# Correcting Satellite Derived Infrared $SST_{skin}$ Considering Aerosol Vertical Distribution


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## Abstract

Infrared satellite observations of skin sea surface temperature ($SST_{skin}$) have become essential for many applications in meteorology, climatology, and oceanography. Tropospheric aerosol concentrations increase infrared signal attenuation and affect the accuracy of infrared satellite $SST_{skin}$ retrievals. Satellite-derived $SST_{skin}$ derived from measurements of the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) and quality-controlled, collocated subsurface drifter temperatures provide data to assess the accuracy of satellite-derived $SST_{skin}$. We used a suite of satellite retrievals and reanalysis data to study the effects of dust aerosol vertical distributions and properties on the retrieval of $SST_{skin}$ from MODIS, of particular importance are the vertical aerosol data resolved by the CALIOP lidar on the Cloud–Aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO) and the NASA Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA-2). Analysis of the results has been aided by numerical RTTOV simulations of the infrared radiative transfer through the atmosphere. In the region off W. Africa in the Saharan outflow area, $SST_{skin}$ retrieved from MODIS generally has cool biases compared to in-situ shipboard radiometric measurements. Dust present at different altitudes has varying effects on the $SST_{skin}$ retrieval. The aerosol introduced colder air temperature anomaly between 700 and 500 hPa introduces more negative bias. The goal of this study is to understand better the characteristics of vertical aerosol effects on satellite retrieved infrared $SST_{skin}$, and to derive empirical formulae for improved accuracies of IR-derived $SST_{skin}$ in aerosol-contaminated regions.


## 1. Motivation

- Knowledge of the accuracy of the SST derived from satellite measurements and models is one of the key factors of climate research and prediction.
- The SST accuracy requirements for climate research are very stringent: ~0.1K.
- But high tropospheric aerosol concentrations in the atmosphere significantly increase infrared signal attenuation and prevent the accurate retrieval of SSTs.
- To assess the impact of aerosols we compare SSTs from multiple sources.

## 2. Data & $SST_{skin}$ Validation

➢ **Shipboard SST dataset: M-AERI and Drifters**

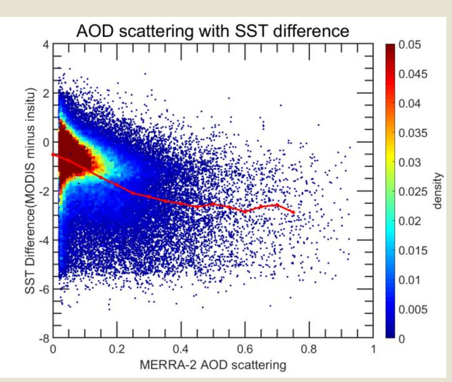
- *The M-AERI is an accurate, self-calibrating, Fourier transform IR spectro-radiometer that measures emission spectra from the sea and atmosphere (Minnett et al. 2001).*
- *RSMAS MUDB available from NASA SEABASS*

➢ **Satellite SST dataset: *MODIS AQUA***

- *Daily L2 SST products from the Long-Term Stewardship and Reanalysis Facility of Group for High Resolution Sea Surface Temperature (GHRSST). Daytime SSTs: MOD28L2/MYD28L2.*
- *The thermal-infrared $SST_{skin}$ was retrieved by nonlinear $SST_{skin}$ algorithms.*
- Spatial resolution: 0.01°
- Temporal resolution: Twice a day

➢ **Model simulation dataset: *MERRA-2 and RTTOV***

- *NASA Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) are used.*
- *Radiative Transfer for TOVS (RTTOV) is a fast-radiative transfer model developed by the EUMETSAT NWP Satellite Application Facility.*




| AOD | For the MODIS AQUA Match-up data (℃ ) | | | | | |
|---|---|---|---|---|---|---|
| | Number | Min (K) | Max (K) | Median (K) | Mean (K) | STD (K) |
| 0-0.2 | 3079 | -4.73 | 2.10 | -0.28 | -0.36 | 0.56 |
| 0.2-0.4 | 775 | -4.33 | 1.83 | -0.54 | -0.70 | 0.80 |
| 0.4-0.6 | 253 | -4.71 | 1.63 | -0.98 | -1.15 | 0.96 |
| 0.6-0.8 | 78 | -3.47 | 0.66 | -1.50 | -1.48 | 0.89 |
| >0.8 | 38 | -4.39 | 1.44 | -1.80 | -1.71 | 1.24 |
| Total | 4223 | -4.73 | 2.10 | -0.36 | -0.50 | 0.70 |

Left: SST differences (MODIS SST- in-situ SST) with MERRA-2 Aerosol Optical Depth. Scatter plot colored by density of points. Right: Statistics of errors of AQUA SST. When AOD > 0.4, the mean $SST_{skin}$ difference can be larger than 1 K.

**Difference between Aqua MODIS SST with in-situ drifting buoys SST**

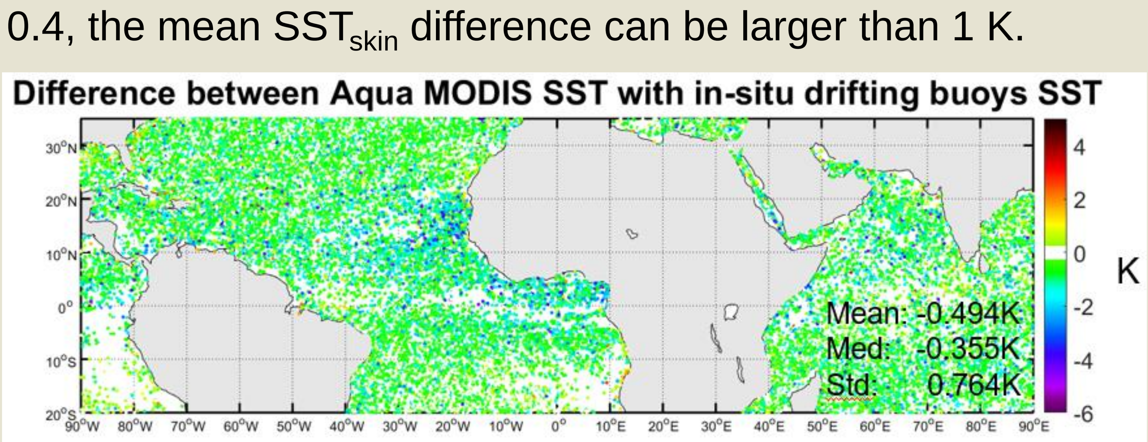
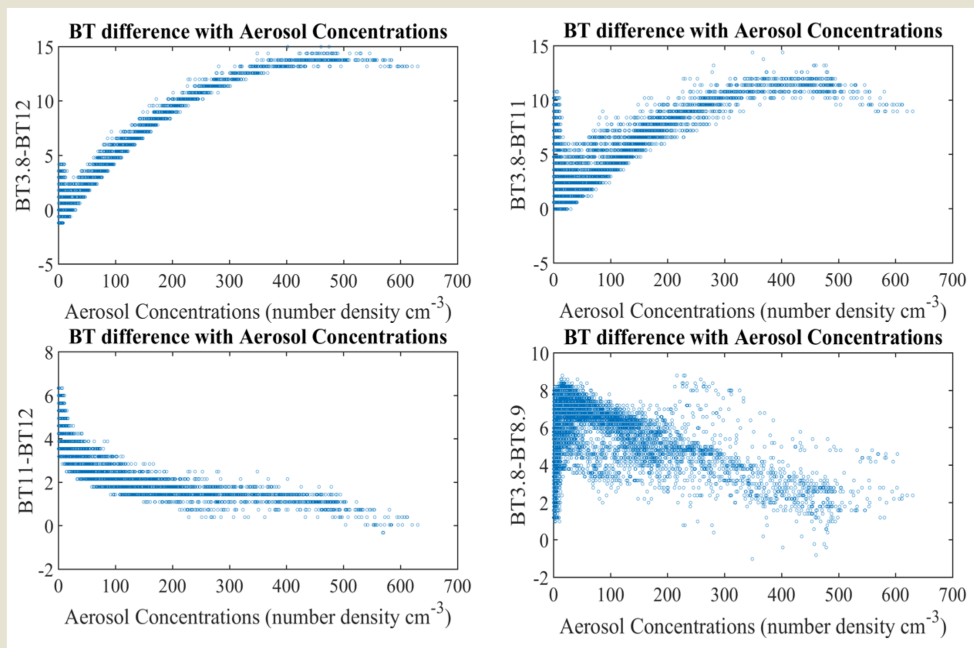



Figure: MODIS Aqua SST difference near the Saharan Outflow area, the quality flag values of MODIS Aqua are 0, 1 and 2. After match-up with in situ SST, the MODIS nighttime $SST_{skin}$ data has a mean error of −0.494 K in this region. The strong Saharan Outflow area 0° N to 25° N and 40° W to 10° E, which has a mean error of −0.772 K.

## 3. RTTOV Model Simulations

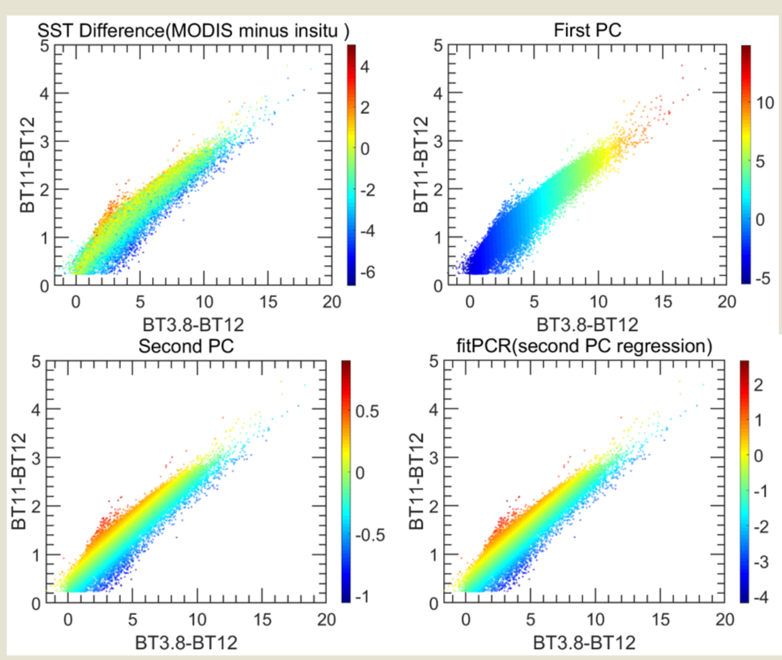
- Surface pressure: 1013hPa
- 1km mineral aerosol at 1013hPa 975hPa 937hPa 898hPa
- MERRA-2 SST and AOD as Input




$$DSDI = a + (b + c \times S_0) \times (BT_{3.8} - BT_{12}) + (d + e \times S_0) \times (BT_{3.8} - BT_{8.9}) + (f + g \times S_0) \times (BT_{11} - BT_{12}) + (h + i \times S_0) \times (BT_{11} - BT_{12})^2 + [\alpha\sqrt{x} + \beta]$$

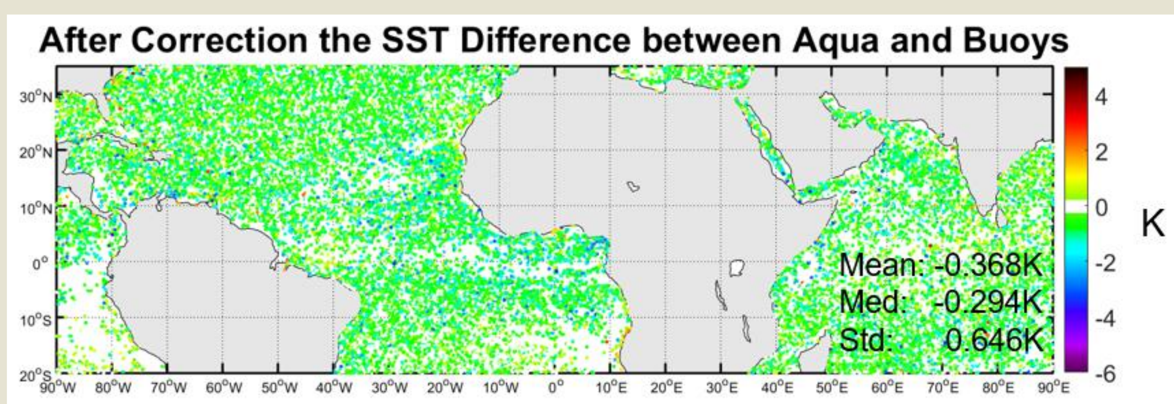
*$S_0$ = sec(Θ)-1 The coefficients are derived by regressions on the BT difference and SST Difference. α and β are determined by regressing SST difference with MERRA-2 columnar AOT.*

## 4. MODIS $SST_{skin}$ Correction




Scatter plot of the $SST_{skin}$ difference with BT3.8-BT12 and BT11-BT12, color means the $SST_{skin}$ difference, it can be used to represent the aerosol introduced $SST_{skin}$ difference based on Principal component (PC) analysis (PCA) method.

**After Correction the SST Difference between Aqua and Buoys**

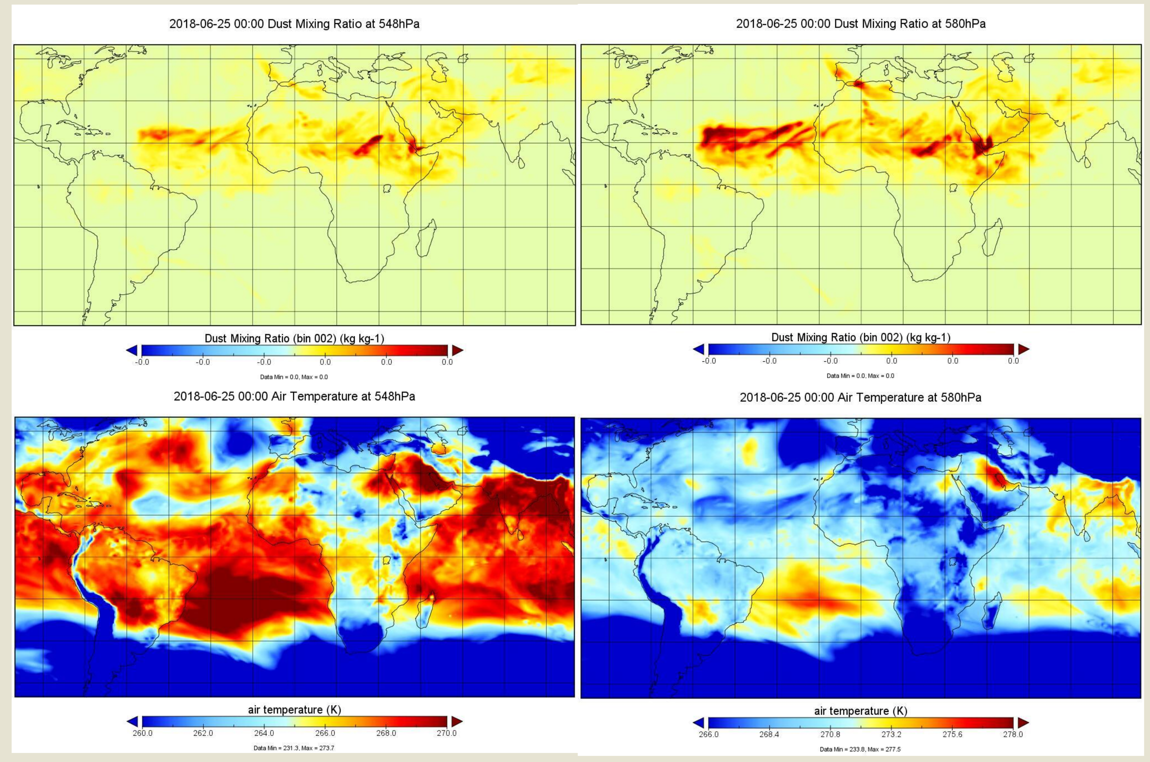



*Difference between Aqua MODIS $SST_{skin}$ with in situ buoy SST after correction. The mean $SST_{skin}$ difference has decreased by 0.263 K. There are a few $SST_{skin}$ differences below -2 K after correction.*

| Quality Level | N | Before correction | | | After correction | | |
|---|---|---|---|---|---|---|---|
| | | Mean | Median | STD | Mean | Median | STD |
| 0 | 86092 | -0.217 | -0.190 | 0.458 | -0.175 | -0.100 | 0.407 |
| 1 | 47030 | -0.482 | -0.435 | 0.649 | -0.215 | -0.120 | 0.587 |
| 2 | 50919 | -0.974 | -0.830 | 1.003 | -0.342 | -0.261 | 0.778 |
| Total | 184041 | -0.494 | -0.355 | 0.764 | -0.231 | -0.295 | 0.598 |

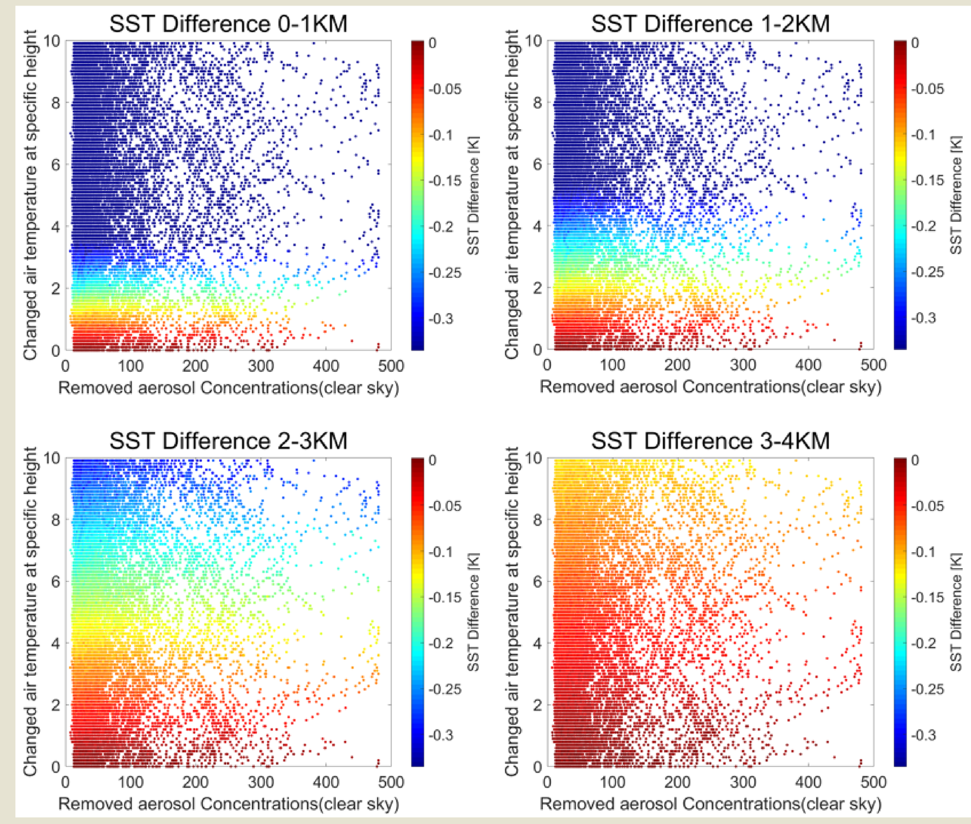
*Table:Error statistics according to MODIS quality flag*

## 5. Aerosol cooling effect

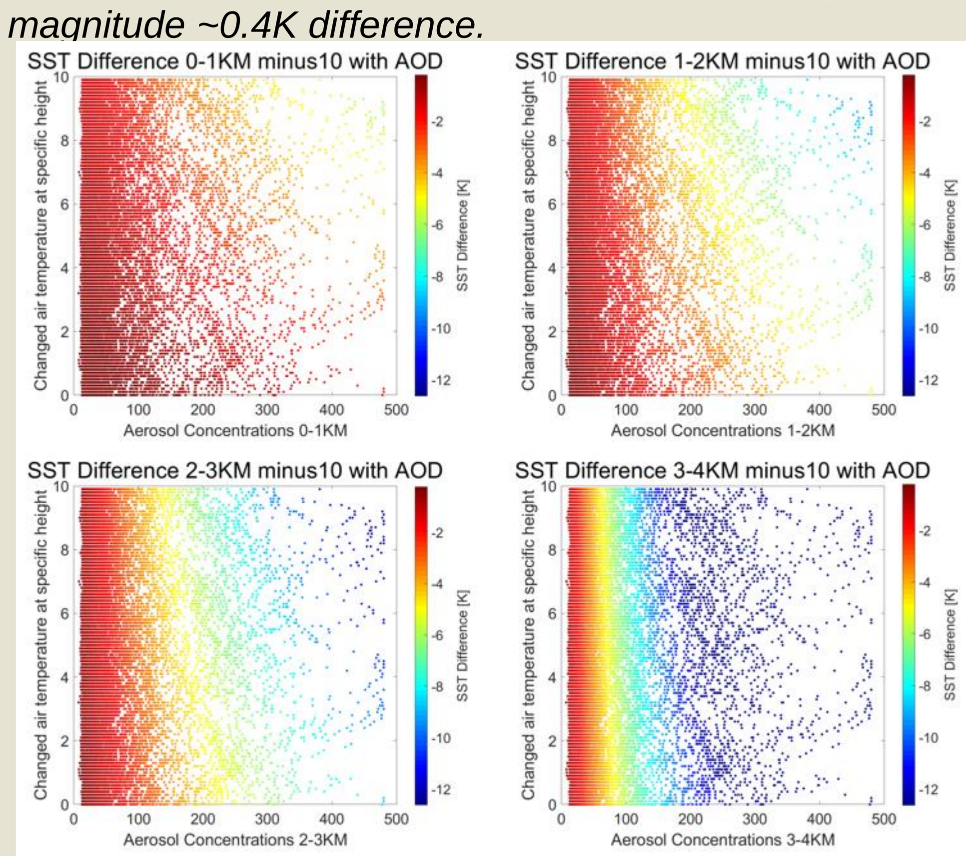



The MERRA-2 air temperature data from polluted days reveals a colder anomaly between 700 and 500 hPa due to aerosols.

## 6. RTTOV Simulation




*Figures: Without Aerosol Just change the temperature of the layer. SST difference is sensitive to lower layer temperature change. There is only small magnitude ~0.4K difference.*




*Figures: Put Aerosol and change the temperature of the layer. SST difference is sensitive to aerosol altitude and layer's temperature.*

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## 8. References


- Luo, Bingkun, et al. "Improving satellite retrieved night-time infrared sea surface temperatures in aerosol contaminated regions." Remote Sensing of Environment 223 (2019): 8-20.
- Merchant, C. J., et al. "Saharan dust in nighttime thermal imagery: Detection and reduction of related biases in retrieved sea surface temperature." Remote Sensing of Environment 104.1 (2006): 15-30.
- Minnett, Peter J., et al. "The marine-atmospheric emitted radiance interferometer: A high-accuracy, seagoing infrared spectroradiometer." Journal of atmospheric and oceanic technology 18.6 (2001): 994-1013.
- Nalli, Nicholas R., et al. "Multiyear observations of the tropical Atlantic atmosphere: Multidisciplinary applications of the NOAA Aerosols and Ocean Science Expeditions." Bulletin of the American Meteorological Society 92.6 (2011): 765-789.