

Global Monthly Visual Basemap, June, 2023

+  
PLANETSCOPE BASEMAPS  
TECHNICAL SPECIFICATION

<b>1. OVERVIEW</b>	<b>4</b>
<b>2. PRODUCTS</b>	<b>5</b>
2.1 Global Basemaps	5
2.2 Select Basemaps	6
2.2.1 Select Visual Basemaps	6
2.2.2 Select Surface Reflectance Basemaps	6
<b>3. TECHNICAL INFORMATION</b>	<b>8</b>
3.1 Basemap Quads	8
3.2 Cadence	9
3.3 Delivery	10
3.4 Metadata	11
3.5 Packaging	13
3.6 Availability	14
<b>APPENDIX – Planet Basemaps Methods</b>	<b>15</b>
1. Web Mercator Tiling Grid	16
2. Finding Tile Overlapping Scenes	16
3. Scene Ranking	16
4. Cloud-Masking	16
5. Radiance to Reflectance Conversion	17
6. Color Adjustment	17
6.1 Visual Color Balancing	17
6.2 Normalization and Harmonization	18
7. “Best-on-Top” Compositing	19
8. Seamline Removal	21
9. Visual Sharpening	21

## GLOSSARY

### **Application Programming Interface (API)**

A set of routines, protocols, and tools for building software applications.

### **Area-of-Interest (AOI)**

A region of interest for a given analysis.

### **Basemap**

An analysis-ready data product created by mosaicking the best PlanetScope imagery available.

### **GeoJSON**

A standard for encoding geospatial data using JSON (see JSON below).

### **GeoTIFF**

An image format with geospatial metadata suitable for use in a GIS or other remote sensing software.

### **JavaScript Object Notation (JSON)**

Text-based data interchange format used by the Planet API.

### **Portable Network Graphic (PNG)**

An image format suitable for web use.

### **Quad**

A single square GeoTIFF, many of which together comprise a mosaic.

### **Relative Spectral Responses (RSRs)**

Refer to how sensitive a sensor is to different wavelengths of light.

### **Scene**

Single image captured by a PlanetScope satellite. Many scenes together compose a mosaic.

### **Timelapse**

A discrete block of time with a defined start and end point. For example, a Q1 Timelapse refers to the time period between Jan 1 and March 31.

### **Tile Server**

A server that provides web tiles to clients over the web.

### **Time-of-Interest (TOI)**

Time of interest for a given analysis.

### **Usable Data Mask 2 (UDM2)**

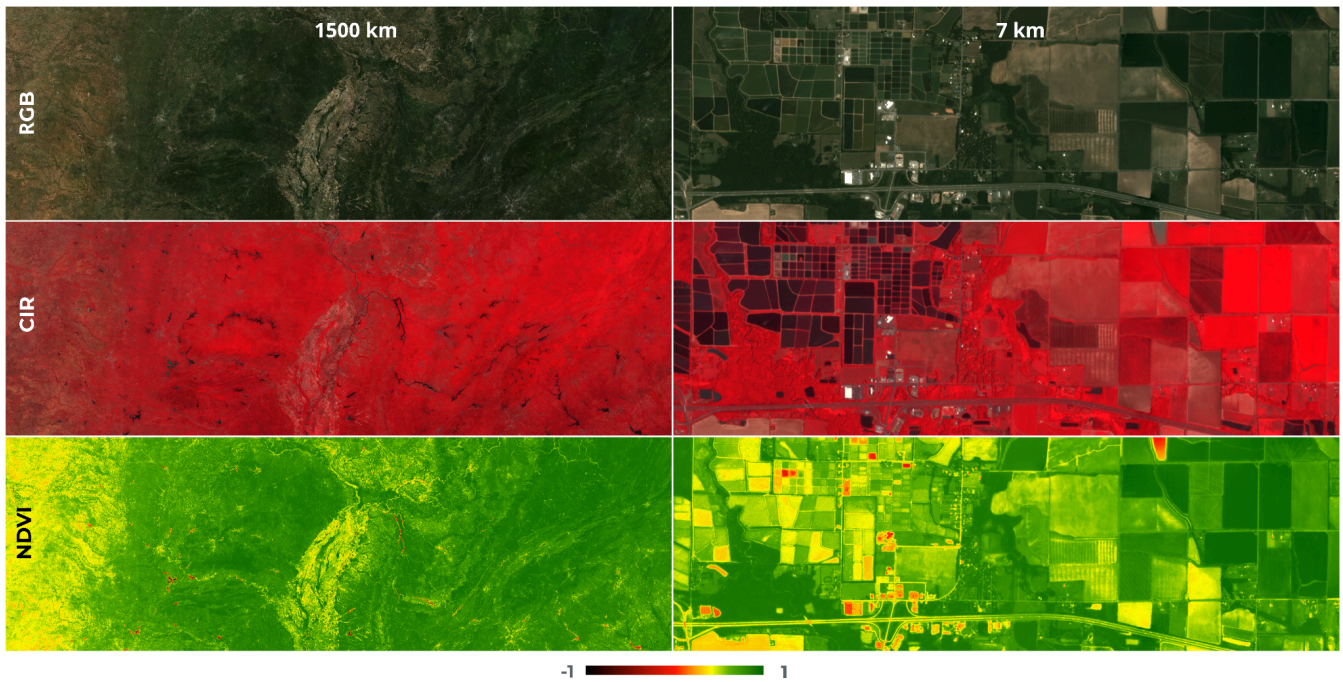
A Usable Data Mask (UDM) provided by Planet for every published image.

### **Web Tile**

A PNG map image served by a tile server at a variety of zoom levels.

# 1. OVERVIEW

PlanetScope Basemaps are analysis-ready data products created by mosaicking the highest quality PlanetScope imagery. Basemaps are designed and optimized for large-scale monitoring of changes over time, such as across countries or continents. Basemaps support both visual and analytics-driven applications, enabling comprehensive analysis and insights. Figure 1 highlights an example of a monthly surface reflectance basemap over the Central Plains, U.S. Basemaps have been applied to a wide range of research projects. For example, to monitor forest biomass (Csillik et al., 2019, Csillik et al., 2020), to monitor on-farm reservoirs (Perin et al., 2021), to monitor map coral reef map probabilities (Li, et al., 2020), to map smallholder cashew plantation expansions (Yin et al., 2023), to map buildings globally (Zhu et al., 2024), and to monitor Africa’s trees covers (Reiner et al., 2023). This document aims to describe the main PlanetScope Basemaps products, and their technical specifications.



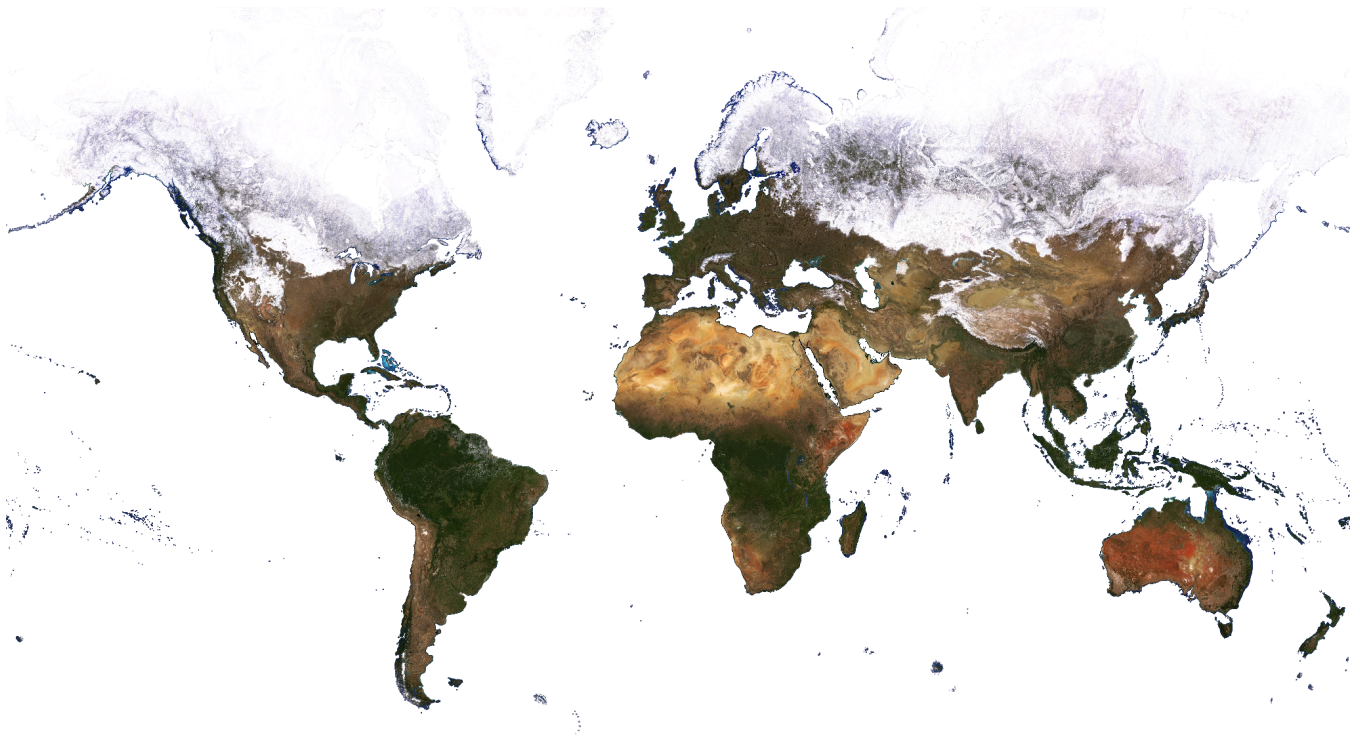
**Figure 1.** Surface Reflectance Basemap of the Central Plains, U.S, June, 2019.

## 2. PRODUCTS

### 2.1 Global Basemaps

Global Basemaps are generated between 74° north and 60° south to minimize distortion at the poles, using PlanetScope and/or [RapidEye](#) imagery. During the basemap generation process, each individual PlanetScope and RapidEye image is recorded. As the specifications for PlanetScope and RapidEye sensors vary, please refer to the [Planet Imagery Product Specification](#) for detailed information on each image type.

These basemaps are color-corrected and designed for both human viewing and computer vision analytics. The Global Basemap product is the Q3 Quarterly Select Visual Basemap, with distinct pricing due to its global nature. While all basemap products can be generated globally, this version is specifically created at a set interval to ensure a consistent global visual product. The Global Basemap is typically utilized in background GIS applications, or as a visual background.



**Figure 2.** Planet Global Basemap Q3 2023.

Table 1. Global Basemap technical specifications.

Source Imagery	Download Bands	Streaming Bands	Frequency	Zoom Level	Color Target
PlanetScope and/or RapidEye* Visual Product	RGB	RGB	Quarterly	15	MODIS

\*RapidEye Imagery is used on Global Basemaps for dates prior to February, 2020.

## 2.2 Select Basemaps

Select Basemaps are generated at Weekly, Monthly, and Quarterly intervals, tailored to customer-specified areas of interest (up to and including globally). These basemaps are categorized into two product types: visual and surface reflectance.

### 2.2.1 Select Visual Basemaps

Visual Basemaps are optimized to minimize the effects of cloud cover, haze, and topographic variations. These basemaps are color-corrected and designed for human viewing and computer vision analytics, enabling users to monitor landscape and infrastructure changes over time and space.

Table 2. Select Visual Basemaps general specifications.

Source Imagery	Download Bands	Streaming Bands	Frequency	Zoom Level	Color Target
PlanetScope and/or RapidEye* Visual Product	RGB	RGB	Weekly Monthly Quarterly	15	MODIS

\*RapidEye Imagery is used for dates prior to February, 2020.

### 2.2.2 Select Surface Reflectance Basemaps

Select Surface Reflectance Basemaps are created using the PlanetScope Surface Reflectance imagery asset type ([analytic\\_sr](#)). These basemaps are optimized to reduce the variability due to atmospheric effects, enabling users to perform spectral, quantitative, and time series analyses. Planet Surface Reflectance Basemaps include both Analytic Surface Reflectance (Analytic SR) and Normalized Surface Reflectance (Normalized SR).

Analytic SR Basemaps preserve the calculated surface reflectance pixel values without any color balancing or adjustments. As a result, these basemaps may exhibit visible seamlines due to the combination of scenes captured by different sensors, on various dates, and at different times of day. They are ideal for situations where precise radiometric accuracy is more important than consistency. These basemaps are particularly effective for shorter time intervals (e.g. weekly) updates, and are well-suited for applications requiring recent imagery or change detection, such as crop health monitoring, and wildfire burn assessment.

Normalized SR Basemaps undergo additional processing steps to improve spatial and temporal consistency, making them less likely to have seamlines. The normalization process involves matching the basemaps to a common reference target. The targets are multi-year monthly composite mosaics, derived using Sentinel-2 imagery, with the goal of enhancing the spatial and temporal consistency of the basemaps, enabling time-series analyses. Nonetheless, the normalization process can result in less accurate absolute pixel spectral response. These basemaps are ideal for use cases where spatial consistency is prioritized, or for generating training data for machine learning algorithms. They are particularly suited for longer time periods (e.g., monthly, quarterly) where multiple scenes are mosaicked together, and additional image processing is beneficial. Applications include land cover classification, forest disease monitoring, and flood risk analysis.

Table 3. Select Surface Reflectance Basemaps general specifications.

Source Imagery	Download Bands	Streaming Bands	Frequency	Zoom Level	Normalization
PlanetScope Surface Reflectance	BGRN	RGB, CIR	Weekly Monthly Quarterly	15	Sentinel-2
PlanetScope 8-Band Surface Reflectance	CB,B,C,GII,Y,R,RE, NIR	RGB, CIR	Weekly Monthly Quarterly	15	Sentinel-2

Table 4. Select Surface Reflectance Basemaps technical details.

Type	Prioritizes	Data	Pixel Values	Normalization
Normalized	Spatial & temporal consistency; training data	4-band, 16-bit	Modified Surface Reflectance	Sentinel-2
8-Band Normalized	Spatial & temporal consistency; training data	8-band, 16-bit	Modified Surface Reflectance	Sentinel-2
Analytic	Spatial accuracy; precise spectral responses	4-band, 16-bit	Surface Reflectance	None
8-Band Analytic	Spatial accuracy; precise spectral responses	8-band, 16-bit	Surface Reflectance	None

### 3. TECHNICAL INFORMATION

#### 3.1 Basemap Quads

Planet Basemaps use the Web Mercator projection (Figure 3), the standard for web mapping applications, because of its efficiency in handling large geospatial datasets. This projection supports a tile-based system, dividing the world into uniform square tiles at multiple zoom levels, allowing for pre-rendered and cached tiles for fast map loading and smooth user interactions in GIS applications. Basemaps are distributed as a grid of GeoTIFF files, which are called “quads.” The size of each quad is 4096 x 4096 pixels.

The naming scheme for quad IDs within each basemap is available in the basemap as the `quad_pattern` property (Table 6). This is generally `{X}-{Y}`, where X and Y are the x and y position of the quad in the grid. For example: `1023-2465`. A sample quad ID is `1023-2465`, indicating that this particular quad is in the position 1023, 2465 in the two dimensional grid that makes up the basemap. Upon download, the name of the downloaded quad is designed to represent the zoom level and the mosaic’s tiling scheme, for example:

`L15-1023E-2465N.tif`.



**Figure 3.** Web Mercator tiling grid with Select Visual Monthly Basemap of Jamaica, April, 2024.



Table 5. Basemaps individual quad specifications.

**INDIVIDUAL QUAD SPECIFICATIONS**

Attribute	Description
Imagery	PlanetScope and RapidEye (Visual) PlanetScope (Surface Reflectance)
Pixel Size <sup>1</sup>	4.77 * cos(latitude) m (4.77 m at the Equator) for zoom level 15 (PlanetScope and RapidEye)
Image Bit Depth	8 bits per pixel (Visual) 16 bits per pixel (Surface Reflectance)
Bands	Red, Green, Blue, Alpha* (Visual) Blue, Green, Red, NIR, Alpha* (Surface Reflectance) Coastal Blue, Blue, Green I, Green II, Yellow, Red, Red Edge, NIR, Alpha* (8 band)
Projection	WGS84 Web Mercator (EPSG:3857)
Size	4096 x 4096 pixels
Processing	Orthorectification Atmospheric correction (Surface Reflectance Basemaps only) May be radiometrically balanced Seamlines may be minimized with tonal balancing

\*The Alpha band indicates areas of the quad where there is no imagery data available.

### 3.2 Cadence

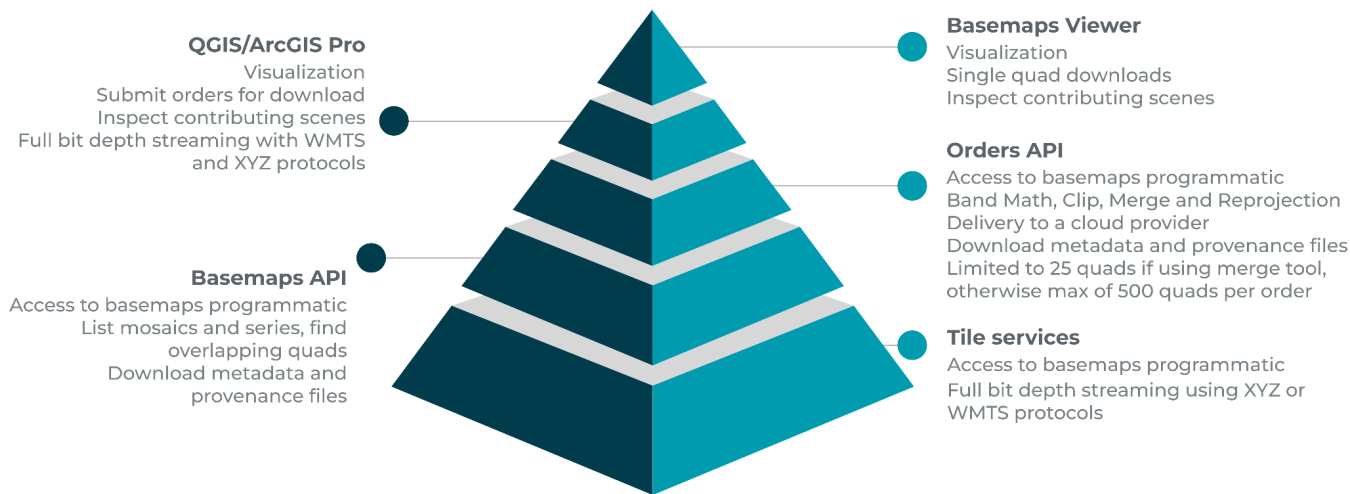
The time period for Select Basemaps starts and ends at 00:00 UTC. Weekly Select Basemaps begin on Monday and end seven days later. Monthly Select Basemaps cover all calendar days of the month, including leap days. Quarterly Select Basemaps include the best imagery from January through March, April through June, July through September, and October through December, respectively. Table 6 details the start and end dates for Weekly, Monthly and Quarterly basemaps.

Table 6. Select Basemaps start and end dates for Weekly, Monthly, and Quarterly cadences.

Cadence	Start (first_acquired)	End (last_acquired)
Weekly	Mondays at 00:00:00 UTC	Sundays at 23:59:59 UTC
Monthly	The first day of each month at 00:00:00 UTC	The last day of each month at 23:59:59 UTC
Quarterly	January 1st, April 1st, July 1st, and October 1st at 00:00:00 UTC	March 31st, June 30th, September 30th, and December 31st at 23:59:59 UTC

<sup>1</sup>The pixel size in meters can be estimated as follows: pixel size at the equator × cos(latitude).

### 3.3 Delivery



**Figure 4.** Basemaps delivery tools and methods.

Basemaps quads can be accessed through various tools and APIs (Figure 4). The [Basemaps Viewer](#) is an online tool for viewing and downloading individual quads, with a [complete tutorial](#) available at Planet University. Other options are the [QGIS](#) or [ArcGIS Pro](#) plugins, which enable users to visualize and search for basemaps within Planet’s catalog and offer multiple filtering options, such as filtering by an AOI or by different types of basemaps. In addition, both plugins allow users to submit requests for downloading or streaming options.

For programmatic access to basemaps, users can utilize the [Orders API](#). This API supports advanced capabilities such as data reprojection, clipping, merging quads, performing band math calculations, and delivering the data to cloud service providers. Nonetheless, there are specific limits on the number of quads per order in the Orders API: a maximum of 25 quads when using the merge tool, and up to 500 quads per order without merging. In addition, if there is a need to list available basemaps within a basemap series, searching for overlapping quads, or downloading AOIs that cover more than 500 quads, then users are recommended to use the [Basemaps API](#). This API is recommended for users seeking endpoints for scalable workflows, direct access to Cloud Optimized GeoTIFF links, and the ability to stream basemaps into web applications. Often, users combine the capabilities of both APIs when writing their own libraries to access basemaps.

Lastly, basemaps can be streamed using Planet [Tile Services](#), which facilitate the access to basemaps in desktop or web mapping applications. Tile services support [XYZ](#) or [WMTS](#) protocols. These services enable web developers and GIS analysts to interact with and derive value from Planet imagery without the need for additional image processing.

### 3.4 Metadata

Basemaps and individual quads have associated metadata, which is distributed in JSON format and can be accessed via the Basemaps or Orders API. The metadata includes a spatial component, with geometries encoded as GeoJSON files. Table 7 shows the metadata fields provided for all Planet Basemaps, and Table 8 depicts the metadata for individual basemaps quads.

Table 7. Basemaps API metadata schema.

BASEMAP METADATA SCHEMA	
Field	Description
bbox	A four element array containing the lat long bounding box (lower left and upper right)
coordinate_system	The EPSG code of the coordinate system in which the quad GeoTIFF are projected, i.e. EPSG:3857 or EPSG:4326
datatype	The datatype for each quad GeoTIFF. One of <code>byte</code> , <code>uint16</code> , <code>int16</code> , <code>uint32</code> , <code>int32</code> , <code>float32</code> , <code>float64</code> , <code>cint16</code> , <code>cint32</code> , <code>cfloat32</code> , <code>cfloat64</code>
first_acquired	The UTC date and time that the first input scene was taken in ISO 8601 format
grid	A JSON field including the quad pattern description, the square quad size in pixels, and the pixel resolution in meters (see below)
id	The internal identifier for this basemap
item_types	The type of source scenes used as input to basemap
interval	For Select Basemaps, this will provide the time interval (for example, "1 mon"). For other basemaps, this will not be present.
last_acquired	The UTC date and time that the last input scene was taken in ISO 8601 format
level	Zoom level of available quads, corresponding to mercator grid level.
links.quads	API link to the list of GeoTIFF quads that make up this basemap
links.self	API link to the mosaic resource
links.tiles	API link to the tileserver URL for the basemap
name	The name of the basemap
product_type	The basemap category this represents. For example <code>timelapse</code> for standard, automated intervals.
published	The RFC 3339 timestamp at which this item was added to the API
grid.quad_pattern	The naming scheme for quads, as a format string with <code>glevel</code> , <code>tilex</code> and <code>tiley</code>
grid.quad_size	The width and height (equivalent) of each quad GeoTIFF in pixels
grid.resolution	The size in meters of pixels in quad GeoTIFFs

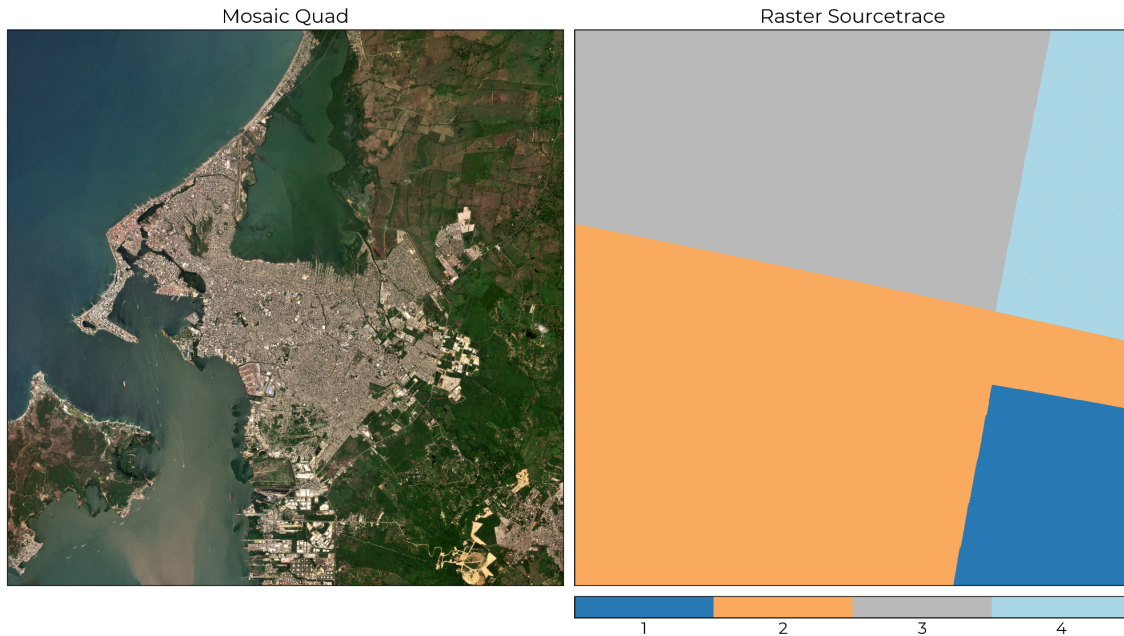
Table 8. Basemap quad metadata schema.

**MOSAIC QUAD METADATA SCHEMA**

Field	Description
bbox	4 element array providing the lower left and upper right coordinates of the bounding box
id	The unique identifier for this quad
links.download	API link to download the GeoTIFF
links.items	RFC 3986 URI representing the canonical location of the items make up the quad.
link.self	RFC 3986 URI representing the canonical location of this object.
links.thumbnail	API link to a thumbnail of this quad
percent_covered	The percentage of the GeoTIFF pixels that are not no-data values
type	Always "Feature" to make dictionary a valid GeoJSON Feature

### 3.5 Packaging

During the basemap generation process, each image used is recorded and can be assessed through the provenance files. These files allow users to trace all pixels used in the basemap production and are available for each basemap tile. Figure 5 shows an example of a raster provenance file overlaid with a single quad over the city of Cartagena, Colombia.



**Figure 5.** Select Visual Monthly Basemap for the city of Cartagena, Colombia, May, 2024, and its raster provenance file (i.e. sourcetrace). Each color in the provenance raster represents a different image used in the basemap production, collected during May 2024.

Basemaps quads along with their associated metadata (JSON), [UDM2](#) assets, and pixel provenance files, raster and vector, can be downloaded through the Basemaps and Orders APIs. An example of a quad download along with metadata and provenance files for a Normalized SR basemap is shown on Table 9.

Table 9. Quad download package example.

File name	Size
484-1310_quad.tif	117 MB
484-1310_provenance_raster.tif	236 KB
484-1310_ortho_udm2.tif	1.2 MB
484-1310_provenance_vector.zip	22 KB
L15-0484E-1310N.dbf	788 B
L15-0484E-1310N.prj	425 B
L15-0484E-1310N.shp	66 KB
L15-0484E-1310N.shx	124 B

### 3.6 Availability

Table 10 depicts the basemaps global date availability.

Table 10. Select Basemaps availability.

Source Imagery	Available After	UDM2	Pixel Provenance
PlanetScope Visual	January 2016	Mixed	Yes
PlanetScope Normalized Surface Reflectance	May 2016	After August 2018	Yes
PlanetScope Analytic Surface Reflectance*	May 2016	After August 2018	Yes
PlanetScope 8-Band Normalized Surface Reflectance	August 2020	Yes	Yes
PlanetScope 8-Band Analytic Surface Reflectance	August 2020	Yes	Yes

\*4-Band Analytic SR Basemaps are only available for dates prior to August 2020.

# + APPENDIX - Planet Basemaps Methods

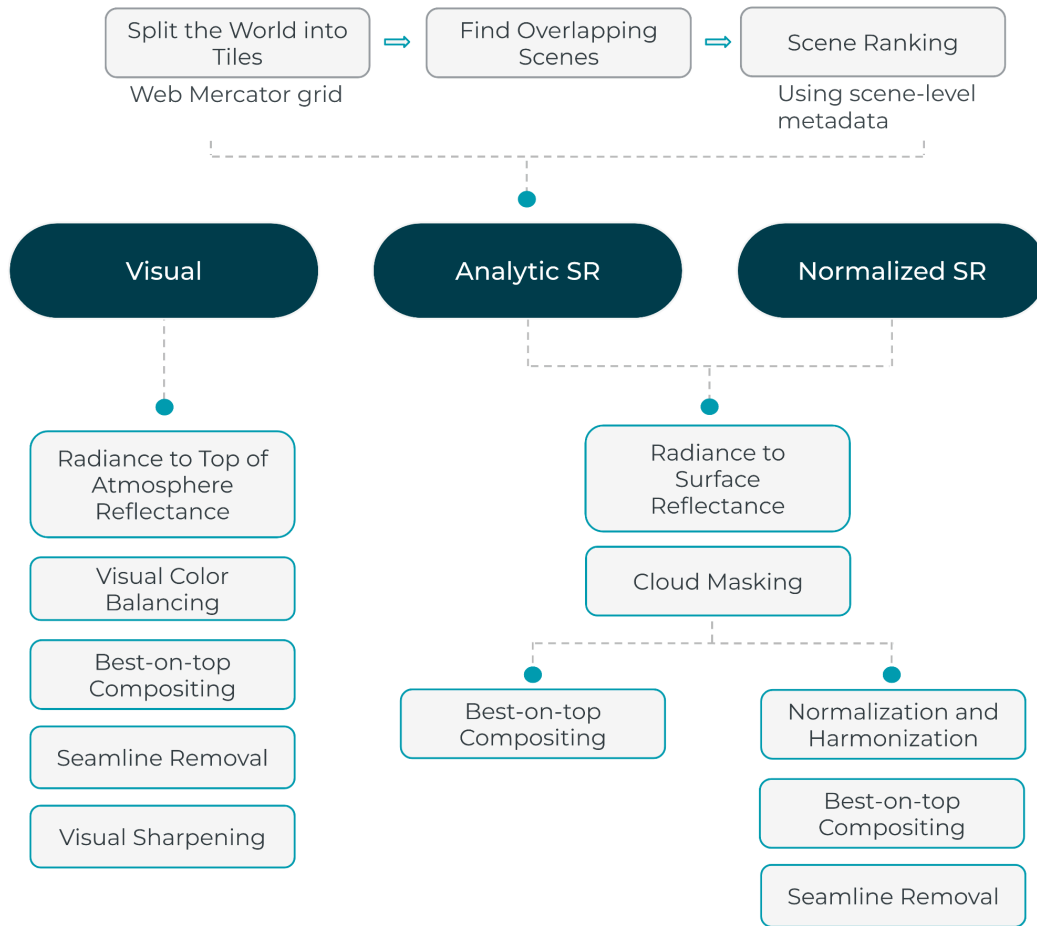


Figure 1. Planet Basemaps major processing steps flowchart.

## 1. Web Mercator Tiling Grid

Planet Basemaps utilize the Web Mercator projection—the standard for web mapping applications—due to its efficiency in storing, retrieving, and displaying large geospatial datasets. This projection supports a tile-based system that divides the world into uniform square tiles at multiple zoom levels, enabling pre-rendered and cached tiles for fast map loading and smooth user interactions, e.g., panning and zooming, in GIS applications.

The Web Mercator projection supports visualization of global basemaps and on-the-fly rendering of approximately 40 TB of data for each zoomed-out view. Moreover, it enables concurrent data access with rapid response times, typically within milliseconds. In addition, Planet Basemaps employ a pyramid structure of downsampled data for efficient visualization, maintaining full tile sets across standard zoom levels (Google, 2024).

However, Web Mercator is suboptimal for spatial analysis that requires precise measurements of distance, area, or direction due to inherent distortions, especially over northern latitudes (Battersby, 2014). For detailed analyses and applications requiring accurate geospatial measurements, Planet Basemaps and Orders APIs support reprojecting data to other suitable projections, which can be user-defined.

## 2. Finding Tile Overlapping Scenes

Planet Basemaps are processed at the tile level, with Web Mercator tiles serving as the smallest processing unit within the pipeline. For example, at zoom level 15, a single tile spans 400 km<sup>2</sup> (20 km x 20 km) and has a resolution of 4.77 meters per pixel at the equator—the pixel size in meters can be estimated as follows: pixel size at the equator × cos(latitude).

In addition, if the Area of Interest (AOI) extends across more than one tile, all overlapping tiles are processed, even if the AOI intersects only a minor portion of a tile—see example on Figure 5. Conversely, if the AOI is smaller than a tile, the entire tile is processed regardless of the AOI's size.

When producing basemaps for a specified AOI and time-of-interest (TOI), PlanetScope scenes are selected by identifying Web Mercator tiles that overlap with the AOI. These scenes are then filtered based on their metadata, for example, by verifying that the scene's extent overlaps with the target tiles. Any scenes that do not meet this filtering criterion are excluded from the basemap production.

## 3. Scene Ranking

After querying for available scenes, these are ranked using scene-level metadata rather than pixel-level. This approach enables the selection of appropriate scenes without the need for costly processing of all potential candidates, a crucial consideration when handling several thousand scenes for a large AOI. For each batch of selections, a linear model is used to calculate a quality score for each scene. This score is derived from a weighted average of various pre-computed metrics—including cloud cover fraction, scene sharpness, presence of haze, cloud shadows, snow, and unusable data (no-data)—stored in the scene metadata. Scenes with higher quality scores are ranked at the top and are more likely to have their pixels used when composing the basemap using the "best-on-top" approach.



## 4. Cloud-masking

Surface Reflectance Planet Basemaps leverages PlanetScope scenes cloud-masks. The latest cloud mask, UDM 2.1, is distributed as an 8-band GeoTIFF format. Each band within UDM 2.1 corresponds to a different class of pixels: Clear, Cloud, Light Haze, Heavy Haze, Cloud Shadow, or Snow. Additionally, there are two supplementary bands: Confidence and Unusable Pixels. The Confidence band indicates the UDM 2.1 model's prediction accuracy for a given pixel's classification, while the Unusable Pixels band helps users identify unusable pixels. For more details on UDM 2.1, visit Planet [webpage](#) and refer to [Planet Imagery Specification](#).

## 5. Radiance to Reflectance Conversion

PlanetScope scenes are collected and initially stored as 12-bit imagery. Radiometric corrections are applied during ground processing and images are scaled to a 16-bit range. This scaling converts the (relative) pixel Digital Numbers (DN) coming directly from the sensor into absolute at-sensor radiances. To convert the DNs to radiance, the DN values are multiplied by a radiometric scale factor of 0.01, resulting in radiance values expressed in watts per steradian per square meter ( $W/m^2 \cdot sr \cdot \mu m$ ). The DNs of the PlanetScope image pixels represent the absolute calibrated radiance values for the image. To convert the pixel values to Top of Atmosphere (TOA) Reflectance, the DN value is multiplied by the reflectance coefficient provided in the accompanying XML file. Then, SR products are derived from TOA reflectance images. The atmospheric corrections are done leveraging the 6S radiative transfer model and ancillary data from MODIS to account for atmospheric effects and variability. A complete description of the processing steps when transforming radiance to reflectance is available on [Planet Imagery Specification](#).

## 6. Color Adjustment

Color adjustment for visual and analytical purposes is a necessary step when mosaicking multiple PlanetScope scenes into a single seamless basemap that is spatially consistent. PlanetScope imagery is collected using a constellation of different satellites, including various generations, that exhibit different relative spectral responses (RSRs), resulting in sensor-to-sensor variability. Furthermore, PlanetScope scenes are captured at different times of the day, leading to additional scene-to-scene variability due to changes in atmospheric aerosol optical depth and varying sun angle elevations.

Visual and Normalized SR basemaps leverage similar vision techniques to minimize the effects of clouds, haze, atmospheric disturbances, and other image variabilities. However, Visual Basemaps optimize for visual consistency, making them ideal for use in visual backdrops or machine learning to track changes over time. Meanwhile, Normalized SR Basemaps are radiometrically consistent and optimized for large-scale time series analyses.

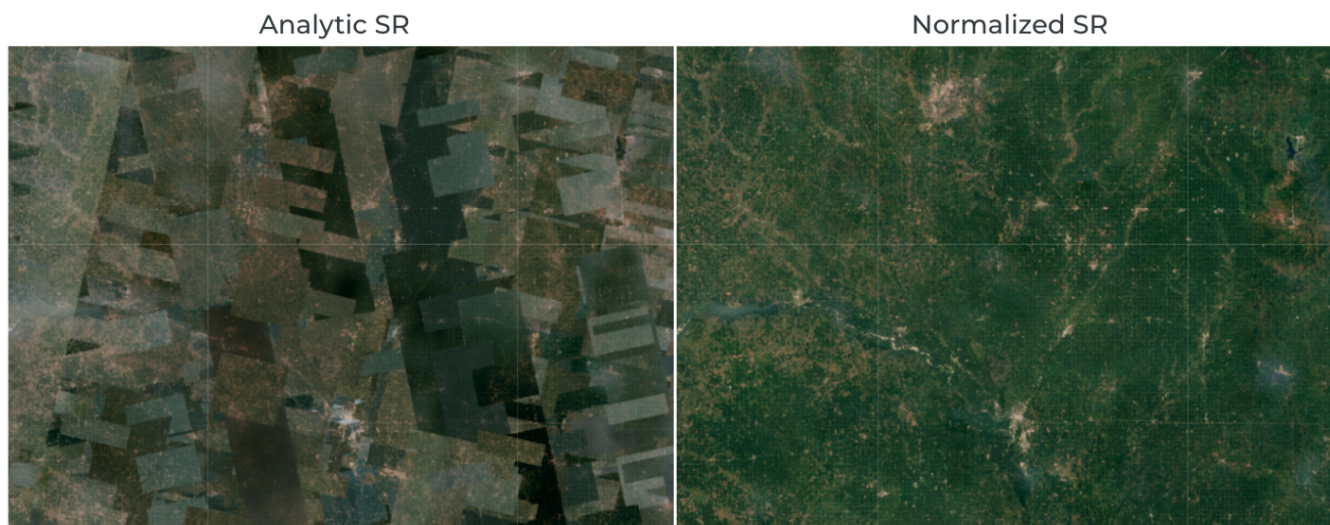
### 6.1 Visual Color Balancing

Visual color balancing simulates manual color correction to enhance the accuracy and visual appeal of the basemap colors. This process employs a MODIS reference basemap and applies a uniform transformation across the entire scene. The color correction uses a 4-curve model comprising three transfer functions for the Red, Green, and Blue bands, along with a master curve applied to all three bands. Each band curve is linear and restricted to positive transformations, ensuring only reasonable adjustments and preventing dramatic changes—this is done to preserve the hue of neutral colors (i.e. clouds/snow stay white). The master curve is designed to be convex and smooth, providing the flexibility needed to accommodate different sensor responses, such as those from PlanetScope and RapidEye. More details on the methodology used to fit the

constrained linear models are provided in the [Scene Level Normalization and Harmonization of Planet Dove Imagery](#) document.

## 6.2 Normalization and Harmonization

Normalized SR Basemaps are enhanced to ensure spatial, temporal, and radiometric consistency, making them suitable for large-scale time series analyses. Specifically, these methods aim to reduce variability between scenes (normalization) and between sensors (harmonization). However, pixel values may be altered, potentially reducing absolute radiometric accuracy. These changes might not be appropriate for certain applications, such as comparing absolute values of spectral responses across multiple sensors. A comparison between Analytic SR and Normalized SR Basemaps is depicted in Figure 2. The Analytic SR basemap highlights the scene boundaries and the differences between different scenes, while the Normalized SR shows a seamless product.

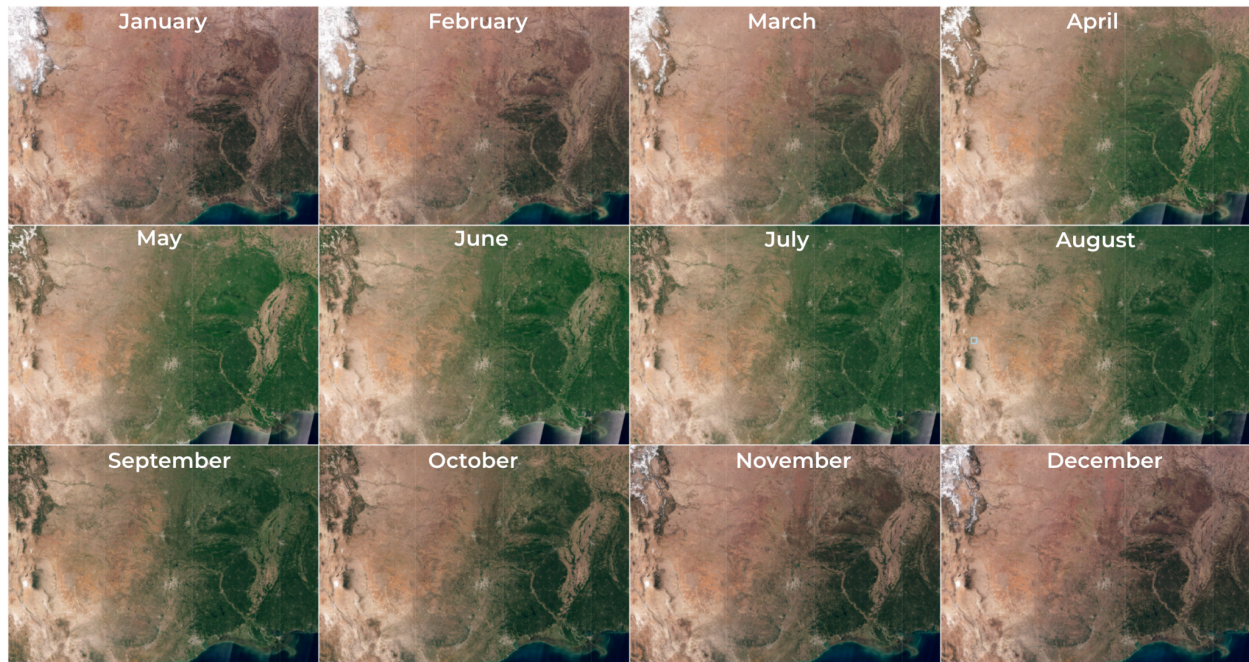


**Figure 2.** Comparison between Analytic SR and Normalized SR Basemaps for a region over Midwestern U.S.

The methods for normalizing and harmonizing basemaps were initially developed as part of the PlanetScope Basemap product's processing steps and were first published by [Csillik et al., 2019](#) and [Kington et al. \(2019\)](#). The normalization step addresses the variability in surface reflectance SR correction for PlanetScope imagery, which relies on MODIS estimates of atmospheric optical thickness. These estimates are collected at a different time of day and at a coarser spatial resolution compared to PlanetScope imagery, resulting in significant variability in PlanetScope SR data, even for scenes with the same RSRs, i.e., from the same satellite generation and sensor. The harmonization step addresses variability in PS data due to different RSRs (i.e., different satellites and sensors).

The normalization and harmonization steps aim to minimize scene-to-scene and sensor-to-sensor variability by loosely matching each scene to a seasonal reference model—which are multi-year monthly composite mosaics derived from Sentinel-2 imagery, see Figure 3. For more details on how the seasonal models are developed, see [Sentinel-2 Seasonal Models](#) and [Time Coincident Normalization](#). Normalizing and harmonizing PlanetScope imagery involves fitting a linear model for each band in each scene based on co-located, non-cloudy PlanetScope and seasonal model reference pixels. The linear model is constrained to produce only realistic transformations even under adverse conditions, such as undetected clouds, sunglint, snow, or significant changes like burn scars. Additionally, the transformation is designed to minimize large changes in band ratios during normalization.

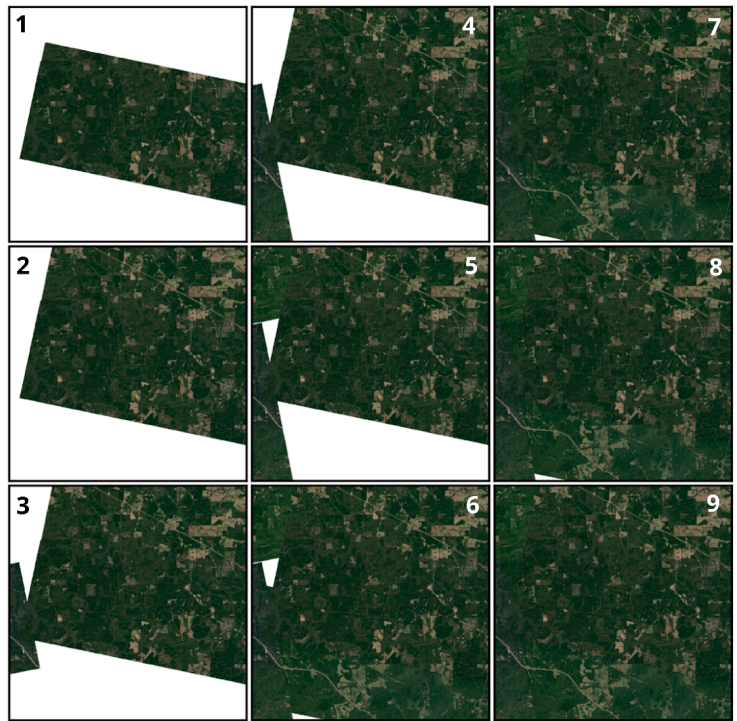
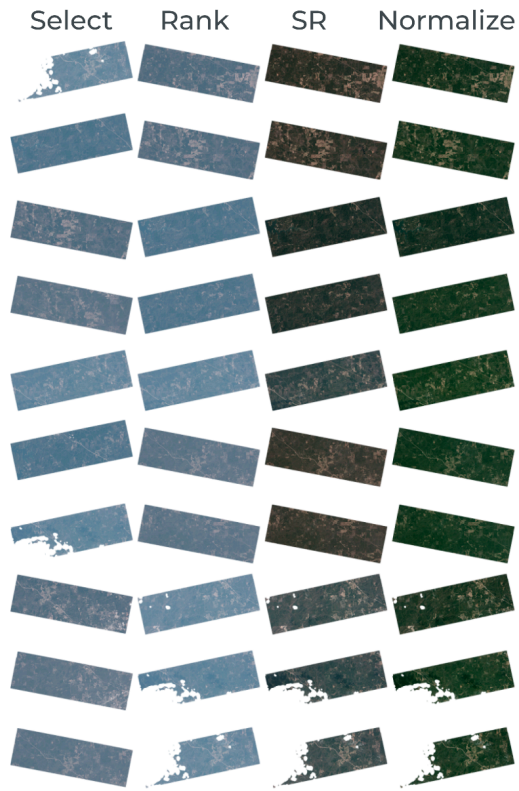
The model parameters and misfit metrics are carefully selected to make the model sensitive to changes in dark features, which are more likely to remain invariant between the multi-year seasonal model and daily scene data. The final model is unique to each scene (i.e. train once, use once problem) transforming the input PlanetScope reflectance coefficients to approximately match the reference spectral response and minimize large deviations between scenes from different days and ambient conditions. This transformation is applied uniformly across the entire scene. As a result, small and medium-scale changes, such as a stand of trees dying or a field being harvested, are preserved. However, changes that affect the entire scene uniformly, such as phenological changes, may be reduced. A complete description of the model implementation is provided in [Scene Level Normalization and Harmonization of Planet Dove Imagery](#).



**Figure 3.** Example of Sentinel-2 seasonal references models for 12 months over the Central Plains, U.S, using data from January, 2017 until December, 2023.

## 7. “Best-on-top” Compositing

Given the AOI and TOI, PlanetScope scenes that overlap a single tile are queried and ranked, with the best quality scenes placed at the top. After scene ranking, the scenes are composited as one of the steps in creating a spatially continuous product. The “best-on-top” algorithm efficiently processes only the necessary scenes to fill the tile, avoiding the need to warp unused scenes to the target tile projection. The creation of a single tile is represented in Figure 4, in which the algorithm takes a list of sorted scenes ranked by their quality metric and “stamps” them into the tile until it is completely filled.



Best-on-top algorithm processing steps for a single tile.

**Figure 4.** Examples of the major processing steps for Normalized SR Basemaps, including scene selection and ranking, transformation of radiance to surface reflectance, normalization and harmonization, and an example of the “best-on-top” algorithm used to composite the PlanetScope scenes.

## 8. Seamline Removal

Seamline removal minimizes the visual appearance of scene edges (see Figure. 2), which is particularly useful for visual interpretation and use cases like supervised imagery classification, where scene boundaries often introduce unwanted spatial artifacts in the final result. During seamline removal, each scene is "flexed" to match its neighbor, with pixel values near a scene boundary undergoing greater changes than those farther away. Unlike common methods, e.g., blurring, feathering, or averaging, PlanetScope Basemaps leverage a Poisson surface reconstruction method to reconstruct the gradient at scene boundaries. These conventional techniques are avoided because they can lead to loss of details, inaccurate data representation, and reduced radiometric accuracy. They may also affect quantitative analyses, such as band math ratio, by allowing significant changes to the pixel values.

The Poisson equation employed during seamline removal is commonly applied to surface gradient reconstruction in 3D modeling and computer graphics to create a smooth, continuous surface from scattered data points. The seamline removal method works by integrating the Poisson equation over the pixel values at the scene's boundaries. The pixel values represent the rate of change (i.e. gradient) across the scenes, and the method relies on finding a scalar function whose gradient best matches the input rate of change. When solving the Poisson equation iteratively, it is possible to limit the pixel value changes by setting predetermined threshold values. By applying these thresholds, the Poisson surface reconstruction can be controlled to avoid substantial changes to pixel values, ensuring that the reconstructed image gradient accurately represents the original data while maintaining visual and quantitative integrity.

Briefly, for a given band, the Laplace operator, a differential operator given by the divergence of the gradient of a scalar function on Euclidean space, for each pixel is calculated by convolving the composite with a 2D Laplacian kernel. This convolution only considers pixels coming from the same source imagery as the center pixel. If the kernel intersects with other scenes, an approximation for the Laplacian is calculated. This provenance-aware convolution allows for a "smooth" Laplacian image to be computed and used in the Poisson equation.

When solving the Poisson equation, for pixel values within the mosaic quad, the solution respects the modified gradients and maintains the fixed pixel values at the edges. This step reconstructs the pixel values in a way that ensures a smooth transition between scenes, eliminating visible seams.

Because seamline removal is applied independently to each band, it may alter band ratios near scene edges. This issue is most apparent when scenes do not match locally, for example, due to unmasked clouds, fields being harvested, and presence of snow. If the differences are too large, the method will retain the original gradient values at the scene edge, resulting in a "hard" seamline to avoid introducing artifacts.

It is important to note that seamline removal may introduce artifacts at tile boundaries in some cases. This is most frequent over water, where normalization cannot fully correct for differences between scenes, e.g., due to waves, sunlint, difference in turbidity and water depth.

## 9. Visual Sharpening

Visual Basemaps include a sharpening kernel filter to improve the visual appearance and interpretability of the basemaps. The sharpening kernel filter aims to accentuate spatial features, making them more useful for various applications that require detailed observation and analysis of the Earth's surface.