

# PLANET Land Surface Temperature TECHNICAL SPECIFICATION

**Version 1.0, May 2023**

Planetary Variables



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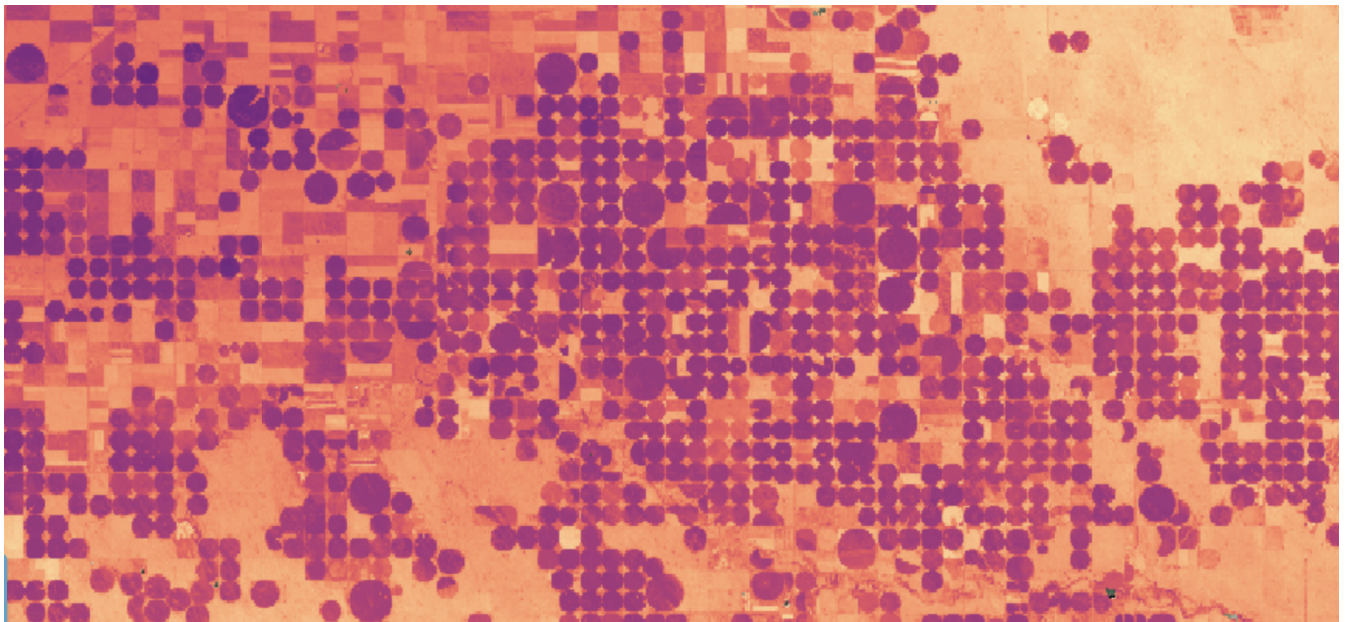
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# 1. LAND SURFACE TEMPERATURE OVERVIEW

Land Surface Temperature (LST) is the thermodynamic temperature of Earth's surface. LST is a key variable controlling energy, and water fluxes over the land surface and atmosphere interface. In view of increasing extreme temperature events and a growing population exposed to these events, LST is increasingly relevant to sustainably manage food and water systems and urban living conditions.

For regional to global-scale modeling and monitoring of land surface processes, there is a need for long-term remote sensing-based LST. As a result, LST has been added as an Essential Climate Variable of the Global Climate Observing System (Belward et al., 2016). Due to its high spatiotemporal resolution, LST is also an indicator of the energy budget of all kinds of land surfaces, for example, croplands, pastures, forests, and urban areas. For agricultural areas, LST will provide critical insight into plant-water dynamics and how ecosystems change with climate and anthropogenic impact. Furthermore, LST is an essential input variable in several soil and plant evaporation models as well as soil water content retrieval methodologies. LST, at various spatial and temporal resolutions, will enable governments, water management institutes, agricultural companies, farmers, and scientists to understand and make decisions on policies and management in relation to the energy, water and carbon cycle.

Planet retrieves Land Surface Temperature globally and daily at 01.30 and 13.30 with a resolution of 1 km and 100 m from satellite passive microwave measurements based on the proprietary method to improve the spatial resolution. Optical imagery from Sentinel-2 is also included in the 100m products to further improve the spatial resolution. Because of the microwave measurements and the proprietary method, Land Surface Temperature observations are available in clear-sky and cloudy conditions, which allow consistent, frequent, and global monitoring. The products were evaluated against TIR-based LST satellite missions and validated using the ground measurements.





The unique features of Planet Land Surface temperature (LST) data can be summarized as:

- Proprietary method to provide LST at 100m and 1km resolution
- LST is retrieved twice a day (at 01:30 and 13:30) from passive microwave observations
- Inclusion of Sentinel-2 data to obtain a better spatial representation (only for 100m product)
- Typically available within 12 hours of satellite overpass
- Not hindered by clouds
- LST performs well over the majority of land surface, with the exception of snow and frozen areas.
- Available since 2002 at 1km resolution, and since 2017 at 100m resolution

## 2. PLANET LST INPUTS

The land surface temperature algorithm is based on a set of observations provided by two passive-microwave radiometers, Sentinel-2 multispectral reflectances (for the 100m product), and a set of ancillary data including a digital elevation model, and a custom global water bodies map. The brightness temperatures, derived from the following passive-microwave radiometers, is the core input for the LST algorithm at 100m and 1 km resolution:

- The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) onboard NASA's Aqua satellite is a twelve-channel, six-frequency, total power passive-microwave radiometer system. It measures brightness temperatures of microwave emissions at multiple frequencies from 6.9 to 89.0 GHz, including the Ka band at 37GHz. Vertically and horizontally polarized measurements are taken at all channels. The Aqua satellite was launched on May 4, 2002 and orbits earth sun-synchronously with an altitude of 705 km. The ascending path crosses the equator at around 13:30 local mean solar time, while the descending path crosses the equator at around 01:30. The AMSR-E sensor was retired in October 2011.
- Advanced Microwave Scanning Radiometer 2 (AMSR2) is the follow-on mission of AMSR-E supported by the Japanese space agency JAXA. The multi-frequency microwave radiometer is onboard the GCOM-W1 satellite and has an additional C-band channel (7.3 GHz) to mitigate Radio Frequency Interference ([De Nijs et al., 2015](#)). The satellite was launched on May 17, 2012 into an sun-synchronous orbit with an altitude of 699.6-km. The ascending path crosses the equator at around 13:30 local mean solar time, while the descending path crosses the equator at around 01:30.

The retrieval algorithm of the 100m resolution product uses additional information from optical data:

- Sentinel-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. The mission supports Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observation of inland waterways and coastal areas. The full mission consists of twin satellites flying in the same sun-synchronous orbit at 786 km but phased at 180°, giving a revisit frequency of 5 days at the Equator in cloud-free conditions. Overpass time of the descending node is 10:30. Each satellite carries an optical instrument payload (the MultiSpectral Instrument) that samples 13 spectral bands from 492 nm to 2202 nm: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. The orbital swath width is 290 km. The Sentinel-2A satellite was launched on June 23, 2015 and the Sentinel-2B satellite on April 25, 2016. More information can be found [here](#).



Table 1: List of inputs currently used in Land Surface Temperature production.

Product	Description
Brightness Temperature Ka-band	AMSR-E and AMSR-2 Level-1B Radiometer C-band Brightness Temperatures (downloaded from <a href="ftp.gportal.jaxa.jp">ftp.gportal.jaxa.jp</a> in HDF5 format). This Level-1B product provides calibrated estimates of geolocated brightness temperatures at 36.5 GHz with a footprint size of 7x12 km. Data has been available from June 2002 to October 2011 (AMSR-E) and from June 2012 (AMSR-2) up to now with a latency of 12 hours. Detailed information is available in the <a href="#">link</a> .
Brightness Temperature W-band	AMSR-E and AMSR-2 Level-1B Radiometer W-band Brightness Temperatures (downloaded from <a href="ftp.gportal.jaxa.jp">ftp.gportal.jaxa.jp</a> in HDF5 format). This Level-1B product provides calibrated estimates of geolocated brightness temperatures at 89 GHz with a footprint size of 3x5 km. Data has been available from June 2002 to October 2011 (AMSR-E) and from June 2012 (AMSR-2) up to now with a latency of 12 hours. Detailed information is available in the <a href="#">link</a> .
Reflectances SWIR and NIR (for 100m only)	SENTINEL-2 Level-1C reflectances (downloaded from <a href="#">Google Cloud</a> or the <a href="#">Earth Observation Data Center</a> based on availability) for the two bands: SWIR (shortwave-infrared around 1610 nm) and NIR (near-infrared around 842 nm). This product provides orthorectified (geometric ortho-correction taking into account a DEM) Top Of Atmosphere reflectance (more details <a href="#">here</a> ). The processing to retrieve level-2 (bottom of atmosphere) and cloud masking is performed in-house using <a href="#">Sen2Cor</a> , <a href="#">fmask</a> and <a href="#">S2Cloudless</a> . Detailed information is available in the <a href="#">link</a> .
Digital elevation model	Digital elevation model (DEM) static map resampled at 100m based on the Copernicus DEM GLO-90 product covering the full global landmass of the time frame of data acquisition (2011-2015). Detailed information is available in the <a href="#">link</a> .
Land Cover map	Custom global land classification including permanent water bodies based on the Copernicus Global Surface Water Bodies product from PROBA-V. Detailed information is available in the <a href="#">link</a> .

### 3. PLANET LST PRODUCTS

The current Planet Land Surface Temperature product line is outlined in Table 2. The Planet LST products are not hindered by clouds, resulting in a consistent number of observations per year. They are available on fixed grids with a 1 km (since 2002 - with a gap from October 2011 to August 2012) and a 100 m resolution (since July 2017)<sup>1</sup>.

Table 2: Planet land Surface product line

Product key		Description
LST_100M	lst	100 m resolution Land Surface Temperature in Kelvin (K) derived from Ka band brightness temperature and Sentinel-2 reflectances available at 01.30 and 13.30..
	qf	Quality flag layer for the 100m resolution Land Surface Temperature available at 1.30 and 13.30.
LST_1KM	lst	1 km resolution Land Surface Temperature in Kelvin (K) derived from Ka band brightness temperature available at 01.30 and 13.30.
	qf	Quality flag layer for the 1km resolution Land Surface Temperature available at 01.30 and 13.30.

<sup>1</sup> Whenever 1km or 100m resolution is mentioned it refers to the actual pixel size of 0.0089 degree for the 1km data and 0.00089 degree for the 100m data, see Table 3..

### 3.1. Product specifications

Satellite observed Land Surface Temperature derived from ka band microwave data is based on the proprietary disaggregation method to increase the spatial resolution. It provides the Land Surface Temperature of the surface at 01.30 (descending orbit) and 13.30 (ascending orbit). The 100 m and 1 km specifications are described in the tables below.

Table 3: 100 m and 1 km data format specifications

Layer	100 m	1 km
Name	Land Surface Temperature 100m	Land Surface Temperature 1km
Version	1.0	1.0
Unit	Kelvin (K)	Kelvin (K)
Sensing depth	Skin temperature	Skin temperature
Pixel size	100x100 m (0.00089 degree)	1000x1000 m (0.0089 degree)
Temporal resolution	Above 50 degrees latitude: 2 obs. daily at 01:30 and 13:30.	Above 50 degrees latitude: 2 obs. daily at 01:30 and 13:30.
	At the equator: at least $\pm 180$ obs. at 01:30 and $\pm 180$ obs. at 13:30 observations annually.	At the equator: at least $\pm 180$ obs. at 01:30 and $\pm 180$ obs. at 13:30 observations annually.
Overpass time	01:30 (DESC) Local Solar Time 13:30 (ASC) Local Solar Time	01:30 (DESC) Local Solar Time 13:30 (ASC) Local Solar Time
Coverage	Global	Global
Data availability	July, 1st 2017 - Present	June, 15th 2002 - October 4th 2011 (AMSRE) July, 25th 2012 - Present (AMSR2)
Satellites used	AMSR-2, Sentinel 2	AMSR-E (June 2002 - October 2011), AMSR-2 (July 2012 - Present)
Available to user (latency)	+/- 24 hours after overpass of the AMSR2 satellite	+/- 12 hours after overpass of the AMSR2 satellite



## 3.2. Quality Flags

The quality product consists of a combination of critical flags and non-critical flags. Critical and non-critical flags are combined into one file for each product and provided each time a product is made. The critical and non-critical flags are described in Table 4 and Table 5. Critical flags indicate that data is of unusable quality for most applications. As such, for pixels covered by a critical flag, we replace the Land Surface Temperature value with a no data value. However, when retrieving our data, users can access the original data by looking at Band 2 in the supplied GeoTIFF files. All values in the flag file > 127 are critical. Non-critical flags mean that the data can be used with caution, taking into account the information given in the flag description. All values in the flag file <= 127 are non-critical.

Table 4: Non-critical data flag layers in binary system<sup>2</sup>

Bit - Flag layer		Description	Notes
4.	Possibly influenced by snow or severe rainfall	Part of the footprints touch an area flagged as severe rainfall or snow.	The critical flag snow or severe rainfall is described in table 6.
7.	Possible frozen surface	This flag indicates areas where frozen surface may occur	surface temperature < 273.15 K. (0 degC)

Table 6: Critical data flag layers in binary system

Bit - Flag layer		Description	Notes
8.	Frozen surface	This flag indicates areas where frozen surface occurs	surface temperature < 263.15 K (-10degC)
9.	Severe rainfall	This flag indicates areas where severe precipitation is detected.	No data is given for areas having severe precipitation events. This data is filtered out during the processing of the raw data.
11.	No overpass	An overpass is when the field of view of a satellite's instrument passes over.	No coverage flag is produced outside of the field of view of a satellite.
13.	Instrumental flaws	This flag indicates unrealistic values due to instrumental flaws.	If the brightness temperature at 36.5 GHz V produces values either over 400K or under 0.9 * the water temperature, the data is considered as unrealistic and is removed.
14.	Out of range	This flag indicates unrealistic values in the downscaling data	surface temperature < 250 K and > 340 K
15.	Waterbody	This flag indicates no valid LST data because of a waterbody	This static data layer is retrieved from a land cover map. This data is filtered out during the processing of the raw satellite data.

<sup>2</sup> See appendix A for a code example of how to decode the flags

### 3.3. Projection, Gridding, and Delivery

Land Surface Temperature products are delivered as gridded raster data and time series. The data is delivered through a subscription model in GeoTIFF format. The subscription model allows for automatic creation as soon as the source data is available, and provides for a HTTP webhook notification when processing is complete. Each automatic creation is called a “fulfillment”. Subscriptions allow for specifying the requested geometry.

Table 6: Raster properties of LST 100 m and LST 1 km

Raster Property	Description
Format	GeoTIFF
Pixel Size	0.00089 degree (±100 m) or 0.0089 degree (±1000 m)
Data type	uint16
NoData	65535
Offset	0
Scale	0.01
Spatial Reference	EPSG:4326
Number of bands	2
Delivery	Gridded data, time series

## 4. PLANET LAND SURFACE TEMPERATURE METHODOLOGY

### 4.1. Downscaling method

The downscaling technology<sup>3</sup> aims to improve the resolution of sensor data, in this case, the brightness temperatures observed by passive microwave sensors. The technique redefines the exact geolocation and reconstructs the antenna footprints of each observation. It uses the abundance of overlaps between these footprints for downscaling at a target resolution. Based on the footprint center, microwave frequency, incidence angle, azimuth angle, and footprint size for a given intensity, footprints are created and disaggregated in equal interval ellipses using an internal gaussian distribution. Within the ellipse-shaped footprints, the center of the footprint contributes more to the observed values than the edges. Water bodies will have a fixed value and will be considered; thus, the land brightness temperature can be retrieved more accurately. This method elucidates the exact source of the signal of each observation point. The output of the downscaling method is brightness temperature for a given frequency at the target resolution.

### 4.2. Inclusion of optical data processing (for the 100m product only)

Land Surface Temperature is also highly variable in space, mainly due to soil properties, topography, agricultural practices, and land cover heterogeneity. Space-borne optical/thermal sensors can help retrieve high-resolution surface parameters. Several studies (Lobell & Asner 2002, Fensholt and Sandholt 2003, Yue et al. 2019) found that soil and plant water content greatly influences the reflection in the shortwave infrared (SWIR) part of the spectrum. The SWIR, combined with the Near-Infrared (NIR) reflectance, which is affected by internal leaf structure and leaf dry matter content but not by water content, will enhance the LST retrieval from reflectances.

The NDSWIR is a satellite-derived index constructed from the NIR and SWIR channels. This index uses a normalized difference formulation index of wavelengths 819/1600 nm, corresponding to bands B08 and B11 for Sentinel-2 as  $(B11 - B08) / (B11 + B08)$ . The NDSWIR product is dimensionless and varies between -1 to +1. Sentinel-2 based NDSWIR composite is produced daily using a weighted backward gaussian. Subsequently the Sentinel-2 based NDSWIR composite is integrated into the downscaling framework when attributing the weight of a brightness temperature per pixel within the footprint (in addition to the 2D gaussian distribution). The output format is similar to the output of the downscaling algorithm without Sentinel-2 input. Applications using NDSWIR include agricultural crop management, forest canopy monitoring, and stress detection. But, optical observations are susceptible to clouds, atmospheric effects, and vegetation errors and thus, cannot be directly used as a Land Surface Temperature value, and instead only as a spatial proxy. Therefore, combining passive microwave signal with Normalized Difference SWIR/NIR (NDSWIR) observations into the downscaling algorithm improves the LST's spatial representation while maintaining the microwave information's temporal consistency and accuracy.

The Sentinel-2 preprocessing is performed in-house using [Sen2Cor](#), [fmask](#) and [S2Cloudless](#). Sen2Cor applies atmospheric, terrain, and cirrus correction to the L1C granule. The processing converts the input (L1C) from Top of the Atmosphere (TOA) to surface reflectances (L2). The preprocessing also produces a scene classification of four different classes for clouds (including cirrus) and six different classes for shadows, cloud shadows, vegetation, soils / deserts, water and snow. Two additional algorithms are also performed in-house: 1) Python FMASK produces a multiclass mask, which includes clouds, cloud shadow, snow (or high reflectance) and water, and 2) S2Cloudless produces a binary map which distinguishes between clouds and non clouds.

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<sup>3</sup> Patent [US10643098](#), [EP3469516B1](#) : Method and system for improving the resolution of sensor data



## 5. PRODUCTS ASSESSMENT

### 5.1. Know limitations and caveats

- **False cloud/shadow detections** may occur in certain cases: 1) if surface conditions change very rapidly, 2) during prolonged cloudiness, or 3) over AOIs with significant terrain and shadowing. Significant effort has gone into developing automated techniques to differentiate between actual change and atmospheric contamination, but in some cases commission errors can still be an issue.
- **Artifacts** may occur during periods of 1) prolonged cloudiness for the 100 m resolution product and 2) snow for both resolution products.
- Planet Land Surface Temperature is not suited for studies over **snow covered surfaces** or **sloped terrain** (> 20 degrees).
- **Dynamic water bodies** may cause wrong surface temperature estimates at the edges.

5.2. 1km product validation

Planet’s 1 km LST product was validated over 114 locations from 01-01-2013 to 31-12-2022. We used an established network of in-situ stations from the United States Climate Reference Network (USCRN) and remotely sensed LST derived from MODIS AQUA. Planet’s 1km LST, MODIS AQUA 1km LST and USCRN surface temperature were intercompared at 1:30 and 13:30, separately. The surface temperature at USCRN stations is measured over grassy or low vegetation (<10 cm) surfaces and the stations cover many climatic and landscape conditions.

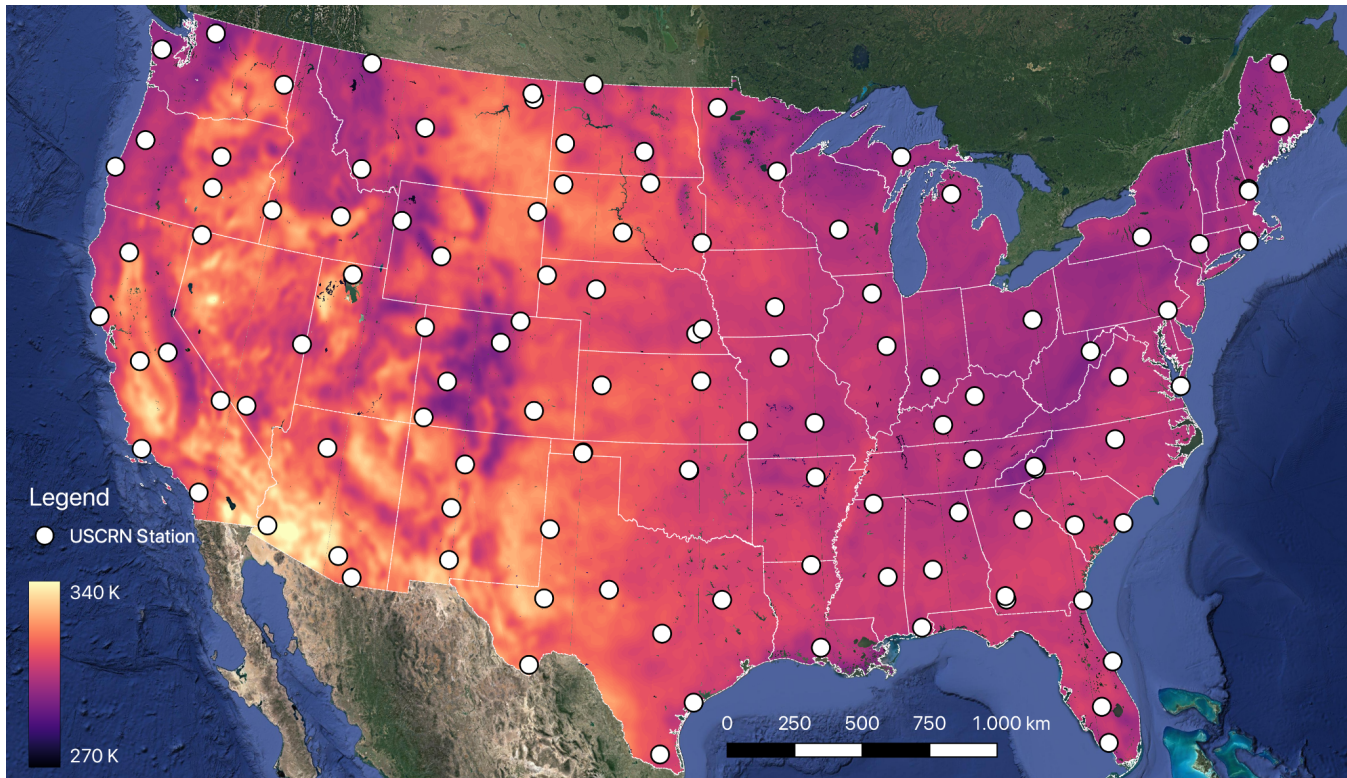


Figure 1: 1 km resolution LST derived by Planet Labs over the Continental United States, averaged over June, 2021 (ascending). The white dots display the location of the USCRN stations used for the comparison.

Planet’s 1km LST presents high correlation to the USCRN in-situ temperature and MODIS with values above 0.9 (Table 7). For both Planet LST and MODIS LST, MAE and ubRMSE values for the night time are in the expected range of 2°C to 3°C. The daytime MAE and ubRMSE values, on the other hand, are slightly higher with MODIS MAE being higher than Planet while ubRMSE is around 4.4°C for Planet and MODIS LST compared to USCRN.

Table 7. Pearson correlation (*r*), mean absolute error (MAE) and unbiased root mean square error (ubRMSE) for Planet’s 1km LST and MODIS LST observations against in-situ measurements when the three observations are available together on the same day. The statistics are based on 10 years of data and averaged over all 114 stations

	1.30 - USCRN		13.30 - USCRN	
vs	Planet	MODIS	Planet	MODIS
Number obs.	53,809		149,421	
Pearson <i>r</i>	0.95	0.93	0.93	0.93
MAE (°C)	2.73	2.36	4.42	5.33
ubRMSE (°C)	2.51	2.61	4.37	4.44



5.3. 100m product validation

A spatial analysis was performed by comparing Planet’s 100m LST with Landsat LST. The revisit time of Landsat is low with one observation every 8 days at best, since TIR-based LST is sensitive to cloud cover.. Therefore, three dates for three regions (Nebraska, Germany, Brazil) were selected with fully clear-sky conditions. The overpass time of Landsat is between 10:00 and 10:25 while Planet LST daytime is at 13:30. Despite the mismatch in observation time, it is still possible to compare both products with each other, assuming there will be a possible bias between both observations.

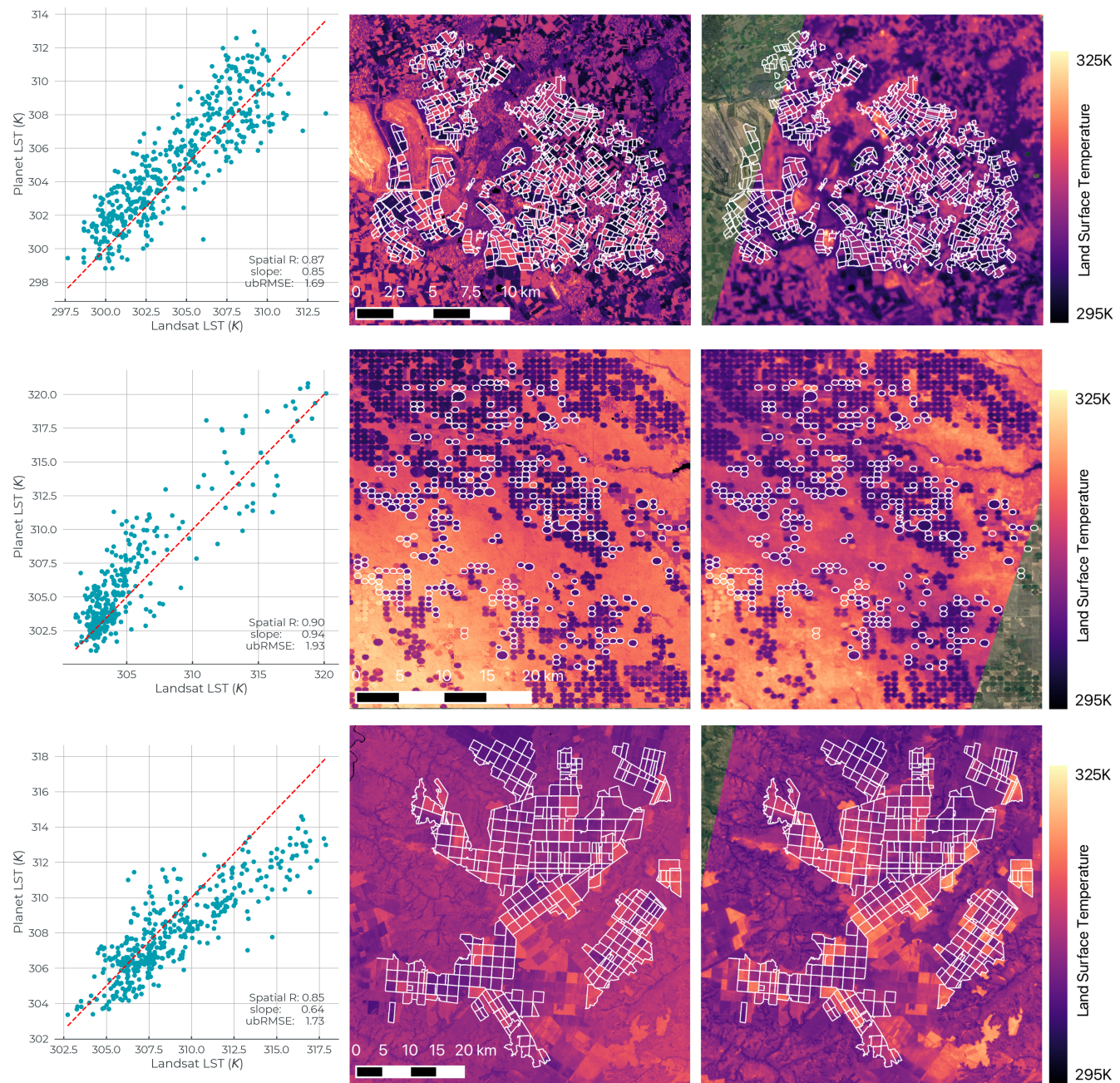


Figure X



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# Appendix A: Decoding bitmap flags using python

The example python code below shows how to decode the flags used in the QF layer.

Python

```
flagstr = [
    '1. Not used for LST',
    '2. Not used for LST',
    '3. Not used for LST',
    '4. Possibly influenced by Snow or severe rainfall',
    '5. Possibly influenced by RFI',
    '6. Not used for LST',
    '7. Possible frozen soil',
    '8. Frozen Soil',
    '9. Snow or severe rainfall',
    '10. Not used for LST',
    '11. No overpass',
    '12. Not used for LST',
    '13. Instrument flaw',
    '14. Out of valid range',
    '15. Open water/Water body',
    '16. Not used for LST',
]

numbers = [12,64,128,141,32768]
for number in numbers:
    pos = 15
    flags= format(number, '016b')
    print("=====")
    print("Decimal number: " + str(number))
    print("Binary string: " + flags)
    print("----- Flags set -----")
    for fl in flags:
        if fl == '1':
            print(flagstr[pos])
        pos = pos - 1
    print("=====\\n")
```