An LST Algorithm for Land Rapid Response

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History

- “Rapid” algorithm developed in 2004
- Pinheiro, A., J. Descloitres, J. Privette, J. Susskind, L. Iredell, and J. Schmaltz. 2007. Near-real time retrievals of land surface temperature within the MODIS Rapid Response System. Remote Sensing of Environment, 106:326–336.
- Level 2 swath imagery produced by Rapid Response system
- Code available from Direct Readout Lab

Today

- Being considered as candidate algorithm for LANCE-MODIS near-realtime system
- Summarize approach and comparisons from paper
- Next steps

Near-real time retrievals of land surface temperature within the MODIS Rapid Response System

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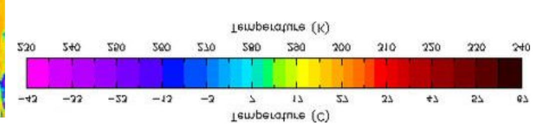
MODIS RR LST Product

- RR LST product is generated for each granule acquired by MODIS Terra and MODIS Aqua.
- Three science data sets in each HDF4.1 product file: T31, T32 and LST.
- Our algorithm was adapted from the MODIS level 2 “swath” product – “standard LST product”.
- Provides day and night products at 1 km spatial resolution, globally and in swath format.



MODIS standard LST swath algorithm

- Generated using a general split-window algorithm by Wan and Dozier (1996).

$$T_s = C + \left(A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_{31}+T_{32}}{2} + \left(B_1 + B_2\frac{1-\varepsilon}{\varepsilon} + B_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_{31}-T_{32}}{2}$$

T31 and T32 are the brightness temperatures for MODIS bands 31 and 32, respectively; and A1, A2, A3, B1, B2, B3 and C are regression coefficients.

- Coefficients (available in a LUT) :
  - are determined through regression analysis of radiative transfer simulations for a wide range of surfaces and atmospheric conditions.
  - are stratified by subranges of near surface air temperature and total column water vapor. These input fields are obtained at 5 km×5 km resolution from the MOD07_L2 product.
- Estimates of the surface emissivity are required for each pixel to retrieve land surface temperature.

Emissivity determination

- Based on a landcover classification approach. The algorithm determines each pixel's land cover class from MODIS gridded land cover product (MOD12Q1).

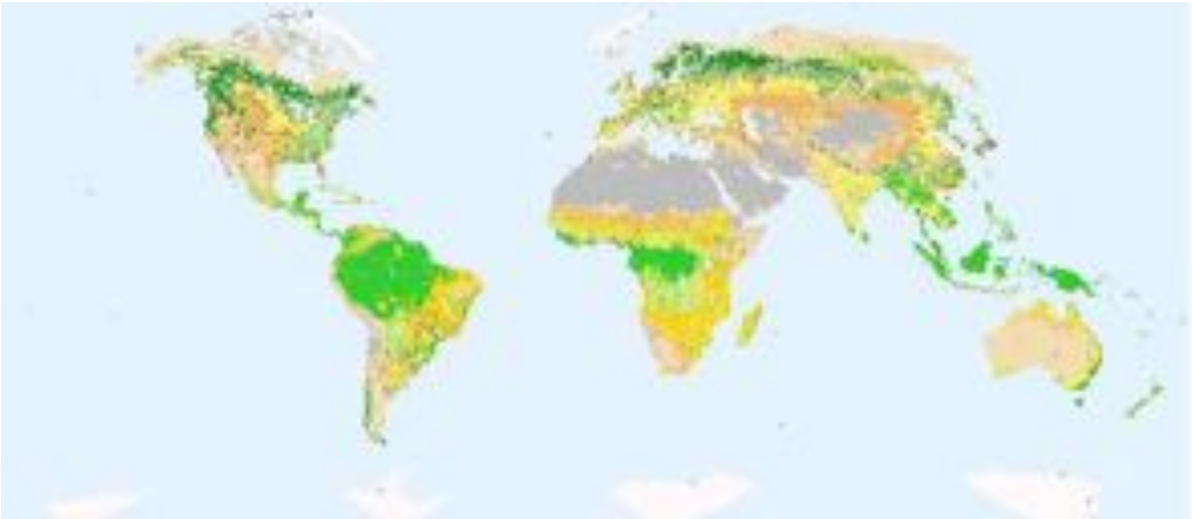


Fig.: MODIS Land cover map (MOD12Q1).

- Once the landcover type for a given pixel is identified, the emissivities ε31 and ε32 are retrieved from a LUT.

- For pixels in which MODIS angle of observation is above 42.3° an adjustment to the emissivity is used to account for directional emissivity variation.

Cloud Mask

- LST values are estimated only for pixels associated with clear-sky conditions, identified by the MODIS cloud mask (MOD35_L2) at 99% confidence for land surfaces, and 66% confidence for inland water bodies.

- A fill value is used for other pixels.

Adaptation of the standard MODIS LST product for use in near-real time

1. Modified radiometric calibration for emissive bands
2. Eliminated algorithm’s dependency on upstream MODIS products
   - Use of climatology for air temperature and water vapor
3. Modified emissivity determination
4. No cloud mask is applied

1. Modified Radiometric Calibration

Standard Algorithm:

Tb is determined by convolving Planck function with the average detector spectral response function - weighted integration method - for each of the two thermal bands. The results are stored in a (large) LUT.

Problem: *Large computational expense needed to load and parse through LUT.*

RR Algorithm:

Tb is determined by adopting the center wavelength method, where the equation is determined at a single representative wavelength (we use optimal central wavelengths for each of the 10 individual detectors).

Result: *Avoid computational expense.*

Note: The use of the single wavelength approach introduces some error in Tb that can be correct with a simple linear correction (see backup slides for more details).

2. Provision of atmospheric data sets

Standard Algorithm:

Atmospheric values are determined from the MODIS product (MOD07_L2).

Problem: *Unavoidably leads to greater latency in the standard LST product.*

RR Algorithm:

Atmospheric values are obtained from a monthly climatology of near-surface air temperature (K) and total water column water vapor (cm) determined from TOVS.
A sensitivity study showed that MODIS LST algorithm is not highly sensitive to errors in the input values of water vapor and surface air temperature.

Result: *Approach is self-contained and external data feeds are not required.*

The TOVS climatology is based on the monthly mean values of 25 years (1979–2003) of TOVS soundings. The water vapor and surface temperature values were adjusted to the average local equator crossing time of Terra (10:30 AM and PM) and Aqua (1:30 AM and PM) satellites.

3. Estimation of target emissivity

Standard Algorithm:

The emissivity values are found by loading the set of 10°×10° MODIS land cover tiles that overlap sections of the swath.

Problem: *Computational expense of identifying and several loading tiles for each swath*

RR LST Algorithm:

RR system loads the relevant latitudinal belt of a global land cover map (*).
The RR algorithm uses a nearest neighbor approach to choose the grid cell within the land cover product.

Result: *Reduce the computation expense of loading several tiles for each swath.*

(*) This global map is in the Plate Carrée projection (Binary MOD12Q1 1km Land Cover), and is available directly from the MODIS land cover developers (http://duckwater.bu.edu/lc/mod12q1.html). The RR algorithm uses the same IGBP land cover classification scheme as does the MOD11_L2 algorithm.

No Cloud Mask Applied

No cloud screening is used in the RR algorithm.

RR LST field is spatially continuous (standard product contains fill values where clouds are detected).

- This decision follows feedback from some users of the standard MODIS LST product who believe that cloud filtering in that product removes useful thermal information.
- This approach is also consistent with other RR products.
- Depending on the application, this may or may not be desirable.

Major differences between products

Table 2
Main characteristics of Rapid Response and standard LST products

Characteristic	Standard LST	Rapid Response LST
Theoretical basis	Wan and Dozier (1996)	Wan and Dozier (1996)
Atmospheric water vapor	MOD07_L2*	TOVS climatology
Near-surface air temperature	MOD07_L2	TOVS climatology
Landcover (LC)	MOD12Q1	Binary MOD12Q1
Projection	Sinusoidal	Plate Carree
Spatial Resolution	$0.08333° \times 0.08333°$	$0.08333° \times 0.08333°$
Format	$10° \times 10°$ tiles, HDF-EOS	Global file, binary
Latency	<2 days	$\sim$3 h
Product format	HDF-EOS	HDF4.1
Cloud screening	Yes (MOD35_L2)	No

* A guide to the official MODIS products is available at http://modis-atmos.gsfc.nasa.gov.

Evaluation of the Rapid Response LST product

- We evaluated the RR product by comparing it to both the standard product and to field data.
- Comparisons were performed for different atmospheric conditions (near-surface air temperature and water vapor) and at different latitudes and longitudes.
- The MODIS standard LST products used in our analysis are from reprocessing Collection 4.

Comparison with the standard LST product

- We assessed the RR product globally for two dates: 1 January 2003 and 1 July 2003:
  - bias (mean difference) between the products,
  - precision (standard deviation)
  - uncertainty (root mean square error).

- These dates likely span earth's atmosphere/climate range for both the northern and southern hemispheres).

- Although we are using global land observations, the dominance of land in the northern hemisphere significantly biases the analysis towards the dominant season in the northern latitudes.

- The standard product was used as the true or reference temperature in the comparison.

- We selected for the comparison only land pixels (landmask=1) and cloud free pixels (as defined in the standard product).

- A total of 483 granules and approximately 200 million pixels were evaluated.

Example of a comparison with the standard LST product

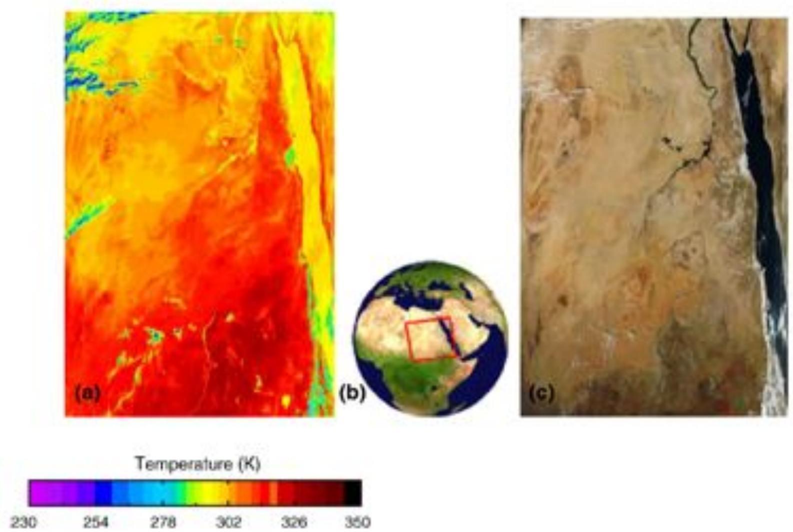


Fig. 2. MODIS Rapid Response a) land surface temperature b) RR granule location, and c) true color observation of north-east Africa and the Red Sea (MODIS Aqua on 1 January 2003, at 11:15 UTC).

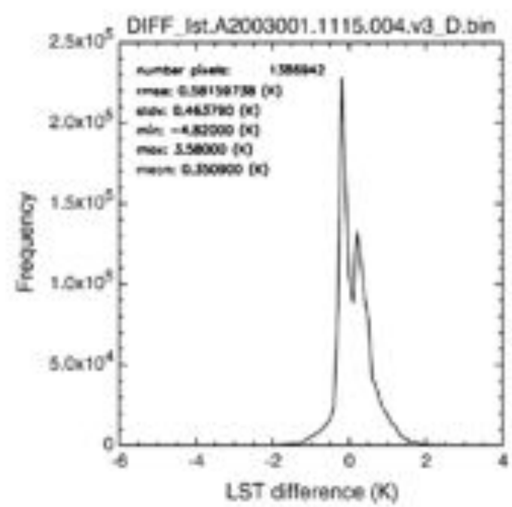


Fig. 4. LST error histogram for granule collected on January 1st, 2003 at 11:15 AM GMT.

Fig. 3. LST error spatial distribution for granule collected on January 1st, 2003 at 11:15 AM UTC.

Summary of global comparison shows good agreement

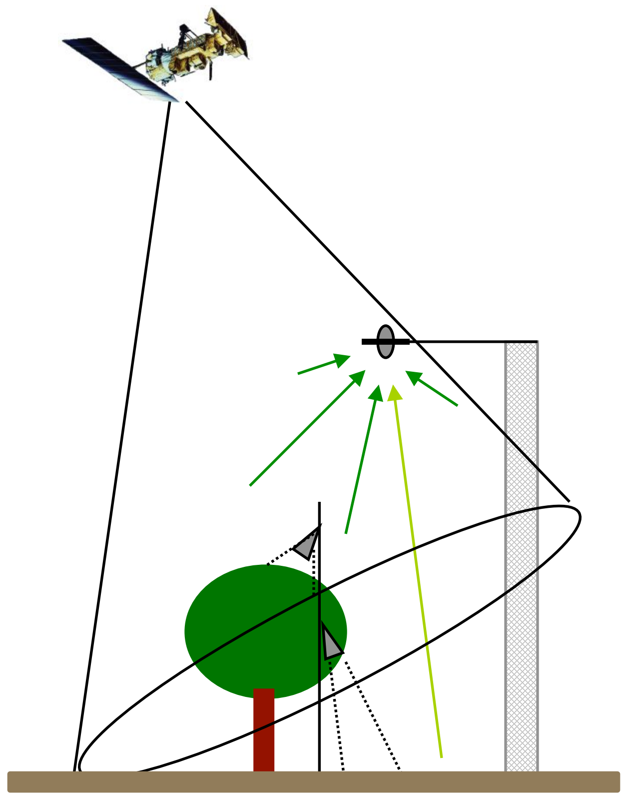
- Products agree well -- RR product is robust
- RR LST product behaves reasonably over the global distribution of land covers and atmospheric conditions.
- Average bias always less than 0.4K
- Differences between products increase for increasing temperatures and differ latitudinally.

Table 3
Statistical comparison of MOD11_L2 and MOD11_RR, for MODIS-Aqua

	Accuracy (K) (bias)	Precision (K) (S.D.)	Uncertainty (K) (RMSE)	No. of pixels (N)	No. of granules (N)
1 January 2003					
All	0.014	0.464	0.554	110, 430,000	239
Day	−0.074	0.357	0.429	56,640,400	101
Night	0.093	0.666	0.799	39,113,340	108
1 July 2003					
All	0.081	0.707	0.935	87,708,800	244
Day	−0.189	0.646	0.779	38,967,300	114
Night	0.362	0.771	1.097	42,280,400	106

Evaluation with field measurements

- Compared the RR product with two sets of published field data used to validate the standard product.
  - Dataset 1: collected by Wan et al. (2002) over inland lakes, grasslands, rice cropland and snow (10 comparisons).
  - Dataset 2: collected by Coll et al. (2005) over rice fields (11 comparisons).



	Average bias (RR_LST – in situ)	Average STDV (RR_LST – in situ)	Average bias (RR_LST – MYD11_l2v.005):	Average STDV for (RR_LST – MYD11_l2v.005):
Dataset 1	0.30 K	0.73 K	0.07K	0.28 K
Dataset 2	-0.86 K	1.04 K	0.12 K	0.28 K

MODIS LST (both RR and standard product) were more accurate for observations within 40° of nadir.

Considerable differences were observed between water vapor estimates from the radiosonde, the MOD07_L2 product, and the TOVS climatology, over all sites.

Summary

- We modified the standard MODIS LST algorithm to fit a near-real time environment, by reducing latency:
  - Removed dependencies on external products by using a TOVS climatology for air temperature and water vapor;
  - Modified the estimation of TOA Tb by using the central wavelength method followed by linear correction;
  - Modified the estimation of emissivity for each pixel by using a global land cover map.

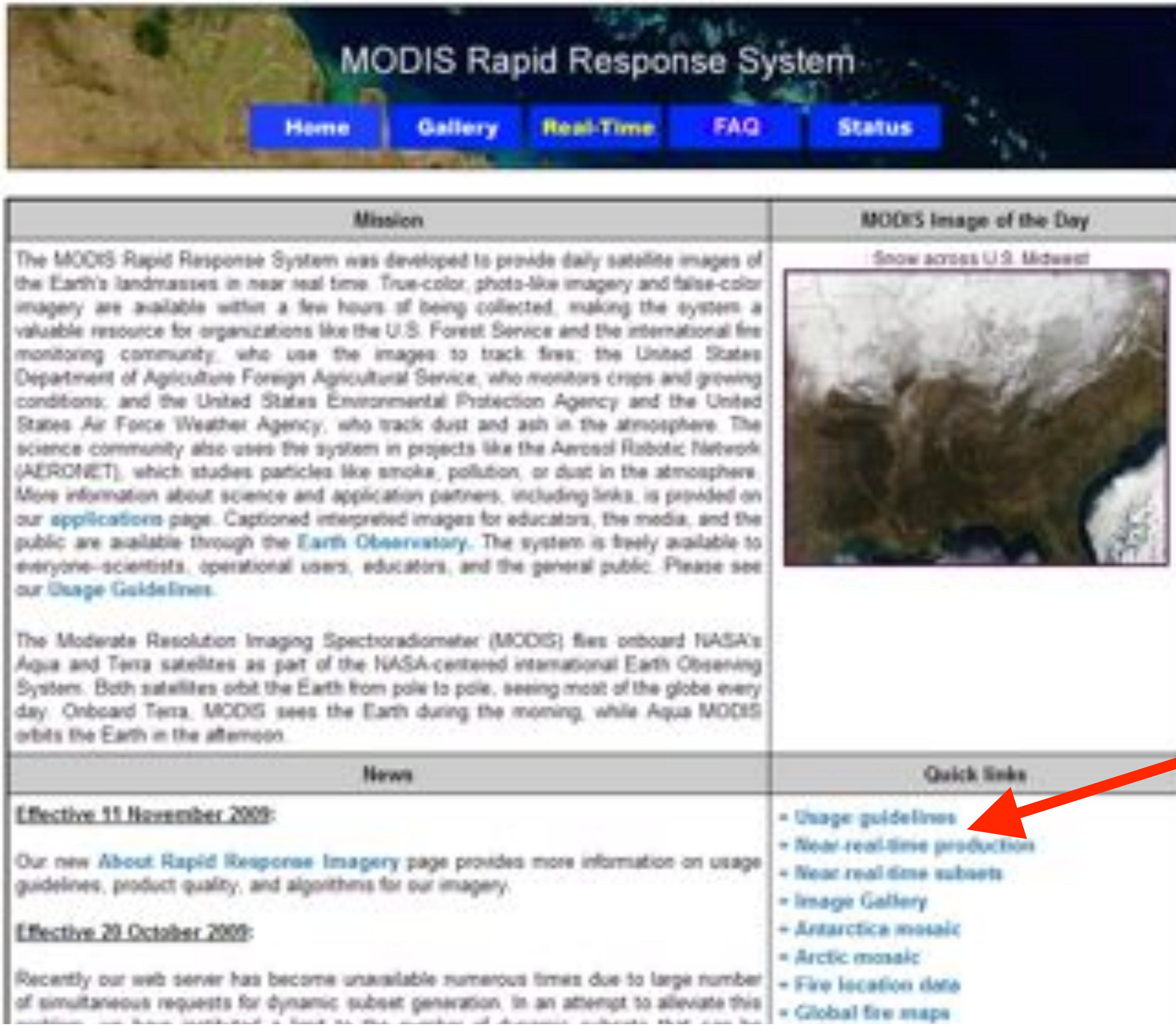
- Comparison of RR LST with MODYD11_L2 product show good agreement, with bias < 0.1 K (most cases): within the accuracy of the MODIS product (1K).

- Comparisons of RR LST with *in situ* data suggest absolute uncertainty < 1 K.

- RR LST code allows for stand alone processing -- available to the DB community.

Next Steps?

- Update climatology
- Update landcover
- Update to Collection 5 standard algorithm
- Alternative “rapid” algorithms



To find RSE Paper

Usage guidelines

BACKUP SLIDES

Correcting the error in Tb

- Near the saturation temperatures (*) errors can exceed 0.1 K (e.g., 0.143 for band 31, detectors 8, 9 and 10 onTerra).

- To reduce these errors, we apply a linear correction to each channel:

$$\mathrm{Tb\_corrected} = \mathrm{Tb\_uncorrected} * \mathrm{slope} + \mathrm{offset}$$

- The slope and offset values were determined by regressing Tb values determined with the wavelength integration method against Tb_uncorrected values.

- Differences between the corrected and uncorrected Tb values are negligible (see dashed lines in Fig. 1), and well below the noise equivalent delta temperatures (NEDT) for the bands.

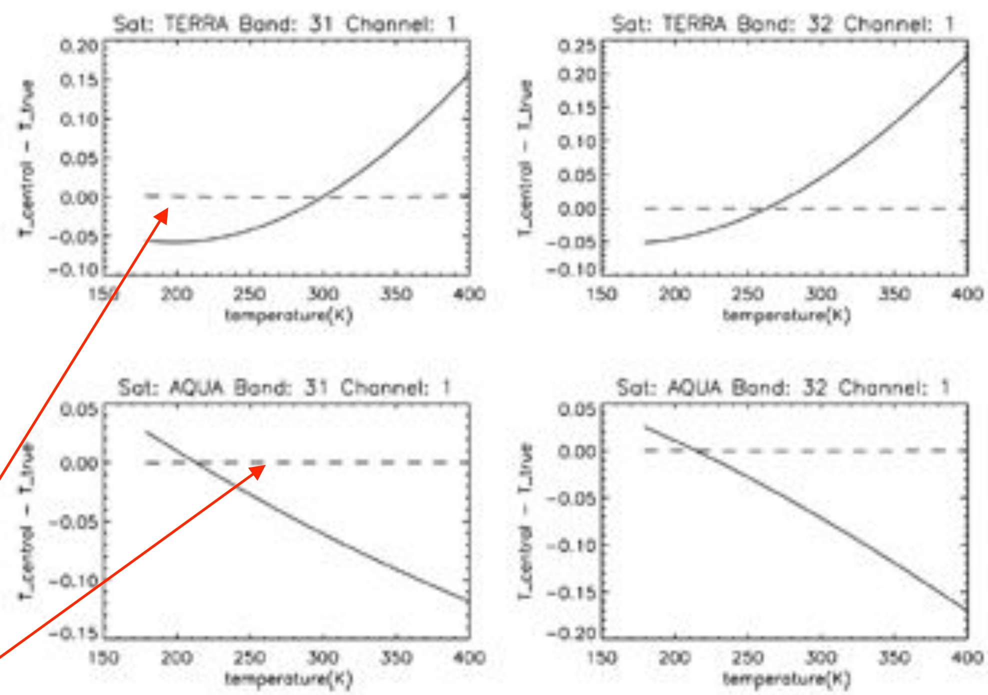


Fig. 1. Error in brightness temperature (Tb) retrievals using the single-wavelength approach before (solid line) and after (dashed line) application of the linear correction.

(*) Terra platform: 392 K for band 31 and 340 K for band 32; Aqua: 387 K for band 31 and 340 K for band 32),

Comparisons with *in situ* data (dataset 1)

Table 4
Validation results using Wan et al.'s (2002) field data

Site	Latitude (#) longitude (#)	Date (mm/dd/yy) time (UTC)	Water vapor			Temperature (K)			RR–MOD11 (K)	RR–in situ (K)
			TOVS	MOD07	In situ	In situ	RR	MOD11 v.004		
Mono Lake, CA	37.9712°N (37.9699°N) 119.001°W (119.007°W)	04/04/00 19:19	0.91	2.2	0.36	283.81	285.60	285.70	−0.10	1.79
Mono Lake, CA	37.9930°N (37.9924°N) 118.9646°W (− 118.9700°W)	07/25/00 19:18	1.51	2.1	–	296.01	296.30	296.34	−0.04	−0.29
Mono Lake, CA	38.0105°N (38.0054°N) 118.9695°W (118.972°W)	10/06/00 19:11	1.21	1.4	0.62	290.17	290.40	290.30	0.10	+0.23
Lake Titicaca, Bolivia	16.2470°S (16.2513°S) 68.7230°W (68.7308°W)	06/15/00 15:26	1.14	1.1	0.29	285.0	285.10	285.38	−0.28	+0.10
Bridgeport, CA	38.2255°N (38.2211°N) 119.2680°W (119.272°W)	04/04/00 19:19 UTC	0.94	2.6	–	308.2	308.90	No data available	No data available	+0.70
Bridgeport, CA grassland	38.2202°N (38.2203°N) 119.2693°W (119.271°W)	07/28/00 06:09 UTC	1.55	1.6	–	281.63	281.9	282.34	−0.44	+0.27
Bridgeport, CA Grassland	38.2202°N (38.2197°N) 119.2693°W (119.263°W)	07/30/00 05:57 UTC	1.55	2.4	–	283.24	282.30	282.68	−0.38	−0.94
Rice field in California	39.5073°N (39.5062°N) 121.8107°W (121.8100°W)	07/28/00 06:10 UTC	0.93	1.4	–	291.20	292.10	292.12	−0.02	+0.90
Rice field in California	39.5073°N (39.5096°N) 121.8107°W (121.813°W)	07/30/00 05:57 UTC	0.93	3.0	–	293.02	292.70	292.70	0.00	−0.32
Bridgeport, CA Snowcover	38.2199°N (38.2149°N) 119.2683°W (119.271°W)	03/12/01 6:36 UTC	0.89	0.4	–	263.70	263.70	263.20	0.50	0.00
Average									−0.07	0.30
Standard deviation									0.28	0.73

[#] Coordinates for centroid of nearest pixel.

Comparisons with *in situ* data (dataset 2)

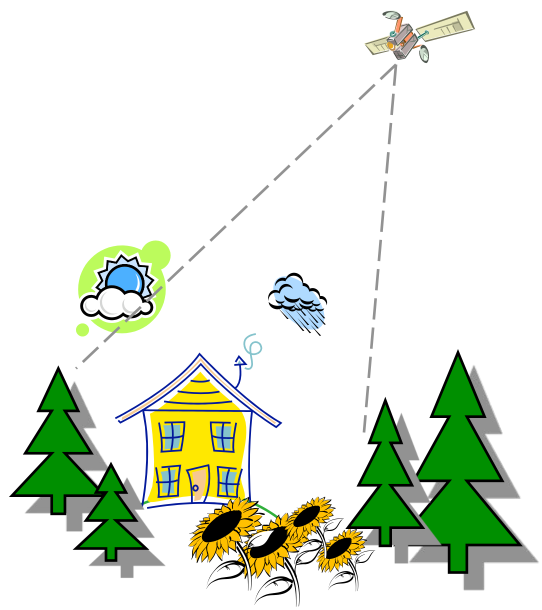
Table 5
Validation results using Coll et al.'s (2005) field data

Site	Latitude (#) longitude (#)	Date (mm/dd/yy) time (UTC)	Water Vapor (cm)		Temperature (K)			RR–MOD11 (K)	RR–In situ (K)
			TOVS	MOD07	In situ	RR	MOD11 (v.004)		
Site #1	39.240833°N (39.2391°N) 0.297219°W (0.30211°W)	07/10/02 10:32	1.96	2.27	301.95[a]	300.40	300.56	−0.16	−1.55
	39.240833°N (39.2365°N) 0.297219°W (0.30247°W)	07/26/02 10:32	2.07	3.20	301.25[b,a]	299.30	299.52	−0.22	−1.95
	39.240833°N (39.2387°N) 0.297219°W (0.29084°W)	07/08/03 10:11	1.95	2.27	301.85[c]	300.20	300.62	−0.42	−1.65
	39.240833°N (39.2415°N) 0.297219°W (0.29208°W)	07/11/03 10:42	1.96	1.35	302.05	302.20	302.3	−0.10	+0.15
	39.240833°N (39.2345°N) 0.297219°W (0.29729°W)	08/09/03 10:11	2.18	2.21	302.85[c]	301.30	301.64	−0.34	−1.55
	39.240833°N (39.2411°N) 0.297219°W (0.29143°W)	08/12/03 10:42	2.20	1.39	304.35	303.9	304.04	−0.14	−0.45
	39.240833°N (39.2396°N) 0.297219°W (0.30083°W)	08/26/03 10:54	2.21	3.15	305.05[b]	302.4	302.88	−0.48	−2.65
Site #2	39.250278°N (39.2417°N) 0.295244°W (0.28807°W)	07/08/04 10:24	1.95	1.82	298.45[a]	298.5	298.46	0.04	−0.04
	39.250278°N (39.2466°N) 0.295244°W (0.29351°W)	07/27/04 10:54	2.13	1.68	301.05	301.00	301.04	−0.04	−0.05
	39.250278°N (39.2512°N) 0.295244°W (0.29594°W)	08/03/04 11:00	2.08	2.68	303.15	303.60	303.06	0.54	+0.45
	39.250278°N (39.2467°N) 0.295244°W (−0.28999°W)	08/12/04 10:54	2.28	1.89	301.85	301.60	301.60	0.00	+0.25
Average								−0.12	−0.86
Standard deviation								0.28	1.04

[#] Coordinates for centroid of nearest pixel.
Note: Cases [a,b] and [c] correspond to less ideal validation conditions.
[a] View angle >40°.
[b] Cirrus clouds.
[c] View angle >60°.

Deep BACKUP SLIDES

Land Surface Temperature (LST)



- What is LST?

  - The effective kinetic temperature of the earth surface "skin".

  - For thermal infrared measurements: thermal emission from the ~10-13 microns depth.

- Why is it important?

  - Key climatological variable
  - Contributes to the magnitude and partitioning of energy fluxes at the earth's surface.
  - Applications: quantify surface's heat and water fluxes, monitor drought conditions and crop health, assess soil moisture content, map geological features, assess water quality, vulcanology, etc.
  - *Climate Data Record (CCSP, NASA, GCOS…).*

MODIS instrument

- 16 emissive bands (3-15 microns) out of a total of 36 spectra bands
- Ground instantaneous field of view of 1 km at nadir
- Scans surface ±55 from nadir
- 10 along track detectors per spectral band (simultaneous)
- Provides daytime and nighttime global coverage every 1 to 2 days
- Radiometric resolution of 12 bits
- Detectors sample onboard calibration before and after each scan.
- Absolute calibration accuracy for thermal bands is 1 % (except fro band 36).
- Focus on bands 31 and 32 for LST algorithm.

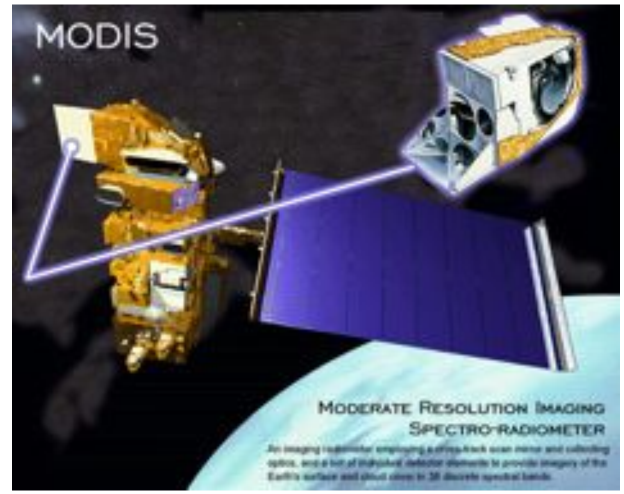


Table 1: MODIS emissive bands for surface temperature retrievals

Band	Band width (μm)	Central wavelength (μm)	Required NeΔT (K)
31	10.780–11.280	11.0186	0.05
32	11.770–12.270	12.0325	0.05

- Product available at MODIS Rapid Response System web page http://rapidfire.sci.gsfc.nasa.gov/).

- Code available at Direct Readout Page: http://directreadout.gsfc.nasa.gov/.

- For More details about implementation, please consult:

Pinheiro, A.C.T.; Descloitres, J.; Privette, J. L, J. Susskind, L. Irendel and J. Schmaltz (2007). *Near Real Time retrievals of Land Surface Temperature within the MODIS Rapid Response System*. Remote Sensing of Environment, **106**, 326-336.