Using the Model Simulation to Improve the Land Surface Temperature Retrieval for JPSS and GOES-R Missions

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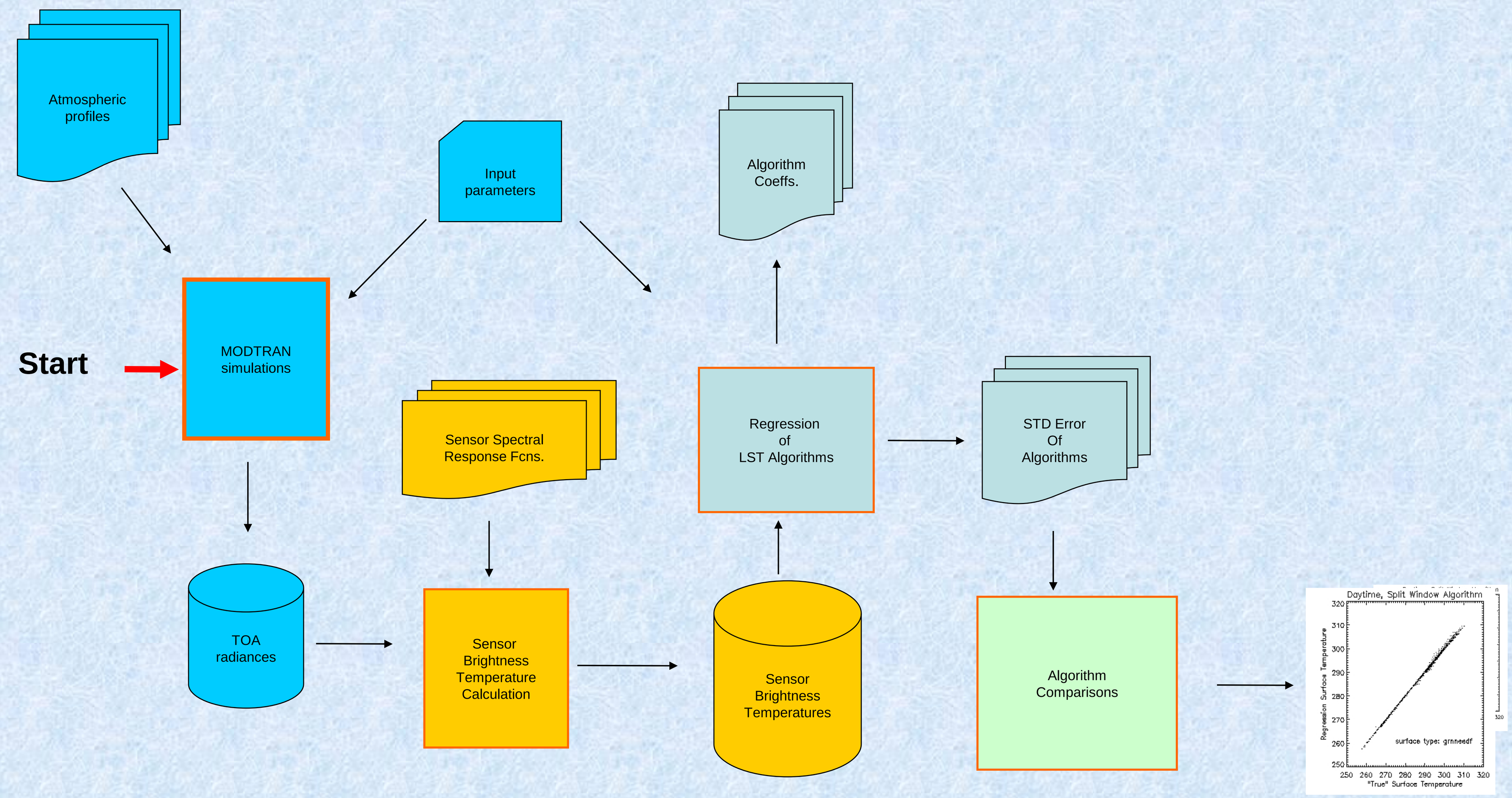
Introduction

Satellite products are being increasingly used in weather and climate prediction systems. Currently, satellite measurements over the ocean have been successfully used to improve numerical weather prediction. However, the utilization of satellite data over land is much less. Land surface temperature (LST) retrievals are more challenging than sea surface temperature retrievals because of surface heterogeneity and the difficulty in simulating surface emissivity. It is important to improve the accuracy of satellite LST product to accelerate its utilization. The radiative transfer model simulations can be used to improve current LST algorithms and test new LST approaches.

Simulation Process and Input Data

In this study, we used the radiative transfer model MODTRAN 5.1 [Berk et al., 2011] to compute the spectral radiance at the top of the atmosphere (TOA). The model input parameters include the vertical profiles of atmospheric properties, the boundary surface temperatures, sensor view angles and solar geometry, as well as the surface emissivity. Here we only consider the high-quality and cloud-free pixels. We selected 126 cloud-free profiles (60 profiles for daytime and 66 profiles for nighttime) as model input. The daytime profiles were typically collected near 10:00 and 15:00 local time, and nighttime profiles near 04:00 and 20:00 local time. To cover a range of environmental conditions, we prescribed a set of LSTs (T_{min} < LST < T_{max}) based on each profile's boundary surface skin temperature T_{skin} and surface air temperature T_{air}. This LST range [T_{min}, T_{max}] defines a conservative set of realistic surface conditions for a given atmospheric state. The view zenith angle is set to be {0.01°, 10.0°, 20.0°, 30.0°, 40.0°, 50.0°, 60.0°, 70.0°}. Solar zenith angles were computed from the time and location of the profiles. In order to cover all surface types, we run the model for the surface emissivity range [0.90, 1.0] with increment of 0.0025 to get the TOA radiance output. Later MODIS emissivity data would be used to generate the emissivity pairs in split-window bands for each IGBP surface type. The radiance data sets are selected according to the emissivity pairs.

Flowchart for VIIRS LST Algorithm Development



Emissivity Determination Process

The emissivity is very important for surface temperature retrieval and validation. MODIS monthly emissivity data and MODIS Land Cover Type data from 2001 to 2012 were analyzed in order to build up the emissivity pairs to represent 17 IGBP surface types. Here we used the MODIS bands 31 and 32 which are spectrally closest to VIIRS bands M15 and M16, respectively. The type-dependent emissivities in MODIS bands 31 and 32 along with their standard deviations for each IGBP were analyzed (E.g., Figure. 1). The standard deviation of type-averaged emissivity in each month are very small, so 12 monthly type-dependent emissivities can be used to represent the emissivity variation within each IGBP type.

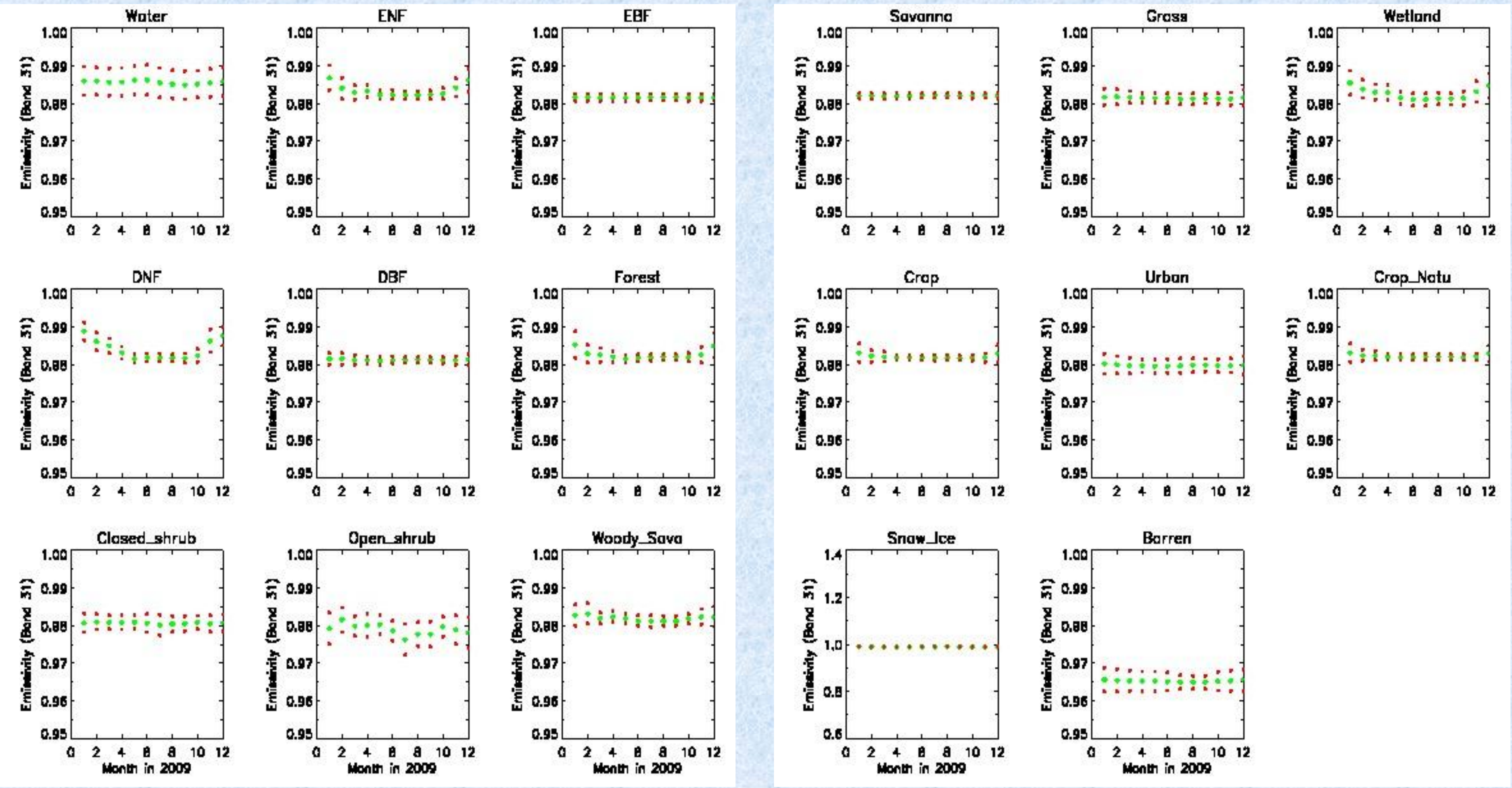


Figure 1. Type-averaged emissivity and their standard deviation for IGBP 0 -16 in band 31. Green: average value; Red: average ± std.

LST Algorithm Coefficients Retrieval

The TOA spectral radiance from MODTRAM output can be converted to the brightness temperature using the Spectral Response Function (SRF) of different sensors. Figure 2. The SRFs from VIIRS, MODIS, and GOES-R.

Band central wavelength:

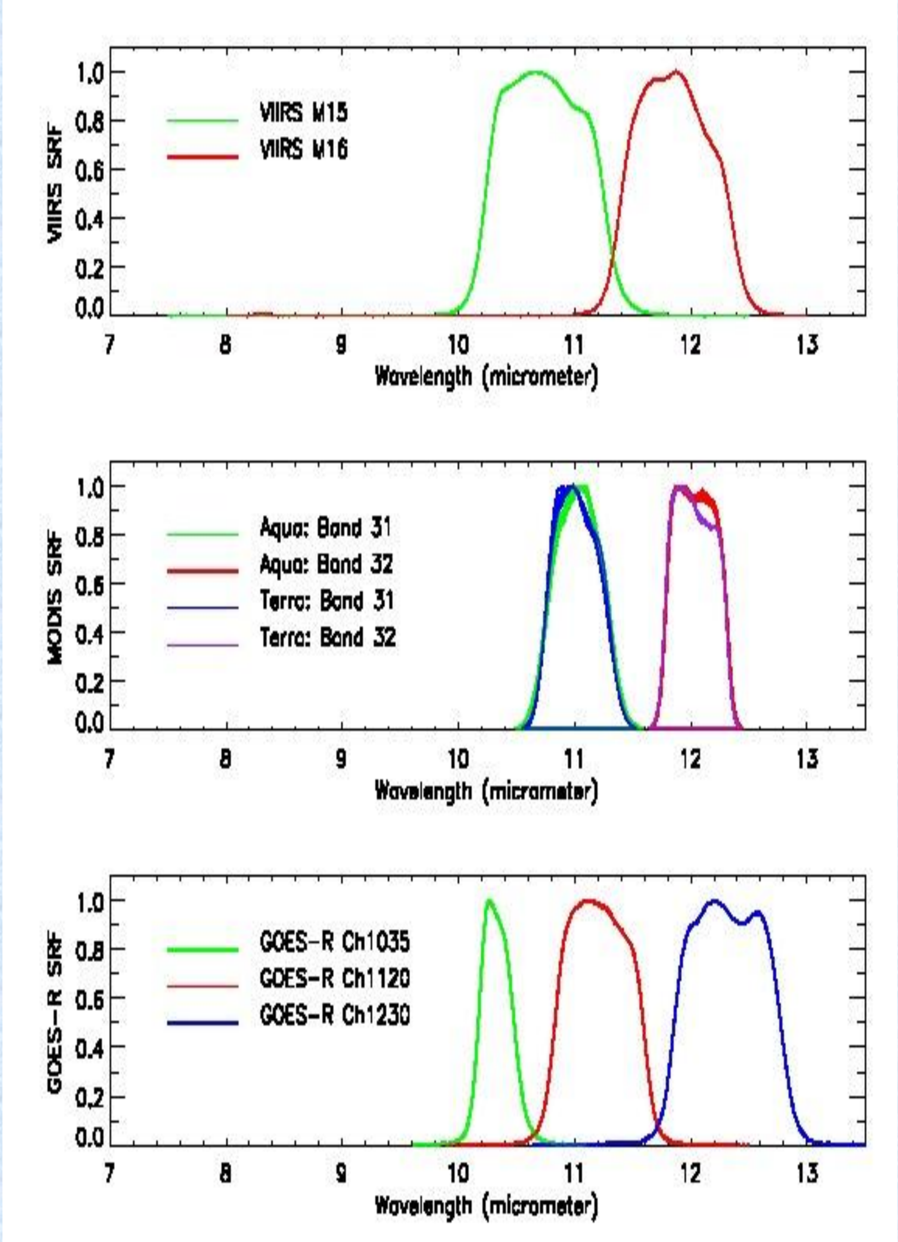
$$\lambda_0 = \frac{\int_{\lambda 1}^{\lambda 2} \lambda \cdot SRF(\lambda) d\lambda}{\int_{\lambda 1}^{\lambda 2} SRF(\lambda) d\lambda}$$

Sensor received radiance:

$$B(T, \lambda_0) = \frac{\int_{\lambda 1}^{\lambda 2} I(\lambda) \cdot SRF(\lambda) d\lambda}{\int_{\lambda 1}^{\lambda 2} SRF(\lambda) d\lambda}$$

Brightness temperature:

$$T = \left(\frac{hc}{k\lambda_0}\right) \frac{1}{\ln\left[\frac{2hc^2}{\lambda_0^5 \cdot B(T, \lambda_0)} + 1\right]}$$



The algorithm coefficients can be determined by regressing the simulated brightness temperatures. Two types of LST algorithms were tested:

(1) Emissivity implicit algorithm used by VIIRS:

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

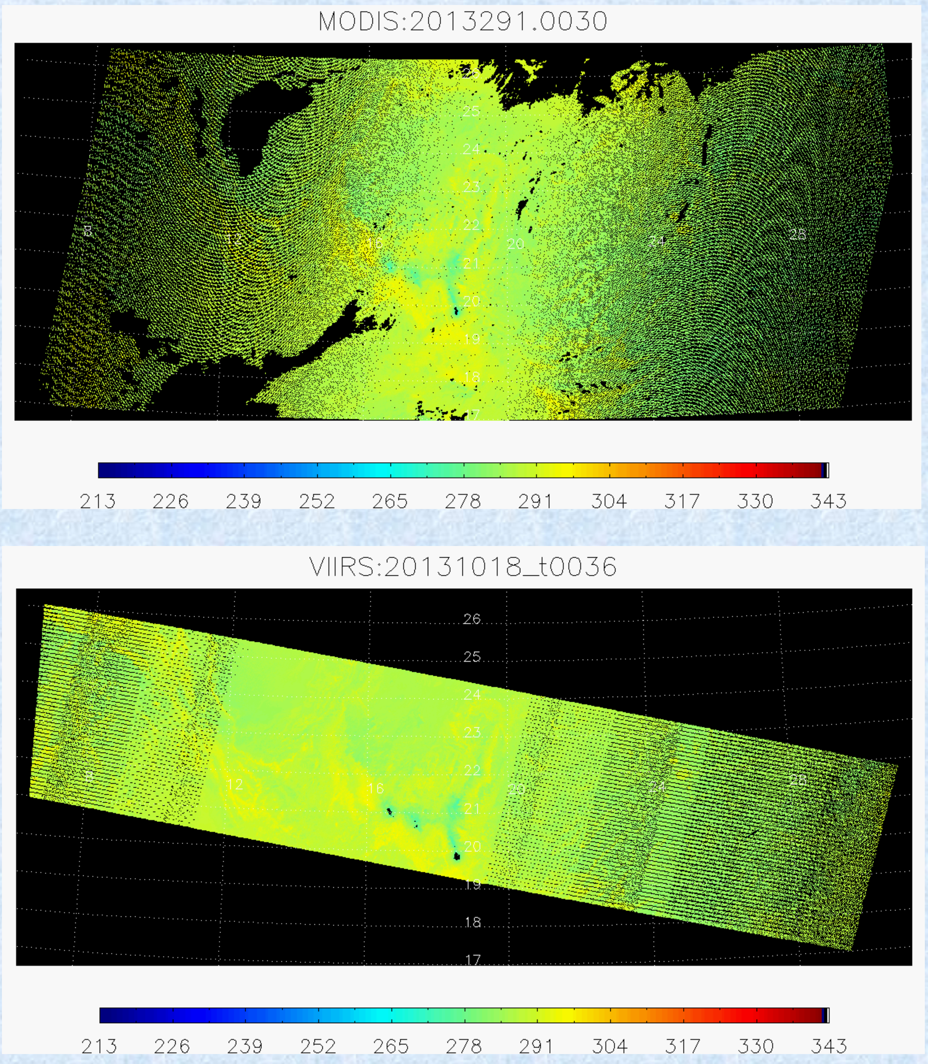
Where a_i denotes coefficients, i denotes the term's sequential position in the equation. For each surface type, there is a set of coefficients. T_{11} and T_{12} are the brightness temperatures of VIIRS bands M15 and M16, respectively. θ is view zenith angle.

(2) Emissivity explicit algorithm used by GOES-R Advanced Baseline Imager (ABI):

$$T_s = C + A_1 T_{11} + A_2 (T_{11} - T_{12}) + A_3 \varepsilon + D (T_{11} - T_{12})(\sec\theta - 1)$$

Where T_{11} and T_{12} are the brightness temperatures of ABI channels 14 and 15, respectively. $\varepsilon = (\varepsilon_{11} + \varepsilon_{12})/2$, where ε_{11} and ε_{12} are the spectral emissivity values of ABI channels 14 and 15, respectively. C, A_1, A_2, A_3, A_4 and D are algorithm coefficients.

Currently all simulated brightness temperature data sets use same weighting factors in regression process. We have tested the impact of filters and weighting factors on the regression results. E.g., we give high weights to the data pairs over reference temperatures, but give low weights to the data pairs which are away from the reference temperature. The results indicate that the filters can improve the standard deviations and maximum absolute bias, but the weighted regression does not affect the standard deviations and algorithm coefficients too much.



MYD11_L2, MODIS/Aqua Land Surface Temperature 5-Minute L2 Swath at 1 km is used as a reference for the cross satellite evaluation over North east Africa on Nov.15, 2013 for nighttime cases.

Top: MODIS /Aqua LST
Bottom: VIIRS LST

For more evaluations of our new LUT, please refer to AMS poster:

(Liu et al. 2014) Evaluation of the Suomi NPP VIIRS Land Surface Temperature Product .

Conclusions

The model simulation is a very useful tool, which can be used to test and improve our existing LST algorithms, as well as develop algorithms for new satellites. There are still some space to further improve LST algorithms. For example, new emissivity pairs can be re-built with higher resolution emissivity data, further correction for water vapor absorption, and extending the temperature ranges by using more atmospheric profiles. These tests can be performed using the model simulation tools.