Evaluation of Emissivity Explicit Land Surface Temperature Retrieval Algorithms for VIIRS

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Introduction

Land surface temperature (LST) is of fundamental importance to many aspects of the geosciences, *e.g.*, the net radiation budget at the Earth surface and to monitoring the state of crops and vegetation, as well as an important indicator of both the greenhouse effect and the energy flux between the atmosphere and the land. As one of the key products of the JPSS mission, it is crucial to keep improving the retrieval algorithm performance.

Among the existing satellite missions, SNPP VIIRS is the only one that is using a surface type based algorithm to retrieve the LST. While it meets the requirement of the mission, pervious study (Liu *et. al.,* 2015) reveals the drawback of such a retrieval algorithm. It strongly relies on an accurate classification of the land cover. The surface type EDR under its current accuracy may introduce an LST retrieval error as high as 1.2K. Given that the surface type EDR will soon change to a yearly product, a negative impact is expected. The high within-type emission variability of some surface types can lead to large uncertainties in the LST retrieval. The study of an emissivity explicit algorithm for VIIRS LST retrieval is necessary.

This research will present the most recent evaluation results of multiple LST retrieval algorithms. In-situ observations from SURFRAD will be used as the reference data set for this purpose.

VIIRS LST retrieval algorithm

The current VIIRS LST retrieval algorithm is a split-window algorithm using the M15 (~10.8 µm) and M16 (~12.0 µm) bands. It is stratified with 17 IGBP surface types and daytime/nighttime conditions:

$$LST_{i,j} = a_0(i,j) + a_1(i,j)T_{11} + a_2(i,j)(T_{11} - T_{12}) + a_3(i,j)(\sec\theta - 1) + a_4(i,j)(T_{11} - T_{12})^2$$

Where, i=1, 2, …, 17, is the index for 17 IGBP surface types, j=0, 1, stands for nighttime and daytime, respectively, a are the retrieval coefficients, and θ the satellite view zenith angle.

Algorithm Candidates for evaluation

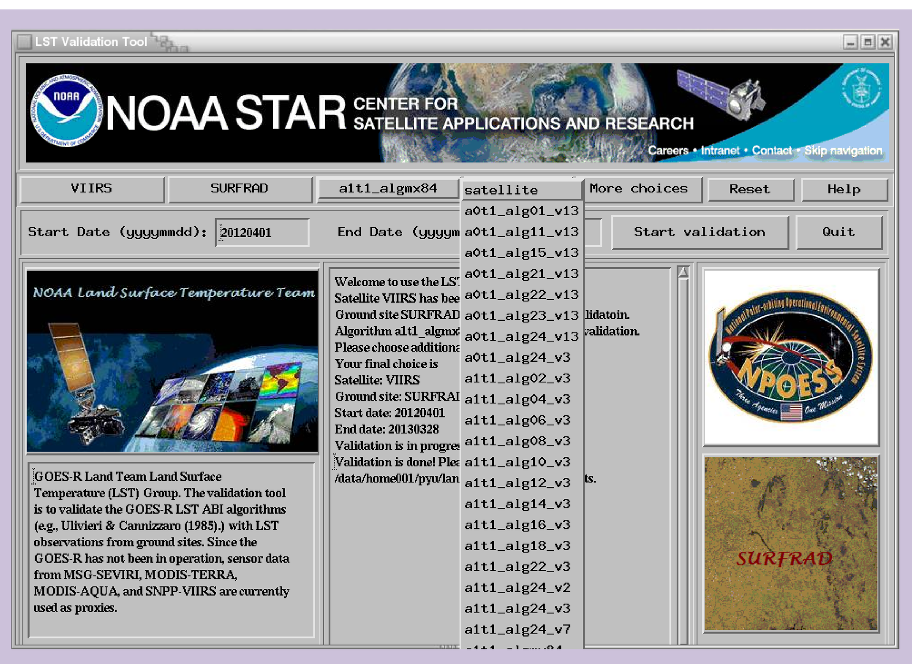
Table 1. Fourteen candidates for algorithm evaluation

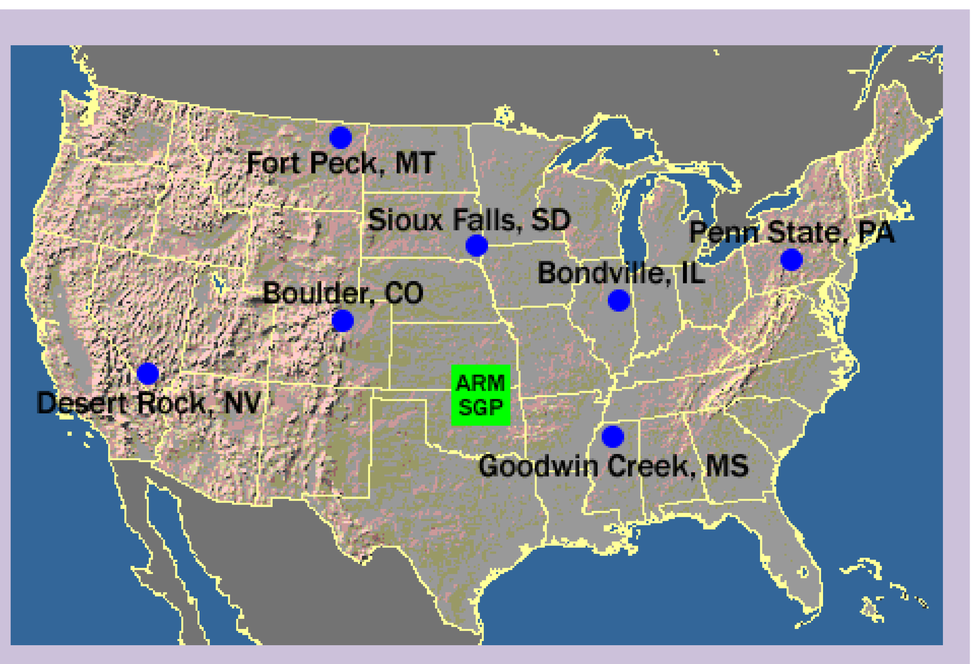
No	Formula[#]	Reference
1	$T_s = C + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}+T_{12}) + (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}-T_{12})$	Wan & Dozier (1996); Becker & Li (1990).
2	$T_s = C + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}+T_{12})$ $+ (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}-T_{12}) + D(T_{11}-T_{12})(\sec\theta - 1)$	Adapted from Algorithm 1
3	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon$	Ulivieri & Cannizzaro (1985).
4	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$	Adapted from Algorithm 3
5	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12})$ $+ A_5(T_{11}+T_{12})\Delta\varepsilon$	Algorithm a
6	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12})$ $+ A_5(T_{11}+T_{12})\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$	Adapted from Algorithm 5
7	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12}) + A_5\Delta\varepsilon$	Algorithm b
8	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12})$ $+ A_5\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta - 1)$	Adapted from Algorithm 7

[#]Note:
T_{11} and T_{12} represent the top-of-atmosphere brightness temperatures of ABI channels 14 and 15, respectively;
$\varepsilon=(\varepsilon_{11}+\varepsilon_{12})/2$ and $\Delta\varepsilon=(\varepsilon_{11}-\varepsilon_{12})$, where ε_{11} and ε_{12} are the spectral emissivity values of the land surface at ABI channels 14 and 15, respectively;
θ is the satellite view zenith angle.
C, A_1, A_2, A_3, A_4, A_5, A_6, and D are algorithm coefficients.
Algorithms 2, 4, 6, and 8 are modified from algorithms 1, 3, 5, and 7, respectively

Eight algorithms are selected among more than 20 for evaluation of the emissivity-explicit retrieval algorithm. Algorithms 2, 4, 6, and 8 are adapted from algorithms 1, 3, 5, and 7. Algorithm 4 is the proposed GOES-R ABI LST algorithm. For algorithms 1, 3, 5, and 7, LST are retrieved within different satellite zenith angle ranges, while algorithms 2, 4, 6, and 8 are not since their formula contain a angle correction term.

Ground sites: SURFRAD





The routine LST validation tool is used to carry out the match-up between the satellite LST and its ground counterpart and the evaluation of the retrieval algorithm performance. It includes multiple satellite sensors, *e.g.,*, SNPP-VIIRS, MODIS-AQUA, MODIS-TERRA, and MSG-SEVIRI.

In-situ LST measurements from seven Surface Radiation Budget Network (SURFRAD) stations for the year of 2013 are used to evaluate the retrieval algorithms.
The VIIRS LST DER was matched to the seven SURFRAD sites in both time (within 1.5 min) and space (within 5km).

Emissivity Data

The CIMSS global emissivity is used to retrieve the LST in this test. Due to the delay, up to one year or so, in generating the most recent data set, only climatology can be available for operational LST retrieval. A negative impact on the retrieval performance is expected. Efforts in generating an emissivity for VIIRS are undergoing in the VIIRS LST AWG group. Long time series satellite products are used to generate the mean global soil emissivity climatology at 1-kilometer resolution. From this data set, an empirical model was applied to produce the dynamic emissivity using the VIIRS global green vegetation fraction product. The vegetation cover ratio was considered as the primary factor adjusting the emissivity over time with geographic match and spectral transformation. Based on this method. Dr. Heshun Wang has produced a draft emissivity data set, which will be tested in this algorithm evaluation research. The methodology can be used to generate both weekly and granular products.

Algorithm evaluation

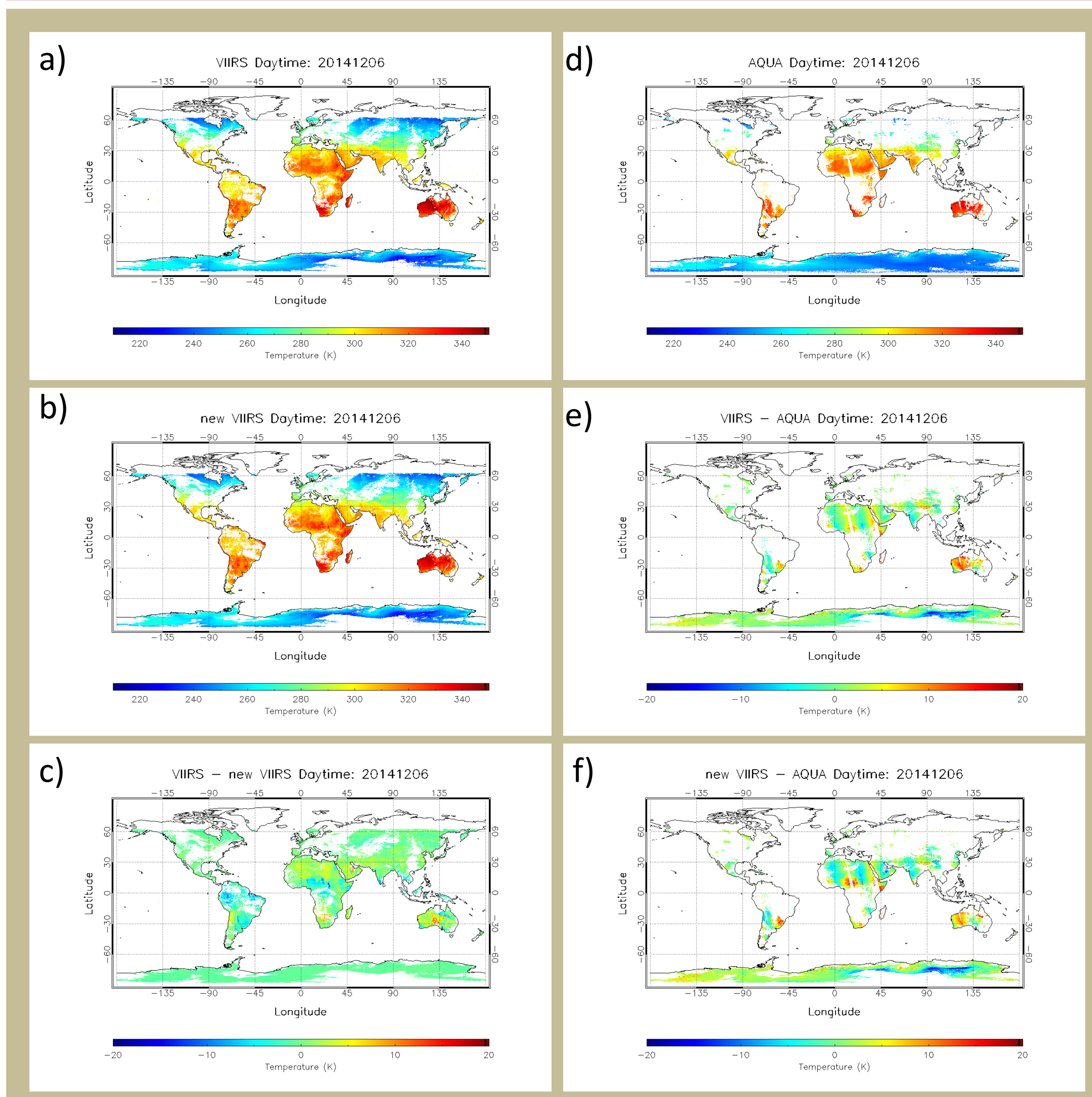


Figure 1. a) Global daytime VIIRS LST; b) Emissivity-based VIIRS LST; c) difference between a and b, d) AQUA LST; e) difference between a and d; f) difference between b and d on 12/06/2014.

As the 1st test of the monthly emissivity field Dr. Heshun Wang generated, it has been applied to the LST retrieval using VIIRS data (Algorithm 7). The formula being used is . The retrieval is stratified by daytime/nighttime, different water vapor ranges, [0., 1.5, 4.0, ∞), and different satellite view zenith angle ranges, [0., 25., 45., 55., 65., ∞). The two are very close in Antarctica, North America, and Asia, while big difference can be found at Australia, Southern Africa, where the emissivity-based retrieved LST can be lower by 10+ K, and Central Africa, part of South America, where the former can be higher by about 10 K. Based on previous analysis, we often observed a large discrepancy between the VIIRS LST and AQUA LST during the southern hemisphere summer in Australia, where VIIRS LST can be 10+ K higher than its MODIS counterpart. The new VIIRS LST is closer to MODIS LST in Australia but their difference in part of Africa and South America becomes larger.

Two years VIIRS data were matched to the seven SURFRAD stations in-situ observations. Eight algorithms were compared with the original IDPS VIIRS LST. CIMSS and the new emissivity data were both evaluated. Only confidently clear satellite data were used. Additional cloud screening procedure were applied to filter out possibly cloud contaminated data, *i.e.*, standard deviation of the neighboring 3x3 pixel box, and the 30-minute SURFRAD downwelling IR radiation time series. The retrieval were carried out on two different stratification based on water vapor, [0., 2., ∞) and [0., 1.5, 4.0, ∞).

Table 2. validation results with SURFRAD: Water Vapor range: [0., 2., ∞); Emissivity: CIMSS

Alg	BON	TBL	DRA	FPK	GWN	PSU	SXF	Overall
IDPS	0.16/1.89	-0.62/1.58	-1.53/1.59	-0.18/2.45	0.67/1.91	-0.43/3.43	0.05/2.25	-0.37/2.22
1	0.72/1.85	-0.46/1.64	-0.16/1.54	0.39/2.31	1.44/2.05	0.22/3.39	0.91/1.98	0.41/2.11
2	0.65/1.88	-0.54/1.71	-0.29/1.61	0.32/2.35	1.41/2.08	0.18/3.40	0.87/1.98	0.34/2.16
3	0.71/1.86	-0.41/1.64	-0.44/1.66	0.48/2.33	1.46/2.03	0.22/3.38	0.95/1.97	0.37/2.16
4	0.64/1.90	-0.50/1.72	-0.57/1.73	0.40/2.37	1.43/2.05	0.18/3.40	0.91/1.97	0.30/2.21
5	0.71/1.85	-0.49/1.63	-0.40/1.51	0.37/2.29	1.40/2.05	0.21/3.38	0.91/1.97	0.34/2.12
6	0.64/1.88	-0.58/1.71	-0.54/1.61	0.30/2.33	1.36/2.07	0.16/3.40	0.86/1.97	0.26/2.17
7	0.70/1.85	-0.49/1.63	-0.42/1.51	0.37/2.29	1.39/2.05	0.20/3.38	0.90/1.97	0.33/2.12
8	0.63/1.88	-0.58/1.71	-0.56/1.59	0.29/2.33	1.35/2.07	0.16/3.40	0.85/1.97	0.26/2.16

Table 3. validation results with SURFRAD: Water Vapor range: [0., 1.5, 4.0, ∞); Emissivity: CIMSS

Alg	BON	TBL	DRA	FPK	GWN	PSU	SXF	Overall
IDPS	0.16/1.89	-0.62/1.58	-1.53/1.59	-0.18/2.45	0.67/1.91	-0.43/3.43	0.05/2.25	-0.37/2.22
1	0.77/1.83	-0.41/1.63	-0.07/1.35	0.35/2.30	1.54/2.06	0.22/3.44	0.96/1.98	0.46/2.09
2	0.69/1.86	-0.50/1.73	-0.23/1.48	0.29/2.33	1.49/2.10	0.19/3.44	0.89/2.00	0.38/2.14
3	0.77/1.84	-0.36/1.65	-0.36/1.52	0.46/2.32	1.56/2.04	0.24/3.43	1.01/1.96	0.43/2.14
4	0.69/1.88	-0.45/1.74	-0.51/1.62	0.39/2.36	1.51/2.08	0.21/3.43	0.94/1.98	0.34/2.19
5	0.76/1.83	-0.44/1.64	-0.32/1.33	0.33/2.28	1.50/2.07	0.21/3.43	0.95/1.97	0.39/2.10
6	0.67/1.85	-0.54/1.72	-0.49/1.44	0.25/2.31	1.44/2.11	0.18/3.43	0.87/1.99	0.29/2.15
7	0.75/1.82	-0.45/1.63	-0.36/1.33	0.32/2.28	1.48/2.07	0.20/3.43	0.93/1.97	0.37/2.10
8	0.68/1.86	-0.53/1.72	-0.47/1.45	0.27/2.31	1.45/2.10	0.19/3.43	0.88/1.99	0.30/2.15

Table 4. validation results with SURFRAD: Water Vapor range: [0., 2., ∞); Emissivity: new

Alg	BON	TBL	DRA	FPK	GWN	PSU	SXF	Overall
IDPS	0.31/1.92	-0.30/1.61	-1.60/1.79	-0.17/2.52	1.10/1.80	-0.06/3.49	0.28/2.28	0.08/2.21
1	0.22/1.88	-0.90/1.71	-0.92/1.85	-0.02/2.33	0.61/1.88	-0.47/3.43	0.28/1.95	-0.21/2.16
2	0.15/1.91	-0.99/1.77	-1.05/1.90	-0.10/2.36	0.56/1.90	-0.52/3.45	0.22/1.95	-0.29/2.20
3	0.21/1.88	-0.87/1.71	-0.94/1.88	-0.01/2.33	0.61/1.89	-0.48/3.43	0.27/1.95	-0.21/2.17
4	0.14/1.91	-0.96/1.77	-1.06/1.93	-0.09/2.36	0.57/1.91	-0.52/3.45	0.22/1.95	-0.29/2.20
5	0.22/1.88	-0.90/1.71	-0.96/1.84	-0.02/2.32	0.61/1.88	-0.48/3.43	0.28/1.95	-0.21/2.16
6	0.15/1.91	-0.98/1.77	-1.08/1.90	-0.10/2.36	0.57/1.90	-0.52/3.45	0.23/1.95	-0.29/2.20
7	0.22/1.88	-0.90/1.71	-0.96/1.84	-0.02/2.32	0.61/1.88	-0.47/3.43	0.28/1.95	-0.21/2.16
8	0.15/1.91	-0.98/1.77	-1.09/1.89	-0.10/2.35	0.57/1.90	-0.52/3.45	0.23/1.95	-0.29/2.20

Table 5. validation results with SURFRAD: Water Vapor range: [0., 1.5, 4.0, ∞); Emissivity: new

Alg	BON	TBL	DRA	FPK	GWN	PSU	SXF	Overall
IDPS	0.31/1.92	-0.30/1.61	-1.60/1.79	-0.17/2.52	1.10/1.80	-0.06/3.49	0.28/2.28	0.08/2.21
1	0.26/1.86	-0.83/1.71	-0.82/1.64	-0.04/2.32	1.68/1.89	-0.46/3.47	0.31/1.94	-0.16/2.12
2	0.19/1.89	-0.91/1.79	-0.95/1.73	-0.10/2.35	1.65/1.92	-0.48/3.46	0.26/1.96	-0.23/2.16
3	0.25/1.86	-0.80/1.71	-0.84/1.68	-0.02/2.32	1.69/1.90	-0.46/3.47	0.31/1.95	-0.15/2.13
4	0.18/1.89	-0.88/1.79	-0.97/1.76	-0.09/2.35	1.65/1.93	-0.49/3.46	0.25/1.97	-0.23/2.17
5	0.26/1.86	-0.83/1.71	-0.86/1.64	-0.04/2.32	1.69/1.89	-0.46/3.47	0.32/1.95	-0.16/2.12
6	0.19/1.89	-0.91/1.78	-0.99/1.71	-0.10/2.34	1.65/1.92	-0.48/3.47	0.26/1.96	-0.24/2.16
7	0.26/1.86	-0.83/1.71	-0.87/1.64	-0.04/2.32	1.69/1.89	-0.45/3.47	0.32/1.95	-0.16/2.12
8	0.19/1.89	-0.91/1.78	-0.99/1.72	-0.10/2.34	1.65/1.92	-0.49/3.47	0.26/1.96	-0.24/2.16

Based on the testing results, the emissivity based retrievals are able to slightly outperform the current VIIRS surface type based algorithm. The precision is around 0.1 K better than the VIIRS LST. The retrievals based on view angle ranges stratification are consistently better than the ones with angle correction term, though only slightly. The statistics from retrievals using the new emissivity is similar to those using CIMSS emissivity. So it should be able to replace the latter in the operational retrieval.

Summary

Eight emissivity explicit LST retrieval algorithms have been evaluated with two sources of emissivity data and all outperform the current VIIRS LST The testing results suggest that the algorithms with view angle ranges stratification are consistently better than the ones with the angle correction term, the algorithms stratified by water vapor ranges of [0., 1.5, 4.0, ∞) are superior to those of [0., 2., ∞), and the retrievals using the new emissivity are comparable to those with the CIMSS emissivity. Though still in its early developmental stage, the new emissivity field by the LST AWG group are ready to be used. Further analysis of different retrieval algorithms are needed and more comparison between the retrievals with the new emissivity, the CIMSS monthly emissivity, and the CIMSS climatologic monthly emissivity will be conducted.