MODIS Sea-Surface Temperatures: Characteristics of the R2019.0 Reprocessing of the Terra and Aqua Missions

Peter J Minnett, Kay Kilpatrick, Goshka Szczodrak,

Miguel Izaguirre, Bingkun Luo, Chong Jia, Chris Proctor,* Sean W. Bailey,*

Edward Armstrong,# Jorge Vazquez-Cuervo,# and Wen-Hao Li.#

Rosenstiel School of Marine & Atmospheric Science, University of Miami, FL, USA

*NASA Goddard Space Flight Center, Greenbelt, MD, USA

#NASA Jet Propulsion Laboratory, Pasadena, CA, USA

Contact: pminnett@rsmas.miami.edu

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Background

- At the end of 2019, OBPG at GSFC completed the reprocessing of SST_{skin} MODIS on Terra and Aqua. L2p data files available at the PO.DAAC.
- Focus here is the 11-12 µm split-window atmospheric correction algorithm based on the NLSST, with coefficients optimized for months and latitude bands, derived from matchups with drifting buoys.
- The regeneration of the R2019 MODIS Matchup-Data Bases at OBPG is a casualty of Covid-19 and will be resumed as soon as possible.
- Previous version is referred to as R2014 (or Collection 6 in older designation scheme).

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Improvements

The major changes in R2019 are:

a) Replacing the NOAA OI "Reynolds" SSTs, with the CMC as the reference field.
b) New cloud screening – Alternating Decision Tree.
c) Aerosol Correction – additive term to atmospheric correction algorithm if aerosol threshold passed.
d) High-Latitude coefficients.
e) Improvement to cloud-ice discrimination.

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

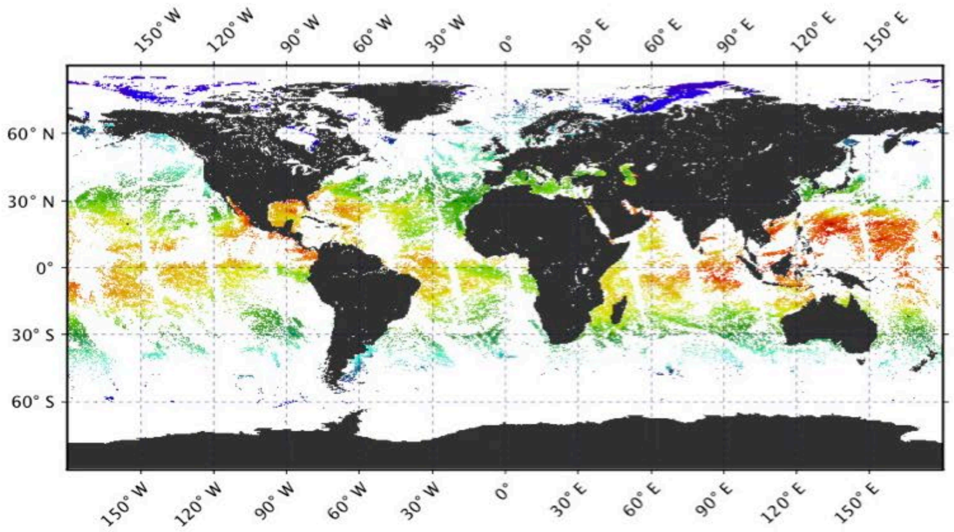
Cloud Screening

- R2014 cloud screening was based on a linear Binary Decision Tree (BDTree) comprising a sequence of tests to identify signature of clouds being present based on spatial and spectral tests. A pixel, or groups of pixels must pass all tests to be classified as cloud-free.
- The BDTree has been found to be too conservative and misclassified clear-pixels as cloudy.
- R2019 uses an Alternating Decision Tree (ADTree) in which similar spatial and spectral tests are applied, but the results from all tests are retained, and a weighted average of outcomes determines the likelihood of being cloud-free.
- Weights are determined by an AI analysis.

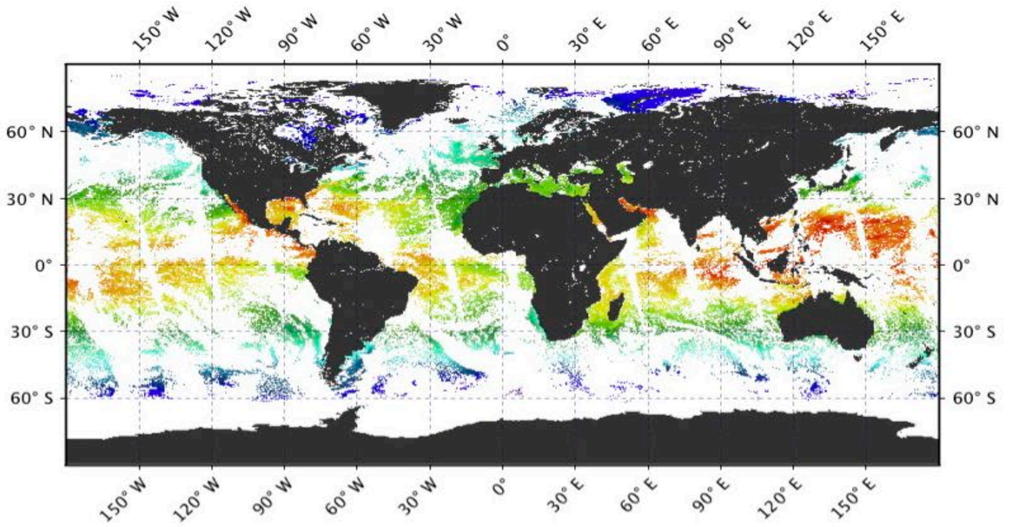
Kilpatrick, K.A., Podestá, G., Williams, E., Walsh, S., & Minnett, P.J. (2019). Alternating Decision Trees for Cloud Masking in MODIS and VIIRS NASA Sea Surface Temperature Products. *Journal of Atmospheric and Oceanic Technology 36*, 387-407. 10.1175/jtech-d-18-0103.1

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

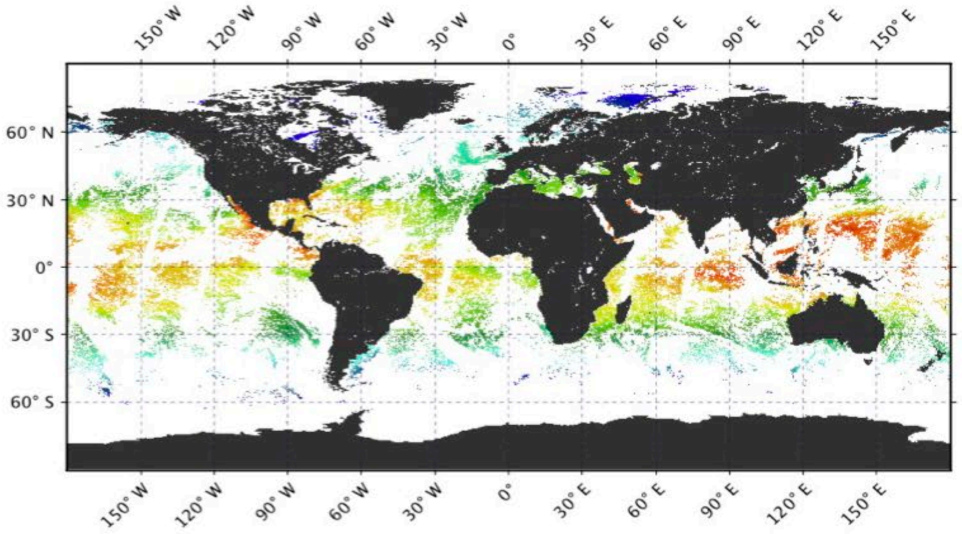
R2014.0.1 AQUA Day time with binary cloud mask



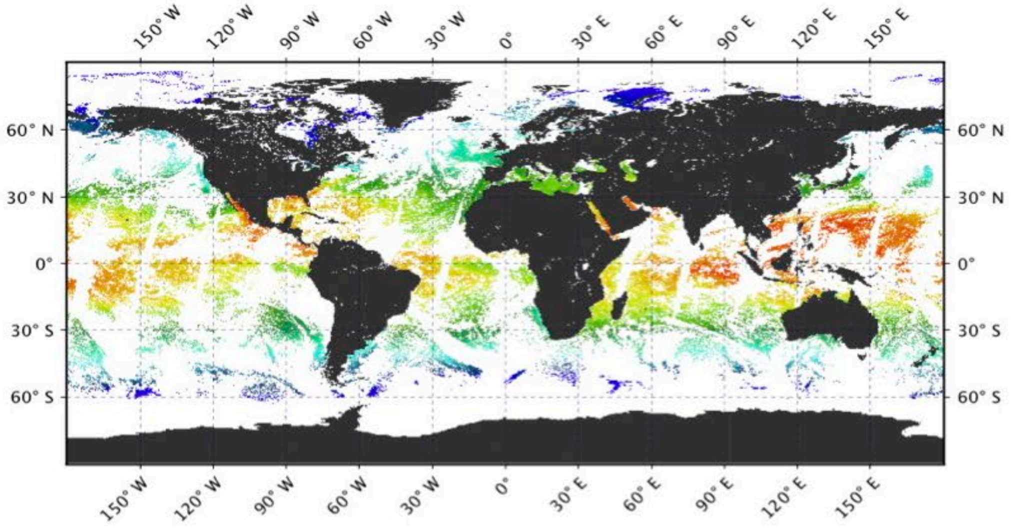
R2014.0.2 AQUA Day time with Adtree cloud mask



R2014.0.1 TERRA Day time with binary cloud mask



R2014.0.2 TERRA Day time with Adtree cloud mask



R2014.0.1 is the previous processing algorithm, with the BDTree

R2014.0.2 is a test set of the previous processing but with AD Tree.

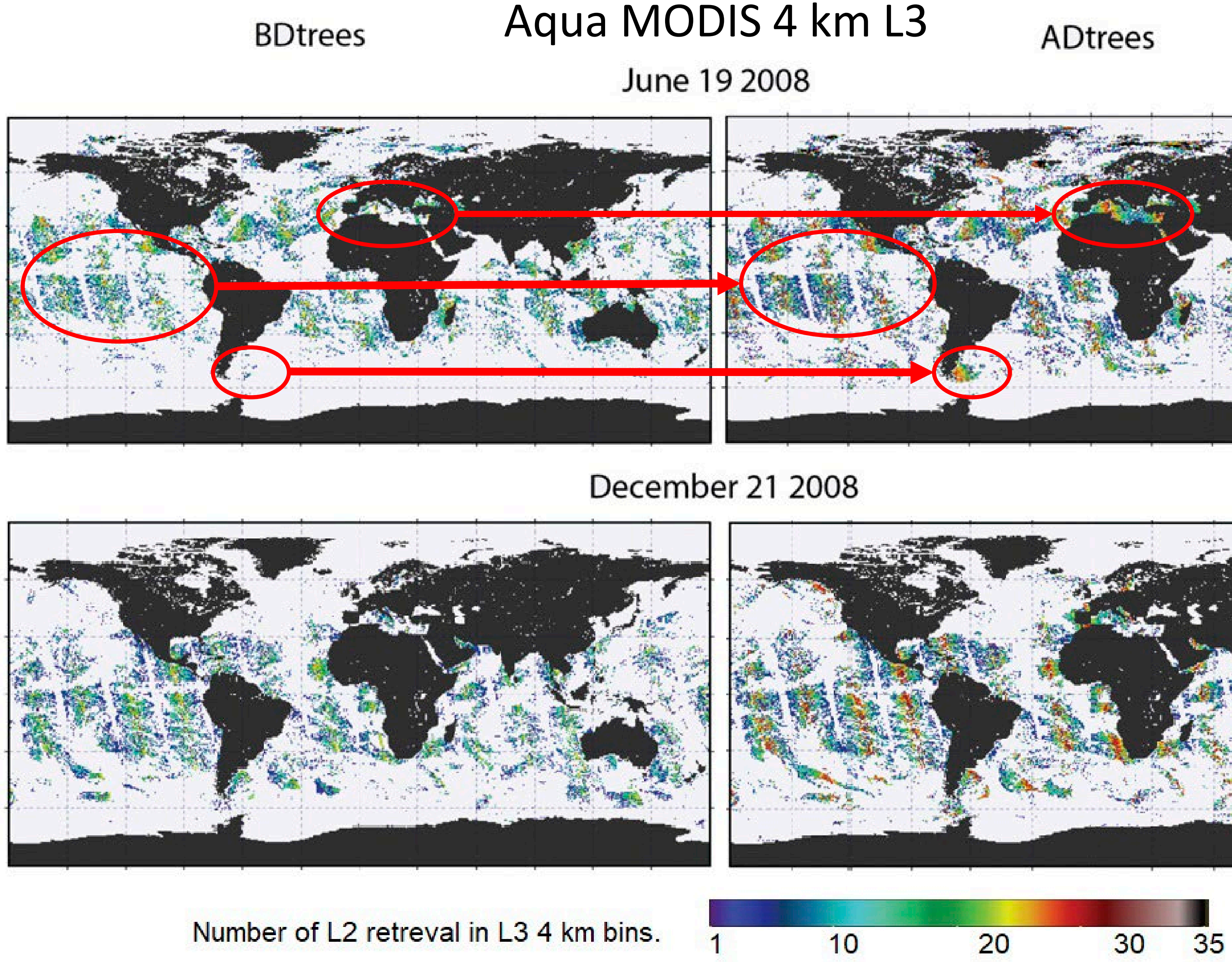
ADTree improves coverage both day and night – see Southern Ocean.

.

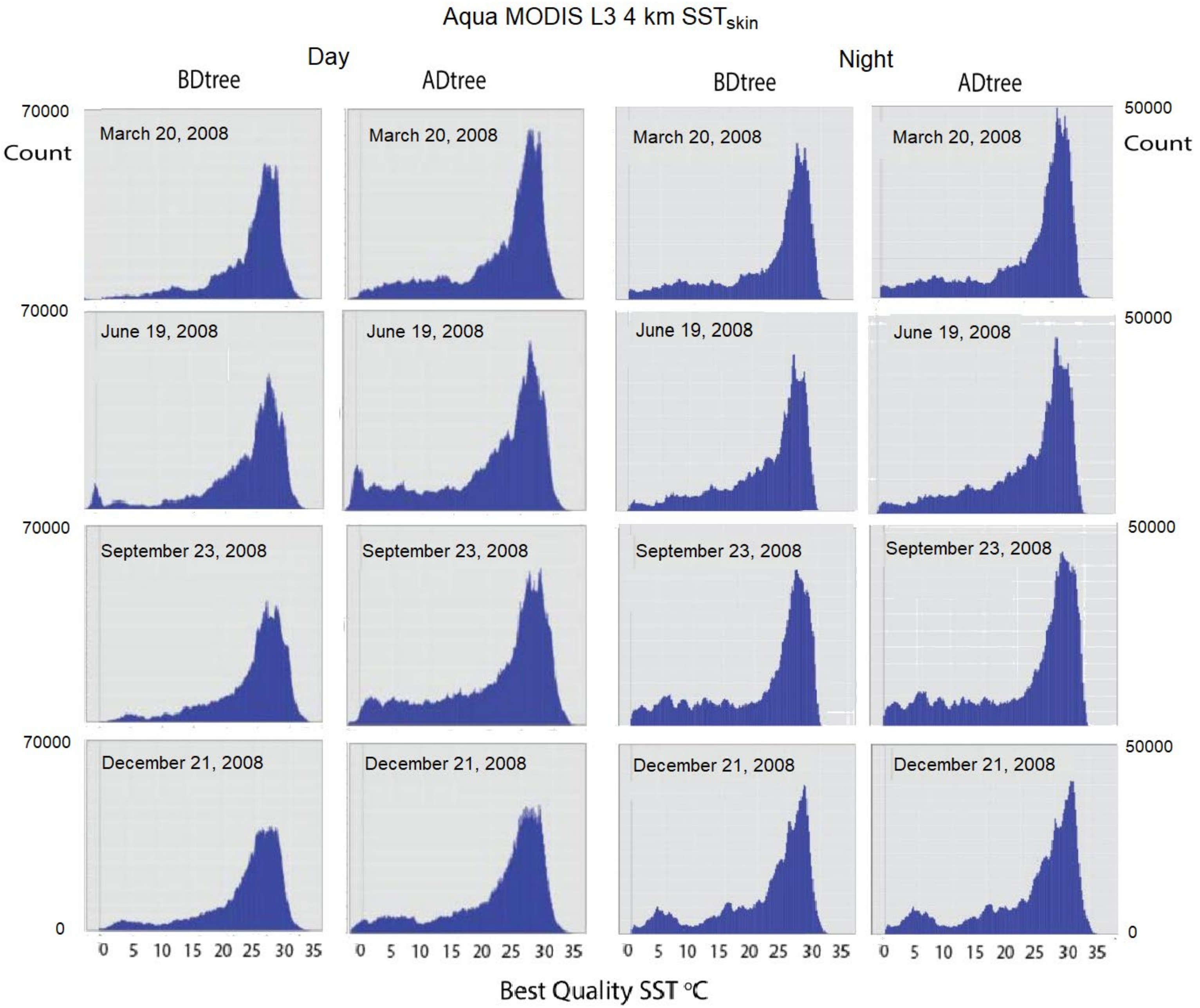
Aqua MODIS 4 km L3

Numbers of retrievals increased: number of L2 retrievals in 4 km L3 bins..

Similarly for all other days.



Increased number of populated L3 cells around the year, for day and night.



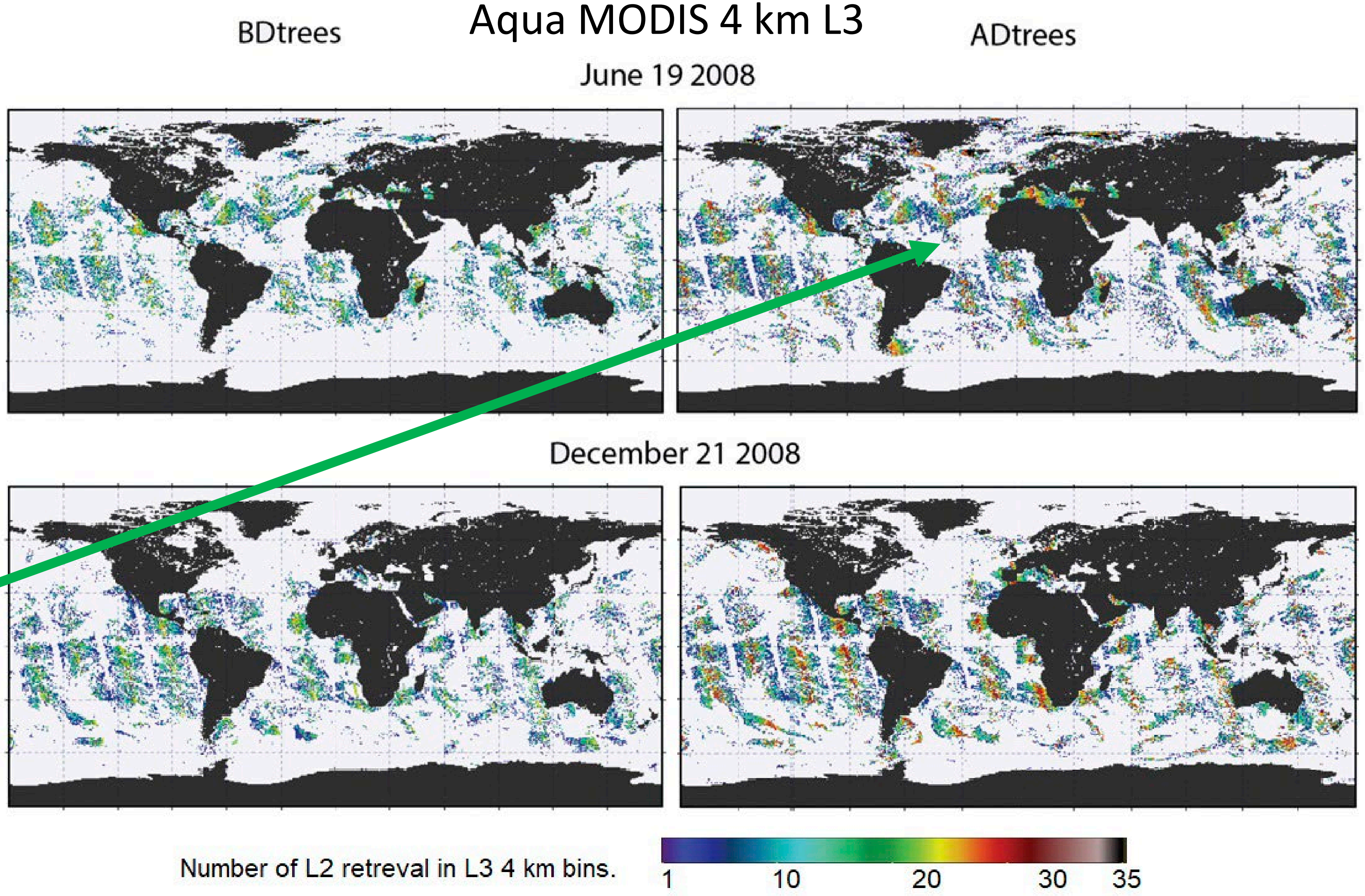
UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Increased number of cloud-free retrievals

Day SST MODIS-A 2008 date	Classifier	No. of clear 4-km L3 bins	% global increase in populated L3 4-km bins ADtree	Mean L2 pixel count per 4-km bin	Sum global 1-km L2 count	% global increase daily clear L2 1-km pixels ADtree
20 Mar	BDtree	3.88×10^6		9.1	3.82×10^7	
20 Mar	ADtree	5.27×10^6	35.7	9.8	4.98×10^7	30.6
19 Jun	BDtree	3.57×10^6		8.7	3.10×10^7	
19 Jun	ADtree	5.59×10^6	56.8	9.2	5.15×10^7	66.3
23 Sep	BDtree	3.83×10^6		8.5	3.24×10^7	
23 Sep	ADtree	5.72×10^6	49.4	9.3	5.31×10^7	64.0
21 Dec	BDtree	3.83×10^6		8.8	3.36×10^7	
21 Dec	ADtree	5.20×10^6	35.7	9.1	4.75×10^7	41.5

Increase in cloud-free retrievals around the year both at L2 and L3

Aqua MODIS 4 km L3



But note aerosol regions still absent

SST Algorithm Developments – Night-time Aerosol Effects

- To avoid degradation of accuracy in MODIS SSTs where there is no aerosol contamination, apply an additional aerosol correction when an aerosol index exceeds a threshold.
- Using analysis of MUDB and RTE (RTTOV) simulations, an index and correction have been derived using measurements at 3.8, 8.9, 11.0 and 12.0 μm.
- Because of the use of mid-IR measurements, the correction can only be used at night.

Luo, B., Minnett, P.J., Gentemann, C., & Szczodrak, G. (2019). Improving satellite retrieved night-time infrared sea surface temperatures in aerosol contaminated regions. *Remote Sensing of Environment 223*, 8-20. https://doi.org/10.1016/j.rse.2019.01.009

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

SST Algorithm Developments – Night-time Aerosol Effects

Dust-induced SST Difference Index (DSDI) algorithm based on simulated brightness temperatures (BTs):

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

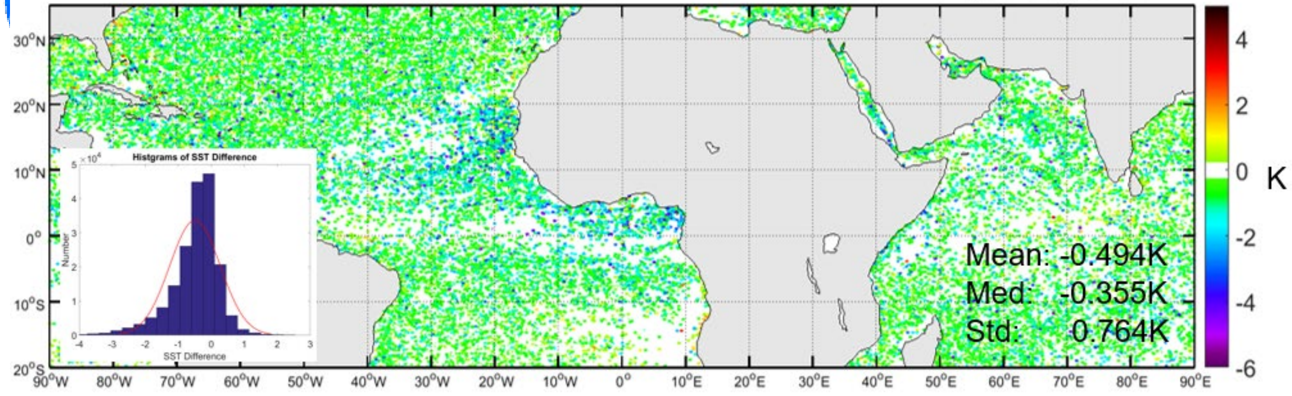
where $S_0 = sec(\theta) - 1$. θ is the satellite zenith angle.

When DSDI > 0.8 and MERRA-2 dust extinction > 0.025, aerosol correction term, added to NLSST atmospheric correction:

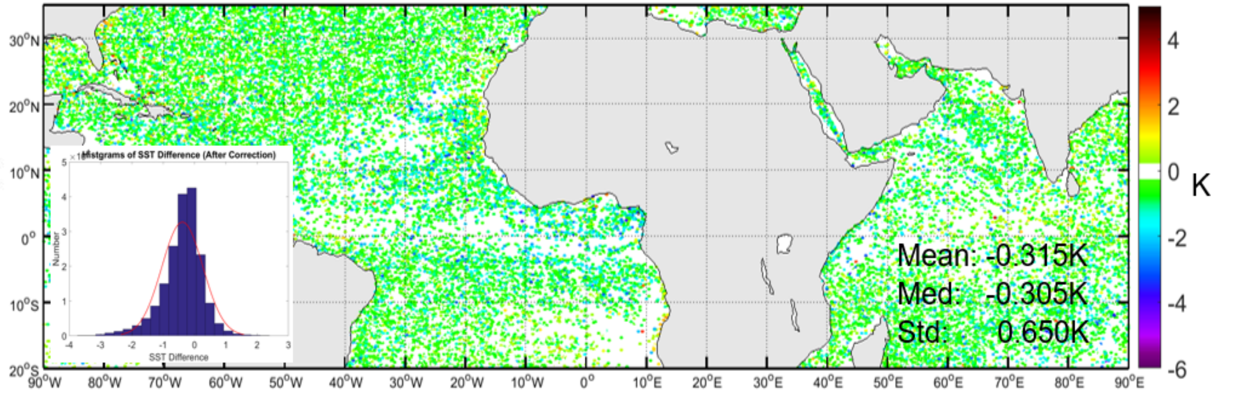
$$DSDI_{Correction} = m \times DSDI + n$$

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

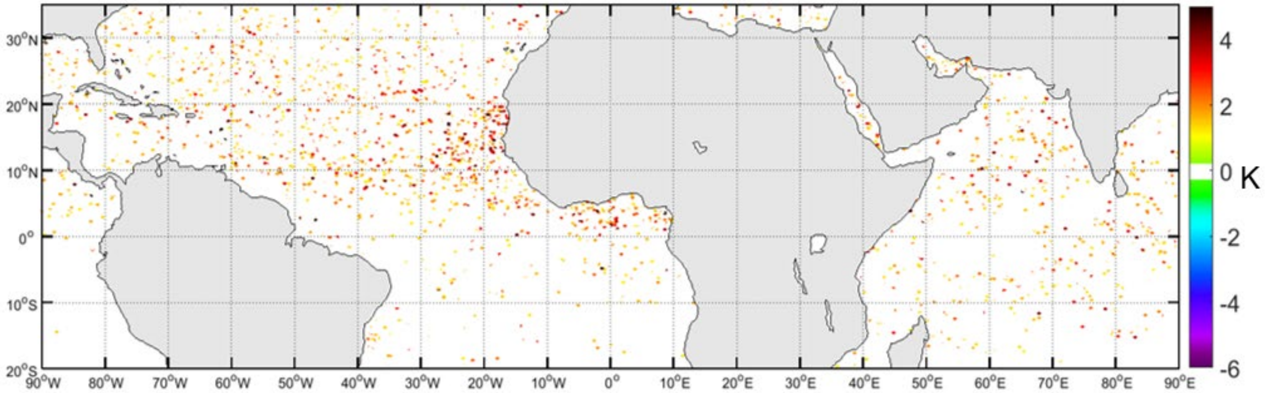
Difference between Aqua MODIS SST with in-situ drifting buoys SST

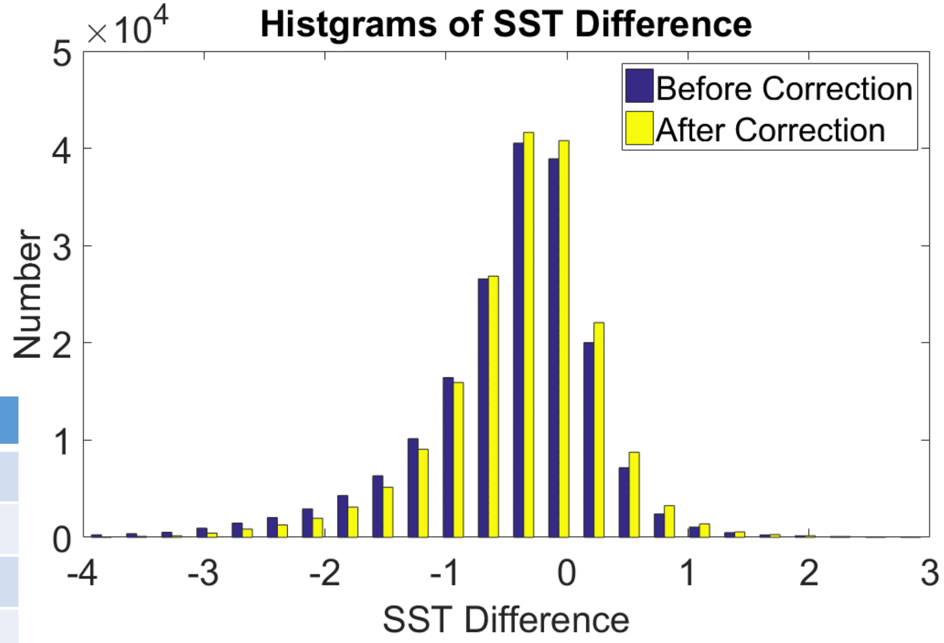


After Correction the SST Difference between Aqua and Buoys



Difference plots of before and after aerosol correction





Quality Flag	N	Before correction (K)			After correction (K)		
		Mean	Median	STD	Mean	Median	STD
0	86092	-0.217	-0.190	0.458	-0.203	-0.185	0.447
1	47030	-0.482	-0.435	0.649	-0.401	-0.380	0.625
2	50919	-0.974	-0.830	1.003	-0.678	-0.612	0.845
All	184041	-0.494	-0.355	0.764	-0.315	-0.305	0.650

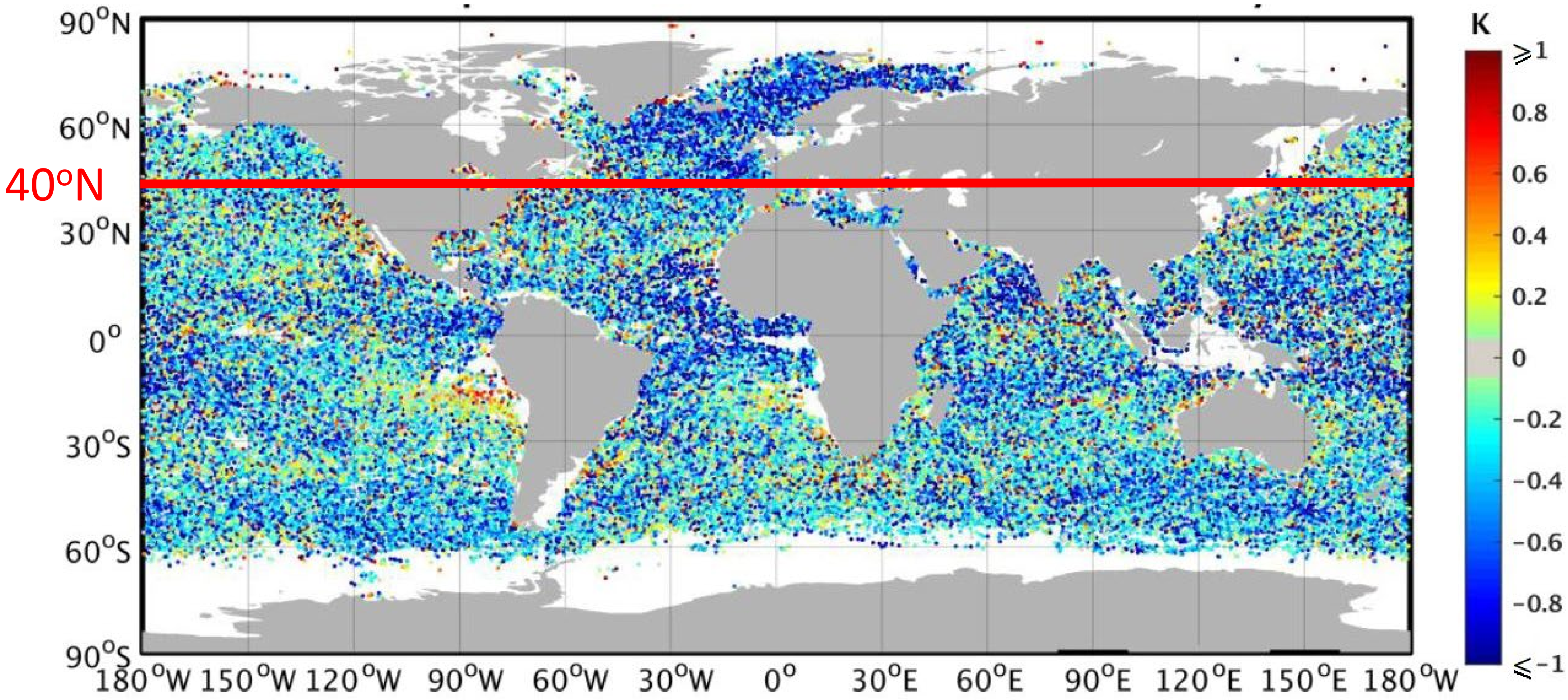
UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Improved High-Latitude SST_{skin}

- Inaccuracies in Arctic SST_{skin} retrievals are generally greater than elsewhere.
- Improvement to Arctic SST_{skin} retrieval accuracy is required for supporting research into Arctic Amplification of the changing climate.
- In R2014, high northern latitude retrievals were derived from matchups > 40°N.
- Not optimized for Arctic retrievals.
- Correction to R2019 based on analysis of Aqua MODIS MUDB 2013-2017, but derived for entire missions of Terra and Aqua.

Jia, C., & Minnett, P.J. (2020). High Latitude Sea Surface Temperatures Derived from MODIS Infrared Measurements *Remote Sensing of Environment. In review.*

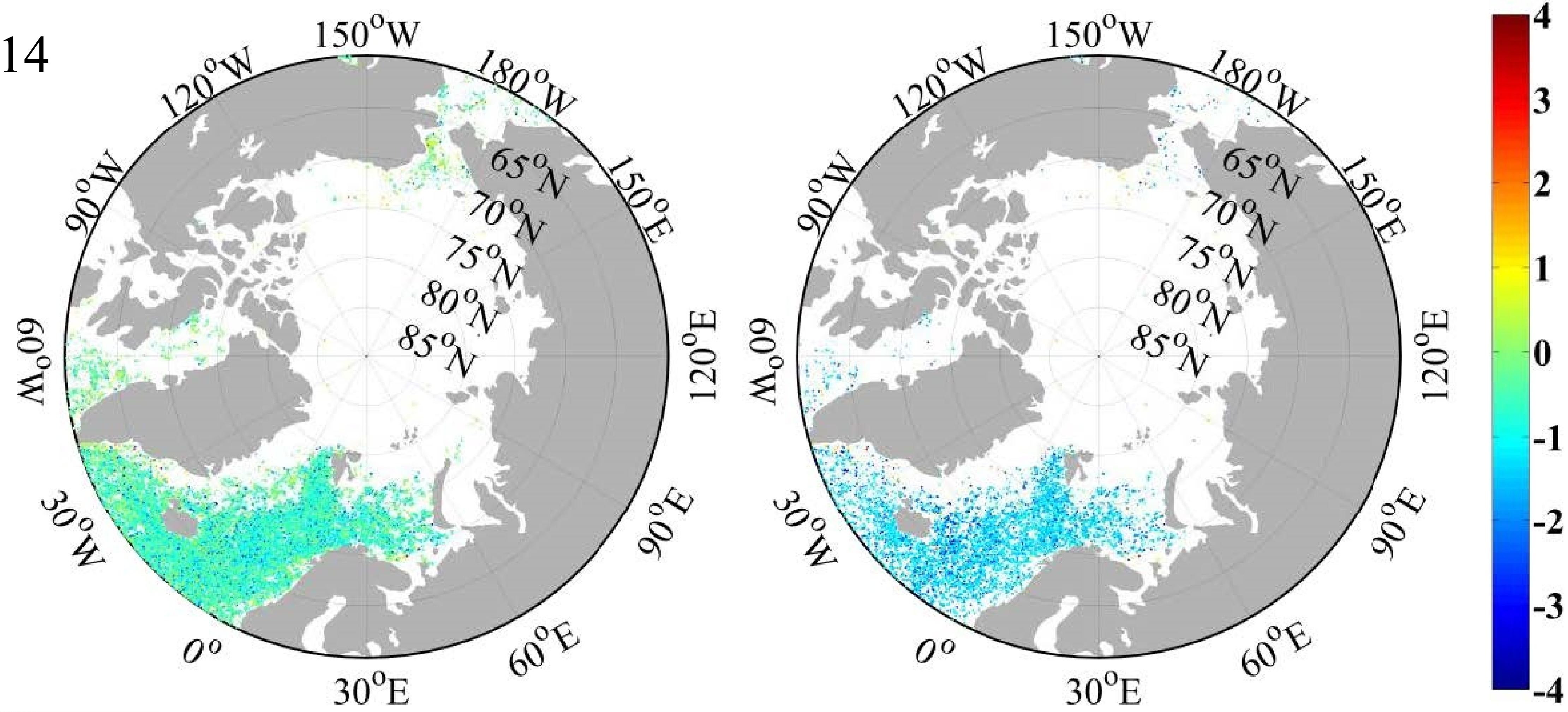
Aqua MODIS SST_{skin} – Buoy T



UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

MODIS SST_{skin} – Buoy T

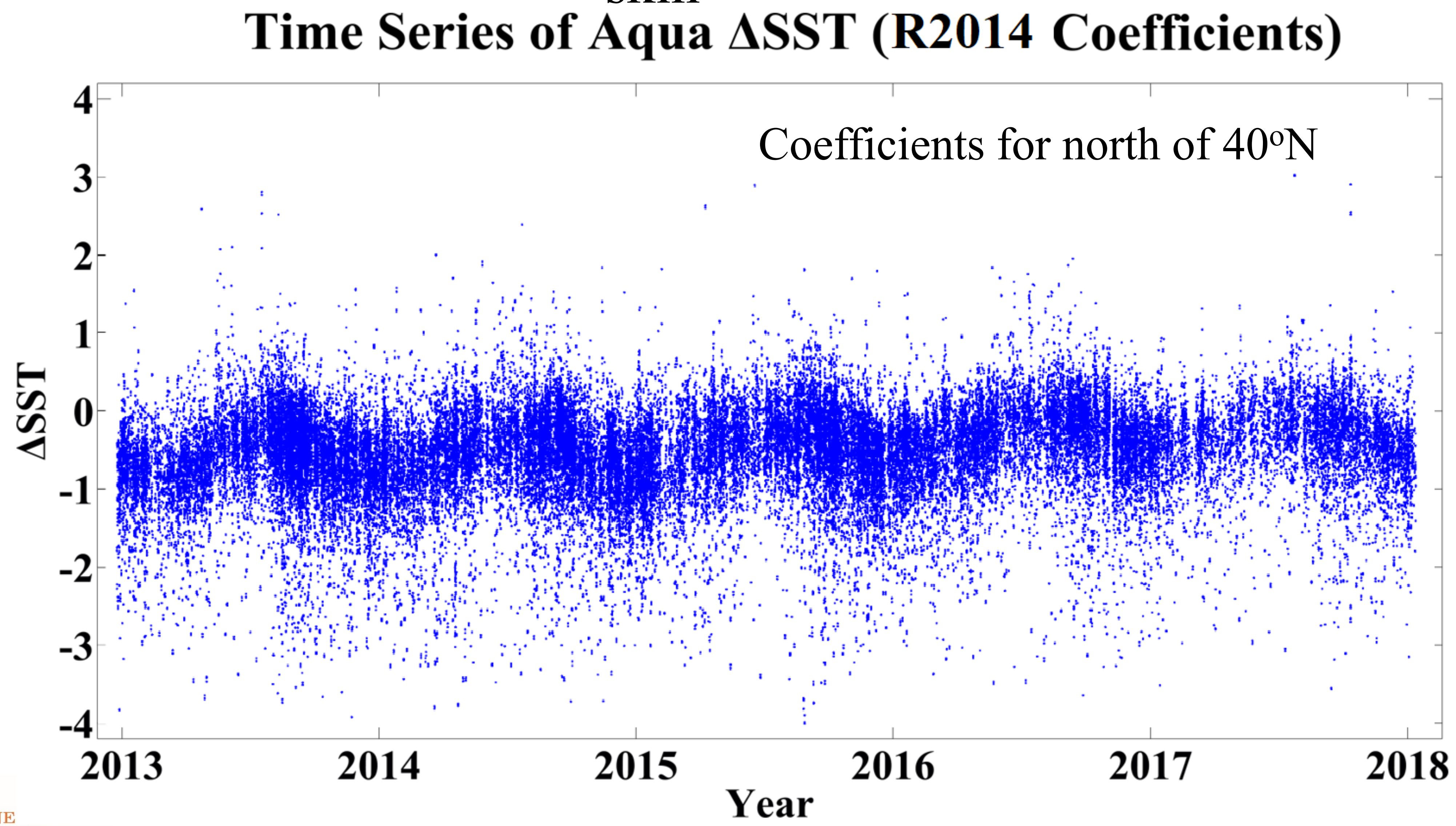
R2014



All

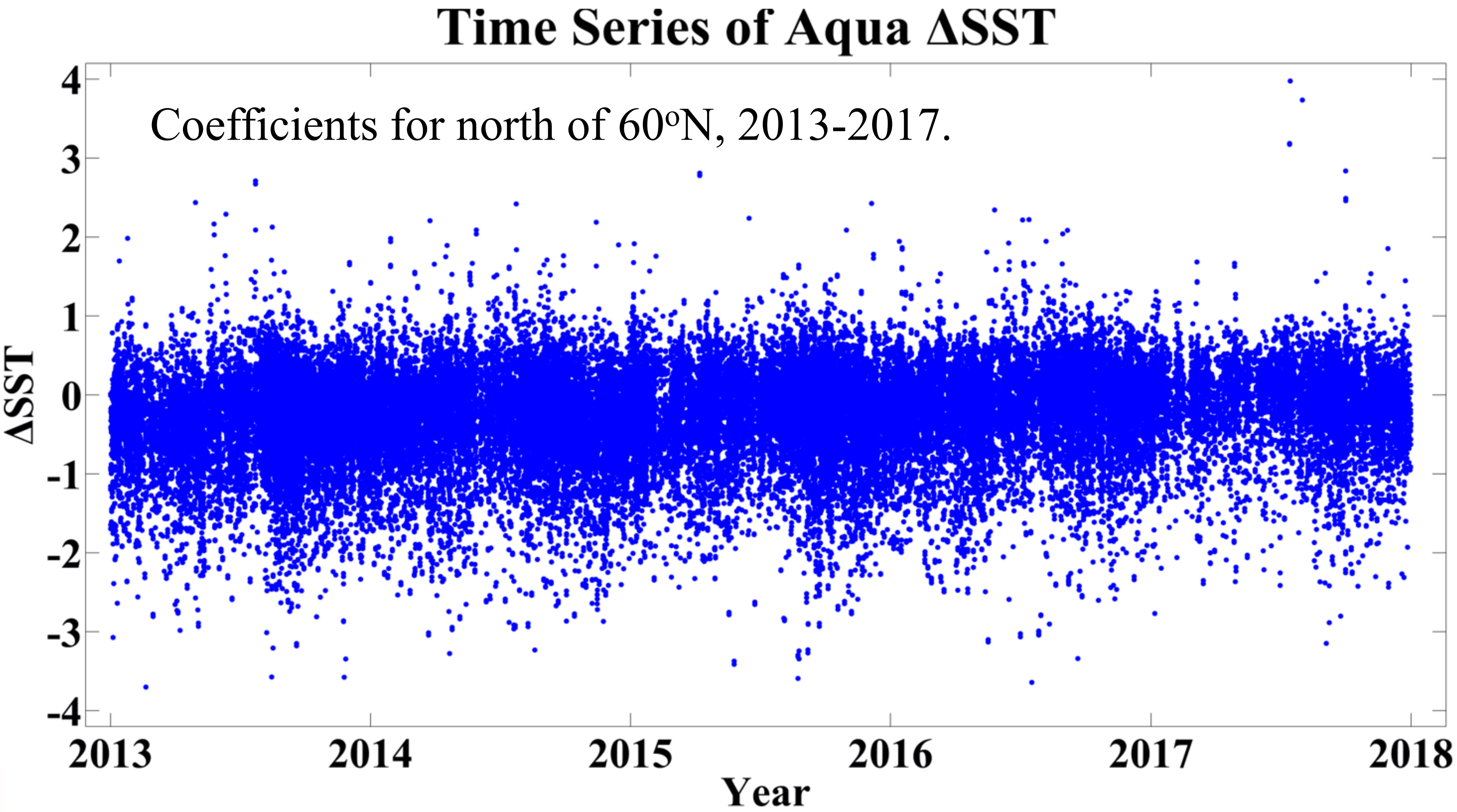
| ΔSST | > 1 K

MODIS SST$_{skin}$ – Buoy T, ≥ 60°N



UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE ATMOSPHERIC SCIENCE

MODIS SST_{skin} – Buoy T, ≥ 60°N



Aqua MODIS Accuracies; > 60^{o}N

Quality Level	N	Original coefficients				New coefficients			
		Mean	Median	STD	RSD	Mean	Median	STD	RSD
0	48799	-0.482	-0.430	0.560	0.448	-0.117	-0.087	0.489	0.405
1	17225	-0.686	-0.640	0.687	0.567	-0.635	-0.589	0.629	0.568
Total	66024	-0.535	-0.475	0.603	0.481	-0.252	-0.185	0.576	0.486

Aqua MODIS SST_{skin} – Buoy T, day and night, 2013-2017.
Original: coefficient for latitudes >40^{o}N; New: coefficients for latitudes >60^{o}N.
Main difference between QL0 and QL1 is path length: QL1 for $\theta > 55^o$.
R2014 data with BDTree cloud screening.

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Discrimination of Cloud and Sea Ice

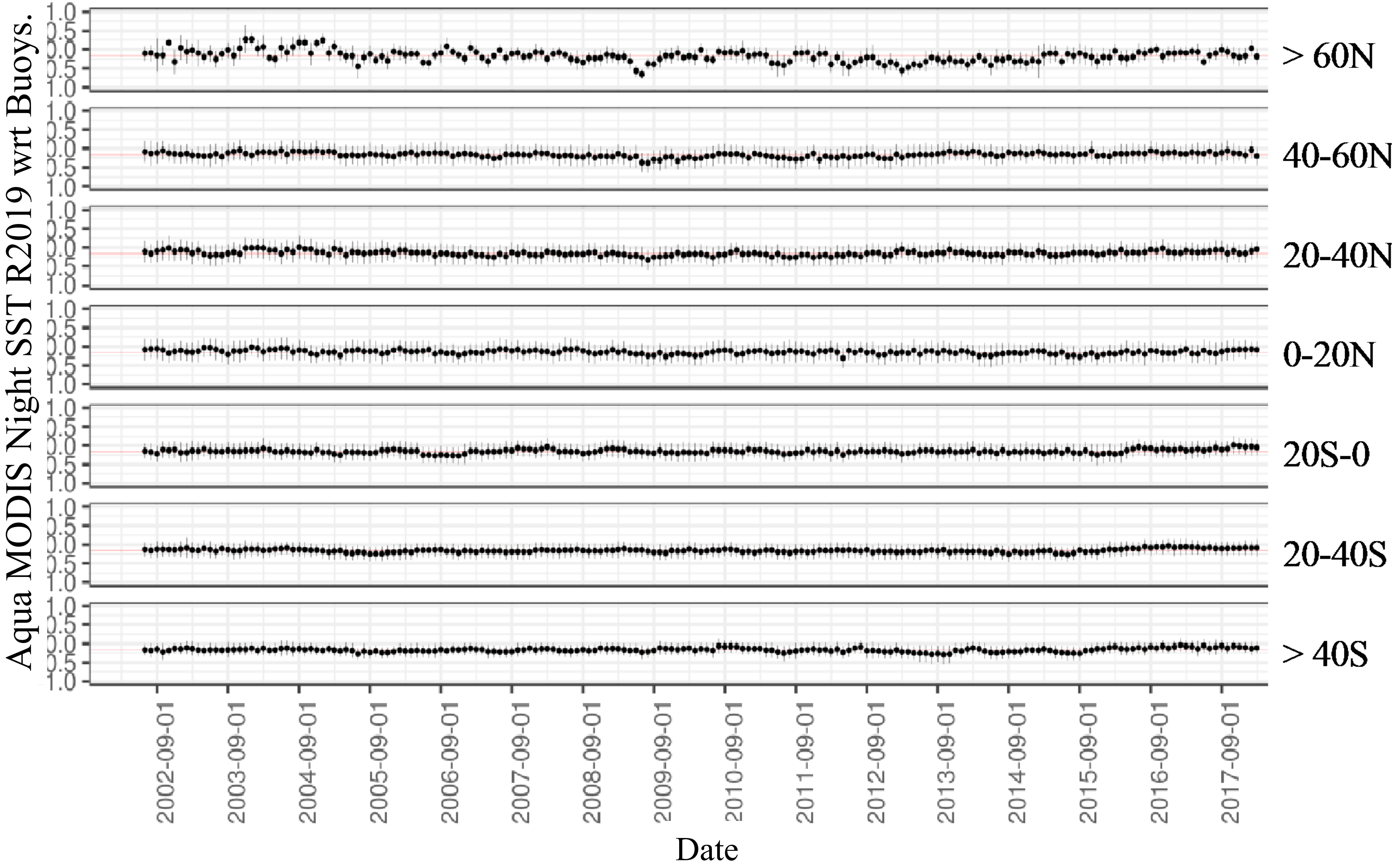
A day time flag for ice was introduced for R2019, using reflectances at 1.6 μm and 671 nm to reduce the misclassification of ice as open water during transitional ice conditions. The reflectance thresholds were determined from spectral histograms of images manually classified as snow or ice from Sentinel-2 MSI calibrated reflectance (Hollstein et. al. 2016).

The thresholds for the ice are:

$$(\rho(671\ \text{nm}) > 0.3)\ \&\ (0.1 > \rho(1.6\ \mu\text{m}) \geq 0.006)$$

Hollstein, A., Segl, K., Guanter, L., Brell, M., & Enesco, M. (2016). Ready-to-Use Methods for the Detection of Clouds, Cirrus, Snow, Shadow, Water and Clear Sky Pixels in Sentinel-2 MSI Images. *Remote Sensing 8*, 666.

Aqua MODIS SST_{skin} - Buoy T



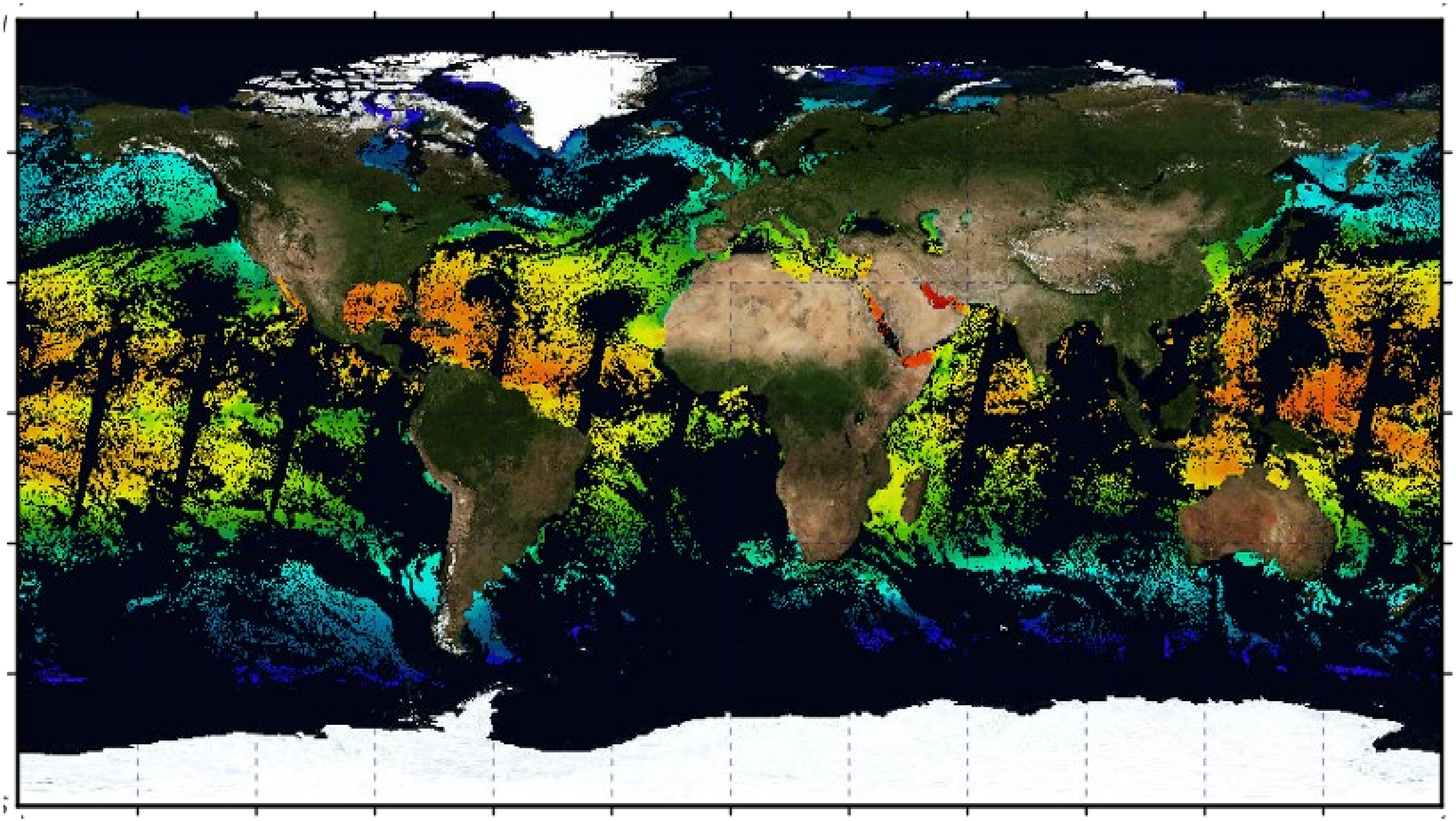
UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Night-time 4µm SST_{skin} (SST4)

- SST4 part of the R2019 reprocessing.
- Benefits from ADTree cloud screening.
- Benefits from coefficient split at 60°N.

$$\boldsymbol{SST4 = a_0 + a_1 * T_{3.9\mu m} + a_2(T_{3.9\mu m} - T_{4.0\mu m}) + a_3(sec(\theta) - 1) + a_4(mirror) + a_5(\theta^*) + a_6(\theta^2)}$$

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE



MODIS AQUA R2019 SST4 4 km daily field for September 23rd, 2016.

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Summary

- Both MODIS's are very stable and accurate instruments in the IR.
- R2019 algorithm developments improved coverage and accuracy.
- R2019 SST_{skin} fields are available at the OBPG (L2 and L3) and PO.DAAC (L2p and L3).
- MUDBs will be available soon.
- Future developments include new approach to SSES derivation and specification.
- Future research will focus on
  - Improvements to aerosol correction, including daytime corrections.
  - High-latitude improvements, including new algorithm formulation with explicit emissivity dependence and exploiting Saildrone data in the Arctic.

Outlook

- Both MODISs are in good physical and radiometric condition after > 20 years on orbit for Terra and > 18 years for Aqua.
- Prospects are good for MODISs and their satellites to continue for several years into the future.
- Funding for missions and science teams is through the NASA Senior Review process, which has a three-year cycle. Currently towards the second year. Proposal for continuing SST_{skin} for another three years have been submitted.

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

On-line ATBDS at

https://oceancolor.gsfc.nasa.gov/atbd/sst/

&

https://oceancolor.gsfc.nasa.gov/atbd/sst4/

Thank you.

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE