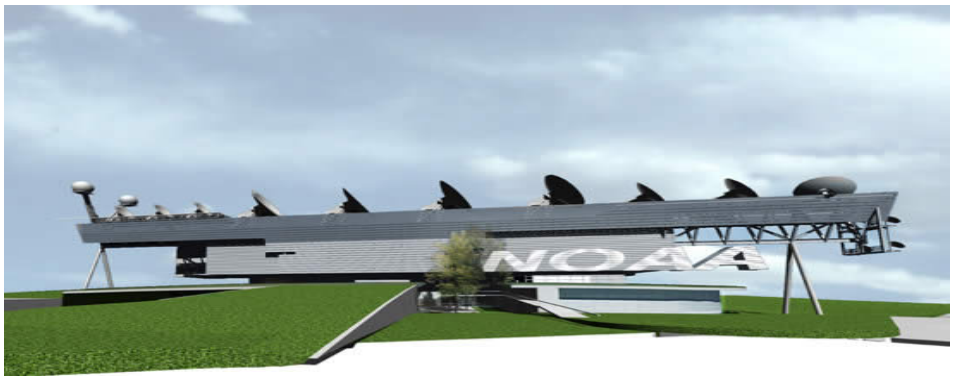
Environmental Satellite Processing Center



VIIRS Surface Reflectance External User's Manual

Version 2.0

DOCUMENT HISTORY
DOCUMENT REVISION LOG

The Document Revision Log identifies the series of revisions to this document since the baseline release. Please refer to the above page for version number information.

DOCUMENT TITLE: VIIRS Surface Reflectance External User's Manual			
DOCUMENT CHANGE HISTORY			
Revision No.	**Date**	**Revision Originator Project Group**	**CCR Approval # and Date**
1.0	March 2017	STAR – Michael Wilson	N/A
1.1	February 2018	STAR – Michael Wilson	N/A
1.2	July 2018	STAR – Michael Wilson	N/A
2.0	July 2018	OSPO – Hanjun Ding & Yufeng Zhu	CCR7618

LIST OF CHANGES

Significant alterations made to this document are annotated in the List of Changes table.

DOCUMENT TITLE: VIIRS Surface Reflectance External User's Manual					
LIST OF CHANGE-AFFECTED PAGES/SECTIONS/APPENDICES					
Version Number	**Date**	**Changed By**	**Page**	**Section**	**Description of Change(s)**
V1.1	Feb 28 2018	Michael Wilson	11	1.1.4, Table 1-2	Changed naming convention from SR_v1-0-8 to SurfRefl_v1r0
			11	1.1.4, Table 1-2	Changed size of file from 115 M to 209 M (due to adding lat/lon to file)
			11 - 12	1.1.4, Table 1-3	Changed all Surface Reflectance ranges from 0-1 to -0.01 – 1.6 (0-1 was incorrect)
			16	2.3.1, Table 2-3	Reflect, trans, and albedo LUTs use 9 M-bands, not 10
V1.2	July 27 2018	Michael Wilson	9	1.1, Table 1-1	Updated Contact Information for Team
			18	3.3, Table 3-2	Changed Sun Glint from using both bits 6-7 to using only bit 6 and leaving bit 7 empty
			18	3.3, Table 3.2	Clarified that the Cloud Mask Quality bits are currently not defined (as these are an IDPS-only feature)
			22	3.3, Table 3.8	There was an extra line for bit 0 that was meant for a different table. It was removed.
V2.0	July 2018	Hanjun Ding & Yufeng Zhu			Updated to operational

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LIST OF ACRONYMS

ATBD	Algorithm Theoretical Basis Document
EDR	Environmental Data Record
EOS	Earth Observing System
GFS	Global Forecast System
GSFC	Goddard Space Flight Center
IDPS	Interface Data Processing Segment
L1RD	Level 1 Requirements Document
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
netCDF4	Network Common Data Format version 4
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
OSD	Office of Systems Development
OSPO	Office of Satellite and Product Operations
PAL	Product Area Lead
PDA	Product Distribution and Access
RAD	Requirements Allocation Document
RDR	Raw Data Record
SDR	Sensor Data Record
SMM	System Maintenance Manual
STAR	Center for SaTellite Applications and Research
V&V	Verification and Validation
VIIRS	Visible Infrared Imaging Radiometer Suite

1. PRODUCTS

This is an external user's manual document describing the Visible Infrared Imaging Radiometer Suite (VIIRS) algorithm for Surface Reflectance. The VIIRS Surface Reflectance algorithm was developed at Goddard Space Flight Center (GSFC) as part of the original National Polar-orbiting Operational Environmental Satellite System (NPOESS) – now Suomi National Polar-orbiting Partnership (NPP) - Interface Data Processing Segment (IDPS). This algorithm has been modified for the Suomi NPP Data Exploitation (NDE) environment through assistance from the Center of Satellite Applications and Research (STAR). After preliminary testing, the algorithm will be delivered to the Office of Satellite and Product Operations (OSPO) to be run operationally.

The intended users of the External User's Manual (EUM) are end users of the output products and the product verification and validation (V&V) teams. The purpose of the EUM is to provide product users and product testers with information that will enable them to acquire the product, understand its features, and user the data. External users are defined as those users who do not have direct access to the processing system, i.e. are outside of OSD. The output files are defined as those leaving the NDE for public use.

1.1 Product Overview

1.1.1 Product Requirements

All of the VIIRS Surface Reflectance requirements are available through the VIIRS Surface Reflectance Requirements Allocation Document (RAD). These requirements identify the users and their needs with respect to file content, format, latency, and quality. This document is available upon request from the Surface Reflectance Product Area Lead (PAL), current as of this document in the table below. The product team includes, but is not limited to, the following individuals from STAR, NASA-GSFC, OSD, and OSPO.

Table 1-1 – Product Team Information

Team Member	Organization	Role	Contact Information
Walter Wolf	STAR	STAR Project Lead	5830 University Research Court College Park, MD. 20740 Phone: 301-683-1314

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1.1.2 Product Description

The VIIRS Surface Reflectance product is generated from a combination of the VIIRS SDR and geolocations provided via the IDPS, and Global Forecast System (GFS), aerosol, cloud mask, and cloud height products available through the NDE. The output products include surface reflectance for channels I1, I2, I3, M1, M2, M3, M4, M5, M7, M8, M10, and M11. Output also includes five bytes of quality flags (QF1, QF2, QF3, QF4, QF5), which are each bitmasks representing various properties of both inputs and outputs. All products are output in netCDF-4. For information on the science algorithms, see the VIIRS Surface Reflectance Algorithm Theoretical Basic Document (ATBD). This document can be obtained from the Product Area Lead (PAL) indentified in the Product Team table in section 1.1.2.

1.1.3 Product History

The VIIRS Surface Reflectance product originally existed as a product in the IDPS. The original system used the VIIRS SDR and geolocation, VIIRS Cloud Mask (VCM), Aerosol Optical Depth Product, and internal NCEP files for surface pressure, precipitable water, and total column ozone. All of these inputs were available internally in the IDPS system. The output was generated in HDF-EOS2 format.

In the NDE system, the original VIIRS SDR and geolocation files are ported to the NDE for use in the Surface Reflectance algorithm. However, the VIIRS Cloud Mask has been exchanged for the Enterprise Cloud Mask (ECM) and NDE Cloud Height product, the Aerosol Optical Depth product has been exchanged for the NDE's version of Aerosol Optical Depth, and the NCEP files have been exchanged for local GFS files available in the NDE framework. The new output is internally generated in HDF-5, before being converted via a postprocessor into NetCDF-4 format.

1.1.4 Product Access

The VIIRS Surface Reflectance product is generated in near-real time from the VIIRS SDR product and auxiliary products from the NDE framework. The data are made available to users on the PDA server at ESPC for real-time use. For access to this server, information about data files, and associated documentation, the PAL should be contacted (see Table 1-1). In general, users are required to fill out the Data Access Request Form located on http://www.ospo.noaa.gov/Organization/About/access.html, and submit to nesdis.data.access@noaa.gov with a copy to the PAL.

After users submit the Data Access Request, the NESDIS Data Access Review Board will evaluate it, and give its approval or rejection. Users will be contacted after the Board makes the decision. For an approved DAR, the user will be assigned an account on the PDA. The user will have to follow detailed procedures on how to pull the data.

The plan is to make historical products for external users available through the NOAA Comprehensive Large Array-data Stewardship System (CLASS) archive at the National Centers for Environmental Information (NCEI). Data should be queried and ordered from CLASS at the following web URL: http://www.class.noaa.gov after the archive starts. Currently, discussion between NJO and CLASS is still ongoing.

Table 1-2 lists the single output file from the VIIRS Surface Reflectance algorithm, along with a description and approximate size. Table 1-3 details the contents of that output file.

Table 1-2 – VIIRS Surface Reflectance Output File

File	Description	Format	Size/file
SR_v1-0-8_npp_s??????????????_e??????????????_c??????????????.nc	The SR (Surface Reflectance) file contains surface reflectances for I-bands 1,2,3 and for M-bands 1,2,3,4,5,7,8,10,11. This file also includes five bitmapped quality flags.	NetCDF-4	~209 MB/file 288 files/day

Table 1-3 – VIIRS EDR File Content Description

Variable	Type	Description	Dim	Units	Range
375m Surface Reflectance Band I1	Short	Surface Reflectance for I1 Band, stored as value * 10000.	1536 x 6400	N/A	-0.01-1.6

375m Surface Reflectance Band I2	Short	Surface Reflectance for I2 Band, stored as value * 10000.	1536 x 6400	N/A	-0.01-1.6
375m Surface Reflectance Band I3	Short	Surface Reflectance for I3 Band, stored as value * 10000.	1536 x 6400	N/A	-0.01-1.6
750m Surface Reflectance Band M1	Short	Surface Reflectance for M1 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M2	Short	Surface Reflectance for M2 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M3	Short	Surface Reflectance for M3 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M4	Short	Surface Reflectance for M4 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M5	Short	Surface Reflectance for M5 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M7	Short	Surface Reflectance for M7 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M8	Short	Surface Reflectance for M8 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M10	Short	Surface Reflectance for M10 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
750m Surface Reflectance Band M11	Short	Surface Reflectance for M11 Band, stored as value * 10000.	768 x 3200	N/A	-0.01-1.6
Latitude_at_375m _resolution	Float	Latitude at 375 meter resolution to match up with the I-Band Surface Reflectances	1536 x 6400	Degrees	-90-90
Longitude_at_375m _resolution	Float	Longitude at 375 meter resolution to match up with the I-Band	1536 x 6400	Degrees	-180-180

		Surface Reflectances			
Latitude_at_750m _resolution	Float	Latitude at 750 meter resolution to match up with the M-Band Surface Reflectances	768 x 3200	Degrees	-90-90
Longitude_at_750m _resolution	Float	Longitude at 750 meter resolution to match up with the M-Band Surface Reflectances	768 x 3200	Degrees	-180-180
QF1 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255
QF2 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255
QF3 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255
QF4 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255
QF5 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255
QF6 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255
QF7 Surface Reflectance	Byte	Bitmasks for Surface Reflectance – see Table 3.2	768 x 3200	N/A	0-255

2. ALGORITHM

2.1 Algorithm Overview

The VIIRS Surface Reflectance algorithm is based on heritage from the Moderate Resolution Imaging Spectroradiometer (MODIS). The system uses a hybrid of look-up tables derived from radiative transfer models combined with a simple retrieval algorithm.

Details of this system are outlined in the VIIRS Surface Reflectance Algorithm Theoretical Basis Document (ATBD), available either through the PAL or the STAR Algorithm Lead. Inputs to the Surface Reflectance algorithm include VIIRS SDRs, geolocation, GFS model data, aerosol data, and the enterprise cloud mask.

2.2 Input Satellite Data

2.2.1 Satellite Instrument Overview

The VIIRS instrument is a scanning radiometer aboard the Suomi National Polar-orbiting Partnership (S-NPP) satellite, and is planned for future inclusion on the JPSS-1 (or J-1) satellite. VIIRS is a scanning radiometer that gathers radiances spanning from visible wavelengths through longwave infrared wavelengths. Radiances and/or reflectances are reported as Sensor Data Records (SDRs) through five imagery bands at 375-meter resolution, sixteen moderate resolution bands at 750-meter resolution, and one day-night band for low light at 750-meter resolution. Data is reported in granules containing approximately 85 seconds worth of retrievals. This is the equivalent of aerial coverage of approximately 3040 km by 570 km per granule. VIIRS also produces geolocation files for both the I-bands and M-bands for ellipsoid or terrain projections as well as Environmental Data Records (EDRs) that remap and reproject the data.

The S-NPP satellite was launched on October 28, 2011 and establishes a bridge between NASA's Earth Observing System (EOS) satellites and the future JPSS line of satellites. The S-NPP satellite contains VIIRS as well as four other instruments measuring the ultraviolet, visible, infrared, and microwave spectra. S-NPP exists in a sun-synchronous orbit with an ascending node equator crossing time of approximately 1330 UTC.

Additional information on the S-NPP platform or the VIIRS instrument is currently available at the following sites:
https://jointmission.gsfc.nasa.gov/suomi_mission_details.html
https://jointmission.gsfc.nasa.gov/viirs.html

2.2.2 Satellite Data Preprocessing Overview

The raw VIIRS data is dumped every orbit (~101 minutes) at Svalbard, Norway. These raw data records (RDRs) are recalibrated and geolocated into VIIRS SDR (and EDR) data in the IDPS system. The VIIRS SDR data is then ported from the IDPS to the NDE system for use in the Surface Reflectance algorithm.

The NDE framework provides the Enterprise Cloud Mask, the Cloud Height product, the Aerosol Optical Thickness product, and GFS derived fields as auxiliary temporal data. The Enterprise Cloud Mask, the Cloud Height product, and the Aerosol Optical Thickness product are all derived from the VIIRS instrument data inside the NDE framework. The GFS fields are provided externally by the National Centers for Environmental Prediction (NCEP) inside the NDE framework.

The Surface Reflectance algorithm will create swath data that matches the input VIIRS SDR data. Distribution of the final product will occur via the Product Distribution Area (PDA) in near-real time. More details about the processing sequence can be found within the VIIRS Surface Reflectance System Maintenance Manual (SMM), available from the Surface Reflectance PAL.

2.2.3 Input Satellite Data Description

The VIIRS instrument is the sole instrument providing data for processing. The input data consists of VIIRS SDRs and geolocation files from the IDPS, as well as the Enterprise Cloud Mask, Cloud Height product, and Aerosol Optical Thickness product generated inside the NDE framework. This is combined with GFS data containing surface pressure, total column ozone, and total precipitable water.

Details on the format of the VIIRS SDR can be found here or be provided on request: https://jointmission.gsfc.nasa.gov/sciencedocs/2015-06/474-00001-03_JPSS-CDFCB-X-Vol-III_0124C.pdf

2.3 Input Ancillary Data

2.3.1 Static Ancillary Files

The VIIRS Surface Reflectance algorithm contains a set of static ancillary data files that are necessary for running the code. These files are delivered with the system. Table 2-1 contains the file names and a brief description of the files.

Table 2-1 – VIIRS Surface Reflectance Ancillary Files

File Name	File Description
aot	Binary lookup table of 20 aerosol optical thicknesses
Vzen	Binary lookup table of 40 viewing zenith angles

Szen	Binary lookup table of 38 solar zenith angles
VIIRS-SR-IncScatAngles-LUT_v1.5.06.02_LP	Binary lookup table containing the scattering angle increment
VIIRS-SR-ScatAngDims-LUT_v1.5.06.02_LP	Binary lookup table containing the location of the maximum scattering angle corresponding to 105 different pairs of solar and sensor zenith angles
VIIRS-SR-IP-AC-INT_v1.5.06.02_LP	Binary lookup table containing a variety of ancillary information including max/min boundaries of retrieved surface reflectance, max/min for aerosol optical depth, max/min for GFS fields (water vapor, ozone, surface pressure), aerosol model limits, Rayleigh optical depth coefficients, and transmittance coefficients for ozone (1 value), water vapor (3 values), and other gasses (6 values)
Reflect	Binary lookup table of reflectivities. This is a four-dimensional table with dimensions of aerosol model (4), aot (20), M-band channel (9), and scattering angle (5527).
Trans	Binary lookup table of transmittances. This is a four-dimensional table with dimensions of aerosol model (4), aot (20), M-band channel (9), and solar zenith angle (15).
Albedo	Binary lookup table of albedos. This is a three-dimensional table with dimensions of aerosol model (4), aot (20), and M-band channel (9).

3. PERFORMANCE

3.1 Product Testing

3.1.1 Test Data Description

Descriptions of all of the VIIRS surface reflectance test data (input, output, and intermediate files) used in unit and system tests are provided in the VIIRS Surface Reflectance Code Test Review document (NOAA/NESDIS/STAR, 2016), and is available on request from the Surface Reflectance PAL.

3.1.2 Unit Test Plans

Descriptions of the VIIRS Surface Reflectance test plans used for unit and system tests are available in the VIIRS Surface Reflectance Code Test Review document (NOAA/NESDIS/STAR, 2016), and is available on request from the Surface Reflectance PAL.

3.2 Product Accuracy

3.2.1 Test Results

Descriptions of the VIIRS Surface Reflectance test plans used for the unit and system tests are provided in the VIIRS Surface Reflectance Code Test Review document (NOAA/NESDIS/STAR, 2016), and is available on request from the Surface Reflectance PAL.

3.2.2 Product Accuracy

The results of verification and validation tests are contained within the VIIRS surface reflectance Algorithm Readiness Review presentation package, available upon request from the project science lead. A summary of VIIRS surface reflectance product performance based on validation is shown in Table 3-1. More details are available in the Stage 1 Science Maturity Review for the Surface Reflectance product.

Table 3-1 – Summary of VIIRS Surface Reflectance Product Performance

Products/Retrievals	Precision	Accuracy	Accuracy Specs
Surface Reflectance	No specific threshold or objective.	Threshold: 0.01+0.1r Objective: 0.005+0.05r	where r denotes the retrieved surface reflectance.

3.3 Product Quality Output

There are seven quality flags in the VIIRS Surface Reflectance file, listed as QF1 through QF7. These fields are bit-mapped quality fields for the inputs and outputs of the algorithm. These are listed in Tables 3-2 through 3-8. Tables are ordered from the most significant bit (7) to the least significant bit (0).

Table 3-2 – QF1 Surface Reflectance

Bit #	Meaning
7	(Empty)
6	Sun Glint: 0: no sun glint detected 1: sun glint detected
5	Low Sun Mask 0: high 1: low
4	Day/Night Flag 0: day 1: night
2-3	Cloud Detection and Confidence 00: confident clear 01: probably clear 10: probably cloudy 11: confidence cloudy
0-1	Cloud Mask Quality 00: poor 01: low 10: medium 11: high

Table 3-3 – QF2 Surface Reflectance

Bit #	Meaning
7	Thin Cirrus Detected – Emissive Test 0: no cloud 1: cloud
6	Thin Cirrus Detected – Reflective Test 0: no cloud 1: cloud
5	Snow/Ice Flag

	0: no snow/ice 1: snow or ice
4	Heavy Aerosol Mask 0: no heavy aerosol 1: heavy aerosol
3	Cloud Shadow Mask 0: no cloud shadow 1: shadow
0-2	Land/Water Background 001: deep ocean 010: shallow water 011: land 100: snow 101: arctic 110: Antarctic and Greenland 111: desert

Table 3-4 – QF3 Surface Reflectance

Bit #	Meaning
7	Bad M10 SDR data 0: no 1: yes
6	Bad M8 SDR data 0: no 1: yes
5	Bad M7 SDR data 0: no 1: yes
4	Bad M5 SDR data 0: no 1: yes
3	Bad M4 SDR data 0: no 1: yes
2	Bad M3 SDR data 0: no 1: yes
1	Bad M2 SDR data

	0: no 1: yes
0	Bad M1 SDR data 0: no 1: yes

Table 3-5 – QF4 Surface Reflectance

Bit #	Meaning
7	Missing Precipitable Water data 0: no 1: yes
6	Invalid Land AM input data 0: valid 1: invalid or over ocean
5	Missing AOT input data 0: no 1: yes
4	Overall Quality of AOT 0: good 1: bad
3	Bad I3 SDR data 0: no 1: yes
2	Bad I2 SDR data 0: no 1: yes
1	Bad I1 SDR data 0: no 1: yes
0	Bad M11 SDR data 0: no 1: yes

Table 3-6 – QF5 Surface Reflectance

Bit #	Meaning
7	Overall Quality of M7 Surface Reflectance Data 0: good

	1: bad
6	Overall Quality of M5 Surface Reflectance Data 0: good 1: bad
5	Overall Quality of M4 Surface Reflectance Data 0: good 1: bad
4	Overall Quality of M3 Surface Reflectance Data 0: good 1: bad
3	Overall Quality of M2 Surface Reflectance Data 0: good 1: bad
2	Overall Quality of M1 Surface Reflectance Data 0: good 1: bad
1	Missing Surface Pressure input data 0: no 1: yes
0	Missing total column ozone input data 0: no 1: yes

Table 3-7 – QF6 Surface Reflectance

Bit #	Meaning
7	Unused
6	Unused
5	Overall Quality of I3 Surface Reflectance Data 0: good 1: bad
4	Overall Quality of I2 Surface Reflectance Data 0: good 1: bad
3	Overall Quality of I1 Surface Reflectance Data 0: good 1: bad
2	Overall Quality of M11 Surface Reflectance Data 0: good

	1: bad
1	Overall Quality of M10 Surface Reflectance Data 0: good 1: bad
0	Overall Quality of M8 Surface Reflectance Data 0: good 1: bad

Table 3-8 – QF7 Surface Reflectance

Bit #	Meaning
7	Unused
6	Unused
5	Unused
4	Thin Cirrus Flag 0: no 1: yes
2-3	Aerosol Quantity 00: climatology 01: low 10: average 11: high
1	Adjacent to Cloud (disabled) 0: no 1: yes
0	Snow Present 0: no 1: yes

3.4 External Product Tools

No external product tools are supplied. The Surface Reflectance output file is in netCDF4 format. External users can choose their own tools to display and analyze these output files with any public available netCDF tools.

4. PRODUCT STATUS

4.1 Operations Documentation

Please see the VIIRS Surface Reflectance System Maintenance Manual, Section 4 "Normal Operations" for detailed information about operational procedures. A set of SPSRB required documentation is available for surface reflectance, including the External Users Manual (this document), the Algorithm Theoretical Basis Document, and the System Maintenance Manual. These documents are available upon request from the PAL.

4.2 Maintenance History

Please see the VIIRS Surface Reflectance System Maintenance Manual, Section 5 "Monitoring and Maintenance" for detailed information about monitoring and maintenance support.

END OF DOCUMENT