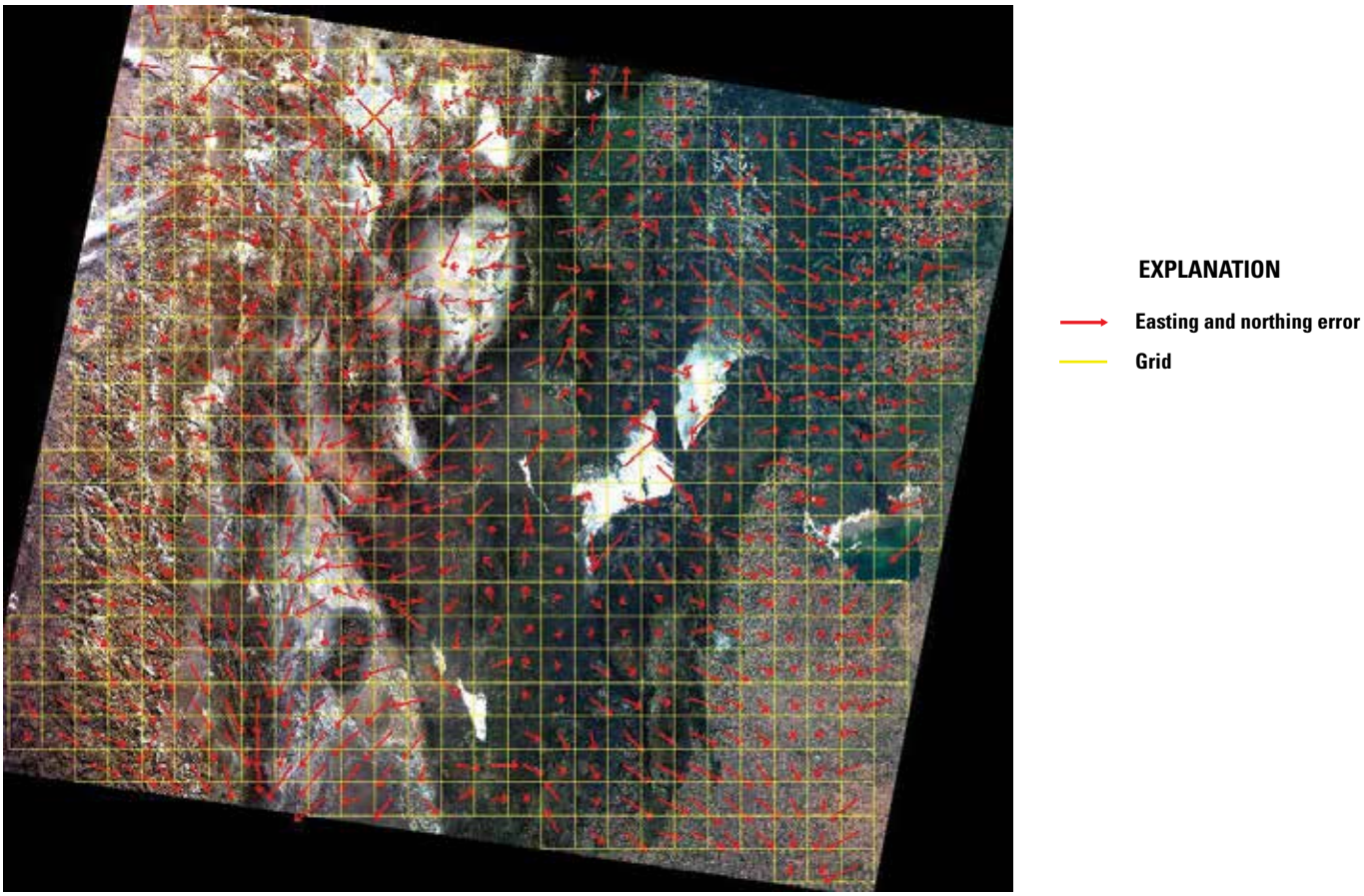
Interior (Band to Band)

The band-to-band alignment analysis was completed using the Earth Resources Observation and Science System Characterization software on two images over central Argentina and eastern Argentina. Amazônia-1 covers a large footprint, and these two scenes were used because the entire scene was cloud free. Band combinations were registered against each other to determine the mean error and root mean square error, as listed in table 4, with results represented in pixels at a 64-meter (m) GSD. Results of band comparisons to the green band (band 2) are provided. Geometric error maps for each green band comparison over the two scenes, as well as the corresponding error plots, are shown in figures 2–15. Geometric error histogram graphs also are shown for the green-to-blue band comparisons for each of the scenes. The geometric error maps indicate the directional shift and relative magnitude of the shift, and the histogram graphs indicate the frequency of observed mean error measurements within the image. The geometric error plots indicate the easting and northing errors between the designated bands. 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.

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

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

Scene ID	Band combination	Mean error (easting)	Mean error (northing)	RMSE (easting)	RMSE (northing)
AMAZONIA_1_WFI_20210512_038_020_L4 (central Argentina)	Band 2–band 1	0.004	−0.015	0.036	0.026
	Band 2–band 3	−0.005	0.004	0.029	0.021
	Band 2–band 4	−0.003	−0.031	0.103	0.112
AMAZONIA_1_WFI_20210709_037_020_L4 (eastern Argentina)	Band 2–band 1	0.005	−0.015	0.037	0.027
	Band 2–band 3	0.001	−0.009	0.036	0.023
	Band 2–band 4	−0.056	0.032	0.142	0.112



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 2. Band 1 (blue) to band 2 (green) geometric error map, central Argentina.

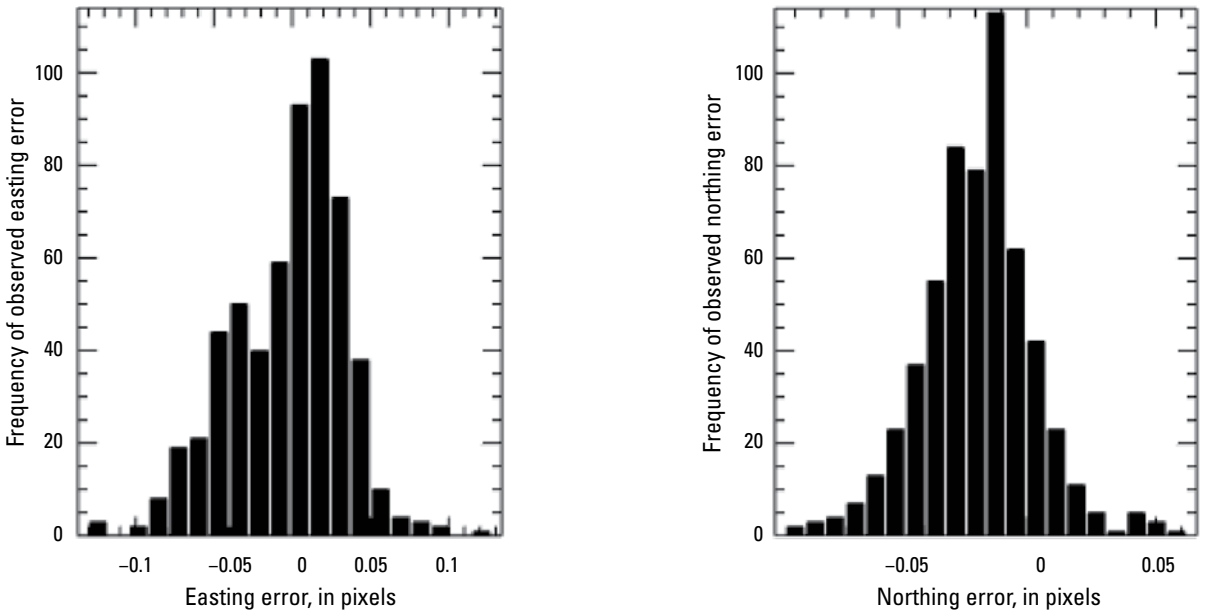


Figure 3. Band 1 (blue) to band 2 (green) geometric error histogram, central Argentina.

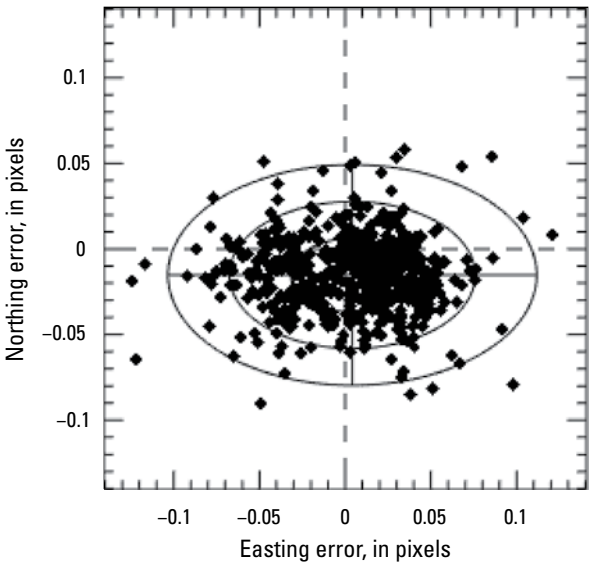
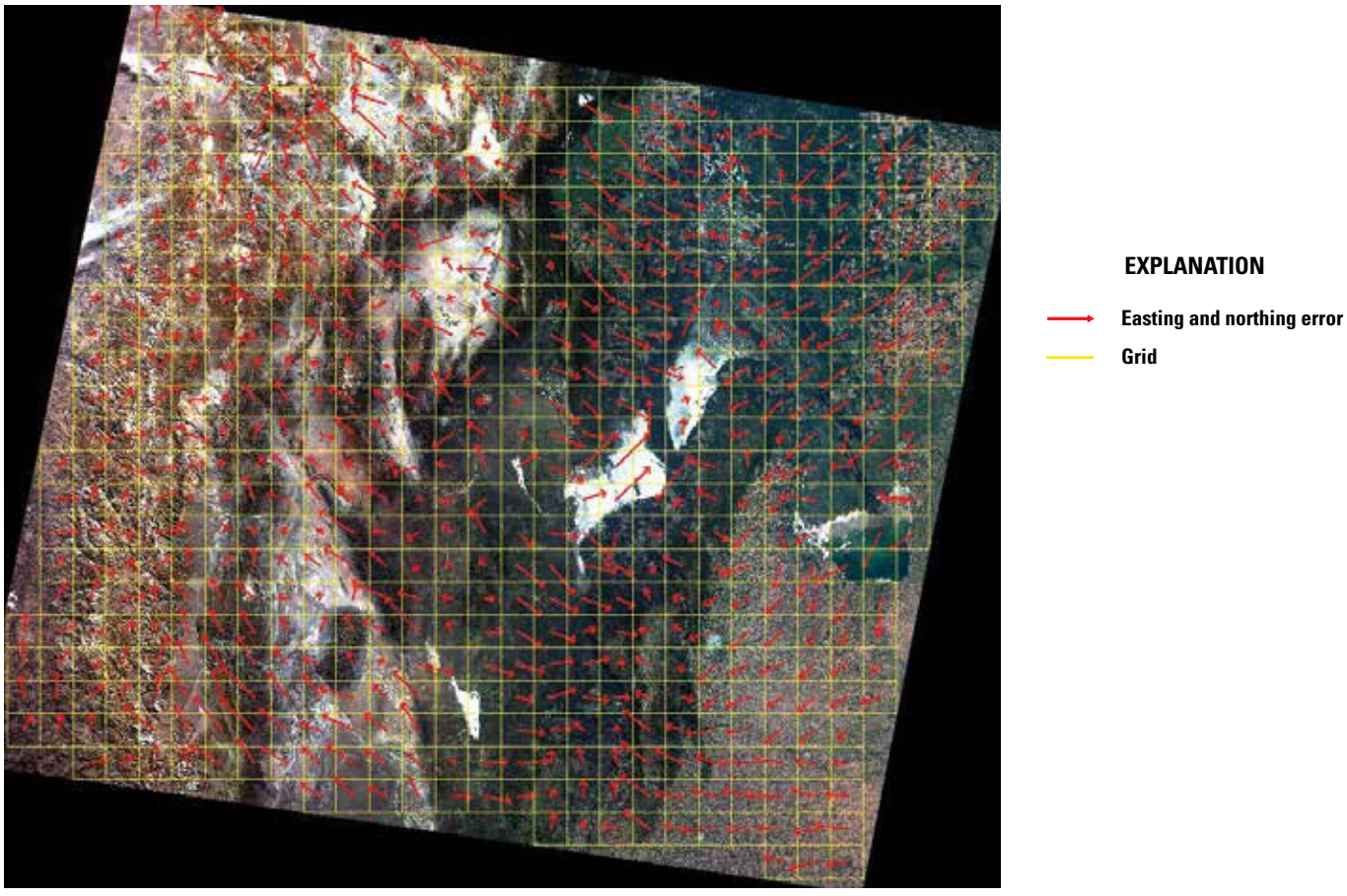


Figure 4. Band 1 (blue) to band 2 (green) geometric error plot, central Argentina.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 5. Band 2 (green) to band 3 (red) geometric error map, central Argentina.

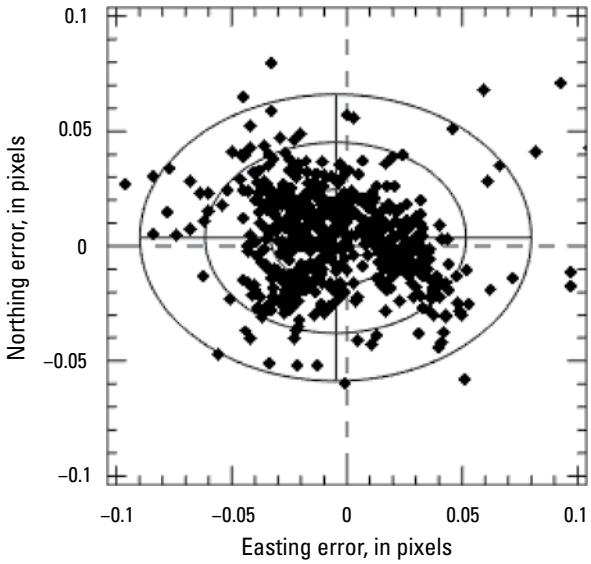
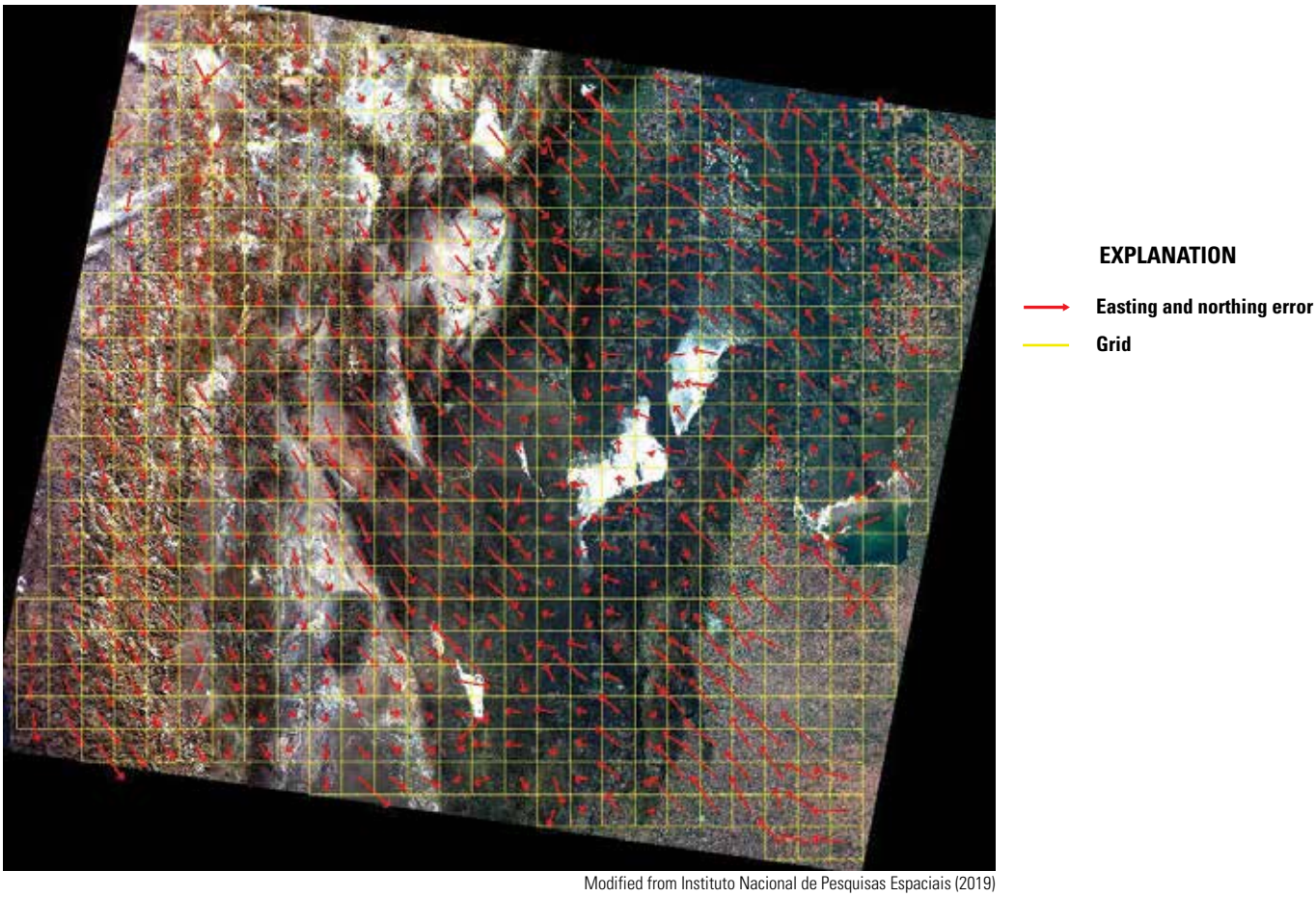


Figure 6. Band 2 (green) to band 3 (red) geometric error plot, central Argentina.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 7. Band 2 (green) to band 4 (near infrared) geometric error map, central Argentina.

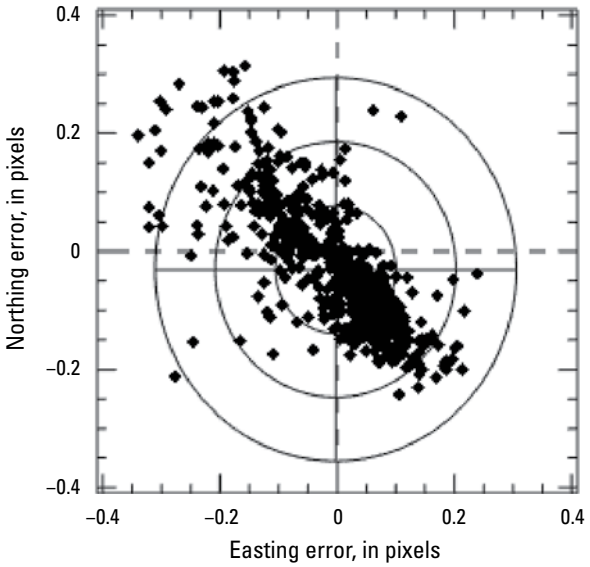
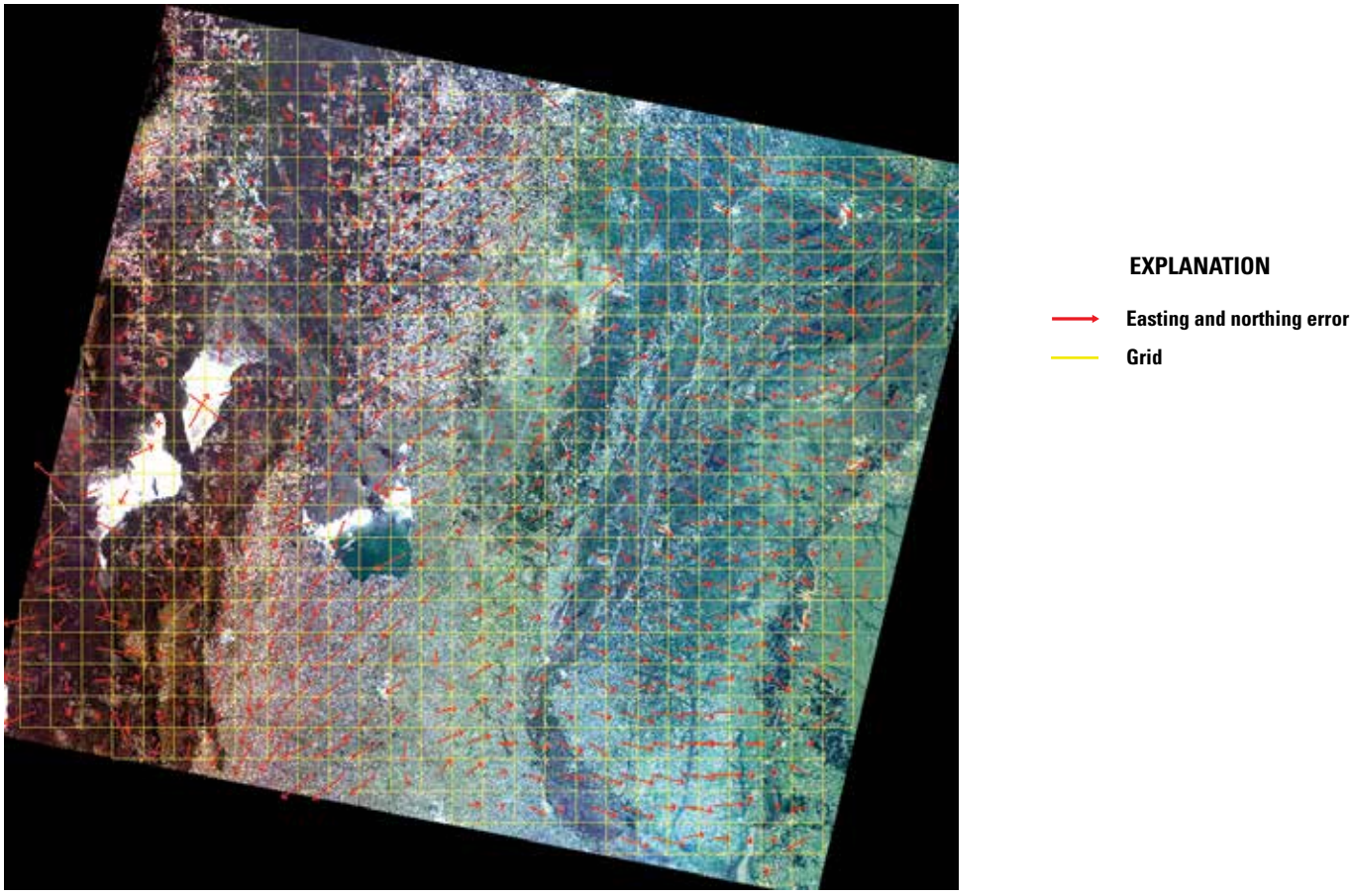


Figure 8. Band 2 (green) to band 4 (near infrared) geometric error plot, central Argentina.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 9. Band 1 (blue) to band 2 (green) geometric error map, eastern Argentina.

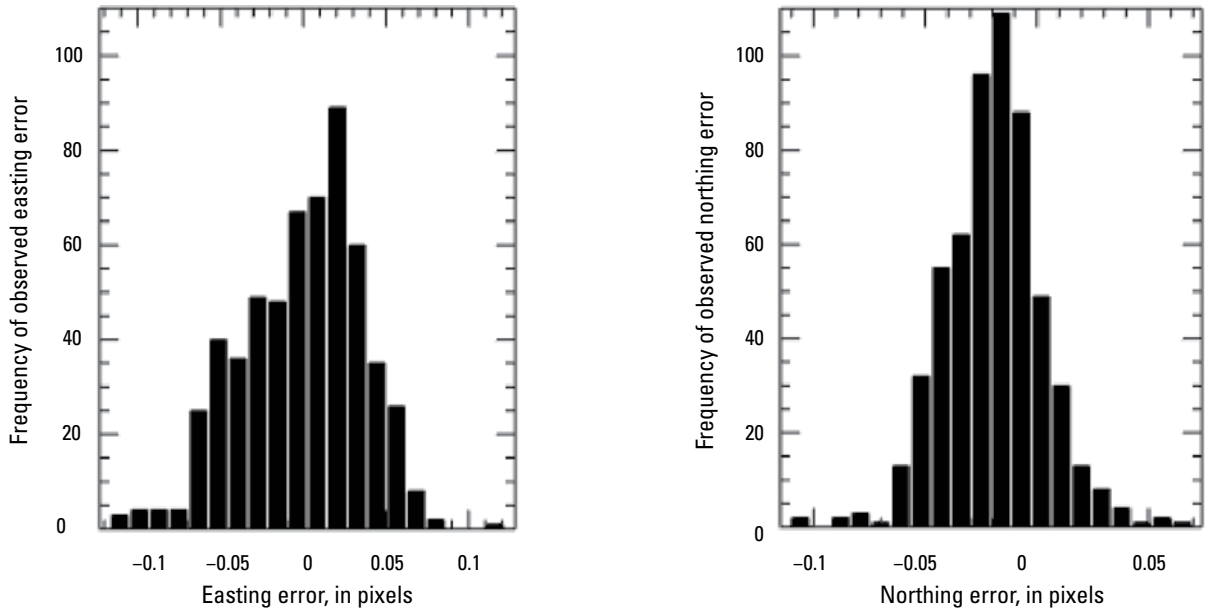


Figure 10. Band 1 (blue) to band 2 (green) geometric error histogram, eastern Argentina.

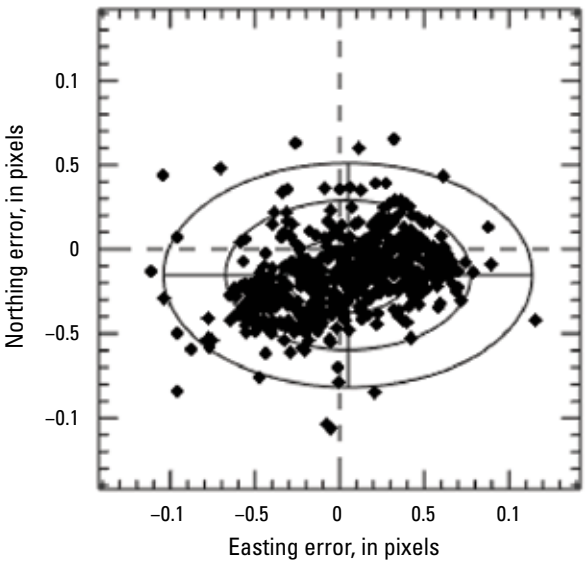
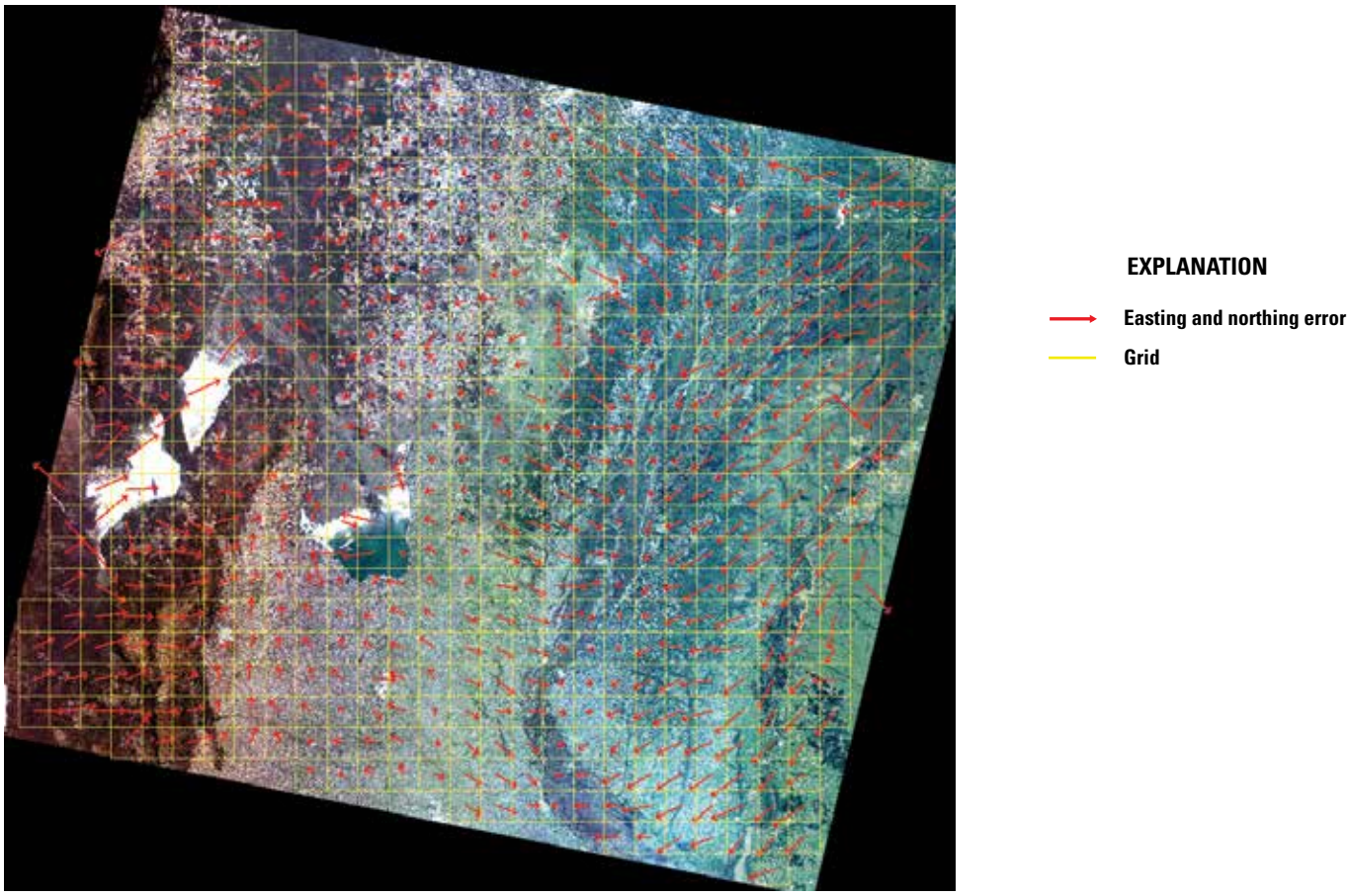


Figure 11. Band 1 (blue) to band 2 (green) geometric error plot, eastern Argentina.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 12. Band 2 (green) to band 3 (red) geometric error map, eastern Argentina.

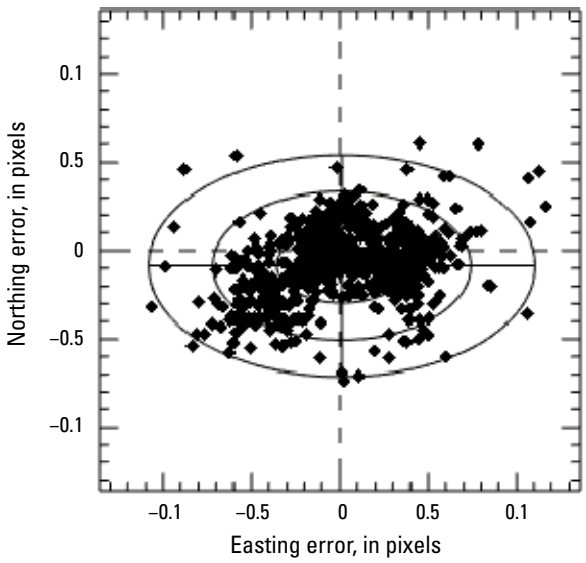
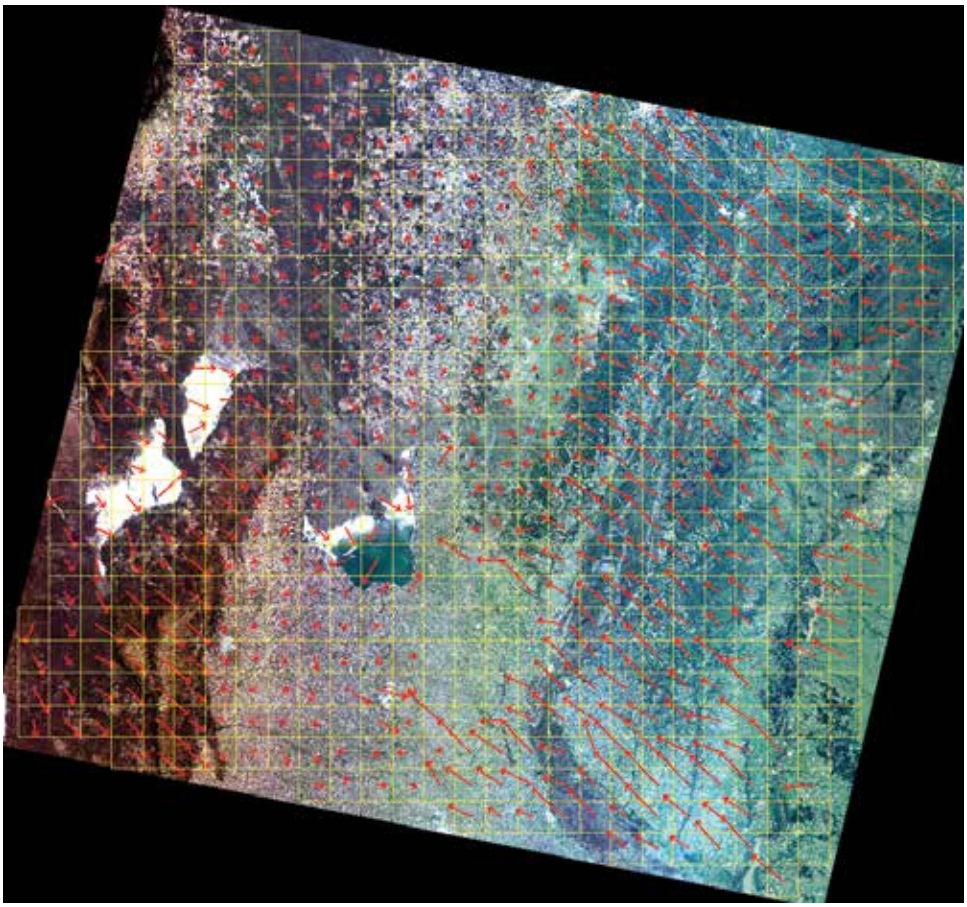


Figure 13. Band 2 (green) to band 3 (red) geometric error plot, eastern Argentina.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 14. Band 2 (green) to band 4 (near infrared) geometric error map, eastern Argentina.

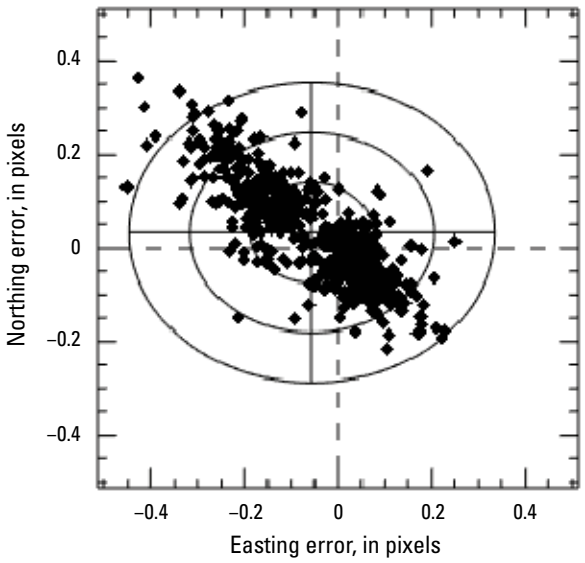


Figure 15. Band 2 (green) to band 4 (near infrared) geometric error plot, eastern Argentina.

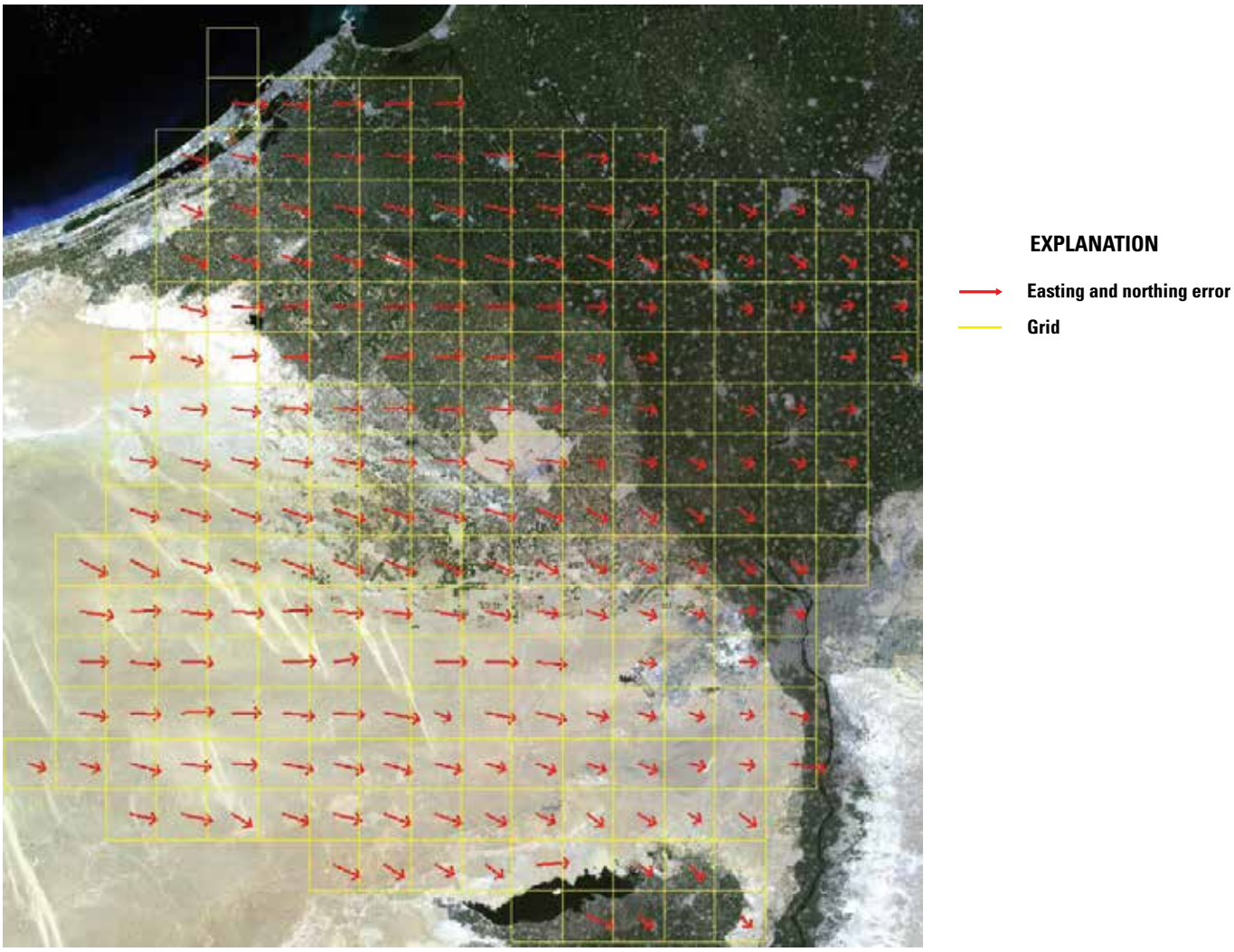
Exterior (Geometric Location Accuracy)

For this analysis, band 2 (green) of four Amazônia-1 images was compared with the corresponding band from two Landsat 8 OLI images over Cairo, Egypt; Lisbon, Portugal; Seville, Spain; and Suez, Egypt, using the Earth Resources Observation and Science System Characterization 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 and root mean square error results are listed in table 5, in pixels at a 60-m GSD (both datasets were resampled to a 60-m GSD). For each of the four images, geometric error maps showing the directional shift and relative magnitude of the shift, when compared with Landsat 8, and relative geometric error histograms and error distribution plots are provided for Cairo (figs. 16 and 17), Lisbon (figs. 18 and 19), Seville (figs. 20 and 21), and Suez (figs. 22 and 23). The Landsat 8 OLI imagery had a control uncertainty of about 8 m (95 percent).

Table 5. Geometric error of Amazônia-1 relative to Landsat 8 Operational Land Imager imagery.

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

Scene ID	Mean error (easting)	Mean error (northing)	RMSE (easting)	RMSE (northing)
AMAZONIA_1_WFI_20210816_021_010_L4 LC08_L1TP_177039_20210816_20210826_ 02_T1 (Cairo, Egypt)	0.913 pixel (54.758 m)	−0.211 pixel (−12.684 m)	0.945 pixel (56.725 m)	0.267 pixel (16.048 m)
AMAZONIA_1_WFI_20210728_029_009_L4 LC08_L1TP_204033_20210728_20210804_ 02_T1 (Lisbon, Portugal)	−0.621 pixel (−37.256 m)	0.915 pixel (54.898 m)	0.713 pixel (42.780 m)	0.992 pixel (59.535 m)
AMAZONIA_1_WFI_20210628_029_009_L4 LC08_L1TP_202034_20210628_20210707_ 02_T1 (Seville, Spain)	−0.544 pixel (−32.610 m)	−0.071 pixel (−4.273 m)	0.620 pixel (37.203 m)	0.331 pixel (19.838 m)
AMAZONIA_1_WFI_20210428_021_010_L4 LC08_L1TP_175040_20210428_20210507_ 02_T1 (Suez, Egypt)	0.042 pixel (2.504 m)	−0.097 pixel (−5.826 m)	0.276 pixel (16.569 m)	0.274 pixel (16.429 m)



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 16. Relative geometric error map comparison for Amazônia-1 and Landsat 8 Operational Land Imager, Cairo, Egypt.

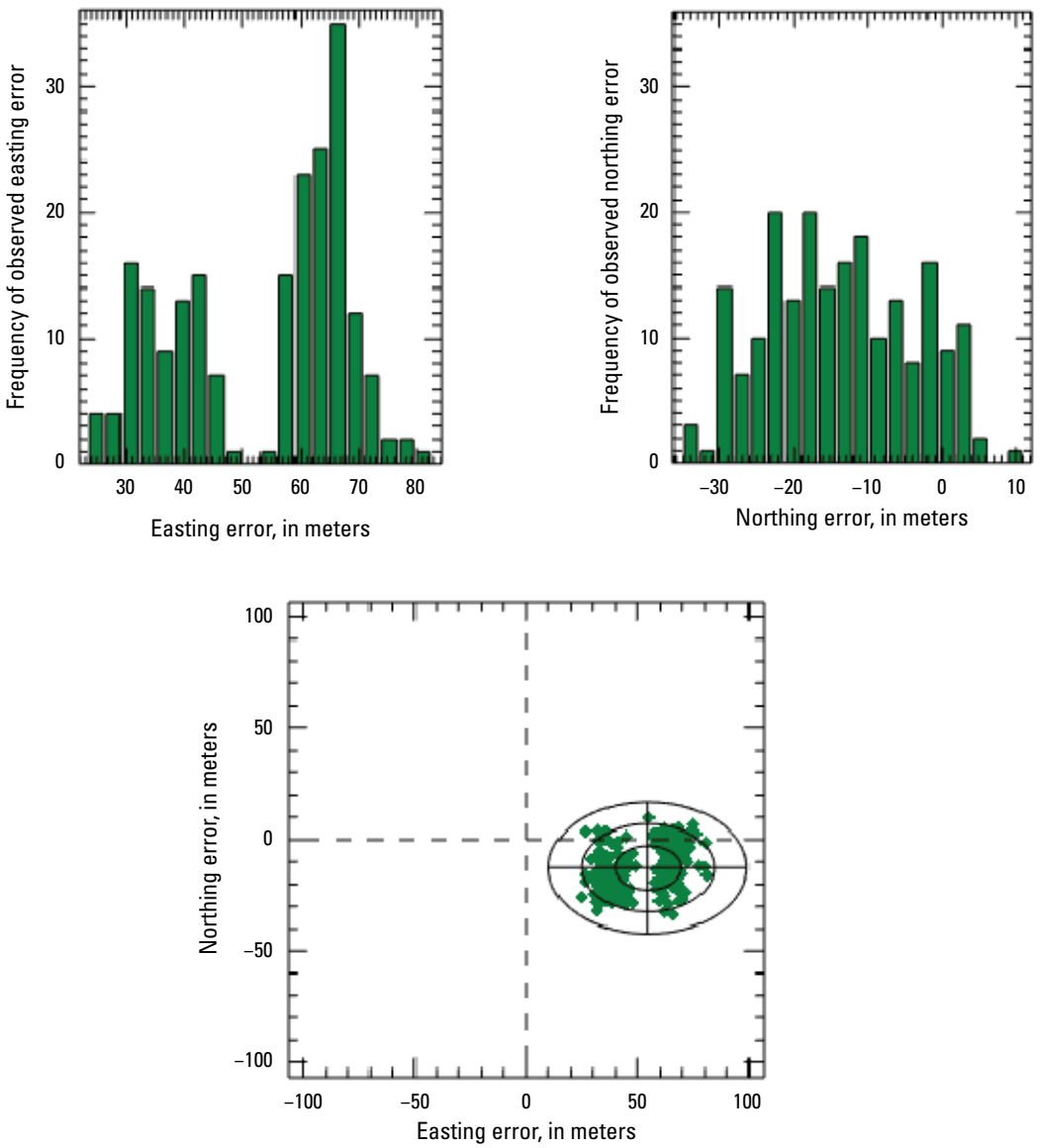
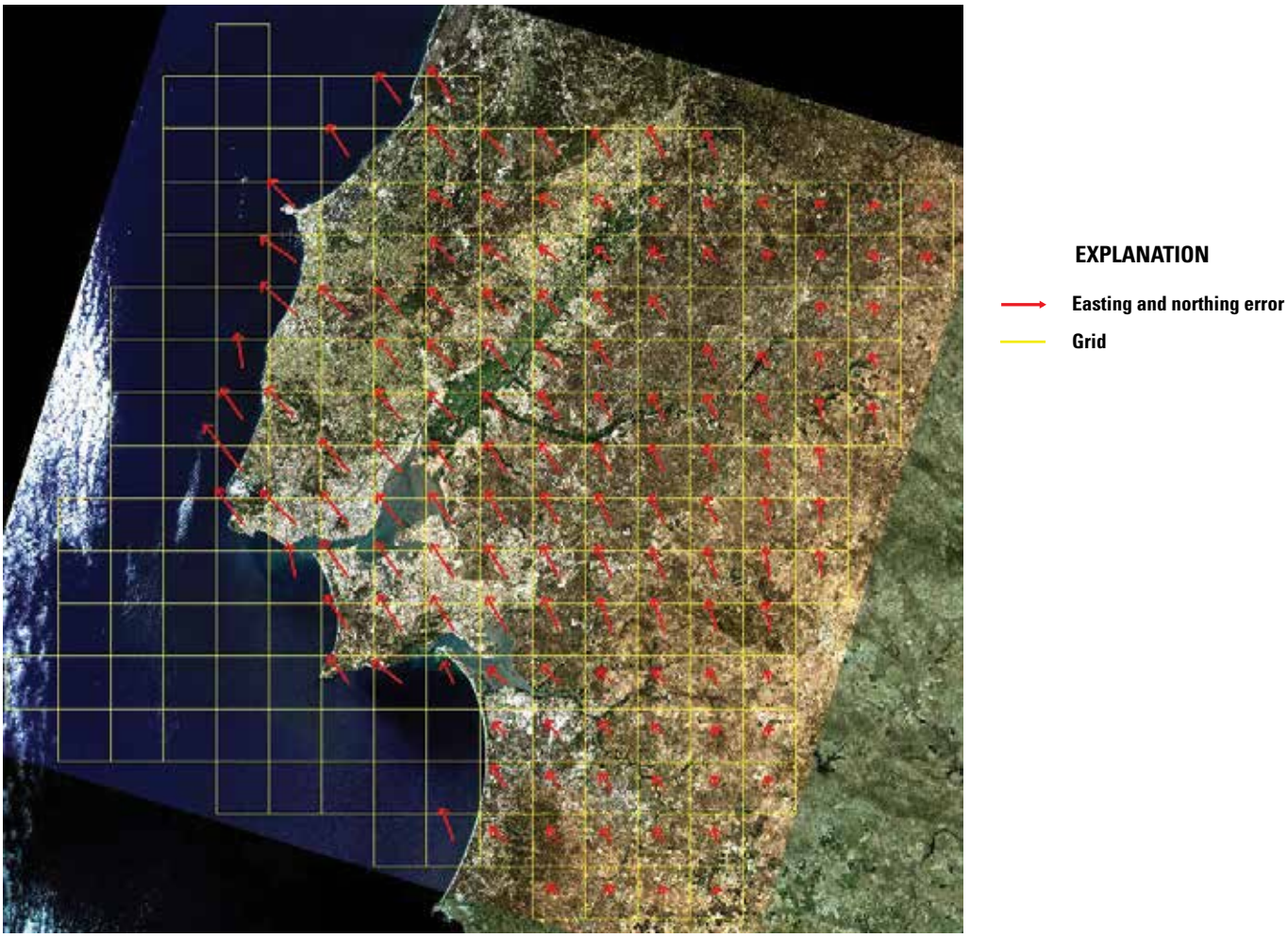


Figure 17. Relative geometric error histograms for easting and northing (upper) and error distribution plot (lower) for Amazônia-1 and Landsat 8 Operational Land Imager, Cairo, Egypt.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 18. Relative geometric error map comparison for Amazônia-1 and Landsat 8 Operational Land Imager, Lisbon, Portugal.

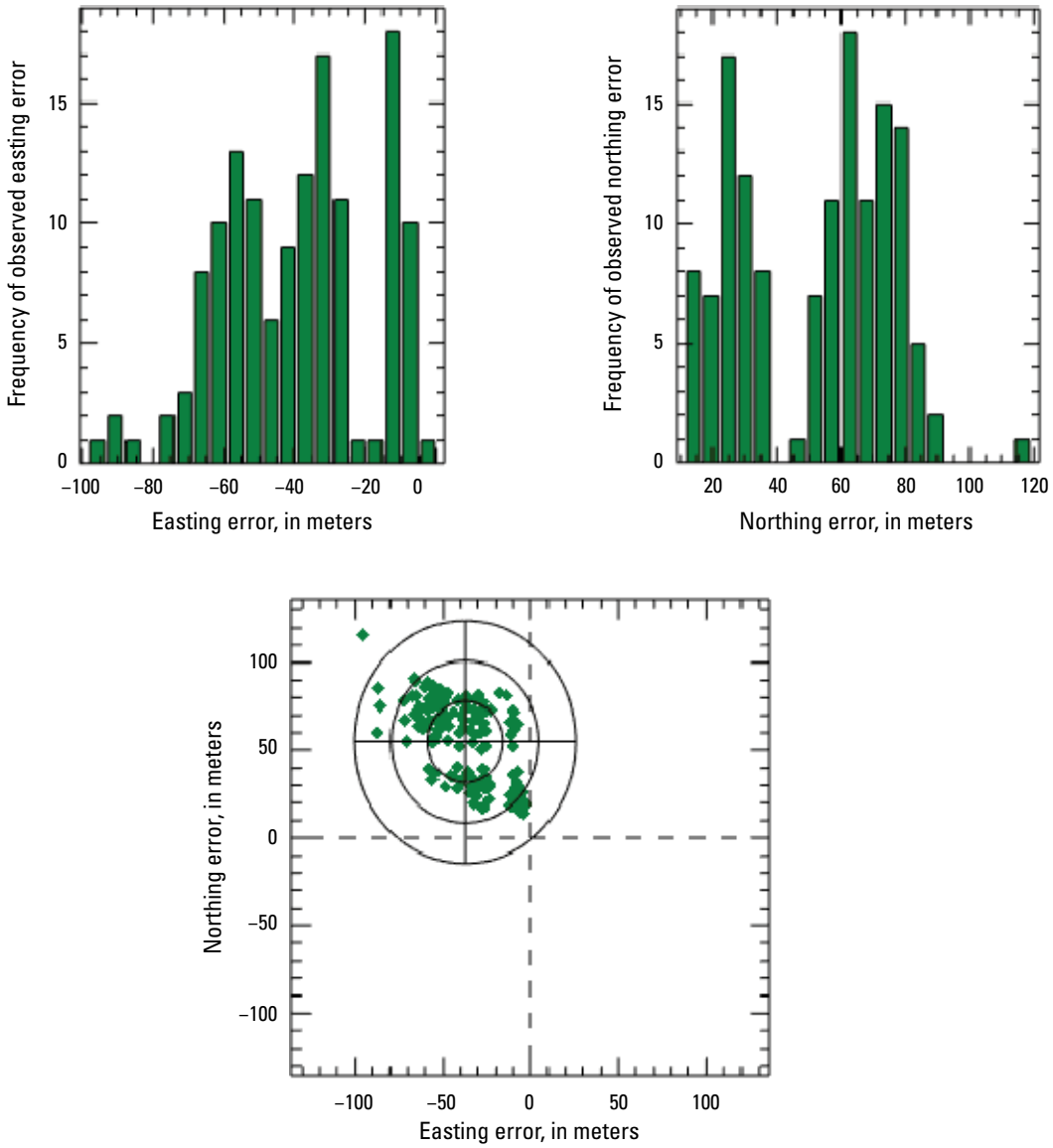
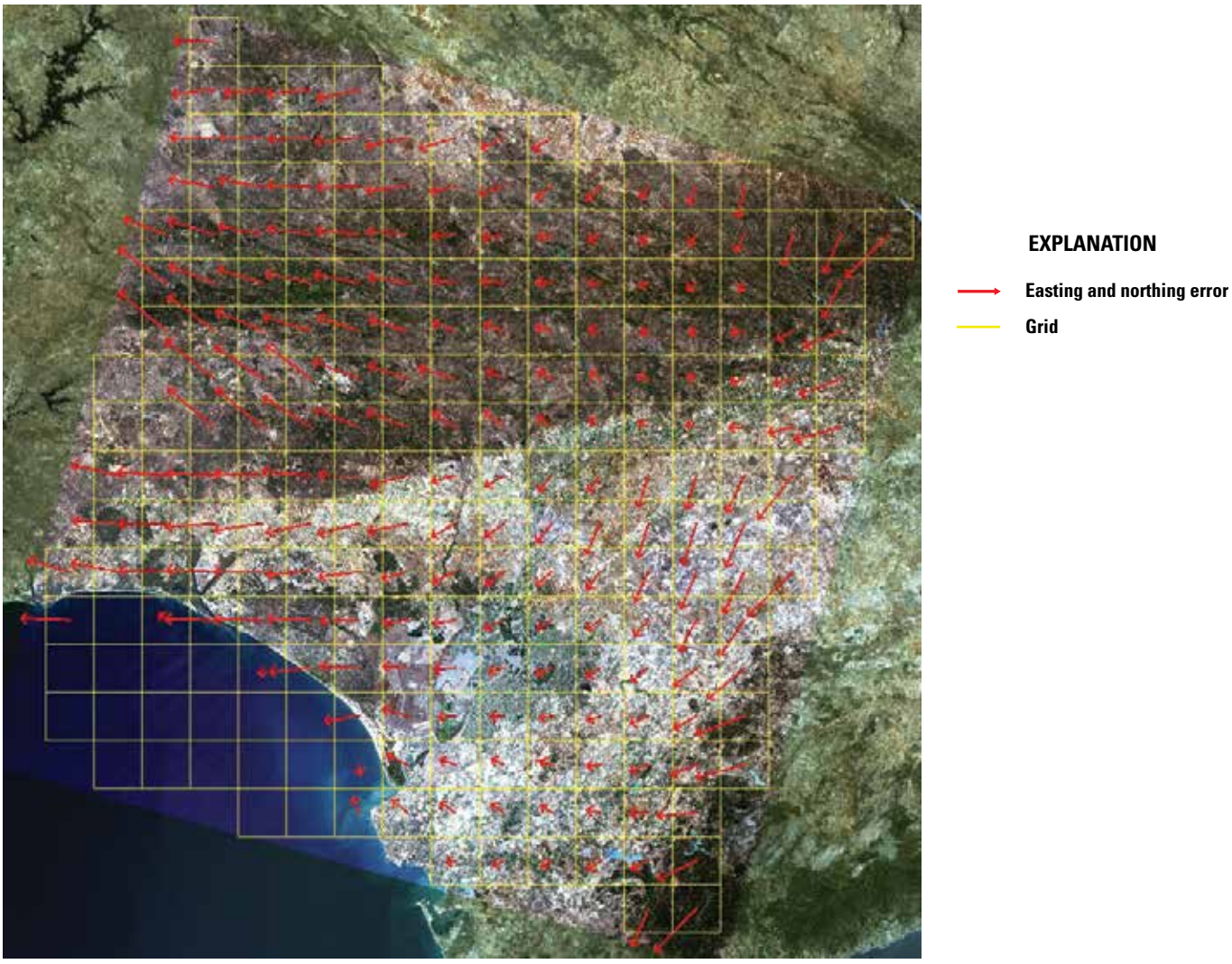


Figure 19. Relative geometric error histograms for easting and northing (upper) and error distribution plot (lower) for Amazônia-1 and Landsat 8 Operational Land Imager, Lisbon, Portugal.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 20. Relative geometric error map comparison for Amazônia-1 and Landsat 8 Operational Land Imager, Seville, Spain.

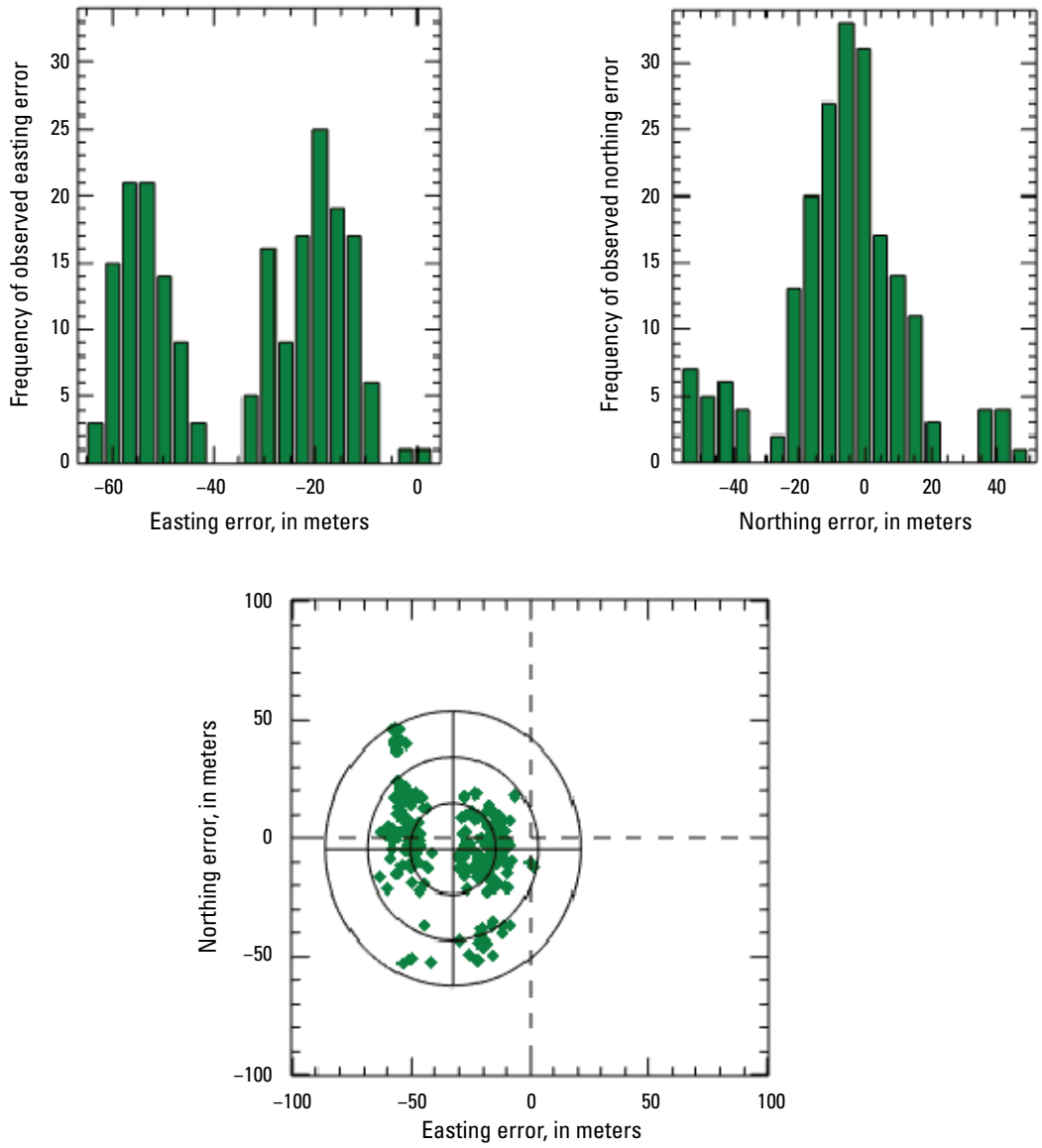
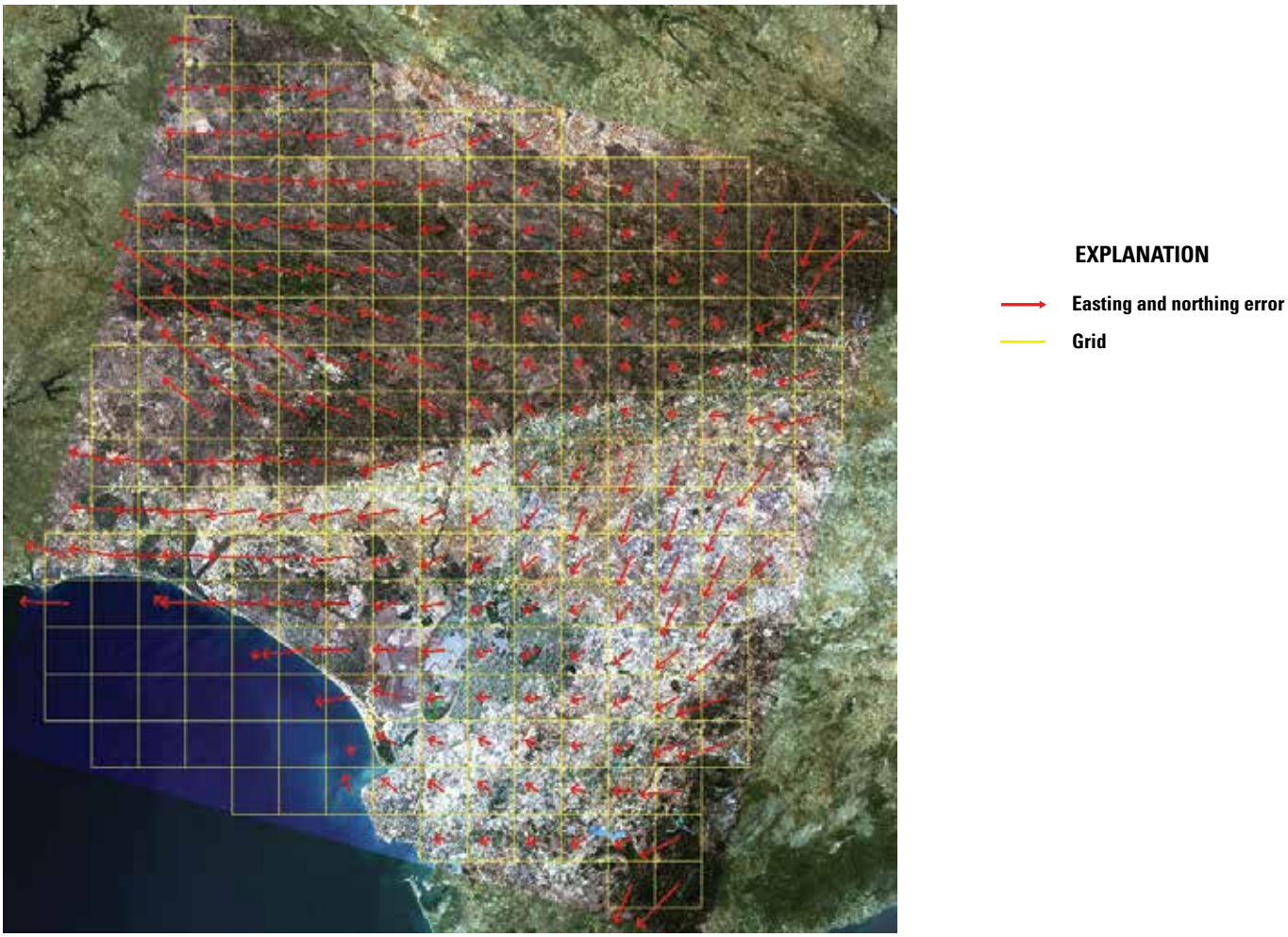


Figure 21. Relative geometric error histograms for easting and northing (upper) and error distribution plot (lower) for Amazônia-1 and Landsat 8 Operational Land Imager, Seville, Spain.



Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 22. Relative geometric error map comparison for Amazônia-1 and Landsat 8 Operational Land Imager, Suez, Egypt.

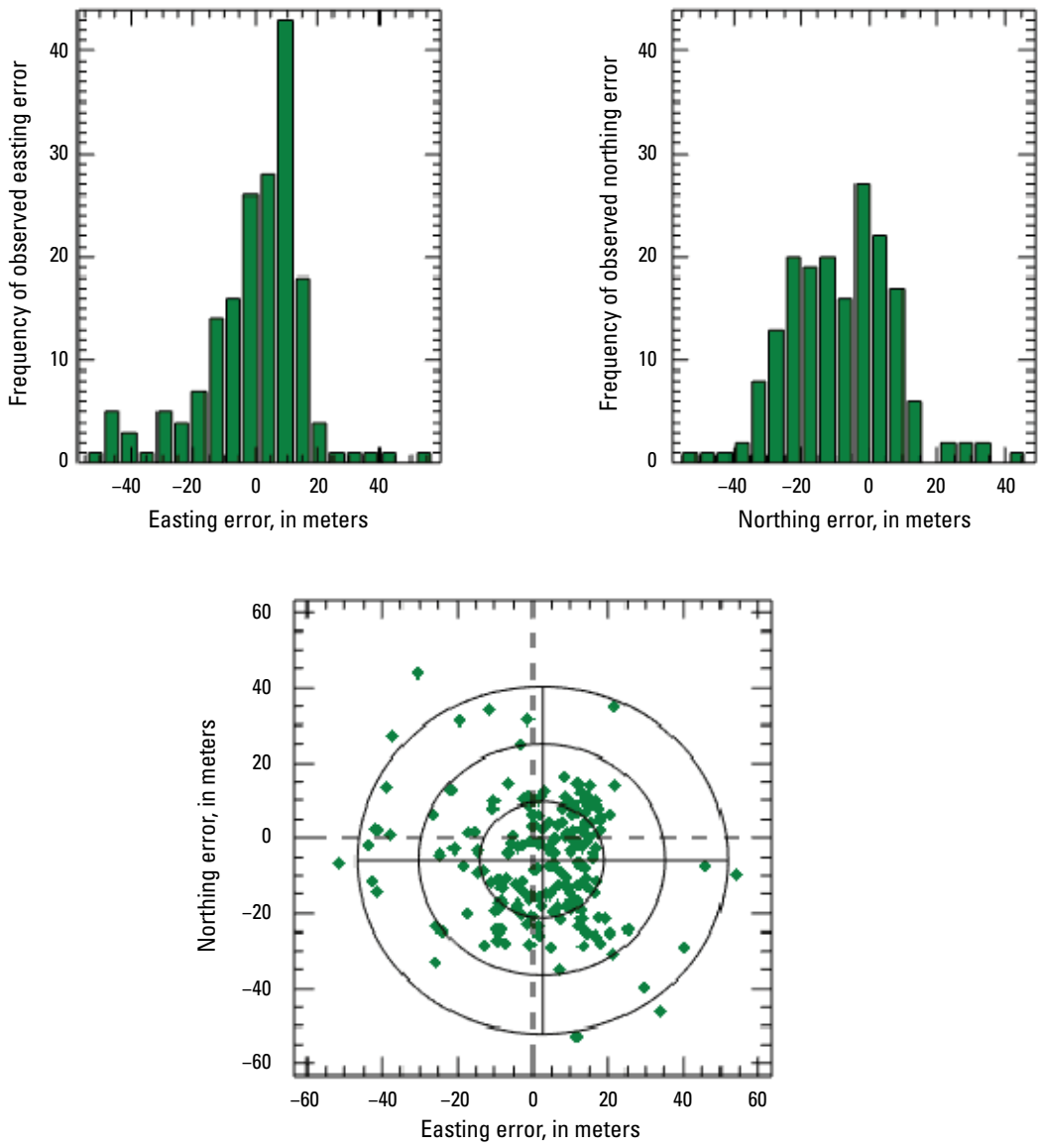


Figure 23. Relative geometric error histograms for easting and northing (upper) and error distribution plot (lower) for Amazônia-1 and Landsat 8 Operational Land Imager, Suez, Egypt.

Radiometric Performance

For this analysis, cloud-free regions of interest were selected within four near-coincident Amazônia-1 and Landsat 8 OLI scene pairs. Once the relative georeferencing error between Landsat 8 OLI and Amazônia-1 has been corrected, Top of Atmosphere reflectance values from the two sensors are extracted. The scatterplots (figs. 24–27) are 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, the 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 Amazônia-1 image over Cairo, when compared with the corresponding Landsat 8 OLI band, is shown in figure 24. A band-by-band comparison for the image over Lisbon is shown in figure 25. A band-by-band comparison for the image over Seville is shown in figure 26. A band-by-band comparison for the image over Suez is shown in figure 27.

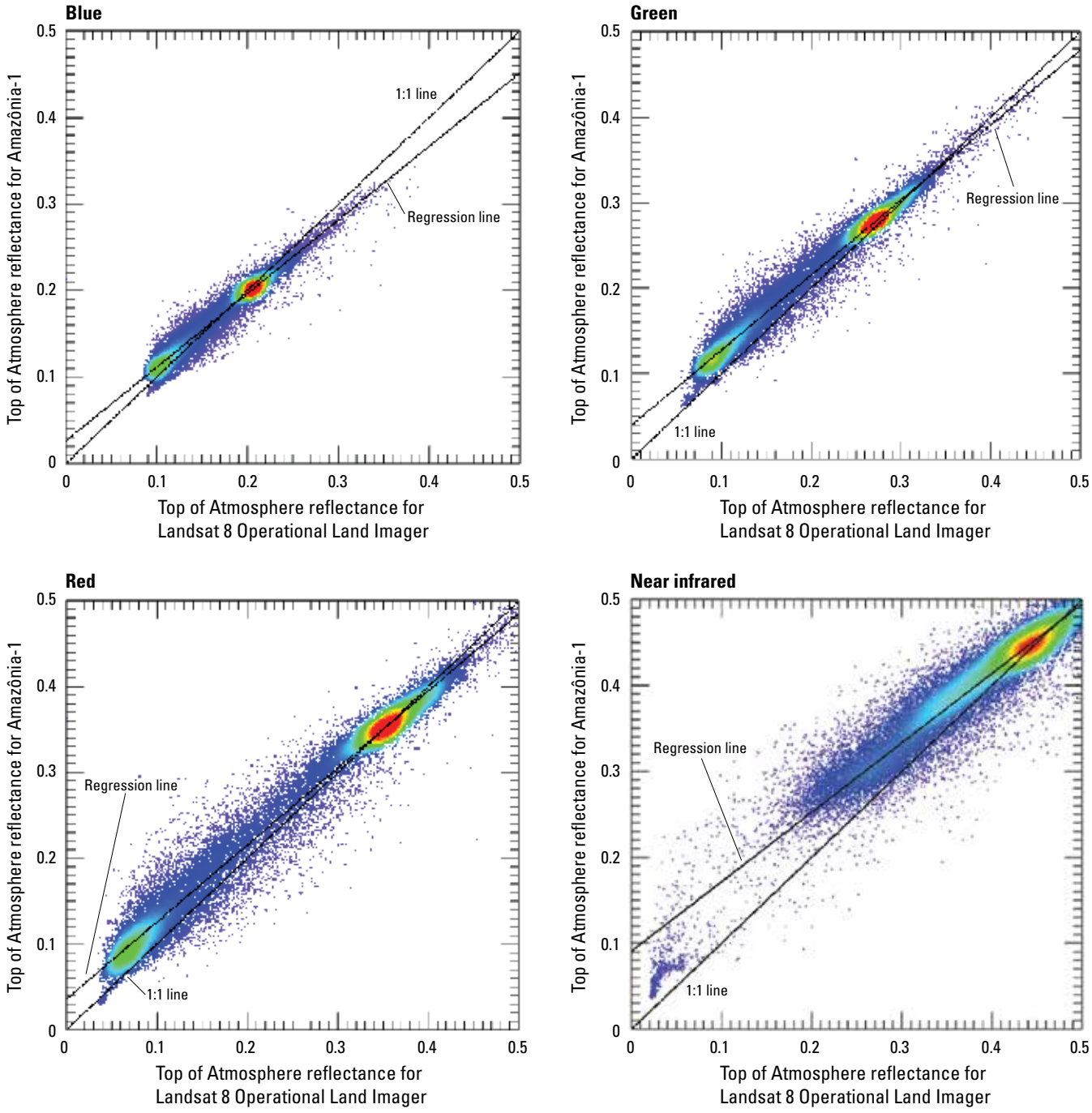


Figure 24. Top of Atmosphere reflectance comparison for Landsat 8 Operational Land Imager and Amazônia-1, Cairo, Egypt.

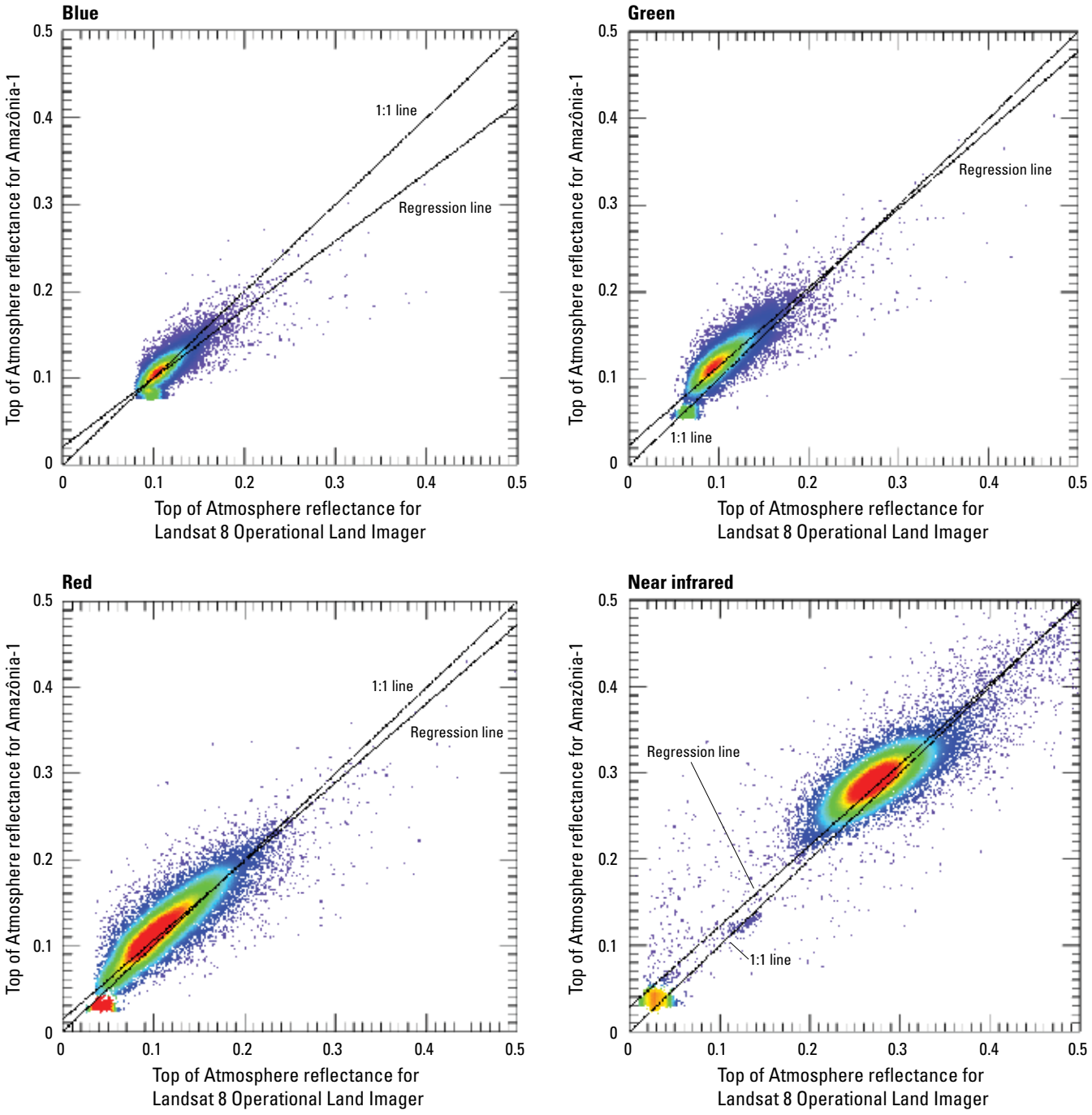


Figure 25. Top of Atmosphere reflectance comparison for Landsat 8 Operational Land Imager and Amazônia-1, Lisbon, Portugal.

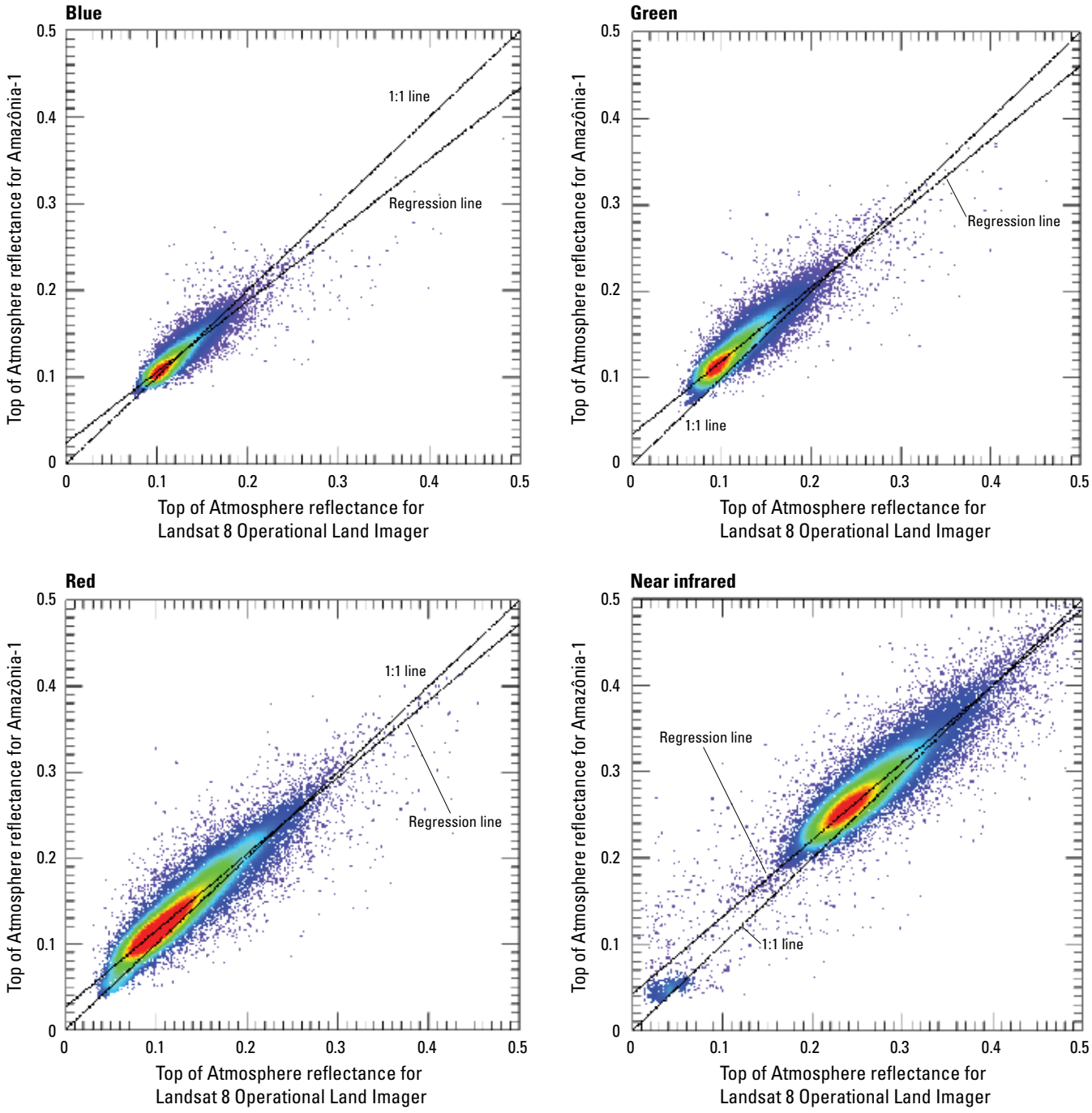


Figure 26. Top of Atmosphere reflectance comparison for Landsat 8 Operational Land Imager and Amazônia-1, Seville, Spain.

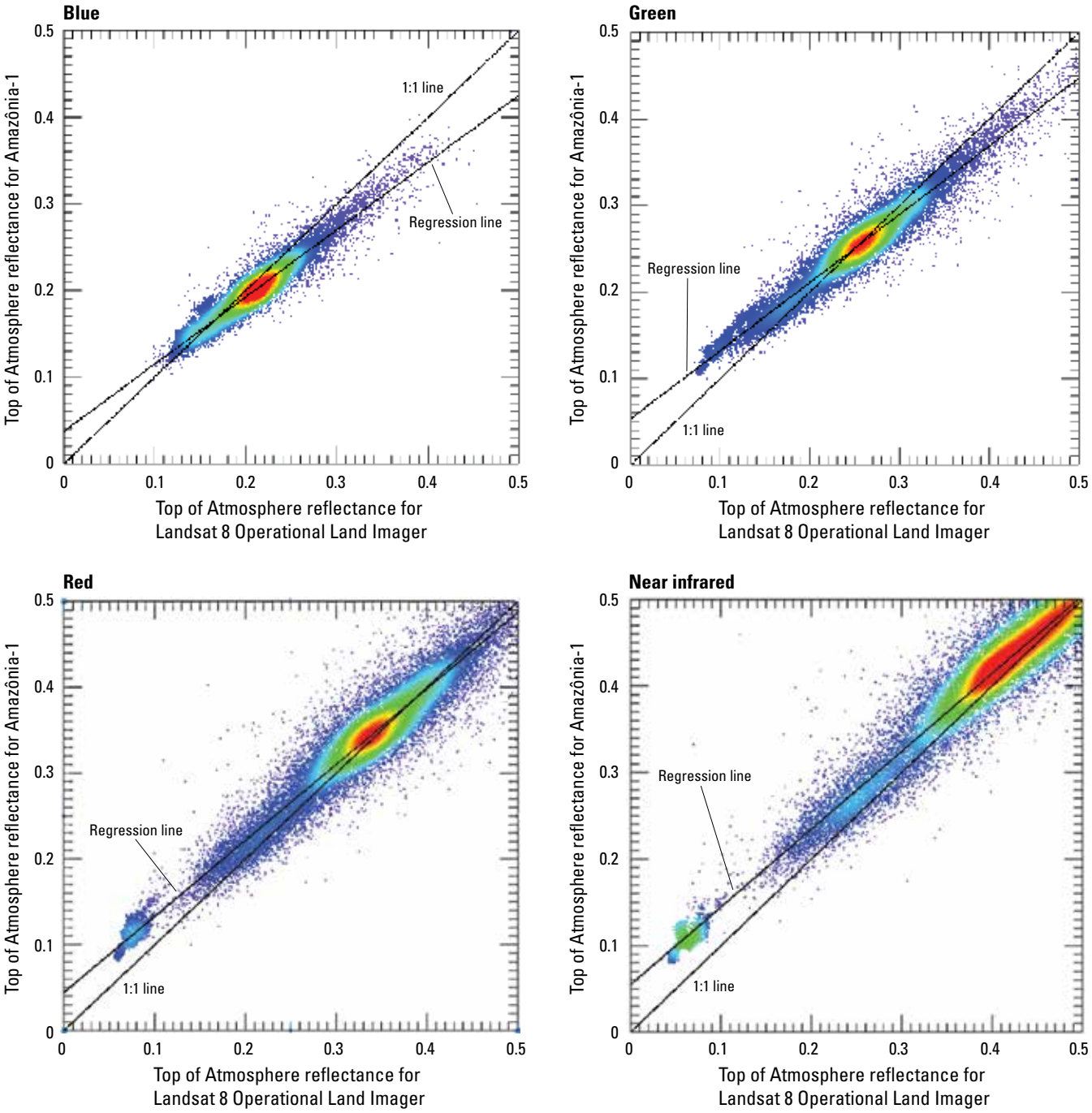


Figure 27. Top of Atmosphere reflectance comparison for Landsat 8 Operational Land Imager and Amazônia-1, Suez, Egypt.

Table 6. Top of Atmosphere reflectance comparison for Landsat 8 Operational Land Imager against Amazônia-1.

[ID, identifier; NIR, near infrared; %, percent; R^2, coefficient of determination]

Scene ID	Statistics	Band 1 (blue)	Band 2 (green)	Band 3 (red)	Band 4 (NIR)
AMAZONIA_1_WFI_20210816_021_010_L4 LC08_L1TP_177039_20210816_20210826_02_T1 (Cairo, Egypt)	Uncertainty (%)	5.560	7.670	11.680	7.300
	R^2	0.795	0.804	0.808	0.747
	Regression offset	0.040	0.062	0.066	0.143
	Regression slope	0.775	0.774	0.786	0.662
AMAZONIA_1_WFI_20210728_029_009_L4 LC08_L1TP_204033_20210728_20210804_02_T1 (Lisbon, Portugal)	Uncertainty (%)	9.760	14.080	19.800	12.250
	R^2	0.703	0.722	0.743	0.721
	Regression offset	0.030	0.041	0.034	0.096
	Regression slope	0.720	0.758	0.768	0.702
AMAZONIA_1_WFI_20210628_029_009_L4 LC08_L1TP_202034_20210628_20210707_02_T1 (Seville, Spain)	Uncertainty (%)	9.760	14.080	19.800	12.250
	R^2	0.761	0.767	0.784	0.771
	Regression offset	0.034	0.048	0.041	0.081
	Regression slope	0.732	0.742	0.783	0.752
AMAZONIA_1_WFI_20210428_021_010_L4 LC08_L1TP_175040_20210428_20210507_02_T1 (Suez, Egypt)	Uncertainty (%)	4.980	6.560	6.530	6.600
	R^2	0.866	0.870	0.865	0.866
	Regression offset	0.043	0.064	0.066	0.089
	Regression slope	0.745	0.747	0.825	0.819

Spatial Performance

For this analysis, edge spread and line spread functions were calculated with resulting full width at half maximum and modulation transfer function at Nyquist frequency analysis outputs, as listed in table 7. At this scale (64-m GSD), only agriculture fields are large enough and have straight edges. A scene from eastern Argentina that has several large fields was identified (image collected July 9, 2021). This field is located at latitude −27°43′10.83″ S., longitude −62°44′43.78″ W. The Amazônia-1 image used for the analysis (AMAZONIA_1_WFI_20210709_037_020_L4; fig. 28) includes the edge transect bounding box. It should be noted that the edge segment selected is from a nonideal farmland edge target. The selection of the edge is the result of our best effort to find a usable human-made target. Thus, the results do not necessarily represent the precise spatial performance of the sensor but provide a rough estimate. The results for band 1 (blue) are shown in figures 29 and 30. In figure 29, the raw transects, the middle transect, and the region of the curve that is used for alignment are shown in the upper plot. The lower plot in figure 29 shows the aligned transect and the edge spread function. The upper plot in figure 30 shows an edge spread function with the relative edge response and a line spread function with a line segment representing full width at half maximum. The lower plot in figure 30 shows a modulation transfer function up to Nyquist frequency (0.5) and the frequency corresponding to the 50-percent modulation transfer function value. The results for band 2 (green) are shown in figures 31 and 32, the results for band 3 (red) are shown in figures 33 and 34, and the results for band 4 (near infrared) are shown in figures 35 and 36.

Table 7. Spatial performance of Amazônia-1.

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

Spatial analysis	RER	FWHM	MTF at Nyquist
Band 1—blue	0.47	1.97	0.067
Band 2—green	0.59	1.62	0.115
Band 3—red	0.58	1.69	0.089
Band 4—NIR	0.45	2.06	0.062

Modified from Instituto Nacional de Pesquisas Espaciais (2019)

Figure 28. Amazônia-1 image of calibration field edge in eastern Argentina.

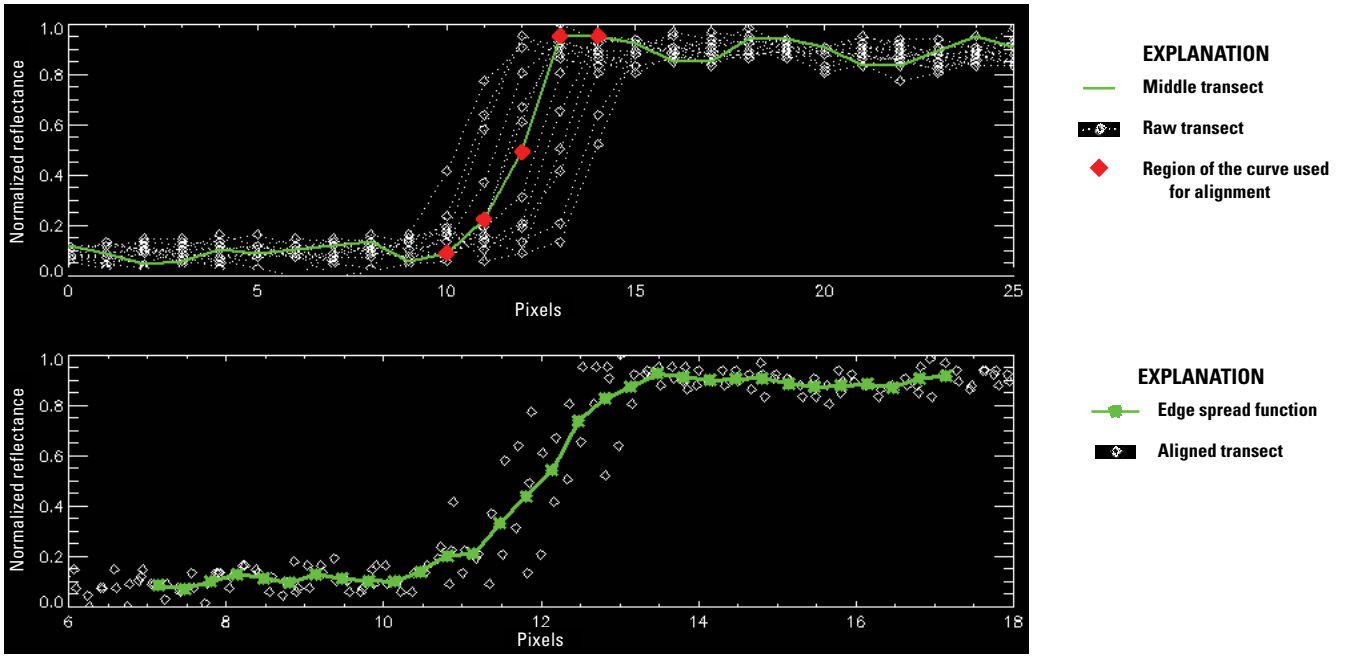


Figure 29. Band 1 (blue) raw edge transects (upper) and shifted transects (lower).

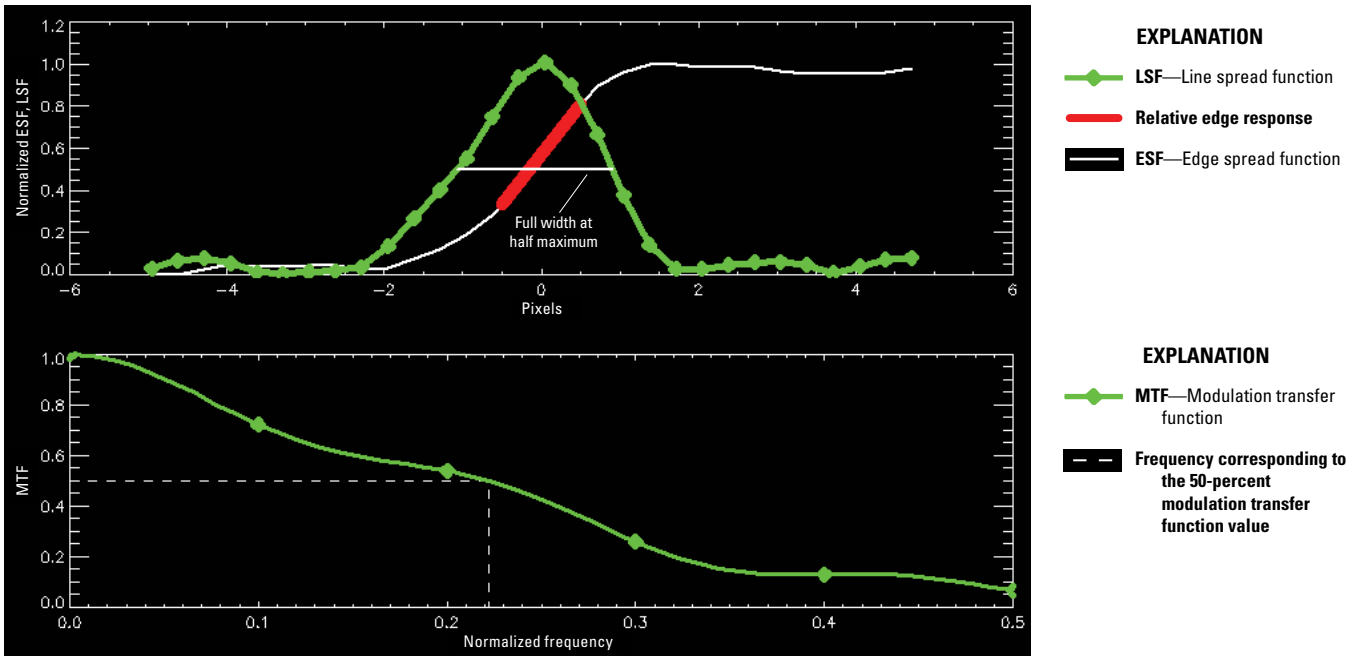


Figure 30. Band 1 (blue) edge spread function and line spread function (upper) and modulation transfer function (lower).

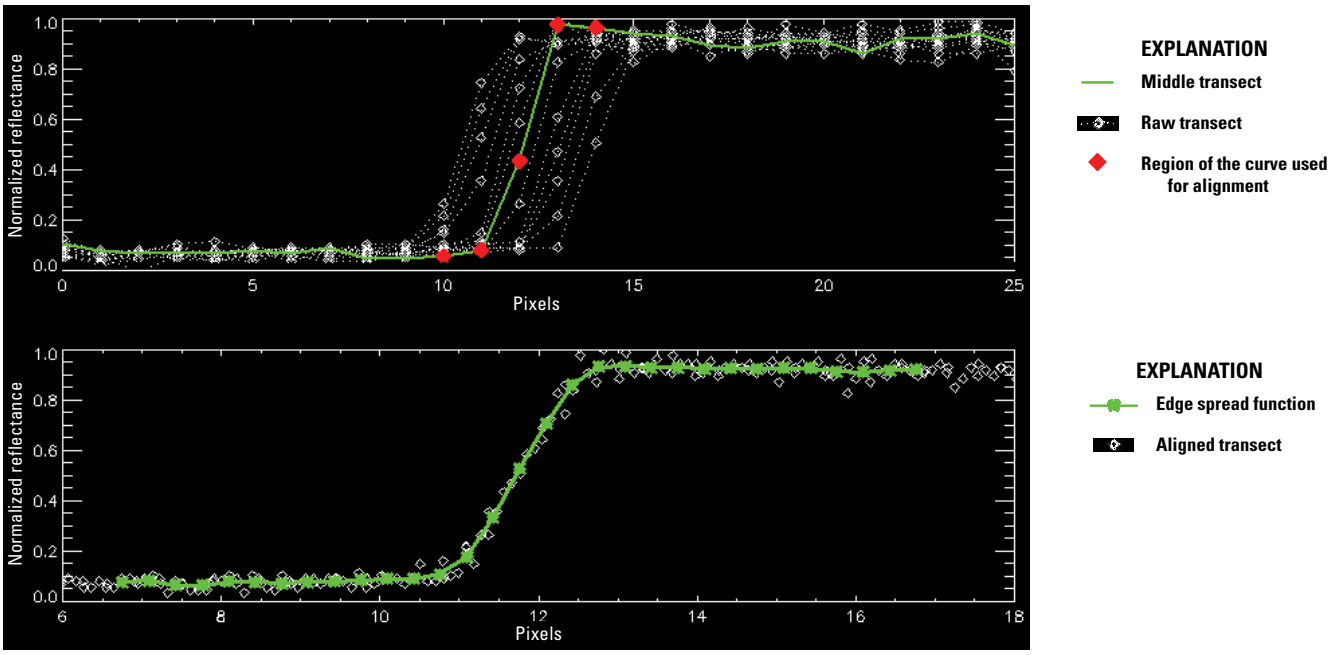


Figure 31. Band 2 (green) raw edge transects (upper) and shifted transects (lower).

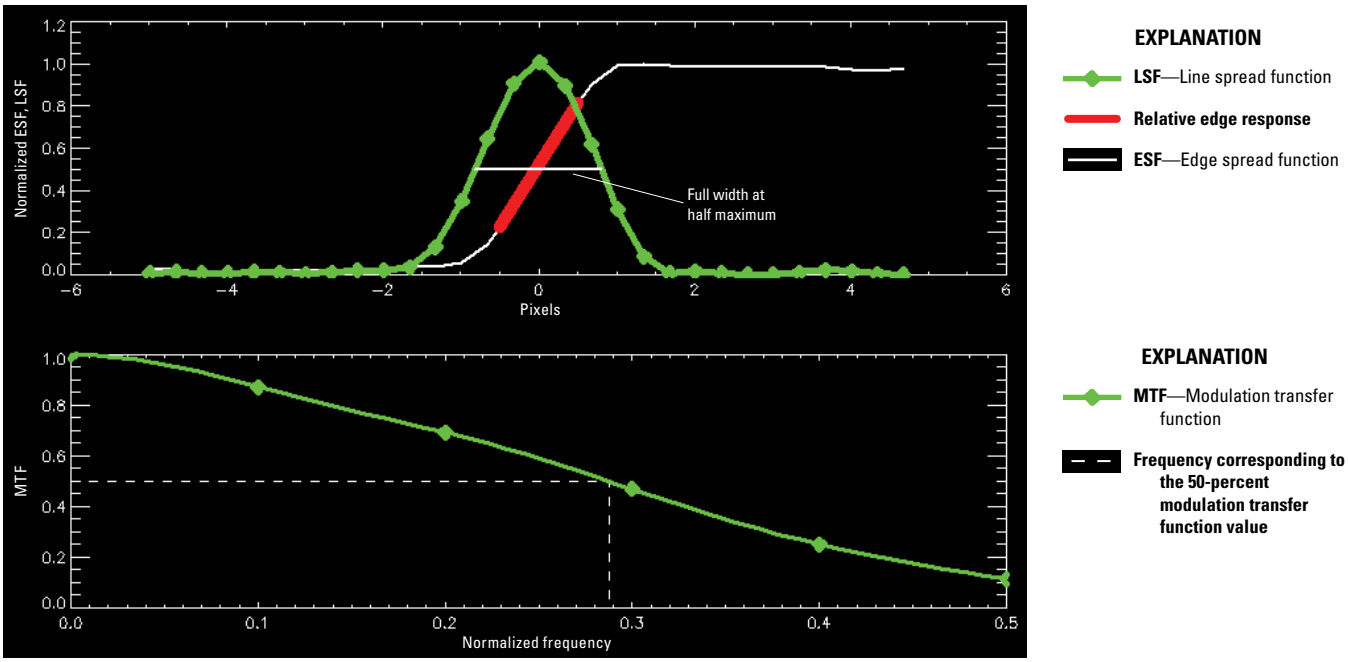


Figure 32. Band 2 (green) edge spread function and line spread function (upper) and modulation transfer function (lower).

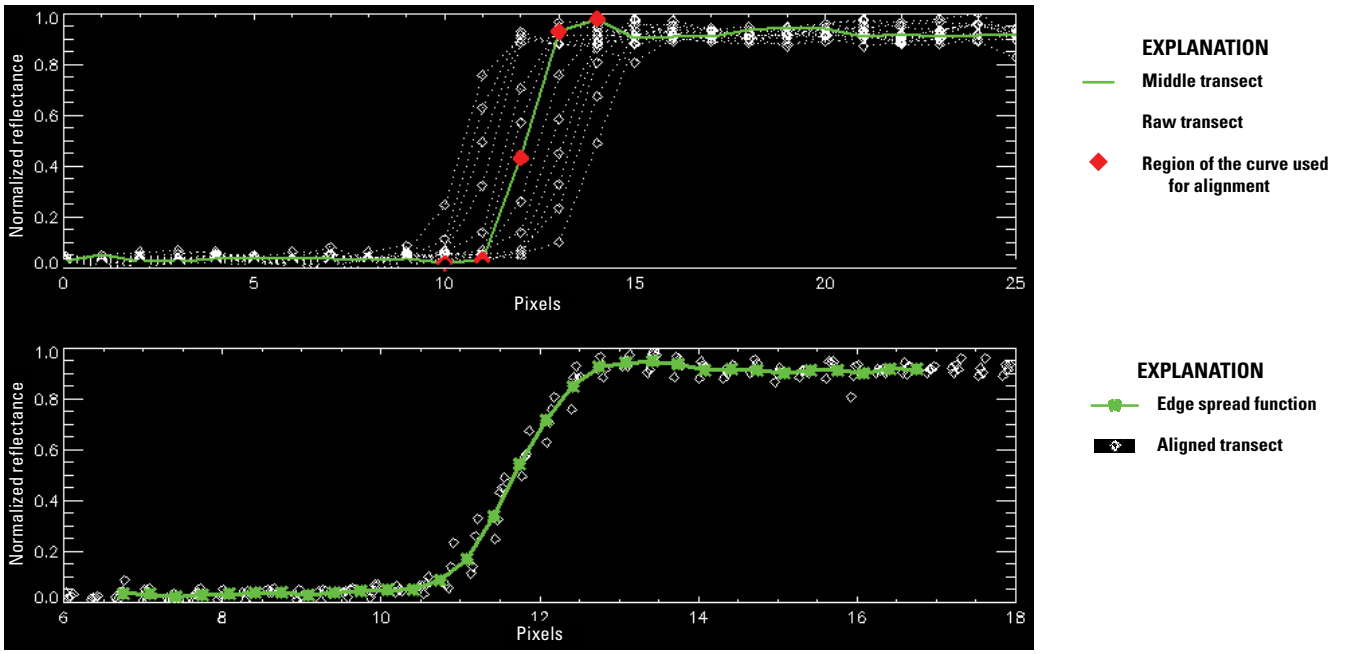


Figure 33. Band 3 (red) raw edge transects (upper) and shifted transects (lower).

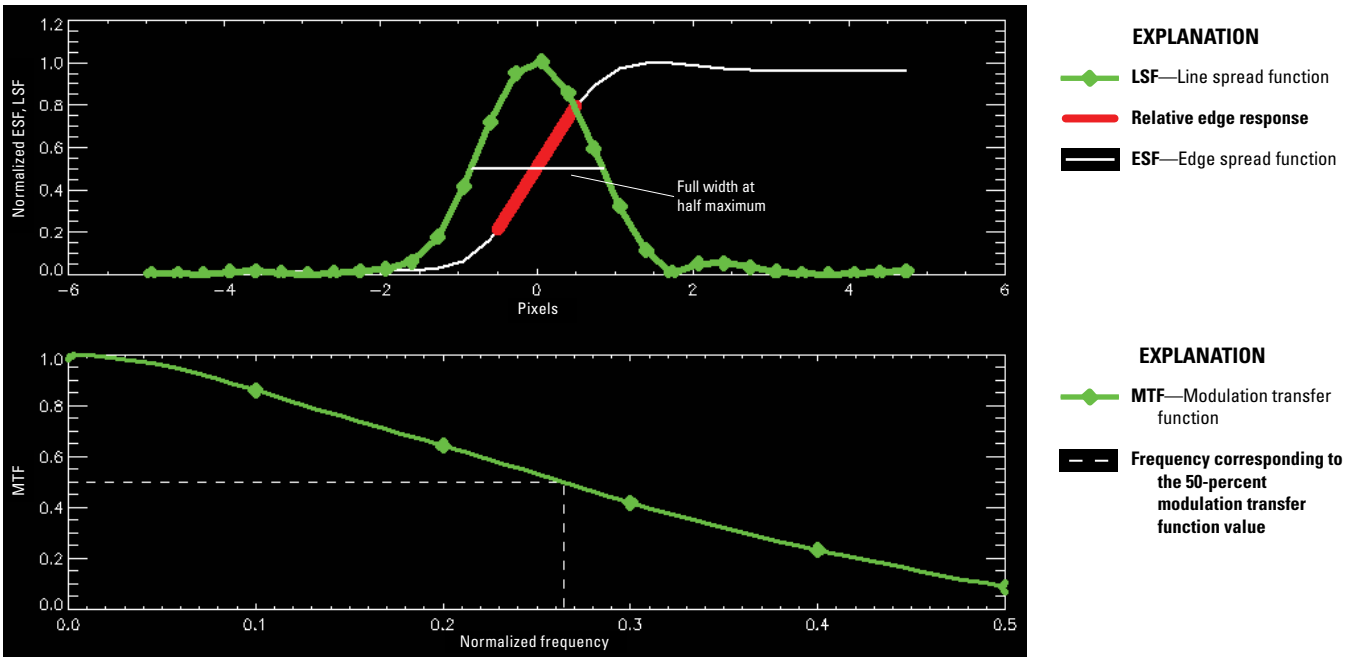


Figure 34. Band 3 (red) edge spread function and line spread function (upper) and modulation transfer function (lower).

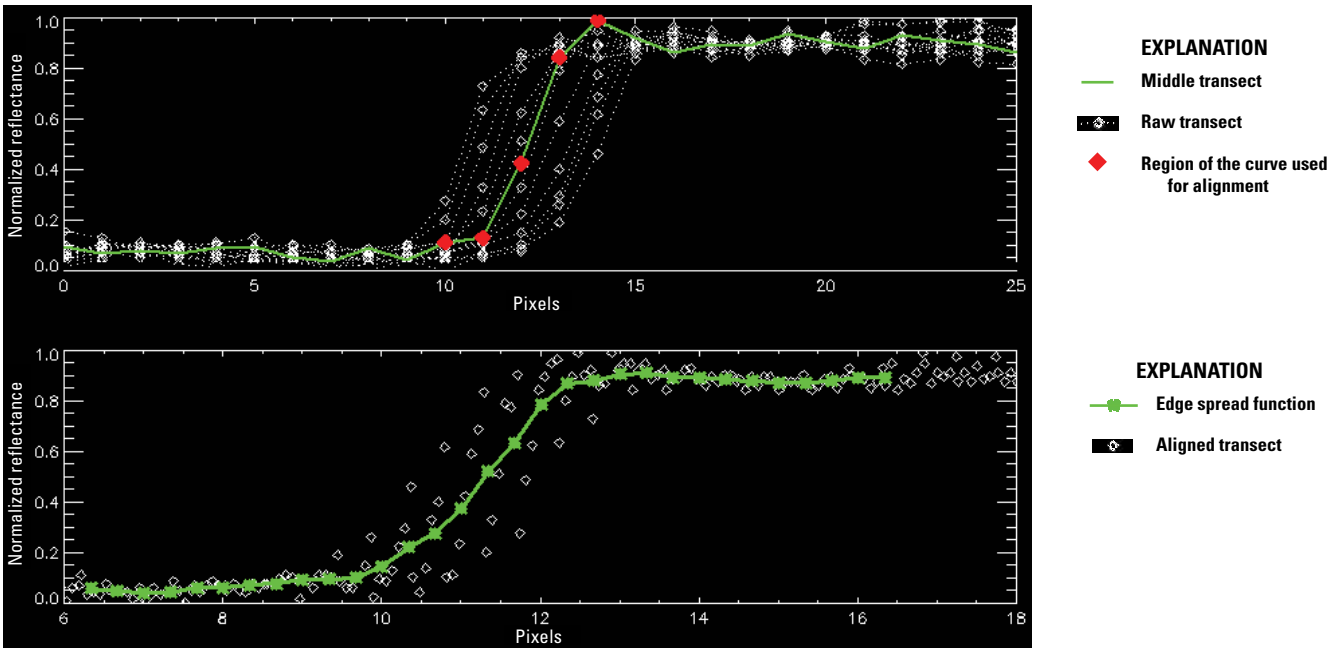


Figure 35. Band 4 (near infrared) raw edge transects (upper) and shifted transects (lower).

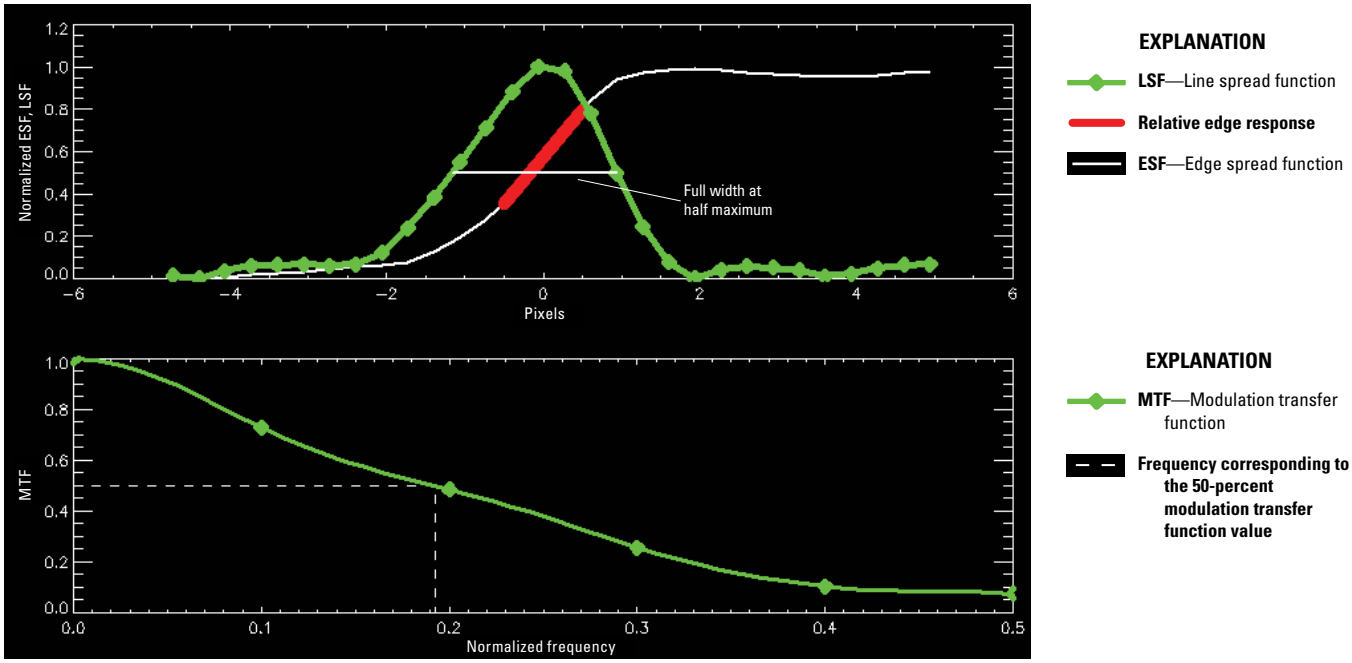


Figure 36. Band 4 (near infrared) edge spread function and line spread function (upper) and modulation transfer function (lower).

Summary and Conclusions

This report summarizes the sensor performance of the Amazônia-1 satellite sensing 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 −3.584 meter (m; −0.056 pixel) to 0.320 m (0.005 pixel) in easting and −1.984 m (−0.031 pixel) to 2.048 m (0.032 pixel) in northing in band-to-band registration, an exterior geometric performance of −37.256 m (−0.621 pixel) to 54.758 m (0.913 pixel) in easting and −12.684 m (−0.211 pixel) to 54.898 m (0.915 pixel) in northing offset in comparison to the Landsat 8 Operational Land Imager, a radiometric performance in the range of 0.030 to 0.143 in offset and 0.662 to 0.825 in slope, and a spatial performance in the range of 1.62 to 2.06 pixels for full width at half maximum, with a modulation transfer function at a Nyquist frequency in the range of 0.062 to 0.115.

In conclusion, the team has completed an ECCOE standardized system characterization of the Amazônia-1 satellite 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 Amazônia-1. 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

Instituto Nacional de Pesquisas Espaciais, 2019, Catálogo: Instituto Nacional de Pesquisas Espaciais digital data, accessed December 14, 2021, at http://www2.dgi.inpe.br/catalogo/explore.

Instituto Nacional de Pesquisas Espaciais, 2020, Amazonia—About the satellite: Instituto Nacional de Pesquisas Espaciais web page, accessed July 26, 2022, at http://www.inpe.br/amazonia1/en/about_satellite/.

Ramaseri Chandra, S.N., Christopherson, J.B., and Casey, K.A., 2020, 2020 Joint Agency Commercial Imagery Evaluation—Remote sensing satellite compendium (ver. 1.1, October 2020): U.S. Geological Survey Circular 1468, 253 p. [Also available at https://doi.org/10.3133/cir1468.] [Supersedes USGS Circular 1455.]

U.S. Geological Survey, 2020a, EROS CalVal Center of Excellence (ECCOE): U.S. Geological Survey web page, accessed March 2021 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 December 2021 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 March 2021 at https://www.usgs.gov/landsat-missions/glossary-and-acronyms.

U.S. Geological Survey, 2022, Land remote sensing satellites online compendium: U.S. Geological Survey web page, accessed July 26, 2022, at https://calval.cr.usgs.gov/apps/compendium.

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 and Lafayette Publishing Service Centers

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20211030N