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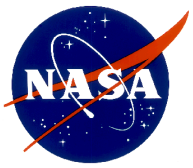

Surface Biology and Geology (SBG)
Observing Terrestrial Thermal Emission Radiometer (OTTER)

Low Latency Products
Algorithm Theoretical Basis Document

SBG-TIR Science Team
Jet Propulsion Laboratory
California Institute of Technology

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List of Acronyms

ASI	Agenzia Spaziale Italiana
ATBD	Algorithm Theoretical Basis Document
Cal/Val	Calibration and Validation
CONUS	Contiguous United States
DAAC	Data Active Archive Center
ET	Evapotranspiration
ETF	Elevated Temperature Features
GEOS	Goddard Earth Observing System
GMAO	Global Modeling and Assimilation Office
GFS	Global Forecast System
HyspIRI	Hyperspectral Infrared Imager
JPL	Jet Propulsion Laboratory
L-1	Level 1
L-2	Level 2
L-3	Level 3
LE	Latent heat flux
LSTE	Land Surface Temperature and Emissivity
MERRA	Modern Era Retrospective-Analysis for Research and Applications
MODIS	MODerate-resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
OTTER	Observing Terrestrial Thermal Emission Radiometer
PT-JPL	Priestley-Taylor Jet Propulsion Laboratory
RAS	Radiance at sensor
SEBS	Surface Energy Balance System
STIC	Surface Temperature Initiated Closure
TIR	Thermal Infrared
VA	Volcanic Activity
VNIR	Visible Near Infrared
WUE	Water Use Efficiency

Contents

1 Introduction

1.1 Purpose

Low latency data products are one of the main science application deliverables of the Surface Geology and Biology (SBG) mission. The low latency products are available within 24 hours of satellite observation. Low latency (<24 hours) is needed for delivering data and information to decision-makers at timescales which are useful for response [*Lee et al., 2022*]. Standard products, in comparison, will be produced at a latency of 72 hours. Low latency products are useful for both water management (evapotranspiration), as well as for hazard response including active wildfires, volcanoes and detecting oil spills [*Cawse-Nicholson et al., 2021*].

Thermal infrared (TIR) low latency products include L-1B radiance, L-2 surface temperature and emissivity (LSTE), L-2 cloud mask, L-3 elevated temperature features (ETF), and L-3 evapotranspiration (ET) (Table 1). In order to generate products within 24 hours of observation time, a number of changes have been made to the standard processing to expedite availability of ancillary data sets. As such, they in some instances will require different ancillary data products and inputs to the standard products (standard products are described in detail in the L-1, L-2, L-3 Algorithm Theoretical Basis Documents (ATBDs)). In this ATBD, we describe the low latency products, highlighting how these products differ in their algorithms, inputs and requirements from the standard products. And we discuss the approach taken to resolve these products globally with necessary ancillary data products.

If data latency is not a primary concern, users are encouraged to use the standard data products, which are created using the best available ancillary data and subject to validation studies. The standard products, their algorithms and validation are described in corresponding SBG TIR ATBDs. Low latency products will be archived for a minimum of 7-days (maximum of 14-days), while standard products will go into long-term archive at the Distributed Active Archive Center (DAAC).

Table 1-1 Overview of low latency products from SBG TIR. ** These products will also be delivered as Cloud Optimized GeoTiff (COG). Definitions: Yes (Y), No (N), Day (D), Night (N), Cloud Optimized GeoTIFF (COG), network Common Data Form (netCDF).

Product Name	Joint product	Product Level	Tiled	Requires TIR and VNIR	Day/Night
Swath Top of Atmosphere TIR Calibrated Radiance Instantaneous L1 Global 60 m**	N	L1	Y	N	D and N
Tiled Surface Temperature and Emissivity **Low Latency** Instantaneous L2 Global 60 m	N	L2	Y	N	D and N
Tiled Cloud Mask **Low Latency** Instantaneous L2 Global 60 m	N	L2	Y	N	D and N
Tiled High Temperature Features **Low Latency** Instantaneous L3 Global 60 m	N	L3	Y	N	D and N
Tiled ET **Low Latency** Instantaneous L3 Global 60 m	N	L3	Y	N (uses LL STARS)	D only

1.2 Scope and Objectives

In this ATBD, we provide:

1. Description of the low latency products, and how they differ from the standard products (algorithms and requirements);
2. Required algorithm-specific adaptations specific to the low latency products from standard products;
3. Required Ancillary data products with potential sources and back-up sources;
4. Plan for the calibration and validation (Cal/Val) of the low latency products, or sensitivity analysis of low latency product accuracy against standard products.

2 Parameter Description and Requirements

Attributes of the low latency data produced by the SBG mission include:

- Spatial resolution of 60 m x 60 m;
- 3-day revisit time.
- Latency as required by the low latency product requirements (less than 24 hours);
- Includes all geographic terrestrial regions visible by the SBG instrument.
- Archived minimum 7-days (maximum 14).

3 L-1 Radiance at Sensor (RAS)

For a detailed description of the standard L-1 radiance products, please refer to the L-1 ATBD [*SBG TIR Level-1 Radiometric Calibration Algorithm Theoretical Basis Document*]. Low Latency products will be processed using separate production line than that of the standard products which rely on Agenzia Spaziale Italiana (ASI) and Jet Propulsion Laboratory (JPL) production lines (Figure 1-1). Low Latency products therefore will not include integrated VNIR and TIR spectral bands or metadata, will differ slightly from the subsequent Standard products, and may not be archived after serving their short-term purposes. Differences between SBG-TIR Level 1 standard products and low latency products data flows are shown in Figures 1-1 to 1-2.

Figure 1-1: SBG-TIR L-1 Standard Products Data Flow

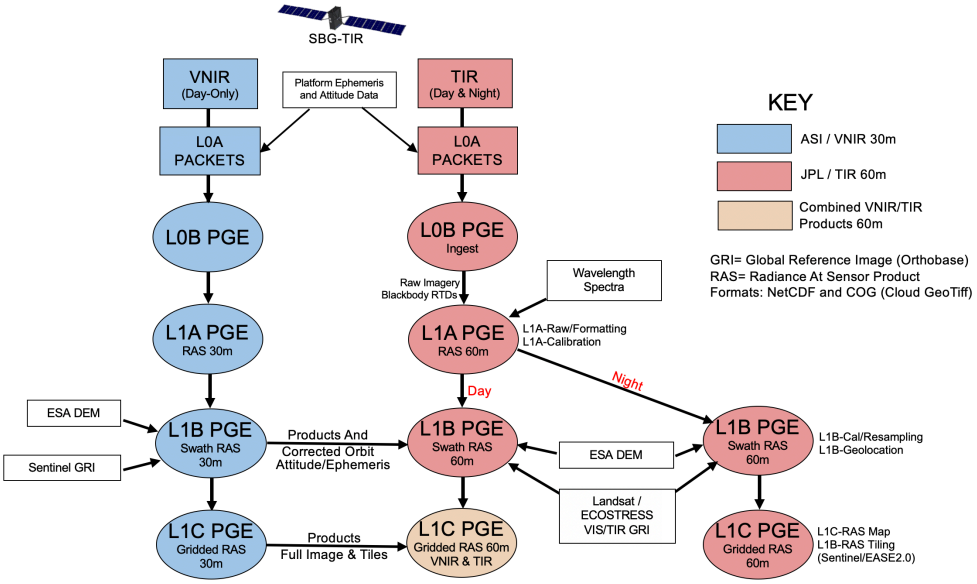


Figure 1-2: SBG-TIR L-l 1 Low Latency Products Data Flow

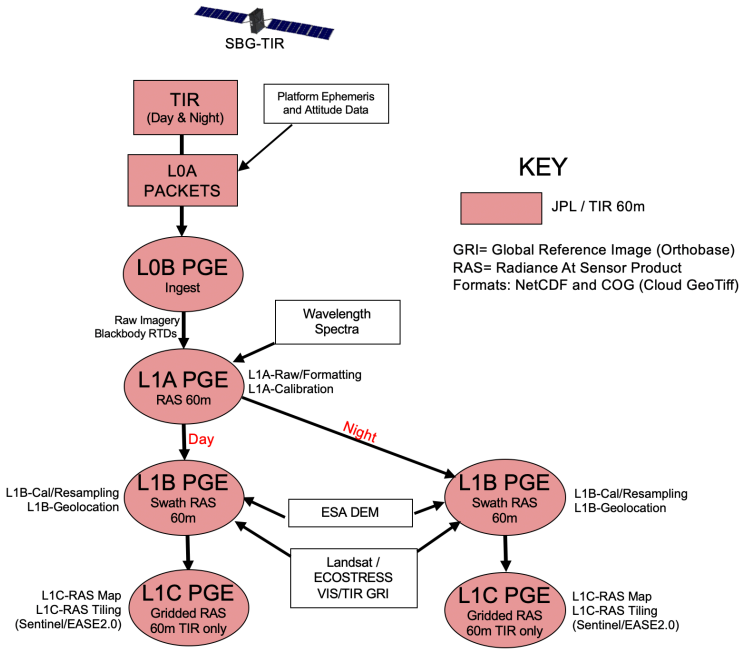


Table 1-2 provides a summary of interplay between Standard and Low Latency products and Day versus Night processing. In addition, the following comments are provided for clarification:

- **L1B does not contain VNIR products.**
- L1C Standard Daytime products contain VNIR data (Not L1C Night or Low Latency products).
- L1B contains (and L1C inherits) orbital correction metadata from ASI for Standard Daytime products, but not for Night or Low Latency products.
- JPL 60m TIR (and TIR/VNIR) products use the Landsat/ECOSTRESS TIR Global Reference Grid (GRI) orthobase. ASI 30m VNIR products use the Sentinel VNIR grid.

Table 1-2: L-1 Standard and Low Latency Product Comparison. Definitions: Yes (Y), No (N), Day (D), Night (N), Cloud Optimized GeoTIFF (COG), network Common Data Form (netCDF).

Product	Coverage	Resol (m)	Joint	Level	Gridded	Requires TIR and VNIR	Day/Night	Format
Standard Products								
L1B_RAD Radiance at Sensor	Global	60	N	L1B	N (Swath)	N	D and N	NetCDF
L1B Geolocation	Global	60	N	L1B	N (Swath)	N	D and N	NetCDF
L1C Radiance at sensor (rectified)	Global	60	Y	L1C	Y	Y	TIR: D and N VNIR: D only	COG
Low Latency Products								
L1B_RAD Radiance at Sensor	Global	60	N	L1B	N (Swath)	N	D and N	NetCDF
L1B Geolocation	Global	60	N	L1B	N (Swath)	N	D and N	NetCDF
L1C Radiance at Sensor (rectified)	Global	60	N	L1C	Y	N	TIR: D and N VNIR: None	COG

4 L-2 Land Surface Temperature and Emissivity (LSTE)

Table 1-3: L-2 Standard and Low Latency Product Comparison. Definitions: Yes (Y), No (N), Day (D), Night (N), Cloud Optimized GeoTIFF (COG), network Common Data Form (netCDF).

Products	Coverage	Resolution (m)	Joint	Gridded	Requires TIR and VNIR	Day/Night	Format
Standard Products							
L2 Surface Temperature and Emissivity	Global	60	Y	Y + N	Y	D and N	NetCDF + COG
L2 Cloud Mask	Global	60	Y	Y + N	Y	D and N	COG
Low Latency Products							
L2 Surface Temperature and Emissivity Instantaneous	Global	60	N	Y	N	D and N	NetCDF + COG
L2 Cloud Mask Instantaneous	Global	60	N	Y + N	N	D and N	NetCDF + COG

For a detailed description of the standard L-2 Land Surface Temperature and Emissivity (LSTE) products, please refer to the L-2 Land Surface Temperature and Emissivity ATBD [*SBG TIR Level-2 Land Surface Temperature and Emissivity Algorithm Theoretical Basis Document*]. Table 1-3 provides a summary of interplay between Standard and Low Latency products. In addition, the following sections are provided for clarification.

4.1 L-2 Low Latency LSTE Algorithm Inputs

- Low latency L-2 LSTE uses low latency L-1 products inputs to produce the L-2 product.
- GEOS5 atmospheric data from forecast is used for the low latency product.
- If meteorology is not available from GEOS5-FP for within the period necessary to produce low latency products (< 24 hours), the National Oceanic and Atmospheric Administration (NOAA) Global Forecast System (GFS) data is used.
    - We will use the previous day's forecast of the present day/hour of the scene's acquisition (therefore using meteorological data from 24 hours previously).

5 L-3 Evapotranspiration (ET)

Table 1-4: L-3 Standard and Low Latency Product Comparison. Definitions: Yes (Y), No (N), Day (D), Night (N), Cloud Optimized GeoTIFF (COG), network Common Data Form (netCDF).

Products	Coverage	Resolution (m)	Joint	Gridded	Requires TIR and VNIR	Day/Night	Format
Standard Products							
L3 ET daily	Global	60	Y	Y	Y	D	COG
Low Latency Products							
L3 ET daily	Global	60	N	Y	N (uses previous 3-day NDVI)	D	COG

For a detailed description of the L-3 Evapotranspiration (ET) product, please refer to the L-3 Evapotranspiration ATBD [*SBG TIR Level-3 Evapotranspiration Algorithm Theoretical Basis Document*]]. Table 1-4 provides a summary of interplay between Standard and Low Latency products. ET daily (millimeters per day) will be produced as the low latency product for L-3 ET. The following sections are provided for clarification on differences between standard and low latency products, and in the flow charts Fig. 1-3.

5.1 L-3 ET Model selection and uncertainty

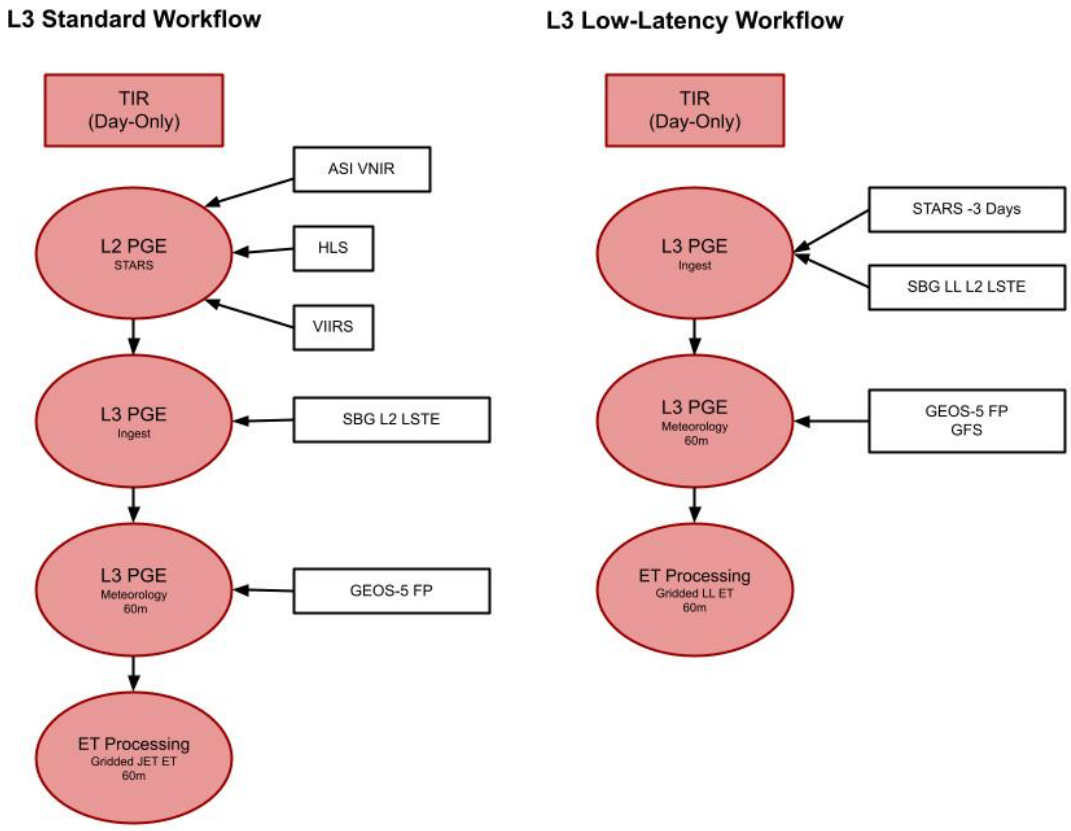
- Low latency ET is produced using one ET model (rather than the ensemble ET models used in the standard L-3 ET JET ensemble– Surface Temperature Initiated Closure (STIC), Priestley-Taylor-JPL updated with soilmoisture (PT-JPL_SM), Moderate Resolution Imaging Spectroradiometer (MODIS) Global Evapotranspiration Model (MOD16), Breathing Earth System Simulator (BESS) model).
    - For low latency, ET is produced using a single model which will be chosen from the current suite of ECOSTRESS Collection-2 models (STIC, PT-JPL_SM, MOD16, BESS). The selection wil lbe based on the results of a global validation study using eddy covariance in situ data, and will identify the best performing model (highest overall accuracy) [*Purdy et al., in prep*].

    - The selected ET model will also be selected based on its required ancillary inputs, and which will be most readily available compared to other ET models, and can therefore be produced in shortest possible time.
- In addition, ET uncertainty is not produced for low latency product (unlike the standard product, which uses an ensemble of the L-3 JET ET ensemble for ET uncertainty).
- Low latency ET is not produced for the DisALEXI-JPL algorithm.

5.2 L-3 ET Low Latency Algorithm Inputs

- For low latency products, the low latency version of the L2 LSTE is used as an input into calculating the low latency Level 3 ET product (see low latency L2 LSTE section above) (**Fig. 1-3, 1-4**).
- For low latency products, NDVI is not concurrently available, and instead 3-day old NDVI is used (produced from the STARS fusion algorithm from 3-days prior).
- For low latency products, meteorology will be taken from GEOS5-FP. If this is not available within a suitable timeframe for data processing, we will use meteorology as used for processing of low latency L2 LSTE:
    - We will use the NOAA GFS data.
    - We will use the previous day's forecast of the present day/hour of the scene's acquisition (therefore using meteorological data from 24 hours previously).

Figure 1-3: SBG-TIR Level 3 Standard and Low-Latency Products Data Flow



5.3 Error budget of low latency ET:

L-3 ET uncertainty arises from 1) instrument error, 2) model uncertainty, and 3) uncertainty of ancillary inputs. In addition, the L-3 low latency ET error budget includes additional uncertainty from 4) L-2 low latency LSTE estimate, and 5) uncertainty of ancillary inputs (which will include 3-day old NDVI and albedo). The uncertainty from 5) 3-day old ancillary inputs is difficult to quantify, but can result in large differences arising from land cover use change (for example, cultivation of an agricultural field).

The SBG ET products will target an error value of 1 mm per day with an estimated 0.1 mm of this attributed to instrument error. This target is consistent with established literature and validation work on the related PT-JPL ET, DisALEXI-JPL ET, MOD16 and MYD16 ET products in recent years. Fisher et al. (2019) found that the RMSE of PT-JPL instantaneous ET was 6%, with R^2 = 0.88, (overall RMSE was 41.3 W/m2 compared to a mean of 182.0 W/m2 and a range of 713.8 W/m2). An examination of the error propagation of PT-JPL ET from

Halverson et al. finds that ET products exhibited strong responses to changes in vegetation and temperature; consistent with previous findings on DisALEXI-JPL ET which established that LST error within 1K enables ET estimates to be accurate to within 1mm/day (Cawse-Nicholson et al., 2020). In 2021, Cawse-Nicholson et. al, evaluated DisALEXI-JPL daily ET and found an RMSE of 0.81 mm/day. Mu et al. found that MOD16 and MYD16 exhibited an RMSE of 0.84 mm/day.

6 L-3 Elevated Temperature Features (ETF)

Table 1-5: L-3 Standard and Low Latency Product Comparison. Definitions: Yes (Y), No (N), Day (D), Night (N), Cloud Optimized GeoTIFF (COG), network Common Data Form (netCDF).

Products	**Coverage**	**Resolution (m)**	**Joint**	**Gridded**	**Requires TIR and VNIR**	**Day/Night**	**Format**
Standard Products							
L-3 Geology Suite	Land	60	Y	Y	Y	D and N	COG
Low Latency Products							
L-3 Elevated Temperature Features Instantaneous	Global	60	N	Y + N	N	D and N	COG

For a detailed description of the L-3 Geology Suite products, please refer to the L-3 Geology Products ATBD [*SBG TIR L-3 Elevated Temperature Features Algorithm Theoretical Basis Document*]]. Table 1-5 provides a summary of interplay between Standard and Low Latency products. Below, the following comments are provided for clarification for the differences between standard and low latency products:

- Planned to operate on Top of Atmosphere LL radiance product (no atmospheric correction required)
- Algorithm will produce an ETF detection layer and Brightness Temperature layer
- Being designed to operate on a reduced number of bands (e.g., 3.98, 11.35, 12 μm)
- Likely will be a simplified statistical threshold approach rather than the more time-intensive machine learning approach being tested for the standard ETF product

7 L-4 Volcanic Activity (VA)

The Volcanic Activity (VA) product is only applied to a 50 km subset of the Observing Terrestrial Thermal Emission Radiometer (OTTER) data centered on each of the world's active and potentially active volcanoes (~1500 sites) [*SBG TIR L-4 Volcanic Activity Algorithm Theoretical Basis Document]*. A low latency VA product will be produced: unlike the full L4 product, the LL-VA will operate on the radiance-at-sensor data and only produce the decorrelation-stretch (DCS) and two index maps (ash and SO_2) over targets with a positive detection. Without atmospheric correction, the uncertainty is expected to be higher.

Products	**Coverage**	**Resolution (m)**	**Joint**	**Gridded**	**Requires TIR and VNIR**	**Day/Night**	**Format**
Standard Products							
L-4 Volcanic Activity Suite	Active Volcanoes	60	Y	Y	Y	D and N	COG
Low Latency Products							
L-4 DCS, SO_2	Active Volcanoes	60	N	Y + N	N	D and N	COG

8 Metadata

- unit of measurement: Watts per square meter (W m^{-2})
- range of measurement: 0 to 3000 W m^{-2}
- projection: Sentinel Tile
- spatial resolution: 60 m x 60 m
- temporal resolution: every 3-days
- spatial extent: all land globally, excluding poleward ±60°
- start date time: near real-time
- end data time: near real-time
- number of bands: not applicable
- data type: float
- min value: 0
- max value: 3000
- no data value: 9999
- bad data values: 9999
- flags: quality level 1-4 (best to worst)

9 Acknowledgements

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10 References

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