PLANET SURFACE REFLECTANCE

VERSION 2.0

Planet's Surface Reflectance (SR) Product is derived from the standard 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.[1]

Surface Reflectance is available for all orthorectified scenes produced by radiometrically calibrated sun-synchronous orbit Dove and RapidEye satellites. The Surface Reflectance product is available in the API as the 'analytic_sr' asset under the PSScene4Band, PSOrthoTile, and REOrthoTile Itemtypes. Support for a SkySat SR product is planned for the near future.

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1 ' https://assets.planet.com/marketing/PDF/Planet_Surface_Reflectance_Technical_White_Paper.pdf

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. The following table 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.	2.0
water_vapor_coverage	Percentage overlap between MODIS data and the scene being corrected.	0.86
water_vapor_mean_quality	Average MODIS ozone quality value for the overlapping NRT data in the range 1-10. This is set to 127 when no data is available.	1
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/cm2.	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[2][2]. 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
Atmospheric Conditions		
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) RapidEye: 0, 4, 8, 12, 16, 20	
Azimuth angle difference	0 - 180, 10 degree increments	Difference in azimuth angle between sun and satellite
Target Elevation	sea level	

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

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	VNIR plus RedEdge for RapidEye	Dove: B: 455 - 515 nm G: 500 - 590 nm R: 590 - 670 nm NIR: 780 - 860 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)[3] data for same-day collects. 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.[4]

The AOD input for a scene is determined from 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 Dove satellites are nadir pointing, satellite zenith angle is fixed at 0 degrees for those corrections.

3 https://earthdata.nasa.gov/earth-observation-data/near-real-time/download-nrt-data/modis-nrt
4 Based on scheme described at http://www.harrisgeospatial.com/docs/FLAASH.html

CHANGES AND IMPROVEMENTS FROM V1

The following improvements were made for the v2.0 release of the SR products

Rather than using a single, average AOD value over a scene for the correction, a map of AOD values interpolated from the overlapping MODIS data is used. This primarily helps reduce visible seams between scenes in a strip where large variations of AOD occur, but can also help improve the corrections within a scene under the same conditions.

Atmospheric correction for non-nadir pointing satellites is added to support RapidEye and other satellites with appreciable view angles. In these cases interpolation between LUTs is performed for the particular view angle for the collect. This does not include a BRDF correction, however.

PRODUCT LIMITATIONS

The Planet Surface Reflectance V1 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.
- 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 RapidEye and SkySat 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 LaCrau and Gobabeb RadCalNet sites, the former being a vegetation covered region and the latter a desert environment. Cloud free scenes that intersected with those sites between January 2017 to October 2019 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 agreement with ground truth measurements, with the results summarized in Tables 3 and 4.

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

Measured Performance (LaCrau + Gobabeb)

Band	Absolute Accuracy %	Precision %	Uncertainty % (1 sigma)
Blue	10.67	11.33	15.56
Green	9.94	9.04	13.34
Red	6.37	7.90	10.15
NIR	2.13	7.20	7.51

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.

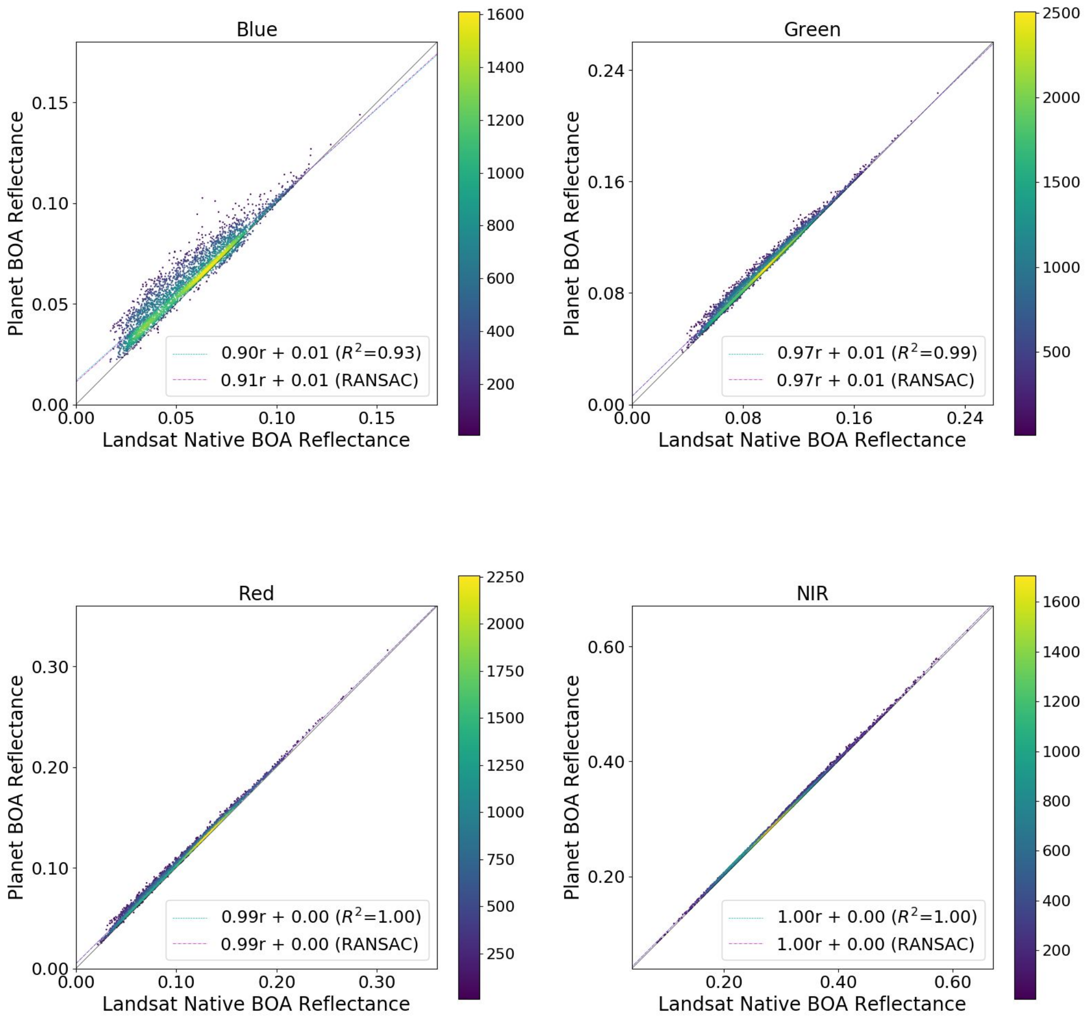


Figure 1: Comparison of Planet SR applied to Landsat-8 TOA imagery with Landsat native SR.

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.[5] 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.

[5] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170002673.pdf, Section 2.1

CROP MONITORING

With Planet's constellation of satellites, farming regions can be revisited on a near-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 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 1 below, two adjacent scenes of farmland in the Sacramento Valley of California show the visual differences between a TOA reflectance image (bottom) and the atmospherically corrected SR product (top).

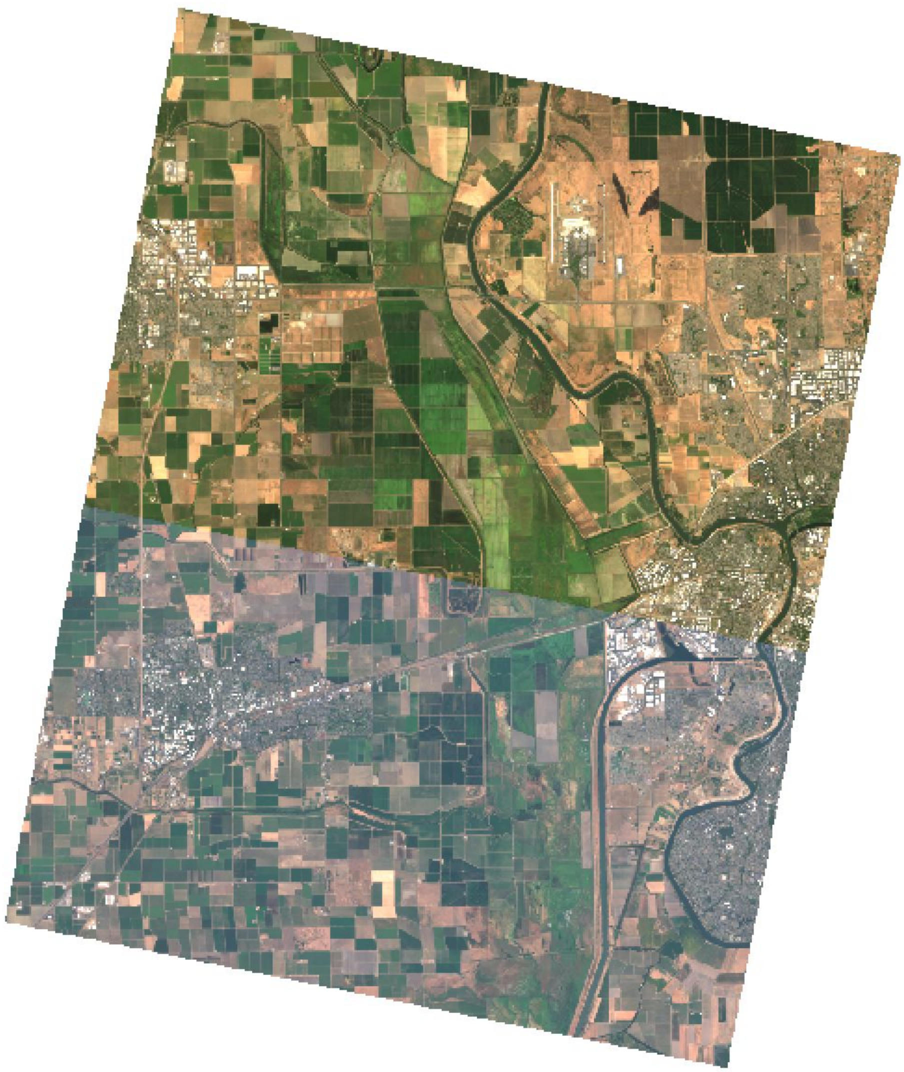


Figure 1: A visual comparison of the SR product (top) and a TOA Reflectance image (bottom) in adjacent scenes captured by the same Dove-R satellite.

By selecting individual fields and comparing the changes in each field through time, the stability of the SR product can be assessed. Figure 2 shows a region selected from a farmland area In the Sacramento Valley area of California. Surface Reflectance assets were generated for crossovers of this area from May to October 2019. Reflectance values were calculated as averages over individual fields within the area of interest (AOI). Fields were identified using a Common Land Unit (CLU) database,[6] which provides generally uniform areas from which to calculate average reflectance values.

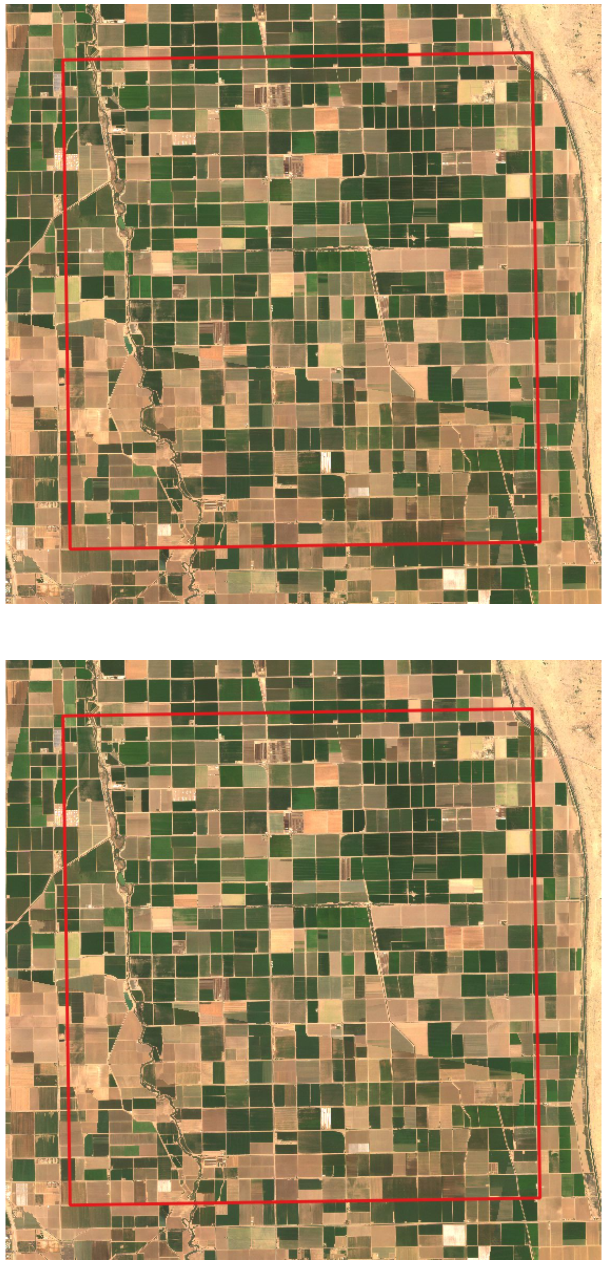
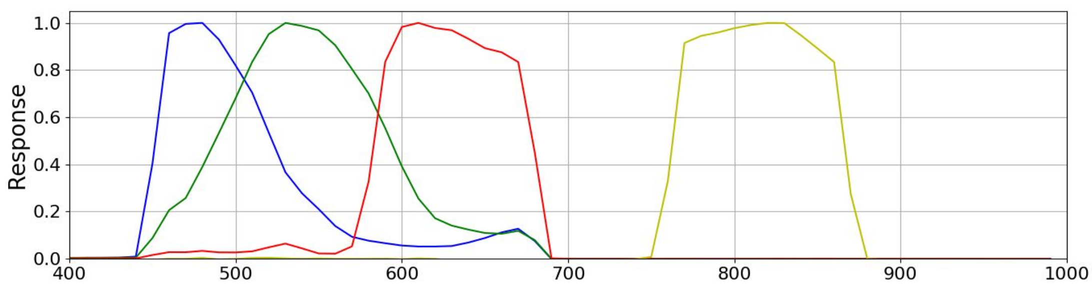


Figure 2: Areas of interest for cropland in the (a) Imperial Valley and (b) Sacramento Valley regions of California.

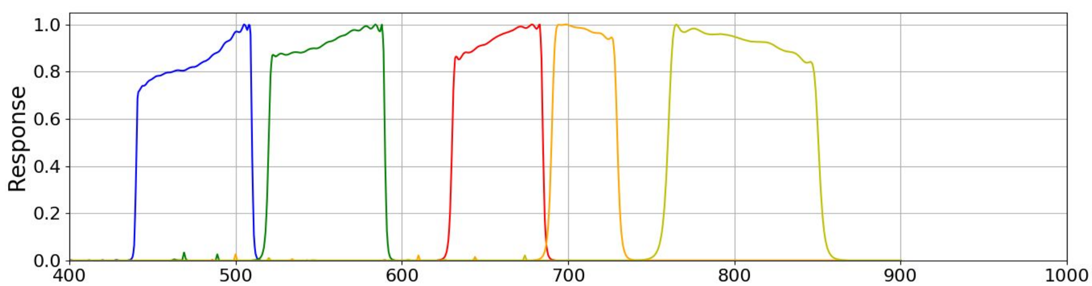
[6] https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-products/common-land-unit-clu/index

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 3 shows the spectral responses of the sensors being compared here. As can be seen, the spectral responses for Dove-R satellites are very similar to both Landsat 8 and Sentinel-2, while the Dove Classic and RapidEye have significant differences. For Dove satellites, differences will be apparent in the following time series comparisons.

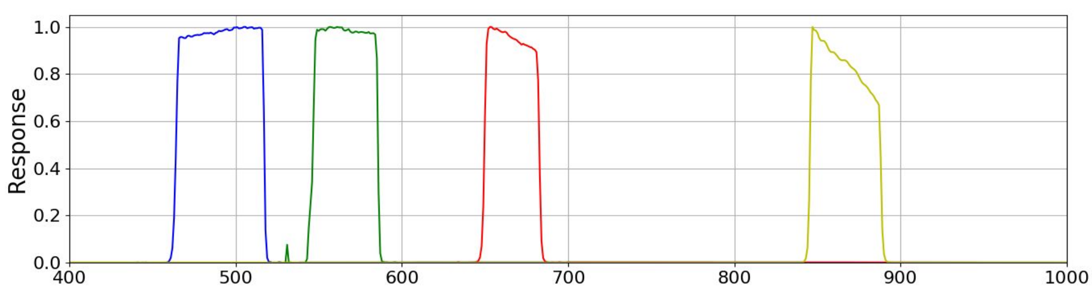
COMPARISON OF SATELLITE SPECTRAL RESPONSES



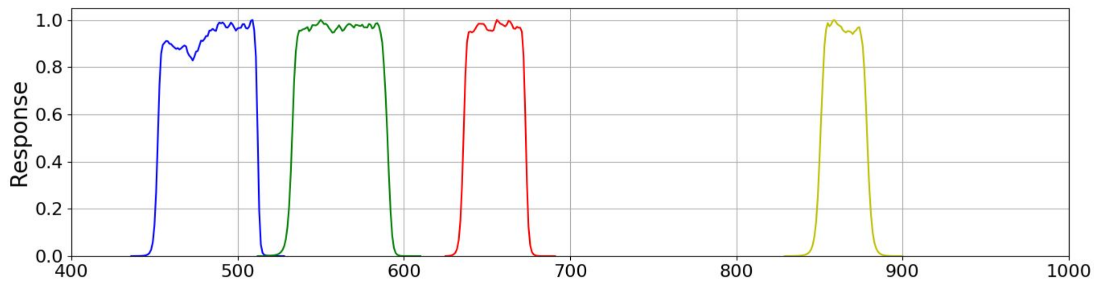
Dove



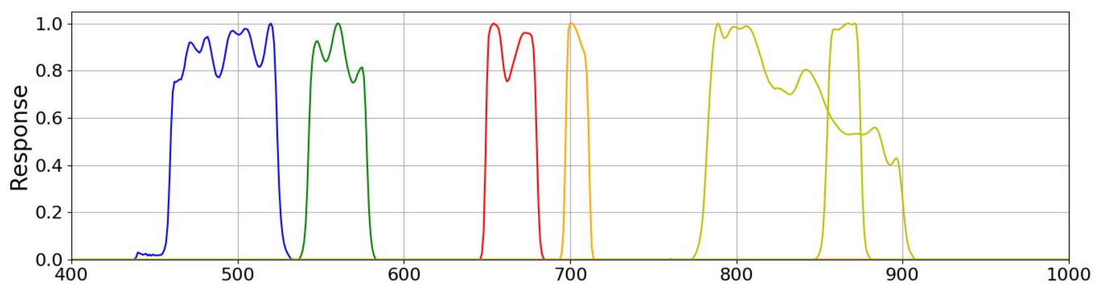
RapidEye



Dove-R



Landsat-8



Sentinel-2

Figure 3: Spectral responses for the satellite sensors used in the time series comparisons. For clarify, only bands for Landsat and Sentinel that correspond to a band in a Planet satellite sensor are included,

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 4 for the summer months of 2019. Image collections were made by both Dove and Dove-R 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 collects captured in the middle of the process.

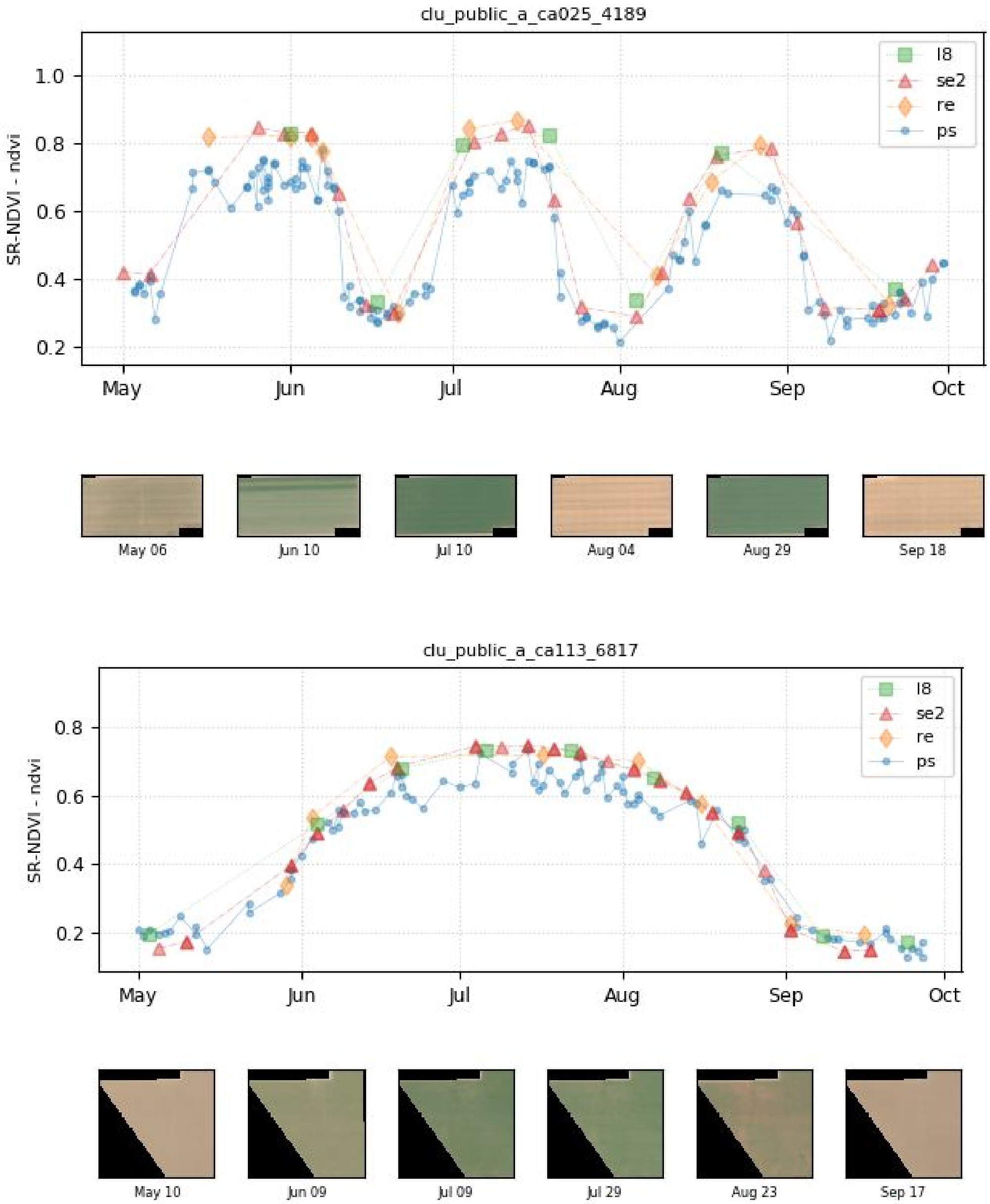


Figure 4: Time series of NDVI and EVI of a field in the Sacramento Valley showing the effect of atmospheric correction as compared to using derived indices without correction. The top plot is for an alfalfa field in the Imperial Valley and the bottom is for a grassy field in the Central Valley.

The low values of NDVI for Dove satellite collects during the peaks in alfalfa and grass growth are the result of the wide red band for those satellite sensors. Figure 5 shows the same plot for the grassy field but including only the Dove-R satellites. The agreement illustrates the benefit of using similar sensors when making direct SR comparisons without the use of spectral band adjustment factors (SBAFs).

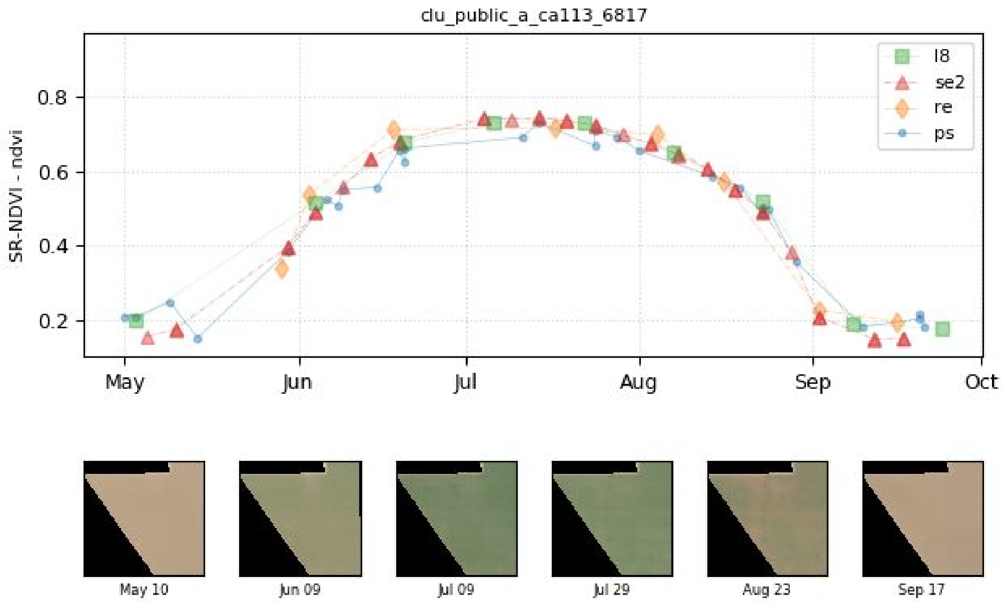


Figure 5: Time series of NDVI of a field in the Sacramento Valley. Same as Figure 4 but including only Dove-R satellites.

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 Dove-R scene and a corresponding Landsat 8 and Sentinel-2 scene for the closest crossover date. As can be seen, the general shape of both the Planet, Landsat 8 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 7 shows a single set of collections near growth peak further illustrating the agreement between Dove-R satellite and both Landsat and Sentinel satellites.

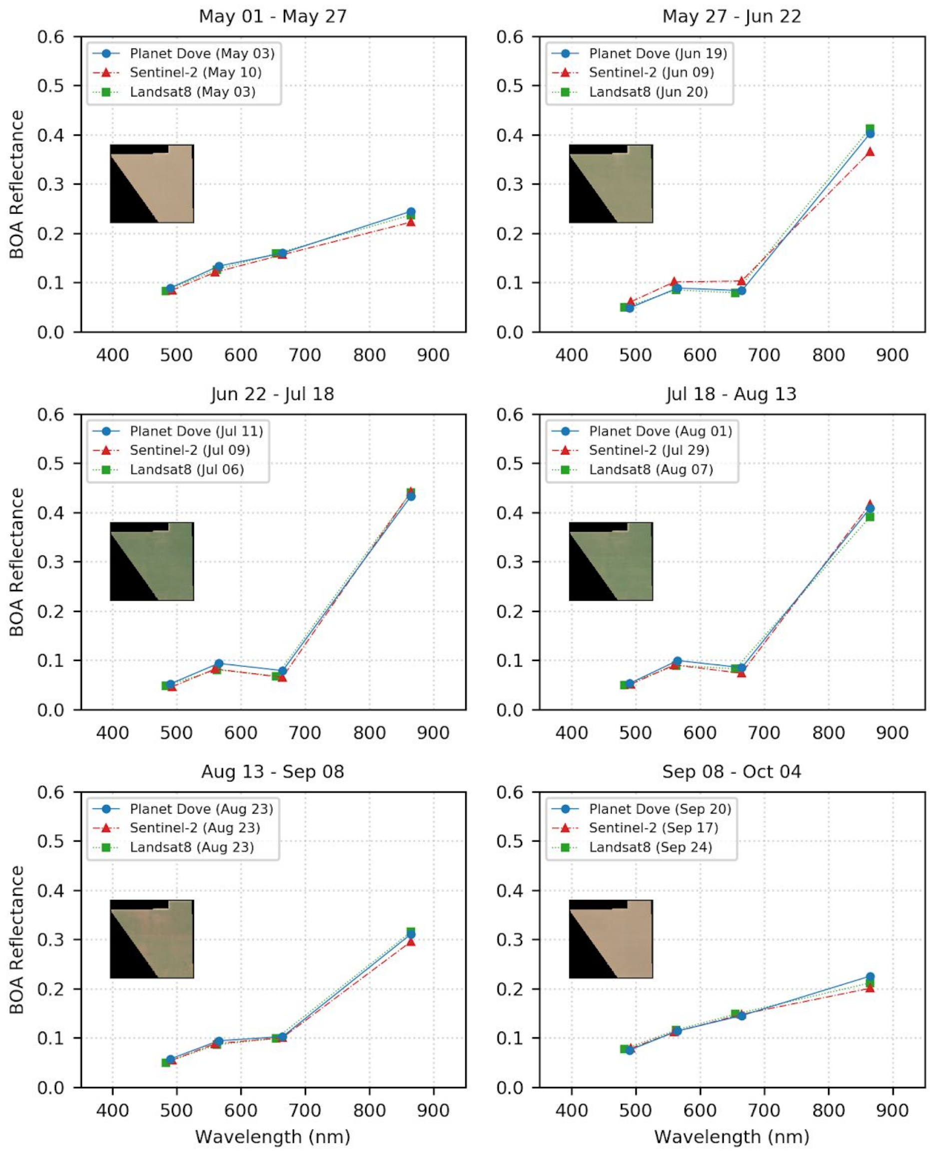


Figure 6: A comparison of Planet and Landsat 8 spectra for a field in the Sacramento Valley for the summer of 2017. Corresponding colors are for scenes collected near the same time. Each Landsat 8 curve is labeled with the day number for when the scene was acquired. The Planet thumbnail is provided as a visual reference.

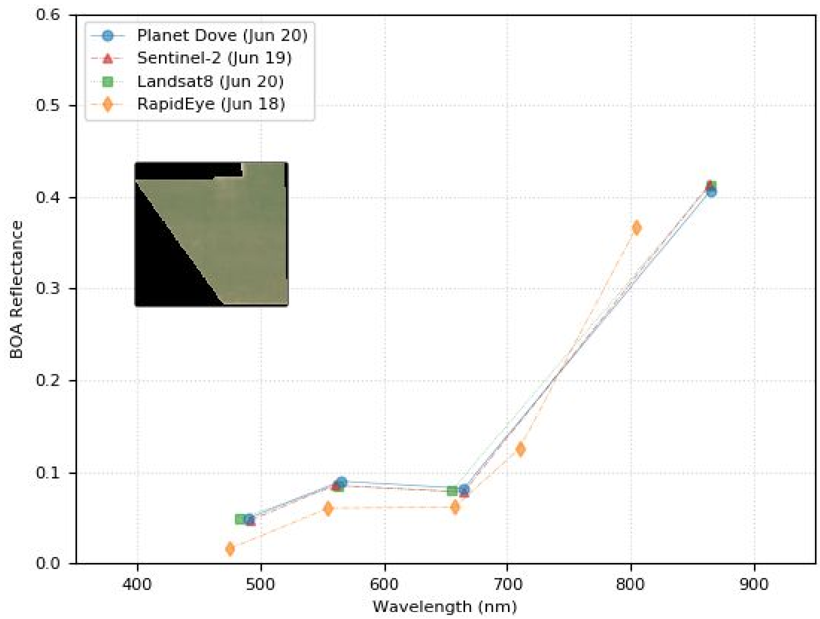


Figure 7: Same as Figure 6 but for a single short time period where all collects were within three days and including a Rapideye collect.

CONCLUSION

Evaluation of the 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.

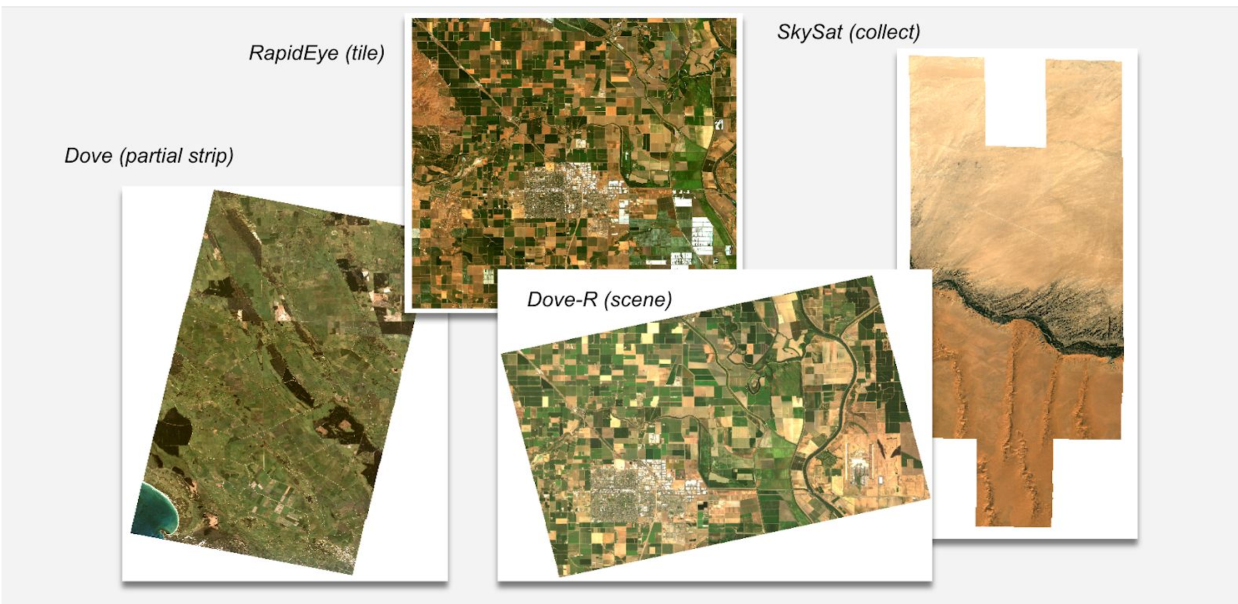


Figure 8: Samples of the available Surface Reflectance products.