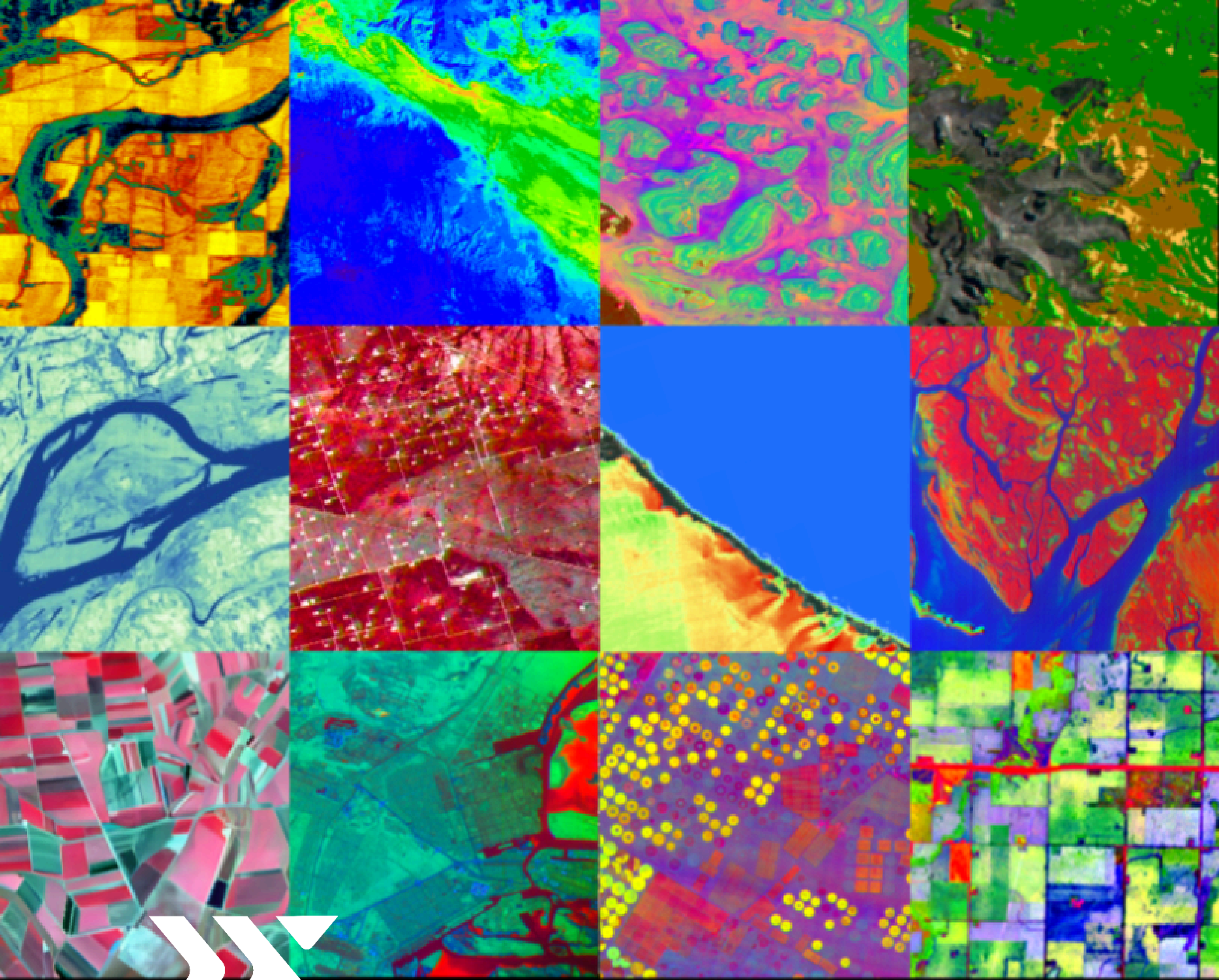

# PIXXEL HYPERSPECTRAL IMAGERY PRODUCT SPECIFICATIONS

For any inquiries, please write to support@pixxel.space.


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## Glossary

| Term | Definition |
|---|---|
| **Application Programming Interface (API)** | A set of protocols enabling software applications to interact with each other. |
| **Area of Interest (AOI)** | A specific Earth surface area defined for targeted satellite data collection. |
| **Atmospheric Correction** | The process of compensating for the influence of Earth's atmosphere on captured satellite imagery. |
| **Bottom of Atmosphere (BOA)** | Earth’s surface as it would appear without atmospheric distortion, obtained through correction algorithms. |
| **Digital Elevation Model (DEM)** | A digital representation depicting Earth’s terrain elevation. |
| **Digital Number (DN)** | A numerical value assigned to each pixel in a digital image, representing the intensity of light or radiation received by a sensor and converted into a discrete digital format for processing and analysis. |
| **GeoJSON** | A standard file format for encoding geographical data using JSON to represent geographic features and their properties. |
| **GeoTIFF** | A geospatial image file format that includes geographic information that can be accessed in GIS or other geospatial software. |
| **Graphical User Interface (GUI)** | A visual interface that allows users to interact, preview, and download Pixxel’s imagery. |
| **Ground Sample Distance (GSD)** | The physical distance on the ground that each pixel in a satellite image represents, indicating the level of detail captured in the image. |
| **Metadata** | Descriptive information about the imagery product that provides further information on the content of the data product, which can be used for additional analysis or processing. |
| **Nadir** | The point on the Earth's surface directly below a satellite. |

| Term | Definition |
|---|---|
| **Near-Infrared (NIR)** | The portion of the electromagnetic spectrum just beyond the visible red light, often used in satellite imagery to detect vegetation health and moisture content. |
| **Off Nadir Angle (ONA)** | The angle between the satellite's positioning direction and the point directly below the satellite on the Earth's surface (nadir). |
| **Orthorectification** | The process of correcting satellite imagery to remove distortions caused by terrain variations and sensor viewing angles, resulting in accurate maps. |
| **Radiometric Correction** | The correction of variations in data that are not caused by the object or image being scanned. These include correction for relative radiometric response between detectors, filling non-responsive detectors, and scanner inconsistencies. |
| **Sensor Correction** | The correction of data variations caused by sensor geometry, attitude, and ephemeris. |
| **SpatioTemporal Asset Catalog (STAC)** | A standardized catalog specification used to discover and index a wide range of geospatial datasets. |
| **Sun Azimuth** | The angle of the Sun as seen by an observer located at the target point, as measured in a clockwise direction from the North. |
| **Sun Elevation** | The angle of the Sun above the horizon. |
| **Sun Synchronous Orbit (SSO)** | A geocentric orbit that combines altitude and inclination so that the satellite passes over any given point of the planet’s surface at the same local solar time. |
| **SWIR** | Short Wave Infrared (900-2500 nm) from the Honeybee satellites. |
| **Top of Atmosphere (TOA)** | The outermost boundary of the Earth's atmosphere in satellite imagery, representing measurements captured by a sensor before any atmospheric effects or interactions are considered. |
| **VNIR** | Visible Near Infrared Product (472-890 nm) from the Firefly satellites. |
| **Quaternion** | Quaternions are mathematical operators that are used to rotate and stretch vectors. Quaternions are an alternate way to describe orientation or rotations in 3D space using an ordered set of four numbers. |

# 1. PIXXEL OVERVIEW

This document describes Pixxel satellite imagery and platform products. It is intended for users of satellite imagery interested in working with Pixxel's product offerings.

## 1.1. COMPANY OVERVIEW

Pixxel is a space data company, building a constellation of hyperspectral Earth imaging satellites and the analytical tools to extract insights from that data. The constellation is designed to provide global coverage, enabling the detection, monitoring, and prediction of global phenomena.

## 1.2. DATA PRODUCT OVERVIEW

Pixxel provides the following data products, with additional offerings available upon constellation expansion:

**VNIR Imagery**

Hyperspectral Visible and Near Infrared (VNIR) Product (472-890 nm) from Pixxel's Firefly satellites operational as of 2025.

**VSWIR imagery**

Hyperspectral Visible Short Wave Infrared (VSWIR) Product (470-2500 nm) from Honeybee-0 and Honeybee constellation upon launch in 2026 and 2027, respectively.

Upon launch of both Firefly and Honeybee constellations, data can be provided either as a VNIR or SWIR product separately or as a combined product.

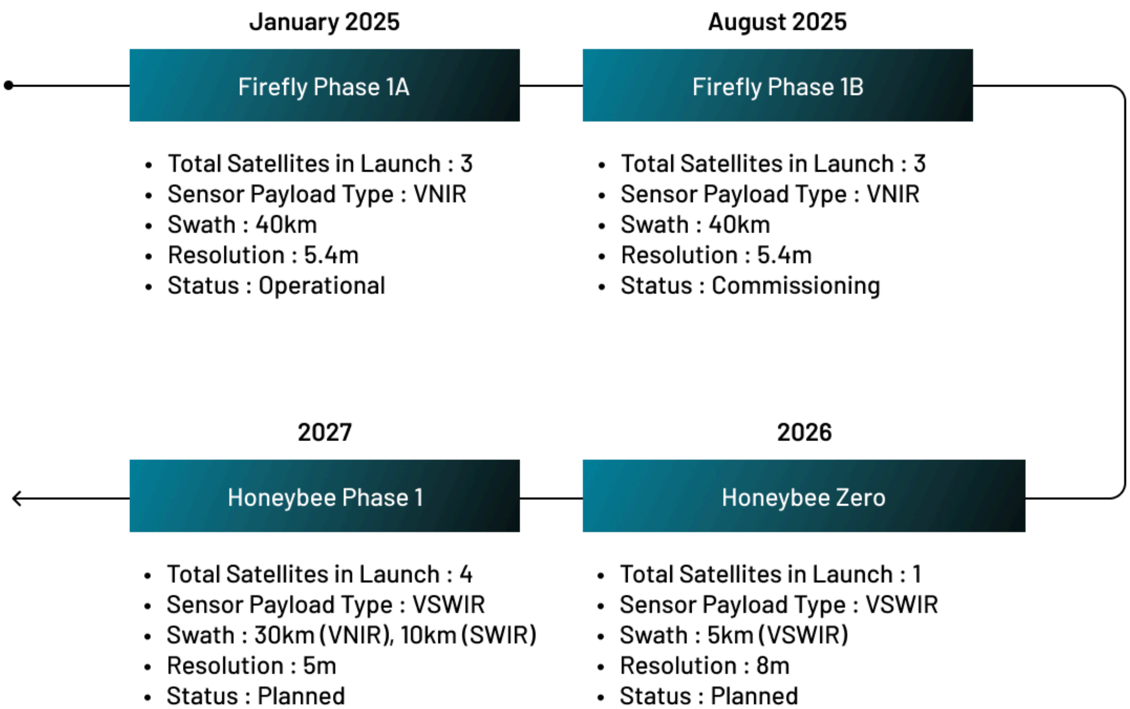
## 1.3. PIXXEL CONSTELLATION OVERVIEW

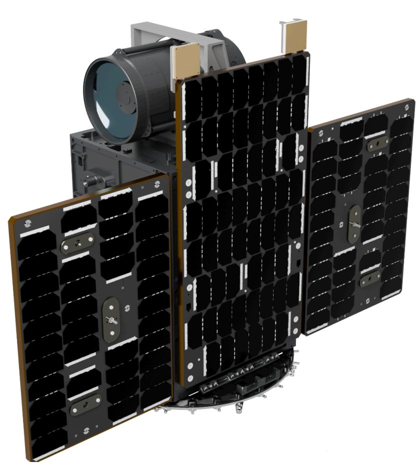
| Satellite | Wavelength range | Spatial Resolution (GSD) | Status |
|---|---|---|---|
| **Fireflies** | 472-890 nm (VNIR) | 5.4 m | 3 launched and operational, 3 undergoing commissioning |
| **Honeybee Zero** | 400-2500 nm (VSWIR) | 8 m | To launch in Q4 2026 |
| **Honeybees** | 470-2500 nm (VSWIR) | 5 m | To launch in Q3/Q4 2027 |

## 1.4. PIXXEL CONSTELLATION LAUNCH ROADMAP

Pixxel’s operational era began with the launch of the first three Firefly satellites in January 2025, delivering 5m VNIR hyperspectral imaging for global monitoring. A second set of three Firefly satellites was launched in August 2025, further enhancing revisit and global coverage.

These operational satellites build on the foundation of Tech Demo-1 (30 m VNIR) and Tech Demo-2 (10 m VNIR), which successfully validated Pixxel’s imaging and processing technologies before being decommissioned. Looking ahead, Pixxel will expand its spectral reach with Honeybee Zero (8m VSWIR), followed by the full Honeybee Constellation (5m VSWIR), which will unlock hyperspectral imaging across the visible and shortwave infrared spectrum.



## 1.5. PIXXEL COMMERCIAL CONSTELLATION AND SENSOR OVERVIEW

| Parameters | Firefly Constellation | Honeybee Constellation |
|---|---|---|
| **Ground Sample Distance (GSD)** | 5.4 meters | 5 meters |
| **Swath** | 40 km | 10 km SWIR<br>30 km VNIR |
| **Wavelength range** | 472 - 890 nm | 470 - 2500 nm |
| **Total available bands** | 135 bands | ~160 VNIR, ~100 SWIR |
| **Total selectable bands** | 45 bands | Total: 72, VNIR - 46, SWIR - 26 |
| **Orbit** | Sun Synchronous Orbit (SSO), 97.65° inclination | Sun Synchronous Orbit (SSO), 97.45° inclination |
| **Altitude** | 589 km | 550 km (TBD) |
| **Equator Crossing Time** | 10 - 11 AM | 10 - 11 AM |
| **Off-nadir angle (ONA)/slew** | +/- 20° | +/- 20° (+/-10° recommended) |
| **Revisit time** | Within ±30° latitude: < 7 days<br>Above +30° and below -30°: < 4 days | 3 - 5 days (based on latitude) |
| **Cloud cover thresholds*** | <20% | <20% |
| **Imagery bit depth** | 10 bits of dynamic range, stretched to fill a 16-bit container | 10 bits of dynamic range, stretched to fill a 16-bit container |

*Predicted cloud cover may have inaccuracies

## 1.6. FIREFLY CONSTELLATION AND SENSOR OVERVIEW

The Firefly constellation is operational as Pixxel's current sensor for imagery products. The sensors on these satellites are equipped to provide hyperspectral imagery of 135 bands total in the 472-890 nm range at a GSD of 5.4 meters.

**Mission Characteristics**

<table>
<tr><th>Parameters</th><th>Firefly Constellation</th></tr>
<tr><td>Ground Sample Distance (GSD)</td><td>5.4 meters</td></tr>
<tr><td>Swath</td><td>38 km</td></tr>
<tr><td>Wavelength range</td><td>472 - 890 nm</td></tr>
<tr><td>Orbit</td><td>Sun Synchronous Orbit (SSO), 97.65° inclination</td></tr>
<tr><td>Altitude</td><td>589 km</td></tr>
<tr><td>Equator Crossing Time</td><td>10 - 11 AM</td></tr>
<tr><td>Bandset Information</td><td>Bandwidths: 4.0 nm - 11.5 nm<br>Range: 472.4 nm - 890 nm, 135 hyperspectral bands (in bandset)
<table>
<tr><th>Band Group</th><th>Number of Bands</th><th>Approximate range</th><th>Average Bandwidth</th></tr>
<tr><td>Blue<br>(470 - 500)</td><td>8</td><td>472.4 - 497.5 nm</td><td>4.4</td></tr>
<tr><td>Green<br>(500 - 570)</td><td>20</td><td>501.2 - 566.9 nm</td><td>4.4</td></tr>
<tr><td>Yellow - Orange<br>(570 - 620)</td><td>18</td><td>570.7 - 619.3 nm</td><td>5.9</td></tr>
<tr><td>Red<br>(620 -700)</td><td>24</td><td>622.5 - 696.4 nm</td><td>6.4</td></tr>
<tr><td>Red-Edge<br>(700 - 750)</td><td>16</td><td>700.0 - 749.1 nm</td><td>5.8</td></tr>
<tr><td>NIR<br>(750 - 900)</td><td>49</td><td>752.2 - 890.0 nm</td><td>8.0</td></tr>
</table></td></tr>
<tr><td>Total available bands</td><td>135 bands</td></tr>
<tr><td>Total selectable bands</td><td>45 bands</td></tr>
<tr><td>Off-nadir angle (ONA)/slew</td><td>+/- 20°</td></tr>
<tr><td>Revisit time</td><td>Within ±30° latitude: < 7 days<br>Above +30° and below -30°: < 4 days</td></tr>
<tr><td>Cloud cover thresholds</td><td><20%</td></tr>
<tr><td>Imagery bit depth</td><td>10 bits of dynamic range stretched to fill a 16-bit container</td></tr>
</table>

## 1.7. HONEYBEE ZERO (HB00) SENSOR OVERVIEW

Honeybee Zero (HB00), planned for launch in Q4 2026, will feature expanded hyperspectral coverage from the visible to the shortwave infrared range. The sensor will be equipped to provide hyperspectral imagery of ~450 bands total in the 400-2550 nm range at a GSD of 8 meters.

**Mission Characteristics**

| PARAMETERS | HONEYBEE CONSTELLATION |
|---|---|
| **Ground Sample Distance (GSD)** | 8 meters |
| **Swath** | 5 km, VSWIR |
| **Wavelength range** | 400 - 2550 nm |
| **Total available bands** | ~450, VSWIR |
| **Orbit** | Sun Synchronous Orbit (SSO), 97.45° inclination |
| **Altitude** | 500 - 550 km (TBD) |
| **Equator Crossing Time** | 10 - 11 AM |
| **Off-nadir angle (ONA)/slew** | +/- 20° (+/-10° recommended) |
| **Revisit time** | 15 days |
| **Cloud cover thresholds** | <20% |
| **Imagery bit depth** | 10 bits of dynamic range, stretched to fill a 16-bit container |

## 1.8. HONEYBEE CONSTELLATION AND SENSOR OVERVIEW

The Honeybee constellation, planned for future launch, will feature expanded hyperspectral coverage from the visible to the shortwave infrared range. The sensor will be equipped to provide hyperspectral imagery of ~250 bands total in the 470-2500 nm range at a GSD of 5 meters.

**Mission Characteristics**

| PARAMETERS | HONEYBEE CONSTELLATION |
|---|---|
| **Ground Sample Distance (GSD)** | VNIR (450 nm - 900 nm) - 5 m<br>SWIR 1 (900 nm - 1700 nm) - 5 m<br>SWIR 2 (1700 nm - 2550 nm) - 8 m |
| **Swath** | 10 km SWIR<br>30km VNIR |
| **Wavelength range** | 470 - 2500 nm |
| **Total available bands** | ~160 VNIR, ~100 SWIR |
| **Total selectable bands** | Total: 72, VNIR - 46, SWIR - 26 |
| **Orbit** | Sun Synchronous Orbit (SSO), 97.45° inclination |
| **Altitude** | 500 - 550 km (TBD) |
| **Equator Crossing Time** | 10 - 11 AM |
| **Off-nadir angle (ONA)/slew** | +/- 20° (+/-10° recommended) |
| **Revisit time** | 3 - 5 days (based on latitude) |
| **Cloud cover thresholds** | <20% |
| **Imagery bit depth** | 10 bits of dynamic range, stretched to fill a 16-bit container |

# 2. FIREFLY BANDSETS

When working with hyperspectral imagery, the flexibility of selecting specific band combinations is a key advantage that enables users to focus on the most relevant spectral information for their applications. Pixxel's Firefly constellation captures data across the VNIR spectrum (472 nm - 890 nm), providing insights into various surface materials, vegetation health, water quality, and more. The Firefly constellation offers a total of 135 available bands within the default bandsets, covering a wide range of spectral information. However, for each individual capture, users can select a maximum of 45 bands (referred to as **selectable bands**), allowing them to customize their acquisition for specific use cases and avoid unnecessary spectral information. For ease of use, Pixxel has established default band combinations that users can select when taking an image.

## 2.1. FIREFLY DEFAULT BAND COMBINATIONS

For users who require the full spectrum of 135 available bands, Pixxel has developed three predefined band combinations, each containing 45 bands. These combinations are designed to cover different portions of the VNIR spectrum, enabling full spectral coverage through three separate collections.

### 2.1.1. UNIFIED-1 (FORMERLY 3A) DEFAULT BAND COMBINATION

Bandwidths: 4.4 nm - 6.6 nm

Range: 472.4 nm - 866.0 nm

Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 4 | 472.4 nm - 482.4 nm | 4.4 nm |
| Green<br>(500 - 570) | 1 | 560.0 nm | 4.4 nm |
| Red<br>(620 -700) | 12 | 660.0 nm - 696.4 nm | 6.1 nm |
| Red-Edge<br>(700 - 750) | 16 | 700.0 nm - 749.1 nm | 5.8 nm |
| NIR<br>(750 - 900) | 12 | 752.2 nm - 866.0 nm | 6.6 nm |

### 2.1.2. UNIFIED-2 (FORMERLY 3B) DEFAULT BAND COMBINATION

Bandwidths: 4.2 nm - 11.0 nm
Range: 489.8 nm - 890.0nm
Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 3 | 489.8 nm - 497.5 nm | 4.2 nm |
| Green<br>(500 - 570) | 2 | 563.8 nm - 566.9 nm | 4.3 nm |
| Yellow - Orange<br>(570 - 620) | 18 | 570.7 nm - 619.3 nm | 5.9 nm |
| Red<br>(620 -700) | 11 | 622.5 nm - 653.9 nm | 6.8 nm |
| NIR<br>(750 - 900) | 11 | 868.3 nm - 890.0 nm | 11.0 nm |

### 2.1.3. UNIFIED-3 (FORMERLY 3C) DEFAULT BAND COMBINATION

Bandwidths: 4.5 nm - 7.4 nm
Range: 485.9 nm - 863.2 nm
Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 1 | 485.9 nm | 4.5 nm |
| Green<br>(500 - 570) | 17 | 501.2 nm - 556.3 nm | 4.4 nm |
| Red<br>(620 -700) | 1 | 657.1 nm | 6.3 nm |
| NIR<br>(750 - 900) | 26 | 787.5 nm - 863.2 nm | 7.4 nm |

## 2.2. FIREFLY DEFAULT APPLICATION BAND COMBINATIONS

Pixxel offers a series of application-focused band combinations, each specifically tailored to provide insights for the more common monitoring use cases, focusing on Vegetation, Water, Urban, Transition Metals, and Rare Earth Metals, all within the VNIR range. These band combinations are optimized to enhance spectral sensitivity and extraction of meaningful data for specific applications, such as water quality analysis, vegetation health assessment, and more. While these default band combinations are designed for a variety of applications, users may contact Pixxel for user-defined band combinations. Additionally, Pixxel offers default bandsets aligned to the Sentinel-2 MSI and Landsat 9 OLI-2 spectral configurations, supporting cross-sensor interoperability.

### 2.2.1. DEFAULT VEGETATION BAND COMBINATION

The default bandset utilizes spectral regions within the VNIR range that are sensitive to plant physiological processes. It includes wavelengths that capture chlorophyll absorption and red-edge reflectance shift (700 nm - 750 nm) to provide detailed insights into photosynthetic activity, chlorophyll content, overall plant health, and species and subspecies plant identification. This band combination is effective for deriving vegetation and chlorophyll indices, which can be used in a wide variety of agricultural, forestry, and biomass-related applications.

Bandwidths: 4.3 nm - 10.9 nm

Range: 485.9 nm - 877.8 nm

Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 4 | 485.9 nm - 497.5 nm | 4.3 nm |
| Green<br>(500 - 570) | 11 | 501.2 nm - 556.3 nm | 4.4 nm |
| Red<br>(620 -700) | 7 | 660.0 nm - 680.4 nm | 6.3 nm |
| Red-Edge<br>(700 - 750) | 16 | 700.0 nm - 749.1 nm | 5.8 nm |
| NIR<br>(750 - 900) | 7 | 863.2 nm - 877.8 nm | 10.9 nm |

### 2.2.2. DEFAULT WATER BAND COMBINATION

The default water band combination is designed to capture spectral features within the VNIR range that are indicative of various water quality parameters, including (but not limited to) turbidity, chlorophyll concentration, and dissolved organic matter. Bands are selected to target the specific absorption peaks and reflectance characteristics of water bodies, such as chlorophyll-a absorption near 680 nm and the reflectance influenced by suspended sediments. This combination is suitable for detecting changes in water properties, identifying water pollutants, assessing eutrophication, and monitoring harmful algal blooms in freshwater and coastal environments.

Bandwidths: 4.4 nm - 10.8 nm

Range: 485.9 nm - 875.6 nm

Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 2 | 485.9 nm - 489.8 nm | 4.4 nm |
| Green<br>(500 - 570) | 5 | 550.6 nm - 560.0 nm | 4.5 nm |
| Red<br>(620 -700) | 18 | 619.3 nm - 692.6 nm | 6.4 nm |
| Red-Edge<br>(700 - 750) | 14 | 707.0 nm - 749.1 nm | 5.8 nm |
| NIR<br>(750 - 900) | 6 | 863.2 nm - 875.6 nm | 10.8 nm |

### 2.2.3. DEFAULT URBAN BAND COMBINATION

The urban band combination focuses on capturing spectral responses characteristic of impervious surfaces, such as concrete, asphalt, and metal rooftops, using the VNIR range. Bands are chosen to maximize the spectral differentiation between built-up materials and surfaces, allowing for accurate classification of land cover in urban environments. This combination is well-suited for analyzing the spectral reflectance properties of impervious surfaces and monitoring land use changes in densely populated areas.

Bandwidths: 4.3 nm - 9.0 nm

Range: 475.6 nm - 890.0 nm

Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 7 | 475.6 nm - 497.5 nm | 4.3 nm |
| Green<br>(500 - 570) | 11 | 501.2 nm - 556.3 nm | 4.4 nm |
| Red<br>(620 -700) | 1 | 660.0 nm | 6.4 nm |
| NIR<br>(750 - 900) | 26 | 790.6 nm - 890.0 nm | 9.0 nm |

## 2.2.4. DEFAULT TRANSITION METAL BAND COMBINATION

The transition metals band combination is optimized for detecting spectral absorption features related to minerals containing transition metals like copper, nickel, and zinc within the VNIR range. Specific bands are selected based on their ability to enhance the visibility of diagnostic absorption features that are associated with these metals, including subtle variations in reflectance. This configuration provides a useful tool for mapping mineral occurrences and supporting exploration activities.

Bandwidths: 4.4 nm - 8.4 nm

Range: 472.4 nm - 868.3 nm

Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 8 | 472.4 nm - 497.5 nm | 4.4 nm |
| Green<br>(500 - 570) | 13 | 501.2 nm - 566.9 nm | 4.3 nm |
| Yellow - Orange<br>(570 - 620) | 6 | 570.7 nm - 587.5 nm | 4.8 nm |
| Red<br>(620 -700) | 3 | 647.6 nm - 653.9 nm | 6.1 nm |
| Red-Edge<br>(700 - 750) | 11 | 716.8 nm - 749.1 nm | 6.0 nm |
| NIR<br>(750 - 900) | 4 | 752.2 nm - 868.3 nm | 8.4 nm |

### 2.2.5. DEFAULT RARE EARTH ELEMENTS BAND COMBINATION

The rare earth element band combination is configured to detect the characteristic spectral features of rare earth minerals using wavelengths in the VNIR range. Bands are selected to capture specific reflectance and absorption features that indicate the presence of rare earth-bearing minerals such as lanthanum, yttrium, and terbium based on minor spectral inflections. This band combination is beneficial for geological exploration, as it enhances the ability to identify and map rare earth elements in a non-invasive manner.

Bandwidths: 4.2 nm - 8.9 nm

Range: 489.8 nm - 890.0 nm

Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue<br>(470 - 500) | 3 | 489.8 nm - 497.5 nm | 4.2 nm |
| Green<br>(500 - 570) | 2 | 563.8 nm - 566.9 nm | 4.3 nm |
| Yellow - Orange<br>(570 - 620) | 8 | 570.7 nm - 593.7 nm | 4.9 nm |
| Red<br>(620 -700) | 2 | 660.0 nm - 663.2 nm | 6.4 nm |
| Red-Edge<br>(700 - 750) | 6 | 733.6 nm - 749.1 nm | 6.5 nm |
| NIR<br>(750 - 900) | 24 | 752.2 nm - 890.0 nm | 8.9 nm |

### 2.2.6. DEFAULT SENTINEL-2 MSI BAND COMBINATION

This bandset approximates Sentinel-2 MSI's multispectral configuration within Firefly's VNIR hyperspectral range (472-890 nm) of 45 selectable bands. The selection prioritizes wavelengths that align closely with Sentinel-2 MSI's discrete spectral sampling across the visible, red-edge, and near-infrared domains to better enable cross-platform analysis.

Bandwidths: 4.3 nm - 8.0 nm
Range: 475.6 nm - 870.9 nm
Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue (470 - 500) | 7 | 475.6 nm - 497.5 nm | 4.3 nm |
| Green (500 - 570) | 12 | 501.2 nm - 566.9 nm | 4.4 nm |
| Yellow - Orange (570 - 620) | 2 | 570.7 nm - 574.4 nm | 4.8 nm |
| Red (620 -700) | 4 | 650.8 nm - 660.0 nm | 6.3 nm |
| Red-Edge (700 - 750) | 10 | 700.0 nm - 746.0 nm | 6.0 nm |
| NIR (750 - 900) | 10 | 775.7 nm - 870.9 nm | 8.0 nm |

### 2.2.7. DEFAULT LANDSAT 9 OLI-2 BAND COMBINATION

This bandset is designed to approximate the Landsat 9 Operational Land Imager (OLI-2) spectral configuration using Firefly's VNIR hyperspectral range (472-890 nm) of 45 selectable bands. It selects wavelengths closely matching Landsat 9 OLI-2's discrete multispectral sampling for cross-platform analysis, enabling consistent workflows such as land cover monitoring, vegetation analysis, and surface water monitoring.

Bandwidths: 4.4 nm - 10.3 nm
Range: 472.4 nm - 880.0 nm
Number of Bands: 45

| Band Group | Number of Bands | Approximate range | Average Bandwidth |
|---|---|---|---|
| Blue (470 - 500) | 8 | 472.4 nm - 497.5 nm | 4.4 nm |
| Green (500 - 570) | 13 | 501.2 nm - 566.9 nm | 4.4 nm |
| Yellow - Orange (570 - 620) | 7 | 570.7 nm - 591.1 nm | 4.8 nm |
| Red (620 -700) | 6 | 643.9 nm - 660.0 nm | 6.2 nm |
| NIR (750 - 900) | 11 | 854.3 nm - 880.0 nm | 10.3 nm |

# 3. PRODUCT PROCESSING

## 3.1. IMAGE PRODUCT LEVELS

| Name | Description | Product Level |
|---|---|---|
| **Bottom of Atmosphere (BOA) Reflectance** | This is radiometric, geometric, and atmospheric (aerosol and water vapor) corrected BOA reflectance data. The image is orthorectified and projected in UTM (WGS84 datum). The data is available in a geoTIFF file format (accompanied by additional metadata).<br>The pixel reflectance values are linearly scaled between 0 - 50000. Thus, to convert the image to 0-1 reflectance range, all the pixel values must be divided by 50000. | L2A |
| **Top of Atmosphere (TOA) Reflectance** | This is radiometric and geometrically corrected TOA reflectance data. The image is orthorectified and projected in UTM (WGS84 datum). The data is available in a geoTIFF file format (accompanied by additional metadata).<br>The pixel reflectance values are linearly scaled between 0 - 50000. Thus, to convert the image to 0-1 reflectance range, all the pixel values must be divided by 50000. | L1C |
| **Geometrically Corrected Radiance** | The L1B is a geometrically corrected dataset. Geolocation is computed photogrammetrically, yielding good band-to-band registration. The output of L1B processing is a multiband geoTIFF, complete with geospatial headers that specify the projection and extent. | L1B |

## 3.2. IMAGE PROCESSING AND CORRECTION

The image processing workflow consists of four major steps: radiometric correction, geometric correction, atmospheric correction, and quality analysis. Before radiometric correction, the raw data downlinked from the satellite is converted to an L0 level for long-term storage. The L0 level data is then used for radiometric correction, where DNs are converted to radiance, and basic striping and high-frequency noise are removed from the data. This data is called L1A. Post L1A, a geometric correction model is applied to georeference and orthorectify the data, storing it as a level L1B. L1B data is used by Pixxel's internal atmospheric correction model and is converted to TOA reflectance (L1C) and BOA reflectance (L2A) data sequentially. Upon completion, a QA/QC check is performed on each image, observations are recorded, and data is stored for delivery. Figure 4.2 illustrates the image processing method. Table 4.2 describes each block in the flowchart.

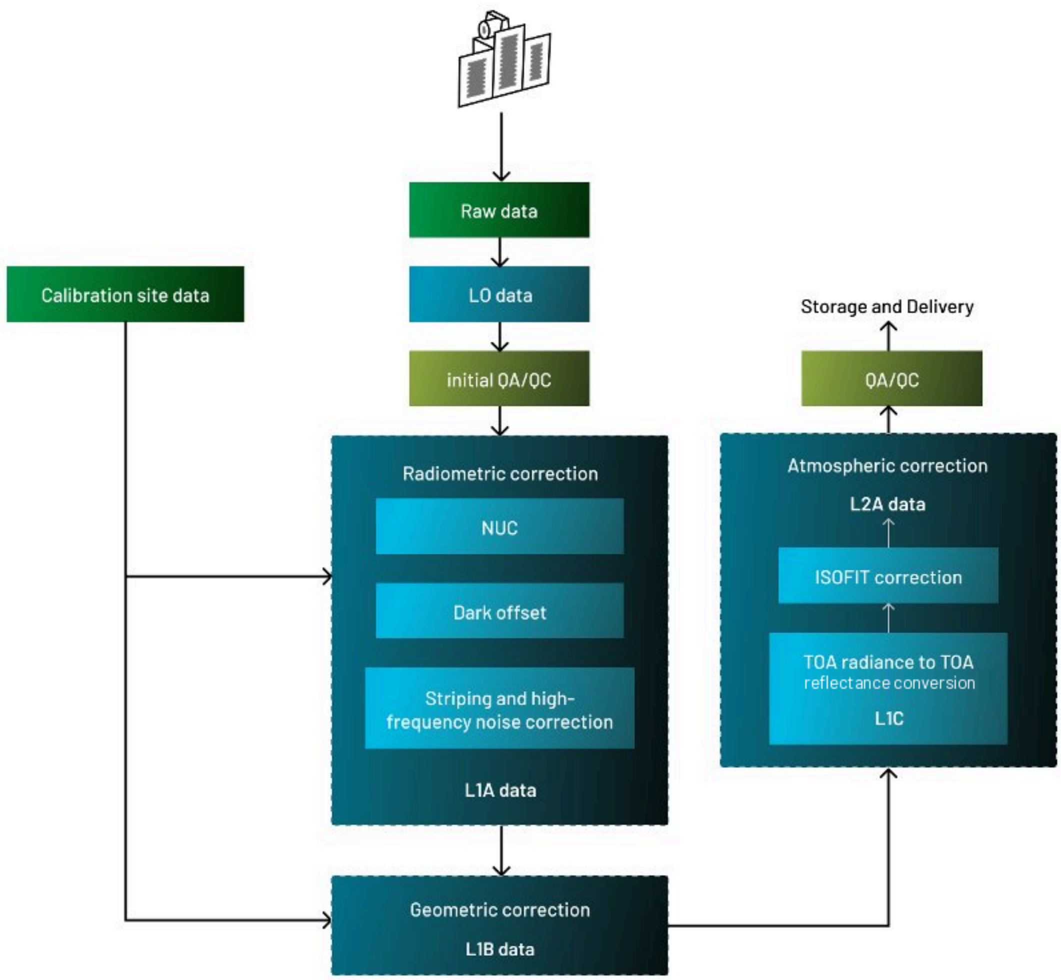



Figure 4.2: Image processing pipeline flowchart

Table 4.2: Image processing steps

| | |
|---|---|
| **Raw data** | This is raw data downlinked from the satellite. |
| **L0 data** | This level is for the long-term archiving of raw data with additional information added at a ground station. |
| **NUC correction** | Non-uniformity coefficients (NUCs) are derived during pre-launch calibration and applied to remove non-uniformities from the image. This step includes gain and dark offset corrections, which flatten the detector response and normalize all pixels to a zero baseline, ensuring uniform radiometric performance across the image. |
| **Striping and high-frequency noise correction** | Minor striping noise and high-frequency noise present in the data post-NUC implementation are corrected through a filtering approach. |
| | |
| **Geo-referencing and Orthorectification** | The radiometrically corrected data is geo-referenced and orthorectification is performed by using the Copernicus DEM/terrain models. The output image of this step is referred to as level L1B. |
| **TOA radiance to TOA reflectance** | The georeferenced and orthorectified TOA radiance image is converted to a TOA reflectance image using extraterrestrial solar irradiance, Earth-Sun distance, and solar zenith angle. This TOA reflectance data level is termed L1C. |
| **Aerosol correction** | The L1B and L1C data are used to estimate and correct the effects of aerosol and water vapor. This step removes the haze effect from the image, making it visibly clearer. |
| **QA/QC** | The L2A, L1C, and L1B data undergo automated and random manual quality assessments, and spectral and geometric quality observations are recorded. |

### 3.2.1. L1A PROCESSING: INITIAL RADIOMETRIC INTERPRETATION & CORRECTION

To generate calibrated hyperspectral products (Pixxel L1C and L2A) suitable for use as Analysis Ready Data (ARD), an initial L1A pre-processing step is performed to remove predictable image artifacts and ensure radiometric consistency. Radiometric correction coefficients and Non-Uniformity Coefficients (NUCs), are determined during pre-launch calibration and validated on-orbit using collections over established vicarious calibration sites. NUC coefficients include both gain and dark offset adjustments, which flatten the detector response and normalize all pixels to a uniform zero baseline.

All Pixxel satellite images are collected at a 10-bit depth per pixel and converted to a 16-bit format once they are downlinked to the ground. During on-ground processing, the radiometric gain and offset values are applied to convert the raw Digital Numbers (DNs) from the sensor into absolute at-sensor radiance units.

The pixel values of Pixxel's L1A product represent absolute calibrated radiance units for the image.

### 3.2.2. L1B PROCESSING: GEOMETRIC CORRECTION

Further radiometric processing (L1C, L2A) requires accurate georeferencing. L1B processing orthorectifies all bands using a calibrated camera model and a terrain model. Geolocation is computed photogrammetrically, yielding good band-to-band registration.

The initial attitude data received from the satellite has poor accuracy due to hardware limitations. This creates a noticeable geolocation error that must be addressed before L1B processing. To rectify this, Pixxel bands are registered against Sentinel-2 reference images to recover an "adjusted pointing" that would lead to the same geolocation upon projection. A proprietary, multi-channel registration technique is employed where four Pixxel bands in a collection are simultaneously registered to the corresponding four 10-meter bands [blue, green, red, NIR] of a contemporaneous Sentinel-2A or 2B truth ortho. The registration creates tie points for those four bands, which are then fed into a least squares fit that deduces the adjusted pointing. This "corrected quaternion list" is then stored for all subsequent product generation. This process is as accurate as the truth orthos, which themselves typically have an absolute geolocation accuracy of around 12 meters CE90.

Also relevant is the geometric accuracy of the terrain model (DEM) used during orthorectification. Freely available, 30-meter Copernicus DEMs have a horizontal accuracy of 6 meters, or approximately one-fifth of a posting. The vertical accuracy of the DEM is approximately 4 meters, or about one-seventh of a posting.

The output of L1B processing is a multiband geoTIFF, complete with geospatial headers that specify the projection and extent. The map projection can be anything but is defaulted to Universal Transverse Mercator (UTM) (EPSG:32629–32748). The hyperspectral stack is trimmed to the common overlap region of all bands. A configurable value is used to fill areas outside the projection. The bit depth is made 16-bit just before saving the file.

***Note:*** *The L1B product is an intermediate processing level used internally for subsequent radiometric and atmospheric corrections. It is only available upon request.*

### 3.2.3. L1C PROCESSING: RADIANCE TO REFLECTANCE CONVERSION

Pixxel's L1C data is processed to provide Top of Atmosphere (TOA) reflectance, converting raw radiance measurements into reflectance values that are corrected for atmospheric and solar variations. This process ensures that the data is normalized, making it more consistent across captures. The following outlines the specific processes involved in the conversion process.

The following formula can express radiance to reflectance conversion:

$$\rho_{\mathrm{TOA}}(\lambda) = \frac{E_{\mathrm{TOA}}(\lambda)}{E_0(\lambda)} \equiv \frac{\pi \times L_{\mathrm{TOA}}(\lambda) \times d^2}{F_0(\lambda) \cos\theta_0 \cos\theta_{\mathrm{v}}}$$

Where:

- $L_{TOA}(\lambda)$ = Radiance at the Top of Atmosphere, measured in W/m²/sr/µm.
- $d$ = Earth-Sun distance in Astronomical Units (AU) for a given acquisition date.
- $F_0(\lambda)$ = Extraterrestrial solar irradiance at a specific wavelength λ, measured in W/m²/µm.
- $\theta_0$ = Solar zenith angle (in degrees), the angle between the Sun and the zenith (vertical at the point of measurement).
- $\theta_v$ = Sensor viewing angle (in degrees), the angle between the sensor and the zenith.

**Steps in L1C Processing**

1) Viewing Angle Correction: Radiance values are dependent on the sensor's viewing angle. To standardize data, a correction using the cosine of the viewing angle ($cos\ \theta_v$) is applied.
2) Earth-Sun Distance Adjustment: Solar irradiance reaching Earth varies due to the changing distance between Earth and Sun throughout the year. To account for this, Kepler's laws to calculate the Earth-Sun distance ($d$) are applied and are used to correct the irradiance values, ensuring reflectance values are accurate throughout the year.

   $$d = 1 - 0.01672\ cos\ (0.9856 \times (doy - 4))$$

   Where $doy$ is the day of the year, and $d$ is expressed in Astronomical Units.

For ease of computation, Earth's surface and atmosphere are assumed to behave as a Lambertian reflector.

### 3.2.4. L2A PROCESSING: ATMOSPHERIC CORRECTION

Pixxel's L2A product provides Bottom-of-Atmosphere (BOA) surface reflectance, derived from L1C Top-of-Atmosphere (TOA) reflectance using Pixxel's piSOFIT atmospheric correction workflow. piSOFIT is Pixxel's customized implementation of NASA JPL's open-source ISOFIT (Imaging Spectrometer Optimal Fitting) model, optimized for Firefly and Honeybee hyperspectral data.

**Methodology**

- Radiative Transfer Modeling: piSOFIT uses a neural-network-based MODTRAN emulator to model the interaction of solar radiation with the atmosphere and Earth's surface.
- Optimal Estimation Inversion: The workflow iteratively adjusts atmospheric parameters (e.g., water vapor, aerosols) and surface reflectance to minimize residuals between observed at-sensor radiance and modeled radiance using a Levenberg-Marquardt optimization approach.
- Bayesian Priors & Uncertainty Quantification: Prior information about atmospheric and surface conditions is incorporated into the inversion, providing improved retrieval stability and per-pixel uncertainty estimates.
- Superpixel Segmentation & Empirical Refinement: piSOFIT segments images into spectrally similar superpixels, solves atmospheric parameters at the superpixel level, and applies an empirical line adjustment to refine surface reflectance for each pixel.

**Outputs**

- The resulting L2A product delivers BOA surface reflectance scaled to 0-50,000 digital numbers.
- Includes per-pixel uncertainty metrics and quality flags derived from the inversion process.
- Corrects for aerosol scattering and water vapor absorption while normalizing for solar geometry and Earth-Sun distance.

## 3.3. IMAGE DELIVERY PACKAGE AND FILE NOMENCLATURE

Pixxel imagery products are delivered as complete, self-contained data packages, ensuring users can quickly ingest the data. Each package includes the primary imagery, along with additional metadata and capture information. A standardized naming convention is applied across all files in the package to support ease of integration into existing geospatial workflows.

### 3.3.1. IMAGE DELIVERY PACKAGE

Pixxel imagery products are delivered as a structured set of files. Each product delivery includes:

- **Primary Image File:** GeoTIFF containing the capture area at the specified processing level.
- **Quality Mask File:** GeoTIFF mask identifying cloud, water, and other quality flags at bit-encoded layers.
- **Footprint Polygon:** GeoJSON file representing the exact acquisition footprint.
- **ENVI Header File:** .hdr file providing band, wavelength, and projection information for direct hyperspectral processing.
- **Thumbnail Preview:** RGB JPEG quicklook for rapid scene visualization.
- **Product Metadata:** An XML file containing the details about the image along with the processing notes.

### 3.3.2. FILE NOMENCLATURE

All files in the delivery follow a consistent naming pattern:

XXnn_YYYYMMDD_aaabbccc_imageID_LnX.<filetype>

Where:

- XXnn: Satellite identifier (e.g., FF01 for Firefly 1)
- imageID: Unique six-digit image identifier.
- YYYYMMDD: Acquisition date (first instance) and product creation date (second instance).
- LnX: Processing level (e.g. L1C, L2A) or product type (e.g., TCI for True Color Image)
- aaa: Average spatial resolution
- bb: Reserved
- ccc: Number of spectral bands in the delivered image.
- filetype: File (e.g., .tif, .geojson, .jpeg, .hdr, .xml).

## 3.4. PRODUCT METADATA (FIREFLY)

Each image product contains an image file in geoTIFF format, an RGB composite thumbnail of the image in JPEG format, a footprint, and a bounding box in geoJSON format. Each of the products is also accompanied by an ENVI header file and metadata file in XML format, with the following parameters:

| PARAMETER | DATA TYPE | DESCRIPTION |
|---|---|---|
| **Satellite Details** | | |
| Satellite | string | The satellite ID to which the image product belongs. Satellite ID “Pixxel-FF01 '' indicates the image product belongs to Pixxel’s FF01 satellite. |
| Sensor Name | string | This field indicates the name of the imaging sensor. For Pixxel’s FF01, the hyperspectral imager is the ‘VNIR’ sensor. |
| **Image Product Details** | | |
| Product Files | string | List of all filenames included in the image product, including image files, metadata, bounding boxes, and header files. |
| Product Format | string | Denotes the product format as a string - defaults to GeoTIFF. |
| Masks | string | List of all masks provided with the image product, such as cloud, cloud-shadow, water, etc. |
| **Image Acquisition Details** | | |
| Acquisition Datetime | string | Date and time in UTC format at the time of image acquisition. |
| Image ID | string | Image ID unique to each image from the sensor. All communication regarding the image with Pixxel and Pixxel Orderdesk has to be referred to by the image ID, along with the order ID. |
| Altitude | number | Height of the satellite in units of kilometers at the time of image acquisition. |
| Satellite Look Angle | float | Angle between the satellite’s pointing direction and nadir in units of decimal degrees at the time of image acquisition. |
| Scene Center X Coordinate | float | Defaults to Easting of the center pixel of the scene in units of meters using the UTM system of reference. Alternatively, denotes geographic longitude of the center pixel of the scene in units of decimal degrees using the WGS 84 standard of reference. |

| PARAMETER | DATA TYPE | DESCRIPTION |
|---|---|---|
| Scene Center Y Coordinate | float | Defaults to Northing of the center pixel of the scene in units of meters using the UTM system of reference. Alternatively, denotes geographic latitude of the center pixel of the scene in units of decimal degrees using the WGS 84 standard of reference. |
| Sun Azimuth Angle | float | Azimuth angle of the sun's position at the time of image acquisition in units of decimal degrees. |
| Sun Elevation Angle | float | Elevation angle of the sun's position at the time of image acquisition in units of decimal degrees. |
| Earth Sun Distance | float | Earth-Sun distance ratio based on astronomical units, depending on the image acquisition day. |
| Rows | number | Number of rows of the image product, or alternatively, scan lines. |
| Columns | number | Number of columns of the image product, or alternatively, samples. |
| Number of bands | number | Indicates the number of bands available in the image product. |
| **Spectral Bands Information** | | |
| Bands UID | string | IDs unique to each band with values ranging from B001 to B150. |
| Central Wavelength | float | Central wavelength of the corresponding band in nanometers. |
| Central Wavelength STD | float | Standard deviation of the central wavelength of the corresponding band in nanometers. The field accounts for spectral variation across detector elements on the focal plane array. |
| FWHM | float | Refers to the full width at half maximum (FWHM) of the corresponding band in nanometers. |
| FWHM Unc | float | Refers to the uncertainty in full width at half maximum (FWHM) of the corresponding band. |
| Solar Irradiance | float | Indicates the solar spectral irradiance values for the corresponding bands in Watts per square meter per micrometer ($W/m^2/\mu m$). |
| Status | boolean ('0' or '1') | Indicates whether the corresponding band is available in the image product. |
| Layer | int | Indicates the layer number of the band in the image product. For example, if the image product contains band UIDs starting from B007, B008, and B011, band B007 is layer 1 and B011 is layer 3 in the image product. |

| PARAMETER | DATA TYPE | DESCRIPTION |
| --- | --- | --- |
| **Processed Image Details** | | |
| Processing Software | string | Indicates Pixxel atmospheric correction model used to create image products. |
| Processing Level | string | Indicates the image product's processing level (such as L1C, L2A). L1C and L2A are available by default. L1B is provided on request. |
| Processing Description | string | Describes the corrections that the image went through for a given processing level. |
| Output Quantity | string | Denotes per pixel output radiometric measurement in reflectance or radiance. |
| Unit | string | Unit of the output radiometric measurement per pixel. For L1B products, the unit is $W/m^2/\mu m/sr$. For L1C and L2A products, the value is unitless. |
| Reflectance gain factor | float | L1C and L2A pixel values are provided in the range of 0 - 50000. Scaling factor to be multiplied with the pixel values to bring the reflectance between 0.0 - 1.0. |
| Reflectance offset factor | float | An additional factor to be added to the pixel values of L1C and L2A products before scaling them by the Reflectance scaling factor. |
| Map Projection | string | Refers to the EPSG codes for Geographic or Projected Coordinate Reference System (CRS) used for the projection of the image. The string also includes the reference Ellipsoid and Datum used for projection. |
| DEM | string | Source filename of Digital Elevation Models used for terrain correction. |
| Top Left X Coordinate | float | Defaults to Easting of the top left corner of the bounding box in meters using the UTM system of reference. Alternatively, denotes geographic longitude of the top left corner of the bounding box in decimal degrees.<br><br>The value forms the upper bound of the image. |
| Top Left Y Coordinate | float | Defaults to Northing of the top left corner of the bounding box in meters using the UTM system of reference. Alternatively, denotes geographic latitude of the top left corner of the bounding box in decimal degrees.<br><br>The value forms the left bound of the image. |

| PARAMETER | DATA TYPE | DESCRIPTION |
| --- | --- | --- |
| Bottom Right X Coordinate | float | Defaults to Easting of the bottom right corner of the bounding box in meters using the UTM system of reference. Alternatively, denotes geographic longitude of the bottom right corner of the bounding box in decimal degrees.<br><br>The value forms the lower bound of the image. |
| Bottom Right Y Coordinate | float | Defaults to Northing of the bottom right corner of the bounding box in meters using the UTM system of reference. Alternatively, denotes geographic latitude of the bottom right corner of the bounding box in decimal degrees.<br><br>The value forms the right bound of the image. |
| Spatial Resolution | float | The pair of values denotes the across-track and along-track Ground Sampling Distance (GSD) in meters. The average value is given in the filename convention of the product. |
| Data Type | string | Type of data representation of each pixel such as unsigned integer 16-bit data. |
| No Data | unsigned int | All pixels having No Data value should be ignored in image processing. These may be found on the edge of the image. |
| Cloud Cover | int | Denotes the percentage of pixels in the image classified as cloud mask. A value of -1 denotes that a cloud cover percentage has not been computed for the image. |
| Created Datetime | string | Date and time in UTC format at the time of image product creation. |
| **Product Version Details** | | |
| Product Version | string | Indicates the version of the Pixxel image product; defaults to 1.0. If the image is reprocessed, the product version is reflected here. The same value is also given in the filename convention of the product. |
| Metadata Version | string | Indicates the version of the Pixxel metadata schema of the .xml file in the product. |

An ENVI-compatible header file is also created from the metadata with the following parameters:

| FIELD | VALUE | |
|---|---|---|
| 1 | **ENVI Description** | Image is from *<satelliteName_sensorID>* with a *<5m>* GSD. Image is *<radiometrically corrected, band registered, georeferenced, orthorectified, and spatially resampled Top-of-Atmosphere reflectance>* data. |
| 2 | **Header offset*** | 0 |
| 3 | **Interleave*** | BIP |
| 4 | **Sensor type** | unknown |
| 5 | **Byte order*** | 0 |
| 6 | **File type*** | TIFF |
| 7 | **Data type*** | 12 |
| 8 | **Wavelength units** | Nanometers |
| 9 | **Lines*** | *<number of rows>* |
| 10 | **Samples*** | *<number of columns>* |
| 11 | **Bands*** | *<number of bands>* |
| 12 | **Band names** | {*< comma-separated list of Band UIDs>*} |
| 13 | **Wavelength** | {*< comma-separated list of Band wavelengths>*} |

| | | |
|---|---|---|
| 14 | **FWHM** | *{< comma-separated list of Band FWHM>}* |
| 15 | **Solar irradiance** | *{< comma-separated list of solar irradiance>}* |
| 16 | **Acquisition time** | *YYYY-MM-DDTHH:mm:ssZ* |
| 17 | **Reflectance scale factor** | 2e-5 |
| 18 | **Sensor look angle** | *<Sensor look angle>* |
| 19 | **Sun Azimuth** | *<Sun Azimuth angle>* |
| 20 | **Sun Zenith** | *<Sun Zenith angle>* |
| 21 | **Data ignore value** | 0 |
| 22 | **Cloud cover** | *<Cloud cover percentage>* |
| 23 | **Default stretch** | optimized linear |
| 24 | **Default bands** | *{< comma-separated list of RGB Band UIDs>}* |
| 25 | **Map info** | *{<Projection name, Reference (tie point) pixel **x** location, Reference (tie point) pixel **y** location, Pixel easting, Pixel northing, x pixel size, y pixel size, Projection zone (UTM only), North or South (UTM only), Datum, Units>}* |
| 26 | **Coordinate system string** | See Note 2. |

The description of each of the listed attributes can be found in the official documentation for [ENVI header files](ENVI header files).

## 3.5. IMAGE DELIVERY PACKAGE CONTENTS

Once processed, your imagery is bundled into a zipped package that includes:

- Stacked GeoTIFF Image: A high-resolution raster image file that includes all the spectral bands you ordered in UTM projection.
- RGB Composite Thumbnail: A quick, visual preview of the captured image in JPEG format.
- ENVI Compatible Header File: A header file to help you work with the GeoTIFF in popular geospatial software.
- Footprint GeoJSON: Provides the spatial footprint of the image in GeoJSON format containing all the points.
- Metadata File: An XML file containing detailed metadata about the image capture, such as capture date, sensor details, processing and copyright information.

# 4. IMAGE QUALITY ATTRIBUTES

Pixxel's hyperspectral imagery undergoes quality control measures to ensure it meets defined standards for geolocation accuracy and spectral alignment. Key image quality attributes are monitored and validated in the image processing workflow (see Section 3.2) to provide reliable data. The following section describes two key image quality parameters: Absolute Geolocation Accuracy (CE90) and Band-to-Band Registration.

## 4.1. ABSOLUTE GEOLOCATION ACCURACY (CE90)

Any lingering geometric errors from the corrected quaternion list and DEM combine during L1B orthorectification. For a Pixxel band that completes processing, a final product CE90 of ~50 meters can be expected.

## 4.2. BAND-TO-BAND REGISTRATION

The hyperspectral camera is calibrated such that all spectral bands have an image-to-ground projection that is mutually consistent. Products that complete L1B processing generally contain scene content well-suited to correlation and therefore exhibit good band-to-band metrics. Provided there are no signal-to-noise (SNR) issues that would preclude accurate correlation, band-to-band registration performance consistent with expected system behavior should be achieved.

To monitor and verify this aspect of product quality, band-to-band registration metrics are collected following L1B processing. This assessment is performed by correlating patches of the L1B ortho imagery between spectrally separated bands, including the first and last bands, which represent the maximum temporal separation within acquisition. This approach enables detection of any systematic or persistent band-to-band misregistration beyond acceptable limits, which would then be flagged for manual review.

# 5. IMAGE TASKING & DELIVERY

In addition to offering high-quality hyperspectral imagery, Pixxel provides users with the Aurora platform, designed to enhance user interaction and streamline satellite imagery management. The Aurora platform serves as the central interface for ordering and delivering images, accessing image archives, and managing purchases. Imagery products are available through the Aurora GUI and API, offering flexibility for different workflows. Through the platform, users can browse and order images, explore Pixxel's image archive, and download imagery in various formats and band combinations to meet their specific project requirements.

**For further details, including setup, API documentation, and platform analytics, please refer to the Aurora User Guide.**

## 5.1. PIXXEL APPLICATION PROGRAMMING INTERFACE (API)

Pixxel's API offers users programmatic access to the full range of imagery products and ordering capabilities available through the Aurora platform. The API enables users to integrate Pixxel's imagery ordering system directly into their workflows, allowing for automated tasking and retrieval of satellite data. Through the API, users can place orders, specify key parameters such as Area of Interest (AOI), cloud coverage thresholds, off-nadir angle preferences, and bandset selection, and track order statuses. Imagery products can be downloaded in various formats and configured for custom spectral band combinations tailored to user needs.

Detailed API documentation is included in the Pixxel Developer Guide.

## 5.2. PIXXEL AURORA GRAPHICAL USER INTERFACE (GUI)

The order desk GUI on the Aurora platform allows users to task and manage their imagery orders and additional resources. Users can access Pixxel's imagery archive of previously captured imagery, enabling image search, preview, purchase, and download existing data.

In addition to exploring the archive, within the order desk, users can place new tasks and specify the following order parameters:

- Area of Interest
- Order Recurrence
- Capture Window Times
- Cloud Coverage Threshold
- Max Off-Nadir Angle Preference
- Bandset Selection

The order desk within Aurora provides real-time feedback, including initial feasibility checks, capture status, and delivery status. Users can also manage all transactions through the platform's integrated payment system.

For further details, please refer to the Aurora User Guide.