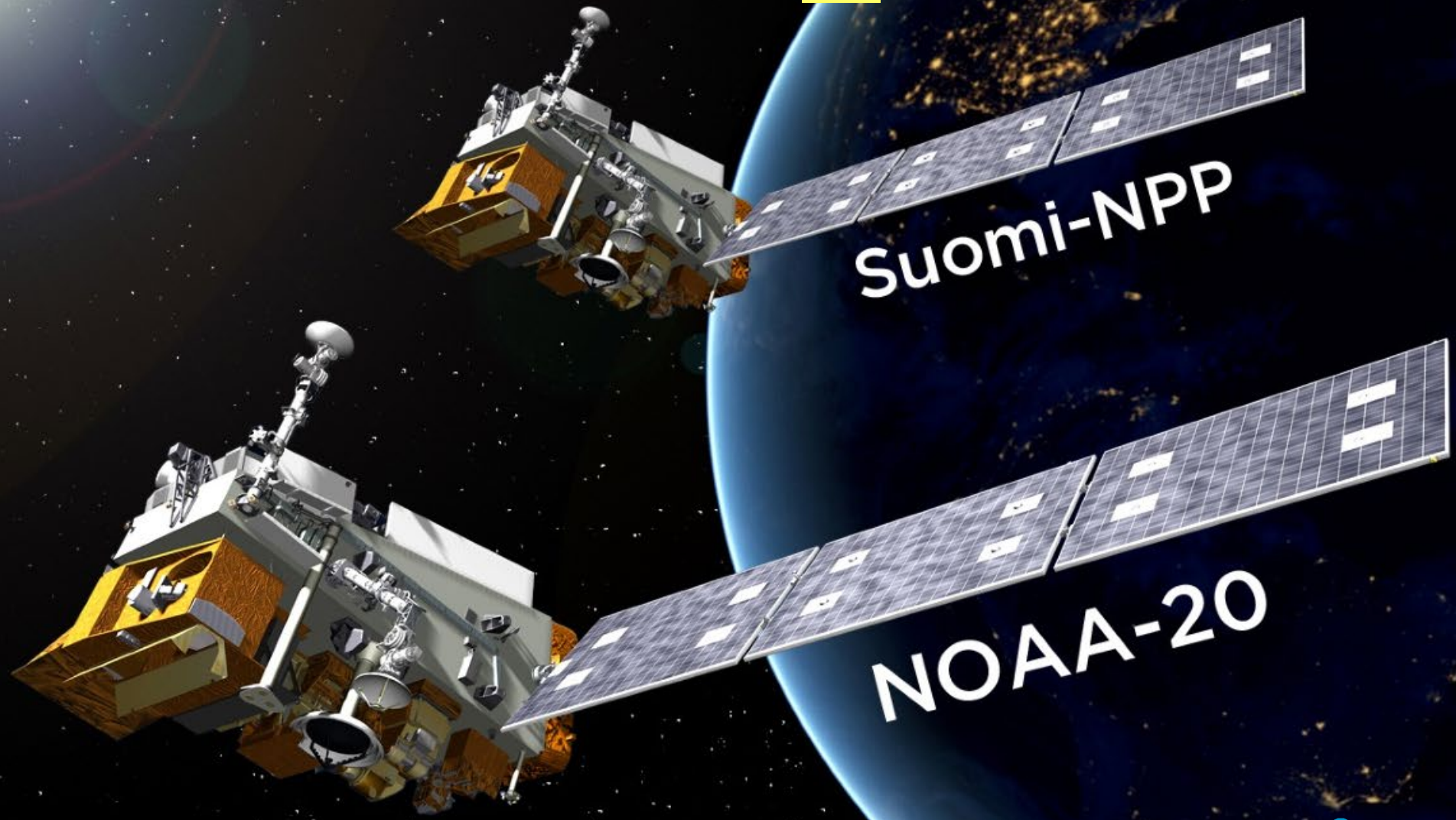
Validated Maturity Science Review For NOAA-20 VIIRS LST Product



JPSS STAR Land Science Team
Presenter: Yunyue Yu
Date: 11/21/2019

LST Cal/Val Team Members

	Name	Organization	Major Task
JPSS-STAR science team	Ivan Csiszar	NOAA/NESDIS/STAR	Land Lead
	Yunyue Yu	NOAA/NESDIS/STAR	EDR Lead, algorithm development/improvement, calibration/validation, team management
	Yuling Liu	NOAA Affiliate UMD/CISESS	product monitoring and validation ; algorithm development/improvement
	Peng Yu	NOAA Affiliate, UMD/CISESS	product monitoring and validation
	Heshun Wang	NOAA Affiliate, UMD/CISESS	Product validation ; gridding software; emissivity development
	Jerry Zhan	NOAA/NESDIS/STAR	user readiness
JPSS-STAR Integration team	Walter Walf	NOAA/NESDIS/STAR	STAR ASSIST Lead
	Valerie Mikles	NOAA Affiliate, SciTech/IMSG	STAR ASSIST, Algorithm System integration
	Christopher Selman	NOAA Affiliate, SciTech/IMSG	STAR ASSIST, Algorithm System integration
	Arthur Russakoff	NOAA Affiliate, SciTech/IMSG	STAR ASSIST, Algorithm System integration
	Daryl Kleist	NOAA/EMC/NCEP	user readiness
NOAA/NCEP	Yihua Wu	NOAA Affiliate, SciTech/IMSG	user readiness
	Weizhong Zheng	NOAA Affiliate, SciTech/IMSG	user readiness
	Xiaoyan Zhang	NOAA Affiliate	user readiness

JPSS Data Products Maturity Definition

1. Beta

- Product is minimally validated, and may still contain significant identified and unidentified errors.
- Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
- Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

2. Provisional

- Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
- Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
- Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
- Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

3. Validated

- Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
- Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
- Product is ready for operational use based on documented validation findings and user feedback.
- Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

Outline

- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback
- Downstream Product Feedback
- Risks, Actions, and Mitigations
- Documentation (Science Maturity Check List)
- Conclusion
- Path Forward

VIIRS LST Product overview

NOAA 20 VIIRS LST Derivation

- Enterprise algorithm based on split window technique
- Emissivity is explicitly used

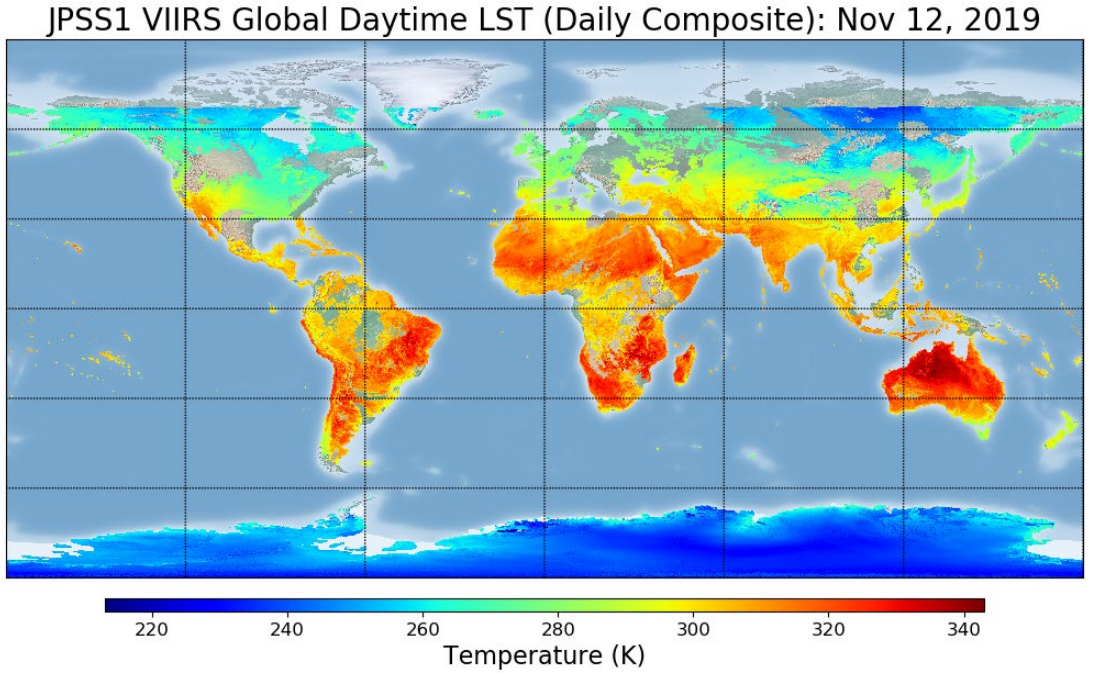
  Emissivity input is from NOAA STAR emissivity product. The spectral emissivity and broadband emissivity at pixel level is included in the LST output.
- Updated LUT

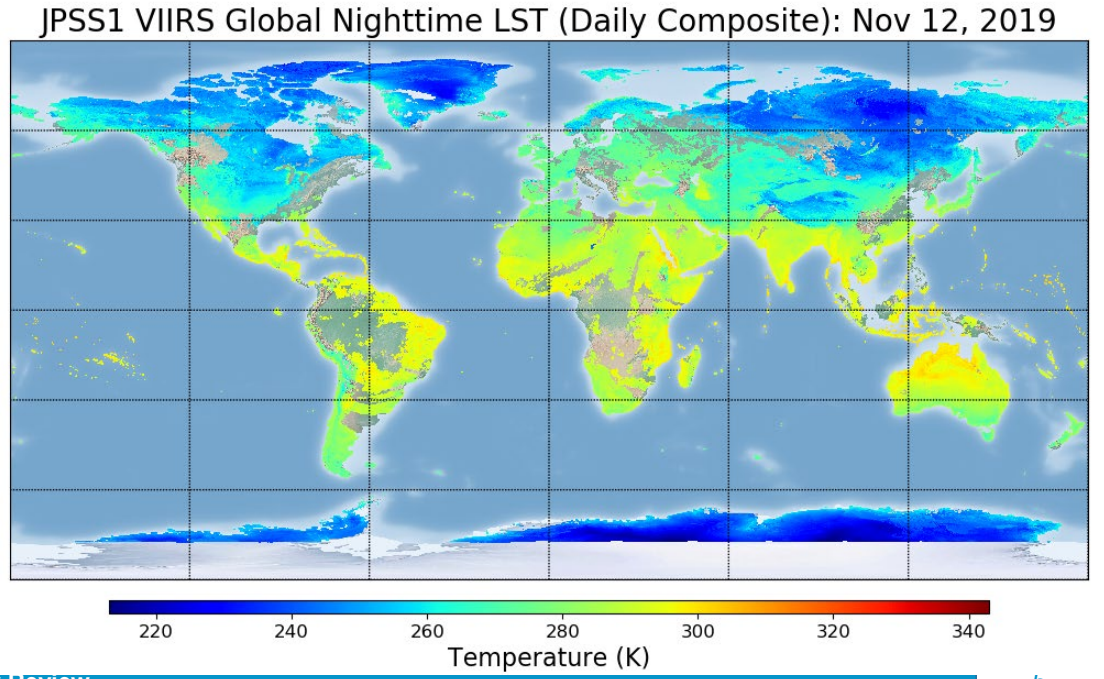
  based on a comprehensive simulation database; has dimension of day/night, view zenith angle and total column water vapor

Operational Status

- Has been available in CLASS since 09/18/2019

  It is in the updated version v1r2 with most recent updates implemented.
- Also available at SCDR under data type “VIIRS-LST” for STAR internal users and interested groups.





Product Requirements

Attribute	Threshold	Observed/validated
Geographic coverage	At least 90% coverage of globe every 12 hours(monthly average)	
Vertical Coverage		
Vertical Cell Size		
Horizontal Cell Size	0.8 Km	0.8 Km
Mapping Uncertainty	1 km at Nadir	1 km at Nadir
Measurement Range	213 – 343 K	235– 335 K from ground validation
Measurement Accuracy	1.4 K	Site dependent mostly within 1.4K
Measurement Precision	2.5 K	~1.9 K over six SURFRAD sites and two BSRN sites
Measurement Uncertainty		

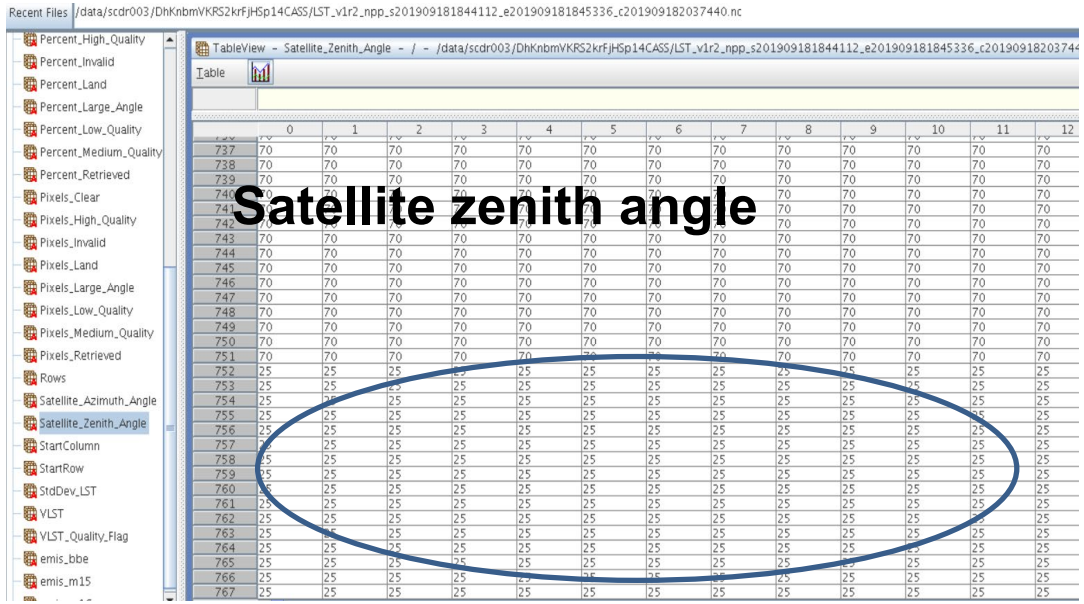
Processing Environment and Algorithms

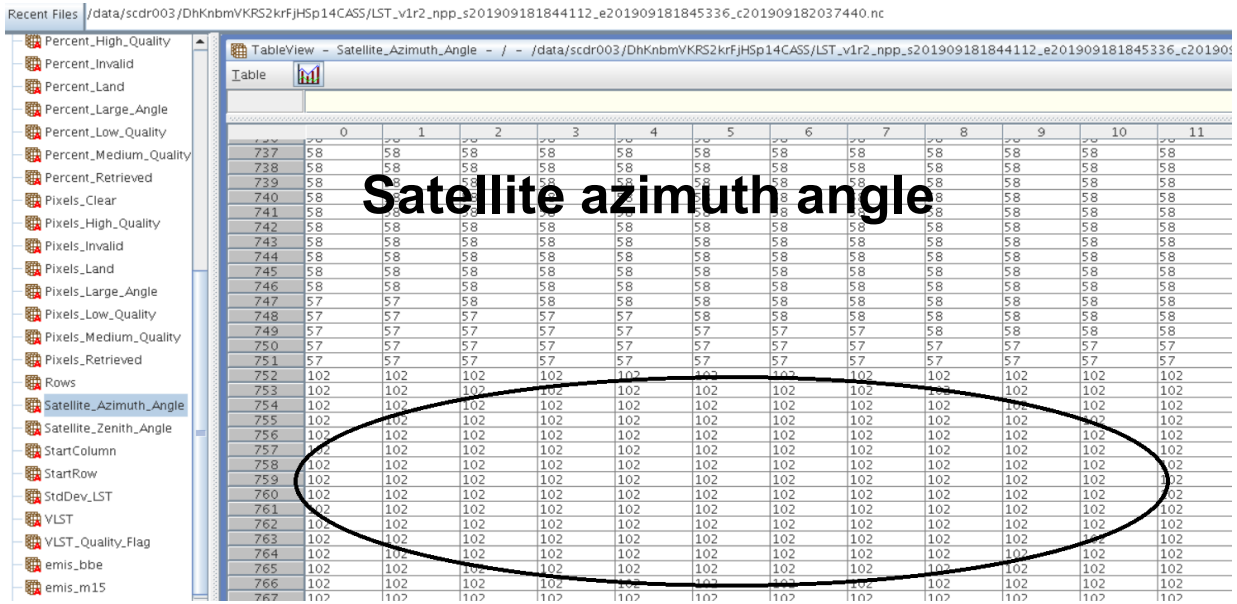
- Processing environment and algorithms used to achieve validated maturity stage:
  - Algorithm version
    - v1r0: initial DAP delivery using v0 LUT
    - v1r1: Framework Test
    - v1r2: recent DAP delivery in July 2019 using v1 LUT
  - Version of LUTs used
    - v0 : alg v1r0
    - v1 : alg v1r2
  - Effective date
    - v1r0: effective since 06/25/2019 for SNPP VIIRS LST only
    - v1r2: effective since 09/17/2019 for both SNPP and NOAA 20 LST

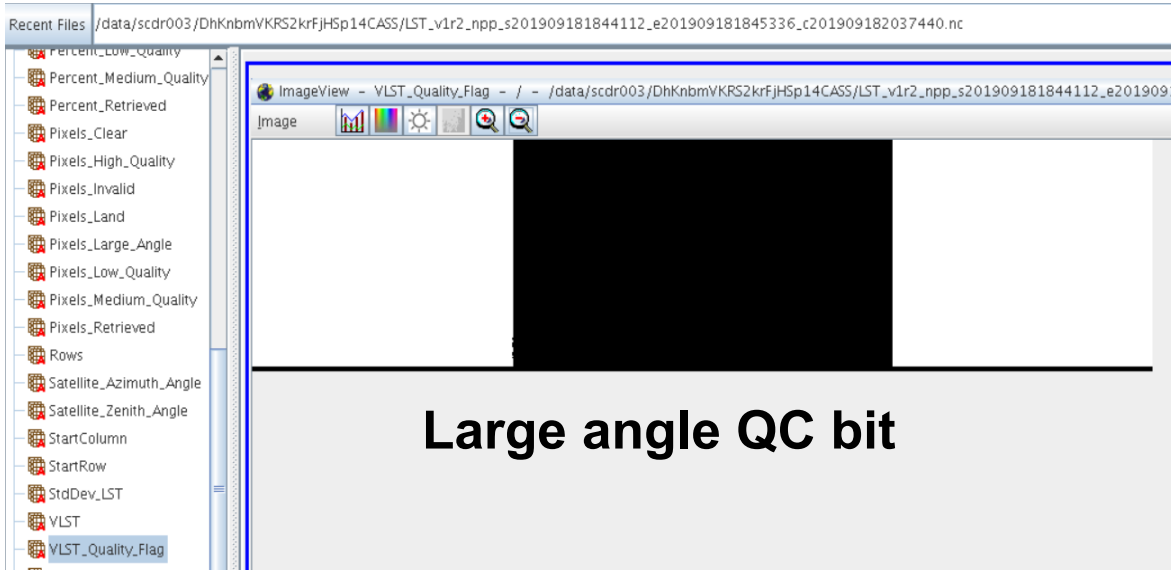
Evaluation of algorithm performance to specification requirements

- Findings/Issues from Provisional Review
  - Improvements since Provisional Review
    - Algorithm Improvements
    - LUT / PCT updates
- Algorithm performance evaluation
  - Validation data sets (type, periods, coverage)
  - Validation strategies / methods
  - Validation results
  - Long term monitoring readiness

Issue 1 : geometric data error

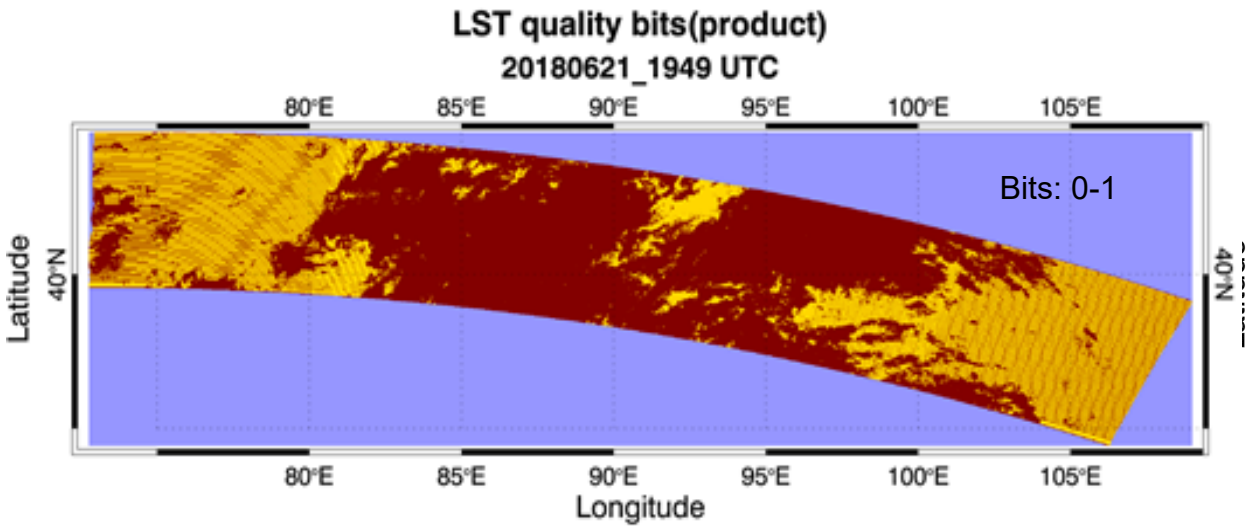


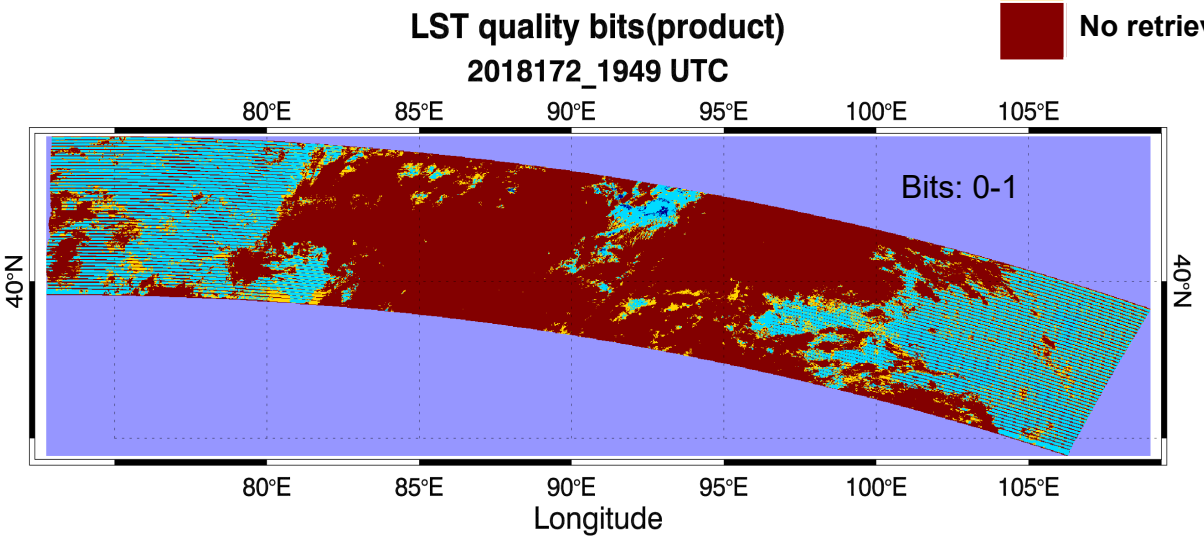




- Happens when the geolocation data are filled value (line 752-767). In which, the view geometry are assigned valid value but should be filled value, which results incorrect LST quality flag
- The problem occurs only to the filled scan lines; about 30 granules per day with such issue.
- It does not have impact on the LST value as LST is fill in this case.
- The issue has been fixed, for the next DAP delivery.

Issue 2: Impact of missing input on Nighttime quality





High
Medium
Low
No retrieval

LST >= 0	Degraded – Sensor Zenith Angle > 40	Active fire	AOD Range	Thin Cirrus	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

AOD/cirrus data missing: low quality flag impact

Solution:

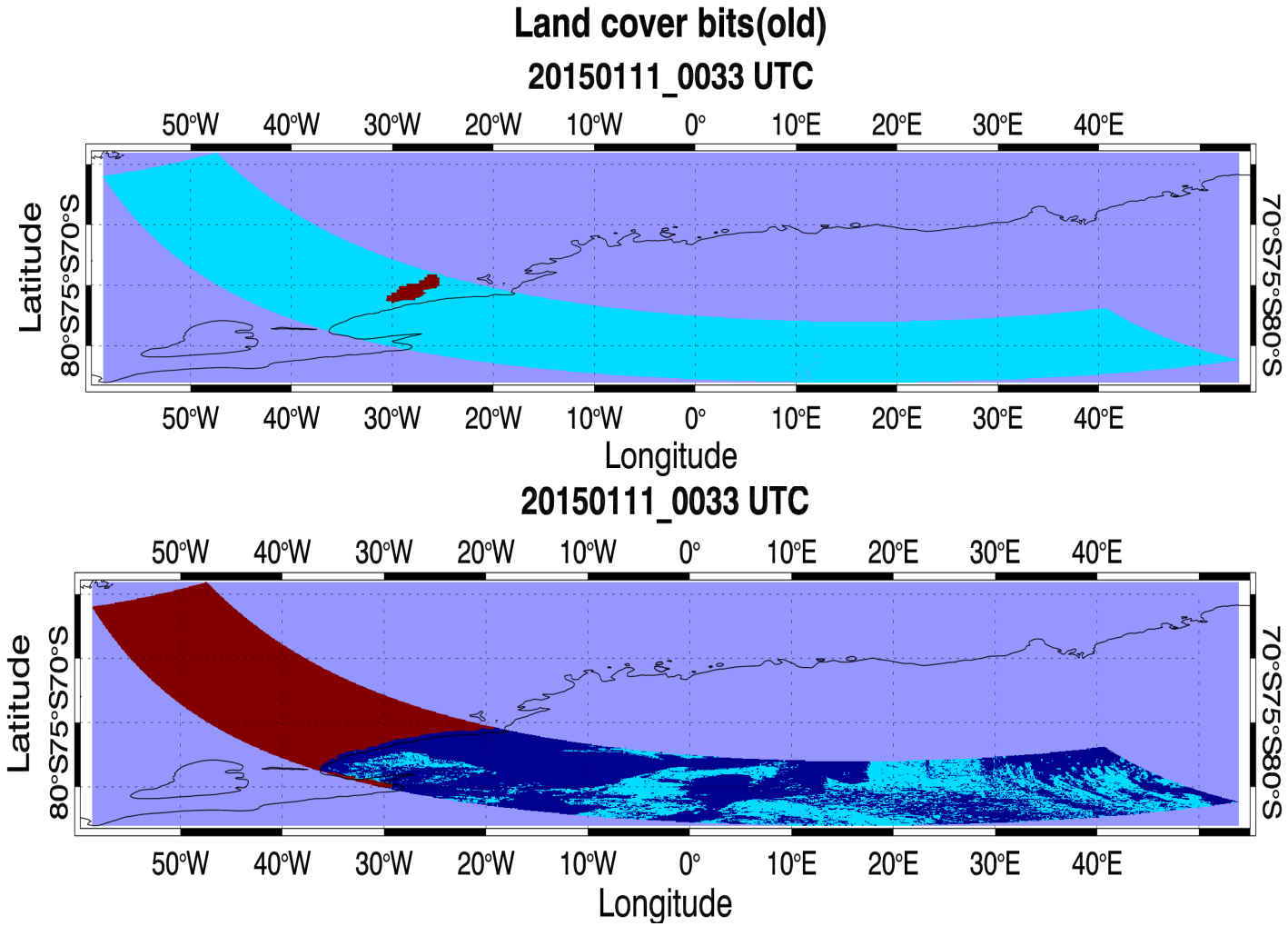
- The AOD criteria is added into the matrix when it is available, otherwise AOD is excluded in the criteria bundle for both daytime and nighttime LST quality
- Above case shows the previous quality flag(left) and updated LST quality flag (right) where the LST quality is not affected by AOD availability so it presents high and medium quality.

Issue 3: Snow cover input changed

Input

NWP snow cover

VIIRS snow cover EDR

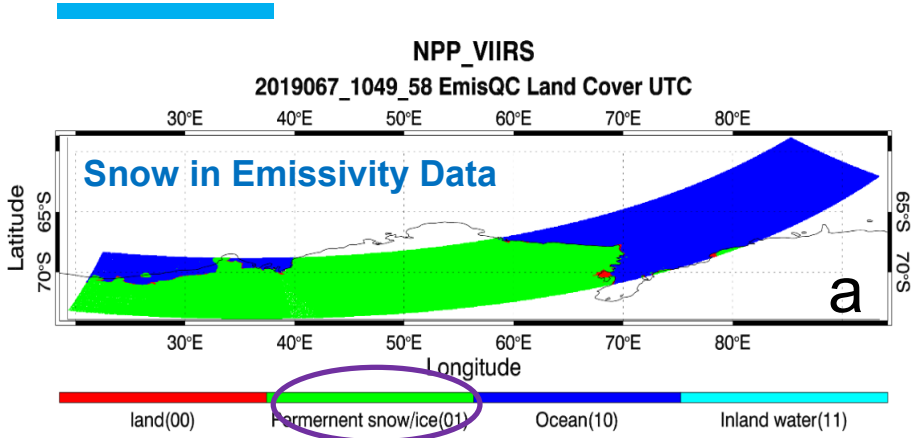


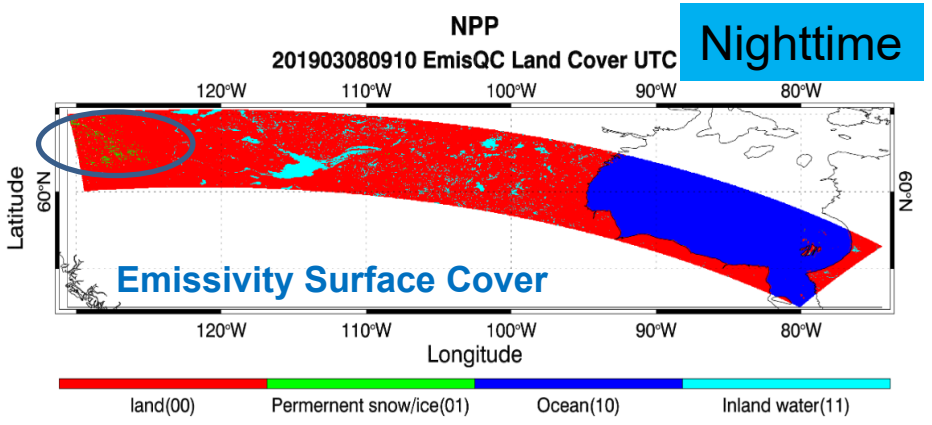
- More details are presented in the VIIRS snow cover EDR compared to the NWP snow cover data.
- The accuracy of the quality flag of surface cover is improved.

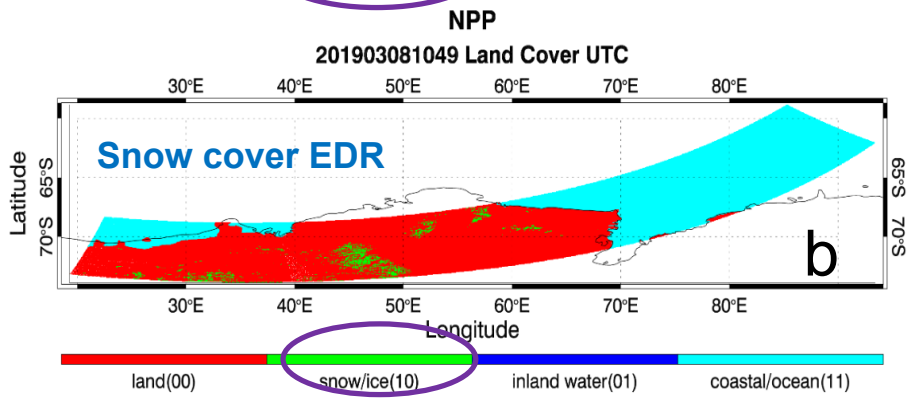
Snow cover input is switched from NWP snow cover to VIIRS Snow Cover EDR. Note that the snow cover EDR only presents the fresh snow so the permanent snow is obtained from emissivity input, which is another update made for LST product.

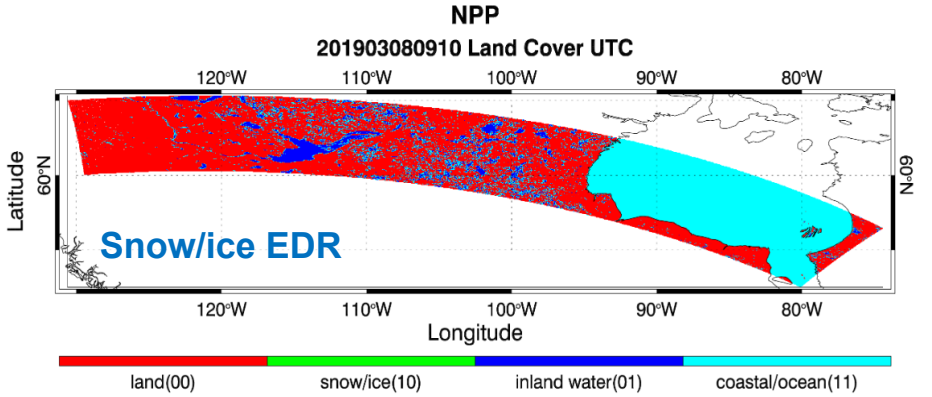
Issue 4: Snow/ice quality flag update

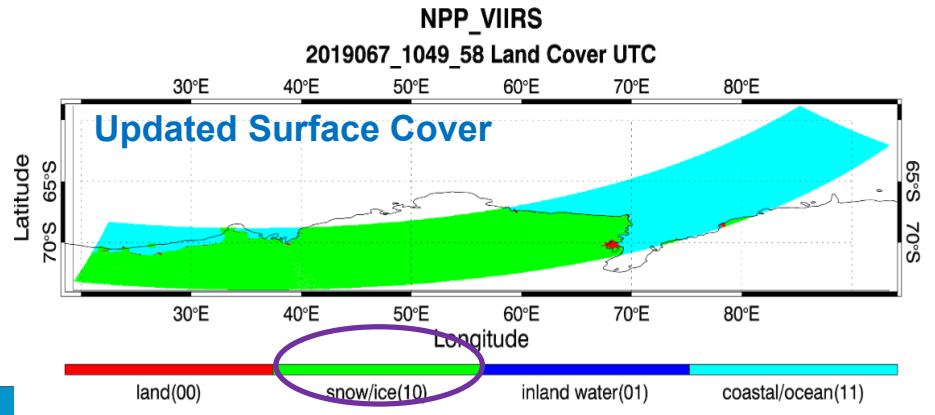
Snow EDR+ Permanent Snow

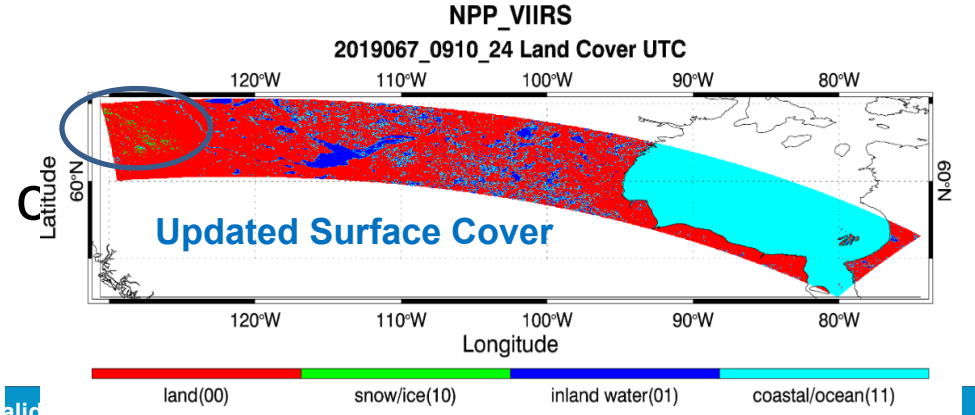








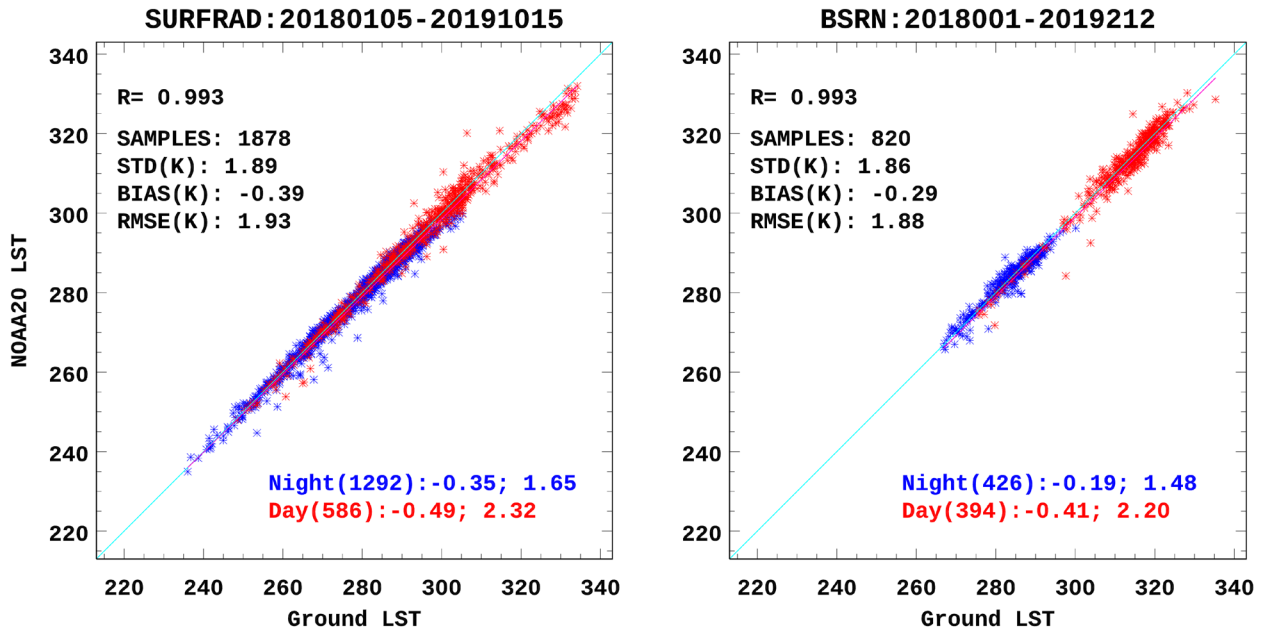


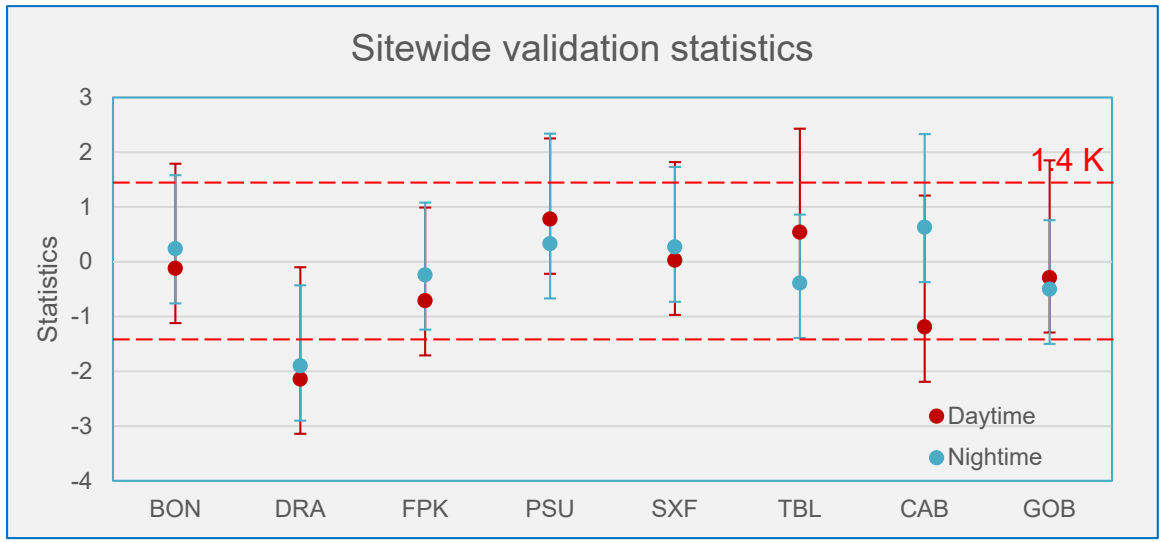


Algorithm performance evaluation

- In-situ ground validation
  - Six sites of SURFRAD network observations
  - Two sites of BSRN observations
- Global evaluation
  - SNPP and NOAA 20 VIIRS LST consistency
  - NOAA20 VIIRS LST comparison with AQUA MODIS LST (MYD11A1 and MYD21A1)
- Long term monitoring tool update

Ground data validation-SURFRAD and BSRN



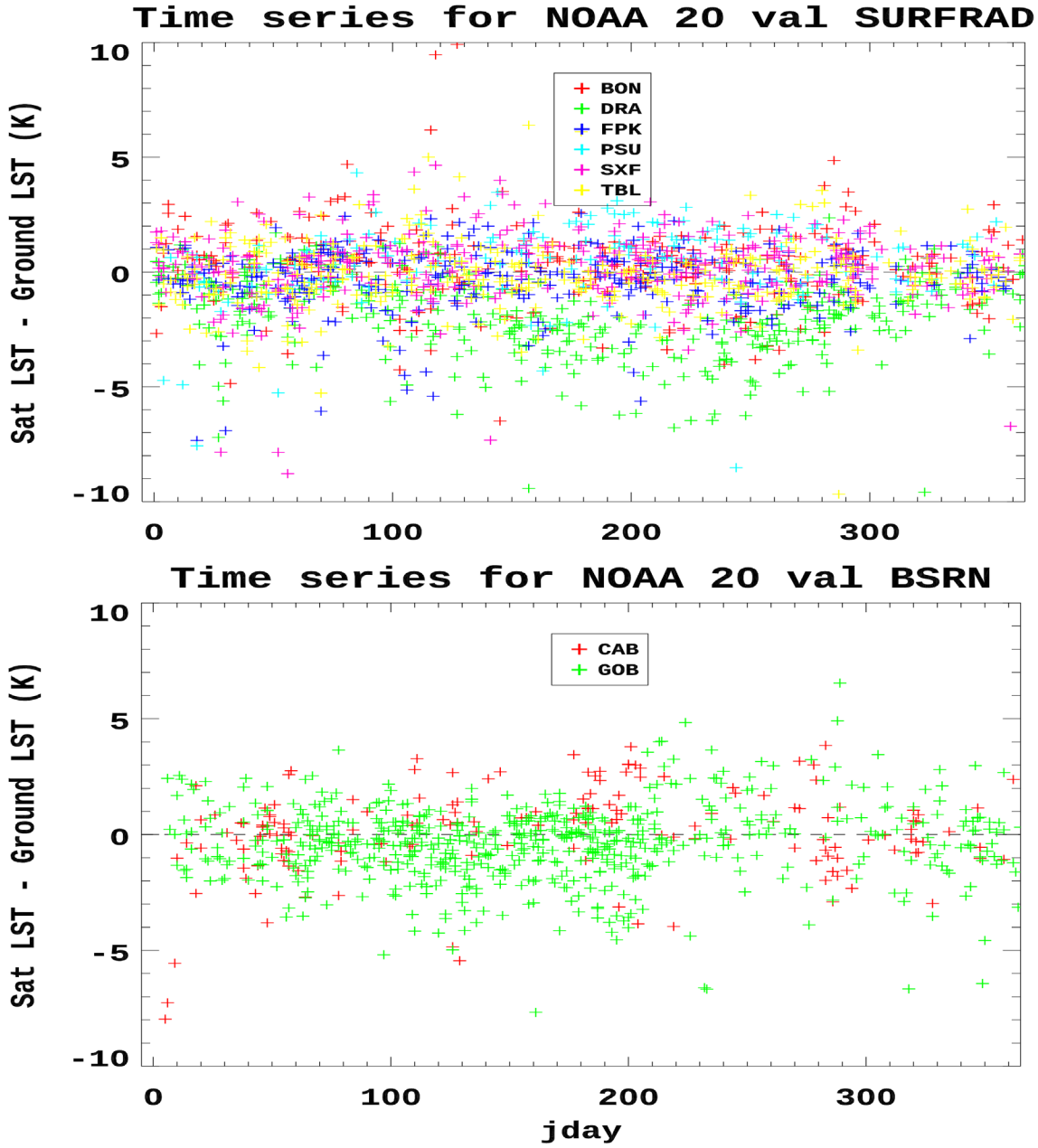


- Data coverage
  Six sites of **SURFRAD** network over continental US for time period from Jan., 2018 to Oct., 2019 (~22 months).
- Two sites of BSRN
  Sites in **Netherland and Namibia** for time period from Jan. , 2018 to Jul. 2019 (~19 months).

- Validation results
  High agreement is observed from the ground validation indicating that the VIIRS LST has a good quality with an accuracy of -0.39 K and -0.29K, precision of 1.89 K and 1.86 K for SURFRAD and BSRN, respectively

Significant underestimation over DRA site is observed, which is a known issue due to surface heterogeneity

Ground validation time series analysis



SURFRAD:
Jan., 2018 to Oct., 2019.
BSRN:
Jan., 2018 to Jul., 2019.

- More LST discrepancy is observed in spring and summer season comparing to fall and winter.
- LST underestimation beyond 5 K is mostly affected by the unidentified cloud residue or neighboring cloud
- BON site presents the seasonal overestimation of the LST in Spring and Fall season attributed to the seasonal plant growing and harvest

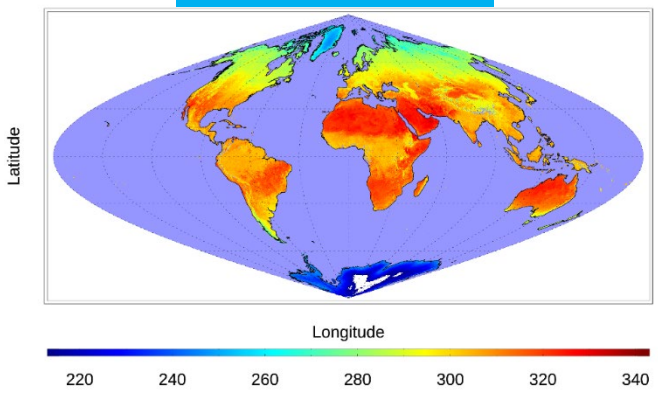
Error Budget

Attribute Analyzed	L1RD Threshold	Pre-Launch Performance	On-orbit Performance Accuracy (precision)	Meet Requirement?
T-based Validation	Accuracy: 1.4K Precision: 2.5K J01	N/A	SURFRAD: -0.39(1.89) Bon: 0.18(1.47) Tbl:-0.14(1.50) Dra:-1.99(1.71) Fpk:-0.41(1.48) Psu:0.41(1.93) Sxf:0.19(1.58)	Yes
	Accuracy: 1.4K Precision: 2.5K J01	N/A	BSRN -0.29(1.86) CAB:0.07(2.12) GOB:-0.39(1.78)	Yes
	Accuracy: 1.4K Precision: 2.5K SNPP	N/A	SURFRAD: -0.34(1.92) Bon: 0.34(2.04) Tbl:-0.28(1.56) Dra:-2.01(1.75) Fpk:-0.36(1.48) Psu:0.59(1.61) Sxf:0.14(1.75)	Yes
	Accuracy: 1.4K Precision: 2.5K SNPP	N/A	BSRN -0.14(1.74) CAB:0.10(1.85) GOB:-0.20(1.70)	

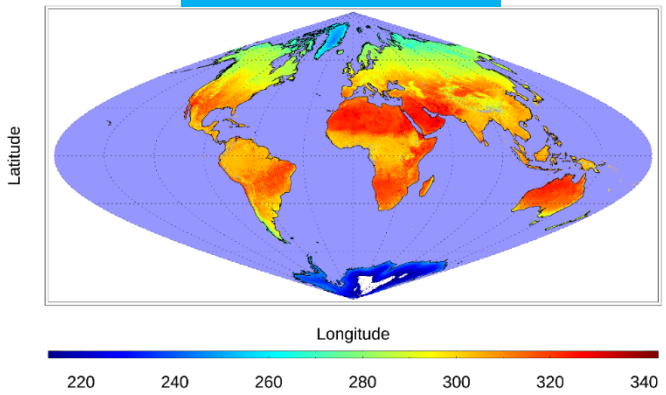
NOAA 20 VIIRS LST vs SNPP VIIRS LST

Daytime

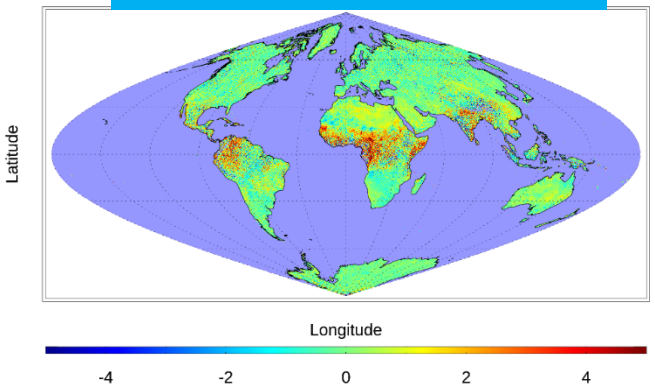
N-20 Mean LST



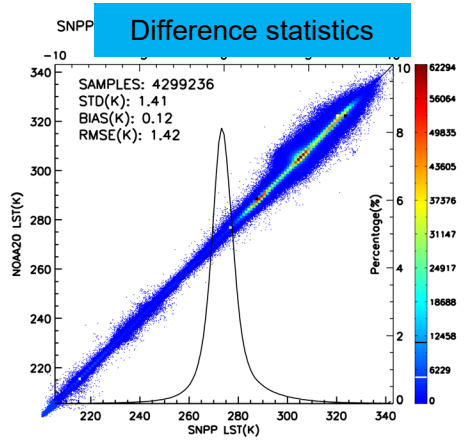
SNPP Mean LST



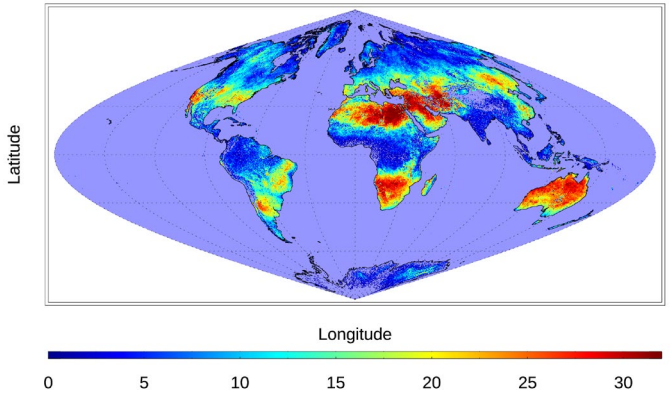
Mean Diff



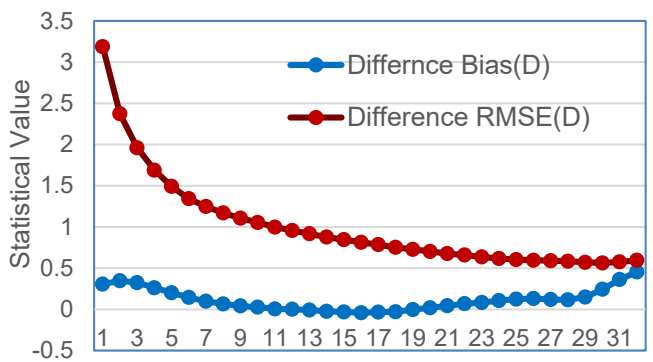
Difference statistics



Data Availability Distribution



Difference Statistics over Data Availability



- Mean of 32-day cycle for the time period of 2019246-2019277.
- Cloud clear data only
- Global mean difference within the 32-day cycle is calculated
- The difference statistics is presented
- The impact of data availability is analyzed.

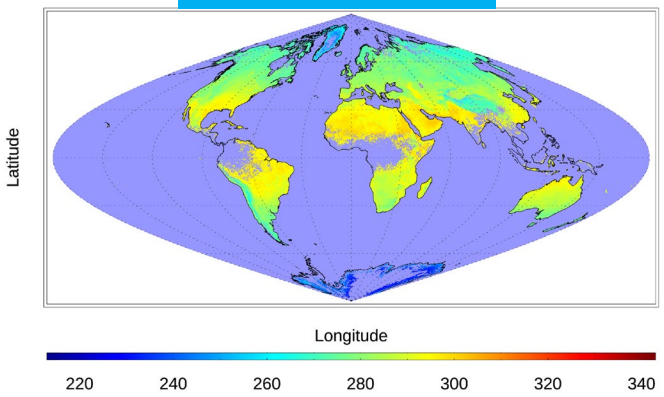
Overall the SNPP VIIRS LST and NOAA 20 VIIRS LST are consistent.

- The difference has a zonal feature with more difference at low latitude area.
- It is affected by the data availability due to cloud coverage and regional climate variation situations.

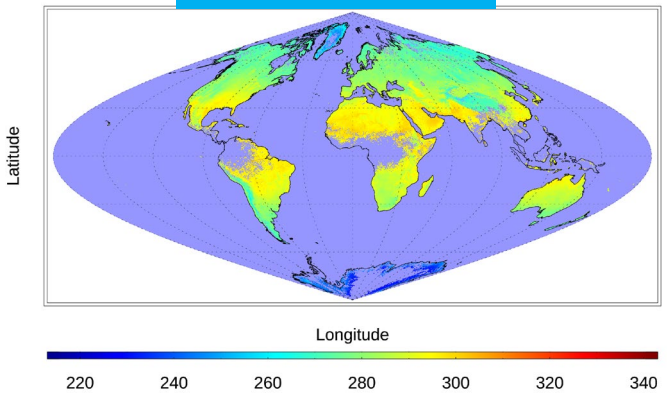
NOAA 20 VIIRS LST vs SNPP VIIRS LST

Nighttime

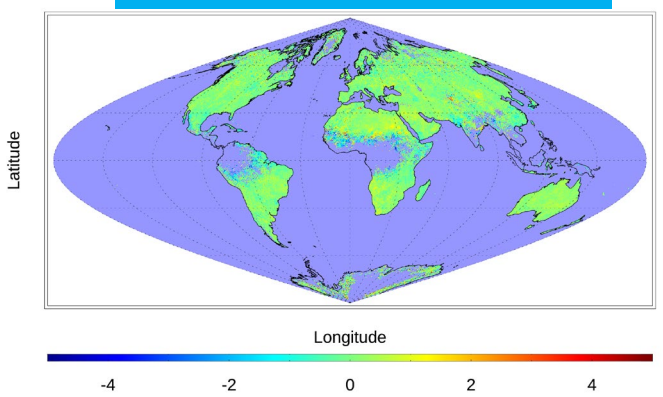
J01 Mean LST



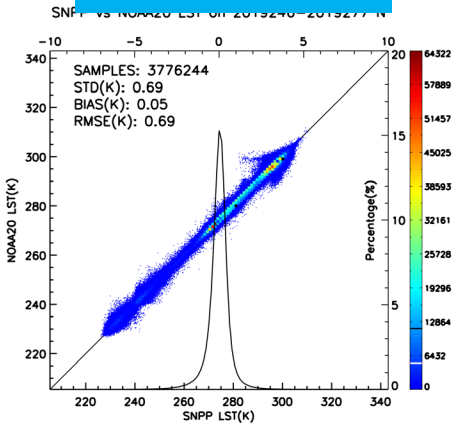
NPP Mean LST



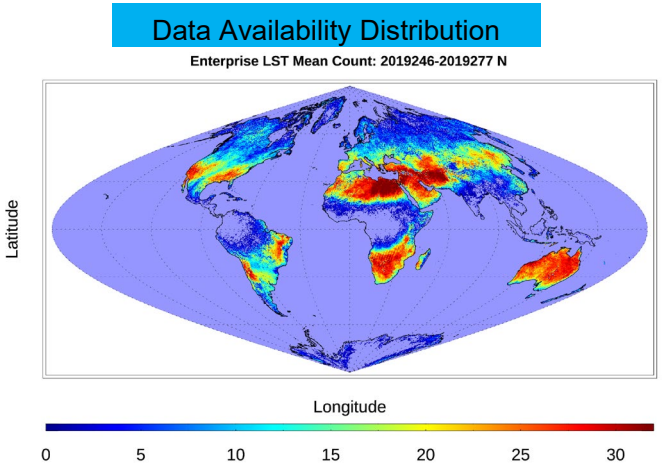
Enterprise Gridded LST Mean Diff



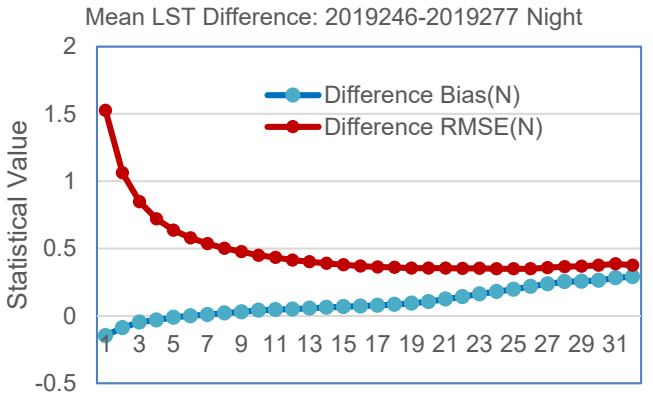
Difference statistics



Data Availability Distribution



Difference Statistics over Data Availability



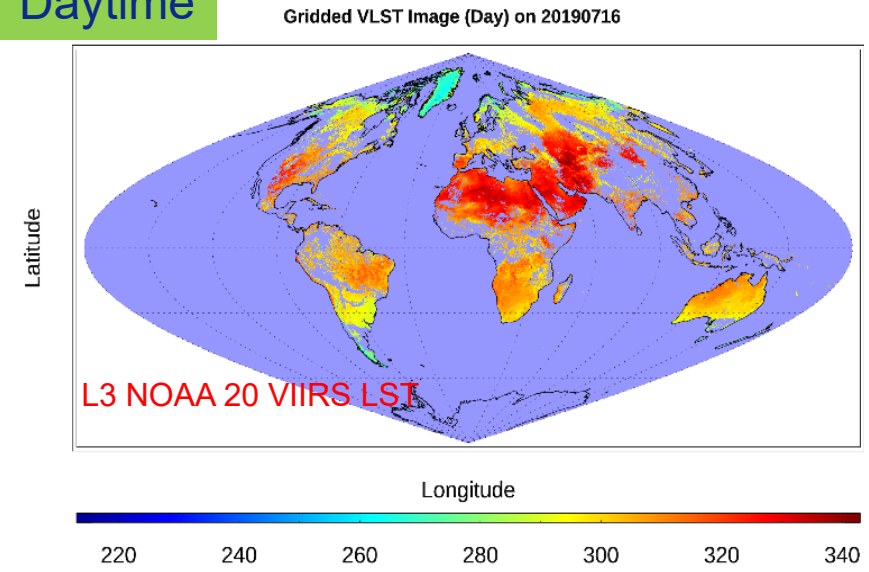
- Mean of 32-day for the time period of 2019246-2019277.
- Cloud clear data only
- Global mean difference within the 32-day cycle is calculated
- The difference statistics is presented
- The impact of data availability is analyzed.

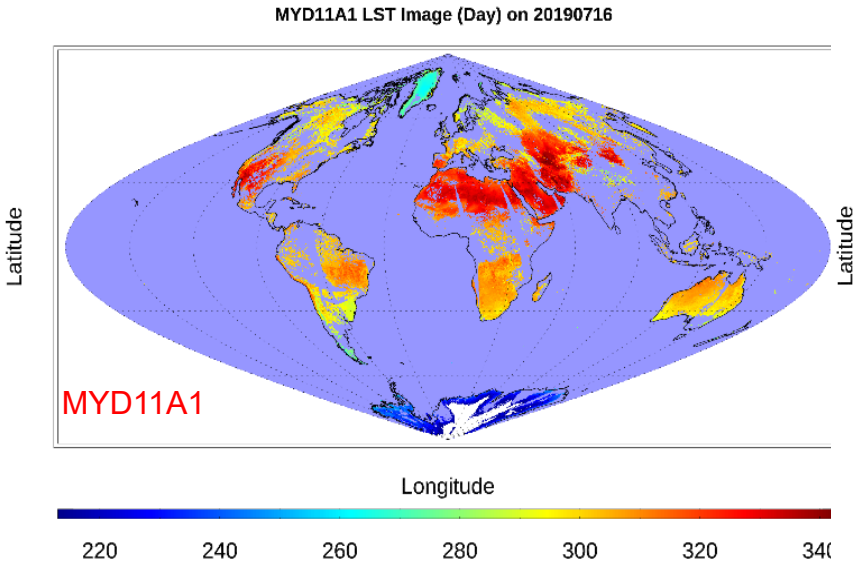
Overall the SNPP VIIRS LST and NOAA 20 VIIRS LST are consistent.

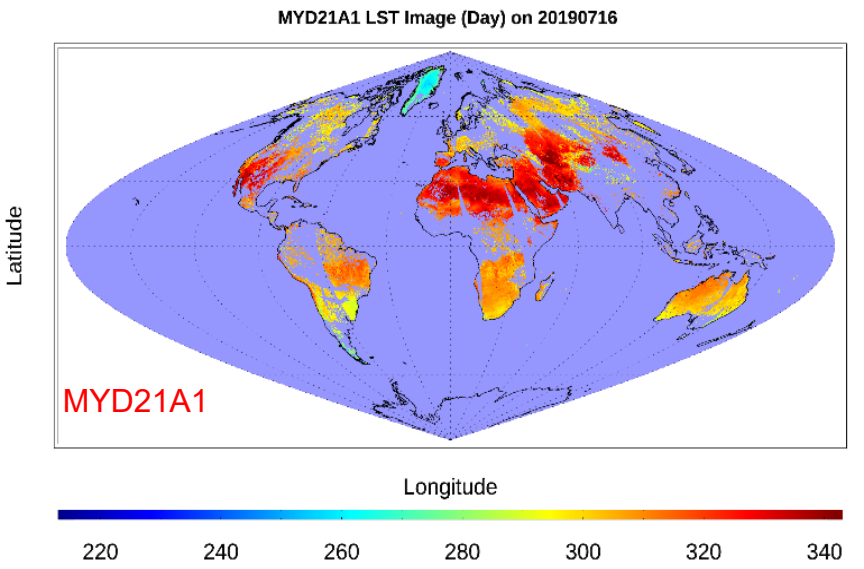
- LST is closer at nighttime compared to daytime estimations. Slightly more difference is observed at low latitude area.
- It is affected by the data availability due to cloud coverage and regional climate variation situations.

NOAA20 VIIRS LST vs MODIS LST

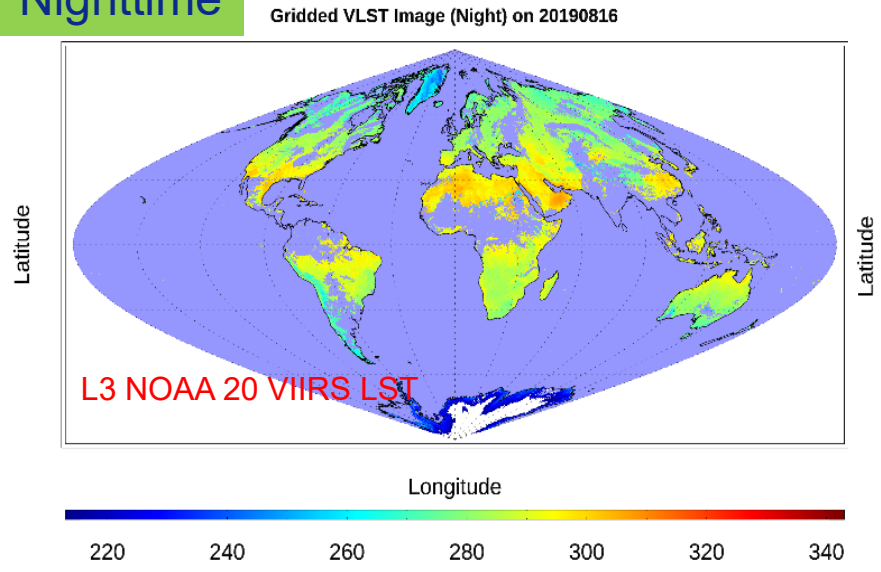
Daytime

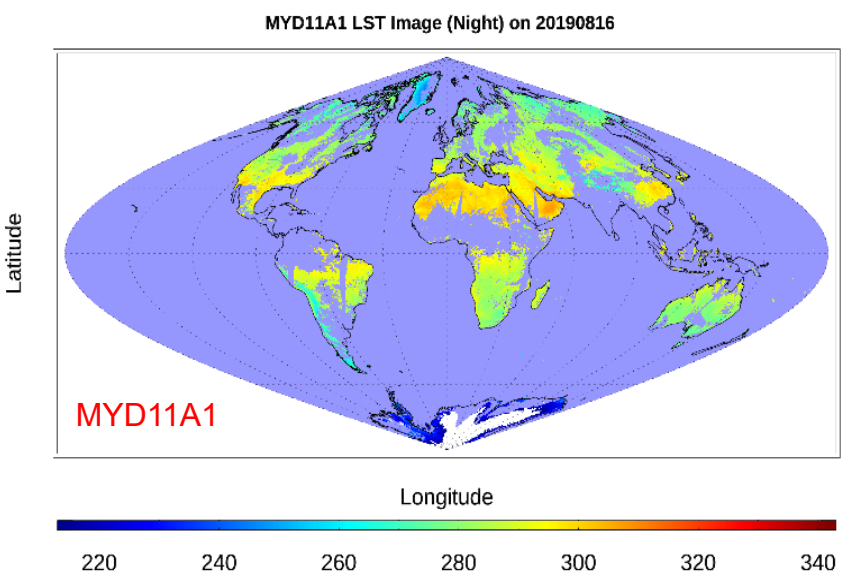


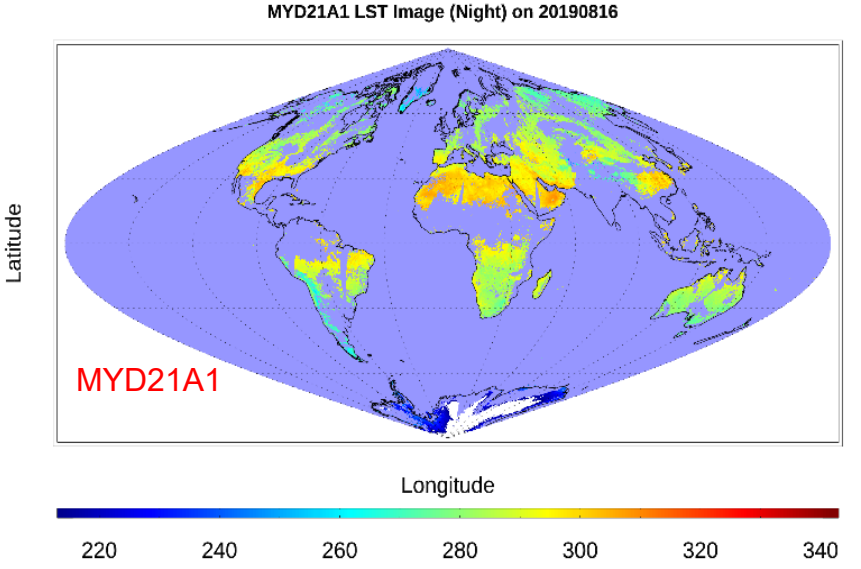




Nighttime



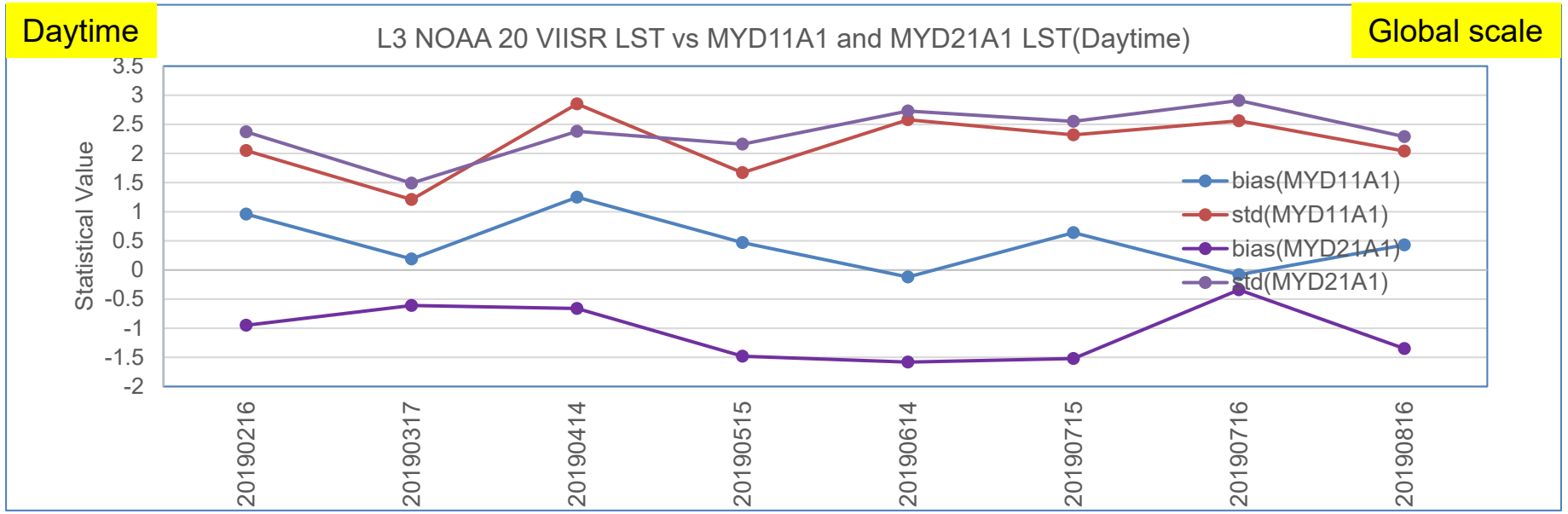




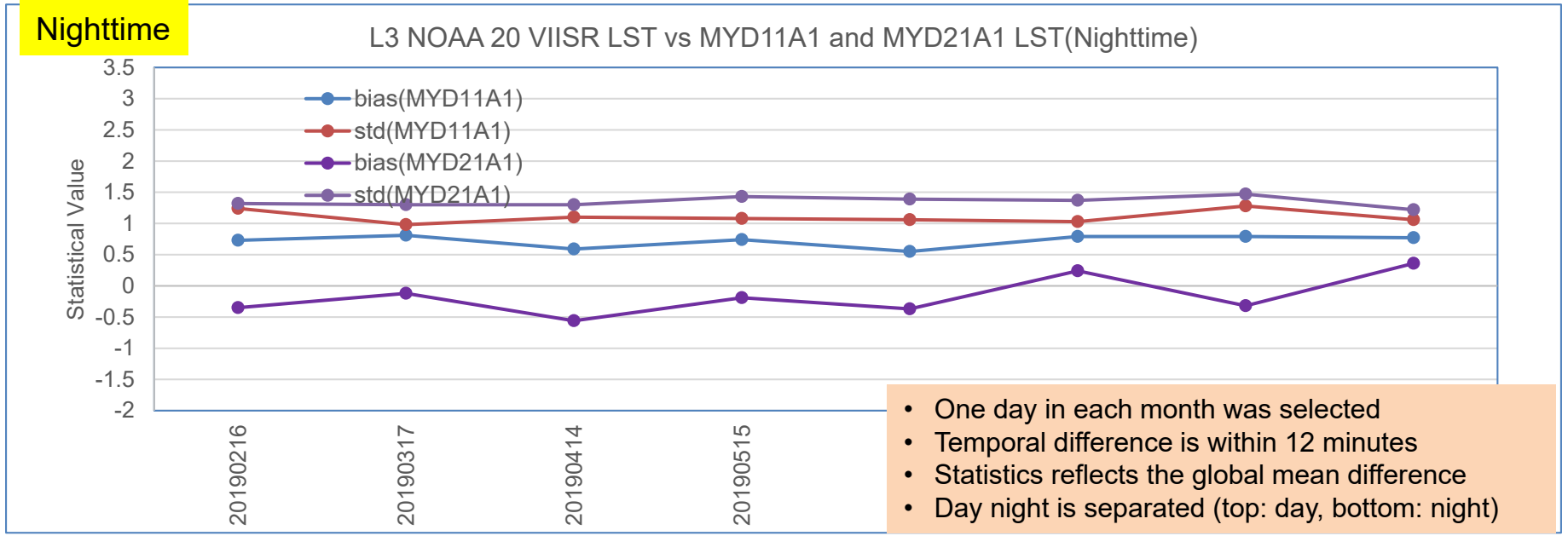
NOAA20 VIIRS LST vs MODIS LST

Daytime

Global scale



Nighttime



- One day in each month was selected
- Temporal difference is within 12 minutes
- Statistics reflects the global mean difference
- Day night is separated (top: day, bottom: night)

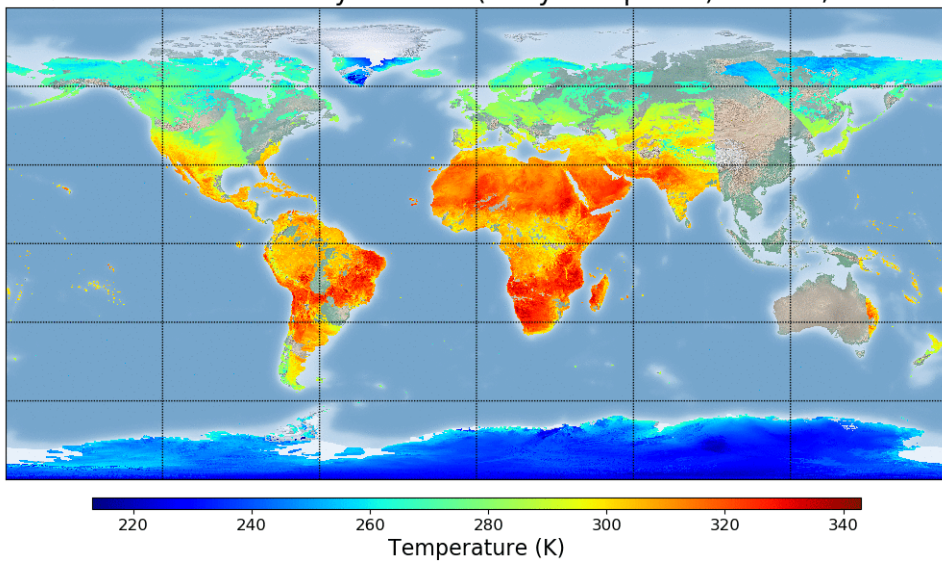
VIIRS LST Long term monitoring

Long Term Monitoring Ready

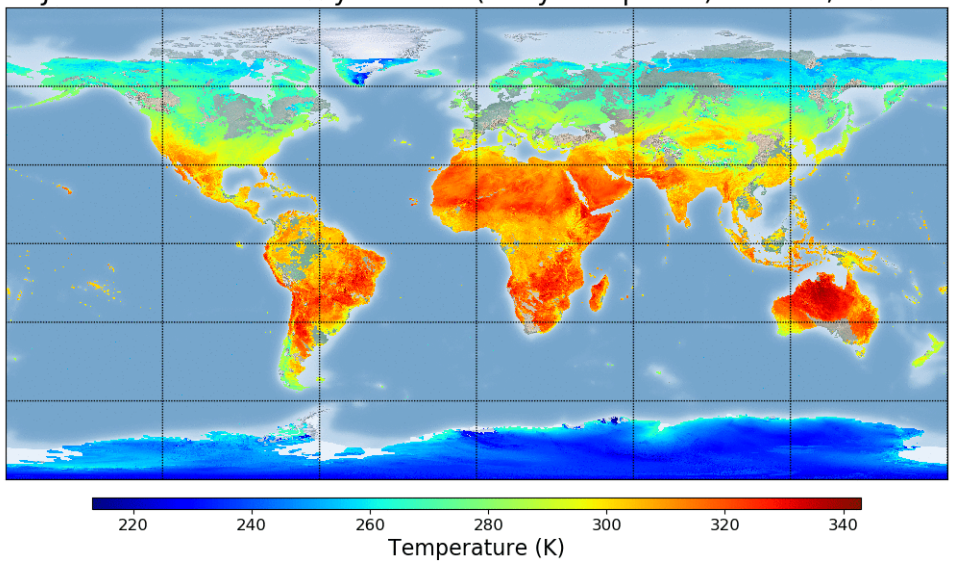
- ✓ The LST monitoring tool has been updated and applied for the LST product monitoring of NOAA-20, as well as for SNPP.
  - It runs weekly; results are automatically distributed via STAR FTP site.
  - Email notification to developer/user is available for the monitoring/alerting with details about the large discrepancies are provided e.g. cloud situation, ground signal stability etc.
  - Subset data is generated, which can be used for deep-dive analysis and future data reprocessing or fulfilling users request; easy to include new subsets upon request.

VIIRS LST Long term monitoring

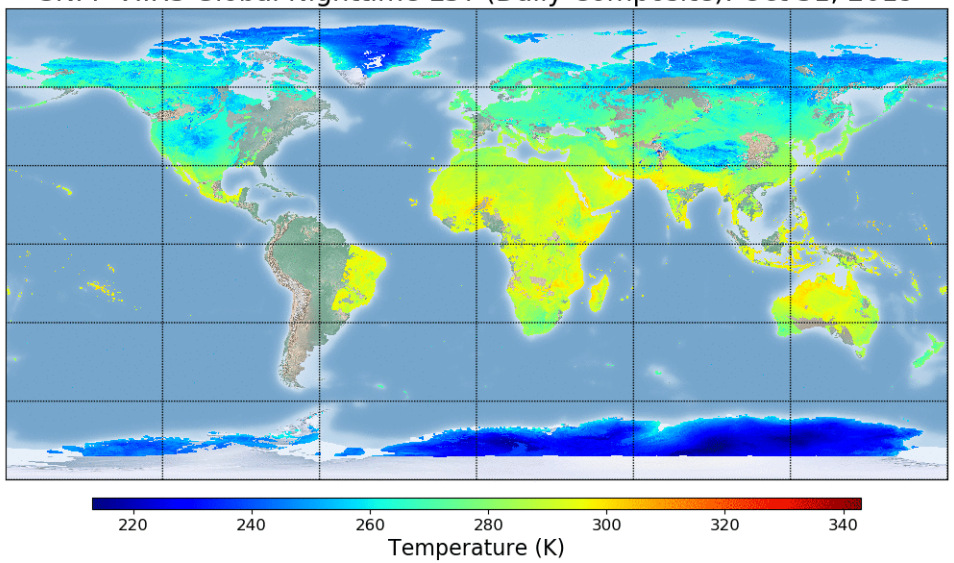
SNPP VIIRS Global Daytime LST (Daily Composite): Oct 31, 2019



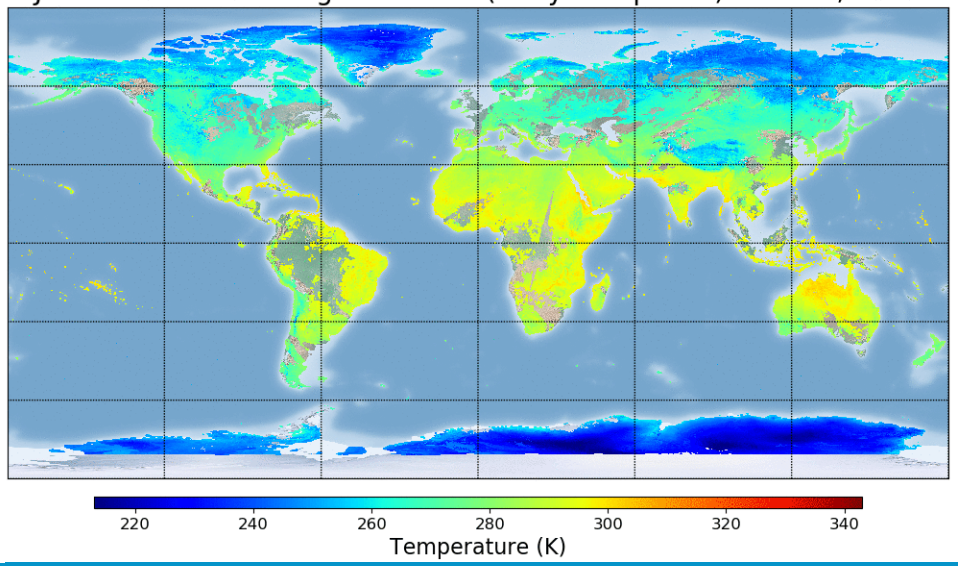
JPSS1 VIIRS Global Daytime LST (Daily Composite): Nov 01, 2019



SNPP VIIRS Global Nighttime LST (Daily Composite): Oct 31, 2019



JPSS1 VIIRS Global Nighttime LST (Daily Composite): Nov 01, 2019



VIIRS LST Long term monitoring

Validation results ftp distribution

Index of /pub/smcd/emb/pyu/LTM/LST/single/SNPP_V

[parent directory]

Name	Size	Date Modified
SNPP_VIIRS-Bondville_IL-validation-lst-color-scatter.png	81.3 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Bondville_IL-validation-lst-scatter.png	77.2 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Boulder_CO-validation-lst-color-scatter.png	81.5 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Boulder_CO-validation-lst-scatter.png	77.0 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Desert_Rock_NV-validation-lst-color-scatter.png	83.9 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Desert_Rock_NV-validation-lst-scatter.png	80.1 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Fort_Peck_MT-validation-lst-color-scatter.png	80.9 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Fort_Peck_MT-validation-lst-scatter.png	75.9 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Goodwin_Creek_MS-validation-lst-color-scatter.png	83.1 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Goodwin_Creek_MS-validation-lst-scatter.png	78.3 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Penn_State_PA-validation-lst-color-scatter.png	81.2 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Penn_State_PA-validation-lst-scatter.png	75.9 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Sioux_Falls_SD-validation-lst-color-scatter.png	82.3 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-Sioux_Falls_SD-validation-lst-scatter.png	77.4 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-SURFRAD-validation-lst-color-scatter.png	82.4 kB	10/17/19, 9:19:00 AM
SNPP_VIIRS-SURFRAD-validation-lst-scatter.png	76.4 kB	10/17/19, 9:19:00 AM

Weekly email notification

Reply | Reply All | Forward | Archive | Junk | Delete | Mo

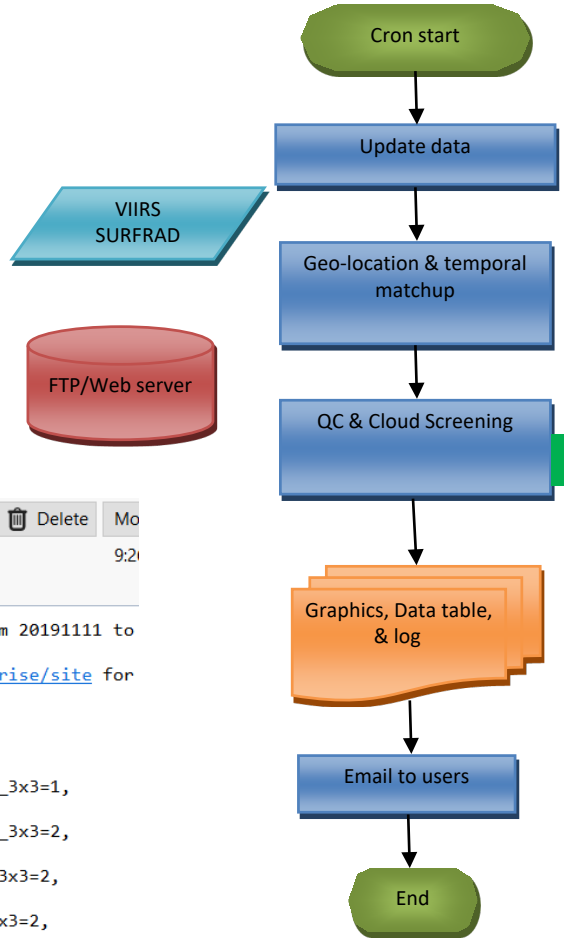
From lstmonitor.awg@gmail.com

Subject **JPSS1 VIIRS Enterprise LST monitoring results: 20191111 20191117** 9:2

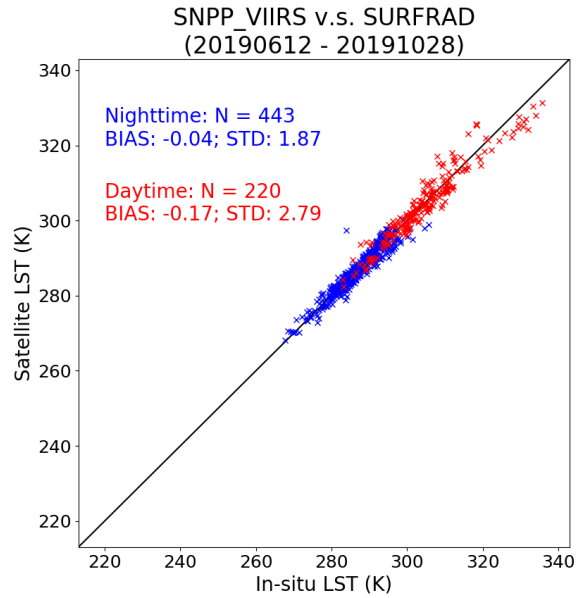
To peng.yu@noaa.gov, Yunyue Yu, Yuling Liu, heshun.wang@noaa.gov

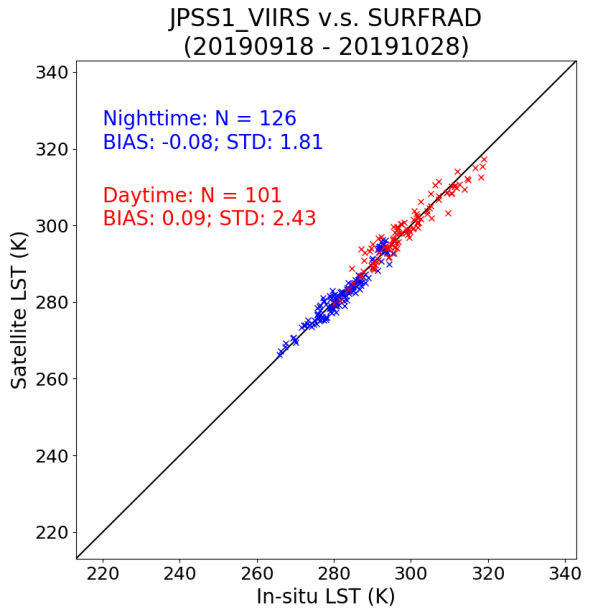
The monitoring for JPSS1 VIIRS Enterprise LST has been completed. The monitoring period is from 20191111 to 20191117.
Please visit ftp://ftp.star.nesdis.noaa.gov/pub/smcd/emb/pyu/LTM/LST/single/JPSS1_VIIRS/Enterprise/site for detaild results.

83 valid data pairs have been found.
Some problems have been found and listd as follows:
Bondville_IL: time=201911140819, lstdiff=-6.08, lst_sat=263.08, lst_gnd=269.17, cloud=1, cloud_3x3=1, std_bt11_3x3=1.61, std_dwt=0.24
Bondville_IL: time=201911141801, lstdiff=-6.01, lst_sat=268.38, lst_gnd=274.39, cloud=2, cloud_3x3=2, std_bt11_3x3=0.21, std_dwt=1.05
Boulder_CO: time=201911110916, lstdiff=-10.32, lst_sat=255.26, lst_gnd=265.59, cloud=2, cloud_3x3=2, std_bt11_3x3=0.72, std_dwt=0.70
Boulder_CO: time=201911140958, lstdiff=-7.22, lst_sat=267.16, lst_gnd=274.38, cloud=2, cloud_3x3=2, std_bt11_3x3=0.13, std_dwt=0.33
Fort_Peck_MT: time=201911131016, lstdiff=-6.16, lst_sat=265.13, lst_gnd=271.29, cloud=2, cloud_3x3=2, std_bt11_3x3=0.08, std_dwt=0.54
Fort_Peck_MT: time=201911131822, lstdiff=-12.39, lst_sat=261.94, lst_gnd=274.32, cloud=2, cloud_3x3=2, std_bt11_3x3=2.39, std_dwt=3.24



Site wide validation results and plots





LTM subset data extension

Deep-dive analysis

Time period: 20190601-20190831

Sites	Num	Cld Not clear	3x3Cld Not clear	3*3 BT15Std	Gnd 30 min Downward radiation STD	All passed
BND	116	4	4	1	2	1
TBL	120	3	2	4	2	0
DRA	164	5	8	4	10	1
FPK	150	3	2	0	0	1
GWN	116	2	6	0	1	0
PSU	107	5	0	0	1	0
SXF	115	3	0	0	0	2

This example summaries the various causes for large discrepancy beyond 6K between satellite LST estimation and ground LST measurements . The first three main influence factors are pixel cloud coverage, neighboring cloud and suspicious cloud detected from the ground site observations.

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Weizhong Zheng/Yihua Wu	**NCEP/EMC**	1) VIIRS NDE LST product is in operational need for model output verification purpose 2) VIIRS NDE LST data reprocessing is critical to providing long-term, consistent and high-quality LST products	
Xiaoyan Zhang	**NCEP/EMC**	RTMA/URMA system data assimilation To assimilate VIIRS LST into RTMA system to adjust the 2m air temperature	User has been able to ingest the L2 VIIRS LST data in their applications. User has got familiar with the NDE LST format and associated quality flags. The preliminary assimilation results indicate the adjust of T2M field looks reasonable.
Jifu Yin	**SMCD**	Near real time I km SMAP soil moisture (SM) product development. VIIRS LST data is used as an input in the NRT 1 km SMAP Soil Moisture Data Product development	User has used the VIIRS LST data in their applications and an improved result is achieved. A new upscaled soil moisture product is going to be developed. The user has obtained the updated L3 data for their applications.

Updated user feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Yuhan Rao	North Carolina Institute for Climate Studies (NCICS)	With the policy of social distancing/activity shut-down, many societal activities will be slowed down or stopped, which could lead to the redistribution of energy consumption and distribution at surface. There could be signals reflected in satellite observations and products. Air quality, day/night band, temperature, the urban/rural contrast change etc. We can use these satellite products including LST to detect these signals as a response to COVID-19's impact.	The user is ready to use the L3 VIIRS LST data.
Jifu Yin	SMCD	I km SMAP soil moisture (SM) product development. VIIRS LST data is used as an input in the NRT 1 km SMAP Soil Moisture Data Product development	The user is going to operationally generate 1 km soil moisture product with daily VIIRS LST as an important input. The user has obtained the latest L3 VIIRS LST data and converted the projection to lat/lon using conversion tools provided by the LST team.
Sofia L. Ermida	Satellite Application Facility on Land Surface Analysis (LSA-SAF)	The L2 enterprise VIIRS LST in 2016-2018 has been requested for multiple sensor LST validation studies.	The user has used the VIIRS LST data in their applications. They are ready for data ingestion.

Downstream Product Feedback

Algorithm	Product	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts
	1 km SMAP Soil Moisture product	LST provides ancillary information on soil moisture distributions, and thus can be used to produce finer resolution satellite soil moisture retrievals. Therefore the VIIRS LST is used as an input for soil moisture product with 1 km spatial resolution. Results show that the upscaled 1 km SM can significantly improve the accuracy of the original coarse spatial resolution SMAP.

Risks, Actions, and Mitigations

- Provide updates for the status of the risks/actions identified during the previous maturity review(s); add new ones as needed

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Nighttime LST quality bit is always "low'	Nighttime quality flag bit is always "low" attributed to the related input missing e.g. AOD is not available at nighttime, thin cirrus detection is only for daytime etc.	Low	**Closed**. The quality flag matrix has been updated by taking into account the input availability. The science code has been updated.
Snow cover input update	NWP snow cover was used for beta stage. Due to its coarse spatial resolution, the surface cover flag may not well represent the snow information at pixel level.	Low	**Open.** The VIIRS snow cover EDR was used as input in replace of the NWP snow cover. Test is on going.
LST discontinuity mitigation	LST discontinuity was observed in some granule data.	medium	**Open**. Performance further LUT test and updated with finer stratification of total column water vapor and geometry information.
Geometry added into the LST output	Upon the user request, the model people needs the geometry data in the LST output. This information is also needed for the L3 LST product.	medium	**close.** The geometry information including the satellite zenith angle and azimuth angle have been added into the LST output.
Permanent snow sometime not flagged as snow surface	Snow EDR only shows fresh snow so the permanent snow is sometime not flagged as snow.	Low	**Open**. The permanent snow is obtained from quality flag of the emissivity input. Better Snow cover data is needed
Quality flag bit order change	The quality flag bits order follows the original GOESR convention. Users might get confused.	Low	**Closed**. The bits order has been updated following the legacy of the JPSS product convention.
Geometry data Not set right	Geometry data carries valid value when the pixel latitude/longitude is fill.	Low	**Open**. The issue has been fixed and will be implemented in the next DAP.

Documentations (Check List, 1 slide)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	**Yes**
Algorithm Theoretical Basis Document (ATBD)	**Yes**
Algorithm Calibration/Validation Plan	**Yes**
(External/Internal) Users Manual	**Yes**
System Maintenance Manual (for ESPC products)	**Yes**
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	**Yes**
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	**Yes**

Peer-review publications:

- Y. Liu, Y. Yu, P. Yu, H. Wang, Y. Rao, Enterprise LST Algorithm Development and Its Evaluation with NOAA 20 Data. *Remote Sens.* 2019, *11(17)*, 2003.
- H. Wang, Y. Yu, P. Yu and Y. Liu, Land Surface Emissivity Product for NOAA JPSS and GOES-R Missions: Methodology and Evaluation, *IEEE Transactions on Geoscience and Remote Sensing*. 2019, doi: 10.1109/TGRS.2019.2936297
- Liu, Y.; Yu, Y.; Yu, P.; Göttsche, F.M.; Trigo, I.F. Quality Assessment of S-NPP VIIRS Land Surface Temperature Product. Remote Sens. 2015, 7, 12215-12241.

Check List - Validated Maturity

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	**Yes**, both direct-comparison with long-term in-situ measurements and cross-comparison with MODIS LST have been conducted.
Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.	**Yes**, all potential issues have been included in the ATBD, review reports, readme files, and published papers.
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	**Yes**, a series of analyses have been conducted, from checking of input to evaluation of all output layers. The content has contained all common points that the users want to know.
Product is ready for operational use based on documented validation findings and user feedback.	**Yes**, the current product has met the requirements and ready for use. Continuous effort will be invested for further improvements.
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	**Yes**, the product will be monitored through the lifetime for periodically and regularly validation and calibration according to the sensor performance.

Requirement Check List – LST

JERD	Requirement	Performance
	Applicable Conditions: Clear Condition only	
JERD-2438	The algorithm shall produce a land surface temperature product with a horizontal cell size of 0.80 km	Yes
JERD-2516	The algorithm shall produce a land surface temperature product with a mapping uncertainty (3 sigma) of 1 km at Nadir	Yes
JERD-2517	The algorithm shall produce a land surface temperature product with a measurement range of 213 – 343 K	Yes
JERD-2518	The algorithm shall produce a land surface temperature product with a measurement precision (1 sigma) of 2.5 K (Note 1)	Yes, details are given in error budget summary
JERD-2519	The algorithm shall produce a land surface temperature product with a measurement accuracy (bias) of 1.4 K (Note 1)	Yes, details are given in error budget summary

Note 1: Accuracy and precision performance will be verified and validated for an aggregated 4 km horizontal cell to provide for adequate comparability of performance across the scan

Conclusion

The LST team recommends the NOAA20 VIIRS LST product validated maturity based on its performance in the ground validation, long term monitoring and global cross-satellite LST comparison.

Some concerns according to the user feedback and long term monitoring:

- Data gap. The NDE NOAA 20 LST has been available since Sep. 2019. The enterprise NDE LST data for the time period from Jan. 5, 2018 to Sep. 16, 2019 is not in anywhere.
- Users mostly rely on the information provided in the LST product for their applications. Considering the significant impact from unidentified cloud, investigation is needed for a proper use of the cloud probability to minimize the residual cloud and customize the cloud clear mask. The use of the cloud probability is also recommended by the ECM team.
- User would like to get pixel level uncertainty information.
- The cross satellite comparison presents angular, regional LST bias particularly at daytime. The LST LUT tuning might be potentially needed.

Path Forward

- Planned improvements
  - Geometry data correction will be implemented in the next DAP delivery
  - LST LUT updates are planned
  - Uncertainty estimation at pixel level, being available to users
  - Investigate use of the cloud probability for cloud mask customization

- Future Cal/Val activities / milestones
  - Extend the radiance based validation of the NOAA 20 VIIRS LST
  - Extend the cross comparison
  - Continue the routine ground validation using SURFRAD and BSRN. Explore other high quality ground observations
  - Involve in the international cooperation on the LST product validation
  - Continue the long-term monitoring of the product quality. Adjustment may be made upon any issue observed.
  - Promote the LST applications and actively involved in the interactions with users