Validated Stage 1 Science Maturity Review for JPSS LST

Presented by Yunyue Yu
Contributors
Yuling Liu, Peng Yu, Zhuo Wang, Leslie Belsma

December 11th, 2014

Outline

- Algorithm Cal/Val Team Members
- Product Requirements
- Evaluation of algorithm performance to specification requirements
  - *Evaluation of the effect of required algorithm inputs*
  - *Quality analysis/validation*
  - *Error Budget*
- Documentation
- Identification of Processing Environment
- Users & User Feedback
- Conclusion
- Path Forward

Data Product Maturity Definition

Provisional Maturity:

- Product quality may not be optimal
- Incremental product improvements still occurring
- Version control is in effect
- General research community is encouraged to participate
- Users urged to consult the EDR product status
- May be replaced in the archive
- Ready for operational evaluation

Validated Stage 1:

Using a limited set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions

Validated Maturity:

- Product performance is defined and documented over a wide range of representative conditions via numerous and ongoing ground-truth and validation efforts
- Clear documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies, regardless of severity level
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose
- Testing has been fully documented
- Ready for long term monitoring
- Product improvements continue through the lifetime of the instrument

LST EDR Cal/Val Team

	Name	Institute	Function
JPSS-STAR	Ivan Csiszar	NOAA/NESDIS/SATR	Land Lead, Project Management
	Yunyue YU	NOAA/NESDIS/SATR	TEDR Lead, algorithm development, validation, team management
	Yuling Liu	*NOAA Affiliate, UMD/ESSIC*	*product monitoring and validation ; algorithm development*
	Zhuo Wang	*NOAA Affiliate, UMD/ESSIC*	*algorithm improvement*
	Peng Yu	*NOAA Affiliate, UMD/ESSIC*	*product validation tool*
	Marina Tsidulko	*NOAA Affiliate, SciTech/IMSG*	*STAR AIT*
	Michael EK	NOAA/EMC/NCEP	user readiness
	Jesse Meng	NOAA Affiliate	user readiness
JPSS/DPA			
	Leslie Belsma	Aerospace Corp	algorithm Manager (JAM) for Land
NASA S-NPP Science Team			
	Miguel Roman	NSAS/GSFC	*Validation data support, product monitoring*
	Sadashiva Devadiga	NASA/GSFC Affiliate, SSC	*Validation data support, product monitoring*

Requirements

Product Requirements from JPSS L1RD

Attribute	Threshold	Objective
Geographic coverage	At least 90% coverage of the globe every 24 hours (monthly average)	
Vertical Coverage		
Vertical Cell Size		
Horizontal Cell Size	4 km	1 km
Mapping Uncertainty	1 Km at Nadir (800 m)	1 km at Edge of Scan (500m)
Measurement Range	**213 – 343 K**	183 – 343 K
Measurement Accuracy	**1.4 K**	0.8 K
Measurement Precision	**2.5 K**	1.5 K

History of Algorithm Changes/Updates

Date	DR#	Reason	Status
12/12/12	5028	LST QA not set correctly in all-ocean granules	**Closed 3/31/13.** Rejected b/c No land products over ocean will ever be used; illustrates larger IDPS architecture issue that land products should not be produced over ocean
11/26/12	4983	VIIRS LST beta Maturity	**Closed 1/25/13** 474-CCR-12-0773 deployed in ops
02/28/12	4608	Split-window algorithm - Baseline Coefficient files. LUT update #2 (same as"Updated LUT" in slides): DR 4608/CCR 12-0355: Corrects errors for both dual split window and split window.	**Closed 06/10/12** Split Window algorithm implemented in IDPS baseline on 10 Aug, 2012.
02/15/12	4582	LST Day Night Land Water Misidentification, The LST EDR appears to have a coding error that may have incorrectly mixed up the Day/Night flag with the Land/Water and Surface Type QA Flag within the QF Byte 3 of the LST EDR... This same Day/Night flag is being correctly encoded in the bit3 of QF Byte1 of the LST EDR.	**Closed 03/29/12** Rejected because EDR team did not observe such error.
09/14/11	4353	Snow/ice field is always "no snow" at night if the Quarterly Surface Type does not indicate so. "Temporal snow" can only be directed daytime by snow/ ice EDR	**Closed 04/26/12.** Reallocated to Cryo team as new DRs: 4699 Out of Date snow cover seeded grid & 4700 Alternative snow/ice grid needed to support algorithms; Both have been addressed.
02/14/11	4203	The OPS LST code, both v1.5.00.48 and v1.5.03.00, do not verify that the value for the Surface Type input falls within the valid range prior to calculating LST	**Closed 1/9/13** Rejected because not a problem to LST production since LST code does check the ST.

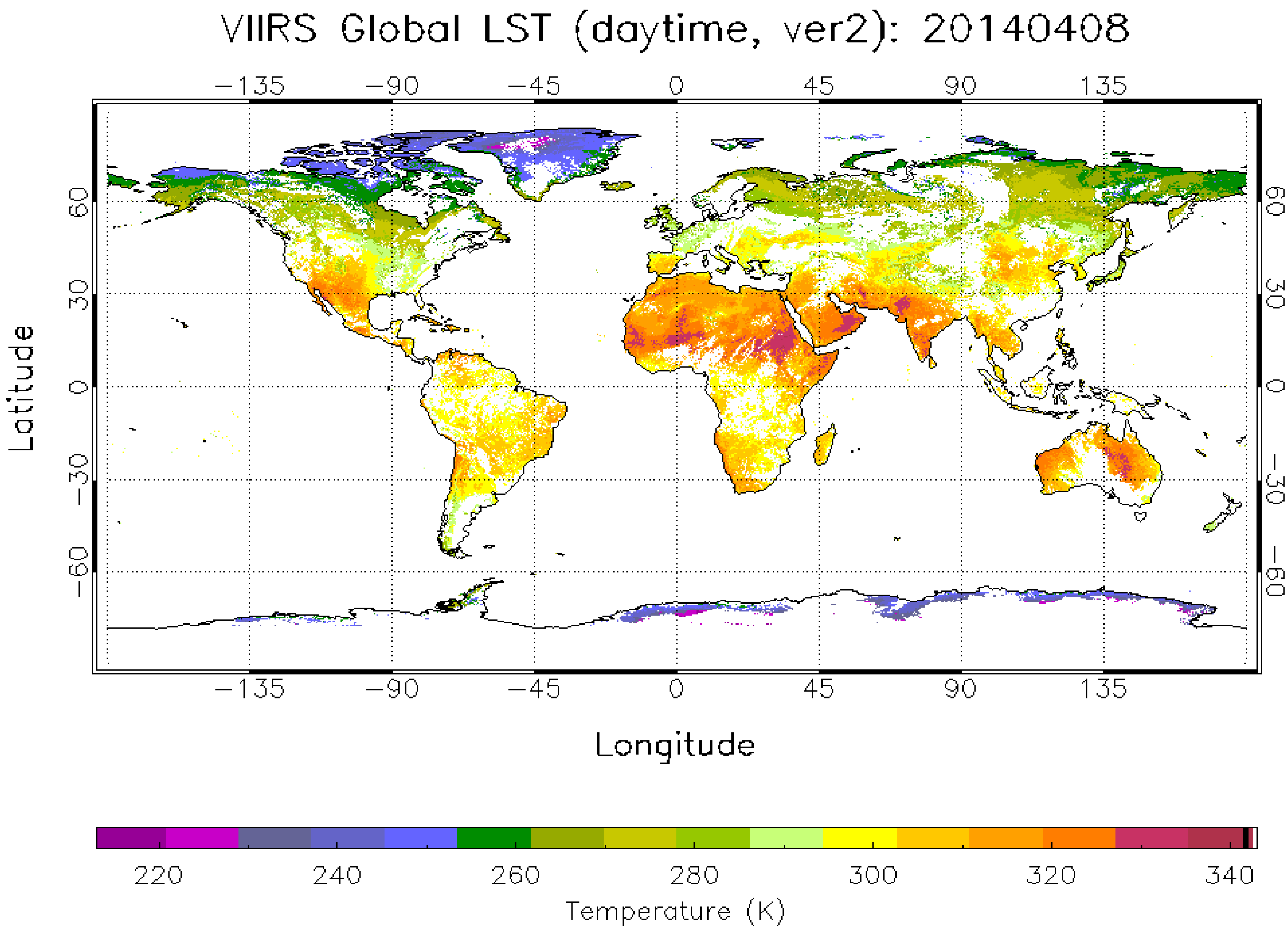
History of Algorithm Changes/Updates

Date	DR#	Reason	Status
12/12/12	5027	VIIRS LST should have NA fill in all-ocean granules	**Closed** IDPS initiated change implemented in IDPS Mx8.0
2/9/13	7055	LST QA is “low quality” when thin cirrus/active fire is et	**Closed** Approved at 5/22/13 AERB Implemented in IDPS Mx8.0
5/23/13	7215	VIIRS LST_SWLST LUT Update	**Closed** CCR-13-1089 Approved at 6/18/13 AERB Implemented in IDPS in Mx8.0
12/4/13	7479	474-CCR-13-1433 VIIRS LST Mx8.0 LST incorrect: Revert to previous SWLST LUT ASAP	**Closed** CCR-13-1433 Approved at 12/20/13 AERB Implemented in IDPS 12/24/134
12/17/13	7493	LST_SWLST LUT Update to correct issues found in DR7215 LUTs	**Closed** Approved at 3/19/14 AERB Implemented in IDPS 4/7/14. LST provisional maturity effective as of implementation of this update.

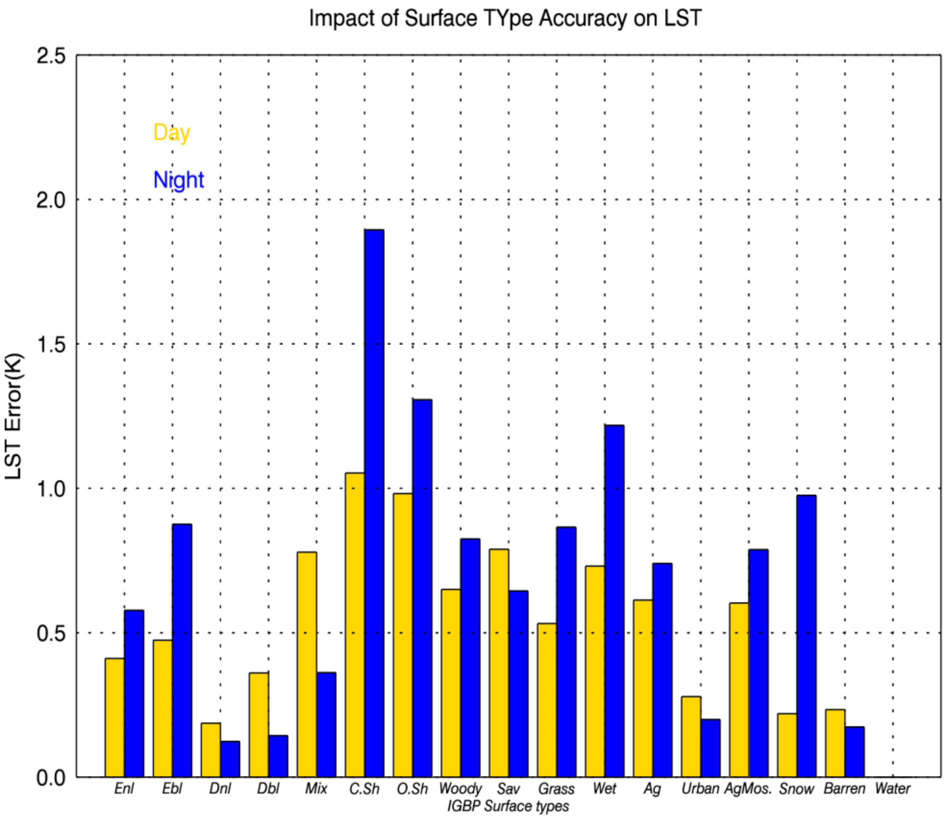
Evaluation of algorithm performance to specification requirements

- Findings/Issues from Provisional Review
  - *Strong impact of surface type uncertainty on LST quality*
  - *Cloud contamination impact is significant*
  - *Lack of high quality validation data set*
- Improvements since Provisional
  - *Algorithm and LUT remain the same*
  - *Significant efforts done on validation and uncertainty analysis*
  - *Long term monitoring tool is in development*
    - in use with daily/weekly/monthly/yearly maps and graphics, providing near-real time quality assessment
  - *Emissivity explicit algorithm is in development*

Evaluation of algorithm performance
---- monitoring tool



Evaluation of algorithm performance ---- Impact of ST input error (1/2)



$$S_i^2 = \sum_{j=1}^{17} \left(P_{ij} * Rmse^2(\varepsilon_{ij}) \right) \qquad S_{sf}^2 = \sum_{i=1}^{17} \frac{S_i^2 * N_i}{N_{total}}$$

P_{ij} is the probability of mis-classfication of surface type i (i=1,2…17) to be j (j=1,2…17)

ε_{ij} is the LST difference between LST calculated with the equation for surface type i and with the equation for surface type j for each pixel with i surface type

S_i^2 represents the error for each IGBP type i under either day or night condition

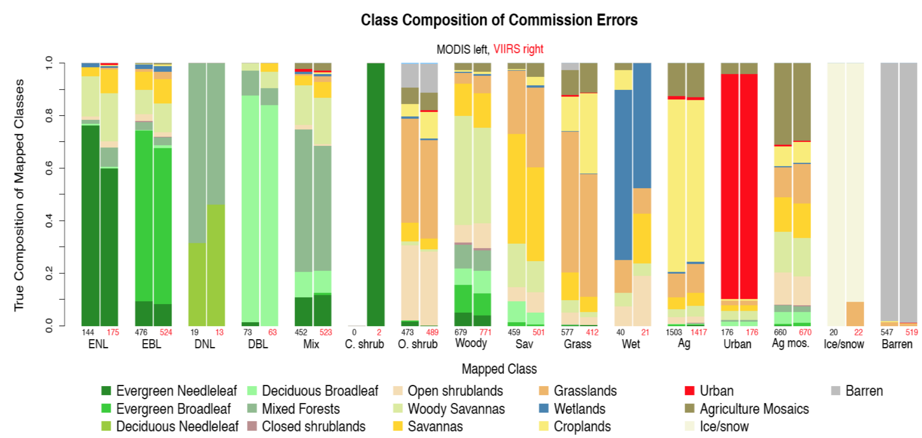
S_{sf}^2 represents the error for all IGBP types and all day/night conditions

N_i represents the number of samples for surface type IGBP i

N_{total} represents the total number of samples for all cases

Impact on LST **(using simulation database)**

Overall Statistics	Impact on LST
All-Day	0.61
All-Night	0.83
All	0.73



*Reference: Damien Sulla-Menashe, VIIRS ST V1 Quality Assessment April 02, 2014 EDR meeting

Evaluation of algorithm performance
---- Impact of Sensor Noise (1/2)

Theoretical estimation of the sensor noise impact

$$S_{(ij)_{bt}}{}^2 = S_{(ij)_{bt11}}{}^2 + S_{(ij)_{bt12}}{}^2$$

where $$S_{(ij)_{bt11}}{}^2 = \left(\overline{\frac{\partial f_{(ij)}}{\partial BT_{11}}}\right)^2 \sigma_{bt11}{}^2 \qquad S_{(i)_{bt12}}{}^2 = \left(\overline{\frac{\partial f_{(ij)}}{\partial BT_{12}}}\right)^2 \sigma_{bt12}{}^2$$

$$S_{bt}{}^2 = \sum_{i=1}^{17} \frac{S_{ij}{}^2 * N_i}{N_{total}}$$

$S_{(i)_{bt}}{}^2$ represents the error caused by sensor noise from both BT11 and BT12 for each IGBP type I under either day or night condition i (i=1,2…17) j(0:night,1:day)

$S_{(i)_{bt11}}{}^2$ represents the error caused by sensor noise from BT11

$S_{(ij)_{bt12}}{}^2$ represents the error caused by sensor noise from BT12

σ_{bt11} and σ_{bt12} represents noise requirements for emissive band at 11micron and 12micron, onboard the VIIRS, respectively

$S_{bt}{}^2$ represents the overall error caused by sensor noise

N_i represents the number of samples for surface type IGBP i

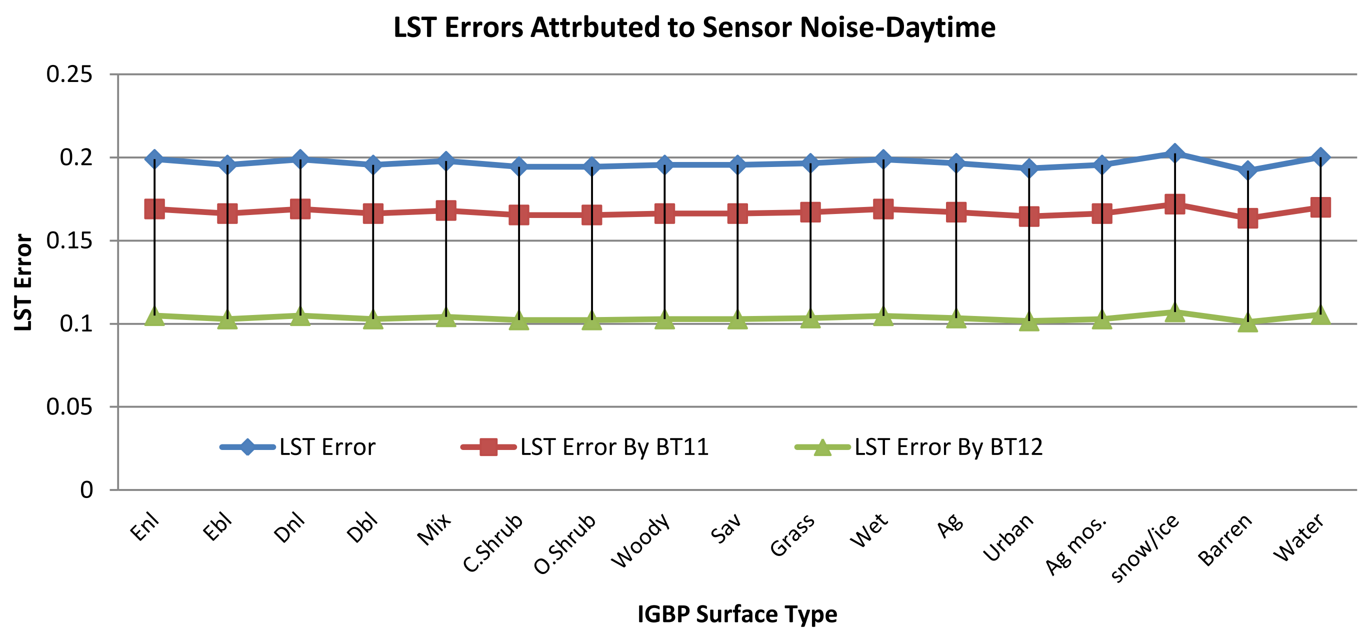
N_{total} represents the total number of samples for all cases

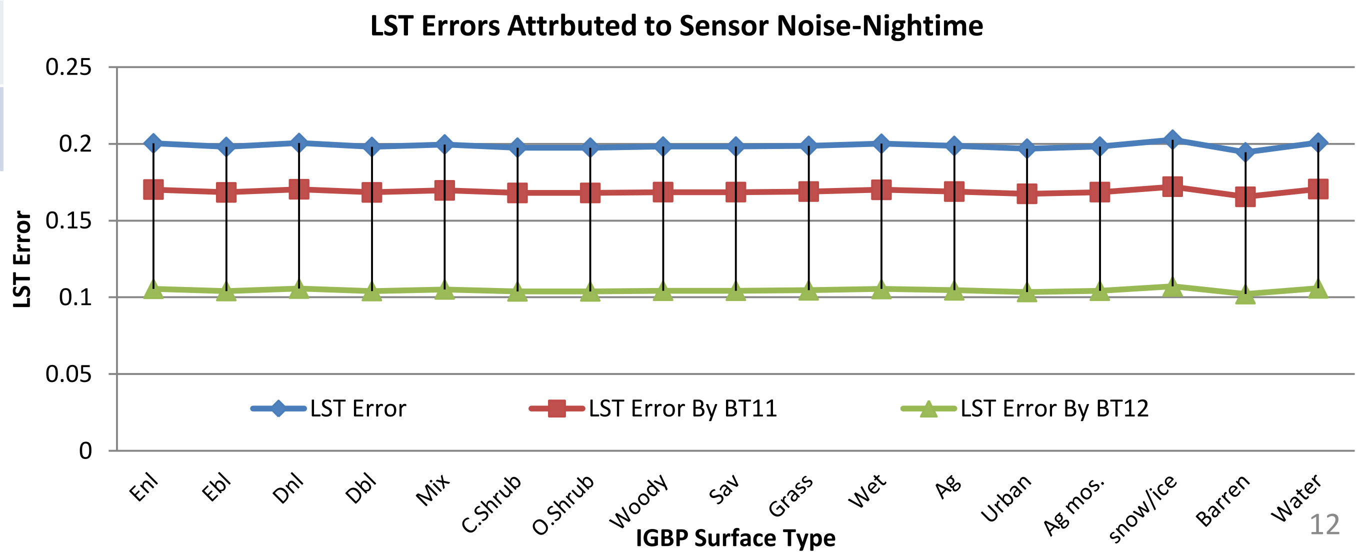
Evaluation of algorithm performance
---- Impact of Sensor Noise (2/2)

Sensor noise level :
σ = 0.070 K

Overall Statistics	Impact on LST*
All-Day	0.197K
All-Night	0.199K
All	0.198K

*Impact on LST is estimated **using simulation database**





Evaluation of algorithm performance
---- Impact of input errors (overall)

Theoretical estimation of the overall impact

$$S_{LST} = \sqrt{S^2{}_{sf} + S^2{}_{bt} + \delta^2{}_{lst}}$$

S_{LST} represents the overall LST uncertainty

$S^2{}_{sf}$ represents the uncertainty caused by surface type

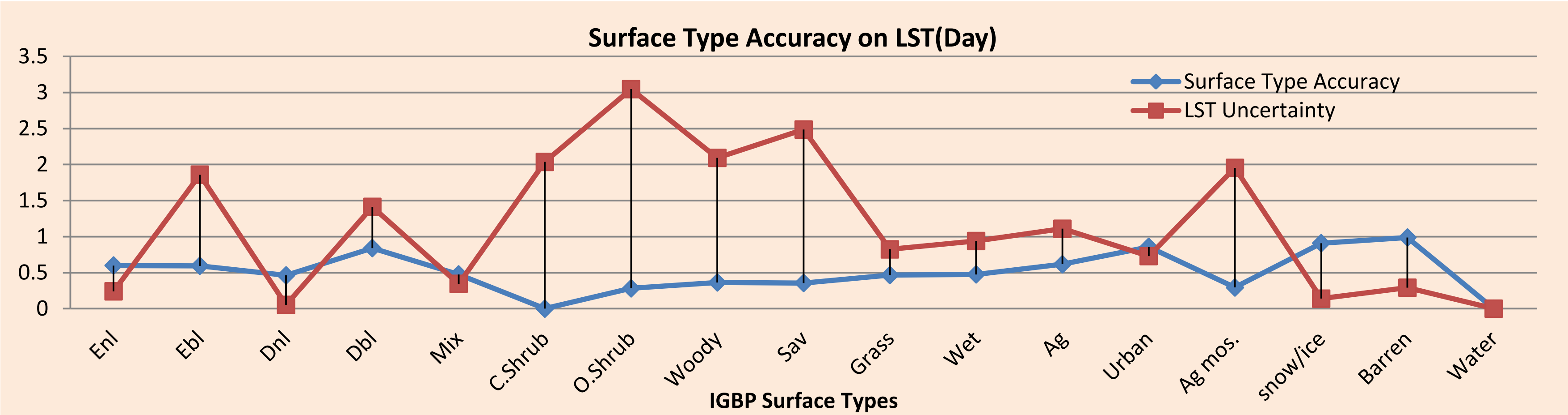
$S^2{}_{bt}$ represents the uncertainty caused by sensor noise

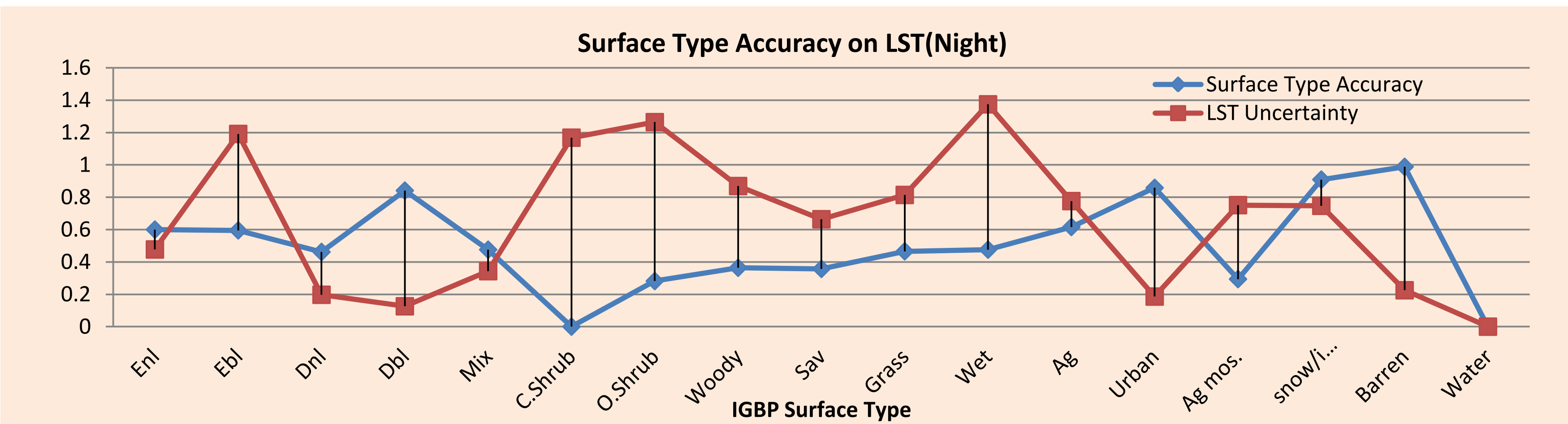
$\delta^2{}_{lst}$ is the algorithm uncertainty, estimated in the coefficients regression procedure bases only on the simulation data.

Overall Statistics	Uncertainty by Surface Type Accuracy	Uncertainty by Sensor Noise	Algorithm Uncertainty	Overall LST product Uncertainty**
All	0.73	0.198	0.46	0.88
All-Day	0.61	0.197	0.42	0.77
All-Night	0.83	0.199	0.51	0.99

Impact on LST is estimated **using simulation database

Evaluation of algorithm performance
---- Impact of ST input error (2/2)





Overall Statistics	Impact on LST
All-Day	1.5K
All-Night	0.8K
All	1.2K

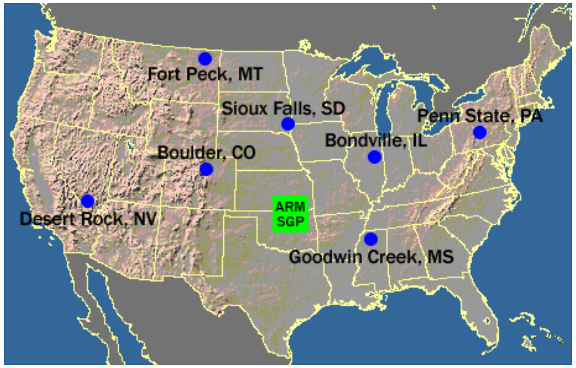
Impact on LST **using real orbit data** on Oct. 22, 2014, daytime (top) and nighttime(bottom)

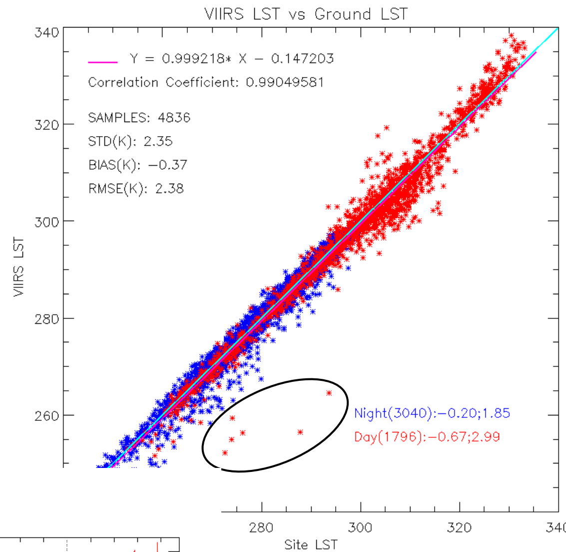
Quality Analysis/Validation

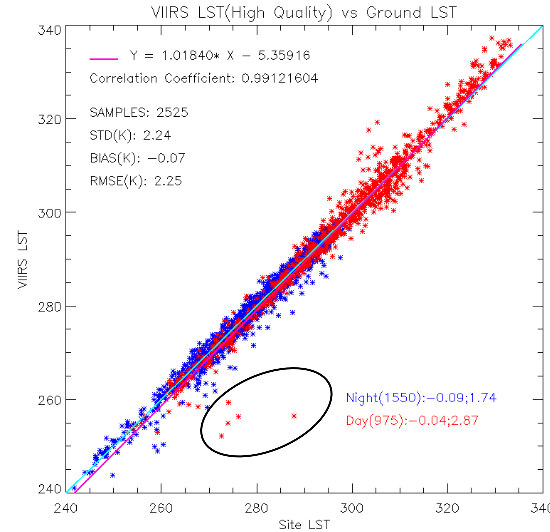
Quality analysis and validation studies on

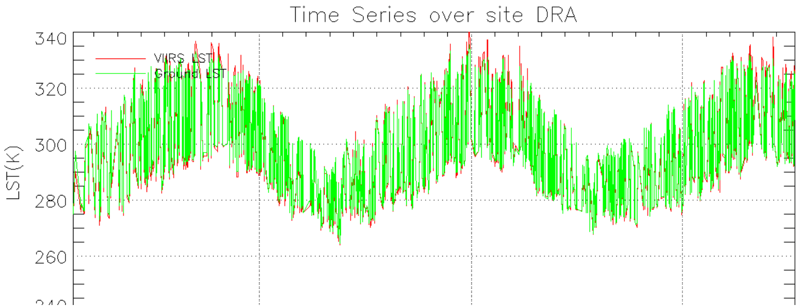
- Ground measurements
  - SURFRAD
  - CRN
  - Africa data
  - China
- Radiance based validation
  - Global (9 areas selected)
- Cross satellite comparison
  - MODIS Aqua LST
  - MSG SEVIRI LST

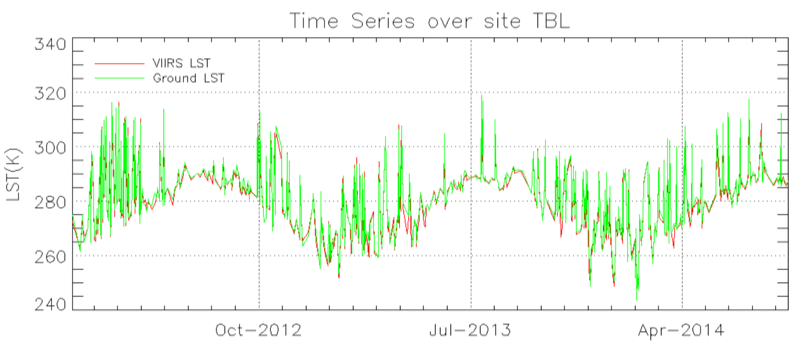
Quality Analysis/Validation ---- SURFRAD Sites (1/2)







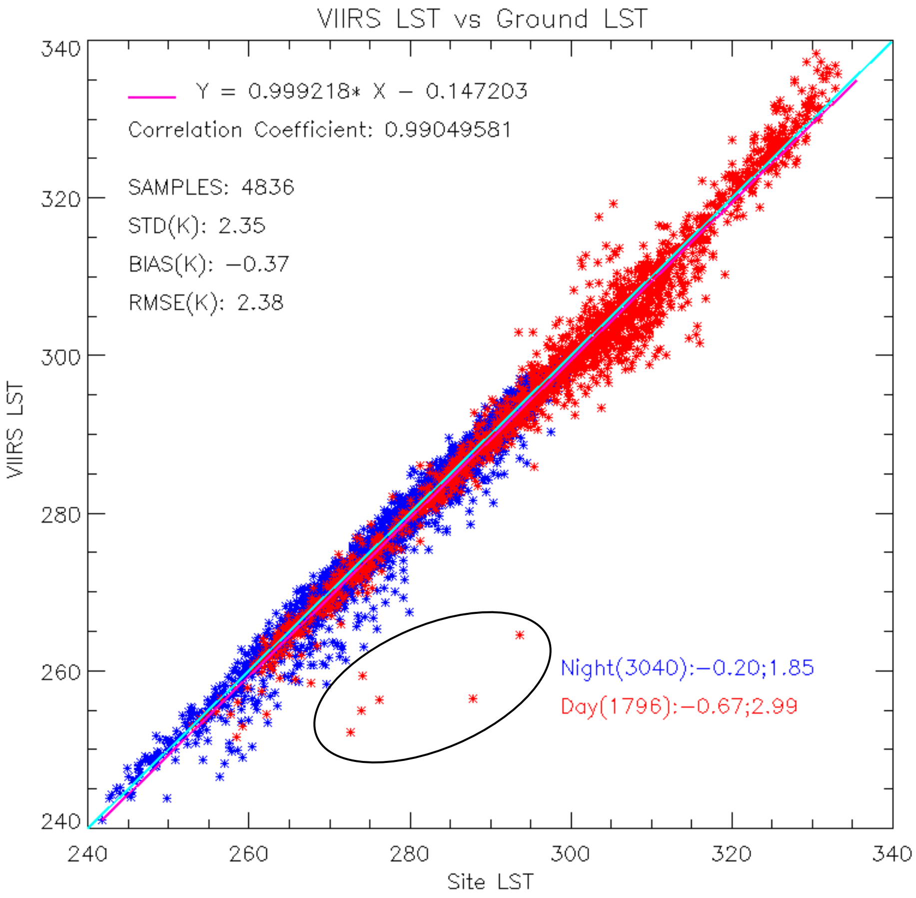


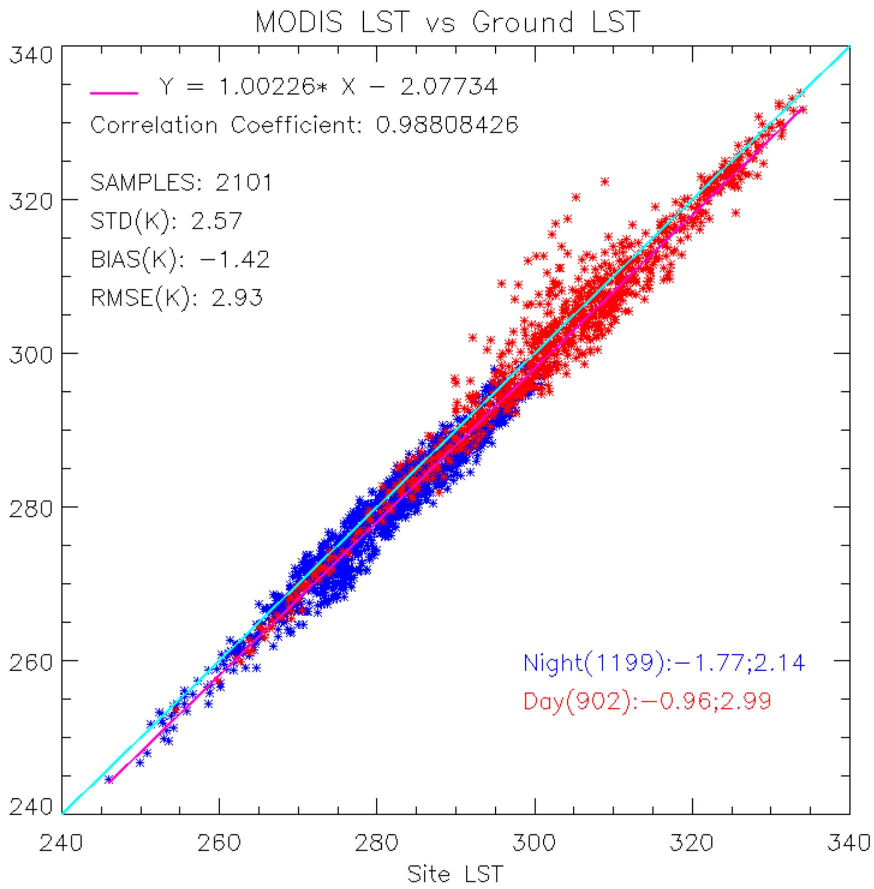


Season	Samples	Overall		Day		Night	
		Bias	STD	Bias	STD	Bias	STD
Spring	1297	-0.54	2.78	-0.69	3.82	-0.46	1.97
Summer	1403	-0.1	2.43	-0.87	3.68	0.26	1.39
Fall	1160	-0.28	1.9	-0.32	2.04	-0.24	1.79
Winter	976	-0.65	2.01	-0.83	1.65	-0.53	2.21

IGBP type	Samples	Overall		Day		Night	
		Bias	STD	Bias	STD	Bias	STD
4	18	-1.41	3.01	-1.82	2.66	-1.26	3.22
6	96	-0.98	1.41	-0.5	1.88	-1.32	0.84
7	955	-0.2	1.59	0.24	2.06	-0.61	0.79
8	286	0.19	2.56	-1.7	2.6	1.38	1.66
10	1048	-0.49	1.81	-0.85	2.3	-0.37	1.59
12	1238	-0.35	2.68	-0.63	3.8	-0.22	1.91
14	857	-0.28	2.54	-1.28	2.4	0.19	2.47
15*	189	-1.72	4.31	-1.72	4.31		
16	149	-0.23	1.55	0.87	1.67	-1.04	0.75

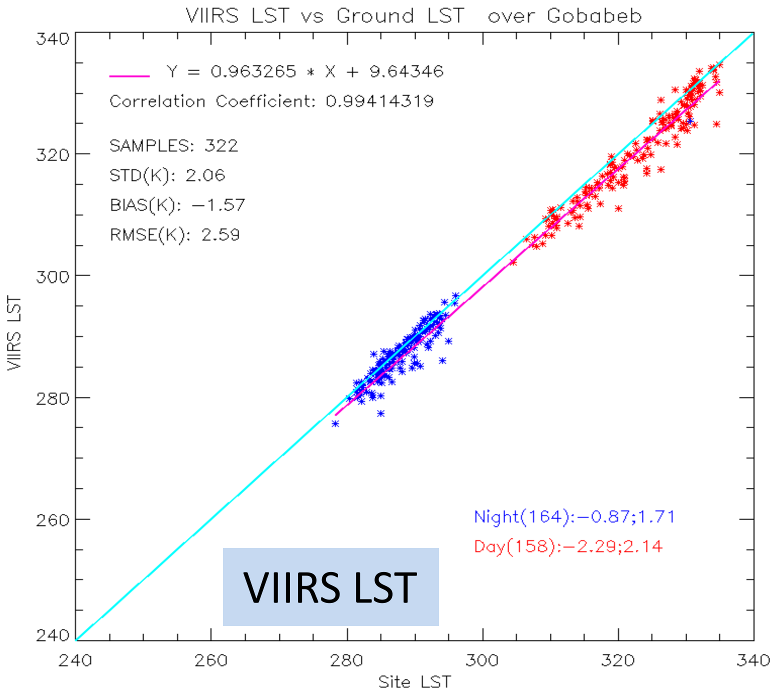
Quality Analysis/Validation
---- SURFRAD Sites (2/2)

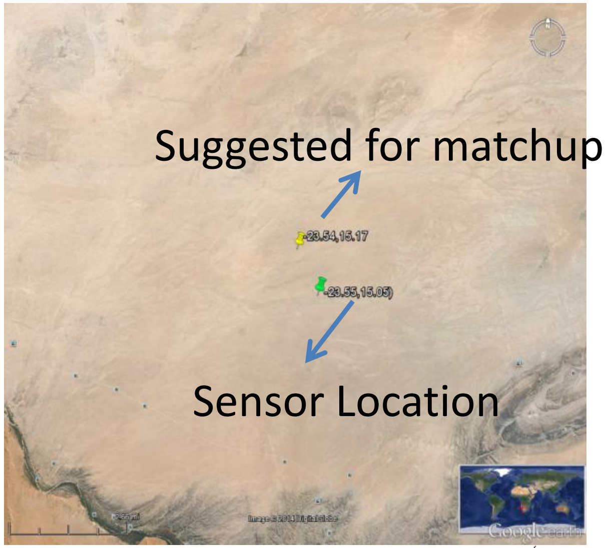


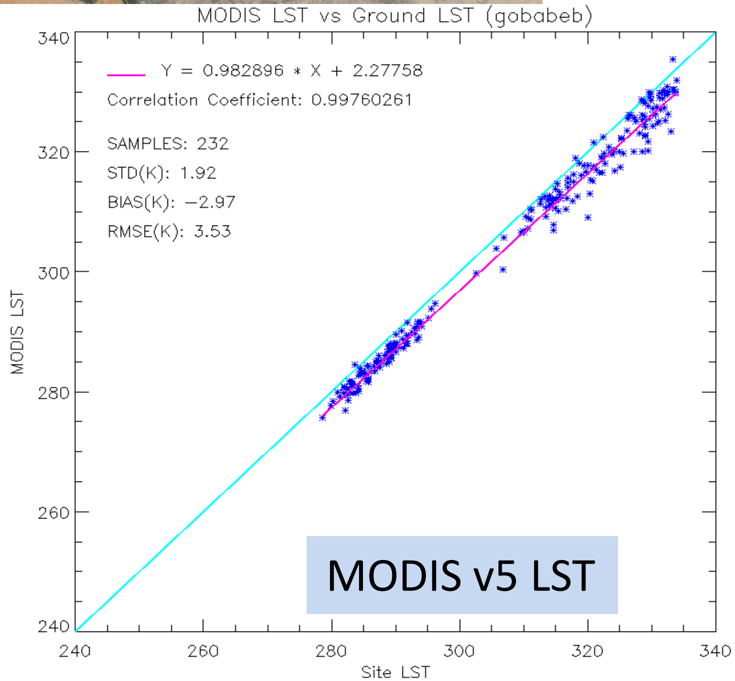


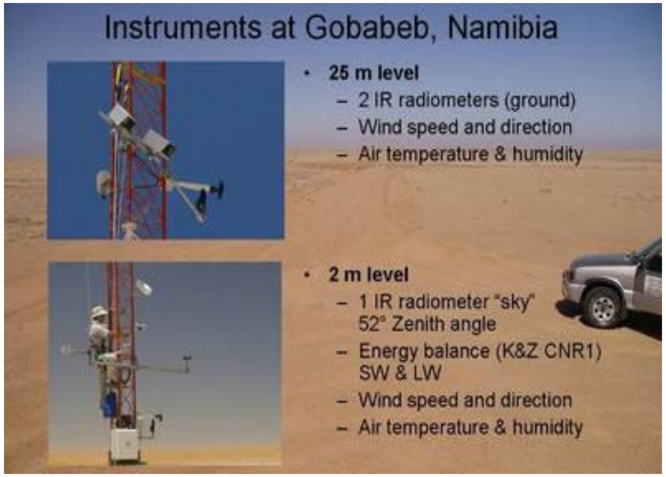
VIIRS Data: Feb. 2012 – Aug. 2014
MODIS Data: Jan. 2012 – Jul. 2013

Quality Analysis/Validation
---- Africa Site*



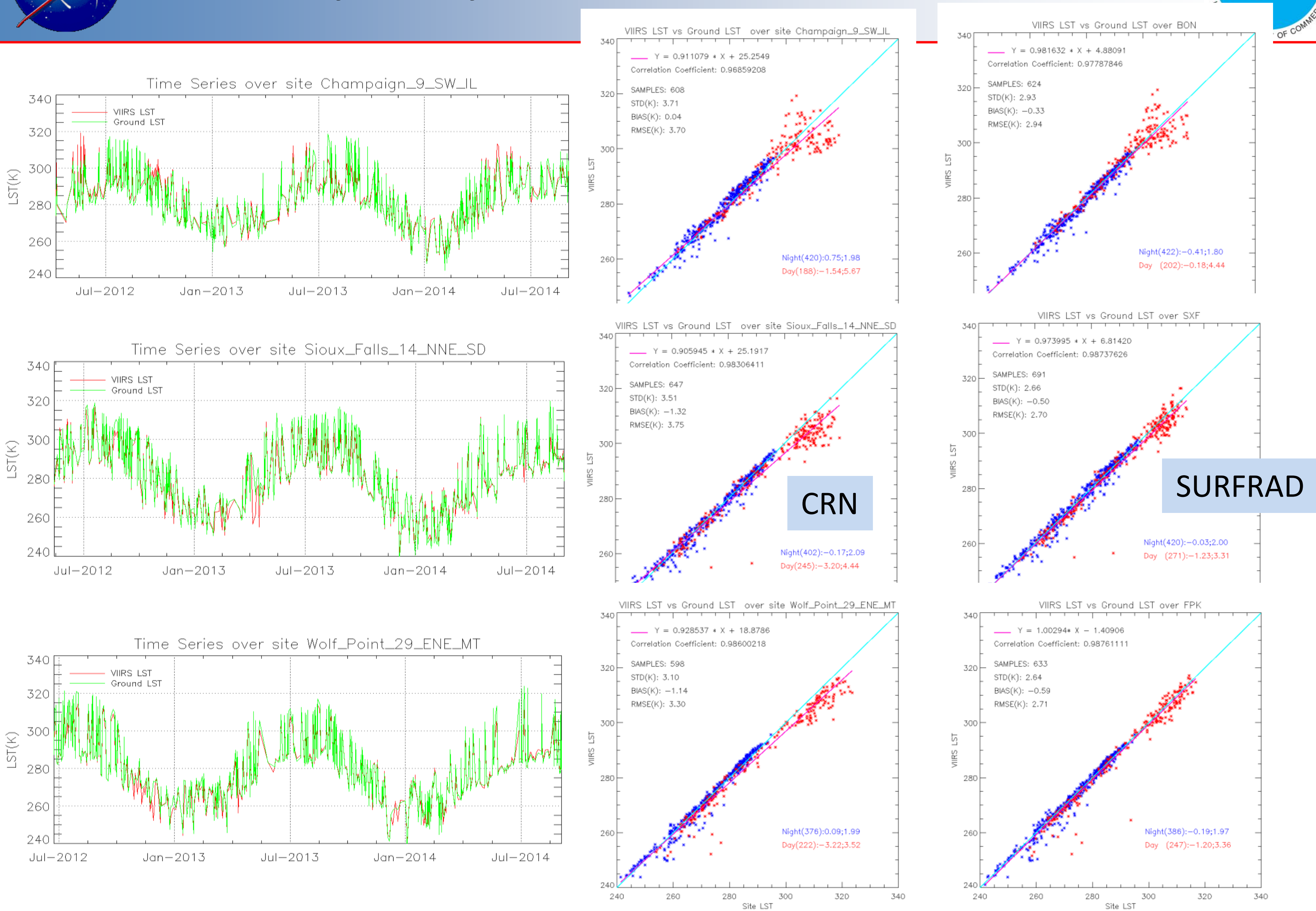




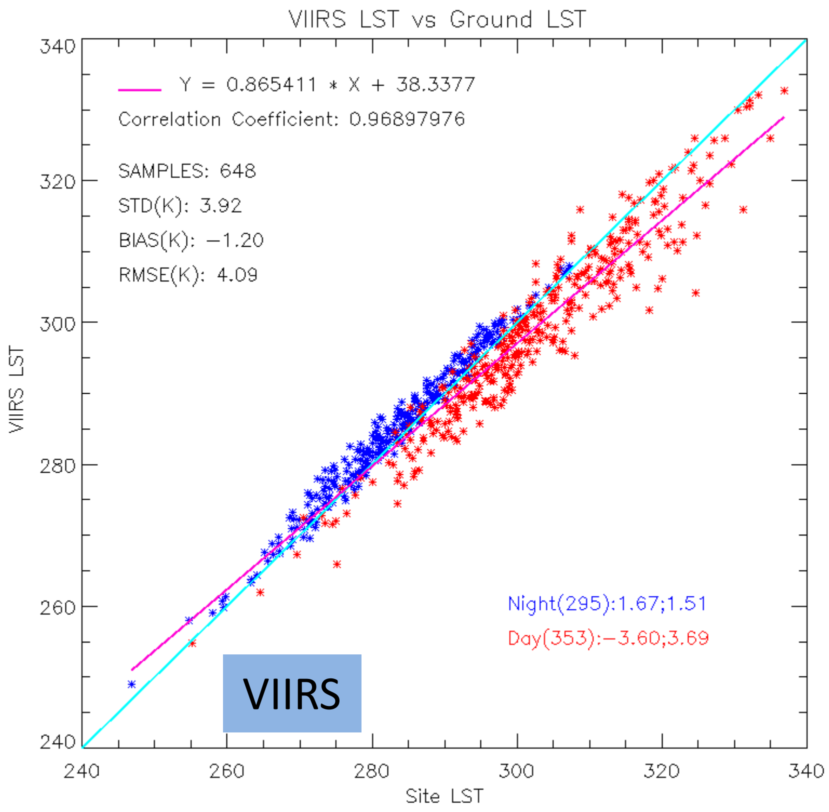


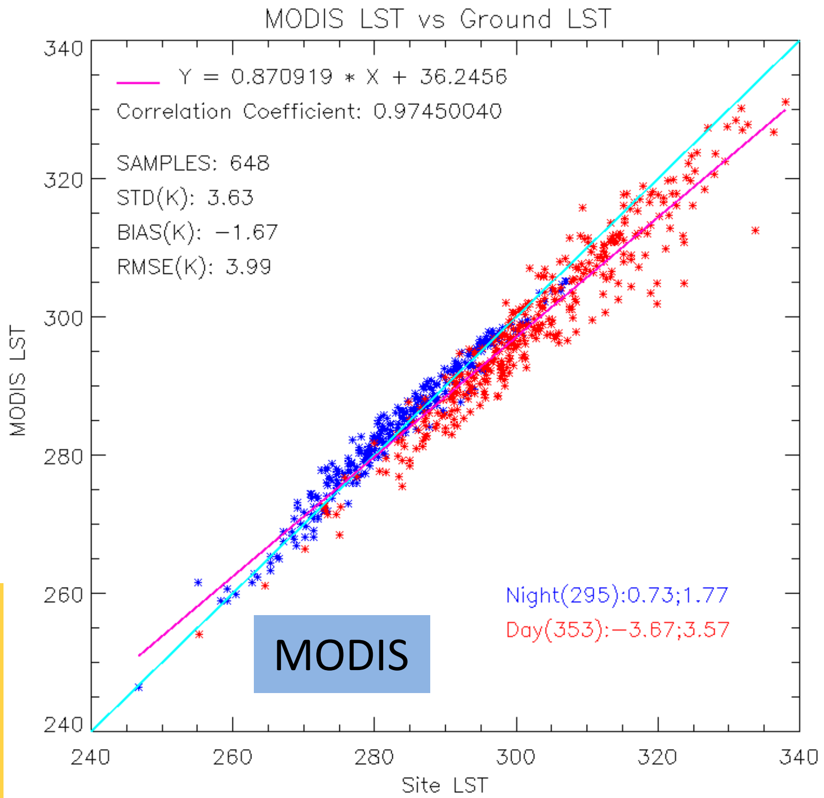
*the Africa site data provided by Frank Goettsche (KIT & EUMETSAT Land SAF), through LST validation collaboration

Quality Analysis/Validation ---- CRN Sites (1/2)



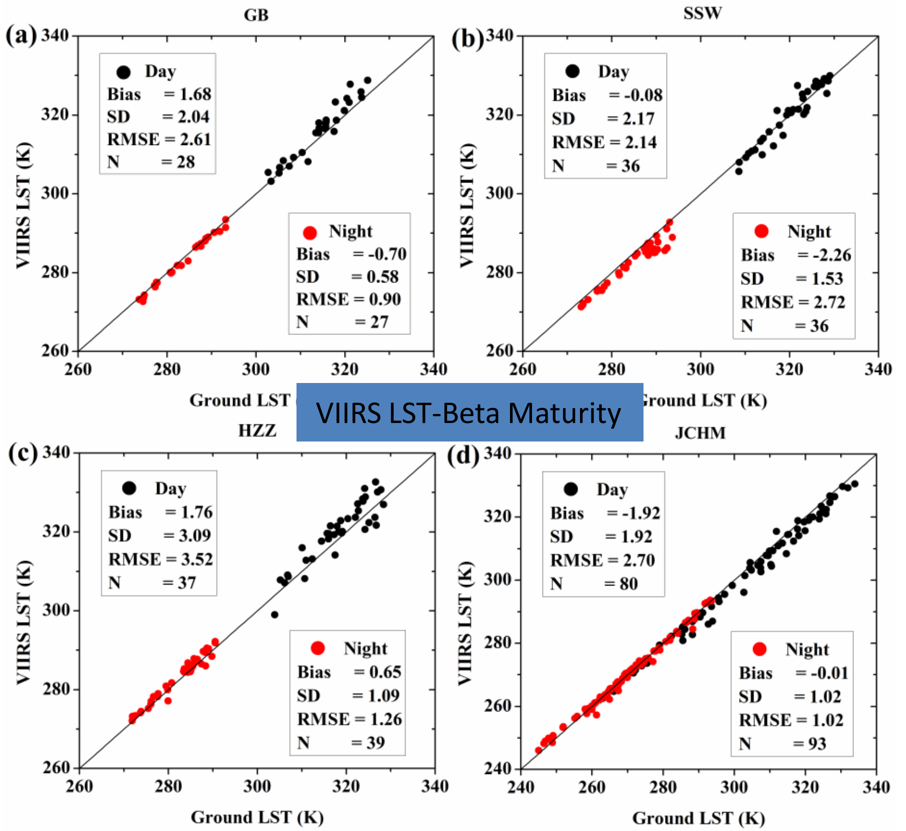
Quality Analysis/Validation
---- CRN Sites (2/2)



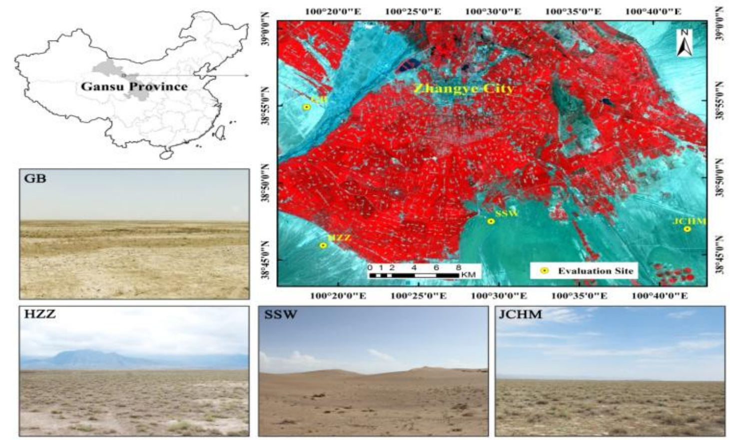


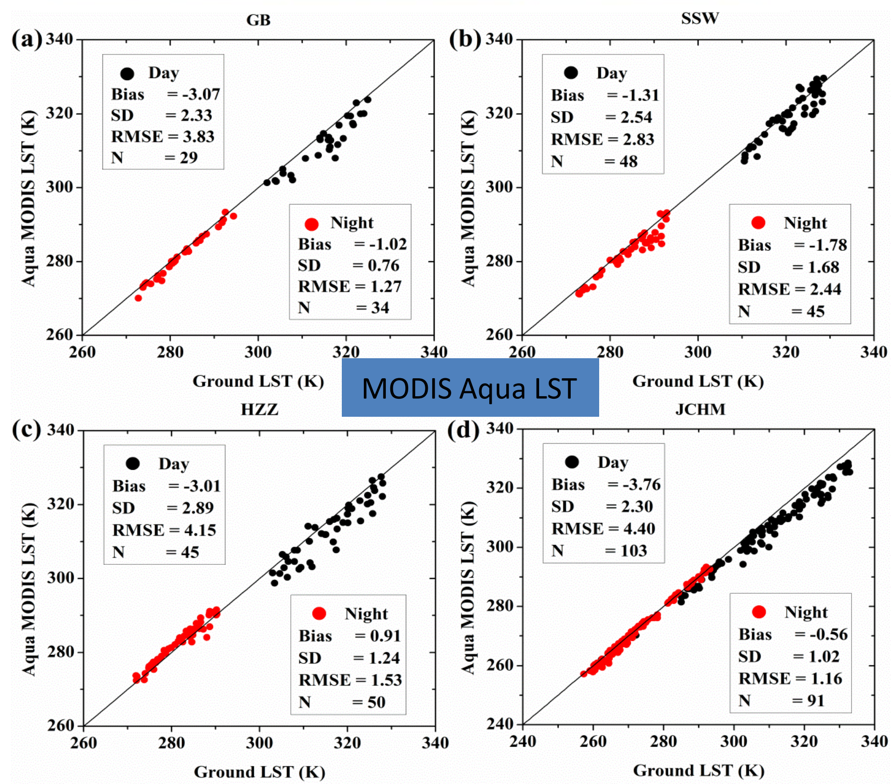
Corresponding matchups for VIIRS and MODIS:
Time span: Jul. 2013 – Sep. 2014
Data: same site, same day, satellite zenith angle within 10 degree

Quality Analysis/Validation ---- China Sites* (2/2)



VIIRS LST-Beta Maturity





MODIS Aqua LST

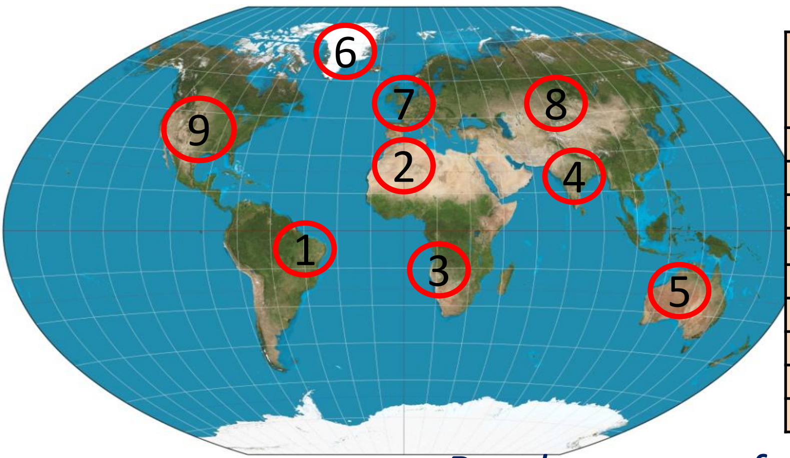
Data collection: arid area of northwest China (Heihe Watershed Allied Telemetry Experimental Research), from June 2012 to April 2013. Four barren surface sites were chosen for the evaluation.

The result generally shows a better agreement for VIIRS LST than that for MODIS LST.

*the China site data provided by Hua Li (China Academy of Science), through LST validation collaboration

Reference: *H. Li, D. Sun, Y. Yu, H. Wang, Y. Liu, Q. Liu, Y. Du, H. Wang and B. Cao(2014), Evaluation of the VIIRS and MODIS LST products in an arid area of Northwest China Remote Sensing of Environment 02/2014; 142:111–121.*

Quality Analysis/Validation
---- Radiance based validation



Validation Results over areas

Areas	Overall			Day			Night		
	Samples	Bias	STD	Samples	Bias	STD	Samples	Bias	STD
Algeria	850088	1.41	0.79	110433	0.22	0.56	739655	1.59	0.66
Australia	5164739	0.54	1.27	3021553	-0.18	1.05	2143186	1.56	0.72
Brazil	3436612	0.48	0.89	1002784	-0.32	0.94	2433828	0.81	0.61
China	1603865	0.83	0.91	528628	0.15	0.8	1075240	1.17	0.17
France	3014553	0.07	0.93	1530488	-0.53	0.91	1484065	0.70	0.39
Greenland	**1059702**	**0.08**	**0.55**	**294543**	**0.62**	**0.50**	**765159**	**-0.13**	**0.41**
Gobabeb	959981	0.52	1.53	595335	-0.5	0.75	364646	2.18	0.90
Indian	2482012	0.39	1.23	656915	-0.98	1.53	1825097	0.88	0.54
USA	3408392	0.43	1.17	1565562	-0.41	0.85	1842830	1.14	0.92

Results over surface type

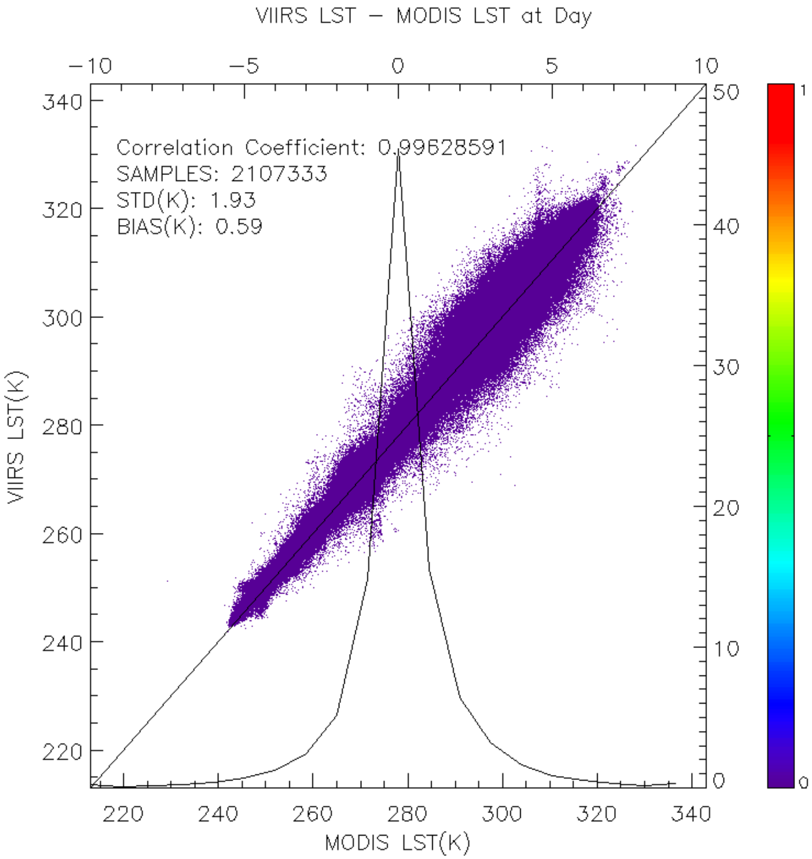
SurfaceType	Overall			Day			Night		
	Samples	Bias	STD	Samples	Bias	STD	Samples	Bias	STD
Evergreen Needleleaf Forests	**216593**	**0.19**	**0.54**	**70324**	**-0.22**	**0.54**	**146269**	**0.38**	**0.41**
Evergreen Broadleaf Forests	207839	-0.4	0.97	107698	-0.68	1.02	100141	-0.09	0.82
Deciduous Needleleaf Forest	13554	0.25	0.74	5932	-0.44	0.46	7622	0.78	0.42
Broadleaf Forests	**385231**	**0.22**	**0.55**	**204843**	**-0.05**	**0.56**	**180388**	**0.54**	**0.32**
Mixed Forests	597413	-0.02	0.8	359702	-0.42	0.76	237711	0.59	0.34
Closed Shrublands	92393	0.94	1.13	30537	-0.21	0.97	61856	1.5	0.69
Open Shrublands	5906708	0.72	1.29	3305495	-0.22	0.85	2601213	1.92	0.53
Woody Savannahs	917791	0.31	0.7	407793	-0.12	0.65	509998	0.66	0.52
Savannahs	3142202	0.48	0.81	1008898	-0.22	0.81	2133304	0.81	0.56
Grasslands	1124800	-0.07	1.42	517457	-1.2	1.25	607343	0.9	0.6
Permanent Wetlands	**28282**	**0.02**	**0.54**	**4013**	**0.09**	**0.91**	**24269**	**0.01**	**0.45**
Croplands	4072551	0.15	1.2	1491236	-1.02	1.21	2581315	0.82	0.44
Urban Built-Up	**190876**	**0.27**	**0.52**	**89295**	**0.04**	**0.5**	**101581**	**0.47**	**0.45**
Croplands/Natural Vegetation Mosiacs	**1276644**	**0.31**	**0.56**	**543193**	**-0.08**	**0.45**	**733451**	**0.59**	**0.45**
Snow Ice	**1142843**	**0.04**	**0.51**	**336615**	**0.54**	**0.55**	**806228**	**-0.17**	**0.31**
Barren	2389775	1.29	0.89	699333	0.54	0.75	1690442	1.6	0.75
Water Bodies	161468	-0.22	0.86	45826	-0.35	1.35	115642	-0.16	0.55

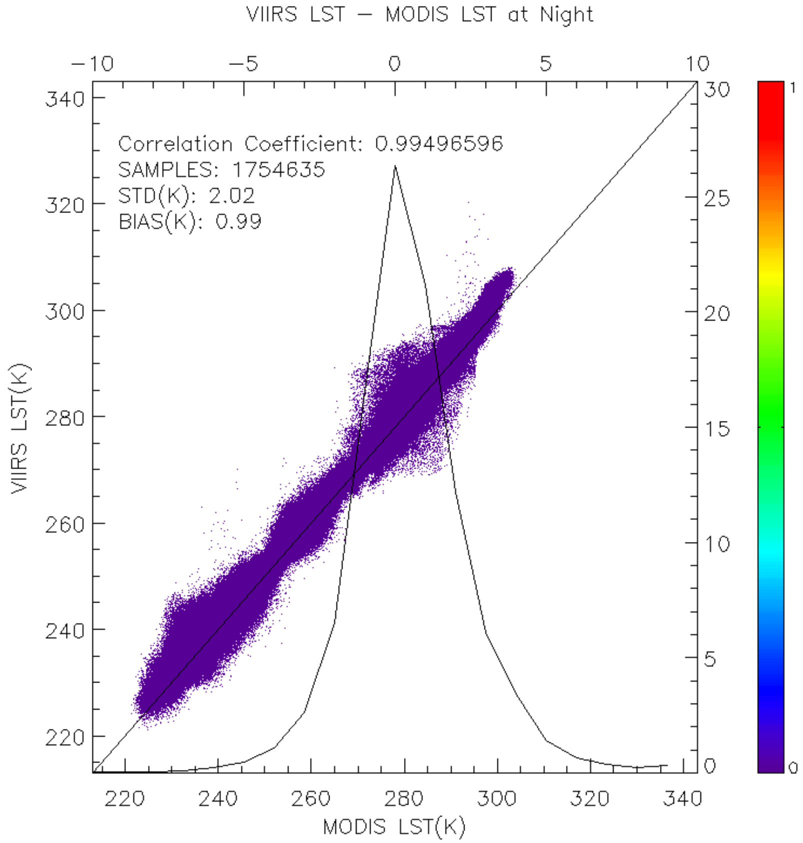
Over temperature range

Temp. Range	Samples	Bias	STD	RMSE
220-230	12978	-0.05	0.18	0.19
230-240	355782	-0.08	0.28	0.29
240-250	622961	0.1	0.57	0.58
250-260	371442	0.54	0.56	0.78
260-270	303642	0.75	0.72	1.04
270-280	1648372	0.89	0.78	1.18
280-290	3732633	1.05	0.82	1.33
290-300	7990823	0.89	0.92	1.28
300-310	2173475	-0.52	1	1.13
310-320	2481185	-0.51	1	1.12
320-330	1578097	-0.22	1.26	1.28
330-340	465266	-0.01	1.28	1.28

Quality analysis/validation
---- Cross satellite comparison (MODIS)

Cross Satellite Comparison: VIIRS vs MODIS Aqua LST (granules)

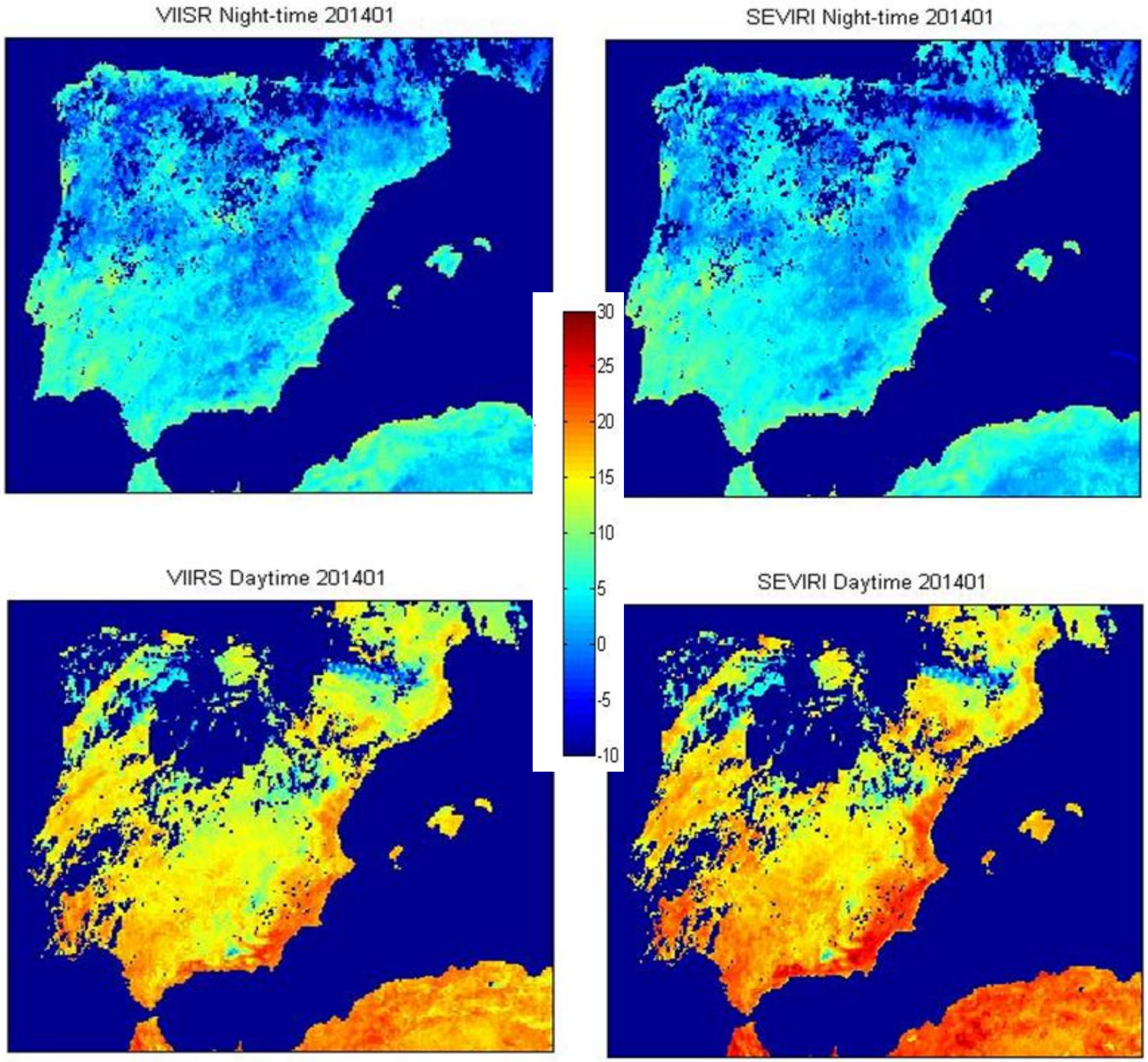




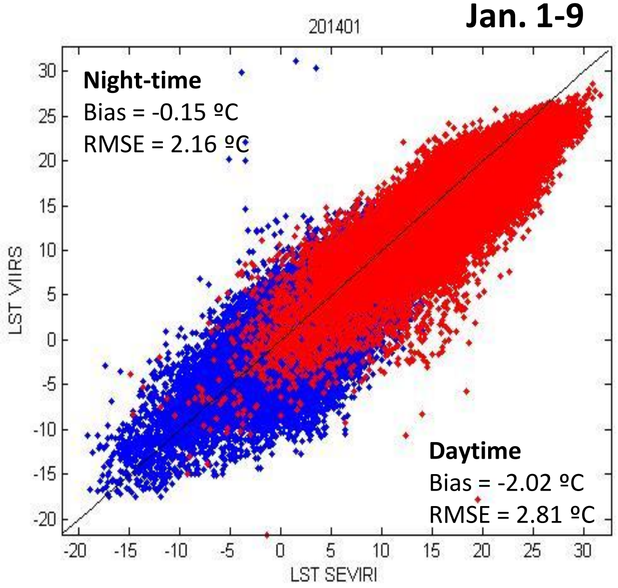
Comparison results from Simultaneous Nadir Overpass (SNO) between VIIRS and AQUA in 2012 over US , Oct-Dec, 2013 over US, polar and low latitude (over 100 scenes). The matchups are quality controlled for both LST measurements.

Quality Analysis/Validation
---- Cross satellite comparison (SEVIRI)

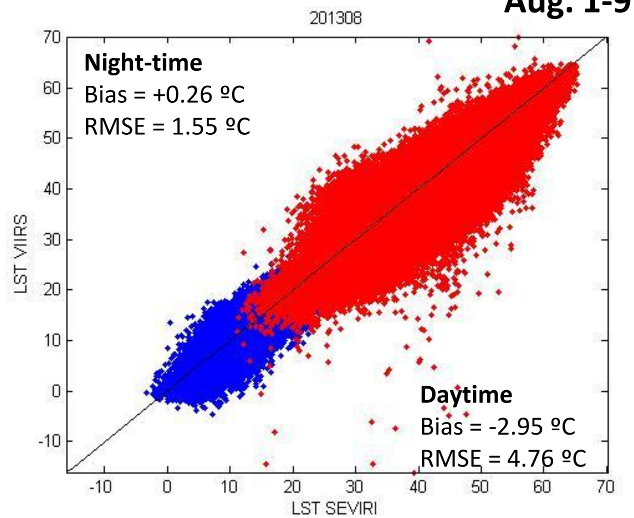
VIIRS **1-9 Jan 2014** **SEVIRI**



Jan. 1-9



Aug. 1-9



Courtesy of Isabel F. Trigo , through US-Portugal Bilateral cooperation program (on remote Sensing)

Error Budget

Count from validation methods:

Attribute Analyzed	L1RD Threshold	Validation Result	Description
In-situ Validation	1.4K(2.5K)	**-0.37(2.35)**	Results are based on the VIIRS data over SURFRAD sites for over 2.5 years . The error budget estimation is limited by ground data quality control, cloud filtering procedure and upstream data error.
R-based Validation	1.4K(2.5K)	0.47(1.12)	A forward radiative transfer model is used, over 9 regions in globe, representing all 17-IGBP types over the seasons. The error budget estimation is limited by profile quality, cloud screening procedure and sampling procedure.
Cross satellite Comparison		0.59(1.93): daytime 0.99(2.02): nighttime	The results are based on comparisons to MODIS LST, over 100 scenes, over low latitude, polar area and CONUSThe error budget estimation is limited by the spatial and temporal difference, sensor difference, angle difference etc.

Count from error sources:

Attribute Analyzed	L1RD Threshold	Theoretical Results	Real data results	Description
Overall	1.4K(2.5K)	0.00(0.46)	**-0.37(2.35)**	Results are based on the VIIRS data over SURFRAD sites for over 2.5 years . The error budget estimation is limited by ground data quality control, cloud filtering procedure and upstream data error.
Surface Type		(0.73)	(1.21)	This error is from surface type EDR quality.
Sensor noise		(0.2)	(0.23)	This error is from sensor noise from M-band 15 and M16
Others			(1.98)	Uncertainty from ground data quality control, viewing angle, cloud contamination, Aerosol effect etc.

Documentation

- A README file for CLASS will be submitted with the Validation Stage 1 Maturity CCR
- A Product User's Guide is not required

Identification of Processing Environment

- IDPS number and effective date
  - IDPS build MX8.4 implemented on 04/07/2014
- Algorithm version
  - Baseline split window algorithm
  - ATBD to be updated
- Version of LUTs used
  - CCR-14-1638 VIIRS LST_SWLST LUT Update,
  - DR 7493 (Land)- VIIRS LST_SWLST LUT Update to correct issues found in DR7215 LUTs
- Version of PCTs used
- Description of environment used to achieve validated stage

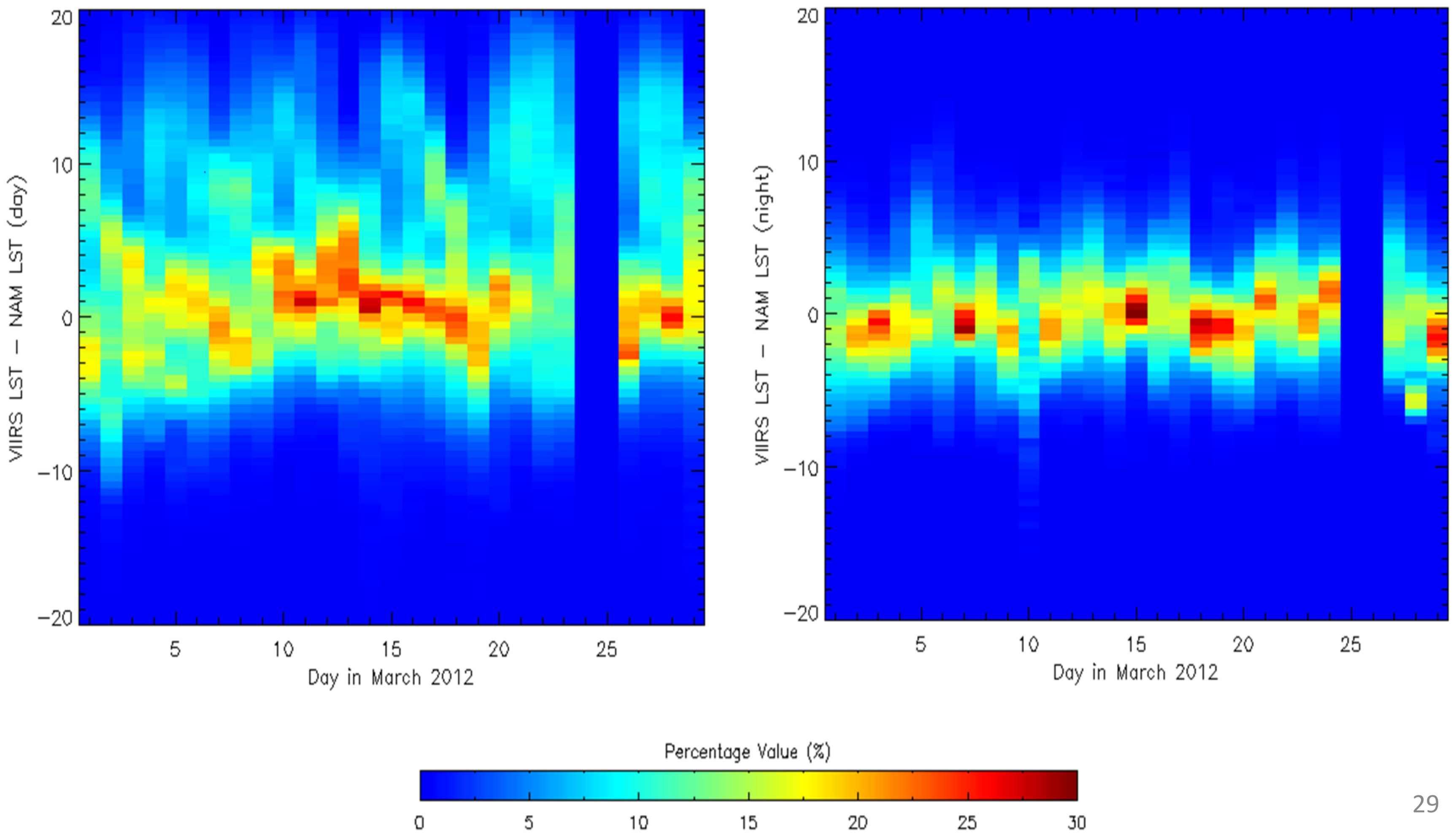
  All data used in the validation is calculated locally using the same LUT as in the operational run. We compared the difference between our local calculation and IDPS calculation; difference by the floating error is neglected in our validation efforts.

Users & User Feedback

- U. S. Users:
  - –NOAA National Weather Service Environmental Modeling Center (Michael EK, Jesse Meng, Weizhong Zheng)
  - –USDA Agricultural Research Services(Martha Anderson)
  - –USDA Forest Service (Brad Quayle)
  - –NOAA/NESDIS Center for Satellite Applications and Research (Jerry Zhan)
  - –NOAA/NESDIS National Climate Data Center (Peter Thorne)
  - –Academy – Univ. of Maryland (Konstantin Vinnikov, Shunlin Liang, Cezar Kongoli)
  - –Army Research Lab (Kurt Preston)
- Foreign Users (coordinated by Earth Temp Network and GlobTemp User Consultation Network): – Edinburgh, UK , 2012
  - – EUMETSAT LSA SAF LST group (Isabel Trigo, Project Manager)
  - – ESA/ESRIN, Italy (Simon Pinnock & Olivier Arino)
  - – Univ. Of Edinburgh, UK (Chris Merchant)
  - – OBSPM, and LSCE, France (Catherine Prigent & Carlos Jimenez, and Catherine Ottlé)
  - – Universitat de les Illes Balears, Spain (Maria Antonia Jimenez Cortes)
  - – eLEAF, The Netherlands (Henk Pelgrum & Wim Bastiaanssen)
  - – Centre for Ecology and Hydrology, UK (Rich Ellis)
  - – Institute of Geodesy and Cartography, Poland (Katarzyna Dabrowska-Zielinska)

Model comparison

Comparisons to NAM (North American Model) over CONUS (5km) :



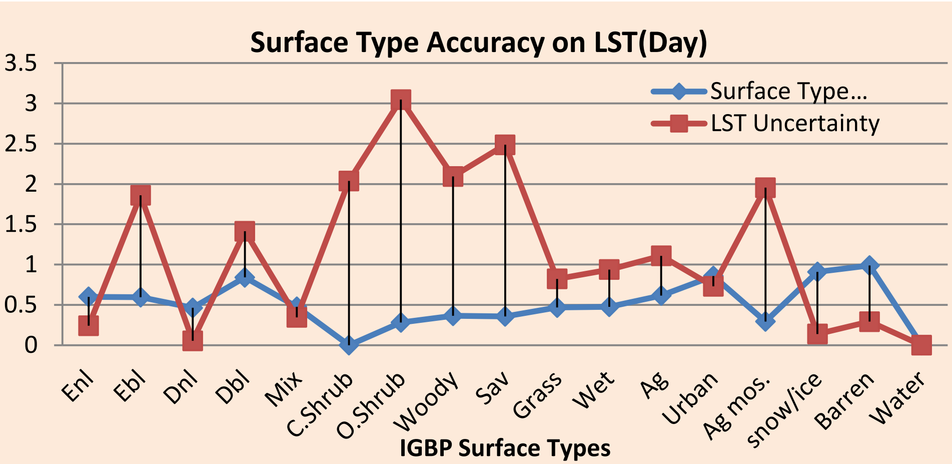
Conclusion

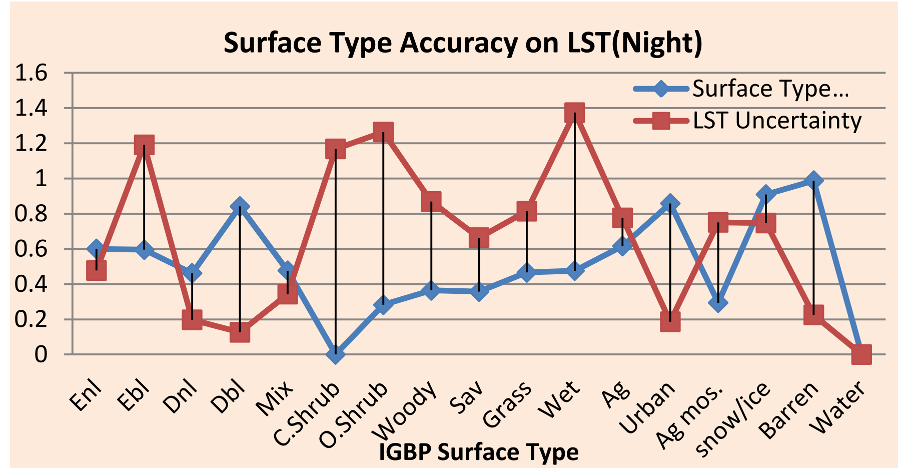
- Cal/Val results summary
  - Overall, VIIRS LST quality meets the L1RD requirement , based on the SURFRAD station in-situ LST estimates from Feb. 2012 to Aug. 2014.
  - Quality of VIIRS LSTs and MODIS LSTs are similar, based on comparisons of over 100 VIIRS/MODIS SNO scenes.
  - VIIRS LST production is stable, based on the weekly LST monitoring.
  - Impact of sensor noise is ignorable; impacts of ST misclassification and cloud contamination are significant.
  - over 60% error sources of the LST derivation can not be identified, due to quantitative and qualitative limitations of in-situ measurement.
  - Practical uncertain is significantly larger than the theoretical analysis.
- Improvement is needed
  - Algorithm improvement
    - emissivity explicit algorithm to replace the ST-dependent algorithm
    - Coefficients stratification
  - Validation improvement
    - Global validation (South America, Australia, polar region data collection)
    - Field Campaign , international cooperation

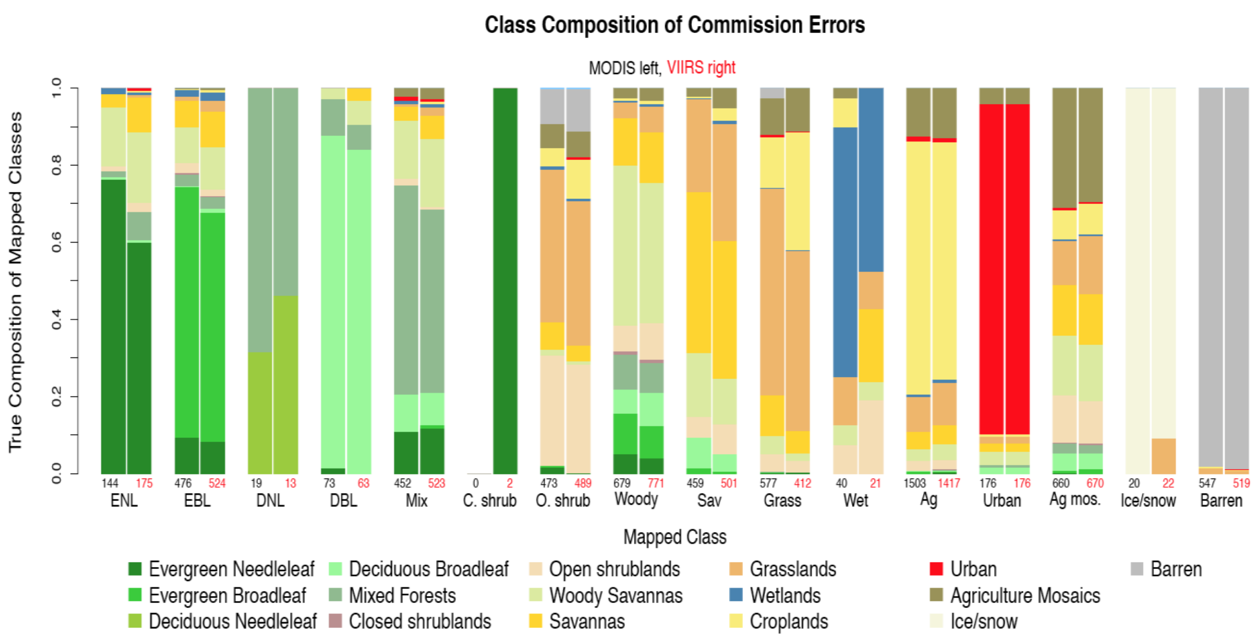
Path Forward

- Algorithm improvement
  - emissivity explicit algorithm development, test, and evaluation
  - Additional cloud filtering for LST production
- Water Vapor correction
  - Coefficients stratification
- Angular correction
- Global /Comprehensive Validation
  - Monitoring tool
  - Global in-situ data collection (South America, Australia, polar region data collection)
  - Upscaling model
  - Cross satellite comparisons (MODIS, Sentinel, SEVIRI, AHI …)
- VIIRS LST data usage in NOAA climate model application
  - Joint project with model group

Impact of Surface Type Error







Impact on LST **using real orbit data** on Oct. 22, 2014, daytime (top-left) and nighttime(top-right)

Overall Statistics	Impact on LST
All-Day	1.5K
All-Night	0.8K
All	1.2K

*Reference: Damien Sulla-Menashe, VIIRS ST V1 Quality Assessment April 02, 2014 EDR meeting