Satellite Products and Services Review Board

Algorithm Theoretical Basis Document For Gridded VIIRS Land Surface Temperature and Albedo Production

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TITLE: Algorithm Theoretical Basis Document for Gridded VIIRS Land Surface Temperature and Albedo Production

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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.

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LIST OF CHANGES

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

DOCUMENT TITLE: Algorithm Theoretical Basis Document Template					
LIST OF CHANGE-AFFECTED PAGES/SECTIONS/APPENDICES					
Version Number	**Date**	**Changed By**	**Page**	**Section**	**Description of Change(s)**

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1 INTRODUCTION

This document provides algorithm description and software design for the Gridded VIIRS Level 3 Land Surface Temperature (LST) and Land Surface Albedo (LSA) development. The product description and requirements are briefly introduced in this section. Section 2 describes the processing outline, input, output data and the composition method. Assumptions and limitations associated with the algorithm is discussed in Section 3. Finally, Section 4 lists the references cited.

LST and LSA are produced at granule level for JPSS mission, currently including S-NPP and NOAA 20 satellites, within the JPSS risk reduction framework. Users further requested that regular gridded daily LST and LSA products should be provided for their applications. Therefore, gridded VIIRS LST and LSA products are generated, based on the enterprise JPSS VIIRS granule LST and LSA products.

Based on users requirement and the VIIRS data characters, the gridded LST product will be from daytime and nighttime observations, while the gridded LSA product will be for daytime observations only. The grid size is determined being 0.009 degree, in Sinusoid projection. A common granule-grid mapping tool is developed (see Appendix A) independently, which is applied in the LST and LSA gridded data production. Considering that each grid value is a best selection of the corresponding granule product value, the gridded LST and LSA products have comparable performance statistics as the corresponding level 2 products.

Product requirements was defined in the satellite missions. Table 1-1 provides the accuracy and precision requirements for the gridded LST and LSA product.

Table 1-1 Product requirements from JPSS L1RD

	JPSS LST	JPSS LSA
Products	Gridded	Gridded
Accuracy	1.4 K	0.05 (albedo units)
Precision	2.5 K	0.08 (albedo units)
Range	213 – 343 K	0 to 1.0 (albedo units)
Refresh Rate	Daily	Daily
Horizontal Resolution	0.009degree	0.009degree
Latency	30 hours	30 hours

The accuracy and precision listed in table 1-1 is only for confidently clear pixels. More details about the requirements, please refer to the document for JPSS risk reduction project requirement (https://www.jpss.noaa.gov/assets/pdfs/technical_documents/level_1_requirements_supplement.pdf).

2 ALGORITHM DESCRIPTION

First of all, a gridding tool has been developed for the data mapping from a granule product to the corresponding gridded product. The gridding tool generates a set of granule-to-tile index and tile-to-granule index files, which provides the mapping between granule-pixel to tile-grid, for the gridded data production. Details of the gridding tool development is given in Appendix A. In this section, therefore, it is focused on how to composite the granule-to-grid mapped data set, for generating appropriated gridded products.

2.1 The algorithm and processes for gridded LST product

A generic high level flowchart of the gridded LST production is given in the Figure 2-1.

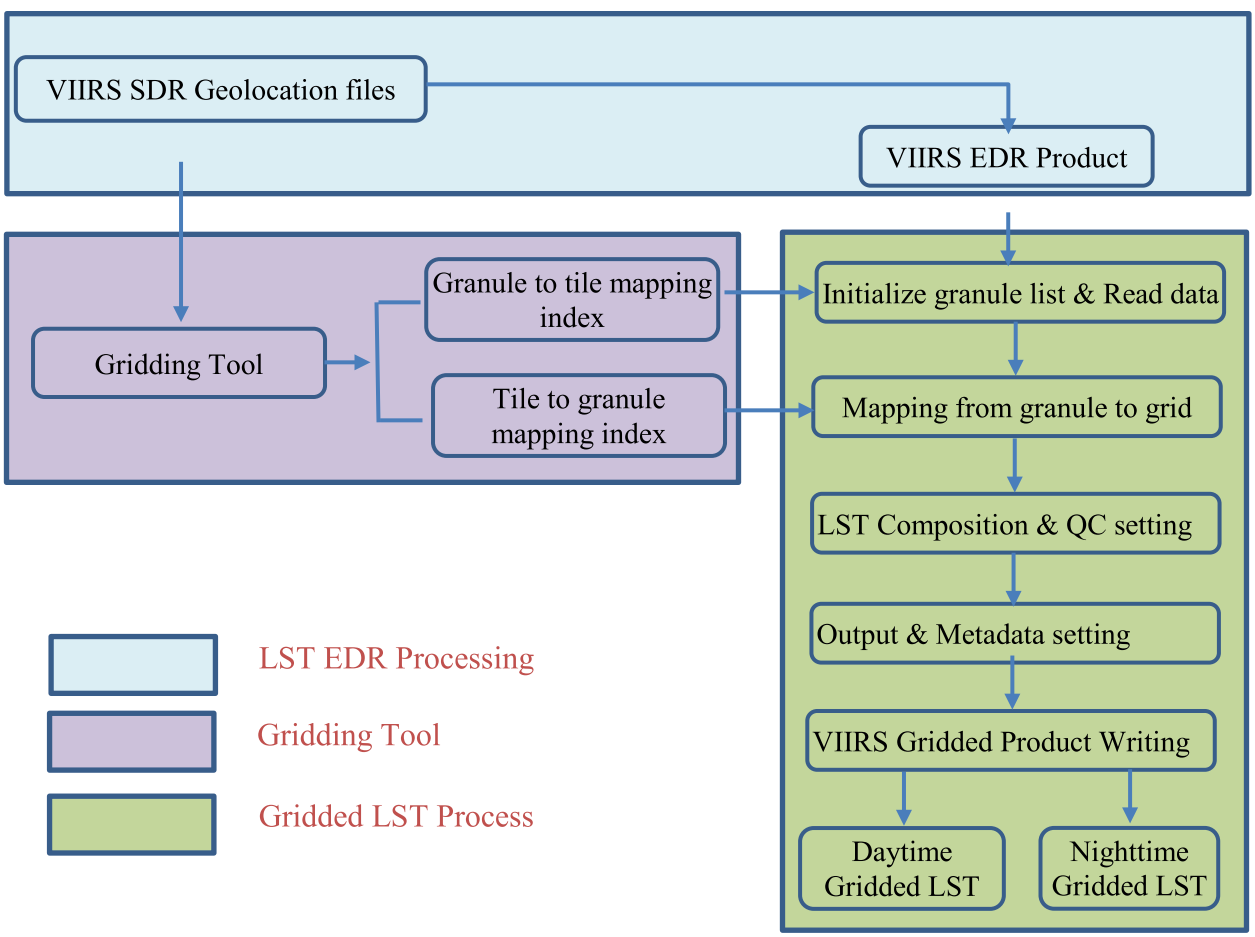


Figure 2-1 High level data flow of the gridded LST production.

The LST gridding algorithm takes the LST granule data as main input, along with the mapping indices generated by the gridding tool. . For each grid cell, the LST value is set following the criteria designed in a composition process, which takes the cloud mask, granule pixel LST value and day/night conditions into consideration. The day and night gridded LSTs and quality flags will be recorded in the output, respectively,product, with metadata as global attributes.

2.1.1 Processing Outline

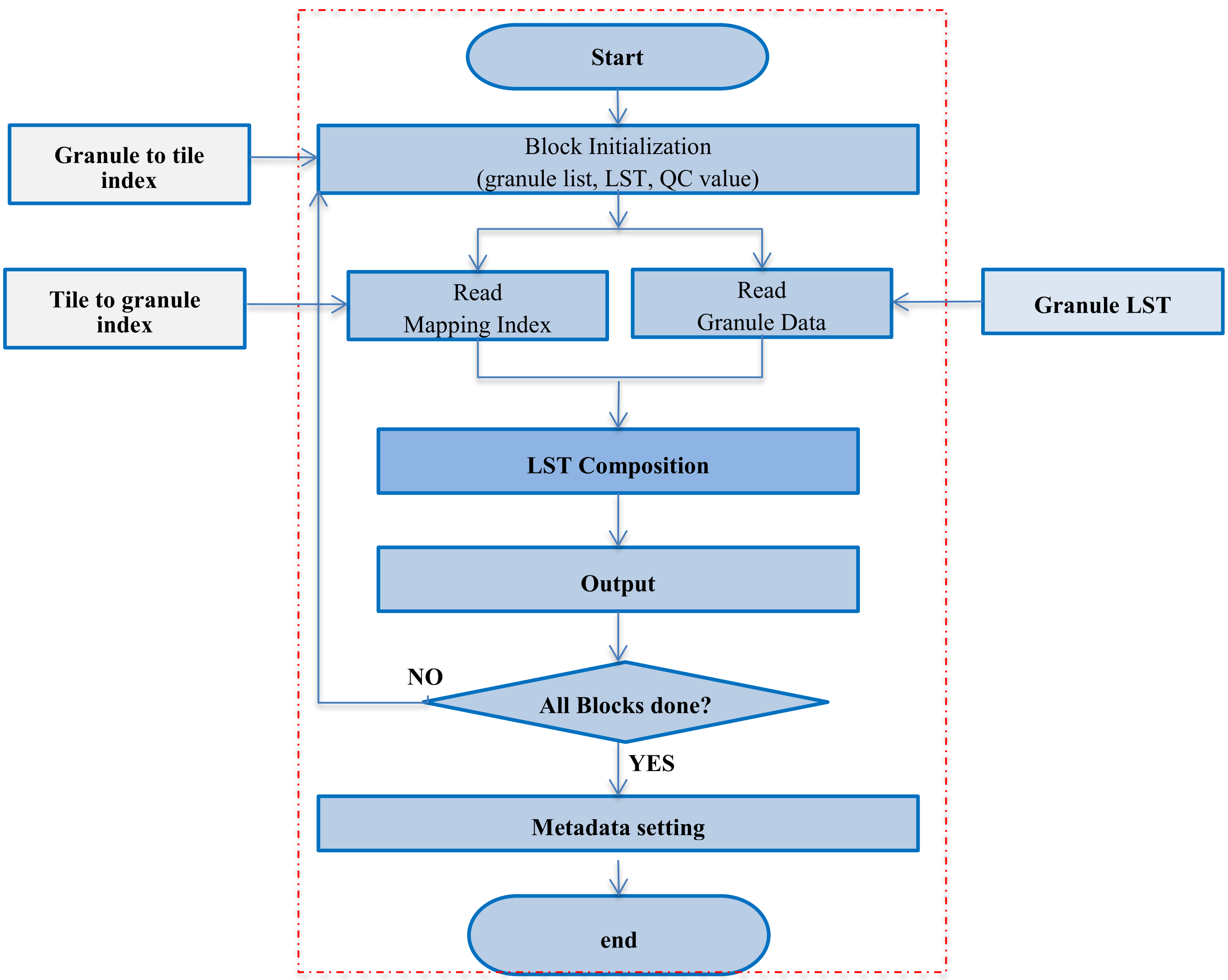


Figure 2-2 High Level Flowchart of the LST production for illustrating the main processing steps.

Considering the memory required for global data processing all at once, strategic block processing is chosen in the software design, i.e to divide the global grids into 8 blocks. Firstly to initialize the granule list, LST value and QC data in each block. At this step, the granule to tile mapping index will be read in to search for all granules in the block. Then those granules will be processed one by one to get the LST value and its QC value. In the meantime, the small tiles inside the block is processed in sequence. The LST value for each grid cell will be updated following the composition method. Global metadata will be set when all block processing is done. Finally the day night gridded LST will be output into a file separately.

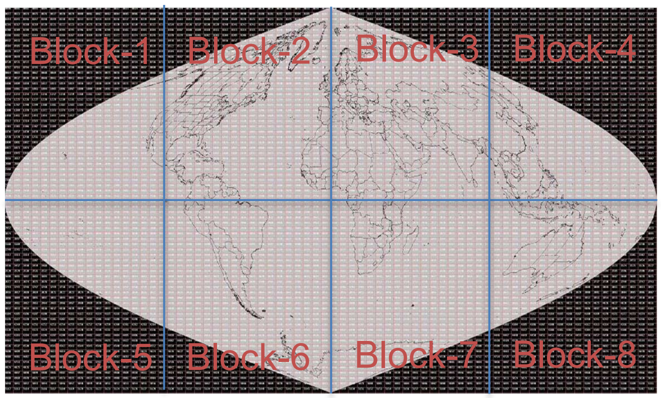


Figure 2-3 Block partition mapping

<< Do we still have the final product in 8 files (one for each block)? I thought we agreed all in one file.   Will revisit this paragraph again>>

2.1.2 Algorithm Input

The gridded LST requires the granule VIIRS LST and mapping index as input. The mapping index data is obtained from the gridding tool, which is stored as IP data. The mapping index file format and structure are described in the section for gridding tool.

Table 2-1 Algorithm input data.

Name	Type	Description	Format	Unit
Granule VIIRS LST	EDR	Granule VIIRS LST EDR	NetCDF	K

Title to granule mapping index file	IP	Output from the STAR gridding tool: tile to granule index map, which lists granule index within each tile.	Binary file with certain format	NA
Granule to tile mapping index file	IP	Output from the STAR gridding tool: granule to tile index map, which lists tile index within each granule.	Text file	NA

2.1.3 Algorithm Output

For each day, there are two LST output files: one for daytime and the other one for nighttime. The file is in NetCDF format with dimension of 43200 by 21600 i.e about 0.0083 degree in latitude and longitude directions for each grid. The algorithm output includes LST values, associated quality flags, view time as well as global metadata as shown in Table 2-2 and 2-3 for daytime and nighttime, respectively. The data is stored with sinusoidal projection. To minimize the file size, the LST value is stored as a scaled value in 16-bit integer type. View time is also scaled into a signed byte with a step of 0.1 hour. The quality flag is 1-byte in bitwise, which contains quality information of LST production for each grid. Table 2-4 gives the details of the quality flag component.

Table 2-2 Algorithm output data.

Variable Name	Descriptions	Data type	Unit	Valid Range	Fill Value	Scale Factor	Offset
LST_Day*	Daily daytime LST	Signed short	K	2600-28600	-32768, -32767	0.005	200
QC_Day*	Quality control flag for daytime LST	Signed byte	None		-128	NA	NA
View_Time_Day*	Time for daytime LST observation	Signed byte	0.1 hr	[-120,120]	-128	0.1	12
Metadata	Global metadata for statistics				NA	NA	NA

Table 2-3 Algorithm output data

Variable Name	Descriptions	Data type	Unit	Valid Range	Fill Value	Scale Factor	Offset
LST_Night*	Daily nighttime LST	Signed short	K	2600-28600	-32768, -32767	0.005	200

QC_Night*	Quality control flag for nighttime LST	Signed byte	None		-128	NA	NA
View_Time_Night*	Time for nighttime LST observation	Signed byte	0.1 hr	Print	-128	0.1	12
Metadata	Global metadata for statistics				NA	NA	NA

Table 2-4 Algorithms Product quality information flags

Bits	Long Name	Comments
1 & 0	Data quality flag	00=high quality 01=Medium quality 10=low quality 11=no retrieval
3 & 2	Cloud Confidence	00=confidently clear 01=probably clear 10=probably cloudy 11=confidently cloudy
5 & 4	Land/water	00=land 01=snow/ice 10=in land water 11=coastal/sea water
7 & 6	*Empty*	For future use

The bitwise quality flag component is described in table 2-4. Because the composition method selects one granule pixel that satisfies the selection criteria, it is one to one correspondence between the selected granule pixel and grid cell. The quality flag of the gridded LST is obtained from the selected granule LST pixel level quality flag. Bit 1-0 represents LST quality. The matrix below (table 2-5) describes the criteria for high, medium and low LST quality. For details, please refer to the enterprise LST ATBD. Bit 3 &2 represents cloud situation and bit 5 & 4 represents the land cover information.

Table 2-5 Product quality information flags

LST >= 0	Degraded – Sensor Zenith Angle > 40	Active fire	AOD Range (AOD available)	Thin Cirrus (Daytime)	Cloud Confidence Indicator		
					Confident Clear	Probably Clear	Probably Cloudy

T	x	X	x	yes	Low	Low	Low
T	x	X	out	x	Low	Low	Low
T	x	X	x	x	Low	Low	Low
T	x	Fire	x	x	Low	Low	Low
T	Out	No	in	no	Medium	Medium	Low
T	In	No	in	no	High	Medium	Low
F	x	X	x	x	No Retrieval	No Retrieval	No Retrieval

In addition to the quality control flags, metadata are provided in the LST product describing the product in detail as shown in Table 2-6. The metadata includes two parts: static metadata and dynamic metadata. One thing that needs to mention that the gridded LST output complies with the Climate and Forecast (CF) metadata convention. And it follows the metadata standard defined for environmental satellite processing and distribution system (ESPDS) development.

Table 2-6 Metadata defined for the LST product file.

Name	**Sample Value**	**Comment**
Conventions	CF-1.5, ACDD-1.3	CF Convention 1.5
standard_name_vocabulary	ACDD-1.3. v39	
project	NPP Data Exploitation	
institution	DOC/NOAA/NESDIS/OSPO > Office of Satellite and Product Operations, NESDIS, NOAA, U.S. Department of Commerce.”	
naming_authority	gov.noaa.nesdis.ncei.	
platform	JPSS-1	S-NPP
instrument	VIIRS	
title	LST-DLY-GLB	
summary	Gridded global daily LST	
history	V1.0	
processing_level	NOAA Level 3	
source	VIIRS-LST-EDR	
production_site	NSOF	
cdm_data_type	Grid	
Geospatial_lat_min	-90	
Geospatial_lat_max	90	
Geospatial_lon_min	-180	

geospatial_lon_max	180	
geospatial_lat_units	Degrees_north	
geospatial_lon_units	Degrees_east	
projection type	Sinusoidal	
longitude_of_projection_origin	0.0	
false_easting	0.0	
false_northing	0.0	
creator_name	DOC/NOAA/NESDIS/STAR > LST Team, Center for Satellite Applications and Research, NESDIS, NOAA, Department of Commerce.	
creator_email	*Yunyue.yu@noaa.gov; Yuling.liu@noaa.gov; heshun.wang@noaa.gov*	
creator_url	https://www.star.nesdis.noaa.gov/jpss/lst.php	
publisher_name	DOC/NOAA/NESDIS/NDE > NPP Data Exploitation, NESDIS, NOAA, U.S. Department of Commerce.	
publisher_email	espcoperations@noaa.gov	
publisher_url	http://www.ospo.noaa.gov/	
long_name	“total_number_retrievals”, "total_number_granules", "percentage_optimal_retrievals", "percentage_sub_optimal_retrievals", "percentage_bad_retrievals", "percentage_no_retrievals", "percentage_confidently_clear_retrievals", "percentage_probably_clear_retrievals", "percentage_probably_cloudy_retrievals", "percentage_confidently_cloudy_retrievals", "percentage_valid_retrievals", "percentage_invalid_retrievals", “percentage_produced”	
Total_number_retrievals	*9.5E7*	A whole number representing the sum of total number of retrievals in the file
Total_number_granules	*252*	Number of total granules used for the gridded LST generation
View_time_max	23.9	From field value of view time

		in UTC format, minimum view time
View_time_min	0.0	maximum view time
Percentage_optimal_retrivals	40	From field value of quality flag – ‘Data Quality Flag’, percentage of high quality data
Percentage_sub_optimal_retrivals	30	From field value of quality flag – ‘Data Quality Flag’, percentage of median quality data
Percentage_bad_retrivals	20	From field value of quality flag – ‘Data Quality Flag’, percentage of low quality data
Percentage_Other_retrivals	10	From field value of quality flag – ‘Data Quality Flag’, percentage of other quality data
Percentage_produced	40	From field value of quality flag – ‘Mandatory QA Flag’, percentage of produced data
Percentage_valid_range	30	From field value of LST, percentage of valid LST pixel within valid range 2600-28600
Percentage_invalid_range	30	From field value of LST, percentage of invalid LST pixel out of LST range of 2600-28600
Percentage_confidently_cloud	30	From field value of quality flag – ‘Cloud Confidence Indicator’, percentage of confidently cloudy pixel
Percentage_probably_cloud	30	From field value of quality flag – ‘Cloud Confidence Indicator’, percentage of probably cloudy pixel
Percentage_probably_clear	20	From field value of quality flag – ‘Cloud Confidence Indicator’, percentage of probably clear pixel
Percentage_confidently_clear	20	From field value of quality flag – ‘Cloud Confidence Indicator’, percentage of confidently clear pixel
lst_min	2700	Minimum LST value(LST not fill)

Lst_max	28500	Maximum LST value (LST not fill)
Lst_mean	25000	Mean LST value (LST not fill)
lst_std	2.6	Standard deviation of LST values(not fill)

2.1.4 Theoretical Description

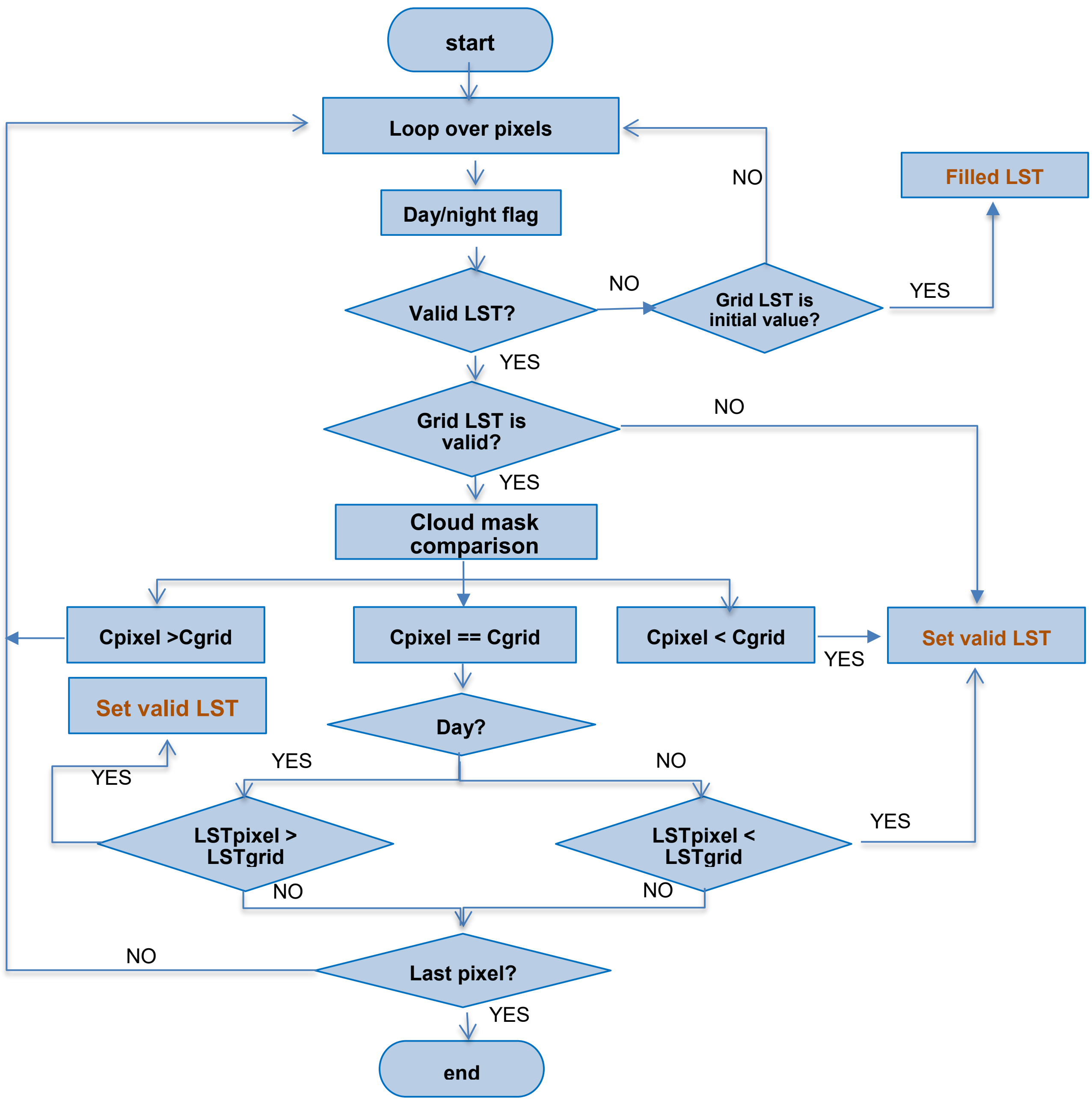


Figure 2-4 Flow chart for LST composition and QC setting.

In figure 2-4, Cpixel represents pixel cloud status; Cgrid represents grid cell cloud status; LST pixel is pixel LST value; LSTgrid is the grid cell LST value and the LST initial value is set to -32768. LST composition method compares the corresponding granule pixel and grid cell. Two criteria including cloud status and LST value are used in the multiple observation selection. The cloud status has the first priority, followed by LST value.

Firstly, when the pixel LST value is not valid, the LST value of the grid cell is set to be fill value if it is still the initial value, otherwise the processing will move forward to the next pixel. When the pixel LST value is valid, the LST value of the grid cell is set to be the pixel LST value if the grid cell LST is not valid.

If both pixel LST and grid LST are valid, the two criteria mentioned above will be considered. When the cloud clear confidence of a granule pixel is higher than that of a grid cell, then the grid cell LST is set to the granule pixel LST. If they have the same cloud status, then the LST value will be considered. For daytime, warmer LST is selected, while colder LST is selected for nighttime. If the cloud clear confidence of a granule pixel is lower than that of the grid cell, then the processing will move forward to the next pixel. Above process will be repeated until the last pixel.

2.2 The algorithm and processes for gridded LSA product

This section describes in detail the procedures for developing and using a land surface albedo (LSA) composition algorithm for generation of Level-3 (L3) VIIRS LSA grid from Level-2 (L2) LSA granules. Before the development of this document we already have the VIIRS LSA granule product [2] operationally produced in NOAA NDE system. The LSA granules provide shortwave daily mean albedo over land pixels and sea-ice surface. It has complete spatial coverage even in cloudy contaminated regions and shows reliable data quality according to long-term validation/monitoring practice.
However, the granule form of Level-2 product is not convenient for users because of two main reasons. First, it kept the observing geometry and spatial range of the raw satellite feed, which has to be obtained from granule-specific geolocation data. Users cannot easily subset the data of an interested area. Second, many retrievals can be generated for the same pixel due to the repeated visit within one day. The revisit frequency is especially high in the Polar Region. Some inconsistency cannot be avoided among the repeated observations due to the inherent uncertainty of radiance correction and direct retrieval algorithm. Therefore, we aims to map LSA values from granule pixels to grid cells in Sinusoidal projection, which is easier to overlay with other albedo products and fits for the interest of the user community. When multiple observations corresponds to one pixel, we select the 'best' daily mean albedo using a composition algorithm.

The main content in this section is a description of the proposed composition algorithm, based on rules considering the cloud condition, solar/view zenith angles, and surface cover type. All these factors will be recorded in the quality flag as reference information. Required input data and the expected output for the LSA product are listed.

2.2.1 Processing Outline

Level 3 LSA product was implemented based on Level-2 data with two processing steps: anchoring the science data to specific geographic points and composition in temporal dimension to produce daily global LSA map that has been gridded into a specific map projection. Thus the L3 LSA algorithm is composed of a gridding process and a composition process. The processing outline of the LSA is summarized in Figure 2-5.

The gridding process is to transform the granules into stacked layers in albedo tiles. The gridding process has been packaged into a mutual tool with the generated gridding index files supporting the mapping process of various land surface products (refer to gridding Section). The mutual gridding process includes 72*72 non-overlapping tiles in Sinusoidal projection. Each tile has the same size and uniform spatial resolution. The output gridding index has been organized in two types of files. First, one granule-to-tile index is tied to each granule and contains the covered tiles' ID of that granule. Second, one tile-to-granule index is tied to each tile; it includes the overlapped granule list of that tile and the pixel-to-cell relationship. Both the two types of gridding index files introduced above have been used in the mapping process. At the start, scanning the global granule-to-tile index files and de-duplicating the covered tiles will result in a list of L2-covered tiles within the day. Then looping over these valid tiles would save computer time and cost. For each tile, the tile-to-granule index file will provide the overlapped granule IDs and the correspondence between granule pixels and tile cells. The index information guides the mapping process of granule albedo to the tile grid before the composition process. After all the tiles done, the composited LSA tiles would be combined to a global map on the earth grid. The metadata items are also calculated at global level.

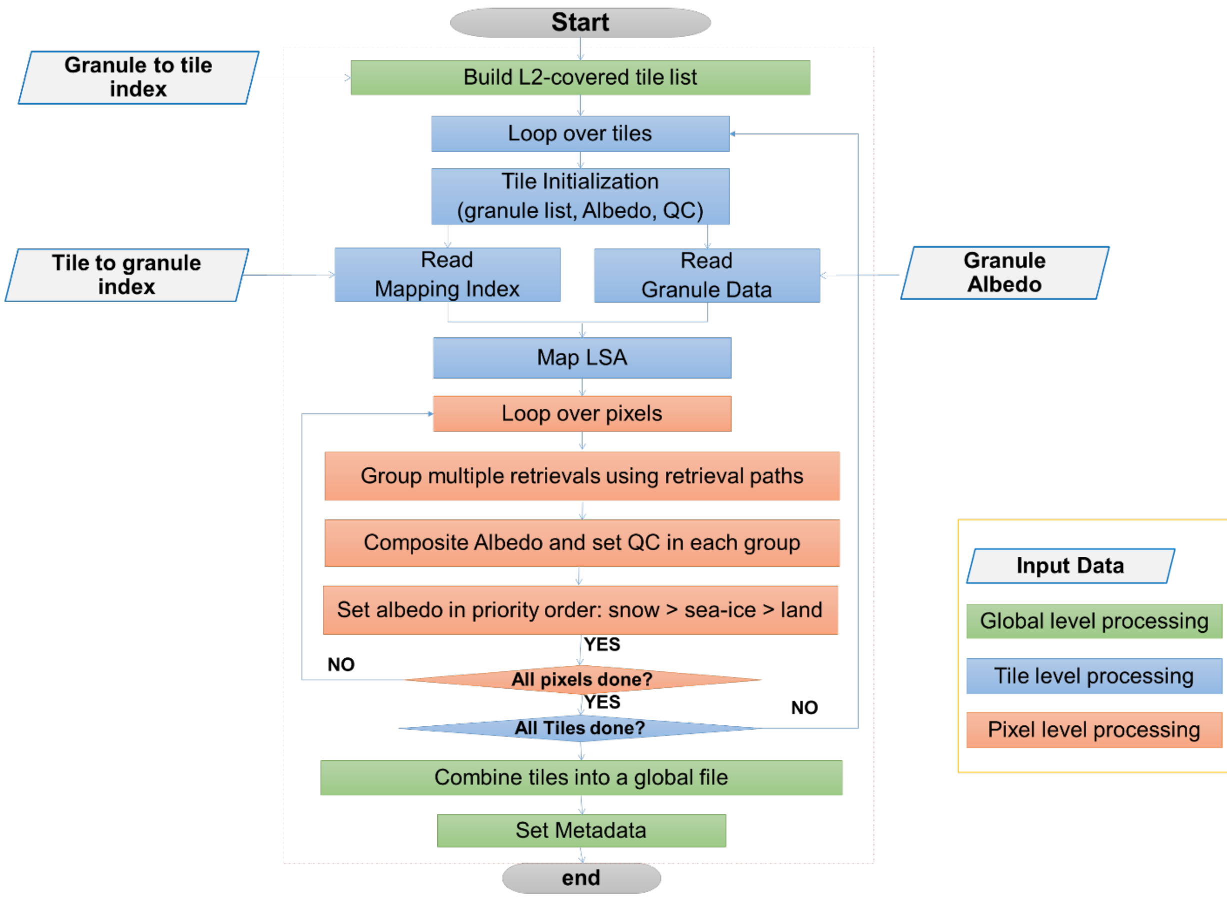


Figure *2-5* **High Level Flowchart of the LSA production for illustrating the main processing steps.** *Note that the detailed content of pixel-level processing is illustrated in Figure 2-6.*

The LSA composition at pixel level is a process of selecting the 'best' retrieval from the time-series observations under the designed rule. The retrieval paths (refer to 'land cover types'), cloud conditions and the geometry angles are the three types of factors considered. These information can be obtained from the L2 product quality information (PQI).

2.2.2 Algorithm Input

This section describes the input needed to process the Level 3 LSA product (Table 2-7).

Table 2-7 Level-2 LSA algorithm input.

Name	Type	Description	Source	Dimension	Format	Unit
VIIRS LSA granules	EDR	Granule-based LSA EDR product	NDE Granule LSA product	granule (3200, 768)	NetCDF	unitless

			(L2)			
Tile info	IP	include the list of intersected granules within each tile and the mapping index from granule to tile	Common gridding tool from STAR	Vary from data	Binary	unitless
Granule info	IP	include the list of intersected tiles within each granule	Common gridding tool from STAR	Vary from data	Text	unitless

2.2.3 Algorithm Output

The LSA values and quality flags data arrays are described in Table 2-8.

Table 2-8 Algorithm output data.

Name	Type	Description	Attributes	Valid Range	Fill Value	Dimension	Unit
VIIRS_Albedo_1km	Output	Tile-based gridded LSA	Scale_Factor, Offset_Factor	[0, 10000]	32767	grid (xsize, ysize)	unitless
QualityFlag	Output	Tile-based Quality Flag		[0, 127]	-1	grid (xsize, ysize)	unitless

The QualityFlag is 1-byte bitwise signed char, which contains quality information of LSA production for each pixel. This information is designed to help users in their applications. Details of each bit is introduced in Table 2-9.

Table 2-9. Product quality information flags.

Byte	Bit	Flag	Source	Effect
0	0-1	Overall Quality	Refer to Table 2-15	00: high quality retrieval 01: medium quality retrieval 10: low quality retrieval 11: no retrieval
	2-3	Cloud Confidence	Level-2 LSA	00: confidently clear 01: probably clear 10: probably cloudy

				11: confidently cloudy
	4-6	Retrieval Path	Level-2 LSA	00: generic 01: desert 10: snow 11: sea-ice
	7	Spare		

Note:
1. The left-most bit is the most significant bit (the high-order bit) in the definition and description of the Quality Flag.
2. For pixels with no retrieval (0-1 bit as 11), the other bits are set as default fill-value.

In addition to the pixel level LSA values and QualityFlag, metadata are needed in the LSA product describing the common and LSA specific information about the product. Table 2.10~2.14 provides the metadata list in gridded LSA product.

Table 2-10 Global Static Attributes.

Attribute Name	Data Type	Value	Description
Conventions	String	CF-1.6	CF Convention 1.6
standard_name_vocabulary	String	ACDD-1.3. v1	Specify the CF Standard Name Table
project	String	NPP Data Exploitation	All files are created by the NDE system.
institution	String	DOC/NOAA/NESDIS/OSPO > Office of Satellite and Product Operations, NESDIS, NOAA, U.S. Department of Commerce.”	
naming_authority	String	gov.noaa.nesdis.ncei.	the organization that provides the “id” attribute, which is the responsible NESDIS data center
platform	String	S-NPP (npp) NOAA-20 (j01)	the satellite(s) used to derive the product
instrument	String	VIIRS	the instrument(s) used to derive the product
title	String	LSA-DLY-GLB	the product short name
summary	String	Earth surface daily mean albedo over land and sea-ice surface	briefly describe the product
history	String	Gridded LSA Version 1	the algorithm name and version used to produce the product
processing_level	String	NOAA Level 3	the level of processing. Level-2 products represent Environmental Data Records (EDRs). Level 3 are products derived from Level-2 (e.g., composites).
source	String	VIIRS_LSA_EDR, VIIRS_gridding_index	all major input files
production_site	String		This attribute must be copied from NDE system file [TBD] and describes the processing site for the product.
production_envir	String		This attribute must be copied from NDE

onment			system file [TBD] and describes the processing string generating the product.
references	String	VIIRS L3 LSA ATBD	Published or Web-based references describing the data or methods used to produce the product.

Table 2-11 Global Dynamic Attributes.

Attribute Name	Data Type	Description
metadata_link	string	A URL that gives the location of more complete metadata or a product information web page.
start_orbit_number	int	This attribute is a sequential whole number set by the S-NPP/JPSS Ground System in the xDR metadata. Orbits are incremented on the northward equatorial node.
end_orbit_number	int	Similar to the above one
day_night_data_flag	string	"day" for LSA product
time_coverage_start	string	This attribute should be set to the UTC start time of an observation as "YYYY-MM-DDThh:mm:ssZ," where YYYY is the four-digit year, MM is the two-digit month, DD is the two-digit day, hh is the UTC hour, mm is the UTC minute, and ss is the UTC second.
time_coverage_end	string	Similar to the above one
date_created	string	Similar to the above one

Table 2-12 Gridded Geographic Metadata.

Attribute Name	Data Type	Value	Description
cdm_data_type	string	Grid	the geographic category
projection type	string	Sinusoidal	the projection type of the grid
longitude_of_projection_origin	float	0	the projection parameters
false_easting	float	0	
false_northing	float	0	
geospatial_lat_min	float	-90	the bounding latitudes and longitudes of the geospatial coverage of the grid
geospatial_lat_max	float	90	

geospatial_lon_min	float	-180	
geospatial_lon_max	float	180	
geospatial_lat_units	string	Degrees_north	
geospatial_lon_units	string	Degrees_east	

Table 2-13 Quality Information Variable Attributes.

Attribute Name	Data Type	Description
percentage_optimal_retrievals	float	Percentage of the total number of retrievals that satisfy an algorithm team defined threshold for high-quality retrievals. Statistic from 'Overall Quality' in 'QualityFlag' with the value of '00'.
percentage_sub_optimal_retrievals	float	Percentage of the total number of retrievals that satisfy an algorithm team defined threshold for medium-quality retrievals. Statistic from 'Overall Quality' in 'QualityFlag' with the value of '01'.
percentage_bad_retrievals	float	Percentage of the total number of retrievals that satisfy an algorithm team defined threshold for poor or failed retrievals. Statistic from 'Overall Quality' in 'QualityFlag' with the value of '10'.
percentage_no_retrievals	float	Percentage of the total number of pixels with no retrievals. Statistic from 'Overall Quality' in 'QualityFlag' with the value of '11'.
percentage_confidently_clear_retrievals	float	Percentage of the total number of retrievals under confidently clear condition. Statistic from 'Cloud Confidence' in 'QualityFlag' with the value of '00'.
percentage_probably_clear_retrievals	float	Percentage of the total number of retrievals under probably clear condition. Statistic from 'Cloud Confidence' in 'QualityFlag' with the value of '01'.
percentage_probably_cloudy_retrievals	float	Percentage of the total number of retrievals under probably cloudy condition. Statistic from 'Cloud Confidence' in 'QualityFlag' with the value of '10'.
percentage_confidently_cloudy_retrievals	float	Percentage of the total number of retrievals under confidently cloudy condition. Statistic from 'Cloud Confidence' in 'QualityFlag' with the value of '11'.
percentage_general_land_retrievals	float	Percentage of the total number of retrievals over land surface except desert and snow-covered area. Statistic from 'Retrieval Path' in 'QualityFlag' with the value of '00'.

percentage_desert_retrievals	float	Percentage of the total number of retrievals over desert. Statistic from 'Retrieval Path' in 'QualityFlag' with the value of '01'.
percentage_snow_retrievals	float	Percentage of the total number of retrievals over snow-covered surface. Statistic from 'Retrieval Path' in 'QualityFlag' with the value of '10'.
percentage_sea_ice_retrievals	float	Percentage of the total number of retrievals over sea-ice surface. Statistic from 'Retrieval Path' in 'QualityFlag' with the value of '11'.
percentage_no_retrievalpath	float	Percentage of the total number of retrievals not from direct estimation. Statistic from 'Retrieval Path' in 'QualityFlag' with fill value.
Min_LSA	float	Minimum value of LSA
Max_LSA	float	Maximum value of LSA
Mean_LSA	float	Mean value of valid LSA
Std_LSA	float	Standard deviation value of valid LSA
total_number_retrievals	int	A whole number representing the summation of the total
total_number_granules	int	Number of Level 2 ganules used to generate the Level 3 LSA

Note: the value of the items in this table are determined at running.

Table 2-14 Creator and Publisher Attributes.

Attribute Name	Data Type	Value	Description
creator_name	string	DOC/NOAA/NESDIS/STAR > LSA Team, Center for Satellite Applications and Research, NESDIS, NOAA, Department of Commerce.	include STAR and the name of the algorithm team responsible for development of the product
creator_email	string	yunyue.yu@noaa.gov; jjpeng@umd.edu yzhou128@umd.edu	e-mail for the algorithm development team. This attribute offers users the opportunity to contact developers directly
creator_url	string	https://www.star.nesdis.noaa.gov/jpss/albedo.php	the product Web site that users can access.
publisher_name	string	DOC/NOAA/NESDIS/NDE > NPP Data Exploitation, NESDIS, NOAA, U.S.	NDE

		Department of Commerce.	
publisher_email	string	espcoperations@noaa.gov	the OSPO ESPC Help Desk e-mail
publisher_url	string	http://www.ospo.noaa.gov/	the OSPO Web site

2.2.4 Theoretical Description

The theoretical details of the VIIRS L3 LSA algorithm development is provided.

2.2.4.1 Composition method

The composition process starts from a time-series LSA array resulted from mapping the L2 granule LSA. The actual question here is how to select the most reliable LSA value from all these candidates? We regarded the median value within the similar group as the 'best' choice for two reasons. First, it would be better to maintain the original retrievals rather than a two-stage calculation that will complicate the uncertainty assessment of the algorithm. Second, the median calculation will eliminate outliers when multiple candidates observations available. Considering the candidate observations may have different quality level, not all observations will go through the median calculation altogether. The L2 LSA would be grouped first and the highest-quality-group will be adopted.

To determine how to select the 'best' LSA observation, a nested grid style of calculation is performed and a hierarchy of criterions are used (Figure 2-6). The L2 LSA observations have been grouped according to the cloud condition and observation angles. The four groups are regarded with different quality level (Table 2-15). The highest quality group will be selected preferentially. Within each group, the observations are categorized into Snow, Sea-ice, and others. Within each category, the median LSA value is assigned as the final value. Among different categories, snow value is prioritized and followed by sea-ice and then others. The median LSA of the prioritized category within the highest priority group is assigned as the L3 LSA of the grid cell.

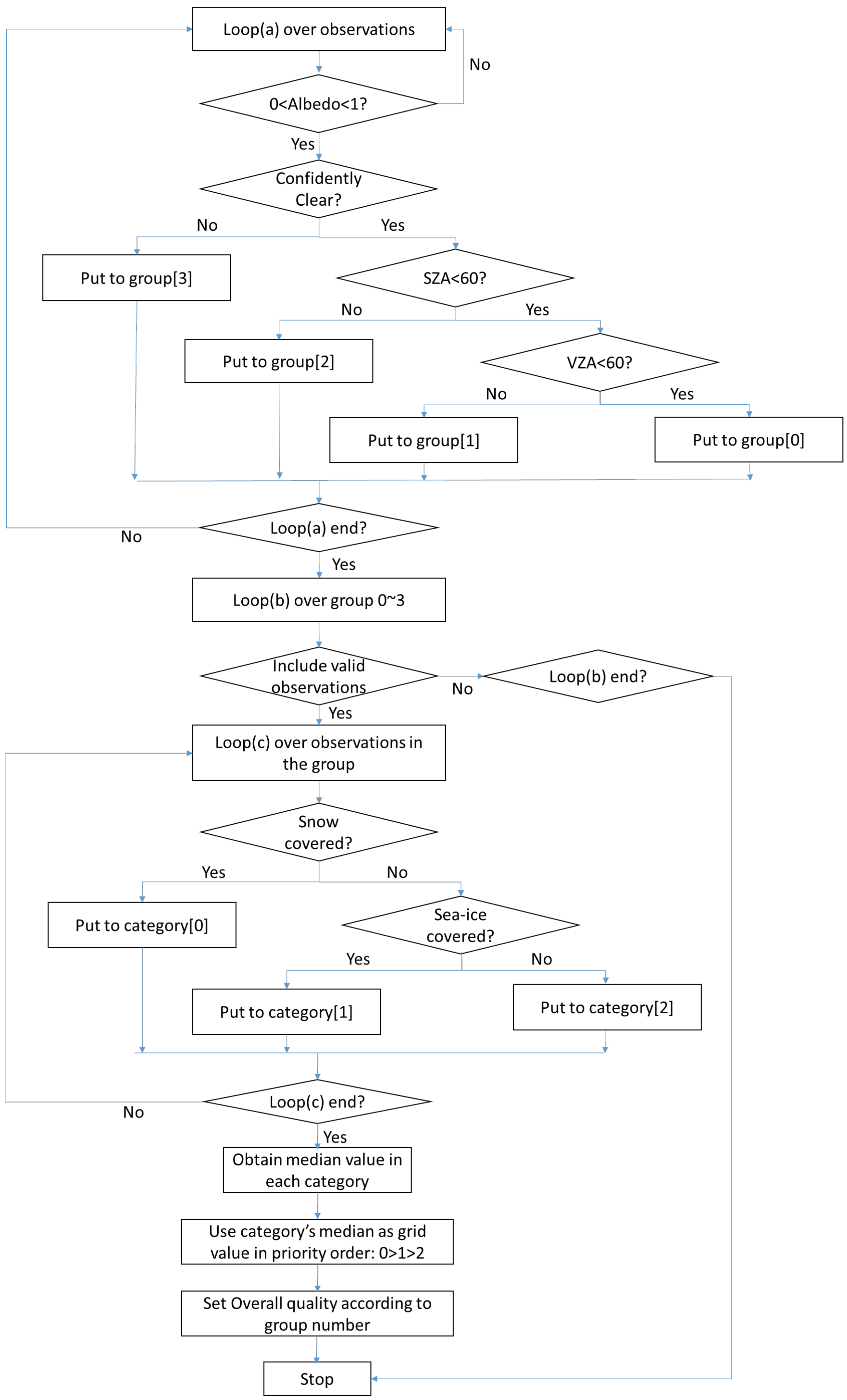


Figure 2-6 Pixel-level processing flowchart in the composition algorithm.

Table 2-15 Rule matrix to determine the L3 albedo selection priority and quality. The italic items describe the characteristics determining the quality of varios groups. The matrix with gray background provides the priority level and quality flag of different categories within various groups. The priority sequence is from 1 to 12. The quality flag '00' denotes high quality; '01' represents medium quality; '10' corresponds to low quality.

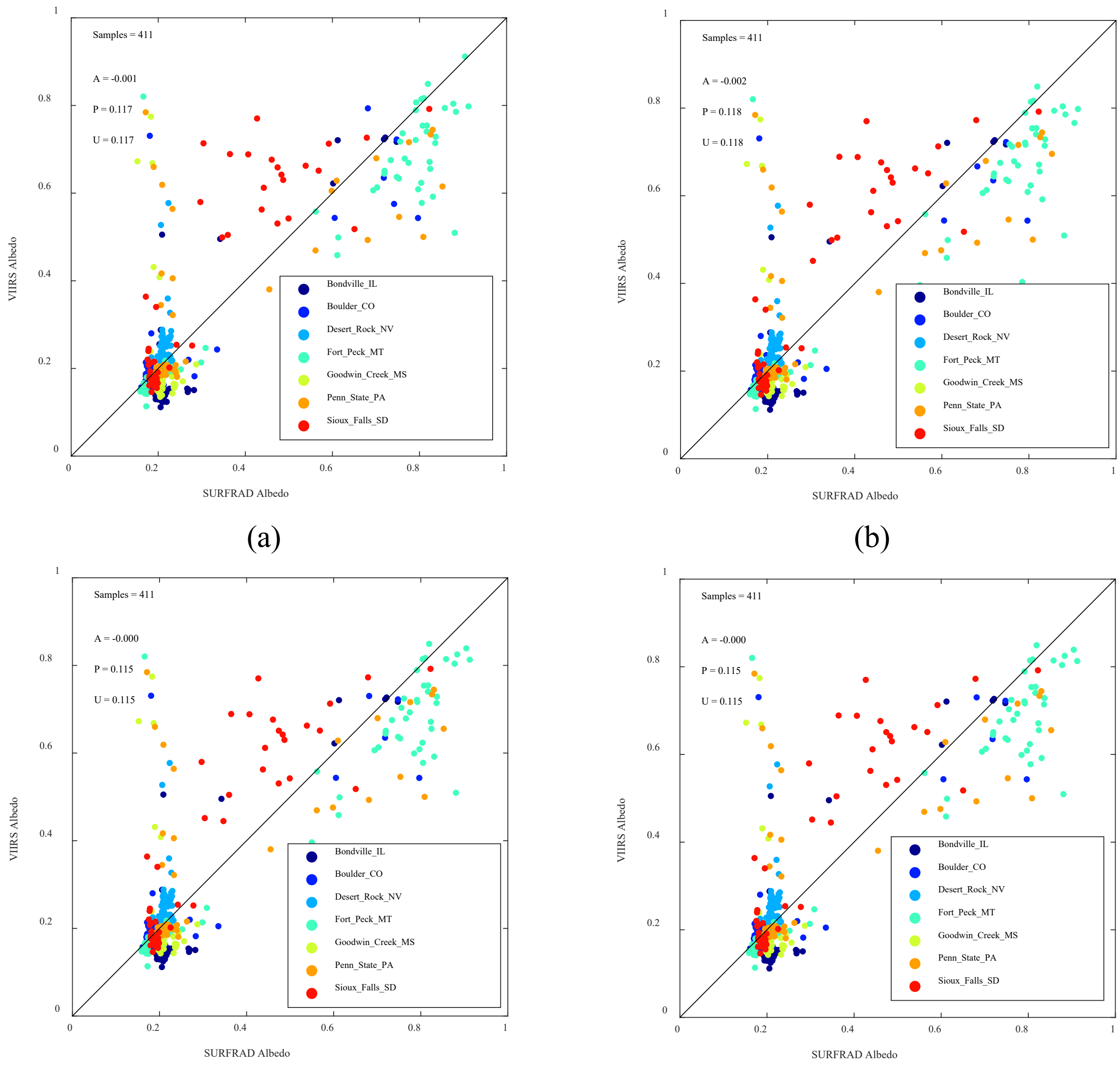
Albedo range	*[0,1]*	*[0,1]*	*[0,1]*	*[0,1]*
Cloud condition	*Confidently Clear*	*Confidently Clear*	*Confidently Clear*	*Probably Clear; Probably Cloudy; Confidently Cloudy*
SZA	*<=60°*	*<=60°*	*>60°*	--
VZA	*<=60°*	*>60°*	--	--
	Group[0]	Group[1]	Group[2]	Group[3]
Snow	Priority: 1 QualityFlag: 00	Priority: 4 QualityFlag: 01	Priority: 7 QualityFlag: 01	Priority: 10 QualityFlag: 10
Sea-ice	Priority: 2 QualityFlag: 00	Priority: 5 QualityFlag: 01	Priority:8 QualityFlag: 01	Priority: 11 QualityFlag: 10
Other	Priority: 3 QualityFlag: 00	Priority: 6 QualityFlag: 01	Priority: 9 QualityFlag: 01	Priority: 12 QualityFlag: 10

2.2.4.2 Algorithm Selection

To select a suitable algorithm for the VIIRS LSA composition, we analyzed the accuracy and sensitivity of five candidate composition algorithms: (a) using observation with smallest SZA; (b) using observation with smallest VZA; (c) mean value of the observations; (d) median value of the observations; (e) the 9-day temporally filtered result. The reason of considering the first two methods is that the geometric angles dramatically influences the albedo uncertainty. The methods 3~4 are commonly used in composition at temporal scale. The last one is a LSA specific method, which is used in the Level-2 algorithm's offline component.

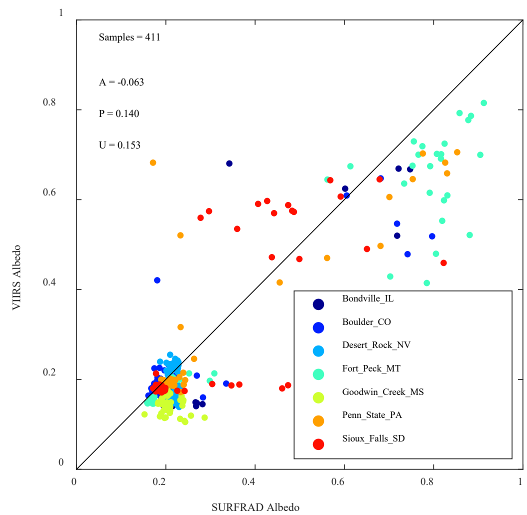
Here is an experiment using a long-term ground observation dataset from the SURFace RADiation (SURFRAD) network as reference data to test the composition methods. The input data were collected from L2 NPP LSA retrievals spanning from Jan 7, 2018 to Sep 17, 2018. We generated L3 composited albedo using these different strategies and compared with the ground measurements to see which algorithm has the highest accuracy. Note that the gap-filled pixels has not been counted in the following comparison, because they are derived from the temporal filtering algorithm same as (e) and keeps the same under different composition strategies.

The (d) median strategy has been selected as the composition method in the current algorithm design, because it has the highest accuracy (Figure 2-7 and Table 2-16) and would be more stable than the (c) mean method when outliers exist. Note that the accuracy demonstrated is only used for comparison among different strategies, which does not reflect the product performance due to the limited sample size; 2) the in-situ dataset contains some measurements with strong heterogeneity.



(a) (b)

(c) (d)



(e)

Figure 2-7 Scatterplots between in situ albedo and the composited NPP VIIRS albedo from various composition strategies. (a) the retrieval with smallest SZA; (b) the retrieval with the smallest VZA; (c) the mean value of the retrievals; (d) the median value of the retrievals; (e) the 9-day temporal filtered albedo from L2 offline output.

Table 2-16 The comparison results from different composition methods using SURFRAD measurements.

Strategy	Accuracy (A)	Precision (P)	Uncertainty (U)
(a) smallest SZA	-0.001	0.117	0.117
(b) smallest VZA	-0.002	0.118	0.118
(c) mean	0.000	0.115	0.115
(d) median	0.000	0.115	0.115
(e) Temporally filtered	-0.063	0.14	0.153

2.2.4.3 Uncertainty Estimation

We note that the L3 LSA value inherited the values of L2 LSA. The uncertainty factors related to the shortwave daily mean albedo value have been discussed in the L2 LSA ATBD (refer to) and would not be demonstrated here.

The additional uncertainty is resulted from the 'nearest neighboring' resampling method used in the gridding process. The granule pixel resolution is 750-m while the grid cell resolution is 1-km. The granule pixel area can represent 56% of the grid cell coverage at most when the former is totally contained in the latter. Assuming the perfect geolocation correction of the L2 data, then the magnitude of the mapping uncertainty in L3 LSA depends on the physical properties of the land composition within a L3 grid cell's given footprint.

3 Practical Considerations

3.1 Programming and Procedural Considerations

The LST/LSA gridding requires no complicated mathematical routines. The gridding tool takes the majority processing time. Therefore it is set to run when each granule data is feed in. So at the end of a day, the mapping index data is ready to use. In addition, both the Tile to granule and granule to tile index IPs from the gridding tool are used for the mapping procedure to improve the processing efficiency. For storage consideration, LST/LSA values should be scaled in two-byte integers, with scale factors and offset defined in the attributes. Quality flags for each pixel value should be bit-flag definitions, to minimize data storage. Besides, parameters such as platform/platform_id, working directory setting, ancillary file name, static metadata etc should be configurable. A configuration file and a static metadata file containing those variables are used in the software development. It provides flexibility when adding or changing the metadata item.

Because the global data processing requires large array operation, block processing is recommended in the LST code development. The LSA code digest one tile at the same time and write the global output file in an append mode.

The gridded products will be assessed and monitored. For LST, a set of quality control flags will be generated for retrieval diagnostics, as presented in Section 2.3. The quality control flags will indicate the retrieval conditions, including the land/non-land surfaces (i.e., land, snow, ice, inland water etc.), LST quality etc. LST maps and statistical information will be generated and reviewed for quality assessment. For LSA, the pixelwise quality flags indicate the overall reliability of each retrieval, the cloud information, and the land cover type. The metadata parameters include statistics from each quality flag and albedo value, which provide global overall information of the daily LSA product for monitoring use.

3.2 Exception Handling

Exceptions e.g. missing granules, granule file error, incomplete mapping index file etc are taken into account in the software design. Missing granules will not interrupt the gridded LST/LSA processing, only the coverage of the gridded LST output might be impacted. Ancillary data file and gridding tool output files are checked in the processing. For granule read error, the file status such as non-exist file, file size error etc is checked when read in the granule file and the error message will be provided.

The LSA code creates a log file for capturing actions, errors, or warnings that occur during algorithm execution. In addition, the program provides a return code to signify the success (or failure) of a job.

4 Evaluation

4.1 Evalution of the gridded LST data

Gridded LST can be evaluated through the comparison with the ground observations and cross compassion with other satellite gridded LST product. The result from the ground data validation of the granule LST can be used to represent the quality of the gridded product because the gridded LST is obtained from the instantaneous correspondent granule pixel LST. For details, please refer to the enterprise VIIRS LST ATBD, which provides quantitative validation of the granule VIIRS LST.

In this study, the gridded VIIRS LST is compared to the gridded MODIS LST MYD11A1 in collection 6. MYD11A1 product is tile based so it is firstly mosaicked to be a global dataset to compare with the global gridded VIIRS LST. Following procedures are used for the matchup between the two gridded products: same grid is compared because both dataset are 1km spatial resolution with Sinusoid projection; the view time difference is within 12 minutes and both grid are under cloud clear condition. The data on June 21, 2018 is selected for the comparison.

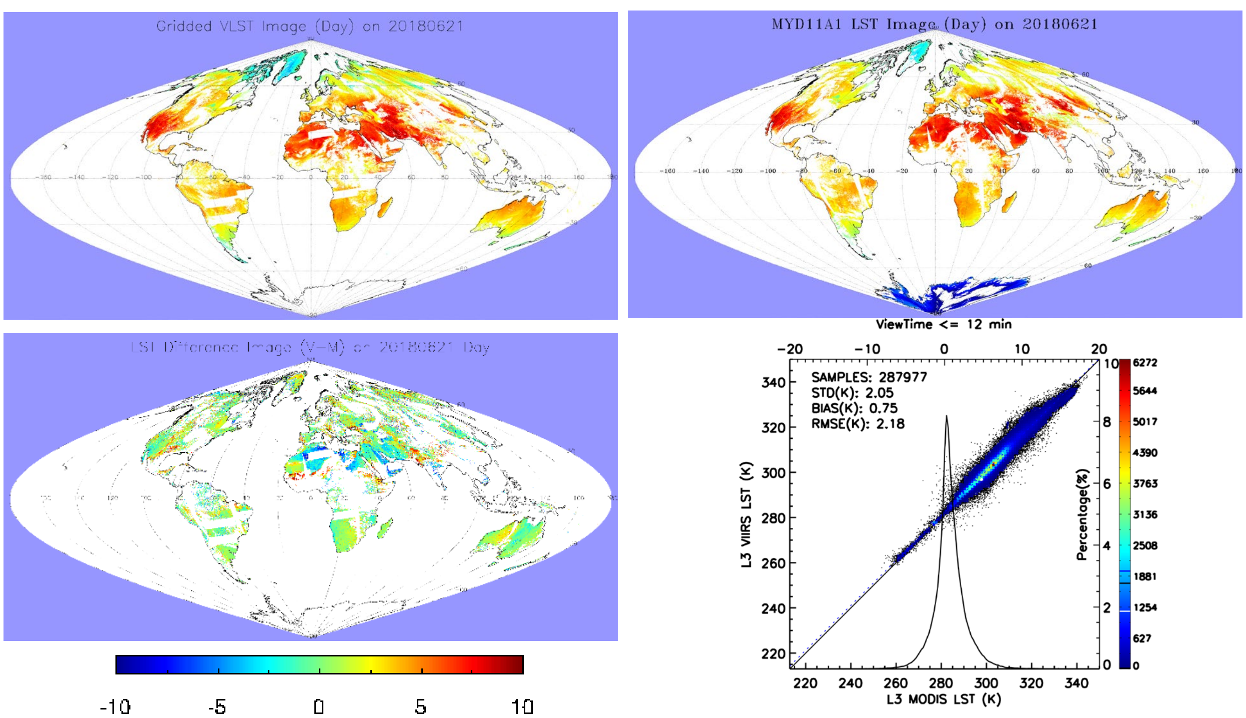


Figure 4-1 Cross comparison: daytime case on June 21, 2018

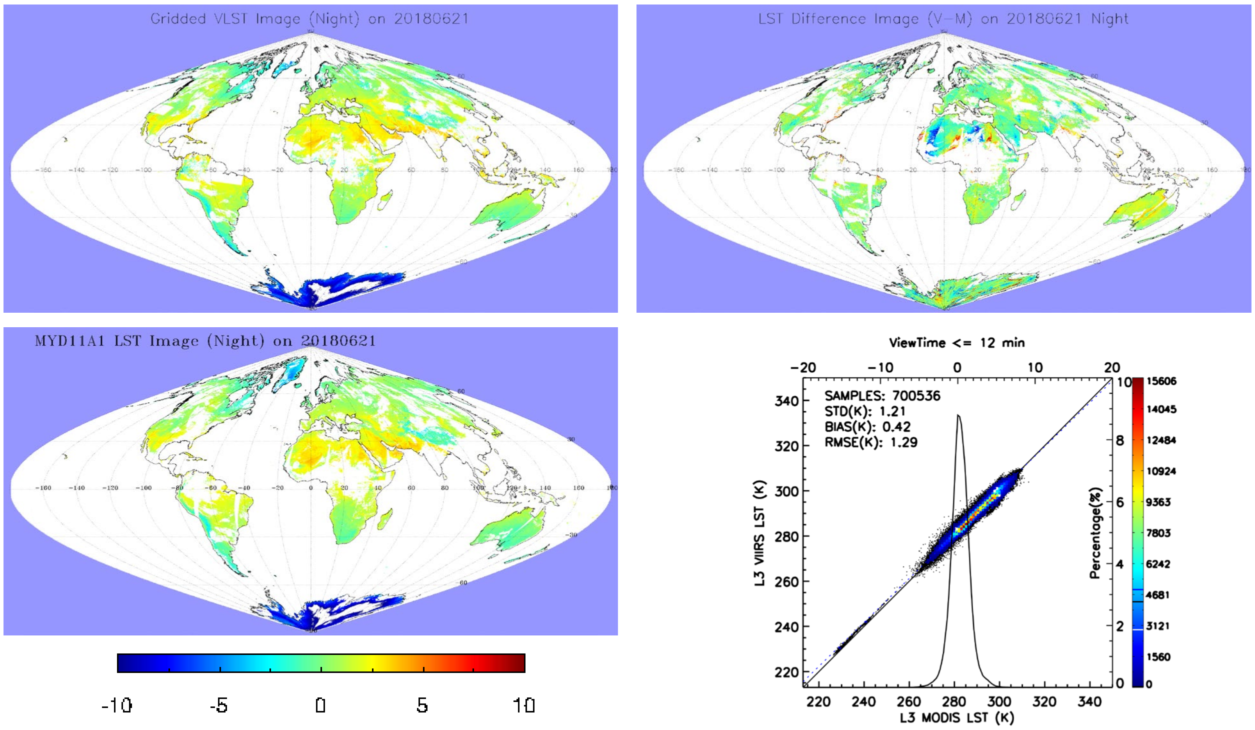


Figure 4-2 Cross comparison: nighttime case on June 21, 2018.

Two cases are selected for the cross comparison, one for daytime and the other one for nighttime. The top left figure shows the gridded VIIRS LST image and the top right shows the gridded MODIS LST image. The bottom left shows the difference map between the gridded VIIRS and MODIS LST. And the bottom right shows the statistical results for the difference, which presents a bias of 0.75K and 0.42 K and RMSE of 2.2 and 1.3 for daytime and nighttime, respectively.

Note that the cross comparison might be impacted by the cloud detection and also by the difference in the viewing time and their composition method between the two LST products.

4.2 Evaluation of the gridded LSA data

We relied on two methods to evaluate the gridded LSA product. First, direct comparison with the in-situ measurements helps to understand the absolute accuracy and precision of VIIRS albedo. Since the L3 albedo value is directly grabbed from Level 2 albedo product, the direct comparison result is consistent as the previous validation attempts for Level 2 albedo product [2]. Second, the cross comparison with the MODIS daily mean albedo provides us information about the difference between these two series of products, which is the main content of this section.

4.2.1 Data sets

4.2.1.1 SNPP VIIRS Level-2 LSA

S-NPP was launched in October, 2011. The Land Surface Albedo (LSA) retrieval algorithms implemented in IDPS has been migrated to NDE within VPLS and implemented as “Enterprise Algorithms”, with significant improvements to the IDPS LSA algorithms. The L2 VIIRS LSA generated from the enterprise algorithm should be the input for this L3 algorithm as design.

4.2.1.2 NOAA-20 VIIRS Level-2 LSA

NOAA-20 was launched on November, 2017. It has an identical instrument suite to S-NPP, so its VIIRS dataset can utilize the LSA algorithm developed for S-NPP directly.

4.2.1.3 MODIS MCD43 datasets

MODIS on board Terra and Aqua has been regarded as the keystone instrument for global quantitative remote sensing of atmosphere, land, and ocean processes. It scans ±55° from nadir and provides solar reflection in visible and near-infrared bands for LSA estimation. The VIIRS sensor was designed to extend and improve upon the series of predecessors including MODIS, so it makes the MODIS product very suitable for the pre-launch testing/validation of the VIIRS Level-3 LSA algorithm.
We collected the MODIS BRDF product (MCD43A1) and the quality data (MCD43B1) within the same period of SNPP and NOAA-20 LSA, and derived daily mean albedo from the BRDF data. The daily mean albedo is defined as the ratio of the daily upward shortwave energy and daily downward shortwave energy per unit area.

$$\alpha_{daily} = \frac{\int_{day} l_u(t)dt}{\int_{day} l_d(t)dt} = \frac{\int_{day} \alpha(t) l_d(t)dt}{\int_{day} l_d(t)dt}$$

$$\alpha(t) = \alpha^w \rho + \alpha^b(t)(1-\rho)$$

Here α^w and α^b refer to white-sky albedo and black-sky albedo respectively, which are calculated from BRDF. ρ is the fraction of scattered skylight in incident radiance, and $l_d(t)$ notes the downward radiation. They were simulated as the functions of solar zenith angle and atmospheric parameters.

4.2.2 Results

4.2.2.1 Test output

Figure 4-3 gives examples of the test results using SNPP and NOAA-20 L2 LSA inputs. It is shown that the LSA value range is reasonable and the spatial distribution of the LSA is consistent with our prior knowledge.

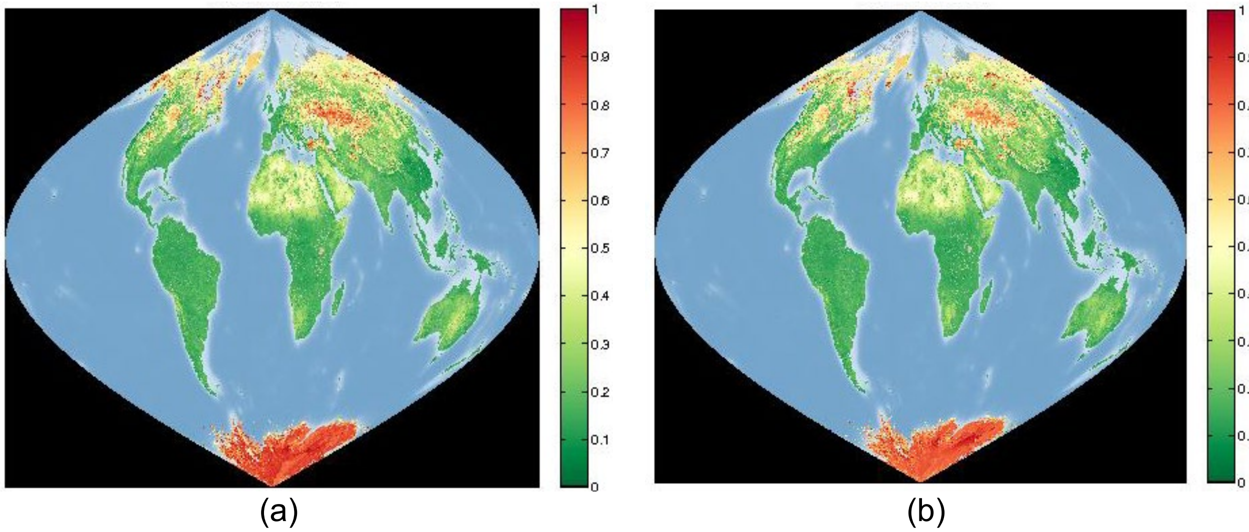


Figure 4-3 Sample LSA image derived from (a) S-NPP VIIRS L2 LSA; (b) NOAA-20 VIIRS L2 LSA on Jan 8, 2019

4.2.2.2 Comparison result

Figure 4-4 demonstrates the cross-comparison results between SNPP and NOAA-20 L3 LSA. They are consistent with each other generally, although with some scattered points (figure 4-4a). Categorizing the retrievals according to their quality level and comparing each category separately, it was found that the low-quality retrievals dominate the scattered match-ups. The match-ups from high-quality retrievals are closely around the 1:1 line, showing the clear-sky retrievals from direct LUT retrievals have reliable and stable quality (figure 4-4b). The medium-quality match-ups are fine but with more scattered points, which are mainly happens at the large-angle retrievals (figure 4-4c). The low-quality retrievals include the majority of scattered points as they come from filled values which are influenced by the time-series data completeness and quality (figure 4-4d).

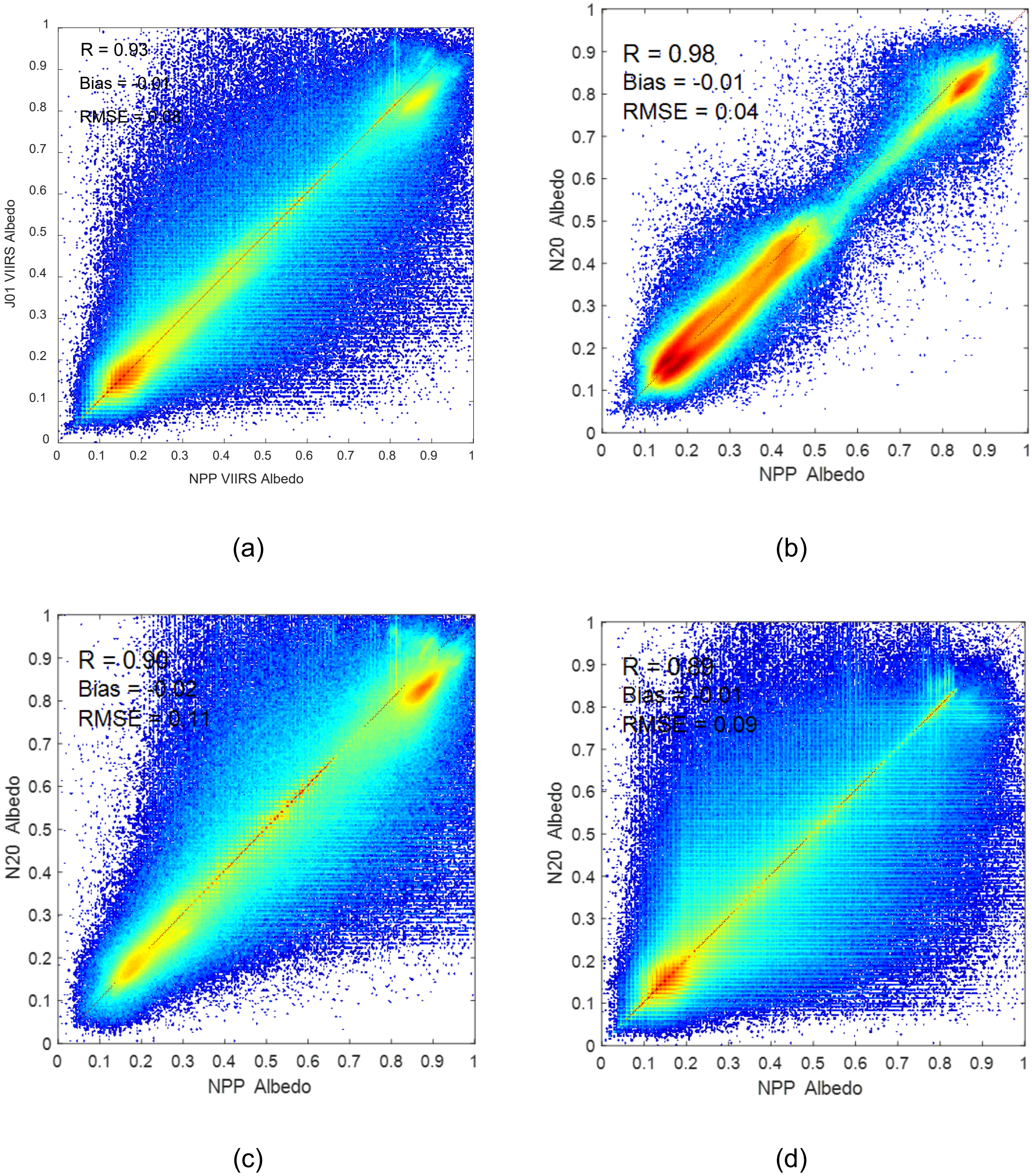
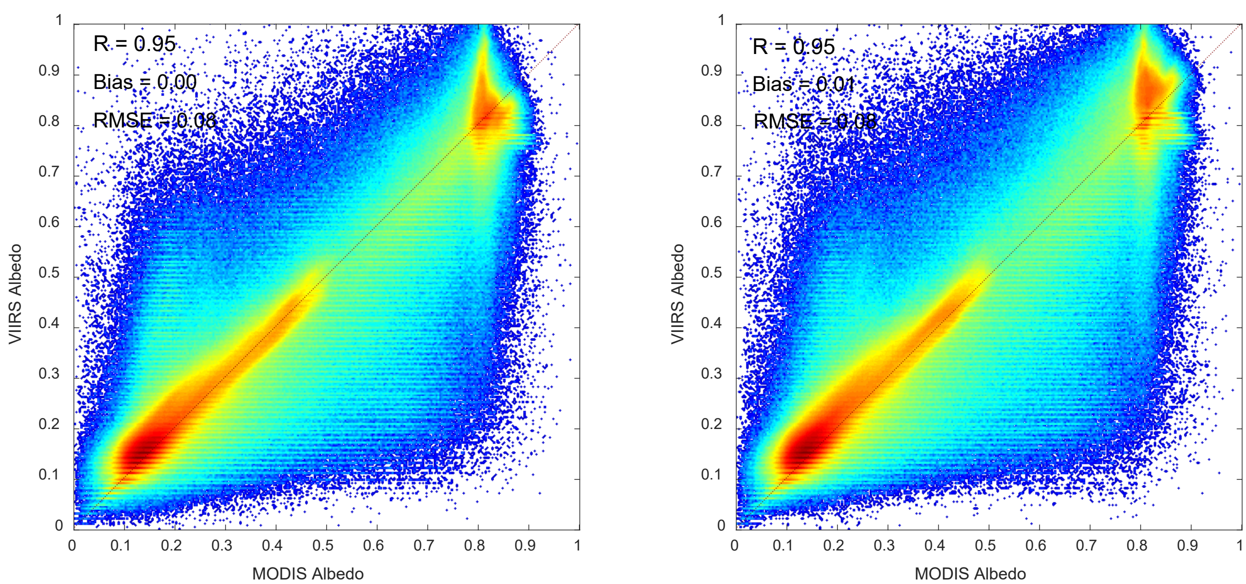

R = 0.93
Bias = -0.01
J01 VIIRS Albedo
NPP VIIRS Albedo
(a)
R = 0.98
Bias = -0.01
RMSE = 0.04
N20 Albedo
NPP Albedo
(b)
Bias = -0.02
RMSE = 0.11
N20 Albedo
NPP Albedo
(c)
RMSE = 0.09
N20 Albedo
NPP Albedo
(d)

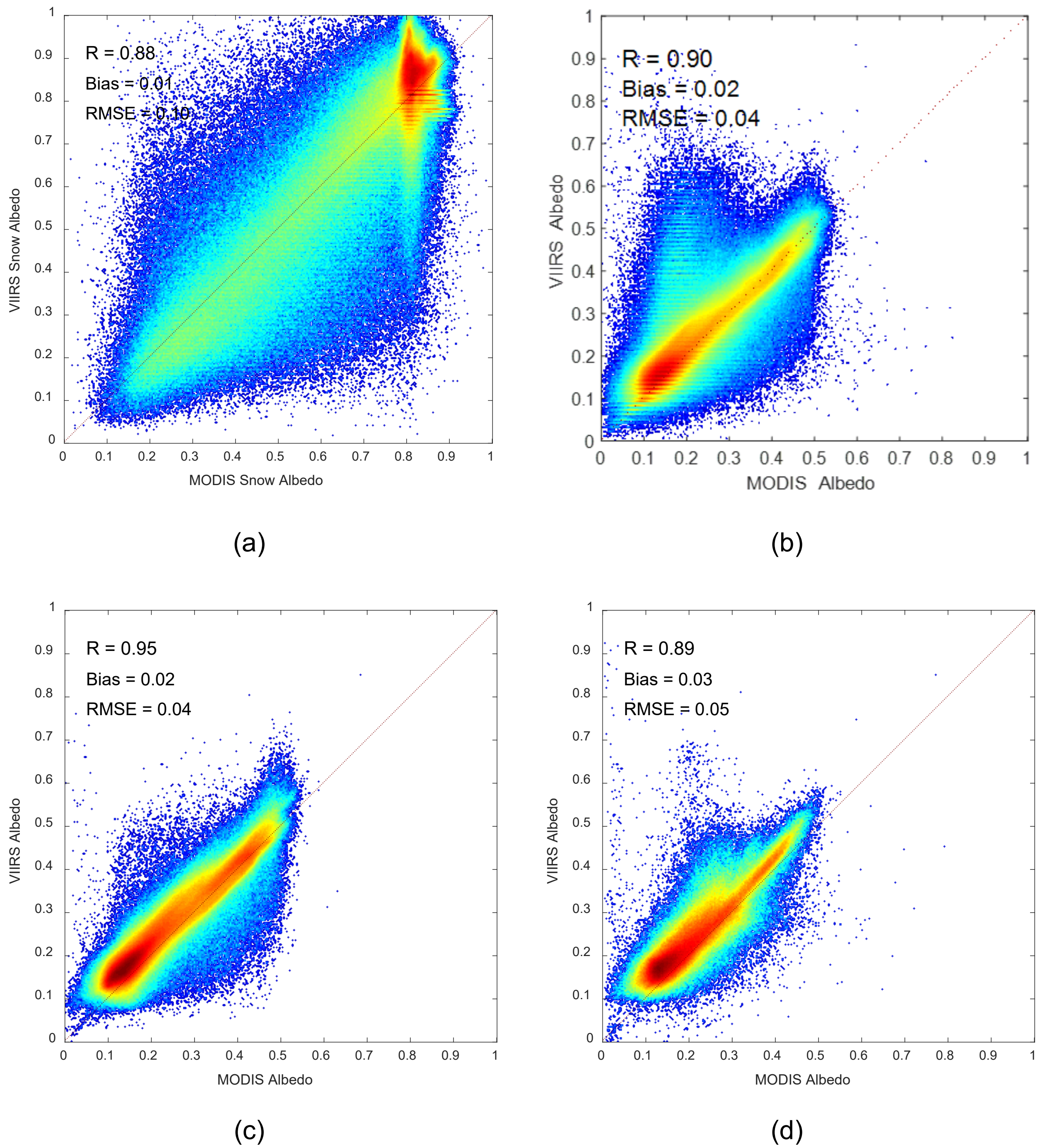
Figure 4-4 Comparison between S-NPP VIIRS L3 LSA and NOAA-20 VIIRS L3 LSA on Jan 8, 2019. (a) global retrievals; (b) high-quality retrievals; (c) medium-quality retrievals; (4) low-quality retrievals.

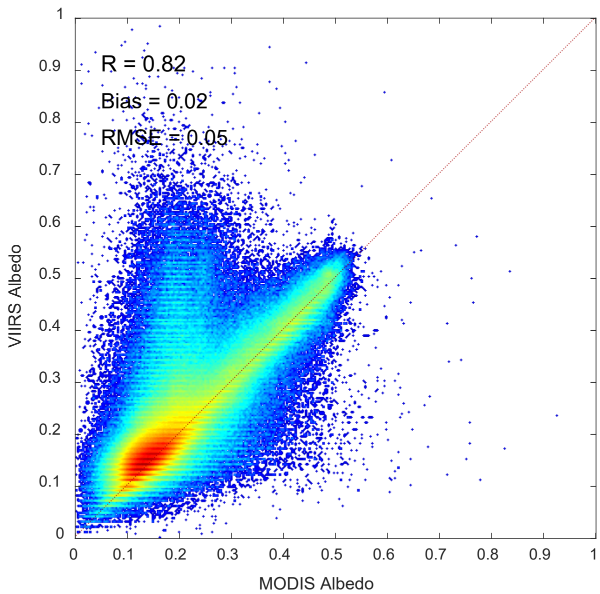
Figure 4-5 demonstrates the cross-comparison results between VIIRS L3 LSA and MODIS daily mean albedo. The VIIRS L3 LSA from NOAA-20 and S-NPP are both evaluated respectively. Their performance are quite consistent with each other. Basically, the VIIRS LSA matches the MODIS daily mean albedo; however, the retrievals over snow-covered pixels have larger albedo value and discrepancy (Figure 4-6a). The difference in snow retrievals is largely due to the snow cover difference. For snow pixels, VIIRS has specific coefficient LUT, so the snow cover quality directly influence the albedo value and the difference is expectable. The snow-free pixels have relatively low albedo value. They exhibit a small tail within which the VIIRS albedo is apparently larger than MODIS value (Figure 4-6b). To figure out the source of this difference, the snow-free pixels have been grouped according to their quality level and compared separately. We found that the scattered match-ups mainly derive from the low-quality retrievals in VIIRS L3 LSA (Figure 4-6e). The high-quality snow-free match-ups are closely around the 1:1 line.



(a) (b)

Figure 4-5 Comparison between VIIRS L3 LSA and MODIS daily mean albedo on Jan 8, 2019. (a) N20 and MODIS; (b) NPP and MODIS.


R = 0.88
Bias = 0.01
RMSE = 0.10
VIIRS Snow Albedo
MODIS Snow Albedo
(a)
R = 0.90
Bias = 0.02
RMSE = 0.04
VIIRS Albedo
MODIS Albedo
(b)
R = 0.95
Bias = 0.02
RMSE = 0.04
VIIRS Albedo
MODIS Albedo
(c)
R = 0.89
Bias = 0.03
RMSE = 0.05
VIIRS Albedo
MODIS Albedo
(d)



(e)

Figure 4-6 Comparison between NPP VIIRS L3 LSA and MODIS daily mean albedo of different groups of retrievals on Jan 8, 2019. (a) snow-free retrievals; (b) snow retrievals; (c) high-quality snow-free retrievals; (d) medium-quality snow-free retrievals; (e) low-quality snow-free retrievals.

5 ASSUMPTIONS AND LIMITATIONS

The gridded LST product assumes that the LST EDR and gridding IP files are available before the gridding process. One limitation is that the selected pixel of the grid could be up to one pixel error due to mapping uncertainty of the gridding IPs. Besides, LST is only available over cloud “clear”, “possible clear” and “probably cloudy” pixels, which results possible data gap in the daily gridded data product.

Regarding the potential improvement in the future, the satellite viewing geometry information will be considered in the data composition method when it is available in the VIIRS granule LST data. The update to add satellite viewing angle and azimuth angle into the VIIRS LST EDR output has been delivered in queue of the operational implementation.

The gridded LSA product assumes that the LSA EDR only include valid retrievals for land and sea-ice pixels. However, the current operational version also include LSA retrievals for sea-water pixels, which are not required and have not been evaluated. The code to assign sea-water pixels to fill-value has been delivered to NDE in queue of turning on in operational status. Furthermore, the pure sea-water granules will be removed from the Level 2 granules. The update for this part will be delivered in July 2019.

6 REFERENC ES

Yu, Y., Liu, Y., Yu, P., Wang, H., Enterprise VIIRS LST ATBD, https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Land_LST_v1.0.pdf

Liang, S., Wang, D., Yu, Y., Peng, J., Enterprise VIIRS LSA ATBD, https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Land_LSA_v1.0.pdf

Appendix A

The VIIRS Gridding Tool

A.1 Introduction

This part provides the description of Gridding Tool (GT) for the VIIRS Level 3 gridded product such as Land Surface Temperature (LST) and Land Surface Albedo (LSA) etc. The GT is a toolkit designed to facilitate the compositing process from level 2 granule products (swath data) to level 3 gridded products. This tool takes the granule-based geolocation data as input, then calculate the grid index for each pixel of the granule, and finally save these mapping index as intermediate product for the gridding purpose. Figure A-1 show the role GT plays in the VIIRS level 3 product, VIIRS level 2 product are produced at granule level, since these products are needed in regular grid for the applications like NWP models, level 3 gridded product are composited from level 2 data. The GT will generate two set of index describing the mapping relationship between pixels and grids. With these indexes, level 2 products could be directly and easily mapped to custom grid.

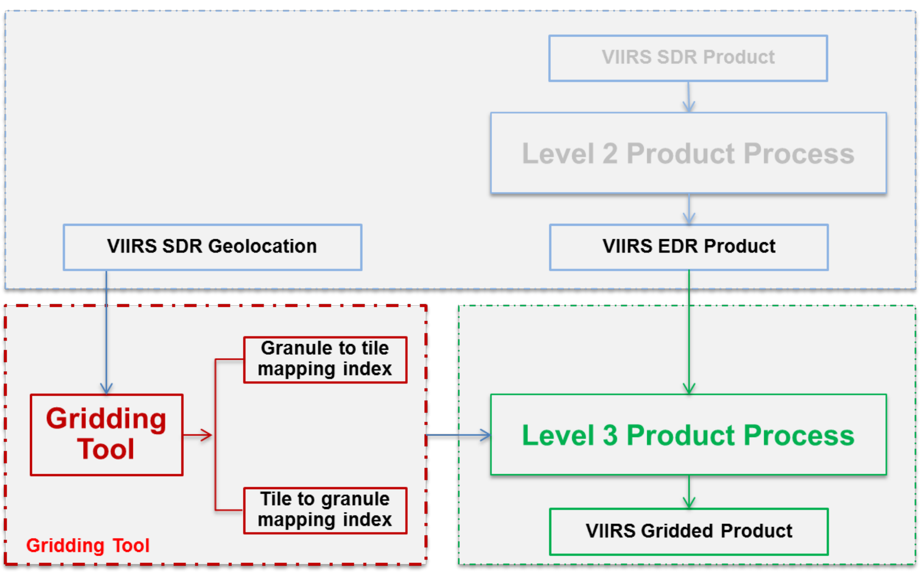


Figure A-1 Gridding tool in VIIRS level 3 product processing

A.2 Methodology

(1) Projection

The GT support two types of projections, the sinusoidal and the equirectangular projection, for VIIRS 1km resolution products, the sinusoidal one is adopted. The granule pixels are forward mapped to the sinusoidal grid according to the following equations:

$$x = (\lambda - \lambda_0) cos\varphi$$

$$y = \varphi - \varphi_0$$

Here, λ is longitude, φ is latitude, $\lambda 0$ and $\phi 0$ is the central meridian, in GT $\lambda 0 = \phi 0 = 0$ In this Sinusoidal grid tiling system, the global is divided into 72 x 72 small tiles with 600 x 300 grids in each tile, the resolution is about 1km (0.0083 degree at equator) for the Moderate band product like LST and LSA.

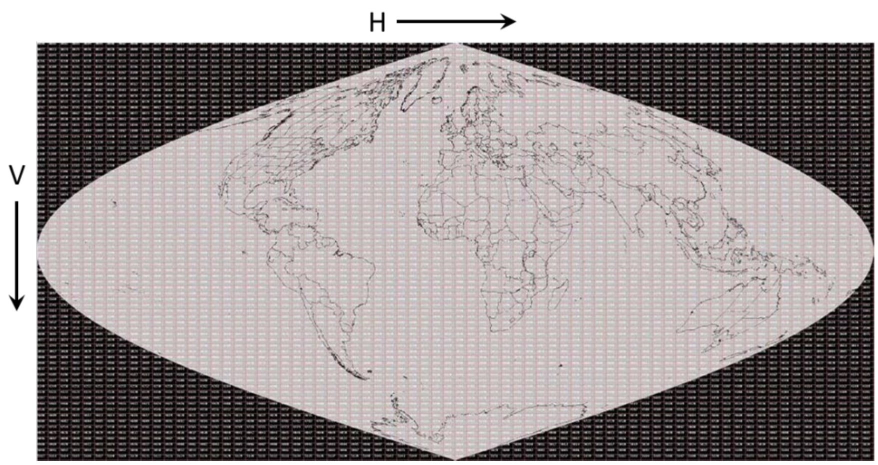


Figure A-2 Sinusoidal grid tilling system

The tile name follows hxxvyy with horizontal tile number start with 0 from left to right and vertical tile number from 0 to 71, north to south. For example, the upper left corner is h00v00, and the bottom right corner is h71v71.

(2) Resampling method

A forward mapping approach is used to calculate the corresponding grid location from the pixel latitude and longitude. To resample the projected data, the single nearest match will be selected to make it is the fastest and most efficient method; however, uncertainty would be introduced due to the different coverage between grid and pixel.

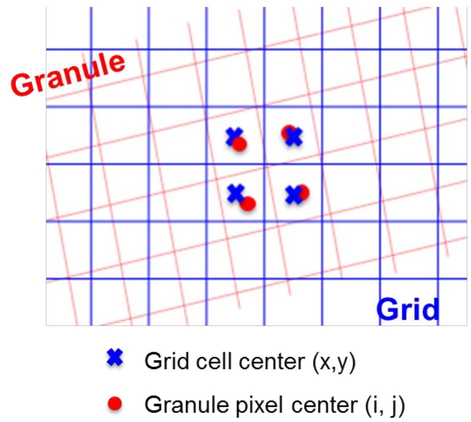
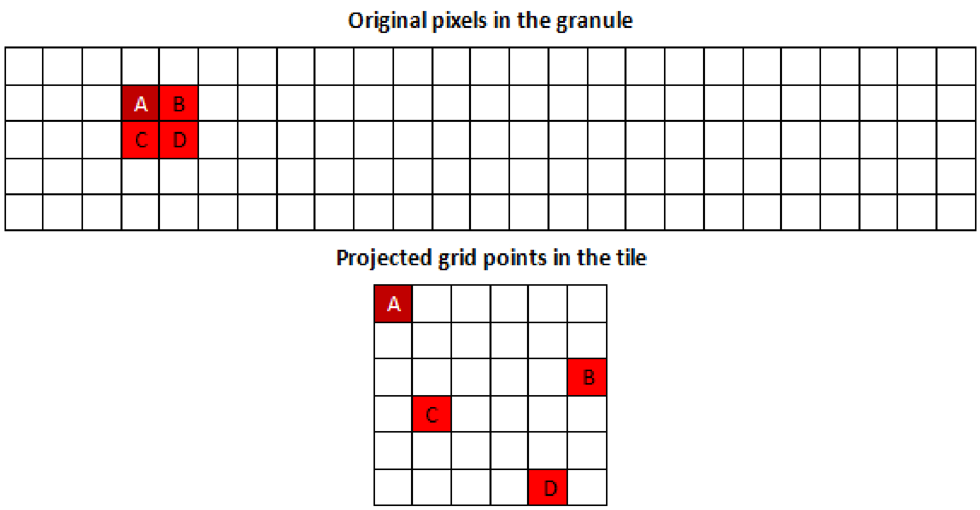


Figure A-3 Forward mapping and resampling

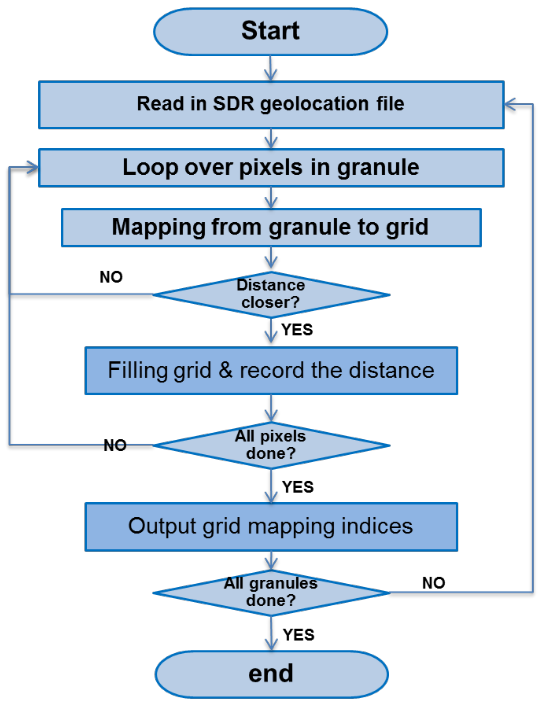
(3) Gaps

When the pixel size is larger than grid cell, for example, at the edge of the scanning, the pixel footprint is much larger than 1km grid, there might be gaps exist during the forward mapping. To avoid these possible gaps, the following steps is implemented in the GT: firstly, instead of pixel by pixel processing, the adjacent 4 pixels in the granule (as figure A-4 shows) works as a group, which will be mapped to the grid each time, after determining these 4 projected grid, the gaps between them, if exist, will be filled using the fill the nearest one from these 4 grids, at the same time, record current distance from the grid to the nearest pixel. Then move to next group and update the overlapped grid if closer matched pixel is available. After looping over all the pixels in the granule, the projected the area in the grid system will be gap-free.



A-4 Illustration of mapping method to avoid gaps, the bottom one demonstrates the smallest grid box enveloping 4 projected pixels

A generic high level flowchart of the gridding tool is given in the Figure A-5. The GT will process on granule each time, since it is daily composition, the gridding indices will be saved as a certain directory for each day. Once a new granule come in, the tile to granule index will append to exist ones until all the granules in this day are processed.



A-5 Flowchart of the grid tool

A.3 Input and output data

As the GT flowchart shows, the only input data required is the granule level geolocation data, which have exactly the same coverage with the level 2 product. The detailed description as Table 1 shows.

Table A-1. Gridding tool input data

Data Name	Description	Data Type	Dimension	Unit
Latitude	VIIRS granule latitudes	double	3200 x 768	degree
Longitude	VIIRS granule longitudes	double	3200 x 768	degree

Two types of gridding indices are designed for the gridding process.

(1) Tile to granule information

These indices is designed for each tile, it record all the granule overlapping with this tile and the projected pixel location in the original granule. Tile to Granule information files is binary file, which contains one header with summarized information and many layers for each granule. The detailed data structure for the header and layer could be found in Table A-2. The header provides the tile ID, total number of granules (layers) and their name list. Following the header, there are a series of layers with same structure. In addition to the granule ID, each grid in this tile saves the corresponding indices in the granule. There are two arrays used here, one with column index and the other with row index, from which the projected pixel could be directly located in the granule.
The naming convention for these indices is as follows:
tile_info_hxxvxx
where hxxvxx is the tile name defined before.

Table A-2 Tile to granule information data structure

Data Name	**Description**	**Data Type**	**Dimension**	**Format or data range**
Header	Tile ID	int32	1	0 - 5183
	Number of granules	int32	1	0 – 28
	Granule name list	char	40 x 16	YYYYMMDD_HHMMSS
Layer	Granule ID	char	1	YYYYMMDD_HHMMSS
	Column indices in granule	Int16	600 x 300	0 – 3199
	Row indices in granule	int16	600 x 300	0 - 767

(2) Granule to tile information

These indices generated for each granule include all the tiles and the layer index for each granule. It works as a catalog and could accelerate the composition when process granule by granule.
Granule to tile information files is simply a text file, containing two columns, one is the tile ID and the other is the layer index in this tile. The naming convention as follows:
granule_tiles_YYYYMMDD_HHMM_SS
where YYYY is the 4-digit year, MM and DD is 2-digit month and day; HH, MM and SS are 2-digit hour, minute and second, respectively.

A.4 Assumption and limitation

All the granule level geolocation data used in the GT are assumed have the same coverage with the level 2 products.

Since the resolution difference between pixel and grid, the nearest neighbor mapping method could introduce uncertainty, which could up to one pixel.

The mapping method is designed without gap in the output data, however, once all granules in 24 hours period could not cover the whole global area, there would be gaps, and the data around the gaps might have larger uncertainty.

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