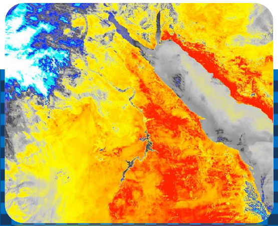

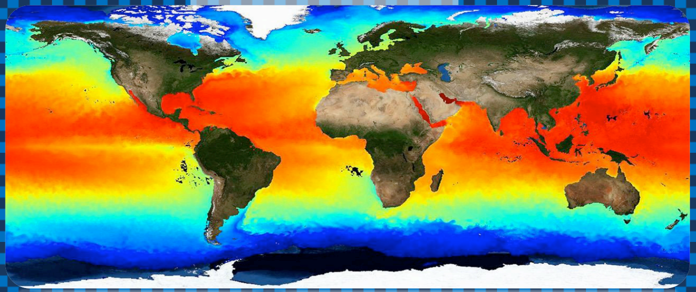

Improving Satellite Retrieved Infrared Sea Surface Temperatures in Aerosol Contaminated Regions

19th International GHRSST Science Team Meeting

Bingkun Luo and Peter J. Minnett

Rosenstiel School of Marine and Atmospheric Science
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CONTENTS

01

PART ONE

Introduction and Data

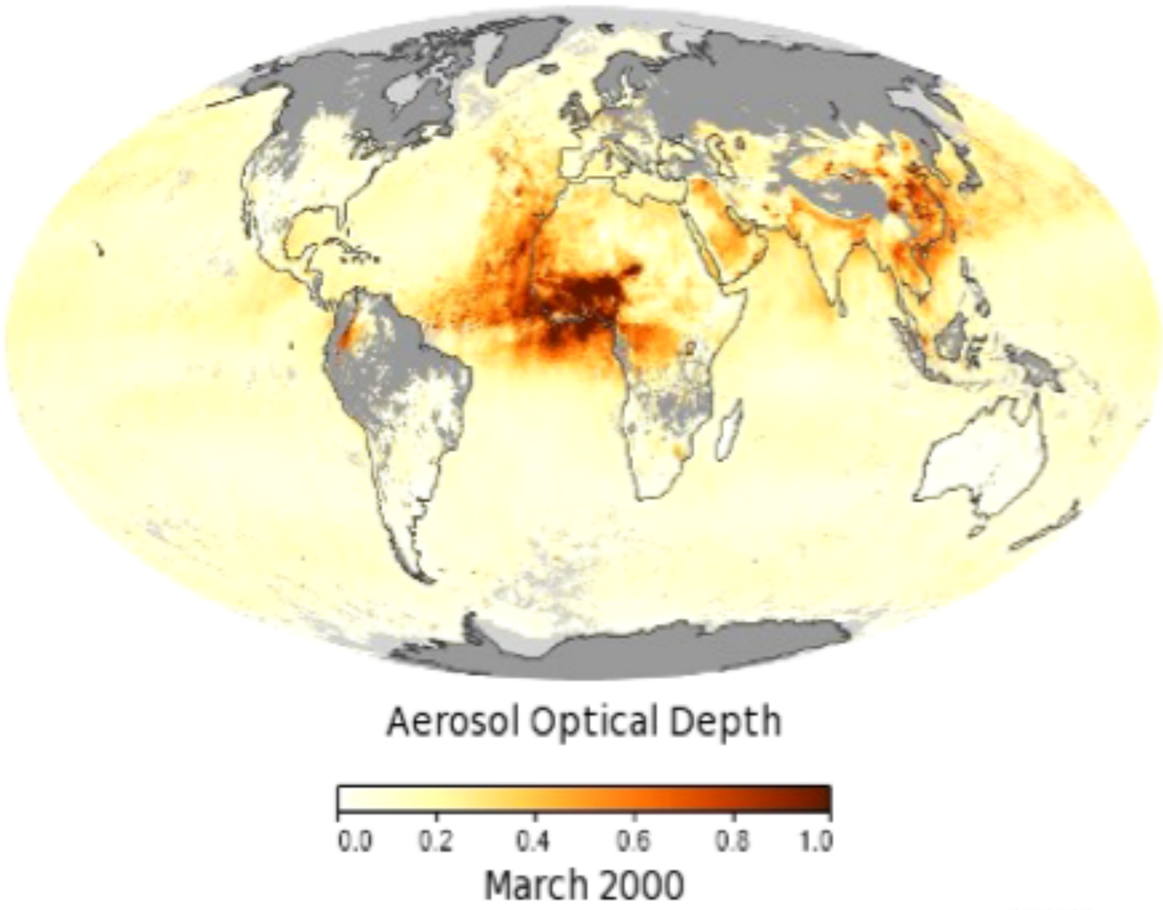
Significance of this study

- The accuracy of the Sea Surface Temperature (SST) derived from satellite measurements 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 retrieval of accurate satellite SSTs.
- Therefore, it is important to quantify the errors and uncertainties of SST and obtain highly accurate satellite derived SST.

This proposed research addresses the following questions:

- How are the errors in SSTs dependent on the aerosol properties?
- How can we improve the atmospheric correction algorithm in aerosol contamination regions to reduce significantly the SST errors?

Analysis fields



Our Analysis fields:
Latitude: 20° S to 35° N
Longitude : 100° E to 100.0° W

Period: From 2006 to 2015

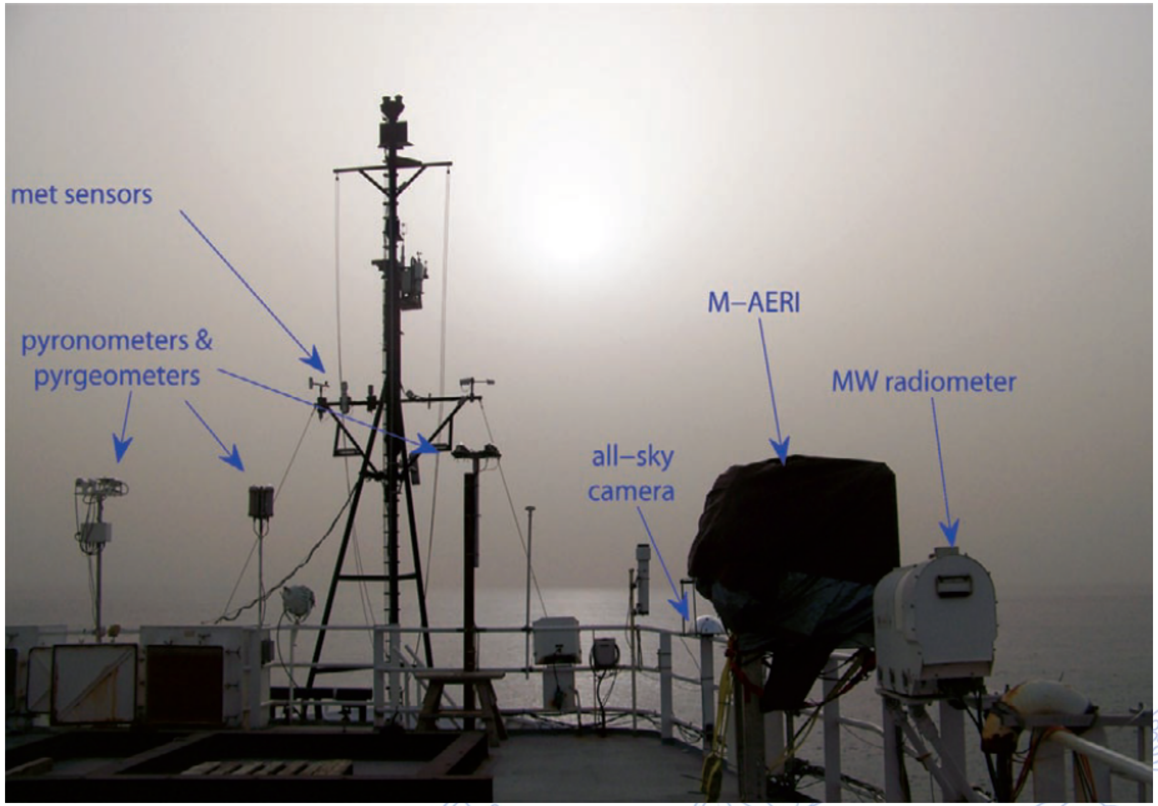
From NASA Earth Observations (NEO):
https://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MODAL2_M_AER_OD

Shipboard SST dataset

The M-AERI is an accurate, self-calibrating, Fourier transform IR spectroradiometer that measures emission spectra from the sea and atmosphere (Minnett et al. 2001).

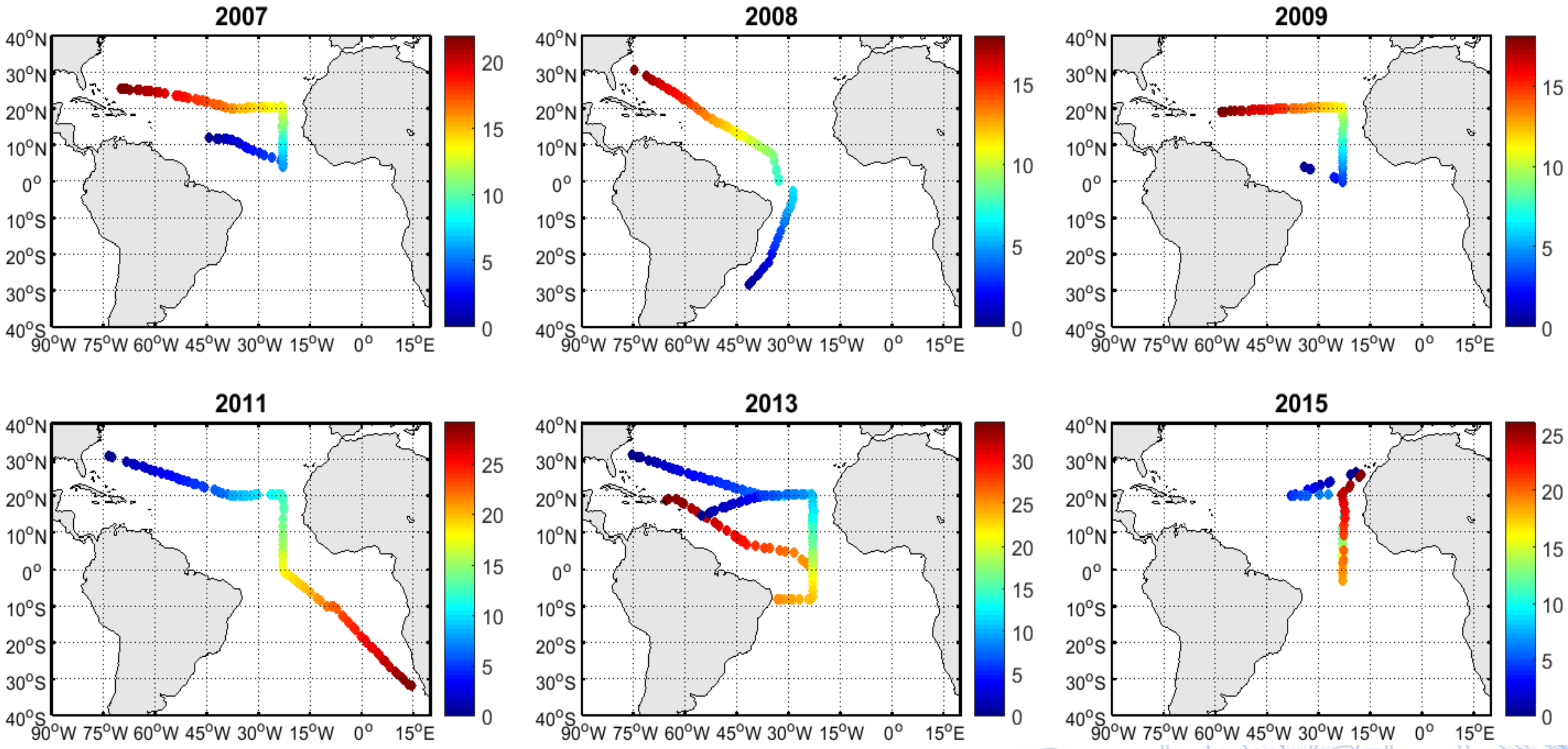
Cruise Details:
2006: May.22th to Jul.15th *2007: May.01st to May.31th*
2008: Apr.29th to May.19th *2011: Jul.21th to Aug.20th*
2013: Jan. 9th to Feb.13th *2015: Nov.17th to Dec.14th*

NOAA Ship R.H.B at Florida. Mar 2 2018



Unenhanced digital color photograph of the forward level-2 of the Ronald H. Brown, taken while holding station along 23°W longitude during PNE/AEROSE-III, on the afternoon of 13 May 2007, during the major Saharan dust outflow pulse. (Nalli et al. 2011).

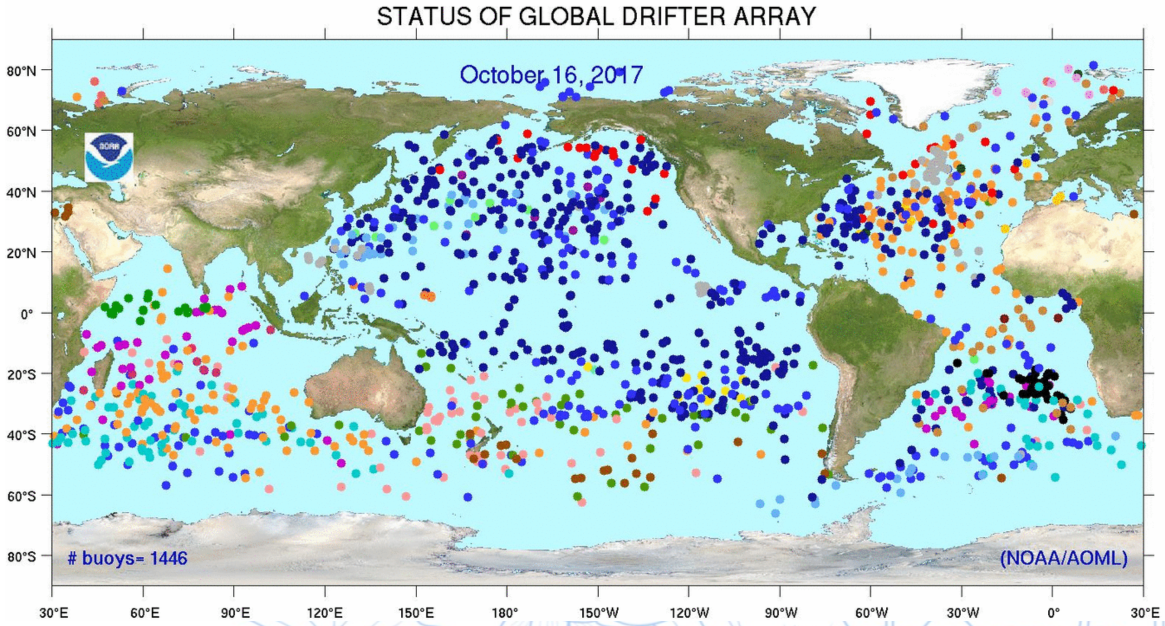
Aerosols and Ocean Science Expeditions (AEROSE) tracks



Color indicates the days since departure

Drifting buoys SST dataset

The data is from GDP Drifter Data Assembly Center (NOAA). NOAA established the in situ sea surface temperature (SST) Quality Monitor (iQuam) to support the validation (Cal/Val) of satellite and blended SST products (Xu and Ignatov, 2016). IQuam consists of quality-controlled measurements from drifters, moored buoys and ships.

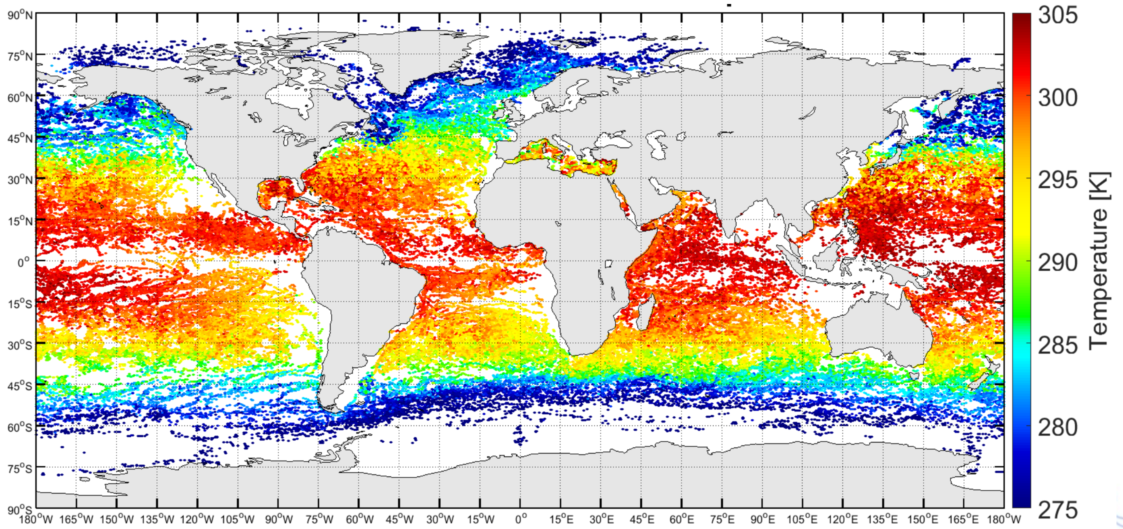


MODIS SST datasets

The MODIS Aqua SST dataset is an L2 product from NASA Jet Propulsion Laboratory (JPL) and GHRSST. It consists of geophysical variables at the same resolution as the source of reconstructed, unprocessed instrument data at full resolution, time-referenced and annotated with ancillary information.
(ftp://podaac.jpl.nasa.gov/allData/ghrsst/data/L2P/MODIS_A/JPL/2015/)

Details:

- Spatial resolution:0.01° .
- Area: 20° S to 35° N
  100° E to 100.0° W
- Temporal resolution: Twice a day.
  Satellite overpass time (SOT) is at about 2:00 AM and 14:00 PM LST.
- The co-location Match-up criteria
  10 km distance and within 30 mins.



RTTOV (Radiative Transfer for TOVS) simulations

MERRA2 Input
2m T 2m Q Sea Surface Temperature 10m V 10m U
Dust Mixing Ratios at each layer as kg/kg
Air temperature Specific humidity Relative humidity
Dust scattering AOD at 550nm
72 Layer data

The conversion of the aerosol mixing ratio (q_i) of aerosol type i in number concentration (N_i) is given by:

$$N_i = q_i \frac{10^2 P}{R_{moist} T M_i^*}$$

P is the atmospheric pressure in hPa, T is the atmospheric temperature in K and R_{moist} is the moist air gas constant. The conversion term $M_i=1.59*10^{-5}$ $gm^{-3}/part.cm^{-3}$

RTTOV
1 km aerosol layer at different bottom pressure levels
Mineral aerosol type
Surface Pressure as 1013hPa
Aerosol concentration
51 Layer data

Vidot, J. (2017, March 6). Note on RTTOV v12 unit conversions for gases, clouds and aerosols. Retrieved May 25, 2017, from https://nwpsaf.eu/site/download/documentation/rtm/docs_rttov12/rttov_gas_cloud_aerosol_units.pdf

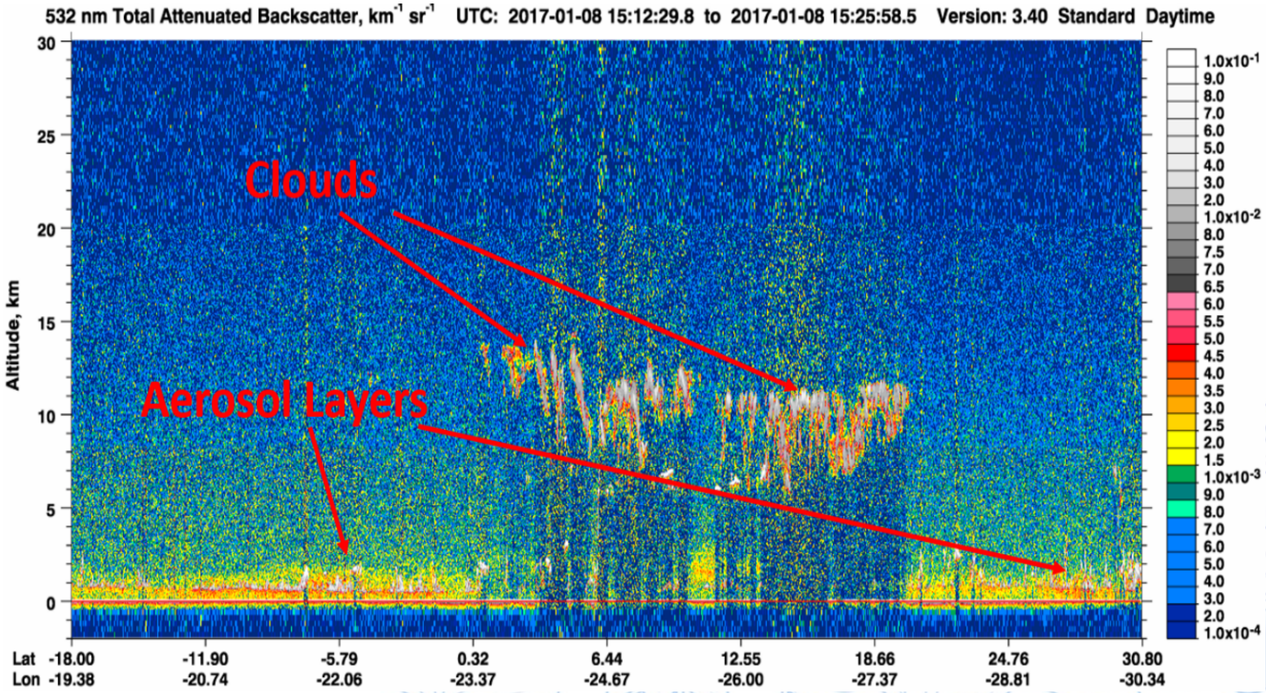
CALIPSO datasets

To study the vertical structure of aerosols, Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observation (CALIPSO) datasets were used. LIDAR data from Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is particularly suitable for measuring the characteristics and physical mechanisms of aerosol layers.

CALIPSO provides:

- column aerosol optical depth.
- column integrated attenuated backscatter.
- layer base and top altitudes.
- number of layers.

The CALIPSO data are limited to measurements along the sub-satellite track as the LIDAR is directed at nadir.

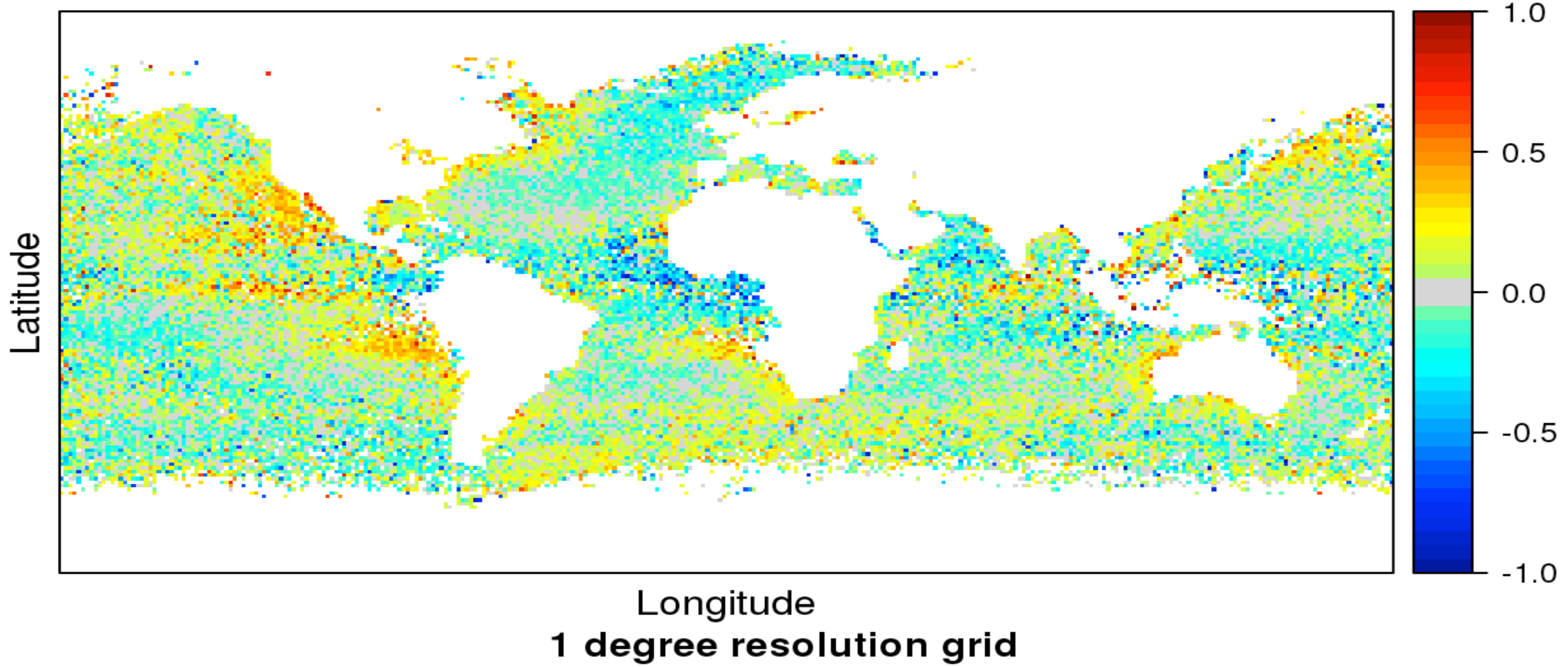


02

PART TWO

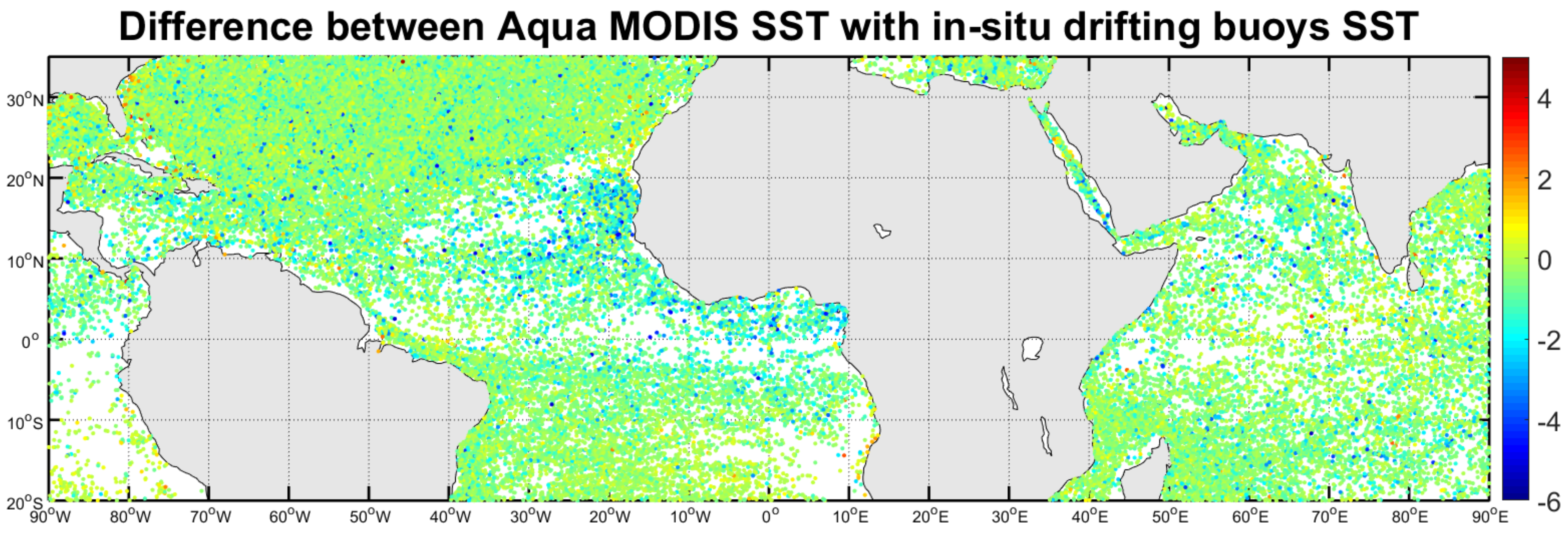
MODIS SST Validation

For MODIS Aqua



Distribution of MODIS SST errors based on matchups with in-situ drifting buoys measurements. (Minnett et al. 2016).

There is a pronounced negative bias in the Saharan outflow area.



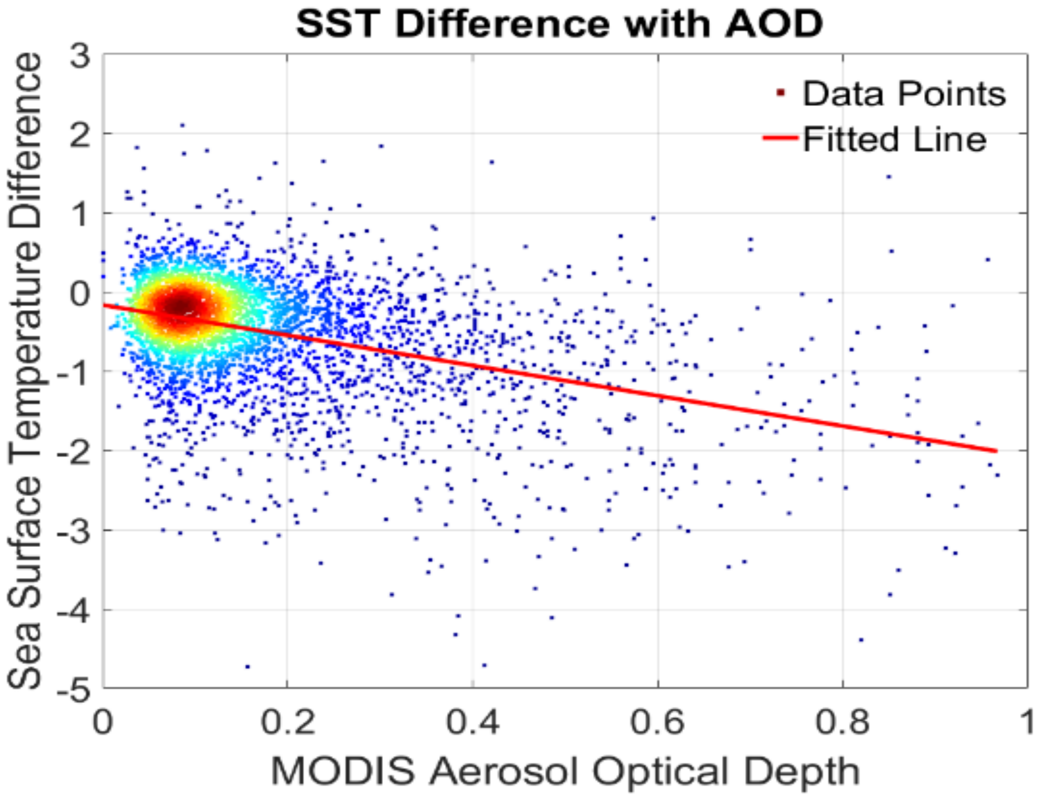
MODIS Aqua SST Difference near Saharan Outflow area, the quality flag values of MODIS Aqua are 0, 1, 2.

The match-ups are collected where the distance of in situ measurement to the nearest pixel being less than 10 km, and the time difference between the satellite and in-situ data is less than 30 minutes. All satellite SST and brightness temperatures are referenced to a 3x3 pixel extraction box (Kilpatrick et. al, 2015).

Statistics of the error between MODIS Aqua SST and In-situ SST

year	For the Matchup Databases			
	Number of matchups	Mean (°C)	STD (°C)	Percentage of total
2010	32896	-0.516	0.759	17.87%
2011	35946	-0.502	0.747	19.5%
2012	29441	-0.509	0.804	15.99%
2013	38637	-0.467	0.759	20.99%
2014	14300	-0.460	0.761	7%
2015	32821	-0.495	0.756	17.8%
Total	184041	-0.494	0.764	100%

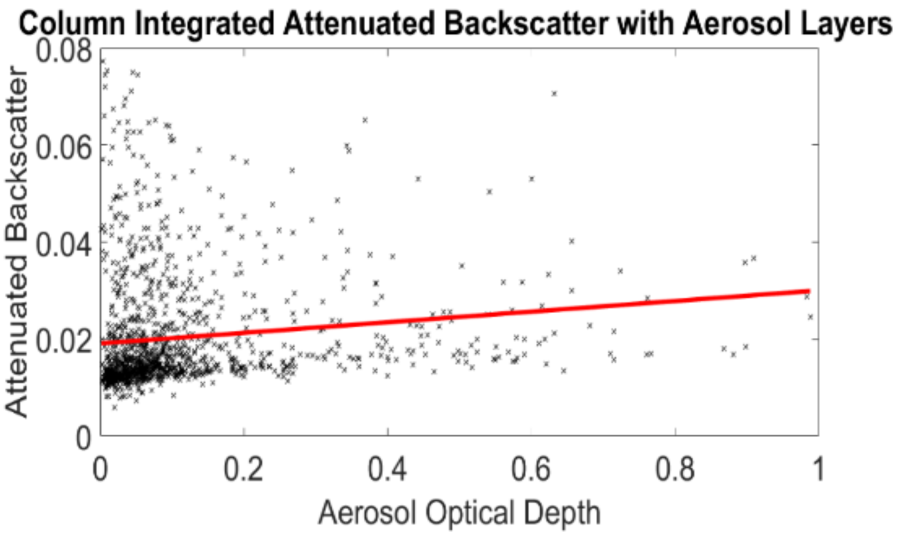
- The mean errors and STD are evenly throughout in my research area for 2010-2015.
- We randomly selected 80% of the data to derive MODIS dust correction algorithms.
- 20% of the data to validate the approach.



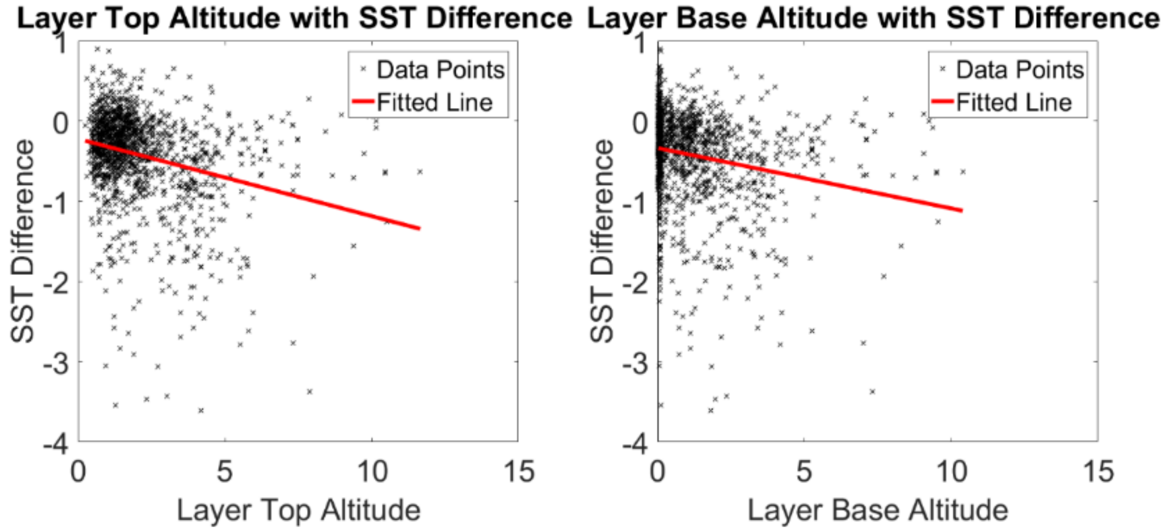
MODIS AOD	For the 2015 Match-up data (℃)					
	N	Min	Max	Median	Mean	STD
0-0.2	3079	-4.73	2.10	-0.28	-0.36	0.56
0.2-0.4	775	-4.33	1.83	-0.54	-0.70	0.80
0.4-0.6	253	-4.71	1.63	-0.98	-1.15	0.96
0.6-0.8	78	-3.47	0.66	-1.50	-1.48	0.89
>0.8	38	-4.39	1.44	-1.80	-1.71	1.24
Total	4223	-4.73	2.10	-0.36	-0.50	0.70

Left: SST differences (MODIS Aqua SST - in-situ SST) with MODIS Aerosol Optical Depth, colored by density of points. The red line is the fitted line.

Right: Statistics of errors of MODIS Aqua SST vs AOD.



Column Integrated Attenuated Backscatter with Aerosol Optical Depth from CALIPSO, the fitted red line clearly shows the aerosol in the atmosphere will attenuate backscatter signal.



MODIS SST_{skin} Difference with CALIPSO Layer Altitudes (Left: Top Altitude. Right: Base Altitude).

The CALIPSO co-location Match-up criteria: 10 km distance and within 30 mins.

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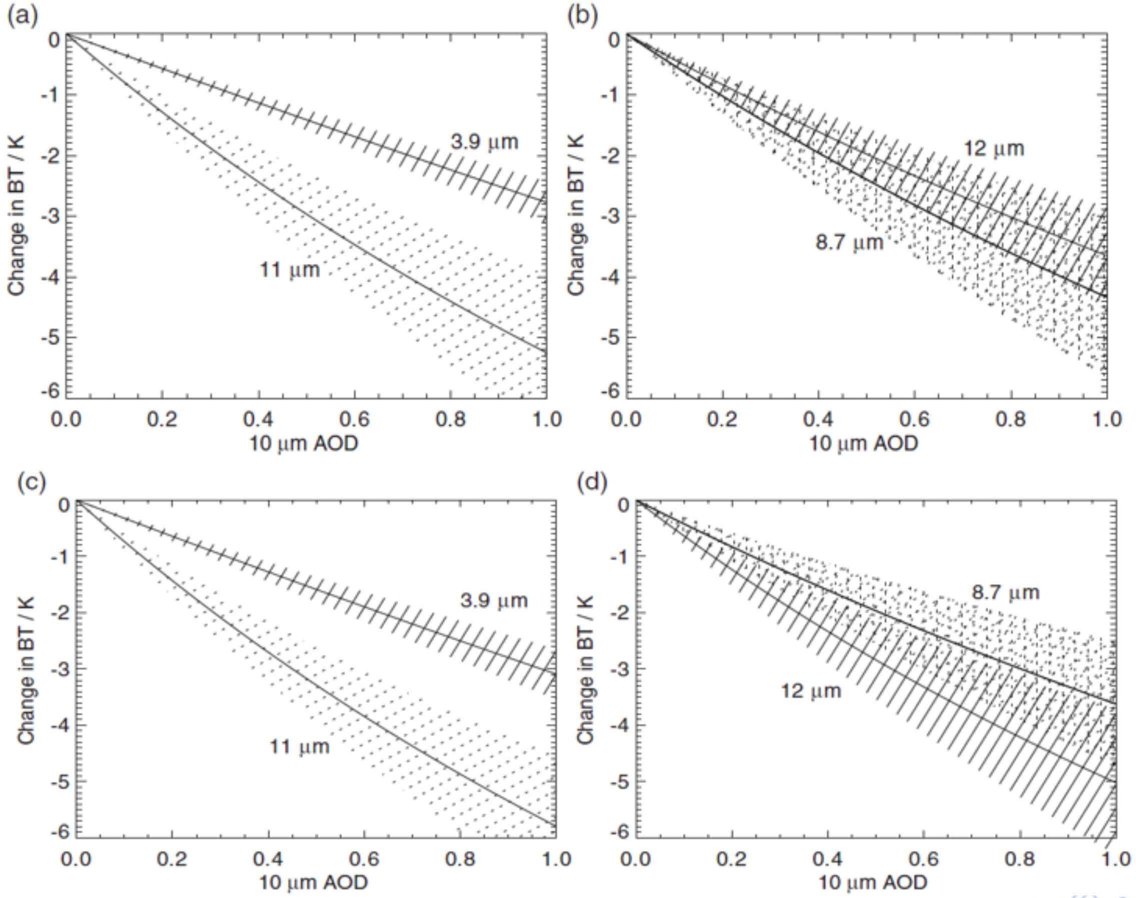
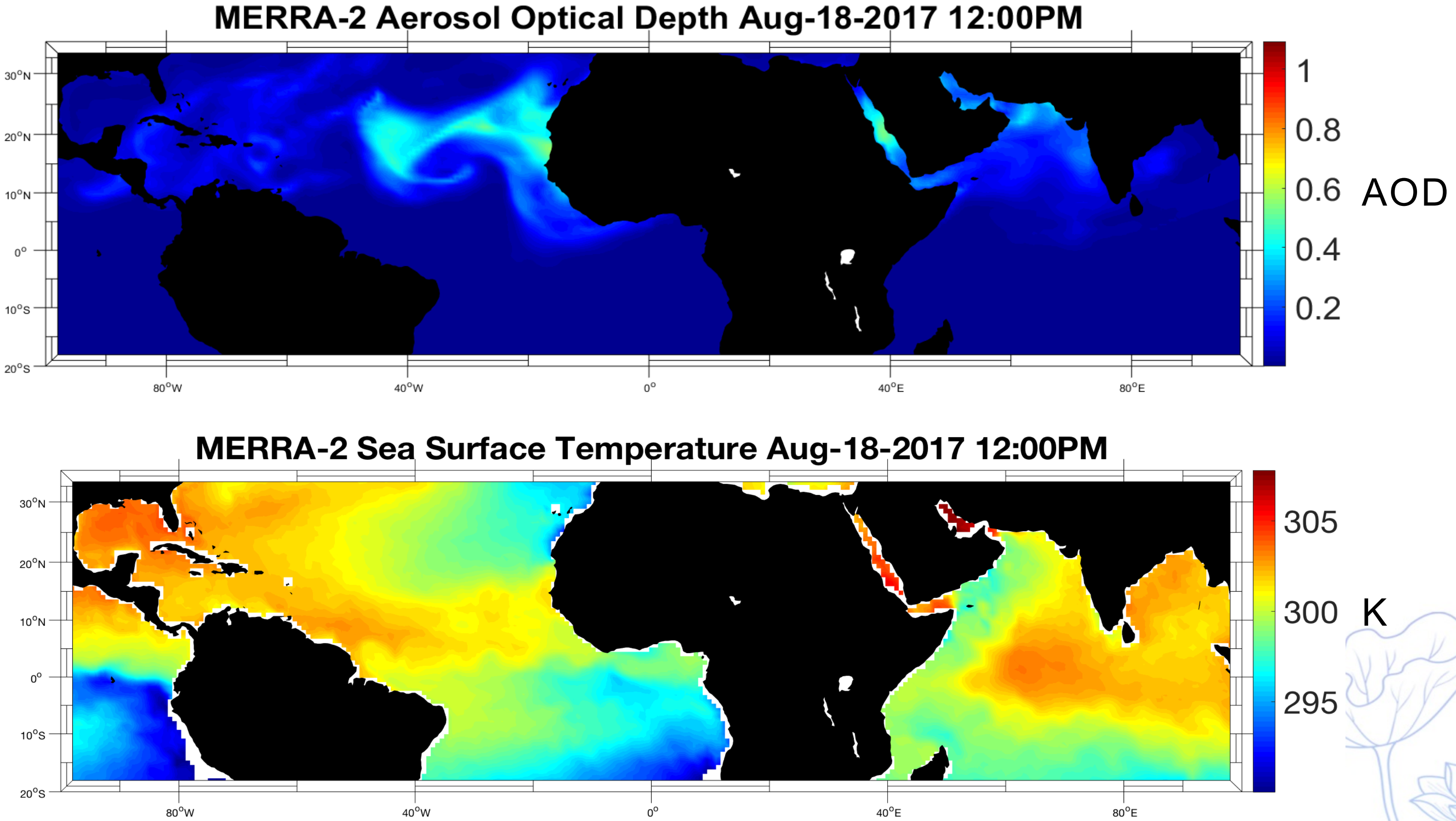
PART THREE

Radiative transfer model (RTTOV) simulation



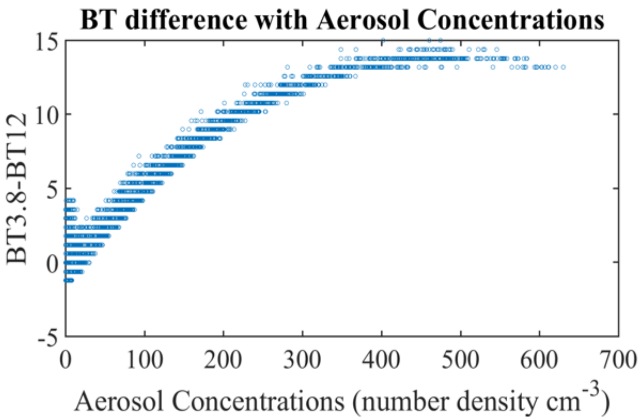
Changes in BT difference versus AOD assuming a layer of aerosol evenly distributed between 2 and 3 km altitude. (a) and (b) use Haywood optical properties. (c) and (d) use OPAC dust parameters. (Merchant et al. 2006).

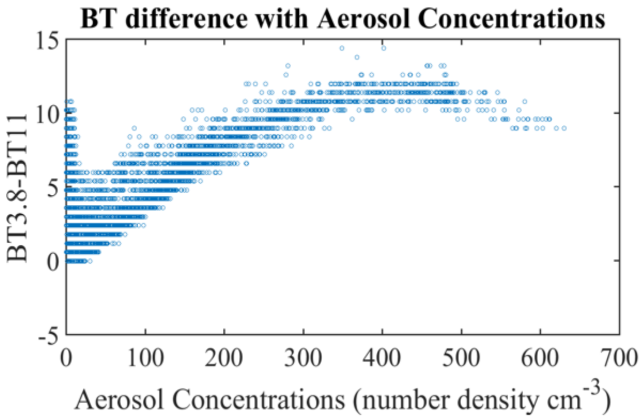
Part 3 Radiative transfer model simulation

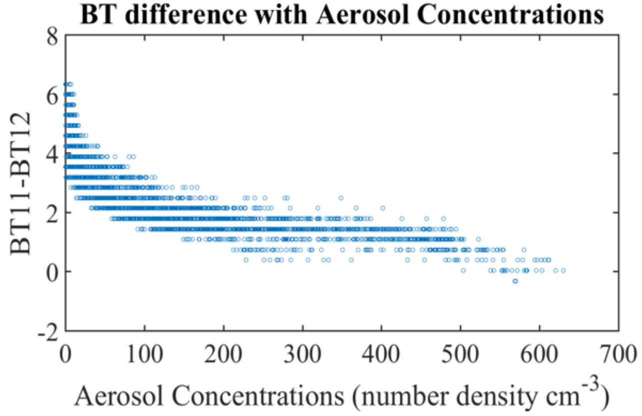


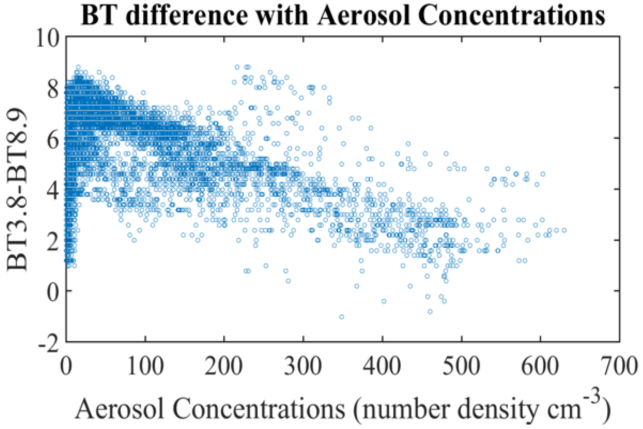
MERRA-2 input SST and AOD data during a dust break on Aug.18 2017.

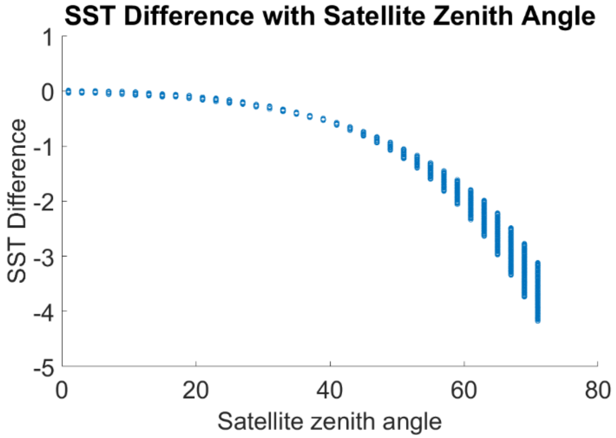
Part 3 Radiative transfer model simulation







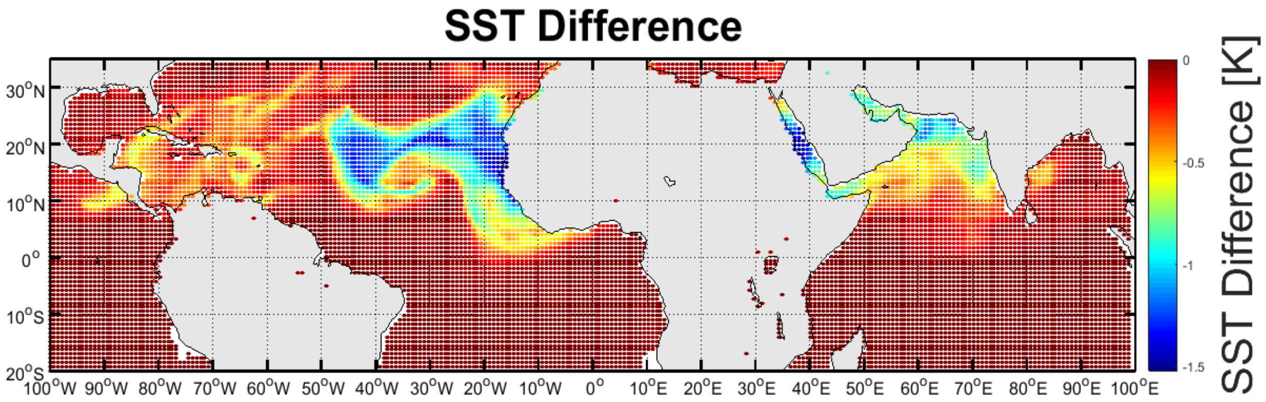


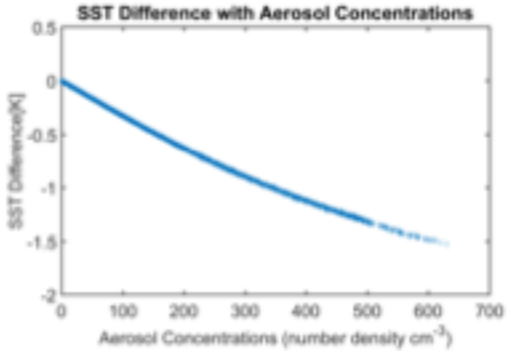


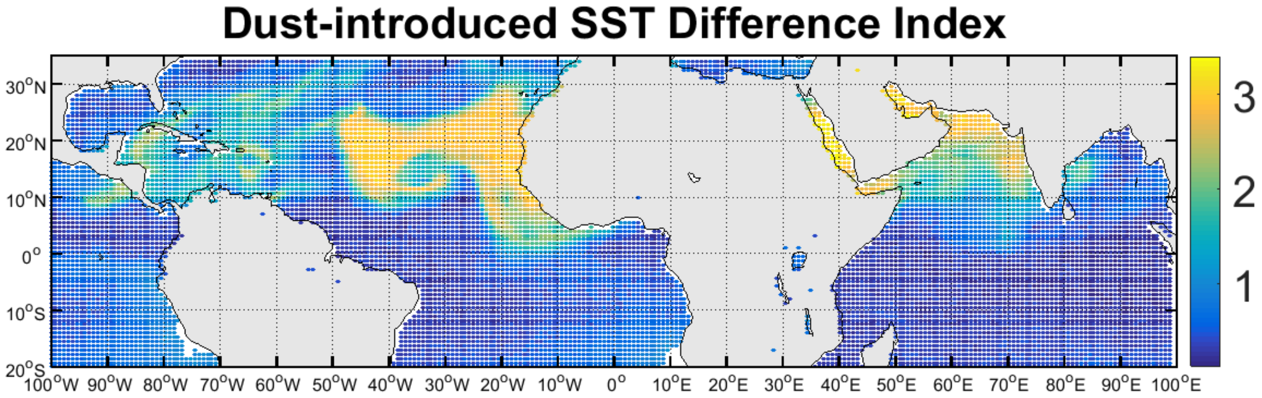
Dust-introduced SST Difference Index (DSDI):

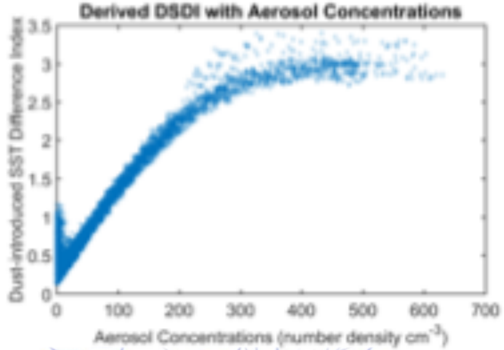
$$DSDI = a + (b + c*S_0) * (BT_{3.8}-BT_{12}) + d * (BT_{3.8}-BT_{8.9}) + (e + f*S_0) * (BT_{11}-BT_{12}) + (g + h*S_0) * (BT_{11}-BT_{12})^2$$

$S_0 = sec(\Theta)-1$ The coefficients are derived by regressions on the BT difference and SST Difference.









- BT$_{11}$- BT$_{12}$, BT$_{3.8}$- BT$_{12}$, BT$_{3.8}$-BT$_{8.9}$ are more useful to derive the DSDI.
- The model can be run with aerosol and without the aerosol to derive the SSTskin difference.
- The derived DSDI distribution is clearly related to the SSTskin difference.

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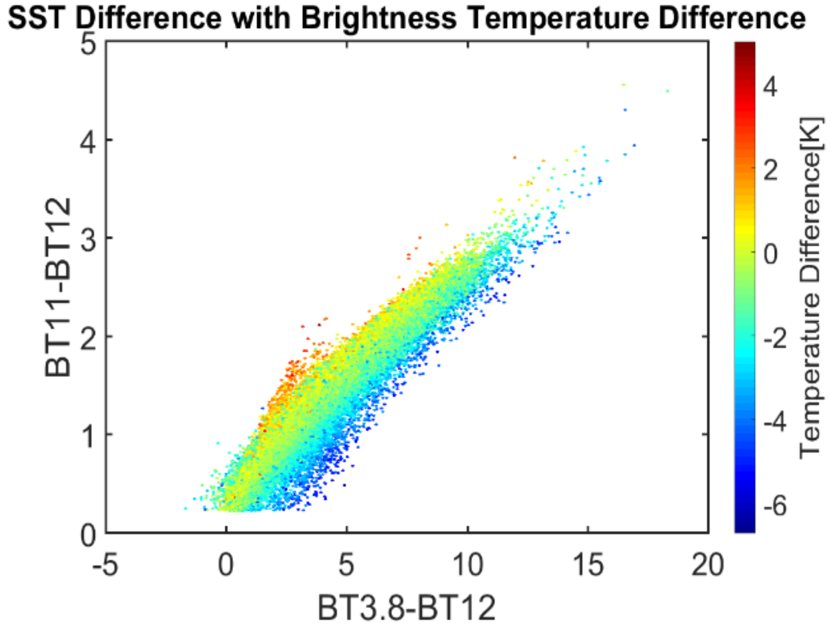
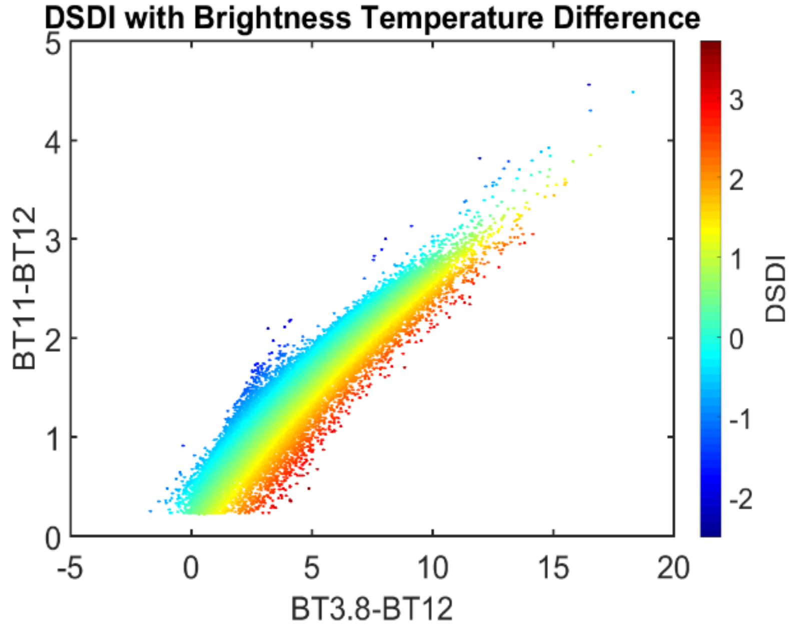
PART FOUR

MODIS SST Correction Algorithm

Part 4 MODIS SST Correction Algorithm



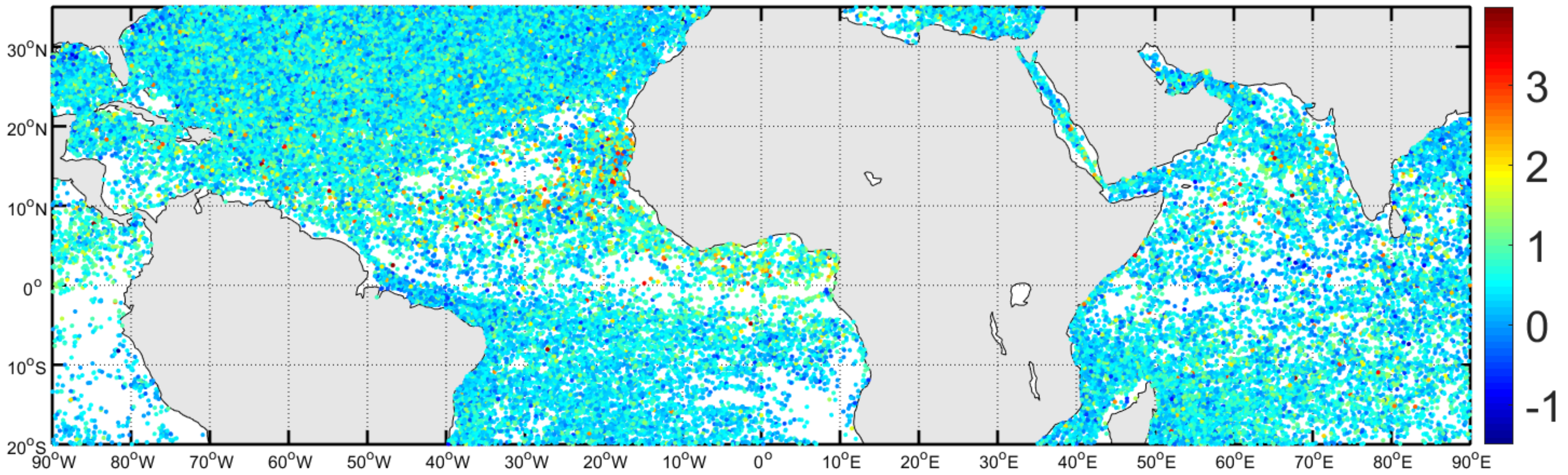


Left: scatter plot of the SST_{skin} difference with $BT_{3.8}$-BT_{12} and BT_{11}-BT_{12}, color means the SST_{skin} difference, it can be used to represent the aerosol introduced SST_{skin} difference.

Right: Derived DSDI with BT difference, corresponding to the left picture and it can be used to correct the SST_{skin} difference.

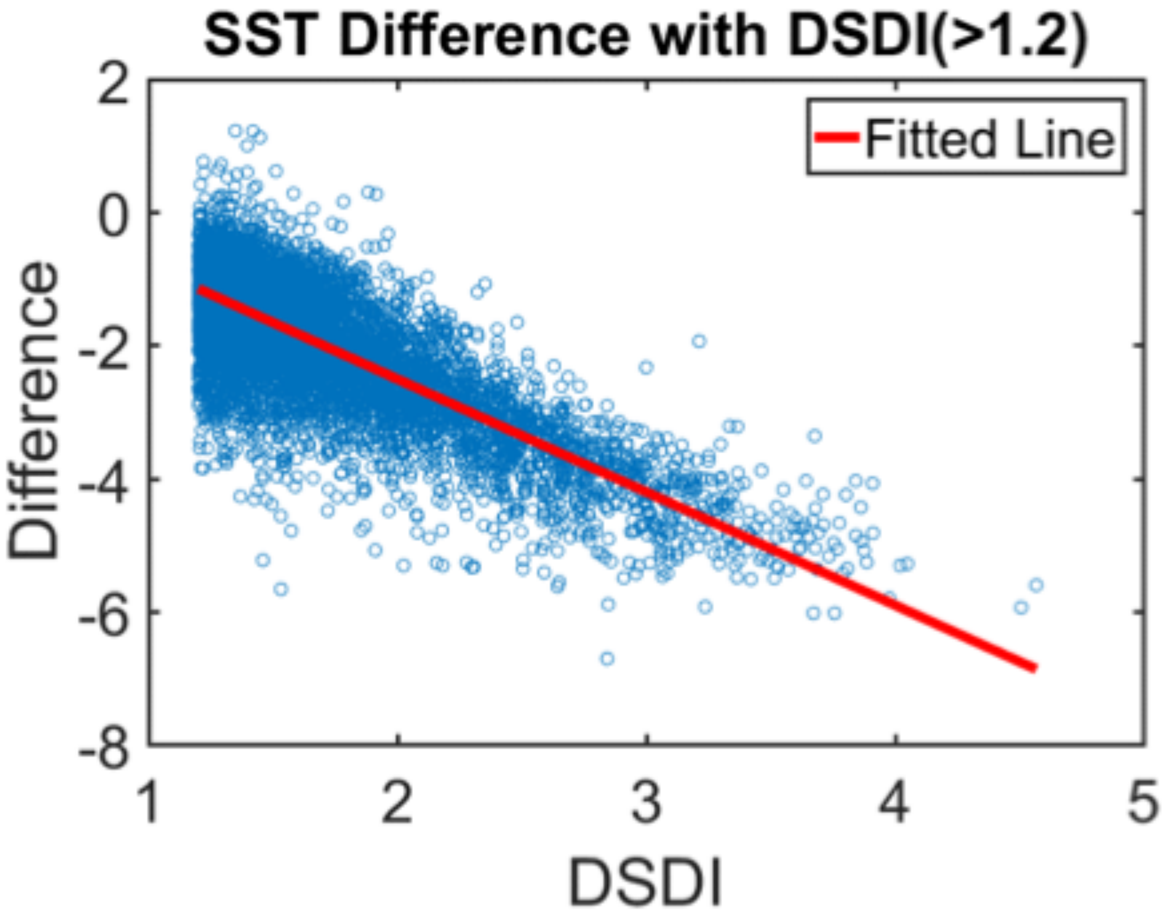
Night-time only & AOD>0.2

Derived Dust-introduced SST Difference Index

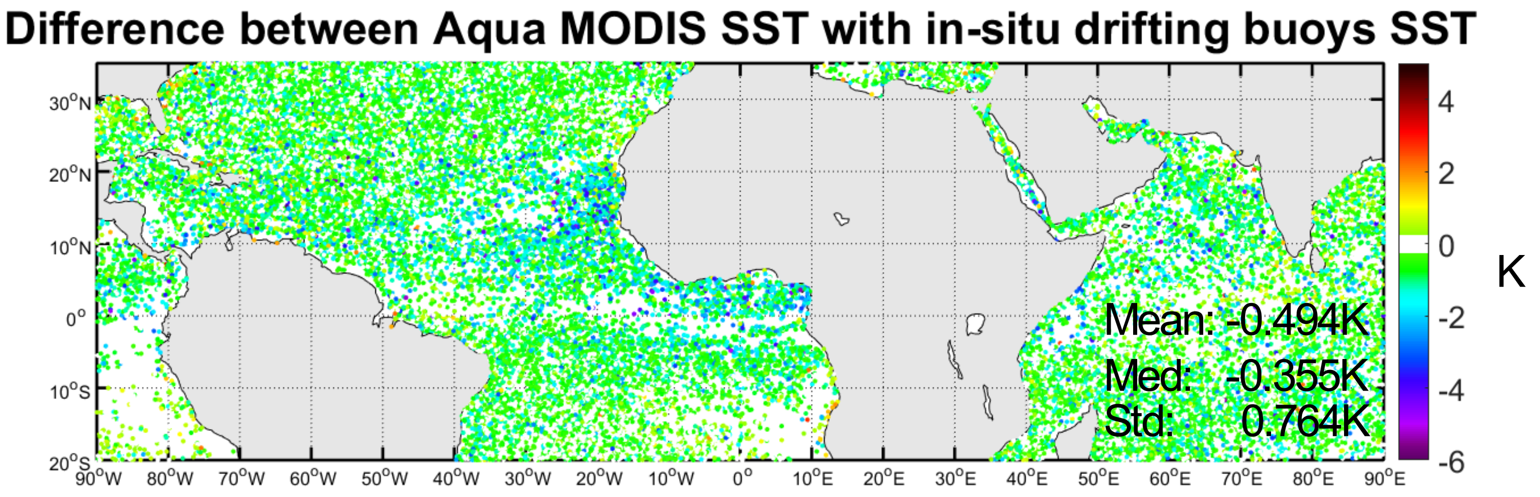


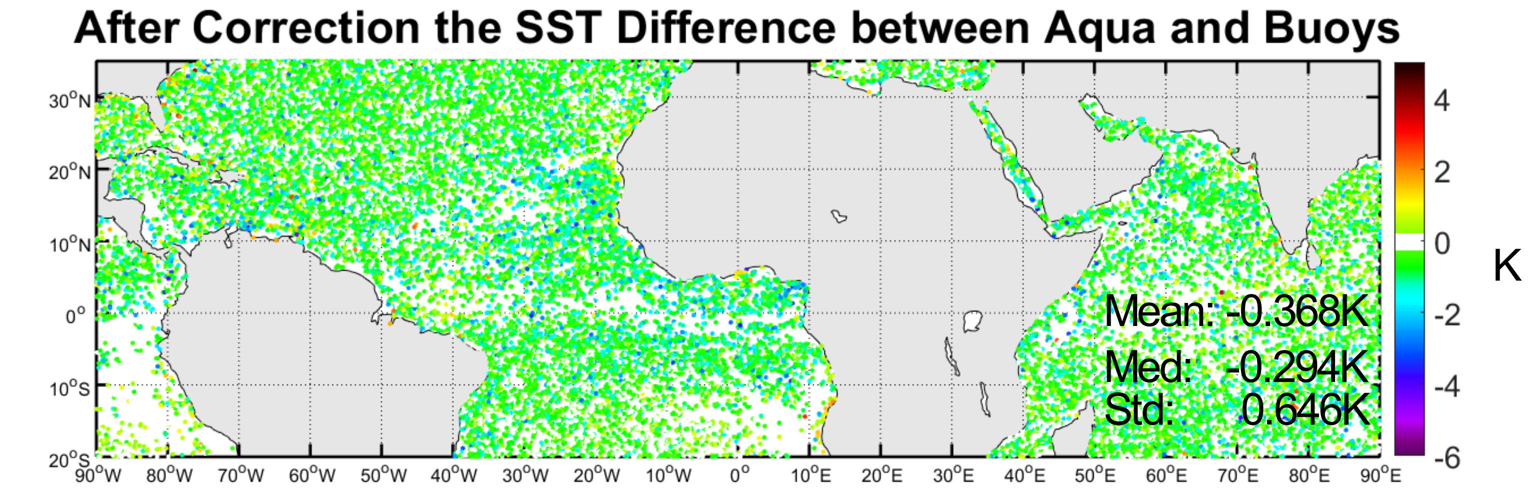
$$DSDI = a + (b + c*S_0) * (BT_{3.8}-BT_{12}) + d * (BT_{3.8}-BT_{8.9}) + (e + f*S_0) * (BT_{11}-BT_{12}) + (g + h*S_0) * (BT_{11}-BT_{12})^2$$

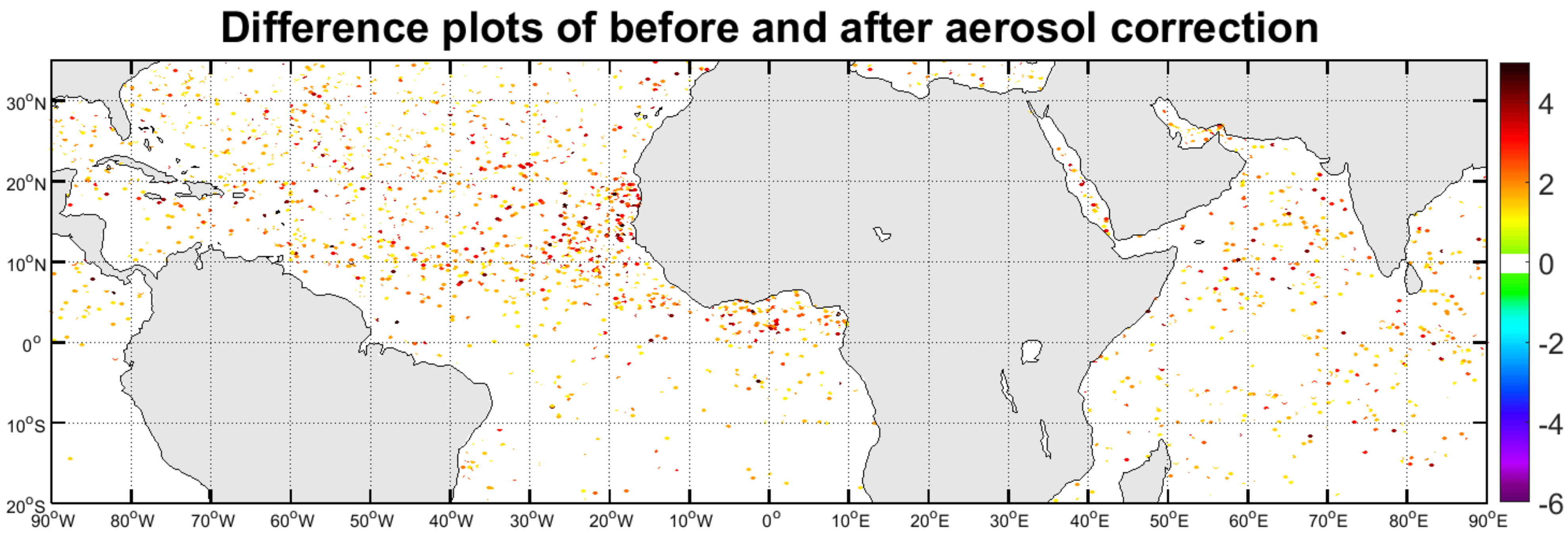
Where $a=1.476$ $b=1.120$ $c=-0.157$ $d=-0.126$ $e=-3.394$ $f=1.257$ $g=-0.153$ $h=0.378$ *and* $S_0 = sec(\Theta)-1$.



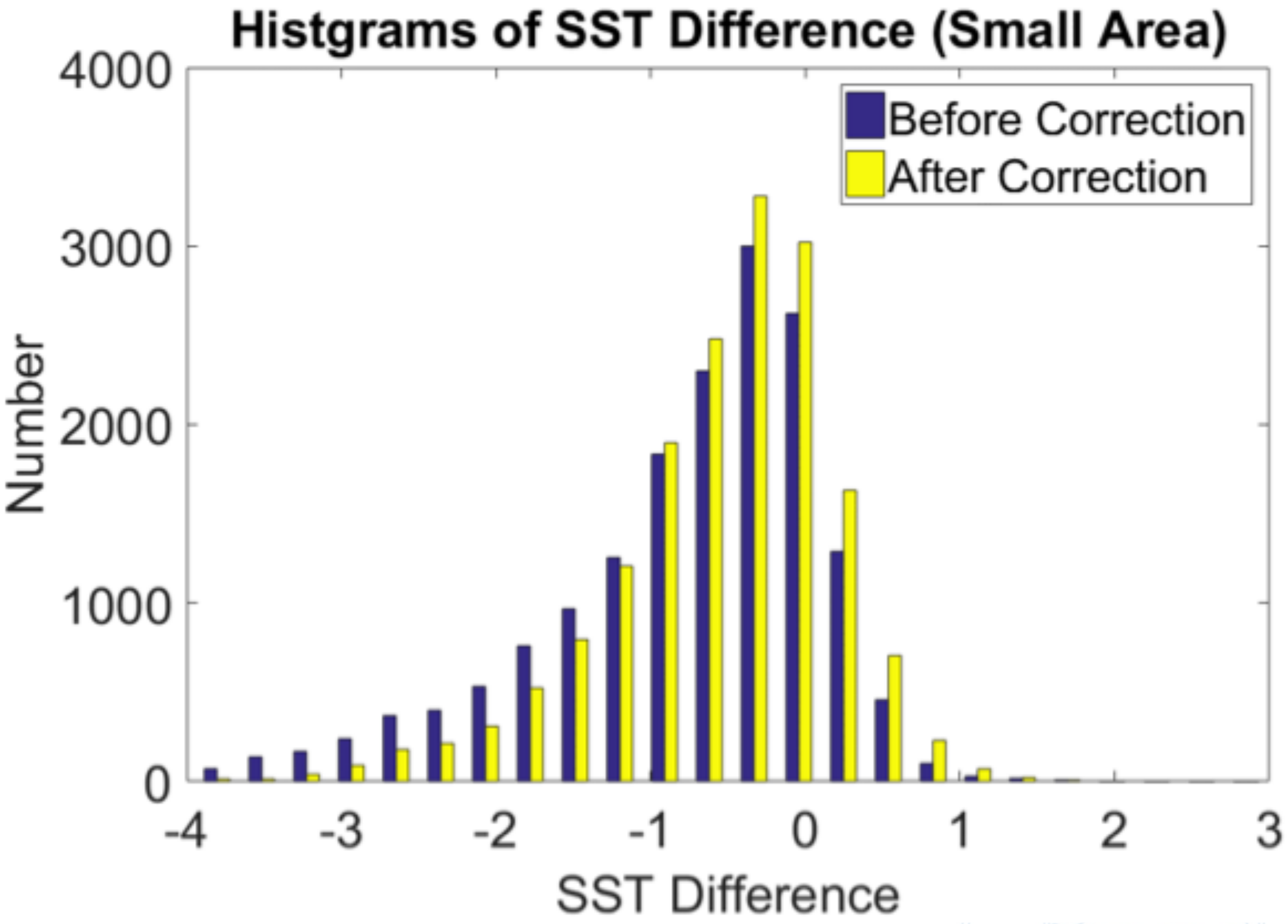
DSDI_Correction = - 1.7 * DSDI + 0.891

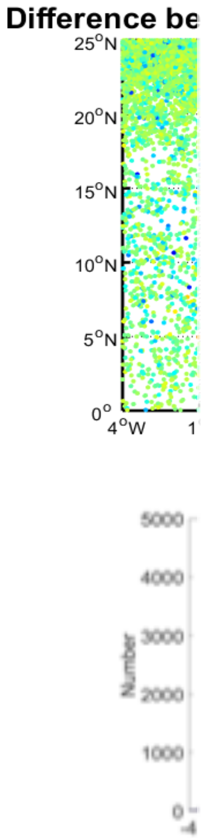

Difference between Aqua MODIS SST with in-situ drifting buoys SST
Mean: -0.494K
Med: -0.355K
Std: 0.764K
K
30°N
20°N
10°N
0°
10°S
20°S
90°W
80°W
70°W
60°W
50°W
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
70°E
80°E
90°E
4
2
0
-2
-4
-6

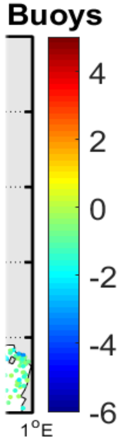

After Correction the SST Difference between Aqua and Buoys
Mean: -0.368K
Med: -0.294K
Std: 0.646K
K
30°N
20°N
10°N
0°
10°S
20°S
90°W
80°W
70°W
60°W
50°W
40°W
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
70°E
80°E
90°E
4
2
0
-2
-4
-6



The difference in SSTskin between before and after aerosol correction. This aerosol correction term is high at Saharan dust outflow area.







E

.510K
.410K
.749K

Error statistics according to MODIS quality flag

Quality Level	N	Before correction			After correction		
		Mean	Median	STD	Mean	Median	STD
0	86092	-0.217	-0.190	0.458	-0.192	-0.180	0.442
1	47030	-0.482	-0.435	0.649	-0.376	-0.360	0.616
2	50919	-0.974	-0.830	1.003	-0.657	-0.585	0.834
Total	184041	-0.494	-0.355	0.764	-0.368	-0.295	0.646

Compared to levels 0 and 1, there is much more benefit for level 2 data.
The difference for level 2 data is reduced by 0.317K.

05

PART FIVE

Conclusion and Future Work

Conclusion:

- The goal of this study was to improve the accuracy of satellite derived SST_{skin} in conditions contaminated by mineral dust aerosols.
- Infrared satellite SST_{skin} discrepancies with in-situ measurements caused by aerosols.
- Simulation of the measured brightness temperatures using the RTTOV radiative transfer model was used in this study to explore the functional form of the aerosol correction.
- The characteristics of the aerosol layer effects on infrared SST_{skin} have been revealed, as well as deriving an empirical formula that better corrects for aerosol-related effects.
- The correction formula is beneficial when applied to infrared measurements of Aqua MODIS.

This work has benefited from discussions with Goshka Szczodrak, Chelle L. Gentemann, Paquita Zuidema, Kenneth J. Voss, Katherine A. Kilpatrick and Miguel A. Izaguirre. The at-sea support by the Captain, Officers, crew and colleagues on board the NOAA Ship Ronald H Brown is acknowledged.

Future Work :

- A correction algorithm for day-time use should be developed.
- The vertical distribution of aerosol influences the accuracy of infrared-derived SSTskin. RTTOV simulated dust layer effects at different heights have an impact on the satellite SST retrieval. CALIPSO provides information about the vertical distribution of aerosol layers, it can be used to derive different coefficients in the correction algorithms.
- The impact of different kinds of aerosol layers should be further explored.
- Such approaches as developed here can be applied to other well-calibrated infrared satellite radiometers such as Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-NPP, NOAA-20 satellites and others in the future.

THANK YOU!

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