New Refinements in the C6 MODIS Standard Products for Land Surface Temperature and Emissivity

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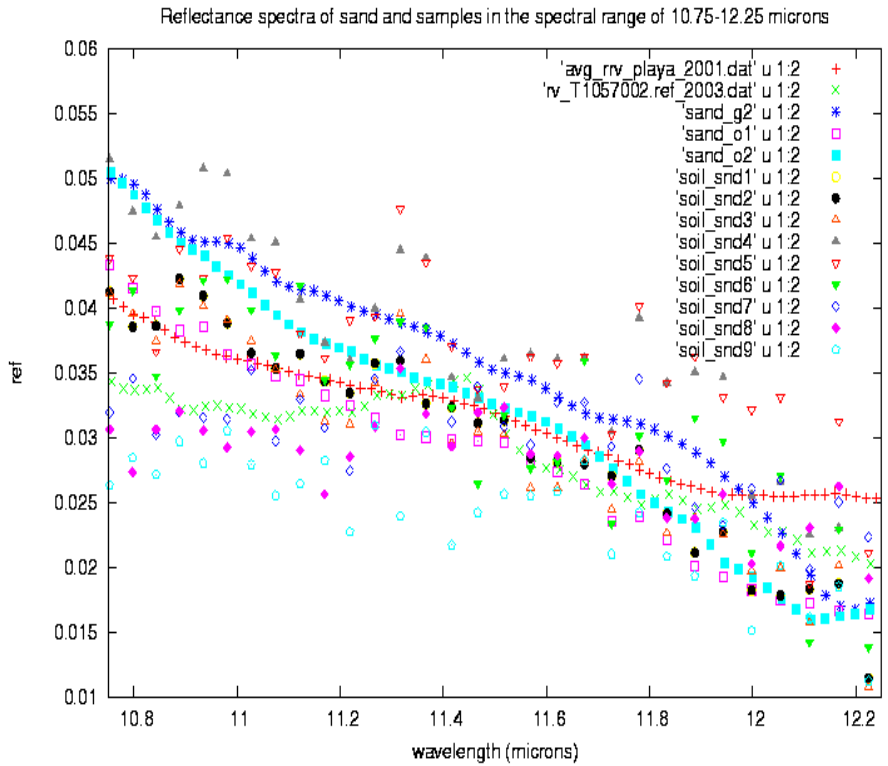
Lessons learned from the validation of the C5 MODIS LST products

1, For the 42 global test sites in different regions used in the C5 LST validation, the LST errors are well within 1K in all sites but five desert sites where some LSTs may be underestimated by more than 3K.

2, The two fundamental causes for the large LST errors in desert regions are
(A)daytime LSTs are beyond the up limit (Ts-air + 16K) used in algorithm development, and
(B) The 0.015 variation range of emis values in MODIS bands 31 and 32 for soil and sand samples (as shown in the variation range of the reflectance values in the right plot) corresponds to large LST errors.

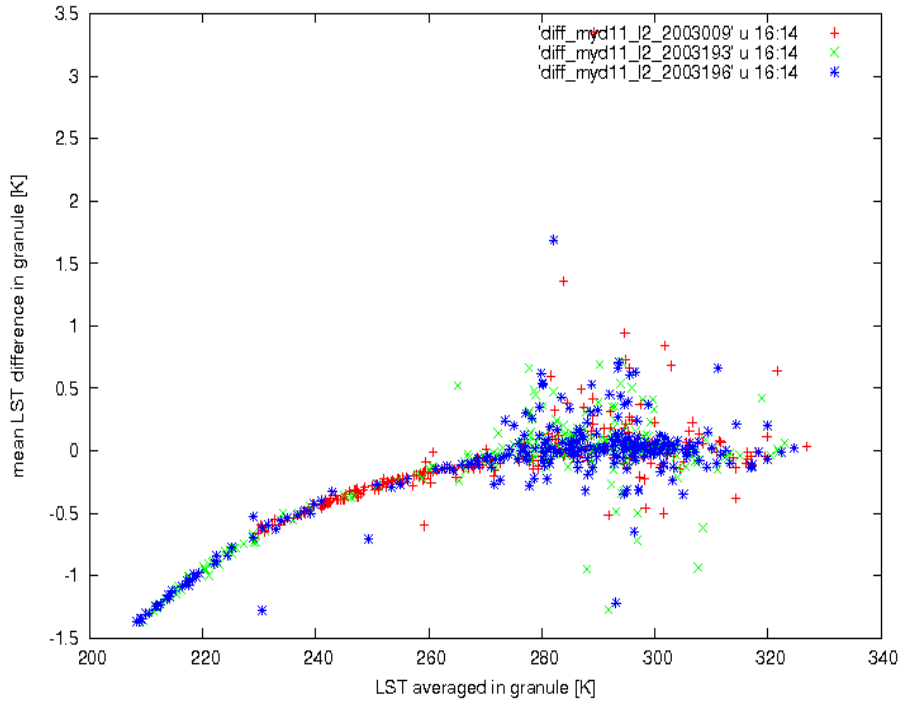
emissivity = 1 - reflectance



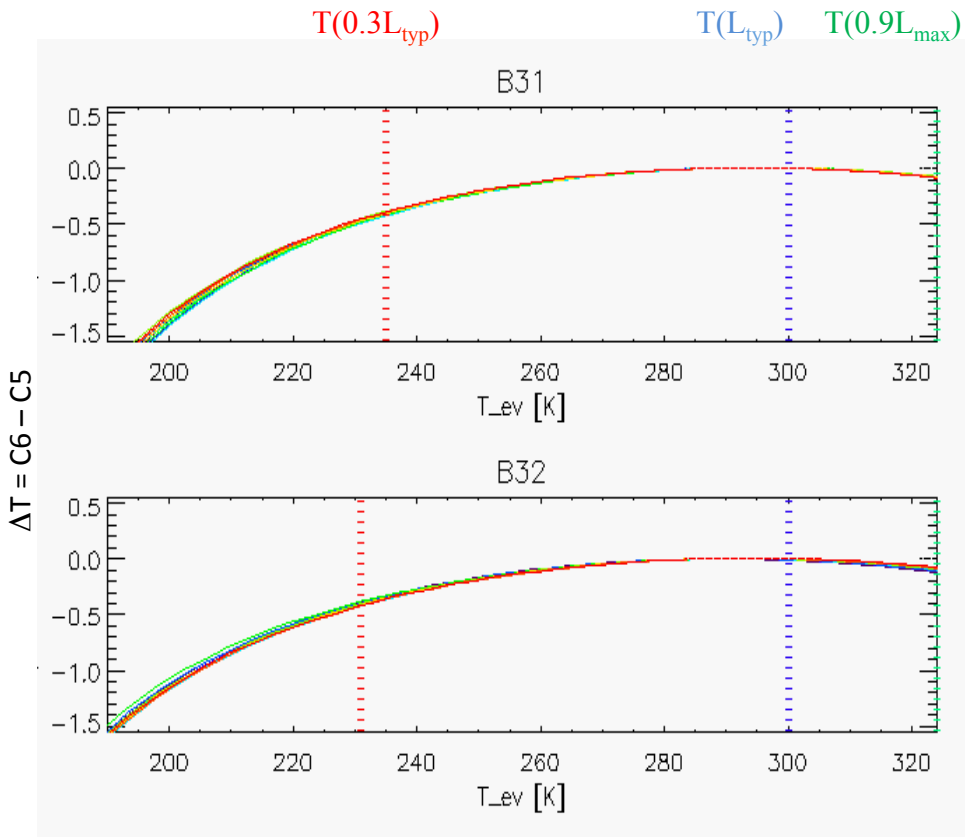
Summary of R-based validation of the C5 MODIS LST products at 32 new sites besides 10 old sites

Site	Location	Latitude, Longitude (°)	Land-cover Type (id #)	MOD11 or MYD11_L2	type of atmos. profiles	mean (std) of LST errors (K)
11	Recife, Brazil	7.96 S, 34.94 W	evergreen forest (2)	MOD11	radiosonde	0.4 (0.4)
12	Moree, Australia	29.555 S, 149.86 E	open shrubland (7)	MOD11	radiosonde	-0.8 (0.9)
13	Port Elizabath, S. Africa	33.95 S, 23.59 E	evergreen forest (2)	MYD11	radiosonde	-0.2 (0.9)
14	WLT Alert,Canada	82.4 N, 62.33 W	shrubland (7)/snow(15)	MOD11	radiosonde	0.2 (0.8)
15	South Pole	89.95 S, 0.05 E	snow/ice (15)	MOD11	radiosonde	-0.5 (0.6)
16	McMurdo,Antarctica	77.75 S, 164.1 E	snow/ice (15)	MOD11	radiosonde	0.1 (0.3)
17	Dye-2, Greenland	66.481 N, 46.28 W	snow/ice (15)	MOD11	NCEP	0.0 (0.5)
18	Summit, Greenland	72.58 N, 38.475 W	snow/ice (15)	MOD11	NCEP	0.1 (0.5)
19	Cherskij, Russia	68.75 N, 161.27 E	snow (15)/shrubland(7)	MOD11	radiosonde	0.3 (0.5)
20	Gaze, Tibet, China	32.3 N, 84.06 E	open shrubland (7)	MOD11	NCEP	-0.6 (0.2)
21	Hainich, Germany	51.079 N, 10.452 E	mixed forest (5)	MOD/MYD	radiosonde	-0.3 (0.5)
22	Paris, France	48.8 N, 2.35 E	urban (13)	MYD11	radiosonde	0.1 (0.4)
23	near Paris, France	48.45 N, 2.25 E	cropland (12)	MYD11	radiosonde	0.0 (0.6)
24	Nimes, France	43.84 N, 4.37 E	urban (13)	MYD11	radiosonde	0.1 (0.4)
25	near Nimes, France	43.828 N, 4.535 E	cropland (12)	MYD11	radiosonde	-0.1 (0.6)
26	Milan, Italy	45.485 N, 9.21 E	urban (13)	MYD11	radiosonde	-0.3 (0.7)
27	near Milan, Italy	45.297 N, 9.26 E	cropland (12)	MYD11	radiosonde	-0.3 (0.6)
28	Cuneo, Italy	44.53 N, 7.62 E	cropland (12)	MYD11	radiosonde	0.0 (0.5)
29	Payerne, Switzerland	46.855 N, 6.965 E	cropland (12)	MYD11	radiosonde	0.0 (0.5)
30	Nenjiang, China	49.07 N, 125.23 E	cropland(12)/snow(15)	MOD11	radiosonde	-0.3 (0.6)
31	Yichun, China	47.76 N, 128.88 E	mixed forest (5)	MOD11	radiosonde	0.1 (0.6)
32	Harbin, China	45.73 N, 126.65 E	urban (13)	MOD11	radiosonde	0.2 (0.8)
33	near Harbin, China	45.9 N, 127.1 E	cropland (12)	MOD11	radiosonde	0.1 (0.8)
34	Algiers, Algeria	36.72 N, 3.03 E	urban (13)	MOD11	radiosonde	-0.2 (0.9)
35	Dar-El-Beida,Algeria	36.65 N, 3.28 E	cropland (12)	MOD11	radiosonde	-0.5 (0.7)
36	Niamey, Niger	13.5 N, 2.14 E	urban (13)	MOD11	radiosonde	-0.3 (1.0)
37	Near Niamey, Niger	13.58 N, 2.07 E	grassland (10)	MOD11	radiosonde	-0.9 (1.1)
38	Tamanrasset, Algeria	22.856 N, 5.455 E	bare soil (16) in desert	MOD/MYD	radiosonde	-1.9 (1.2)
39	Bechar, Algeria	31.62 N, 2.33 W	bare soil (16) in desert	MOD/MYD	radiosonde	-1.5 (0.6)
40	Farafra, Egypt	27.04 N, 27.97 E	bare soil (16) in desert	MYD11	radiosonde	0.9 (0.4)
41	SVU, Egypt	26.285 N, 32.78 E	bare soil (16) in desert	MYD11	radiosonde	-1.6 (0.5)
42	In-salah, Algeria	27.18 N, 2.6 E	bare soil (16) in desert	MOD/MYD	radiosonde	-3.0 (0.8)

The effect of new C6 L1B data on the LST retrieval



The above plot shows the mean LST difference in granule vs LST averaged in granule based on MYD11_L2 data in AS409 and AS422. The trend curve indicates that the new C6 L1B data do not change the LSTs retrieved from data of bands 31 and 32 in range of 280-330K but it reduces the LST in cold regions by 1.3K around 208K at most. The scatter points departed from the trend curve represent the effect of the different column water and surface air temperature values in the C5 and C6 MYD07_L2 products on the LST retrieval of a small number of pixels near clouds in wet conditions, especially at large viewing zenith angles by swath edges.



C6 Test Granule 2012088.0950

Courtesy of Brian Wenny [brian.wenny@sigmaspace.com]

Therefore, the validation results of the C5 LSTs retrieved by the split-window algorithm in range of 280-330K are also valid for corresponding C6 LSTs.

The effect of newC6 Terra MODIS L1B data on the LST is within ±0.2K in the whole region.

New Refinements for the C6 Daily MODIS LST PGE (PGE16)

1, Two new sets of coefficients in the generalized split-window algorithm were developed for bare soil/sand pixels in separate conditions of daytime and nighttime, and the range of (LST – Ts-air) is set as from 8 – 29K for daytime LST and from -10 – 4K for nighttime LST, in order to well address the problems of very wide temporal variation range for daytime LST changes and possible large uncertainties in Ts-air values provided by the M*D07_L2 products.

2, A new optional algorithm was developed to adjust the emissivity difference in bands 31 and 32, i.e., the (em31 – em32) value, by a value limited in a region of ±0.0063 for bare soil/sand pixels by comparing the (Tb31 – Tb32) value to its value predicted from Ts-air and cwv values, and store the (em31 – em32) values in the UPD files for temporal averages.
The effect of this (em31 – em32) adjustment on the LST retrieval is within ±2K.

3, Apply these two sets of coefficients and the new algorithm in the first daily executive to retrieve LSTs for bare soil/sand pixels and output the LSTs to M*D11_L2 and M*D11A1.

4, In the new optional Executive 2, average the (em31 – em32) values in the 2-4 UPD files in order to reduce the impact of the uncertainties in Ts-air and cwv values of M*D07_L2.

5, In Executive 3, incorporate the new sets of split-window algorithm coefficients to the day/night algorithm to improve the LST and emis retrieval. The retrieved emis values in the view angle bins for the current day's daytime and nighttime observations are separately outputted to M*D11B1 for bands 20, 22, 23 and 29, in order to preserve the viewing angle dependence in emis values in these bands. Usually the viewing angles of MODIS daytime and nighttime observations in the same day are quite different.

Comparisons of the LST values in C41, C5 and C6 LST Products

Table 1A, Mean and standard deviation of LST difference values in the C6, C5 and C41 MOD11B1 Products at some typical sites in 2007.

site name	latitude/longitude	land cover type	daytime LST		nighttime LST	
			C5 - C6	C41 – C6	C5 – C6	C41 – C6
Lake Tahoe	39.11, -120.03	inland lake	0.01 ±0.16	0.43 ±0.16	-0.06 ±0.18	-0.12 ±0.18
Mojave	35.129, -115.65	open shrublands	0.01 ±0.17	1.48 ±0.19	-0.12 ±0.17	1.41 ±0.17
Tamanrasset	22.78, 5.52	bare soil/sand	-2.84 ±0.16	-0.68 ±0.20	-1.80 ±0.17	-0.44 ±0.19
In-salah	27.22, 2.5	bare soil/sand	-3.50 ±0.20	-0.20 ±0.24	-2.27 ±0.17	-0.01 ±0.18
Sonoran	31.9, -114.47	bare soil/sand	-3.27 ±0.18	-1.01 ±0.22	-2.71 ±0.18	-1.18 ±0.31
north Tassili	27.0, 7.65	bare soil/sand	-3.79 ±0.19	-0.70 ±0.24	-2.95 ±0.16	-0.48 ±0.17

Table 1B, Mean and standard deviation of LST difference values in the C6, C5 and C41 MYD11B1 Products at some typical sites in 2007.

site name	latitude/longitude	land cover type	daytime LST		nighttime LST	
			C5 - C6	C41 – C6	C5 – C6	C41 – C6
Lake Tahoe	39.11, -120.03	inland lake	-0.01 ±0.17	0.55 ±0.23	-0.05 ±0.18	0.22 ±0.19
Mojave	35.129, -115.65	open shrublands	0.11 ±0.17	1.37 ±0.24	-0.15 ±0.17	1.12 ±0.16
Tamanrasset	22.78, 5.52	bare soil/sand	-2.84 ±0.19	-0.62 ±0.25	-1.82 ±0.16	-0.35 ±0.16
In-salah	27.22, 2.5	bare soil/sand	-3.57 ±0.16	-0.75 ±0.29	-2.41 ±0.16	-0.43 ±0.17
Sonoran	31.9, -114.47	bare soil/sand	-3.72 ±0.18	-1.57 ±0.25	-2.86 ±0.15	-1.05 ±0.17
north Tassili	27.0, 7.65	bare soil/sand	-4.15 ±0.17	-1.34 ±0.22	-3.15 ±0.18	-0.94 ±0.17

Summaries:

1, C6 LST values are almost identical to C5 values at the first two sites;

2, C6 LST values are closer to and higher than C41 values in the four bare soil/sand sites.

Comparisons of the band 29 emissivity values in C41, C5 and C6 LST Products

Table 2A, Mean and standard deviation of emissivity values in band 29 in the C6, C5 and C41 MOD11B1 Products at some typical sites in 2007.

site name	latitude/longitude	land cover type	mean and standard deviation in the whole year		
			C6	C5	C41
Lake Tahoe	39.11, -120.03	inland lake	0.986 ± 0.007	0.985 ± 0.007	0.982 ± 0.011
Mojave	35.129, -115.65	open shrublands	0.915 ± 0.020	0.921 ± 0.020	0.923 ± 0.016
Tamanrasset	22.78, 5.52	bare soil/sand	0.926 ± 0.009	0.917 ± 0.018	0.931 ± 0.020
In-salah	27.22, 2.5	bare soil/sand	0.820 ± 0.018	0.856 ± 0.062	0.806 ± 0.038
Sonoran	31.9, -114.47	bare soil/sand	0.763 ± 0.022	0.838 ± 0.075	0.759 ± 0.032
north Tassili	27.0, 7.65	bare soil/sand	0.716 ± 0.019	0.814 ± 0.097	0.714 ± 0.029

Table 2B, Mean and standard deviation of emissivity values in band 29 in the C6, C5 and C41 MYD11B1 Products at some typical sites in 2007.

site name	latitude/longitude	land cover type	mean and standard deviation in the whole year		
			C6	C5	C41
Lake Tahoe	39.11, -120.03	inland lake	0.986 ± 0.006	0.984 ± 0.006	0.982 ± 0.011
Mojave	35.129,-115.65	open shrublands	0.910 ± 0.018	0.919 ± 0.017	0.905 ± 0.018
Tamanrasset	22.78, 5.52	bare soil/sand	0.924 ± 0.011	0.918 ± 0.019	0.912 ± 0.018
In-salah	27.22, 2.5	bare soil/sand	0.817 ± 0.018	0.869 ± 0.058	0.798 ± 0.030
Sonoran	31.9, -114.47	bare soil/sand	0.756 ± 0.020	0.840 ± 0.078	0.739 ± 0.033
north Tassili	27.0, 7.65	bare soil/sand	0.705 ± 0.021	0.820 ± 0.101	0.692 ± 0.035

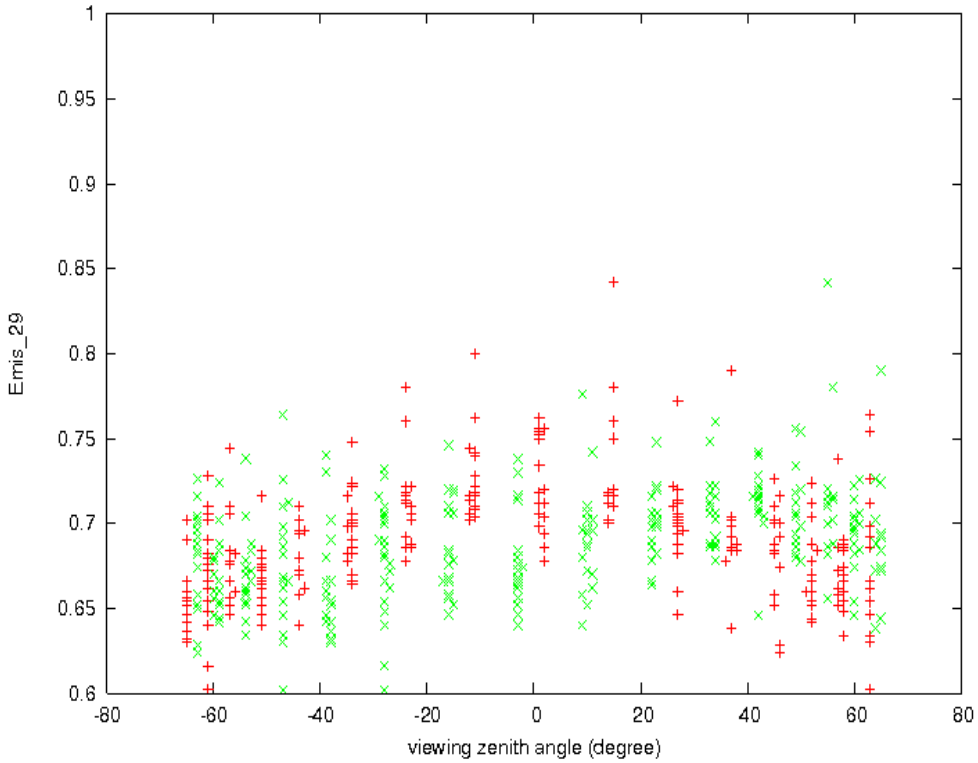
Summaries:

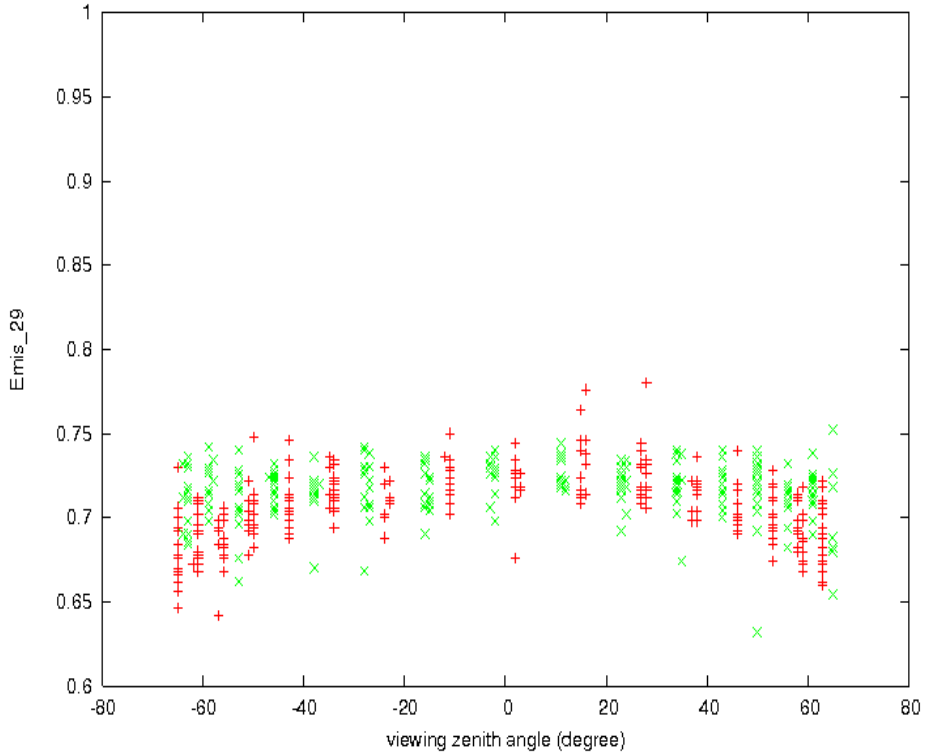
1, C6 em29 values are closer to C5 values at the first two sites but closer to C41 values in the four bare soil/sand sites;

2, The standard deviation values of em29 are smaller for all sites in C6;

3, The mean em29 values in MOD11B1 and MYD11B1 products are closer for all sites in C6.

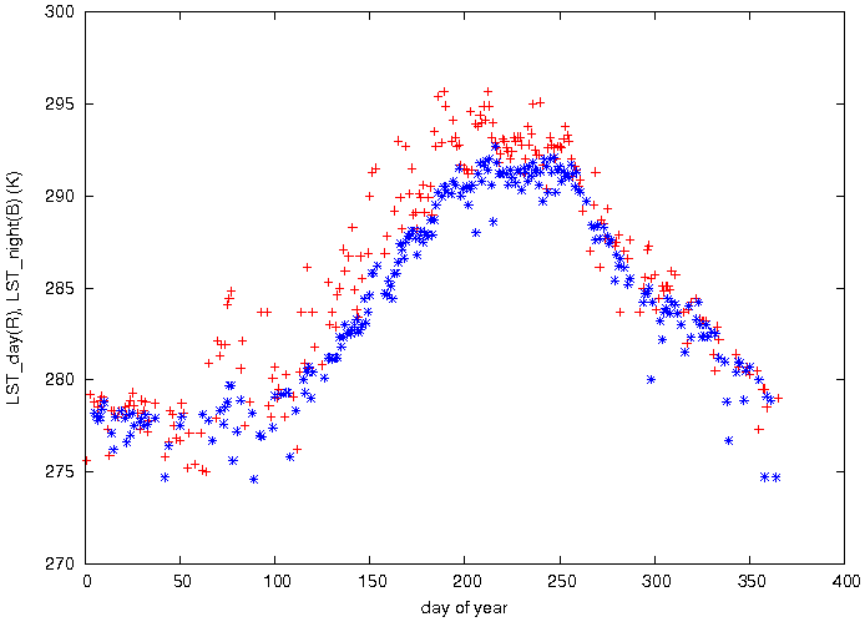
Comparisons of the viewing angle dependence in the band 29 emissivity values at the north Tassili site in the C41 and C6 MYD11B1 LST Products

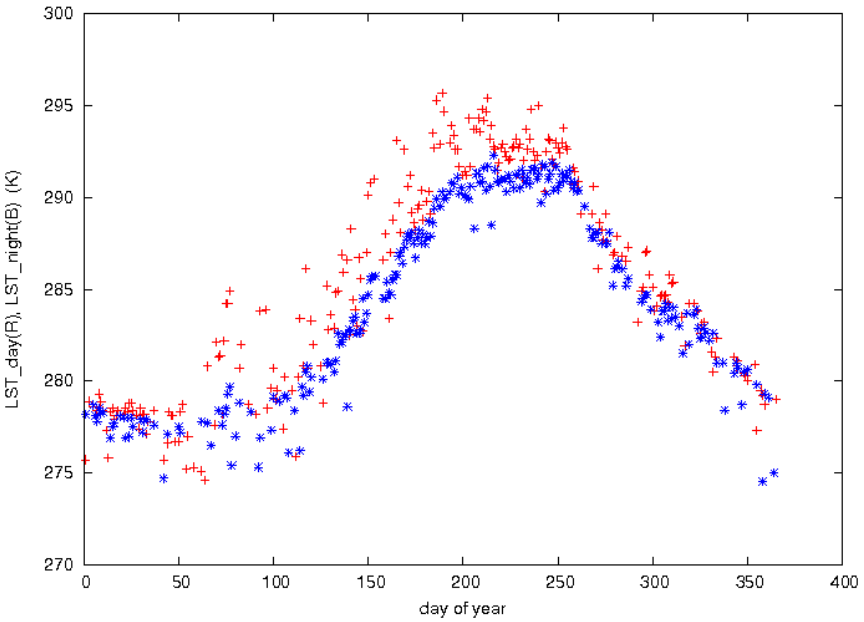


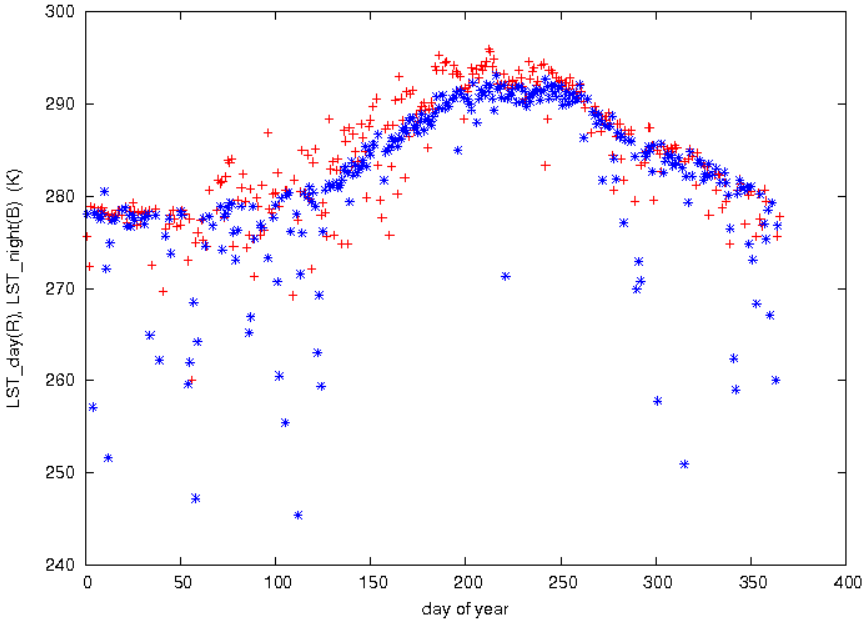


The viewing angle dependence in the band 29 emissivity values in the C6 MYD11B1 LST product is much better than in the C41 product because the C6 LST/E product provides more stable results.

Comparison of the C6 LST Product to C5 and C41



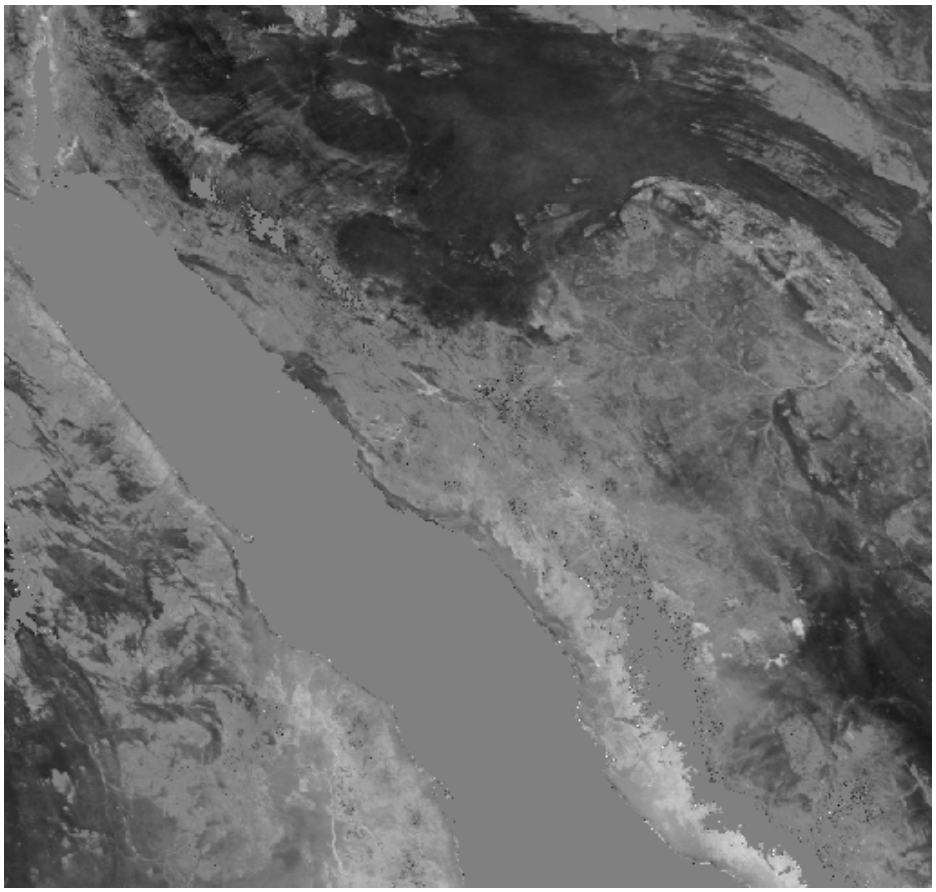




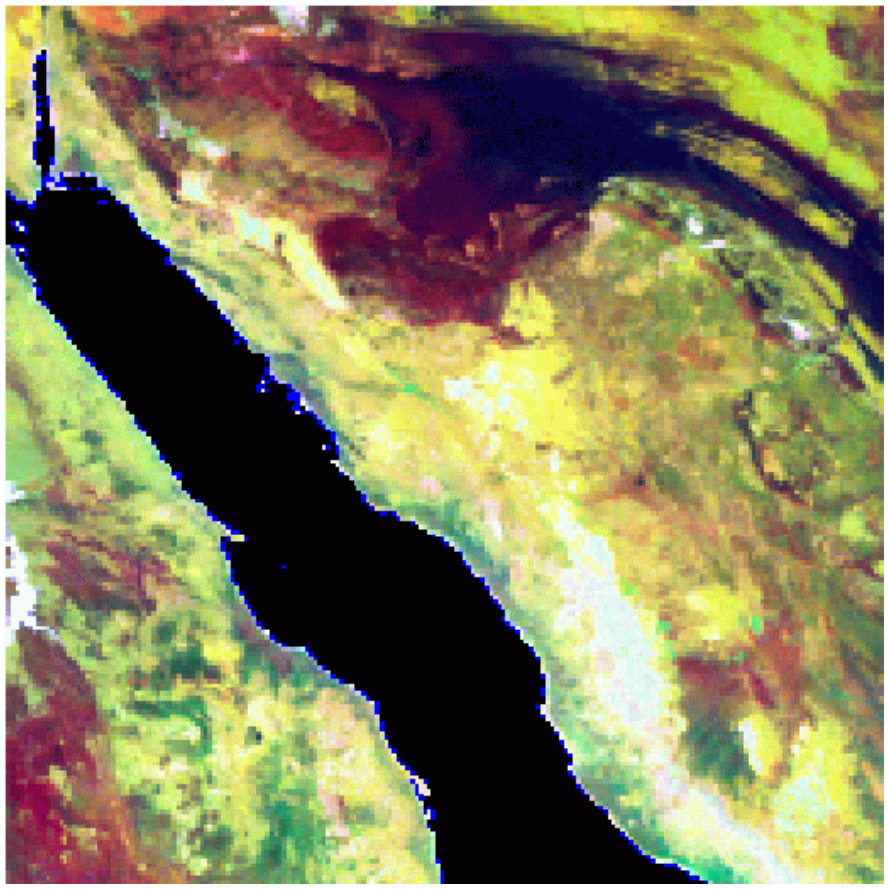
LST_day (red) and LST_night (blue) at Lake Tahoe, CA, retrieved by the day/night algorithm in the MYD11B1 product in 2007 in C6 (above), C5 (upper right) and C41 (lower right).

Note that Lake Tahoe does not freeze in the whole year so the low LST values in the C41 are due to cloud contaminations.

Qualitative Evaluation of the ($\varepsilon_{31} - \varepsilon_{32}$) Adjustment Values



The image on the left is for the adjustment value of (ε31 – ε32) times 20000 plus offset 128 in tile h21v06. The grey area is Red Sea where there is no (ε31 – ε32) adjustment. Positive adjustments in the brighter areas and negative adjustments in the darker areas.



The image on the right side is the composite image with em22, em29 and em31 values in the monthly MYD11B3.A2007182.h21v06 as RGB components. It is nice to have good correlations in these two images.

Conclusion

C6 M*D11 products are better than C5 and C41 products.

Work Plan

1. To deliver V6 codes for all the LST PGEs in April 2013.

2. To make more sensitivity study and error analysis of the (em31 – em32) adjustment in bare soil/sand regions.

3. Science data analysis will be made for the correlations of LST/E data in the C6 product with other independent data sets such as NDVI, ground measurement data of precipitation and soil moisture.

4. Radiance-based validation will be performed for the C6 Terra and Aqua MODIS LST products over different test sites world-wide with emphasis on desert sites.

A short list of references

Coll, C., Wan, Z., & Galve, J.M., (2009). Temperature-based and radiance-based validation for the V5 MODIS land-surface temperature product. *JGR,* 114, D20102, doi:10.1029/2009JD012038.

Wan, Z., (2008). New refinements and validation of the MODIS land-surface temperature/emissivity products. *Remote Sensing of Environment*, 112, 59-74.

Wan, Z., & Li, Z.-L., (2008). Radiance-based validation for the V5 MODIS land-surface temperature product. *International Journal of Remote Sensing*, 29, 5373-5395.

Coll, C., Caselles, V., Galve, J.M., Valor, E., Niclòs, R., Sánchez, J.M., & Rivas, R. (2005). Ground measurements for the validation of land surface temperatures derived from AATSR and MODIS data. *Remote Sensing of Environment*, 97, 288-300.

Tang, B.-H., Li, Z.-L., & Yuyun, B., (2009). Estimation of land surface directional emissivity in mid-infrared channel around 4.0μm from MODIS data, *Optics Express*, 17, 3173-3182.

K. Wang, Z. Wan, P. Wang, M. Sparrow, J. Liu, X. Zhou and S. Haginoya, "Estimation of surface long wave radiation and broadband emissivity using Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature/emissivity products", *J. Geophys. Res. - Atmos.*, 110, D11109 (2005).

Snyder, W.C., Wan, Z., Zhang, Y., & Feng, Y.-Z. (1998). Classification-based emissivity for land surface temperature measurement from space. *International Journal of Remote Sensing*, 19, 2753-2574.

Wan, Z., & Dozier, J. (1996). A generalized split-window algorithm for retrieving land-surface temperature from space. *IEEE Trans. Geoscience and Remote Sensing,* 34, 892–905.

Wan, Z., & Li, Z.-L. (1997). A physics-based algorithm for retrieving land-surface emissivity and temperature from EOS/MODIS data. *IEEE Trans. Geoscience and Remote Sensing*, 35, 980-996.

Wan, Z., Zhang, Y., Zhang, Y.Q., & Li, Z.-L. (2002). Validation of the land-surface temperature products retrieved from Moderate Resolution Imaging Spectroradiometer data. *Remote Sens. of Environ*, 83, 163-180.

Wan, Z., Zhang, Y., Zhang, Y.Q., & Li, Z.-L. (2004). Quality assessment and validation of the global land surface temperature. *International Journal of Remote Sensing*, 25, 261-274.

http://www.icess.ucsb.edu/modis/LstUsrGuide/usrguide.html