Development and Testing of the VIIRS Land Surface Temperature Using Global MODIS Proxy Data and Global Synthetic Data

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Introduction

Abstract:

The Visible/Infrared Imager/Radiometer Suite (VIIRS) Dual Split-Window Land Surface Temperature (LST) algorithm represents a significant departure from conventional split-window approaches that have been employed for retrieval of LST. As with the VIIRS Sea Surface Temperature algorithm, the LST algorithm utilizes a dual split-window approach, with both Short-wave Infrared (SWIR) channels at 3.70 µm (M12) and 4.05 µm (M13), and Long-wave Infrared (LWIR) channels at 10.76 µm (M15) and 12.01 µm (M16) to correct for atmospheric water vapor. By comparison, the MODIS generalized split-window algorithm only uses the LWIR bands in the retrieval of surface temperature because of the concern for both solar contamination and large emissivity variations in the SWIR bands. In this paper, we assess whether these concerns are real and whether there is an impact on the precision and accuracy of the LST retrieval. We have taken two separate approaches to perform this testing, one based solely on global synthetic data and the other based entirely on proxy data from Tera MODIS. Results of both the split-window and dual split-window algorithms will be assessed by either comparisons to synthetic "truth" or results of the MODIS retrieval. We will also show that the results of the testing with proxy data are consistent with those obtained using the global synthetic data.

VIIRS LST EDR System Specifications:

LST is defined as the skin temperature of the uppermost layer of the land surface. The LST EDR is required only for horizontal cells over land that are categorized as "Confident Clear" by the VIIRS Cloud Mask, however retrieval is made on all pixels with valid M15 and M16 brightness temperatures that are not identified as Confident Cloudy nor Sea Water, and is labeled for the appropriate quality. The EDR is produced during both day and night.

Appendix D, Paragraph 40.3:

Paragraph	Attributes	System Specification
	a. Horizontal Cell Size (HCS)	
40.6.1-1	1.Nadir	0.75 km
40.6.1-12	2. Edge of Swath	1.30 km
40.6.1-2	b. Horizontal Reporting Interval	HCS
40.6.1-3	c. Horizontal Coverage	Land
40.6.1-4	d. Measurement Range	213 K – 343K (-76°F – 158°F)
40.6.1-5	e. Measurement Accuracy	2.4 K
40.6.1-6	f. Measurement Precision	0.5 K
40.6.1-7	g. Mapping Uncertainty	1.5 km
40.6.1-11	j. Measurement Uncertainty, Nadir	2.5 K
40.6.1-13	k. Exclusion: AOT > 1.0	

VIIRS LST EDR Retrieval Algorithms

Baseline dual split window algorithm:

Establish one dual split window regression equation for each of the 17 IGBP surface types (Land Cover regression method) using 4 VIIRS LWIR bands, 3.74 µm (M12), 4.05 µm (M13), 10.76 µm (M15), and 12.01 µm (M16), with added solar zenith angle correction for daytime retrievals.

$$LST_{day} = a_0 + a_1T_{M15} + a_2(T_{M15} - T_{M16}) + a_3(\sec\theta - 1) + a_4T_{M12} + a_5T_{M13} + a_6T_{M12}\cos\phi + a_7T_{M13}\cos\phi + a_8(T_{M15} - T_{M16})^2$$

$$LST_{night} = b_0 + b_1T_{M15} + b_2(T_{M15} - T_{M16}) + b_3(\sec\theta - 1) + b_4T_{M12} + b_5T_{M13} + b_6T_{M12}^2 + b_7T_{M13}^2 + b_8(T_{M15} - T_{M16})^2$$

Fallback split window algorithm:

Revert back to a 2-band, 10.76 µm (M15) and 12.01 µm (M16) split window algorithm for both day and night fallback situations (e.g., sun glint and poor quality inputs).

$$LST_{day} = c_0 + c_1T_{M15} + c_2(T_{M15} - T_{M16}) + c_3(\sec\theta - 1) + c_4(T_{M15} - T_{M16})^2$$

$$LST_{night} = d_0 + d_1T_{M15} + d_2(T_{M15} - T_{M16}) + d_3(\sec\theta - 1) + d_4(T_{M15} - T_{M16})^2$$

where T_{M12}, T_{M13}, T_{M15}, and T_{M16} are measured TOA brightness temperatures, a_i, b_i, c_i, and d_i are known regression coefficients.

Four main source of errors that impact LST EDR performance:

- Emissivity variations within each IGPB land surface type
- Accuracy of the VIIRS Land Surface Type EDR
- Errors in atmospheric correction (due mainly to water vapor)
- Sensor performance errors

Performance Testing with Global Synthetic Data

Testing Procedure:

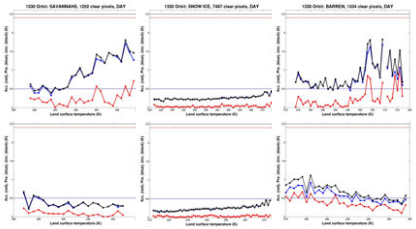
Based upon NGST global synthetic data composed of heterogeneous land types (using PRA land cover data base classified into 17 IGBP types).

Generate initial sets of regression coefficients from subset of the global synthetic data for NPOESS orbits without sensor noise and with N6 sensor noise model (the worst case).

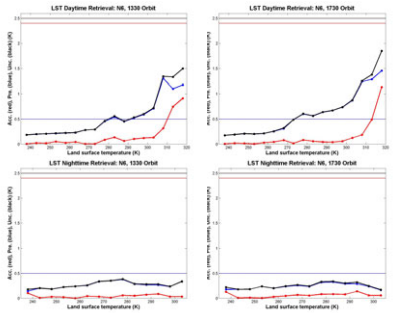
Derive the predicted LST EDR performance on both the NPOESS 1330 and 1730 orbital planes.

Summarize the 4-band dual split window algorithm performance by computing the EDR accuracy, precision, and uncertainty for global average and individual land surface type, and compare to the 2-band split window algorithm (fallback).

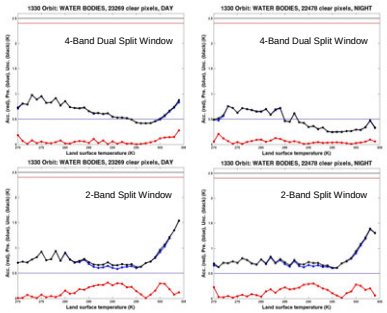
LST EDR Performance Per IGPB Types:



LST EDR Performance for Global Average:



Performance for 4-Band and 2-Band Algorithms:



NPOESS LST Performance on 1330 Orbital Plane with N6 Sensor Noise								
IGBP Land Type	Samples Size		Accuracy (K)		Precision (K)		Uncertainty (K)	
	Day	Night	Day	Night	Day	Night	Day	Night
Evergreen Needleleaf	66	50	0.022	0.060	0.364	0.203	0.364	0.212
Deciduous Broadleaf	160	171	0.005	0.023	0.758	0.231	0.758	0.232
Mixed Forests	103	106	0.031	0.086	0.368	0.202	0.370	0.219
Woody Savannahs	933	680	0.075	0.047	0.552	0.276	0.557	0.280
Savannahs	646	548	0.064	0.069	0.621	0.247	0.625	0.256
Grasslands	148	145	0.047	0.155	0.568	0.256	0.570	0.300
Permanent Wetlands	44	31	1.013	0.467	2.685	0.241	2.874	0.533
Croplands	299	283	0.012	0.079	1.517	0.365	1.517	0.374
Snow Ice	3290	2272	0.019	0.013	0.237	0.222	0.238	0.223
Barren	647	512	0.091	0.141	0.489	0.346	0.497	0.374
Water Bodies	1411	1042	0.082	0.038	0.370	0.301	0.379	0.304
Global	7747	5840	0.012	0.031	0.562	0.283	0.562	0.285

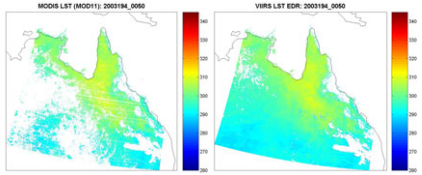
NPOESS LST Performance on 1730 Orbital Plane with N6 Sensor Noise								
IGBP Land Type	Samples Size		Accuracy (K)		Precision (K)		Uncertainty (K)	
	Day	Night	Day	Night	Day	Night	Day	Night
Evergreen Needleleaf	76	0	0.019	-	0.516	-	0.517	-
Deciduous Broadleaf	175	43	0.052	0.055	0.762	0.292	0.764	0.297
Mixed Forests	129	0	0.201	-	0.483	-	0.524	-
Woody Savannahs	681	211	0.233	0.133	0.713	0.292	0.750	0.321
Savannahs	477	178	0.218	0.145	0.804	0.253	0.833	0.292
Grasslands	202	35	0.271	0.269	0.602	0.372	0.660	0.461
Permanent Wetlands	52	0	0.124	-	2.360	-	2.364	-
Croplands	236	119	0.473	0.125	2.107	0.423	2.160	0.442
Snow Ice	2953	2124	0.031	0.023	0.261	0.197	0.626	0.236
Barren	718	103	0.064	0.298	0.626	0.236	0.630	0.381
Water Bodies	1397	381	0.235	0.008	0.461	0.217	0.517	0.217
Global	7096	3194	0.001	0.049	0.690	0.253	0.690	0.258

Testing with Global MODIS Proxy Data

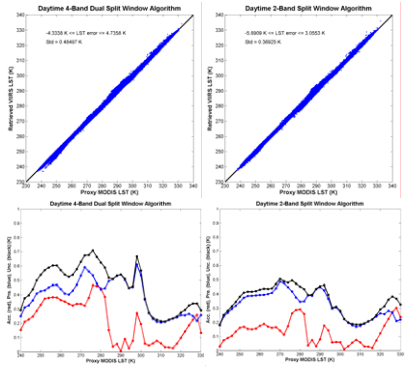
Testing Procedures:

- Fully populate the VIIRS LST regression coefficients using MODIS proxy data constructed from 150 day and 132 night granules.
- Only the best quality MODIS clear pixels with expected error < 0.5 K from nadir to 1.3 km are used.
- Regression coefficients are trained on separate subset of pixels identified by MODIS as > 98% pure IGBP types.
- Algorithm performance is assessed with MODIS majority type pixels.

Retrievals on MODIS Granule MOD2003194_0050:



VIIRS Retrievals Comparison Against MODIS LST:



VIIRS LST Retrievals of Daytime Global MODIS Proxy Data					
IGBP Land Types	Sample Size	Dual Split Window		Split Window	
		µ	σ	µ	σ
Evergreen Needleleaf Forest	142877	0.171	0.311	0.178	0.312
Evergreen Broadleaf Forest	155270	0.096	0.302	0.027	0.288
Deciduous Needleleaf Forest	16374	0.840	0.478	0.294	0.328
Deciduous Broadleaf Forest	97997	0.100	0.279	-0.056	0.280
Mixed Forests	187264	0.201	0.376	0.157	0.357
Closed Shrublands	7529	-0.294	0.316	-0.175	0.300
Open Shrublands	178548	0.371	0.386	0.091	0.371
Woody Savannahs	230295	0.118	0.297	0.031	0.284
Savannahs	305722	-0.270	0.330	-0.126	0.323
Grasslands	294346	0.161	0.364	0.083	0.357
Permanent Wetlands	9591	1.085	0.838	0.475	0.666
Croplands	463272	0.061	0.366	0.028	0.344
Urban Build-Up	12005	0.244	0.410	-0.012	0.356
Croplands/Natural Vegetation Mosaics	95164	-0.033	0.333	0.047	0.326
Snow Ice	197411	0.121	0.079	0.005	0.062
Barren	235399	0.928	0.735	0.147	0.625
Water Bodies	81549	0.122	0.362	0.119	0.364
Global	2710613	0.165	0.485	0.049	0.369

Concluding Remarks

Retrieval results of the NGST global synthetic data showed the VIIRS LST EDR meets accuracy and uncertainty requirements.

Requirement for precision is not likely to be satisfied for LST above 275 K for daytime retrievals due to (real-world) variations in emissivity within each IGBP land surface type.

The predicted accuracy, precision, and uncertainty for the LST EDR based on the NGST global synthetic data are 0.012, 0.562, and 0.562 for daytime retrievals, and 0.031, 0.282, and 0.285 for nighttime, respectively.

LST regression coefficient LUT for 17 IGBP surface types, day and night, 4-band dual split-window and 2-band split window algorithms has been populated based on MODIS proxy data.

Retrieval results show that the pre-launch LST regression coefficient LUT generated from the global MODIS proxy data are a reasonable surrogate until the post-launch cal/val exercise.

Results of testing with proxy data are consistent with those obtained using the NGST global synthetic data.

Results show little degradation in performance using the 2-band split window fallback algorithm comparing to the 4-band dual split window baseline. Split window retrievals are slightly closer to MODIS performance than those of dual split window algorithm.