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Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Land Surface Temperature (LST) EDR

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Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Land Surface Temperature (LST) EDR

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Preface

This document is under JPSS Ground AERB configuration control. Once this document is approved, JPSS approved changes are handled in accordance with Class I and Class II change control requirements as described in the JPSS Configuration Management Procedures, and changes to this document shall be made by complete revision.

Any questions should be addressed to:

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Change History Log

Revision	Effective Date	**Description of Changes** (Reference the CCR & CCB/ERB Approve Date)
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Rev B
Date: 19 May 2010
Subcontract No: 7600002744

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

OPERATIONAL ALGORITHM DESCRIPTION DOCUMENT FOR VIIRS LAND SURFACE TEMPERATURE (LST) EDR

SDRL No. S141
SYSTEM SPECIFICATION SS22-0096

RAYTHEON COMPANY
INTELLIGENCE AND INFORMATION SYSTEMS (IIS)
NPOESS PROGRAM
OMAHA, NEBRASKA

IAW DFAR 252.227-7036, Raytheon hereby declares that, to the best of its knowledge and belief, the technical data delivered under Subcontract No. 7600002744 is complete, accurate, and complies with all requirements of the Subcontract.

TITLE: NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS) OPERATIONAL ALGORITHM DESCRIPTION DOCUMENT FOR VIIRS LAND SURFACE TEMPERATURE

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Operational Algorithm Description VIIRS Land Surface Temperature (LST) EDR

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Under
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This document has been identified per the NPOESS Common Data Format Control Book – External Volume 5 Metadata, D34862-05, Appendix B as a document to be provided to the NOAA Comprehensive Large Array-data Stewardship System (CLASS) via the delivery of NPOESS Document Release Packages to CLASS.

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Revision/Change Record

Document Number D38714

Revision	Document Date	Revision/Change Description	Pages Affected
---	3-30-04	Initial Release.	All
A1	2-22-05	Reflects Science To Operational Code Conversion.	Pg 2
A2	8-31-05	Minor Edits On-Going. Implemented TM NP-EMD.2004.510.0047 in B1.3.	All
A3	7-27-07	Updated to match ops code.	All
A4	8-2-07	TMs NP-EMD-2006.510.0081, NP-EMD.2005.510.0132, NP-EMD.2005.510.0133, and NP-EMD.2006.510.0010 have been implemented in B1.5. Delivered to NGST.	All
A5	12-10-07	ECR A-103, EDRPR 1.8 CP 3 updates -Format changes for CDFCB-X compliance - Remove LST Granule Level QF Output and Description.	All
A6	9-12-08	Reformatted document to implement template D41851 format. Modified graceful degradation and data quality notification sections. New cover sheet, update references, acronym list, prepare for peer review. Delivered to NGST.	All
A7	9-15-08	Implemented TM NP-EMD-2008.510.0021	8, 12, 13
A8	12-9-08	Addressed NGST comments from last delivery.	All
A9	2-18-09	Added Thin Cirrus quality flag to Quality Byte 0 (PCR019663) Updated for TIM	Tables 6, 8, & 9 All
A	3-18-09	Incorporated TIM comments and final preparation for ARB/ACCB.	All
B1	11-04-09	Incorporated RFA No. 376 and updated for SDRL	All
B2	3-3-10	NP-EMD.2009.510.0077_LST_v4.15.1_OAD_Updates-RevB.DOC	All
B	5-19-10	Prepared for TIM/ARB/ACCB	All

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1.0 INTRODUCTION

1.1 Objective

The purpose of the Operational Algorithm Description (OAD) document is to express, in computer-science terms, the remote sensing algorithms that produce the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) end-user data products. These products are individually known as Raw Data Records (RDRs), Temperature Data Records (TDRs), Sensor Data Records (SDRs) and Environmental Data Records (EDRs). In addition, any Intermediate Products (IPs) produced in the process are also described in the OAD.

The science basis of an algorithm is described in a corresponding Algorithm Theoretical Basis Document (ATBD). The OAD provides a software description of that science as implemented in the operational ground system -- the Data Processing Element (DPE).

The purpose of an OAD is two-fold:

1. Provide initial implementation design guidance to the operational software developer.
2. Capture the “as-built” operational implementation of the algorithm reflecting any changes needed to meet operational performance/design requirements.

An individual OAD document describes one or more algorithms used in the production of one or more data products. There is a general, but not strict, one-to-one correspondence between OAD and ATBD documents.

1.2 Scope

The scope of this document is limited to the description of the core operational algorithm required to create the VIIRS Land Surface Temperature (LST) EDR. The theoretical basis for this algorithm is described in Section 3.3 of Land Surface Temperature (LST) Visible/Infrared Imager/Radiometer Suite (VIIRS) Algorithm Theoretical Basis Document (ATBD), D43756.

1.3 References

1.3.1 Document References

The science and system engineering documents relevant to the algorithms described in this OAD are listed in Table 1.

Table 1. Reference Documents

Document Title	Document Number/Revision	Revision Date
Land Surface Temperature: Visible/Infrared Imager/Radiometer Suite Algorithm Theoretical Basis Document	D43756 Rev. B	18 Feb 2009
VIIRS Radiometric Calibration Algorithm Theoretical Basis Document	D43777 Rev. B	26 Mar 2008
VIIRS Surface Temperature Module Level Software Architecture	Y2473 Ver. 5 Rev. 12	30 July 2004
VIIRS Surface Temperature Module-Level Interface Control Document	Y3281 Ver. 5 Rev. 4	Dec 2003
VIIRS Surface Temperature Module Level Data Dictionary	Y0011652 Ver. 5 Rev. 3	Dec 2003

Document Title	Document Number/Revision	Revision Date
VIIRS Land Surface Temperature Unit Level Detailed Design	Y2502 Ver. 5.1 Rev. 5	25 June 2004
VIIRS Radiometric Calibration Unit Level Detailed Design	Y2490 Ver. 5 Rev. 4	30 Sep 2004
Operational Algorithm Description Document for VIIRS Cloud Mask (VCM) Intermediate Product (IP)	D36816 Rev. A11	17 Oct 2008
Operational Algorithm Description Document for VIIRS Aerosol Products (AOT, APSP & SM) IP/EDR	D39292 Rev. B1	18 Mar 2009
Operational Algorithm Description Document for Common Geolocation	D41869 Rev. A7	17 Sep 2008
Operational Algorithm Description Document for VIIRS Geolocation (GEO) Sensor Data Record (SDR) and Calibration (CAL) SDR	D41868 Rev. A15	12 Nov 2008
Operational Algorithm Description Document for VIIRS Surface Type (STYP) EDR	D38696 Rev. A	29 Oct 2008
NPP EDR Production Report	D37005 Rev. D	11 Feb 2009
EDR Interdependency Report	D36385 Rev. E	28 Jan 2009
NPP Mission Data Format Control Book (MDFCB)	D48190-01 Rev. B	03 Sep 2009
CDFCB-X Volume I - Overview	D48190-01 Rev F	08 Dec 2009
CDFCB-X Volume II – RDR Formats	D34862-01 Rev. D	03 Jun 2009
CDFCB-X Volume III – SDR/TDR Formats	D34862-02 Rev. E	09 Dec 2009
CDFCB-X Volume IV Part 1 – IP/ARP/GEO Formats	D34862-03 Rev. E	09 Dec 2009
CDFCB-X Volume IV Part 2 – Atmospheric, Clouds, and Imagery EDRs	D34862-04-01 Rev. E	09 Dec 2009
CDFCB-X Volume IV Part 3 – Land and Ocean/Water EDRs	D34862-04-02 Rev. E	09 Dec 2009
CDFCB-X Volume IV Part 4 – Earth Radiation Budget EDRs	D34862-04-03 Rev. E	09 Dec 2009
CDFCB-X Volume V - Metadata	D34862-04-04 Rev. F	09 Dec 2009
CDFCB-X Volume VI – Ancillary Data, Auxiliary Data, Reports, and Messages	D34862-05 Rev. H	09 Dec 2009
CDFCB-X Volume VII – NPOESS Downlink Formats	D34862-06 Rev. C	08 Dec 2009
CDFCB-X Volume VIII – Look Up Table Formats	D34862-07-01 Rev. C	09 Dec 2009
NPP Command and Telemetry (C&T) Handbook	D568423 Rev. C	30 Sep 2008
Data Processor Inter-subsystem Interface Control Document (DPIS ICD)	D35850 Rev. Y	03 Feb 10
Processing SI Common IO Design Document	DD60822-IDP-011 Rev. A	21 June 2007
D35836_G_NPOESS_Glossary	D35836 Rev. G	10 Sep 2008
D35838_G_NPOESS_Acronyms	D35838 Rev. G	10 Sep 2008
NGST/SE technical memo – LST OAD Update	NP-EMD.2004.510.0047	19 Nov 2004
NGST/SE technical memo – NPP_VIIRS_IST_LST_STIP_BugsFix	NP-EMD-2006.510.0081	31 Oct 2006
NGST/SE technical memo – LST OAD Update_Drop2.5.2	NP-EMD.2005.510.0132	21 Oct 2005
NGST/SE technical memo – LST_Drop2.5.2_UT	NP-EMD.2005.510.0133	21 Oct 2005
NGST/SE technical memo – NPP_VIIRS_LST_QFFillValues_SPCR_ALG979	NP-EMD.2006.510.0010	30 Jan 2006
NGST/SE technical memo – VIIRS LST Quality Flags Update	NP-EMD.2008.510.0021	15 Apr 2008
IDFCB Volume III - Retained Intermediate Product Formats	D36953-03 REV. C	15 Jan 2009
NGAS/A&DP technical memo – LST_v4.15.1_Code_Updates-RevA.DOC	NP-EMD.2009.510.0076	15Dec2009
NGAS/A&DP technical memo –	NP-EMD.2009.510.0077	23Dec2009

Document Title	Document Number/Revision	Revision Date
LST_v4.15.1_OAD_Updates-RevB.DOC		

1.3.2 Source Code References

The science and operational code and associated documentation relevant to the algorithms described in this OAD are listed in Table 2.

Table 2. Source Code References

Document Title	Reference Tag/Revision	Revision Date
VIIRS LST Science-grade Software	2.01	Jan 2006
VIIRS LST Operational Software	B1.5 (OAD Rev A4)	July 2007
NGST/SE technical memo – NPP_VIIRS_IST_LST_STIP_BugsFix	NP-EMD-2006.510.0081	31 Oct 2006
NGST/SE technical memo – LST_Drop2.5.2_UT	NP-EMD.2005.510.0133	21 Oct 2005
NGST/SE technical memo – NPP_VIIRS_LST_QFFillValues_SPCR_ALG979	NP-EMD.2006.510.0010	30 Jan 2006
NGST/SE technical memo – VIIRS LST Quality Flags Update	NP-EMD.2008.510.0021	15 Apr 2008
VIIRS LST Operational Software	Build 1.5.x.1-L (PCR019663) (OAD Rev A9)	18 Feb 2009
ACCB (no code update)	OAD Rev A	18 Mar 2009
SDRL (no code update)	OAD Rev B1	04 Nov 2009
NGAS/A&DP technical memos – LST_v4.15.1_Code_Updates-RevA.DOC NP-EMD.2009.510.0076 (PCR 022280) LST_v4.15.1_OAD_Updates-RevB.DOC NP-EMD.2009.510.0077 (PCR 022281)	Sensor Characterization (Build SC-8) (OAD Rev B2)	02 Mar 2010
ACCB	OAD Rev B	19 May 2010

2.0 ALGORITHM OVERVIEW

The purpose of the LST Module is to retrieve the LST for each cloud-free land pixel at VIIRS moderate-resolution. Brightness temperature data from the VIIRS SDR, VIIRS Aerosol Optical Thickness (AOT) Intermediate Product (IP), VIIRS Cloud Mask (VCM) IP, and VIIRS Surface Type (STYP) EDR are used to decide whether the pixel is processed and whether a 4-band dual split-window baseline algorithm or a 2-band split-window fallback algorithm is used. The 2-band split window algorithm may be optioned (run time switch) to supersede the dual split-window algorithm as the baseline algorithm. LST is retrieved using a regression equation with separate coefficients for each of the 17 International Geosphere-Biosphere Program (IGBP) land cover types. Moderate resolution pixel level LST in Kelvin and the associated 3-byte LST quality information are written to the VIIRS LST EDR. The LST Processing Chain is shown in Figure 1.

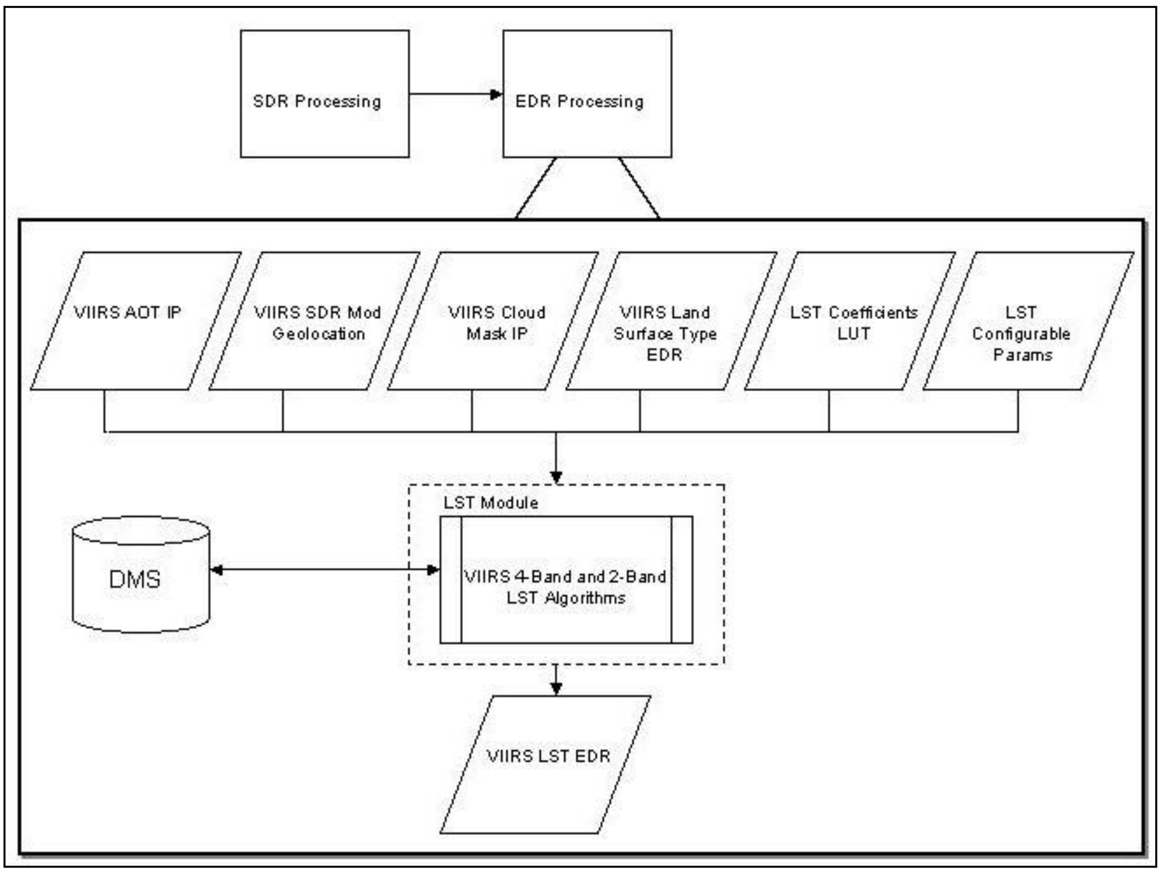

Figure 1. LST Processing Chain

2.1 Land Surface Temperature EDR Description

The VIIRS LST ATBD, D43756, describes in detail the VIIRS LST retrieval algorithm.

2.1.1 Interfaces

To begin data processing, the Infrastructure (INF) Subsystem Software Item (SI) initiates the LST algorithm. The INF SI provides tasking information to the algorithm indicating which granule to process. The Data Management Subsystem (DMS) SI provides data storage and retrieval capability. A library of C++ classes implements the SI interfaces, depicted in Figure 2.

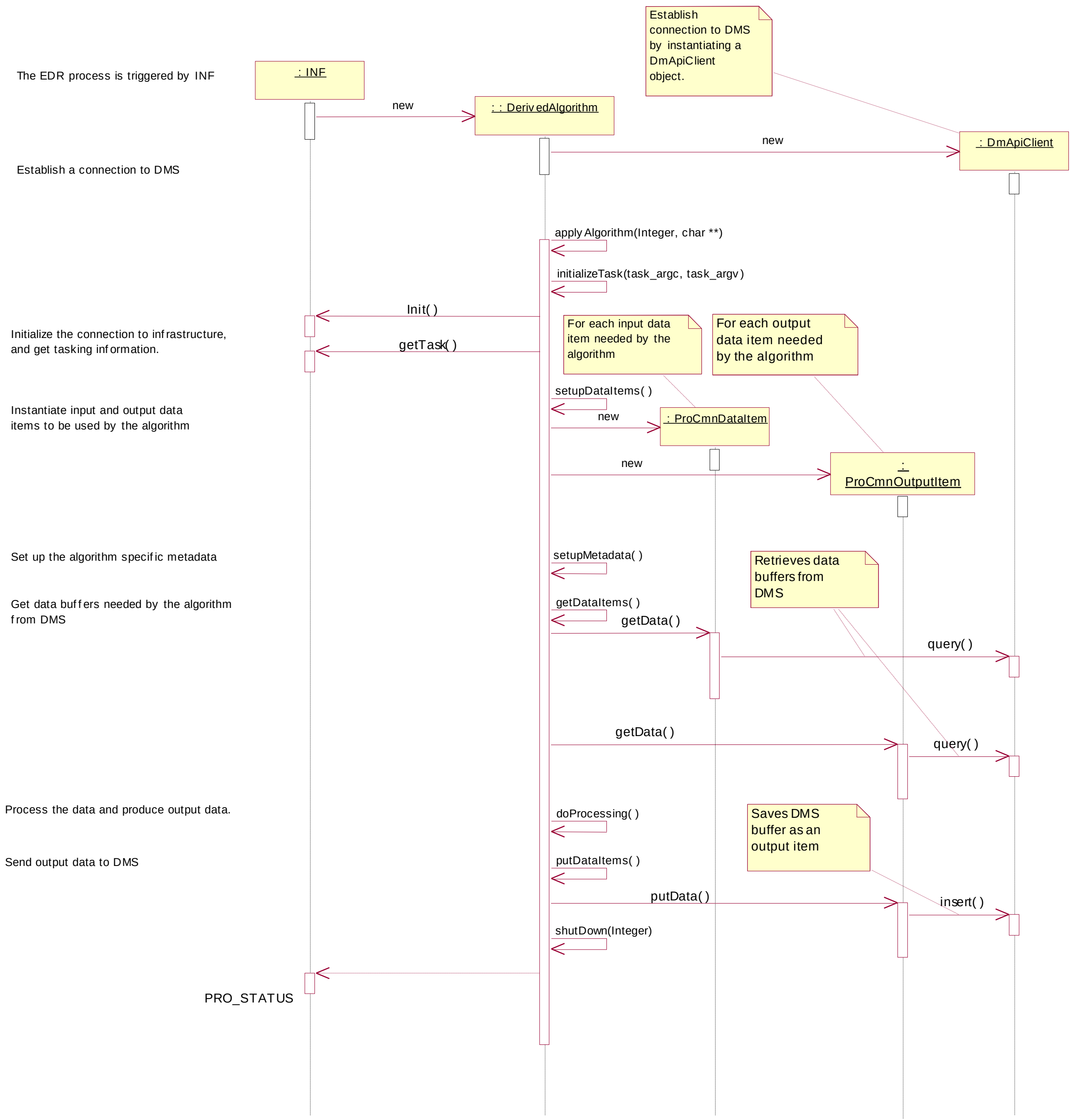

Figure 2. IPO Model Interface to INF and DMS

2.1.1.1 Inputs

Refer to the CDFCB-X, D34862, for a detailed description of the inputs. For the AOT parameter format, refer directly to Volume III of the IDFCB, D36953. All temperatures are expressed in Kelvin (K) units. Table 3 shows the LST main inputs and Table 4 shows the LST EDR Auxiliary / Ancillary data inputs.

Table 3. LST Main Inputs

Input	Type	Description	Units/Valid Range
BT_M12	Float32	Brightness Temperature of Band M12	K / Please refer to VIIRS Radiometric Calibration ATBD
BT_M13	Float32	Brightness Temperature of Band M13	K / Please refer to VIIRS Radiometric Calibration ATBD
BT_M15	Float32	Brightness Temperature of Band M15	K / Please refer to VIIRS Radiometric Calibration ATBD
BT_M16	Float32	Brightness Temperature of Band M16	K / Please refer to VIIRS Radiometric Calibration ATBD
VIIRS SDR MOD geolocation Data	Float32	VIIRS SDR MOD geolocation structure / -Sensor Zenith Angle -Solar Zenith Angle	Sensor Zenith Angle degree / $0^o \leq$ SenZenAngle $\leq 71.62^o$
			Solar Zenith Angle degree / $0^o \leq$ SolZenAngle $\leq 180^o$
VIIRS Cloud Mask IP	Uint8	VIIRS_CLOUD_MASK_IP_TYPE Land/Water Background Flag	Unitless / 000 = Land & Desert 001 = Land no Desert 010 = Inland Water 011 = Sea Water 101 = Coastal
		Day/Night Flag	Unitless / 0 = Night 1 = Day
		Confidence Indicator	Unitless / 11 = Confident Cloudy 10 = Probably Cloudy 01 = Probably Clear 00 = Confident Clear
		Sun Glint Flag	Unitless / 00 = None 01 = Geometry Based 10 = Wind Speed Based 11 = Geometry & Wind
		Thin Cirrus	Unitless / 0 = No 1 = Yes

Input	Type	Description	Units/Valid Range
VIIRS Land Surface Type EDR	Uint8	VIIRS_Surface_Type_EDR_Type Surface Type Flag	Unitless / Valid Range: 1 to 17, 0 = Invalid 1 = Evergreen Needleleaf Forests 2 = Evergreen Broadleaf Forests 3 = Deciduous Needleleaf Forests 4 = Deciduous Broadleaf Forests 5 = Mixed Forests 6 = Closed Shrublands 7 = Open Shrublands 8 = Woody Savannas 9 = Savannas 10 = Grasslands 11 = Permanent Wetlands 12 = Croplands 13 = Urban and Built-Up Lands 14 = Cropland/Natural Vegetation Mosaics 15 = Snow and Ice 16 = Barren 17 = Water Bodies 18-31 = Invalid
		Fire Flag	Unitless / 0 = No Fire 1 = Active Fire
		Snow Cover Flag	Unitless / 0 = No Snow 1 = Snow Cover
VIIRS Aerosol Optical Thickness	Float32	VIIRS_AOT_IP_TYPE Aerosol Optical Thickness at 550 nm (slant path)	Unitless AOT ≥ 0
VIIRS_LST_LUT	Float64	viirs_Lst_Coeffs_LUT term: dual window[9], split - window[5] Indices representing coefficients a0… a8	Term Unitless
		daynight[2] Key to LUT daynight dimension	Unitless / 0 = night 1 = day
		surfacetype[17] IGBP Surface Types Land Surface Type EDR	Unitless / 0 to 16
		algorithm[2] Key to LUT algorithm dimension	Unitless / 0 = “dual” 1 = “split”

Input	Type	Description	Units/Valid Range
		regime[1] This is a placeholder only (not used)	Unitless / regime = 0
VIIRS_LST_COEFFICIENTS	Float32	Structure containing all configurable parameters for LST min_Bt_M12_M13	 180 K
		max_Bt_M12_M13	350 K
		min_Bt_M15	180 K
		max_Bt_M15	350 K
		min_Bt_M16	180 K
		max_Bt_M16	350 K
		day_Sol_Zen_Ang_Lim	1.4835 Radians
		min_Sens_Zen_Lim	0.0 Radians
		Max_Sens_Zen_Lim	0.8779 Radians
		min_Term_Lim	1.4835 Radians
		max_Term_Lim	1.7453 Radians
		lstMinTemp	213 K
		lstMaxTemp	343 K
		max_Sens_Zen_Lim	0.6981 Radians
LST Data Quality Notification	Structure	Reports erroneous pixels through a DQN	-999.71 to –999.69 Check for –999.7 is needed

Table 4. LST EDR Auxiliary / Ancillary Data Inputs

Input	Type	Description/Source	Units/Valid Range
Solar Zenith Angle	Float32	VIIRS SDR MOD	Radians / 0 to π
Sensor Zenith Angle	Float32	VIIRS SDR MOD	Radians / 0 to 1.25

2.1.1.2 Outputs

Primary outputs of the LST algorithm, as shown in Table 5, are a temperature value and a 3-byte LST quality flag (QF) for each moderate resolution pixel. For a description of the file metadata please reference Volume V of the CDFCB-X, D34862. Refer to the CDFBC-X, D34862, Vol. VI, Part 3, for a detailed description of the outputs.

The LST field in the EDR is scaled to fit into a Uint16 from calculated Float32 value.

Table 5. Output LST EDR Content

Output	Data Type/Size	Description	Units / Valid Range
Land Surface Temperature	Uint16	LST is determined for each pixel in the granule. The output is to be scaled so it will fit into a Uint16.	Scaled Kelvin / 0 to 65527 (Unscaled range: 183.2 K to 350.0 K)

Output	Data Type/Size	Description	Units / Valid Range
Land Surface Temperature Quality Byte 0	Uint8	Two-dimensional array of M_VIIRS_SDR_ROWS by M_VIIRS_SDR_COLS of Quality. Assurance bitmap with test information for each pixel in the granule. (See Table 6.)	Unitless / None
Land Surface Temperature Quality Byte 1	Uint8	Two-dimensional array of M_VIIRS_SDR_ROWS by M_VIIRS_SDR_COLS of Quality. Assurance bitmap with test information for each pixel in the granule. (See Table 6.)	Unitless / None
Land Surface Temperature Quality Byte 2	Uint8	Two-dimensional array of M_VIIRS_SDR_ROWS by M_VIIRS_SDR_COLS of Quality. Assurance bitmap with test information for each pixel in the granule. (See Table 6.)	Unitless / None
lstScale	Float32	The scale value for the Land Surface Temperature. This can be found by subtracting the minimum acceptable temperature of 183.2 K from the maximum of 350.0 K and dividing this result by 65527. The maximum and minimum temperatures are configurable.	Unitless / None
lstOffset	Float32	The offset value is the minimum acceptable temperature of the LST. The minimum temperature is 183.2 K and it is configurable.	Unitless / None

Table 6. LST Pixel Level QF Output Bits and Descriptions

Byte	Bit	Flag Description Key	Result
0	0-1	LST Quality	Bit 1 Bit 0 0 0 = High 0 1 = Medium 1 0 = Low 1 1 = No Retrieval
	2	Algorithm	0 = 4-band dual-split window 1 = 2-band split-window
	3	Day/Night	0 = Night 1 = Day, ($0^o \le$ Solar Zenith Angle $\le 85^o$)
	4	SWIR (M12 and M13) Brightness Temperatures availabilities	0 = both available 1 = at least one not available
	5	LWIR (M15 and M16) Brightness Temperatures availabilities	0 = both available 1 = at least one not available
	6	Active Fire	0 = no active fire 1 = active fire
	7	Exclusion – Thin Cirrus	0 = no thin cirrus 1 = thin cirrus
1	0	Clear Measurement Precision Degradation–	0 = no degradation 1 = degradation
	1	Retrieved LST out of expected reporting range	0 = within range, (213 K ≤ *LST* ≤ 343 K) 1 = out of range
	2-3	Cloud Confidence Indicator	Bit 1 Bit 0 0 0 = Confidently Clear 0 1 = Probably Clear

Byte	Bit	Flag Description Key	Result
			1 0 = Probably Cloudy 1 1 = Confidently Cloudy
	4	AOT Condition	0 = within range, (AOT ≤ 1.0) 1 = outside range
	5	Horizontal Reporting Interval	0 = within Horizontal Cell Size, Nadir to 1.3 km (0^o ≤ Sensor Zenith Angle ≤ 50.3^o) 1 = out of range
	6	Sun Glint	0 = None 1 = Present
	7	Terminator	0 = Beyond Terminator 1 = Inside Terminator, (85^o < Solar Zenith Angle ≤ 100^o)
2	0-2	Land/Water Background	Bit 2 Bit 1 Bit 0 0 0 0 = Land and Desert 0 0 1 = Land / No Desert 0 1 0 = Inland Water 0 1 1 = Sea Water 1 0 1 = Coastal
	3-7	Surface Type	00001 = Evergreen Needleleaf Forests 00010 = Evergreen Broadleaf Forests 00011 = Deciduous Needleleaf Forests 00100 = Deciduous Broadleaf Forests 00101 = Mixed Forests 00110 = Closed Shrublands 00111 = Open Shrublands 01000 = Woody Savannahs 01001 = Savannahs 01010 = Grasslands 01011 = Permanent Wetlands 01100 = Croplands 01101 = Urban Built-Up 01110 = Croplands/Natural Vegetation Mosiacs 01111 = Snow Ice 10000 = Barren 11111 = Invalid Surface Type (not within range) 10001 = Water Bodies

2.1.2 Algorithm Processing

The objective of the LST algorithm is to calculate LST at each pixel in a moderate resolution (750 m) granule with all available input. Two similar regression algorithms are used to perform this retrieval:

1) A baseline 4-band dual-split window algorithm uses brightness temperatures from two pair of VIIRS wavebands—one pair in the Medium-Wavelength Infrared (MWIR)

atmospheric window (Bands M12 and M13) and the other pair in the Long-Wavelength Infrared (LWIR) atmospheric window (Bands M15 and M16), and

2) A fallback 2-band split-window algorithm where only the LWIR band pair M15 and M16 are used. The 2-band spit-window algorithm can be optioned via a run time switch to supersede the dual split-window algorithm as the baseline algorithm.

Quality assessment flags for each pixel are stored in the LST Flag output.

2.1.2.1 Main Module – RetrieveLst

2.1.2.2 LST Retrieval Logic

The logic flow of the LST retrieval algorithm is provided in Figure 3. The core logic occurs in two functions, `setLstQualFlags()` and `calculateLst()`. In the current implementation, LST QFs additionally serve as decision flags. Their values are used in the decision of whether LST can be retrieved and, if so, which algorithm to use.

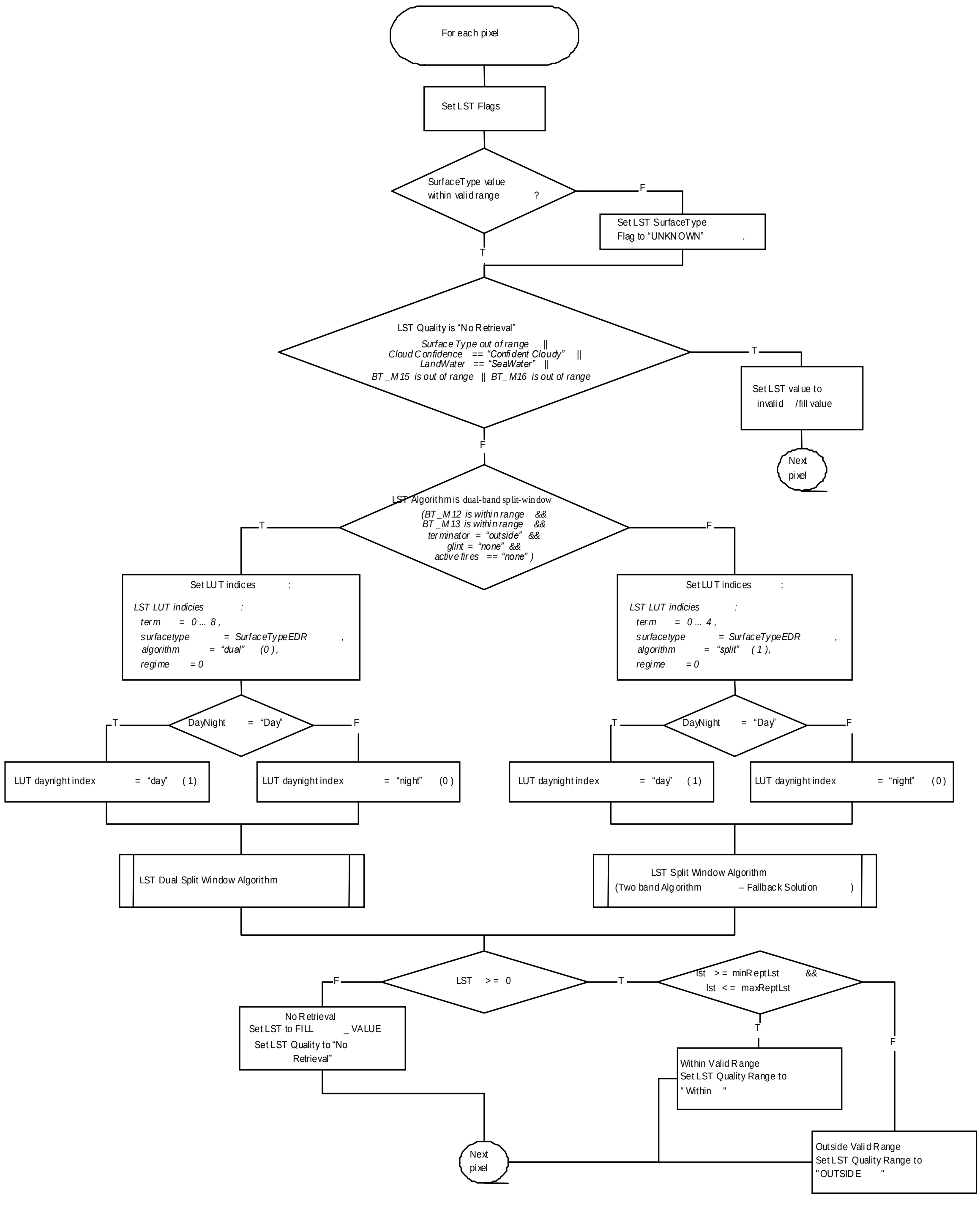

Figure 3. LST Retrieval Logic Flow

LST is not retrieved if any of the following conditions occur:

- The pixel is cloudy (i.e., Cloud Confidence Flag is “Confidently Cloudy”), or
- The pixel is an ocean pixel (i.e., LandWater Flag is “SeaWater”), or
- Band M15 brightness temperature is outside the LST defined range, or
- Band M16 brightness temperature is outside the LST defined range, or
- Land STYP is outside the LST defined range.

These pixels are marked with an LST QF of “No Retrieval” and are output with fill values.

For pixels that are processed, LST is retrieved by either the dual-band split-window algorithm or the split window fallback algorithm. In general, the dual-band split-window algorithm is used under optimal conditions: no solar glint, no active fires, outside the terminator, and “in-range” brightness temperatures for the M12 and M13 bands. Otherwise, the split-window fallback algorithm is used. See Table 9, Section 2.1.2.3. for the logic to determine which algorithm is used. The 2-band split window algorithm may be optioned to supersede the dual split-window algorithm as the baseline algorithm via a run time algorithm mode switch (Config.algmode). A switch value of “0” specifies that the dual split-window algorithm is to be used as the baseline algorithm. A switch value of “1” specifies that the 2-band split window algorithm will supersede the 4-band dual spit- window algorithm as the baseline algorithm. The run time algorithm mode switch should be set to 0 as the default run mode for initial operations at IDPS, corresponding to use of the 4-band split-window algorithm as the baseline algorithm. Determination of whether the 2-band split-window LST algorithm should supersede the 4-band split window will be made during calibration/validation of the LST algorithm. If it is determined as a result of performance evaluated during calibration/validation that the 2-band split window algorithm should supersede the 4-band split-window algorithm then the algorithm mode switch should be set to 1 resulting in the 2-band split-window algorithm being run as the baseline algorithm.

Core equations for the dual-band split-window and split-window fallback algorithms are specified in Table 10. The implementation is presented in `calculateLst()`. The daytime dual-band split-window algorithm varies slightly from its nighttime counterpart in that a solar zenith angle correction is made for the daytime retrieval.

For an off-nominal condition where a negative LST is retrieved, the LST field is filled and the LST quality bit field is set to “No Retrieval”.

Table 7 contains the list of configurable algorithm parameters.

Table 7. List of Configurable Algorithm Parameters

Algorithm Parameter	Description	Assigned Values
LST_MIN_M12_M13_BT	Minimum brightness temperatures for M12 and M13	180 K
LST_MAX_M12_M13_BT	Maximum brightness temperatures for M12 and M13	350 K
LST_MIN_M15_BT	Minimum brightness temperature for M15	180 K
LST_MAX_M15_BT	Maximum brightness temperature for M15	350 K
LST_MIN_M16_BT	Minimum brightness temperature for M16	180 K
LST_MAX_M16_BT	Maximum brightness temperature for M16	350 K

Algorithm Parameter	Description	Assigned Values
LST_DAYNIGHT_SOL_ZEN_LIMIT	Solar zenith angle defining day/night boundary	1.4835 Radians
LST_MIN_HCS_SENS_ZEN_LIMIT	Sensor zenith angle at Nadir * PI/180	0.0 Radians
LST_MAX_HCS_SENS_ZEN_LIMIT	Sensor zenith angle at the edge of scan	0.8779 Radians
LST_MIN_TERMINATOR_LIMIT	Minimum solar zenith angle defines the terminator region	1.4835 Radians
LST_MAX_TERMINATOR_LIMIT	Maximum solar zenith angle defines the terminator region	1.7453 Radians
lstMinTemp	Minimum reported temperature	213 K
lstMaxTemp	Maximum reported temperature	343 K
Algmode	0 equals dual mode, 1 equals splt mode	0

2.1.2.3 LST Quality Flag Logic

The LST Flags consist of three 8-bit words and are shown in Table 8. The logic to set these flags is performed in function `setLstQualFlags()` and provided in Table 8 and Table 9.

Overall LST pixel quality is represented by the quality bit field. Pixel quality is flagged as "No Retrieval" and the corresponding LST will be filled:

(BT_M15 is outside range) or (BT_M16 is outside range) or
(Cloud Confidence is "Confidently Cloudy") or (STYP is outside range) or
(LandWater Flag is "SeaWater")

LST < 0 (determined after attempt is made to retrieve LST).

The logic to set the bit field under various retrieval conditions is shown in Table 9.

Table 8. LST QF Logic

LST Flag	Input Source	Flag Setting
Band M12 Brightness Temperature Quality	viirs_mod_SDR_bt_type	if (180 K < BT_{M12} < 350 K) set to "within range" otherwise set to "out of range" end if
Band M13 Brightness Temperature Quality	viirs_mod_SDR_bt_type	if (180 K < BT_{M13} < 350 K) set to "within range" otherwise set to "out of range" end if
Band M15 Brightness Temperature Quality	viirs_mod_SDR_bt_type	if (180 K < BT_{M15} < 350 K) set to "within range" otherwise set to "out of range" end if
Band M16 Brightness Temperature Quality	viirs_mod_SDR_bt_type	if (180 K < BT_{M16} < 350 K) set to "within range" otherwise set to "out of range" end if
AOT Condition	VIIRS_AOT_IP	if (AOT > 1.0) set to "out of range" otherwise set to "within range" end if
Day/Night	VIIRS_CLOUD_MASK_IP_TYPE	if (0 deg <= Solar Zenith Angle <= 85 deg) set to "Day" otherwise set to "Night" end if
Terminator	VIIRS_CLOUD_MASK_IP_TYPE	if (85 deg < Solar Zenith Angle <= 100 deg) set to "Inside Terminator" otherwise set to "Beyond Terminator" end if

LST Flag	Input Source	Flag Setting
Horizontal Reporting Interval	VIIRS_CLOUD_MASK_IP_TYPE	if (0 deg <= Sensor Zenith Angle <= 50.3 deg) set to “within range” otherwise set to “out of range” end if
Sun Glint	VIIRS_CLOUD_MASK_IP_TYPE	if (VCM Glint Flag == “No Glint”) set to “None” otherwise set to “Present” end if
Active Fire	VIIRS Surface Type EDR	LST Active Fire Flag = SurfaceType EDR Active Fire Flag
Cloud Confidence Indicator	VIIRS_CLOUD_MASK_IP_TYPE	LST Cloud Confidence Indicator = VCM Cloud Confidence Indicator
Land/Water	VIIRS_CLOUD_MASK_IP_TYPE	LST LandWater = VCM LandWater flag
Exclusion – Thin Cirrus	VIIRS_CLOUD_MASK_IP_TYPE	LST Thin Cirrus = VCM Thin Cirrus flag
SurfaceType	VIIRS Surface Type EDR	LST SurfaceType = SurfaceType EDR Surface Type
Algorithm	Logical combination of LST Flags	if (BT_{M12} is “within range”) and (BT_{M13} is “within range”) and (Terminator is “Beyond Terminator”) and (Glint is “No Glint”) and (Active Fire is “No Active Fire”) and (algmode is not set ot “Split”) set to “Dual” otherwise set to “Split” end if
Degraded – Sensor Zenith Angle > 40	viirs_mod_SDR_bt_type	If (Sensor Zenith Angle > 40) set to LST_ZSEN_DEGRAD
Quality	Logical combination of LST Flags	See Table 9

Table 9. LST QF/Quality Bit Field Logic Table (Retrieval Cases Only)

No Land	LST >= 0	Algorithm Used	Active Fire	Horizontal Reporting Interval	AOT Range	Thin Cirrus	Cloud Confidence Indicator		
							Confident Clear	Probably Clear	Probably Cloudy
F	T	x	x	x	x	yes	Low	Low	Low
F	T	x	x	x	out	x	Low	Low	Low
F	T	x	x	out	x	x	Low	Low	Low
F	T	x	fire	x	x	x	Low	Low	Low
F	T	S	no	in	in	no	High	Medium	Low
F	T	D	no	in	in	no	High	Medium	Low
T	F	x	x	x	x	x	No Retrieval	No Retrieval	No Retrieval

LST >= 0: T = True; F = False
Algorithm Used: S = Split-Window, D = Dual Split-Window
Active Fire: no = no active fire; fire = active fire
Horizontal Reporting Interval: out = Outside Range, in = Within Range
AOT Range: out = Outside Range, in = Within Range
Thin Cirrus: yes = Thin Cirrus, no = No Thin Cirrus
x = “don’t care”

Refer to Table 8 to obtain the algorithm determination logic.

2.1.2.4 LST LUT Coefficient Selection

A unique set of regression coefficients is derived offline for each land type. Each LST core equation (Table 10) uses a different set of coefficients for a given land STYP and day/night condition. Access to the coefficients is achieved by setting the values of the indices based on the given pixel viewing conditions and indicating the algorithm approach to be used. Once indices are specified, coefficients are retrieved for the desired LST algorithm by indexing on the "term" index. Currently, the "regime" index is set to "0" and has only one value. It is a placeholder for possible future improvement by further stratification of atmospheric conditions or geolocations. For the dual split-window algorithm, there are nine coefficients. For the split-window fallback algorithm, there are five coefficients. For the latter, four additional zero-valued coefficients are present as "fillers" in the LUT file.

Example:

> LUTCoeffs[n][1][14][0][0], where n is indexed from 0 to 8, corresponds to the coefficients a_0 to a_8 of the dual split algorithm under daytime viewing conditions with no solar glint or active fire and with a pixel viewing surface type 14.

Table 10. LST Core Equations

VIIRS dual split-window LST algorithm
Daytime:
$LST = a_0 + a_1 T_{M15} + a_2 (T_{M15} - T_{M16}) + a_3 (\sec\theta - 1) + a_4 T_{M12} + a_5 T_{M13} + a_6 T_{M12} \cos\varphi + a_7 T_{M13} \cos\varphi + a_8 (T_{M15} - T_{M16})^2$
Nighttime:
$LST = b_0 + b_1 T_{M15} + b_2 (T_{M15} - T_{M16}) + b_3 (\sec\theta - 1) + b_4 T_{M12} + b_5 T_{M13} + b_6 T_{M12}^{\;2} + b_7 T_{M13}^{\;2} + b_8 (T_{M15} - T_{M16})^2$
VIIRS split-window LST algorithm (Two-band Fallback solution)
Daytime:
$LST = a_0 + a_1 T_{M15} + a_2 (T_{M15} - T_{M16}) + a_3 (\sec\theta - 1) + a_4 (T_{M15} - T_{M16})^2$
Nighttime:
$LST = b_0 + b_1 T_{M15} + b_2 (T_{M15} - T_{M16}) + b_3 (\sec\theta - 1) + b_4 (T_{M15} - T_{M16})^2$
where, LST is the retrieved land surface temperature, a_n and b_n are coefficients retrieved from the LST LUT and are dependent on surface type and day/night conditions, θ is the sensor zenith angle, φ is the solar zenith angle, T_λ is the brightness temperature at λ = VIIRS Band M15, M16, M12 or M13. The equations above correspond to the LST ATBD, D43756, Section 3.3.2, Equations (14), (15) and (16) with minor modifications (i.e., in order to simplify the software; coefficients for the daytime and nighttime equations for the fallback solution are equal).

2.1.3 Graceful Degradation

2.1.3.1 Graceful Degradation Inputs

There are two cases where input graceful degradation is indicated in the Land Surface Temperature EDR.

1. The primary input denoted in the algorithm configuration guide cannot be successfully retrieved but an alternate input can be retrieved.
2. An input retrieved for the algorithm had its N_Graceful_Degradation metadata field set to YES (propagation).

Table 11 details the instances of these two cases for LST. Note that the shaded cells indicate that the graceful degradation was done upstream at product production.

Table 11. LST Graceful Degradation

Input Data	Satellite	Baseline Data	Primary Backup	Secondary	Tertiary	Graceful

Description		Source	Data Source	Backup Data Source	Backup Data Source	Degradation Done Upstream
Surface Type EDR	NPP, PM1, TR1	VIIRS_LN_04.4.1 VIIRS	VIIRS_GD_08.4.3 VIIRS Quarterly Surface Type IP	N/A	N/A	No
Aerosol Optical Thickness	NPP, PM1, TR1	VIIRS_GD_15.4.1 VIIRS AOT IP	VIIRS_GD_25.4.1 NAAPS	VIIRS_GD_15.4.1 Climatology	N/A	Yes, backup only.

2.1.3.2 Graceful Degradation Processing

None.

2.1.3.3 Graceful Degradation Outputs

None.

2.1.4 Exception Handling

When LST cannot be retrieved due to conditions such as invalid SDR data, cloud-contaminated pixel, invalid STYP, or sea-water pixel classification from the VCM IP Land/Water Flag, LST pixel values are set to MISS_FLOAT32_FILL.

In addition to this, code is added to check the bounds of the input into the LST EDR. Table 3 contains all inputs for LST EDR and the valid ranges of these inputs. Table 7 contains input values to LST that are configurable and can be changed without having to recompile. The "assigned values" field lists the current value of this input. These inputs are put into a global file.

Very few operations in the algorithm (beyond address references) have the potential to cause exceptions. There are no divide operations in any routine that could be a division by zero.

2.1.5 Data Quality Monitoring

Each algorithm uses specific criteria contained in a Data Quality Threshold Table (DQTT) to determine when a Data Quality Notification (DQN) is produced. The DQTT contains the threshold used to trigger the DQN as well as the text contained in the DQN. If a threshold is met, the algorithm stores a DQN in DMS indicating the test(s) that failed and the value of the DQN attribute. For more algorithm specific detail refer to the CDFCB-X, D35850.

2.1.6 Computational Precision Requirements

The Land Surface Temperature is a scaled value ranging from 0 to 65527. The loss of precision from replacing this value (resolution of the scaled output versus the required accuracy and precision of the LST EDR) with a scaled 16-bit integer is acceptable. After calculation, the value is scaled by 65527 / 166.8. The loss of precision by scaling is approximately 0.00255 K.

2.1.7 Algorithm Support Considerations

INF and DMS must be running before the Land Surface Temperature algorithm is executed.

2.1.8 Assumptions and Limitations

2.1.8.1 Assumptions

The LST retrieval algorithm assumes VIIRS 750 M SDR, VIIRS AOT IP, VCM IP, and VIIRS STYP EDR are available before processing.

2.1.8.2 Limitations

The LST EDR is retrieved under clear condition with known STYP classification and valid brightness temperatures from at least the VIIRS M15 and M16 bands, and with AOT<1 to have a retrieved pixel of high quality. A pixel of low quality is retrieved if AOT is out of the acceptable bounds.

Precipitable Water (PW), atmospheric transmittance and surface emissivity corrections discussed in Section 3.3.4 of the ATBD, D43756, are not implemented.

3.0 GLOSSARY/ACRONYM LIST

3.1 Glossary

The current glossary for the NPOESS program, D35836_G_NPOESS_Glossary, can be found on eRooms. Table 12 contains those terms most applicable for this OAD.

Table 12. Glossary

Term	Description
Algorithm	A formula or set of steps for solving a particular problem. Algorithms can be expressed in any language, from natural languages like English to mathematical expressions to programming languages like FORTRAN. On NPOESS, an algorithm consists of: A theoretical description (i.e., science/mathematical basis) A computer implementation description (i.e., method of solution) A computer implementation (i.e., code)
Algorithm Configuration Control Board (ACCB)	Interdisciplinary team of scientific and engineering personnel responsible for the approval and disposition of algorithm acceptance, verification, development and testing transitions. Chaired by the Algorithm Implementation Process Lead, members include representatives from IWPTB, Systems Engineering & Integration IPT, System Test IPT, and IDPS IPT.
Algorithm Verification	Science-grade software delivered by an algorithm provider is verified for compliance with data quality and timeliness requirements by Algorithm Team science personnel. This activity is nominally performed at the IWPTB facility. Delivered code is executed on compatible IWPTB computing platforms. Minor hosting modifications may be made to allow code execution. Optionally, verification may be performed at the Algorithm Provider's facility if warranted due to technical, schedule or cost considerations.
Ancillary Data	Any data which is not produced by the NPOESS System, but which is acquired from external providers and used by the NPOESS system in the production of NPOESS data products.
Auxiliary Data	Auxiliary Data is defined as data, other than data included in the sensor application packets, which is produced internally by the NPOESS system, and used to produce the NPOESS deliverable data products.
EDR Algorithm	Scientific description and corresponding software and test data necessary to produce one or more environmental data records. The scientific computational basis for the production of each data record is described in an ATBD. At a minimum, implemented software is science-grade and includes test data demonstrating data quality compliance.
Environmental Data Record (EDR)	[IORD Definition] Data record produced when an algorithm is used to convert Raw Data Records (RDRs) to geophysical parameters (including ancillary parameters, e.g., cloud clear radiation, etc.). [Supplementary Definition] An Environmental Data Record (EDR) represents the state of the environment, and the related information needed to access and understand the record. Specifically, it is a set of related data items that describe one or more related estimated environmental parameters over a limited time-space range. The parameters are located by time and Earth coordinates. EDRs may have been resampled if they are created from multiple data sources with different sampling patterns. An EDR is created from one or more NPOESS SDRs or EDRs, plus ancillary environmental data provided by others. EDR metadata contains references to its processing history, spatial and temporal coverage, and quality.
Model Validation	The process of determining the degree to which a model is an accurate representation of the real-world from the perspective of the intended uses of the model. [Ref.: DoDD 5000.59-DoD Modeling and Simulation Management]
Model Verification	The process of determining that a model implementation accurately represents the developer's conceptual description and specifications. [Ref.: DoDD 5000.59-DoD Modeling and Simulation Management]
Operational Code	Verified science-grade software, delivered by an algorithm provider and verified by IWPTB, is developed into operational-grade code by the IDPS IPT.
Operational-Grade Software	Code that produces data records compliant with the System Specification requirements for data quality and IDPS timeliness and operational infrastructure. The software is modular relative to the IDPS infrastructure and compliant with IDPS application programming

Term	Description
	interfaces (APIs) as specified for TDR/SDR or EDR code.
Raw Data Record (RDR)	[IORD Definition] Full resolution digital sensor data, time referenced and earth located, with absolute radiometric and geometric calibration coefficients appended, but not applied, to the data. Aggregates (sums or weighted averages) of detector samples are considered to be full resolution data if the aggregation is normally performed to meet resolution and other requirements. Sensor data shall be unprocessed with the following exceptions: time delay and integration (TDI), detector array non-uniformity correction (i.e., offset and responsivity equalization), and data compression are allowed. Lossy data compression is allowed only if the total measurement error is dominated by error sources other than the data compression algorithm. All calibration data will be retained and communicated to the ground without lossy compression. [Supplementary Definition] A Raw Data Record (RDR) is a logical grouping of raw data output by a sensor, and related information needed to process the record into an SDR or TDR. Specifically, it is a set of unmodified raw data (mission and housekeeping) produced by a sensor suite, one sensor, or a reasonable subset of a sensor (e.g., channel or channel group), over a specified, limited time range. Along with the sensor data, the RDR includes auxiliary data from other portions of NPOESS (space or ground) needed to recreate the sensor measurement, to correct the measurement for known distortions, and to locate the measurement in time and space, through subsequent processing. Metadata is associated with the sensor and auxiliary data to permit its effective use.
Retrieval Algorithm	A science-based algorithm used to ‘retrieve’ a set of environmental/geophysical parameters (EDR) from calibrated and geolocated sensor data (SDR). Synonym for EDR processing.
Science Algorithm	The theoretical description and a corresponding software implementation needed to produce an NPP/NPOESS data product (TDR, SDR or EDR). The former is described in an ATBD. The latter is typically developed for a research setting and characterized as “science-grade”.
Science Algorithm Provider	Organization responsible for development and/or delivery of TDR/SDR or EDR algorithms associated with a given sensor.
Science-Grade Software	Code that produces data records in accordance with the science algorithm data quality requirements. This code, typically, has no software requirements for implementation language, targeted operating system, modularity, input and output data format or any other design discipline or assumed infrastructure.
SDR/TDR Algorithm	Scientific description and corresponding software and test data necessary to produce a Temperature Data Record and/or Sensor Data Record given a sensor’s Raw Data Record. The scientific computational basis for the production of each data record is described in an Algorithm Theoretical Basis Document (ATBD). At a minimum, implemented software is science-grade and includes test data demonstrating data quality compliance.
Sensor Data Record (SDR)	[IORD Definition] Data record produced when an algorithm is used to convert Raw Data Records (RDRs) to calibrated brightness temperatures with associated ephemeris data. The existence of the SDRs provides reversible data tracking back from the EDRs to the Raw data. [Supplementary Definition] A Sensor Data Record (SDR) is the recreated input to a sensor, and the related information needed to access and understand the record. Specifically, it is a set of incident flux estimates made by a sensor, over a limited time interval, with annotations that permit its effective use. The environmental flux estimates at the sensor aperture are corrected for sensor effects. The estimates are reported in physically meaningful units, usually in terms of an angular or spatial and temporal distribution at the sensor location, as a function of spectrum, polarization, or delay, and always at full resolution. When meaningful, the flux is also associated with the point on the Earth geoid from which it apparently originated. Also, when meaningful, the sensor flux is converted to an equivalent top-of-atmosphere (TOA) brightness. The associated metadata includes a record of the processing and sources from which the SDR was created, and other information needed to understand the data.
Temperature Data Record (TDR)	[IORD Definition] Temperature Data Records (TDRs) are geolocated, antenna temperatures with all relevant calibration data counts and ephemeris data to revert from T-sub-a into counts. [Supplementary Definition] A Temperature Data Record (TDR) is the brightness temperature value measured by a

Term	Description
	microwave sensor, and the related information needed to access and understand the record. Specifically, it is a set of the corrected radiometric measurements made by an imaging microwave sensor, over a limited time range, with annotation that permits its effective use. A TDR is a partially-processed variant of an SDR. Instead of reporting the estimated microwave flux from a specified direction, it reports the observed antenna brightness temperature in that direction.

3.2 Acronyms

The current acronym list for the NPOESS program, D35838_G_NPOESS_Acronyms, can be found on eRooms. Table 13 contains those terms most applicable for this OAD.

Table 13. Acronyms

Term	Expansion
AM&S	Algorithms, Models & Simulations
API	Application Programming Interfaces
ARP	Application Related Product
CDFCB-X	Common Data Format Control Book - External
DMS	Data Management Subsystem
DPIS ICD	Data Processor Inter-subsystem Interface Control Document
DQTT	Data Quality Test Table
INF	Infrastructure
ING	Ingest
IP	Intermediate Product
LST	Land Surface Temperature
LUT	Look-Up Table
MDFCB	Mission Data Format Control Book
PW	Precipitable Water
QF	Quality Flag
SDR	Sensor Data Records
SI	Software Item or International System of Units
SST	Sea Surface Temperature
STYP	Surface Type
TBD	To Be Determined
TBR	To Be Resolved
VCM	VIIRS Cloud Mask

4.0 OPEN ISSUES

Table 14. TBXs

TBX ID	Title/Description	Resolution Date
None		