Planet Surface Reflectance

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INTRODUCTION

The Planet Surface Reflectance (SR) Product is derived from the standard Planet Analytic Product (Radiance) and is processed to top of atmosphere reflectance and then atmospherically corrected to bottom of atmosphere reflectance. This product ensures consistency across localized atmospheric conditions, minimizing uncertainty in spectral response across time and location.

Surface Reflectance is available for all orthorectified scenes produced by radiometrically calibrated sun-synchronous orbit SuperDove, SkySat, and RapidEye satellites.

PRODUCT DESCRIPTION

The SR product is provided as a 16-bit GeoTIFF image with reflectance values scaled by 10,000. Associated metadata describing inputs to the correction is included in a GeoTIFF *ImageDescription* metadata header as a JSON encoded string. Table 1 lists the values stored in the GeoTIFF header.

Table 1: SR product metadata keys and descriptions.

SR GeoTIFF METADATA

Key	Description	Example
aerosol_model	6S aerosol model used	continental
aot_coverage	Percentage overlap between MODIS data and the scene being corrected	0.9
aot_method	Method used to derive AOD value(s) for an image. 'Map' indicates that per-pixel AOD values are used based on an interpolated map over the scene; 'fixed' indicates a single value for the entire image used when there is not enough data coverage to produce a map.	map
aot_mean_quality	Average MODIS AOD quality value for the overlapping NRT data in the range 1-10. This is set to 127 when no data is available	1.0
aot_source	Source of the AOD data used for the correction	mod09cma_nrt
aot_std	Standard deviation of the averaged MODIS AOD data	0.331
aot_status	A text string indicating state of AOD retrieval. If no data exists from the source used, a default value 0.226 is used	Missing Data - Using Default AOT

aot_used	Aerosol optical depth used for the correction. This will be the average when an AOD map is used for the correction.	0.292
atmospheric_correction_algorithm	The algorithm used to generate LUTs	6SV2.1
atmospheric_model	Custom model or 6S atmospheric model used	water_vapor_and_ ozone
luts_version	Version of the LUTs used for the correction	3
ozone_coverage	Percentage overlap between MODIS data and the scene being corrected	0.9
ozone_mean_quality	Average MODIS ozone quality value for the overlapping NRT data. This will always be 255 if data is present	260
ozone_method	Method used to derive ozone value(s) for an image. Currently only 'fixed' is used, indicating a single value for the entire image	fixed
ozone_source	Source of the ozone data used for the correction	mod09cmg_nrt
ozone_status	A text string indicating state of ozone retrieval. If no ozone data is available for the scene being corrected, the corrections falls back to a 6SV built-in atmospheric model	Data Found
ozone_std	Standard deviation of the averaged MODIS ozone data.	0.0011
ozone_used	Ozone concentration used for the correction, in cm-atm	0.28
satellite_azimuth_angle	The angle in degrees between the solar zenith and satellite view directions. For Dove satellites, azimuth angle is assumed to be 0 and the solar zenith angle measured relative to it.	279.15
satellite_zenith_angle	Satellite zenith angle in degrees, fixed to nadir pointing for Dove satellites.	10.87
solar_azimuth_angle	Sun azimuth angle in degrees. For Dove satellites this is relative to the satellite.	68.4346
solar_zenith_angle	Solar zenith angle in degrees	17.645
sr_version	Version of the correction applied	1.0
water_vapor_coverage	Percentage overlap between MODIS data and the scene being corrected	0.86
water_vapor_mean_qualit	Average MODIS ozone quality value for	1

y	the overlapping NRT data in the range 1-10. This is set to 127 when no data is available	
water_vapor_method	Method used to derive water vapor value(s) for an image. Currently only ‚fixed‘ is used, indicating a single value for the entire image	fixed
water_vapor_source	Source of the water vapor data used for the correction	mod09cma
water_vapor_status	A text string indicating state of water vapor retrieval. If no water vapor data is available for the scene being corrected, the corrections falls back to a 6SV built-in atmospheric model	Data Found
water_vapor_std	Standard deviation of the averaged MODIS AOD data	0.071
water_vapor_used	Water vapor concentration used for the correction in g/cm^2	2.1

Example of the metadata JSON


```
{
  Atmospheric_correction: {
    aerosol_model: "continental",
    aot_coverage: 0.86,
    aot_mean_quality: 1,
    aot_method: "map",
    aot_source: "mod09cma",
    aot_status: "Data Found",
    aot_std: 0.223,
    aot_used: 0.233,
    atmospheric_correction_algorithm: "6Sv2.1",
    atmospheric_model: "water_vapor_and_ozone",
    luts_version: 3,
    ozone_coverage: 0.86,
    ozone_mean_quality: 260,
    ozone_method: "fixed",
    ozone_source: "mod09cmg",
    ozone_status: "Data Found",
    ozone_std: 3e-8,
    ozone_used: 0.26,
    satellite_azimuth_angle: 279.15,
    satellite_zenith_angle: 10.87,
    solar_azimuth_angle: 68.4346,
    solar_zenith_angle: 17.645,
```

sr_version: "2.0",
water_vapor_coverage: 0.86,
water_vapor_mean_quality: 1,
water_vapor_method: "fixed",
water_vapor_source: "mod09cma",
water_vapor_status: "Data Found",
water_vapor_std: 0.071,
water_vapor_used: 2.1
}
}

ATMOSPHERIC CORRECTION METHODOLOGY

Surface reflectance is determined from top of atmosphere (TOA) reflectance, calculated using coefficients supplied with the Planet Radiance product. Calculating SR is a pixel-by-pixel operation using lookup tables (LUTs) that have been generated using the 6SV2.1 radiative transfer code[1]. The LUTs map TOA reflectance to bottom of atmosphere (BOA) reflectance for all combinations of selected ranges of physical conditions relevant for Planet imagery. A separate set of LUTs are used for each satellite sensor type using its individual spectral response. The following table lists the inputs to the 6s atmospheric model and the ranges of values used.

Table 2: 6sv2.1 inputs to generate LUTs and value ranges for each input.

LUT Inputs		
Input	Values	Notes
H2O, O3, pressure and temperature profile	Water vapor and ozone concentrations or one of the following built-in atmospheric models: midlatitude_summer, midlatitude_ winter, tropical, subarctic_ summer, subarctic_winter	Internal models provided by 6S
Aerosol type	continental	Internal model provided by 6S
Aerosol optical depth (AOD)	0.02, 0.04, 0.06, 0.07, 0.08, 0.09, 0.1, 0.12, 0.14, 0.16, 0.18, 0.2, 0.22, 0.25, 0.3, 0.35, 0.4, 0.55, 0.75	
Geometry		
Solar Zenith Angle	10, 20, 30, 40, 50, 60, 70, 80	Zenith angle for the center of the scene footprint is used
Satellite Zenith Angle	Range is fleet specific: Dove: nadir pointing (0)	

[1] http://6s.ltdri.org/

	RapidEye: 0, 4, 8, 12, 16, 20 SkySat: 0, 4, 8, 12, 16, 20, 24, 28	
Azimuth angle difference	0 - 180, 10 degree increments.	Difference in azimuth angle between sun and satellite
Target Elevation	sea level	
Surface Conditions		
Reflectance Type	Lambertian	Corrections for BDRF effects would be applied to the SR product
Reflectance Values	0 - 1.0, increments of 0.025	
Spectral Conditions		
Bands	8 Bands for SuperDove VNIR for SkySat VNIR + RedEdge for RapidEye	Dove: Coastal Blue: 431 - 452 nm Blue: 465 – 515 nm Green I: 513 - 549 nm Green: 547 – 583 nm Yellow: 600 - 620 nm Red: 650 – 680 nm RedEdge: 697 – 713 nm NIR: 845 – 885 nm SkySat: Blue 450-515 nm Green 515-595 nm Red 605-695 nm NIR 740-900 nm RapidEye: B: 440 - 510 nm G: 520 - 590 nm R: 630 - 685 nm RE: 690 - 730 nm NIR: 760 - 850 nm
Spectral Response	Defined for each sensor type	Every Planet satellite with the same sensor type uses the same set of LUTs. RapidEye satellites have a separate, single set of LUTs.

When converting an image to surface reflectance, water vapor and ozone inputs are retrieved from MODIS near-real-time (NRT)[2] data for same-day collections. When available, the standard MODIS data is used. As future sources become available, such as provided by the VIIRS derived atmospheric data, those will be added to the sources available to be used in the correction process. In the event that there is no overlapping water vapor or ozone data, a 6S atmospheric model is chosen based on the local latitude and time of year of the image acquisition following the scheme used by the FLAASH atmospheric correction tool.[3] The AOD input for a scene is determined from

[2] https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/61/
[3] Based on scheme described at https://www.spectral.com/our-software/flaash/l

MODIS NRT aerosol data, finding an overlapping region and interpolating a value of AOD for each image pixel within that region. If the AOD coverage is less than 50%, then the average AOD of the partial overlap area is used instead. Water vapor and ozone values always use the average. When looking up reflectance values from the LUTs, tables with the closest matching values of water vapor and ozone concentrations are used. Tables built with the two closest solar zenith angles are interpolated between and a linear interpolation is performed for AOD, TOA reflectance and satellite zenith angle. Since Planet Dove satellites are nadir pointing, satellite zenith angle is fixed at 0 degrees for those corrections. For SkySat and RapidEye, reflectance values are interpolated based on the LUT entries with values of solar zenith angle and satellite zenith angle that are closest above and below the satellite view zenith angle.

CHANGES AND IMPROVEMENTS

Over time bug fixes and improvements are made to the atmospheric correction process and algorithm. Which specific version was used to produce a surface reflectance product can be determined by examining the sr_version key in the metadata added to the GeoTIFF. Two significant changes have been made since the original release of the SR product: (1) Use of a per pixel AOD map and interpolation for view angle (v2.0) and (2) Use of MODIS Aqua data as a fallback when MODIS Terra data is not available (v2.1).

PRODUCT LIMITATIONS

The Planet Surface Reflectance V2 product corrects for the effects of the Earth's atmosphere, accounting for the molecular composition and variation with altitude along with aerosol content. Combining the use of standard atmospheric models with the use of MODIS aerosol data, this provides reliable and consistent surface reflectance scenes over Planet's varied constellation of satellites as part of our normal, on-demand data pipeline. However, there are some limitations to the corrections performed:

- In some instances when MODIS data is available for a given day, there is nonetheless no data overlapping a Planet scene or the area nearby. In those cases, AOD is set to a value of 0.226 which corresponds to a “clear sky” visibility of 23km, the aot_quality is set to the MODIS “no data” value of 127, and aot_status is set to ‘Missing Data - Using Default AOT’. If there is no overlapping water vapor or ozone data, the correction falls back to a predefined 6SV internal model based on the image date and latitude.
- The effects of haze and thin cirrus clouds are not corrected for.
- Aerosol type is limited to a single, global model.
- All scenes are assumed to be at sea level and the surfaces are assumed to exhibit Lambertian scattering - no BRDF effects are accounted for. Some variation due to BRDF effects can be expected from SkySat and RapidEye SR products.
- Stray light and adjacency effects are not corrected for.

PRODUCT ASSESSMENT

Validation

The performance of Planet's atmospheric correction algorithm has been validated against the La Crau, Baotou Sands and Railroad Valley RadCalNet sites, the former being a vegetation covered region and the latter two more desert environments. Cloud free scenes that intersected with those sites between January and October 2024 were collected and analyzed. The same analysis was performed separately for RapidEye for the time period January 2010 to October 2019 . Calculated reflectances show good overall agreement with ground truth measurements, with the results summarized in Tables 3 and 4.

Table 3: Measured performance of SuperDove satellites against RadCalNet ground truth.

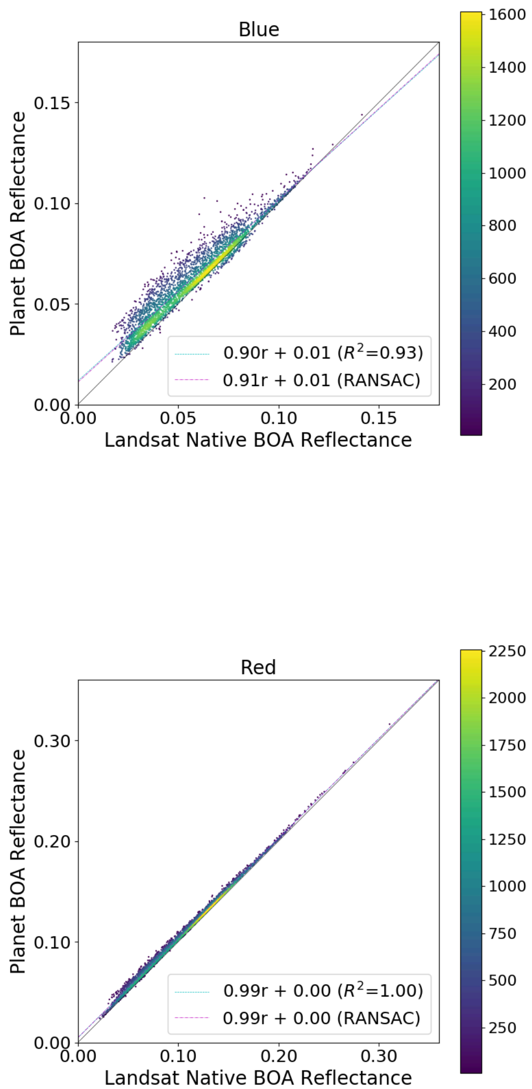
Measured Performance (La Crau + Baotou Sands + Gobabeb + Railroad Valley)			
Band	Absolute Accuracy %	Precision %	Uncertainty % (1 sigma)
Coastal Blue	-6.25	12.44	13.92
Blue	-5.17	9.26	10.61
Green I	-2.69	8.64	9.05
Green II	-1.30	9.44	9.53
Yellow	2.98	10.82	11.23
Red	1.89	9.92	10.10
Sentinel Red Edge I	1.87	10.14	10.32
NIR	5.93	10.35	11.93

Table 4: Measured performance of RapidEye satellites against RadCalNet ground truth.

Measured Performance (LaCrau + Gobabeb)			
Band	Absolute Accuracy %	Precision %	Uncertainty % (1 sigma)
Blue	-4.34	32.02	32.32
Green	6.70	17.39	17.40
Red	0.01	16.34	16.34
NIR	0.19	12.04	12.04

Comparisons have also been made between Planet surface reflectance and both Landsat 8 and Sentinel-2 native SR products by applying Planet's correction algorithm directly to Landsat and Sentinel-2 top-of-atmosphere imagery . An example is shown in Figure 1 where Planet SR is compared to Landsat 8 native SR for samples collected from May to October of 2019 for a large area of cropland in California's Central Valley.

Figure 1: Comparison of Planet SR applied to Landsat-8 TOA imagery with Landsat native SR.



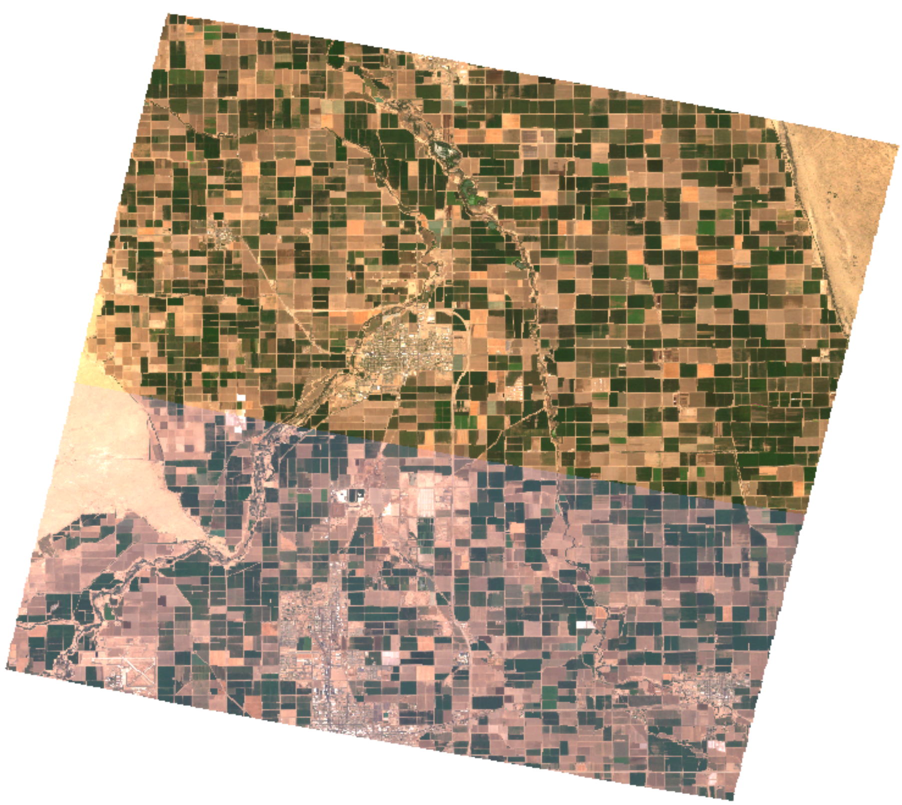
The plots in Figure 1 show higher variance in reflectance values for shorter wavelengths, mostly due to differences between Planet's estimate of AOT, using MODIS data, and Landsat's estimate of AOT, based on matching the relationship between red and blue band reflectances to historical MODIS data for each scene[4]. The better agreement in the red and NIR bands means that applying the Planet correction to Landsat 8 (and Sentinel-2) imagery is a useful approach to comparing NDVI values between Planet and non-Planet imagery.

Crop Monitoring

With Planet's constellation of satellites, farming regions can be revisited on a nearly daily basis enabling real time monitoring of crop health and insights on day to day changes in the fields. Combined with the physics-based atmospheric correction methodology used to produce the Planet SR product, crops can be monitored with a high degree of precision and in near real time. The following section details an assessment of the SR Product for temporal monitoring of crops and an assessment of the correction on derived indices and band reflectances as compared to the Landsat 8 SR and Sentinel-2 products.

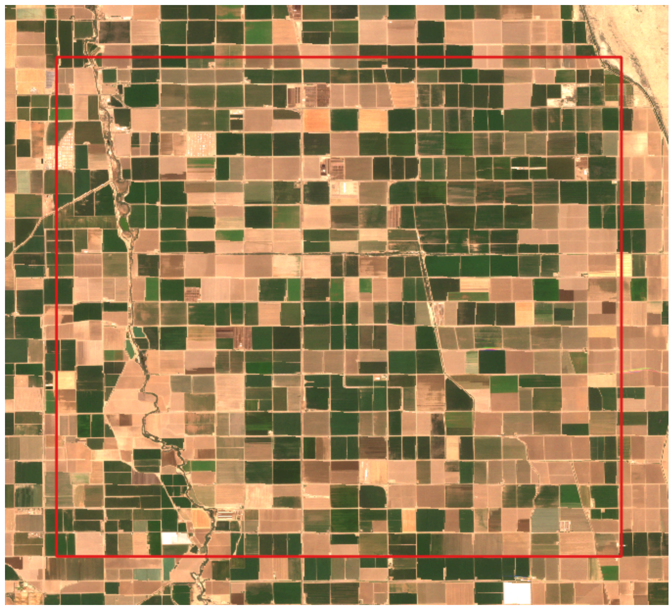
In Figure 2 below, two adjacent scenes of farmland in the Imperial Valley of California show the visual differences between a TOA reflectance image (bottom) and the atmospherically corrected SR product (top). Figure 3 shows a smaller region within the Imperial Valley that includes fields used in the detailed examples of time series analyses and crop spectrum comparisons described later in this document.

Figure 2: TOA reflectance and SR scenes from a single strip of images.



[4] https://hls.gsfc.nasa.gov/algorithms/atmospheric-correction/

Figure 3: Area of interest for cropland in the Imperial Valley region of California.

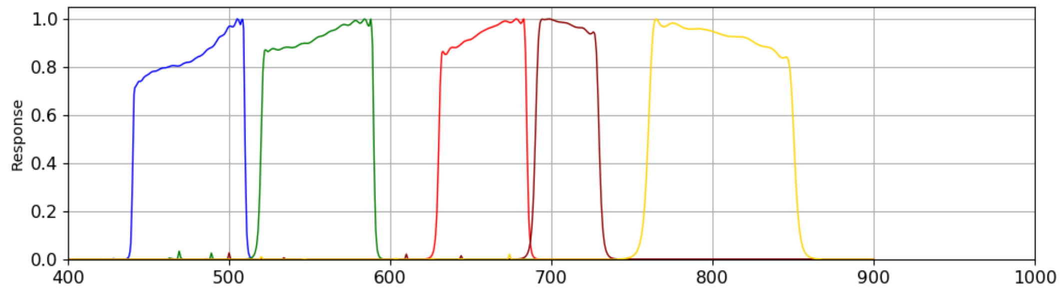


SATELLITE SPECTRAL RESPONSES

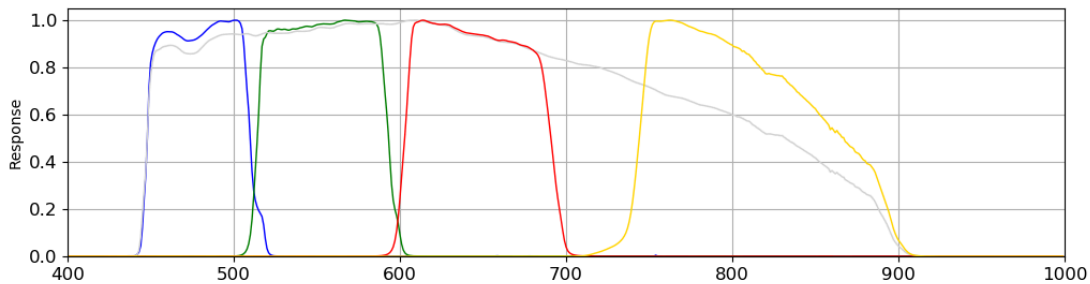
When comparing measured reflectance values from different satellites, it's important to consider the spectral response of the satellite's sensor: two otherwise perfectly calibrated sensors will derive different SR values for the same area, even when collected at the same time, if those sensors have a different relative spectral response (RSR) for each band. Figure 4 shows the spectral responses of the sensors being compared here. As can be seen, the spectral responses for the Planet SuperDove satellites are very similar to Sentinel-2, while the SkySat and RapidEye sensors have significant differences. The close similarity between the spectral responses for SuperDove and Sentinel-2 results in a corresponding similarity between their respective time series data, but with SuperDove providing a daily cadence.

Figure 4: Spectral responses for the satellite sensors used in the time series comparisons along with other satellite fleets for which surface reflectance is supported.

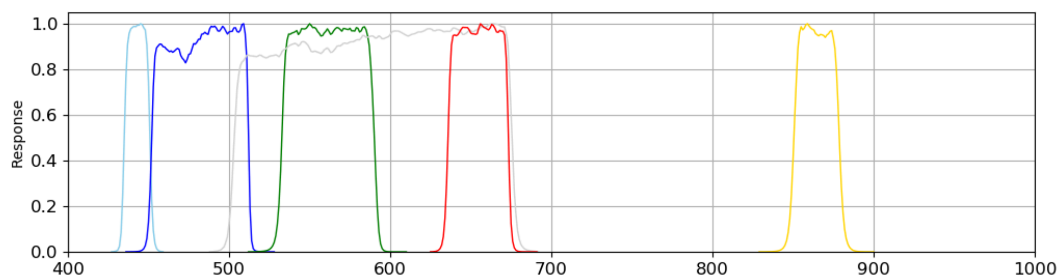
RapidEye



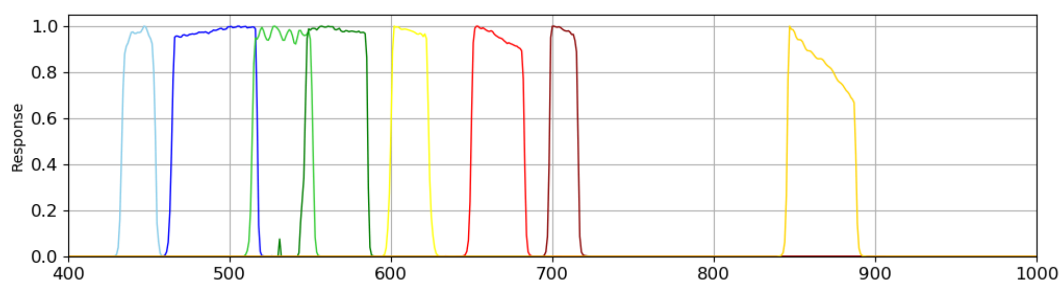
SkySat



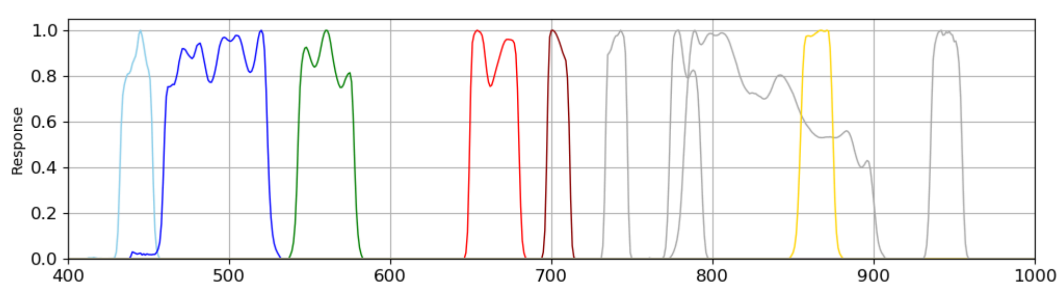
Landsat-8



SuperDove

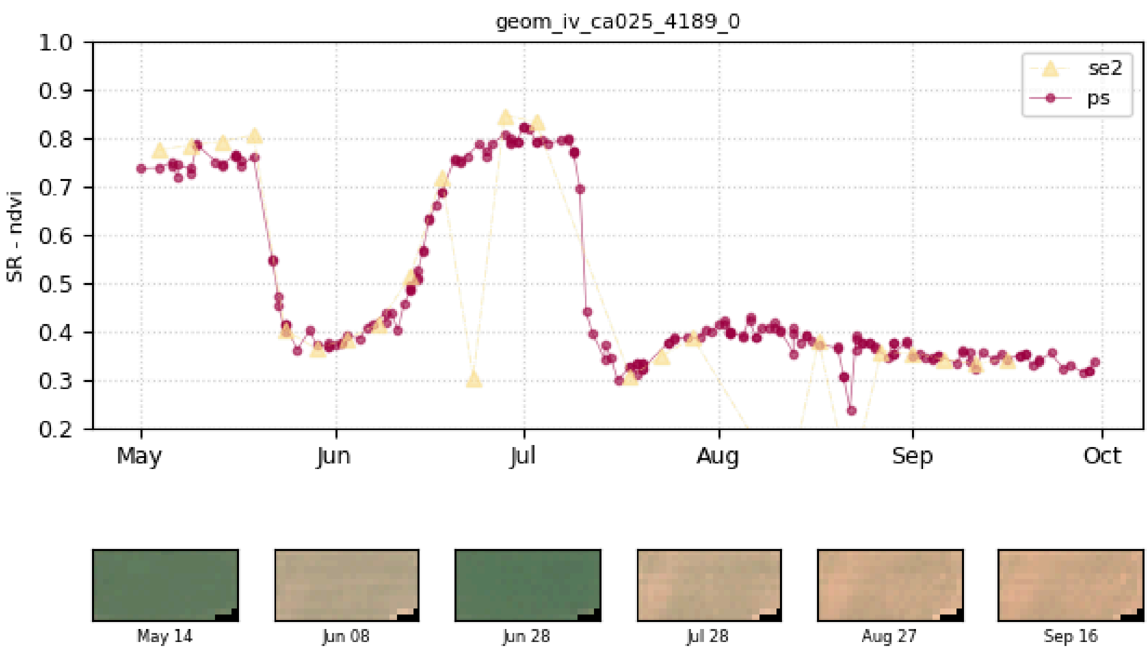


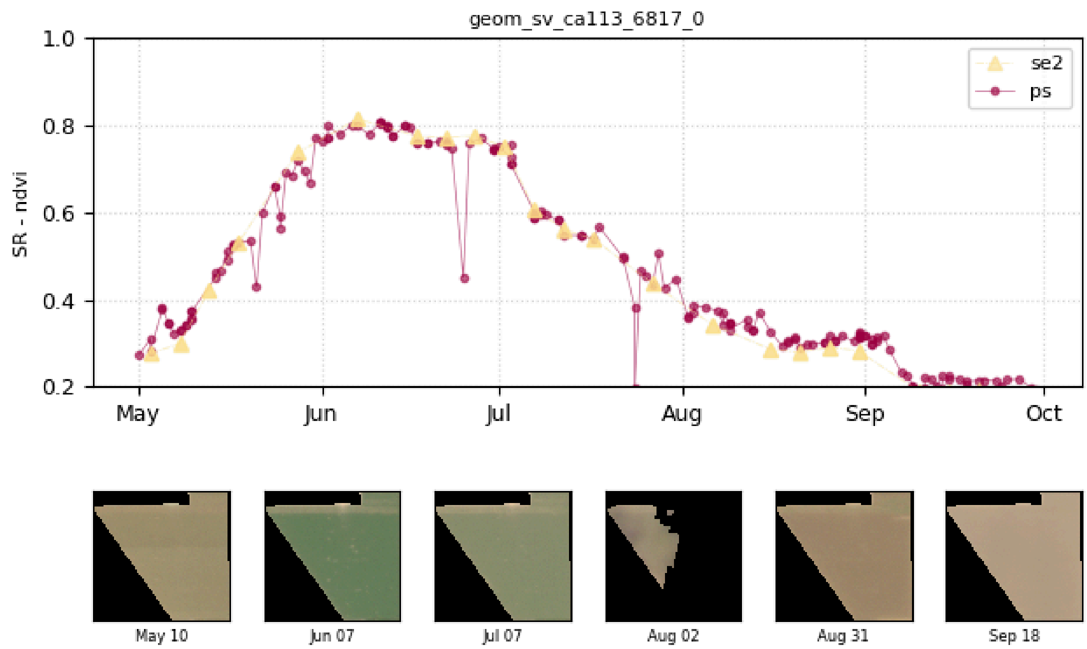
Sentinel-2



Example time series plots of the derived NDVI vegetation index for an alfalfa field in the Imperial Valley area of California and a grassy field in California's Central Valley are provided in Figure 5 for the summer months of 2024. Image collections were made by multiple Planet SuperDove satellites and are displayed by capture date. Dips and spikes in the curves generally represent clouds/shadows in or near the scene which cause additional atmospheric scattering that is not corrected for. The curves illustrate the usefulness of daily collects where sharp drops in index value are evident during harvesting time with some images captured in the middle of the process.

Figure 5: Time series of NDVI for both PlanetScope SuperDoves and Sentinel-2 for the summer of 2024. Sentinel-2 surface reflectance was derived from processing Sentinel radiance products to SR using the FORCE atmospheric correction program. The top plot is for an alfalfa field in the Imperial Valley and the bottom is for a grassy field in the Central Valley of California.





The low values of NDVI for SuperDove satellite collects during the peaks in alfalfa and grass growth are the result of the wide red band for those satellite sensors. The good agreement illustrates the benefit of using similar sensors when making direct SR comparisons without the use of spectral band adjustment factors (SBAFs).

In Figure 6 below, a comparison is provided showing average per-band surface reflectances for the field in the Sacramento Valley at different points of the growing season. Each plot is a single Planet SuperDove scene and a corresponding Sentinel-2 scene for the closest crossover date. As can be seen, the general shape of both the Planet and Sentinel-2 spectra agree as the surface cover changes over the summer with small differences partly due to the non-simultaneity of the collects. Figure 6 shows a single set of collects near the peak in growth, further illustrating the good agreement between Planet's SuperDove satellite and Sentinel satellites.

Each curve is labeled with the month and day for when the scene was acquired. The Planet thumbnail is provided as a visual reference.

Figure 6: A comparison of Planet and Sentineo-2 spectra for a field in the Sacramento Valley for the summer of 2024. Corresponding colors are for scenes collected near the same time.

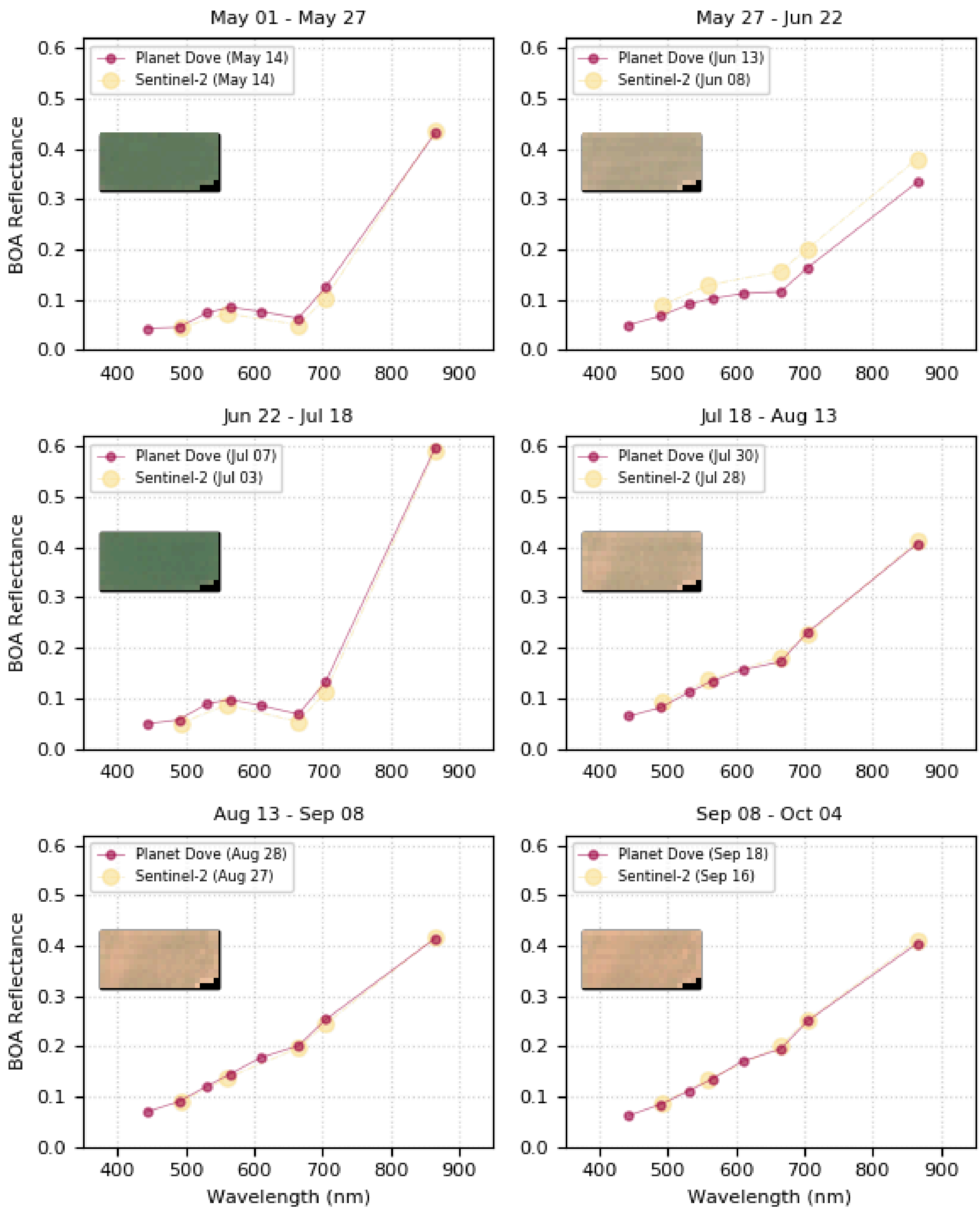
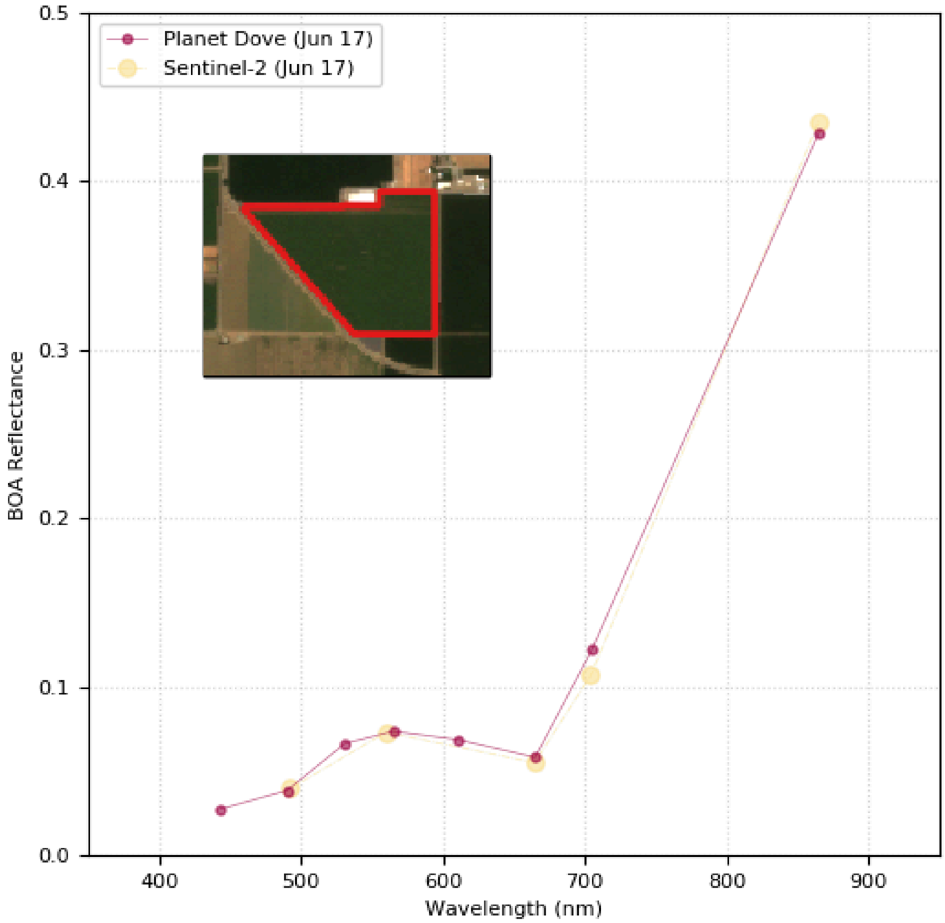


Figure 7: Similar to Figure 6 but for a single day from the Sacramento Valley dataset where a single same day crossover between a SuperDove and Sentinel-2B was analyzed. In this case the two satellites crossed the target field, outlined in red, approximately two minutes apart on June 17, 2024.



CONCLUSION

Evaluation of the Planet Surface Reflectance product presented in this white paper shows that it is consistent with other industry standard surface reflectance datasets. Results demonstrate that the absolute SR values are closely aligned between coincident image products with both Landsat 8 and Sentinel-2, and temporal analysis of derived vegetation indices show the datasets are highly correlated. This analysis supports the use of the Planet SR product where accurate and consistent vegetation indices are required with RapidEye providing an 11 year catalog of historical surface reflectance data. Planet's unique global scale high cadence imagery now paired with accurate surface reflectance presents a solution to a wide range of monitoring applications.

Figure 8: Samples of the available Surface Reflectance products.

You can explore Planet's Surface Reflectance product at https://www.planet.com/explorer/.