MODIS & S-NPP VIIRS Sea-Surface Temperatures

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Overview

1. Ship-borne radiometers for algorithm improvements and assessment of accuracies of satellite-derived SSTs:
    a) M-AERI & ISAR deployments
    b) MODIS & VIIRS matchups
2. SST algorithm improvements
    a) Alternating Decision Tree Cloud Screening
    b) Aerosol corrections
    c) Optimal Estimation of MODIS SSTs.
3. Generation of CDRs
    a) M-AERI accuracies.
    b) Drifting buoy accuracies.
    c) Saildrone deployments.

M-AERI & ISAR deployments

- M-AERI (Marine-Atmospheric Emitted Radiance Interferometer) is Fourier-Transform IR spectroradiometer with SI-traceable calibration. Initial installations began in 1996.
- Three Mk2 M-AERI's are deployed on Royal Caribbean Cruise Line ships.
- One Mk3 deployed on the NOAA Ship *Ronald H Brown* on a circumnavigation: USA – South Africa – India – Australia – Hawaii – Panama – USA.
- M-AERIs now operate autonomously over satellite internet link.
- ISAR (Infrared Sea-Surface Temperature Autonomous Radiometer) is a filter radiometer with SI-traceable calibration.
- ISARs first deployed on NYK ships on July 11, 2005. Terminated May

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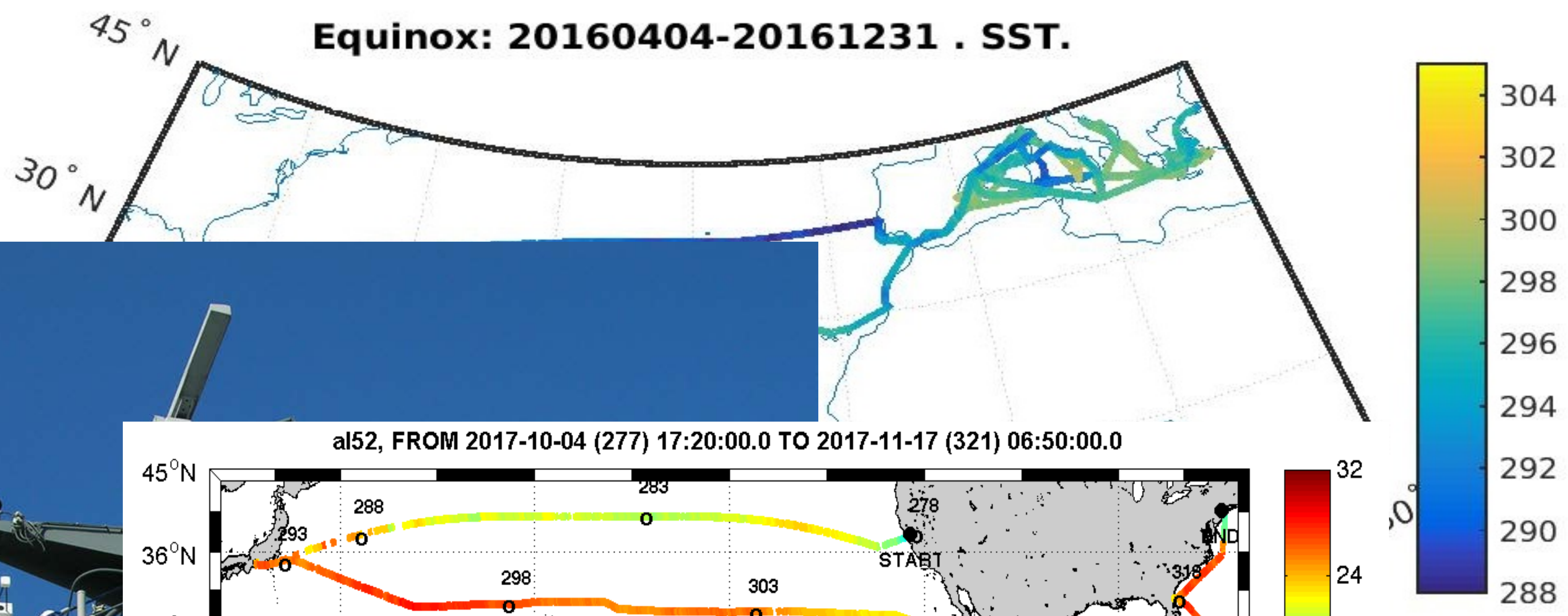
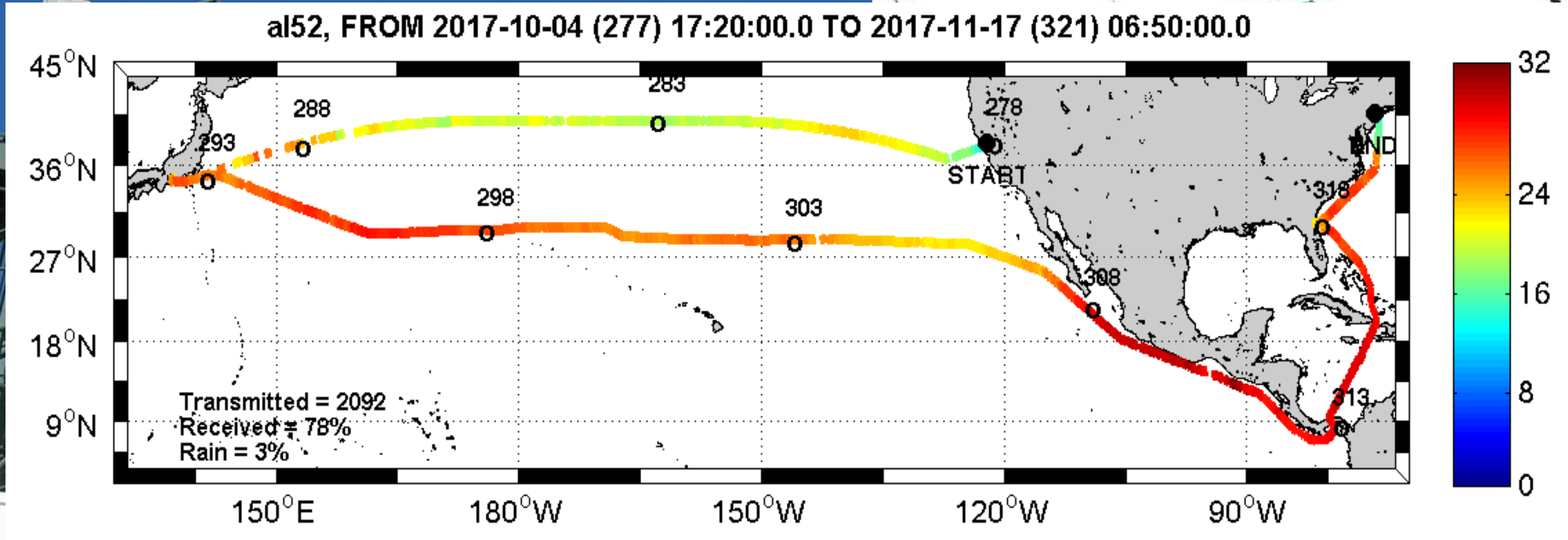
M-AERI Mk



ı M-AERI



Track of the M/V *Andromeda Leader* from 4 October to 17 November 2017. The colors indicate the skin SST derived from ISAR measurements, in °C, given on the scale at right.

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MODIS matchups

Gross statistics of the comparison of skin SST derived from MODIS on Aqua and M-AERI measurements.						
Ship	Year	Mean K	Median K	St. Dev. K	Robust St. Dev. K	N
Atmospheric correction algorithm: LW Bands 31 & 32 (SST)						
Allure of the Seas	2015	-0.007	0.009	0.437	0.315	1124
Celebrity Equinox	2016	0.068	0.111	0.474	0.342	1563
Atmospheric correction algorithm: MW Bands 22 & 23 (SST4)						
Allure of the Seas	2015	-0.086	-0.014	0.352	0.254	1153
Celebrity Equinox	2016	0.084	0.125	0.375	0.270	1597
Highest quality, night-time data: confidently cloud-free & satellite zenith angle <45°.						

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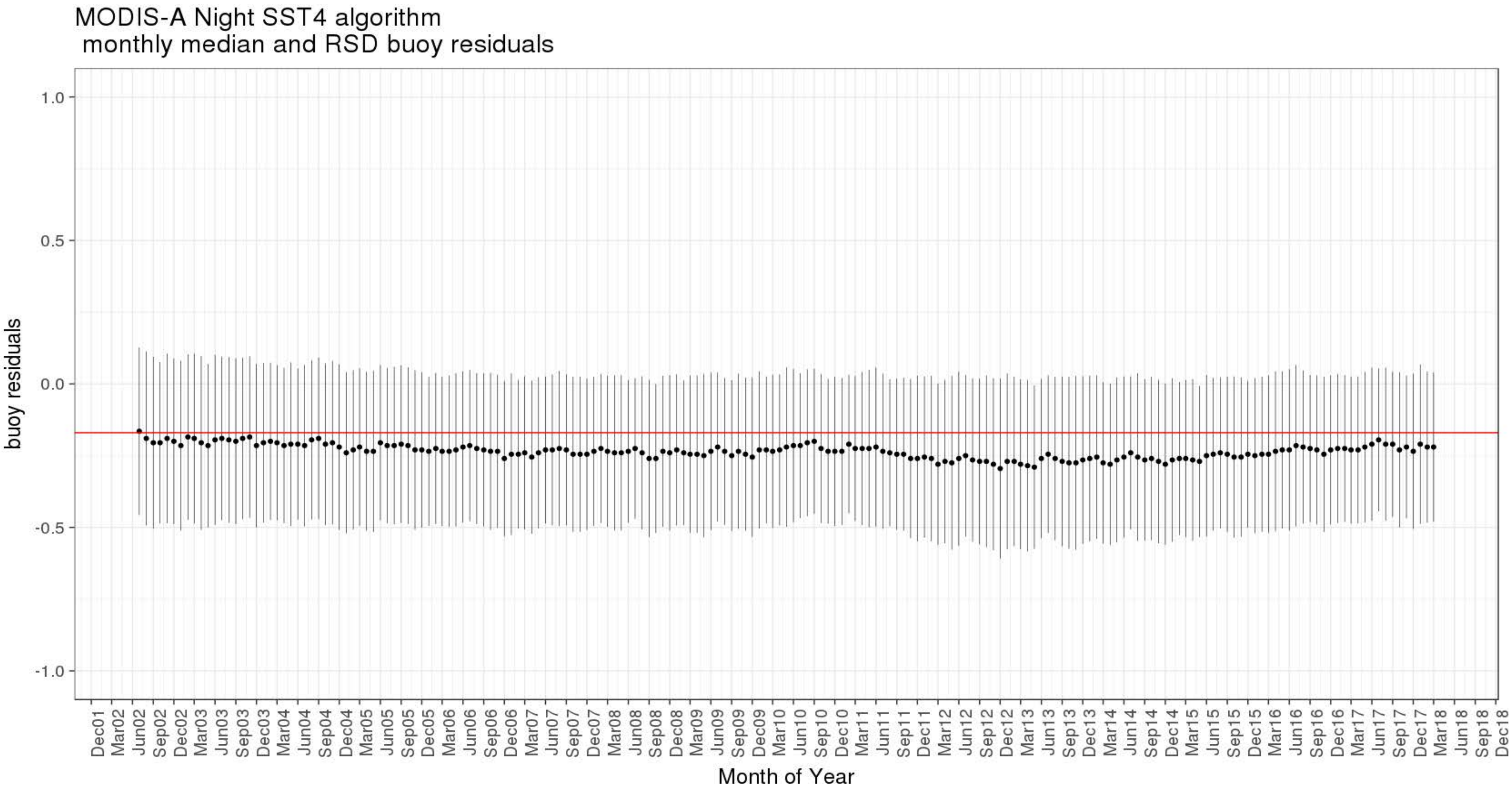
Aqua MODIS SST4 Median and RSD vs drifters



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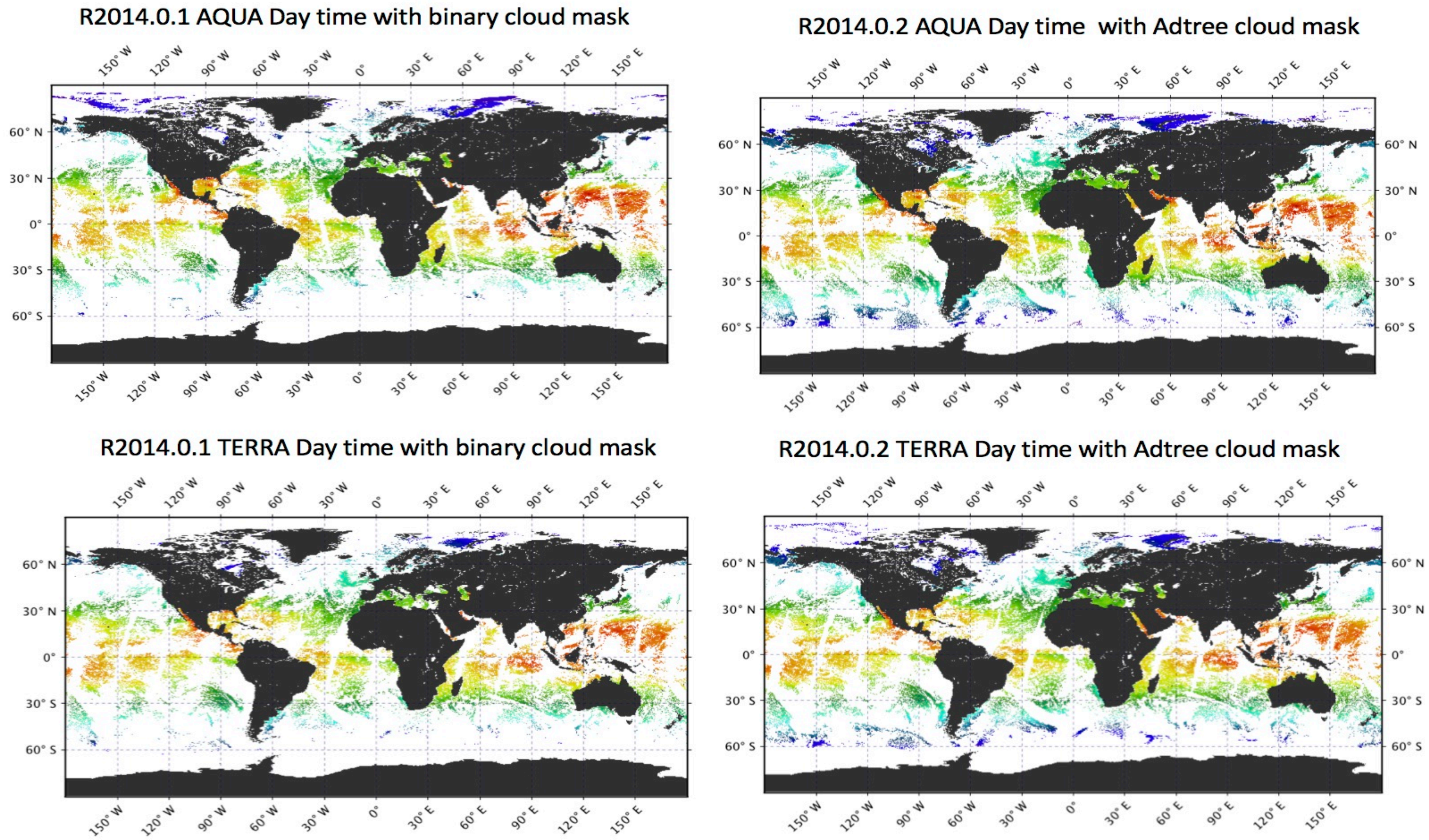
SST Algorithm Developments – Cloud Screening

New cloud mask developed – Alternating Decision Trees.



Kilpatrick, et al. (2018). Alternating Decision Trees for cloud masking MODIS and VIIRS NASA SST products. *Journal of Atmospheric and Oceanic Technology*. In

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SST Algorithm Developments – Aerosol Effects

- Two step approach: 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.

Dust-induced SST Difference Index (DSDI) algorithm based on simulated brightness temperatures (BTs) at infrared wavelengths of 3.9, 8.7, 10.8 and 12.0 µm,

$$DSDI = a + (b + c \times S_0) \times (BT_{3.8} - BT_{12}) + d \times (BT_{3.8} - BT_{3.9}) +$$

$$(e + f \times S_0) \times (BT_{11} - BT_{12}) + (g + h \times S_0) \times (BT_{11} - BT_{12})^2$$

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

When DSDI > 0.8, aerosol correction term, added to NLSST atmospheric correction:

$$DSDI_{Correction} = 0.628 \times DSDI^2 - 4.528 \times DSDI + 2.071$$

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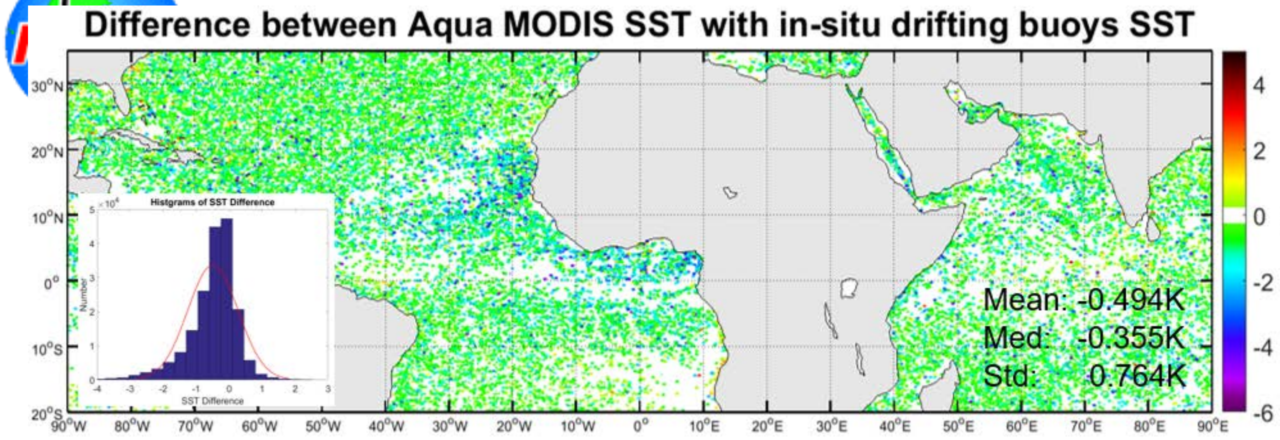
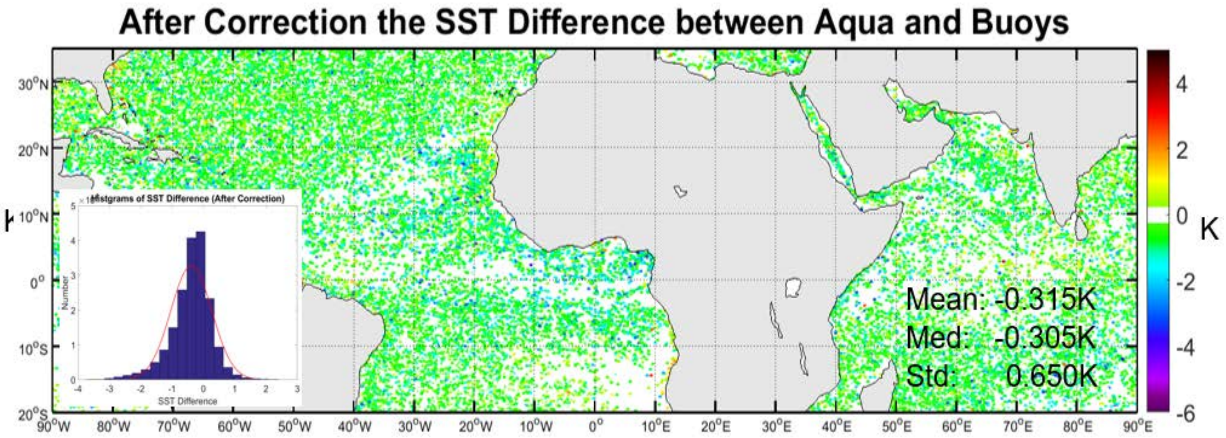
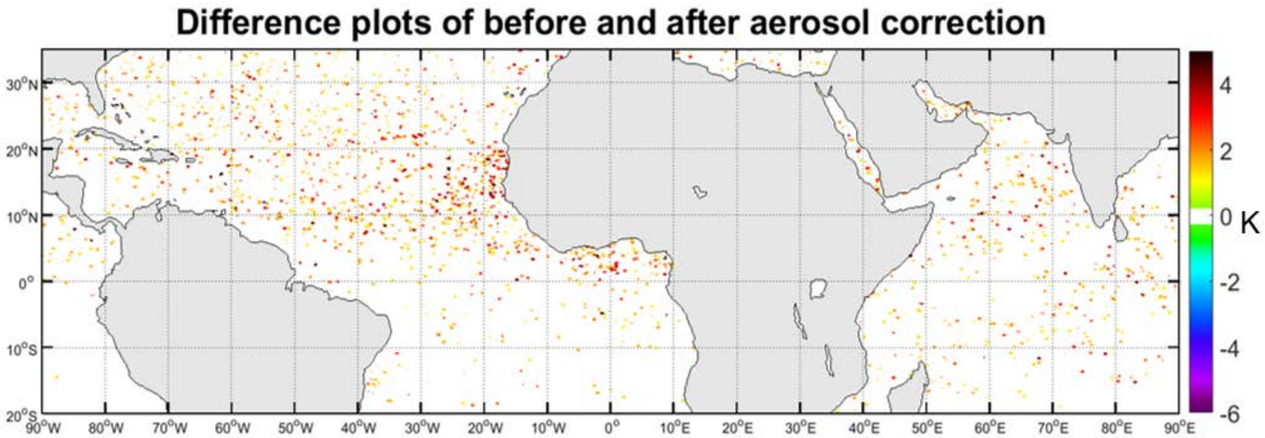
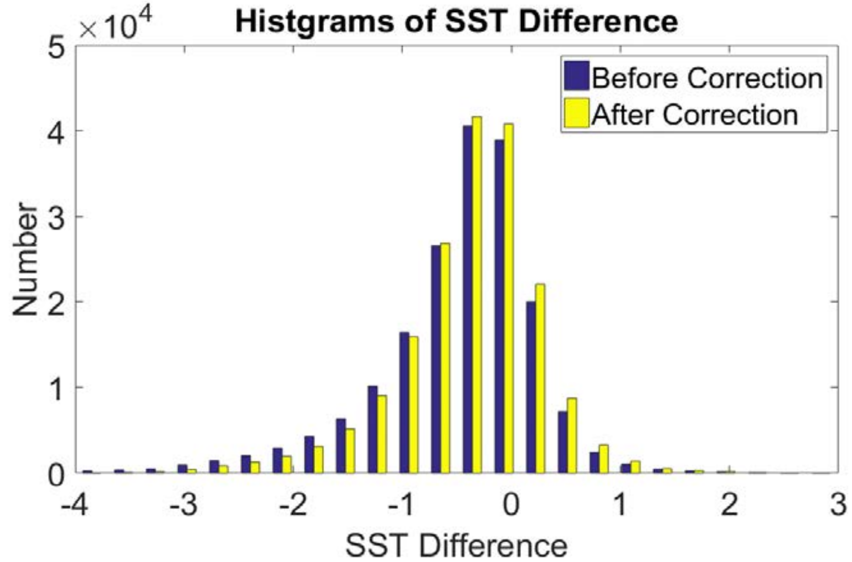








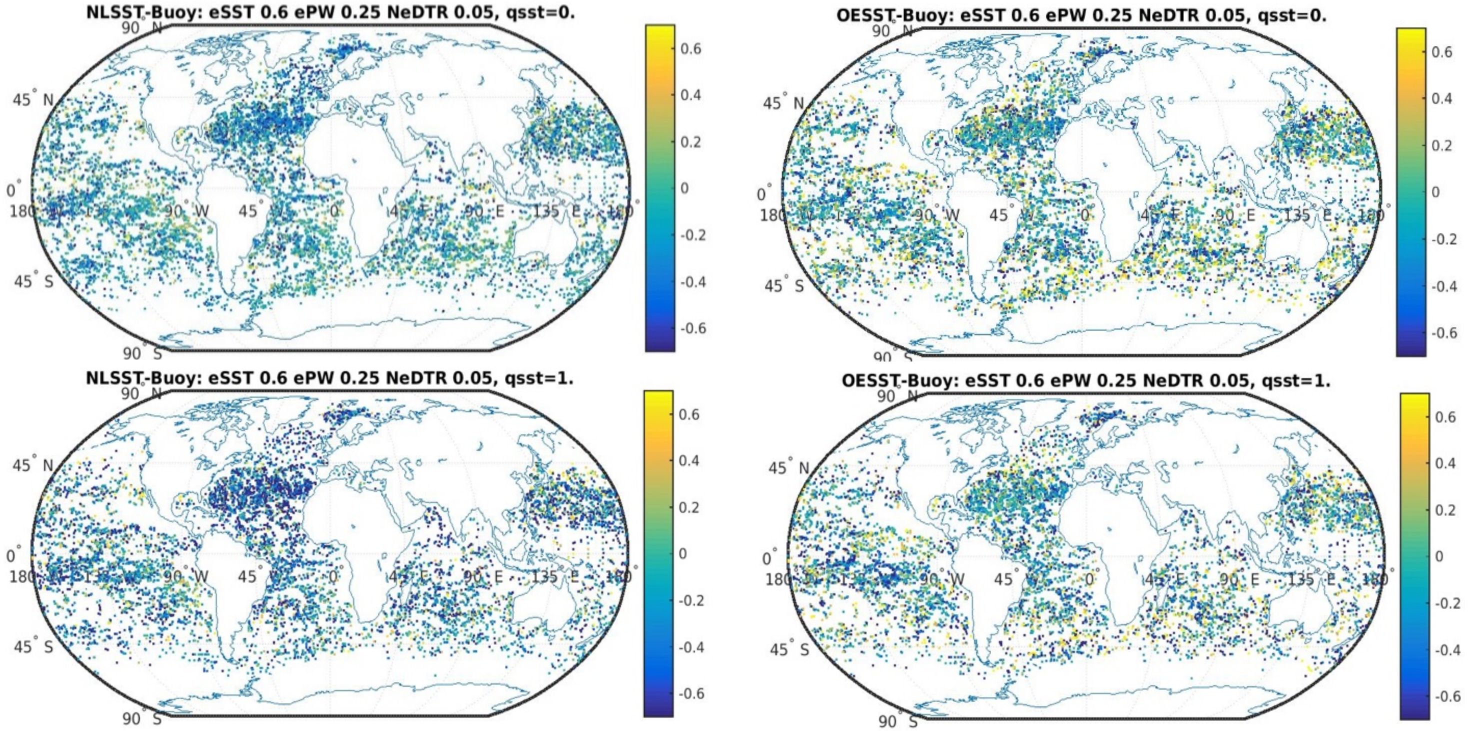
Quality Flag	N	Before correction (K)			After correction (K)		
		Mean	Median	STD	Mean	Median	STD
0	86092	-0.217	-0.190	0.458	-0.203	-0.185	0.447
1	47030	-0.482	-0.435	0.649	-0.401	-0.380	0.625
2	50919	-0.974	-0.830	1.003	-0.678	-0.612	0.845
All	184041	-0.494	-0.355	0.764	-0.315	-0.305	0.650

Luo, B., Minnett, P.J., Gentemann, C., & Szczodrak, G. (2018). Improving satellite retrieved infrared sea-surface temperatures in aerosol contaminated regions. *Remote Sensing of Environment, In review.*

Combining NLSST and Optimal Estimation MODIS SSTs

Determine whether the combined NLSST and OE approach derives a more accurate SST_{skin} (for cloud free conditions) than currently available from MODIS NLSSTs.

Hybrid estimates may be less dependent on atmospheric variability than NLSST retrievals.



MODIS SST_{skin} – in situ temperature difference for the 2009 match-up database data for NLSST and OESST Quality = 0 (top) and quality = 1 (bottom)

QFlag	ε_{SST}	ε_{WV}	$\varepsilon_{11}=\varepsilon_{12}$	NL-Buoy		OE-Buoy	
				Mean	RSD	Mean	RSD
0	0.4	0.05	0.04	-0.187	0.345	-0.152	0.472
1	0.4	0.05	0.04	-0.403	0.512	-0.233	0.495

Slight degradation in RSD for QF = 0 when using OE; but improvement, especially in the mean, for QF = 1

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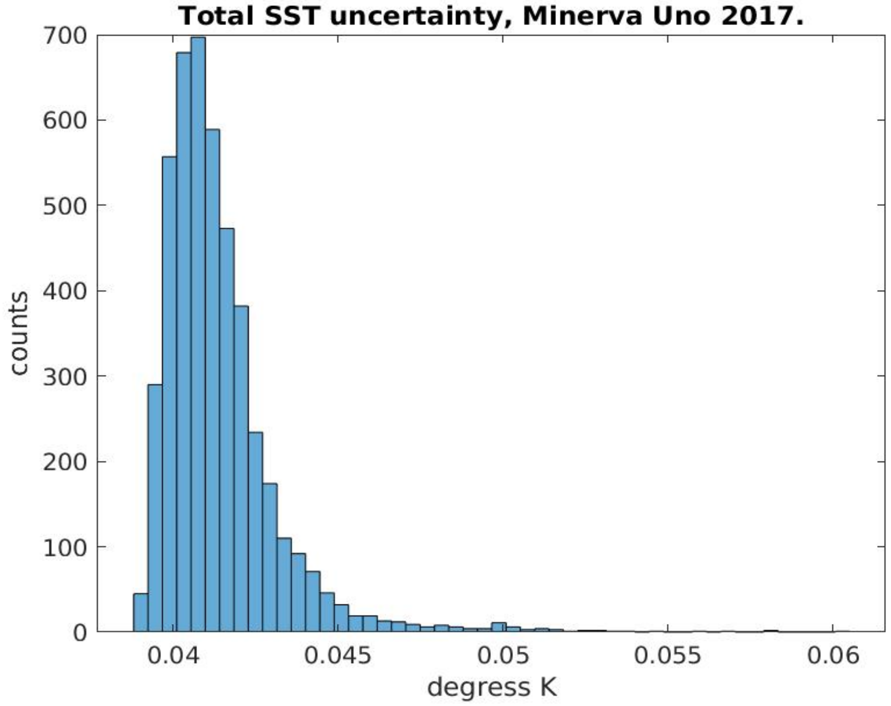
Temperature Differences *vs* Assessment of Accuracy

- Statistics shown here (and in many papers and reports) of differences between satellite and validating SSTs are often interpreted as an assessment of the accuracy of the satellite measurements – assumes contributions to the differences from the validating sensor and from the method of comparisons are negligible. This is not always the case.
- To generate SST CDRs, a rigorous assessment of the accuracies of the measurements used to validate the satellite SST retrievals is needed.

M-AERI Mk2 accuracies – CEOS NPL Workshop

At λ= 7.7 µm (1302 cm^{-1})			
Parameter	Type A Uncertainty Value [K]	Type B Uncertainty in K	Uncertainty in Brightness temp in K
Repeatability of Measurement	0.0349		0.0349
Reproducibility of Measurement	0.0178 (0.0089)		0.0178
Linearity of radiometer		0.0003	0.0003
Primary calibration		0.0086	0.0086
Drift since calibration			0
RMS total	0.0392 (0.0360)	0.0091	0.0402 (0.0372)



International Shipborne Radiometer Network (ISRN) L2R specifications.

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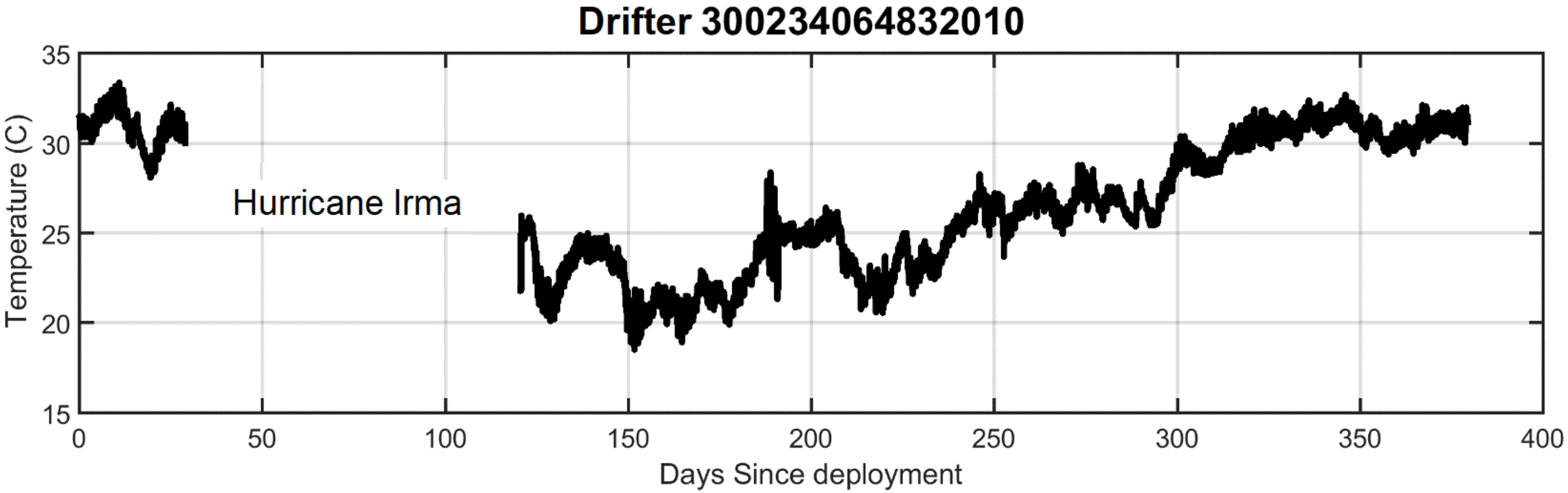
Drifting buoy thermometer accuracies

- The underpinning of the MODIS SST algorithms to drifting buoy matchups places great importance on the accuracy of the buoy thermometers.
- Thermometers are calibrated prior to deployment, but do they retain calibration at sea over months to years?
- Drifting buoys from three manufacturers are moored off RSMAS dock for long-duration deployment to assess calibration drift and effects of bio-fouling.
- A reference thermometer, with SI-traceable calibration, in a modified buoy provides a benchmark.



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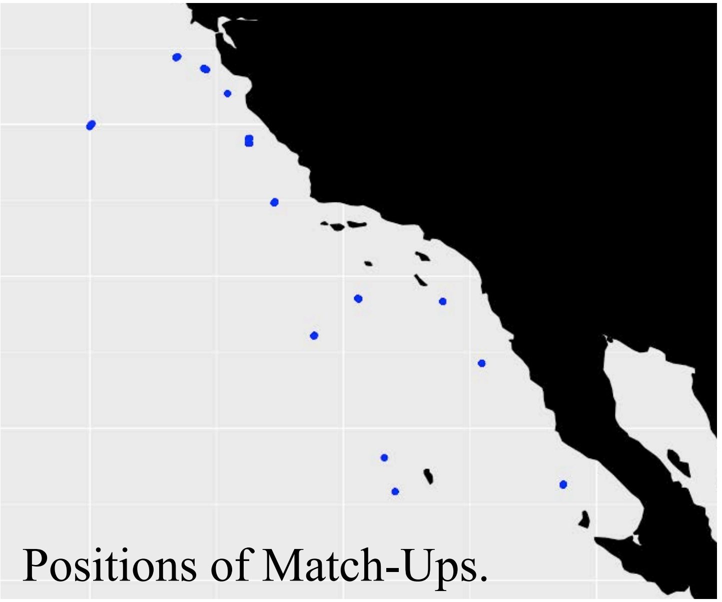
Saildrone deployments.

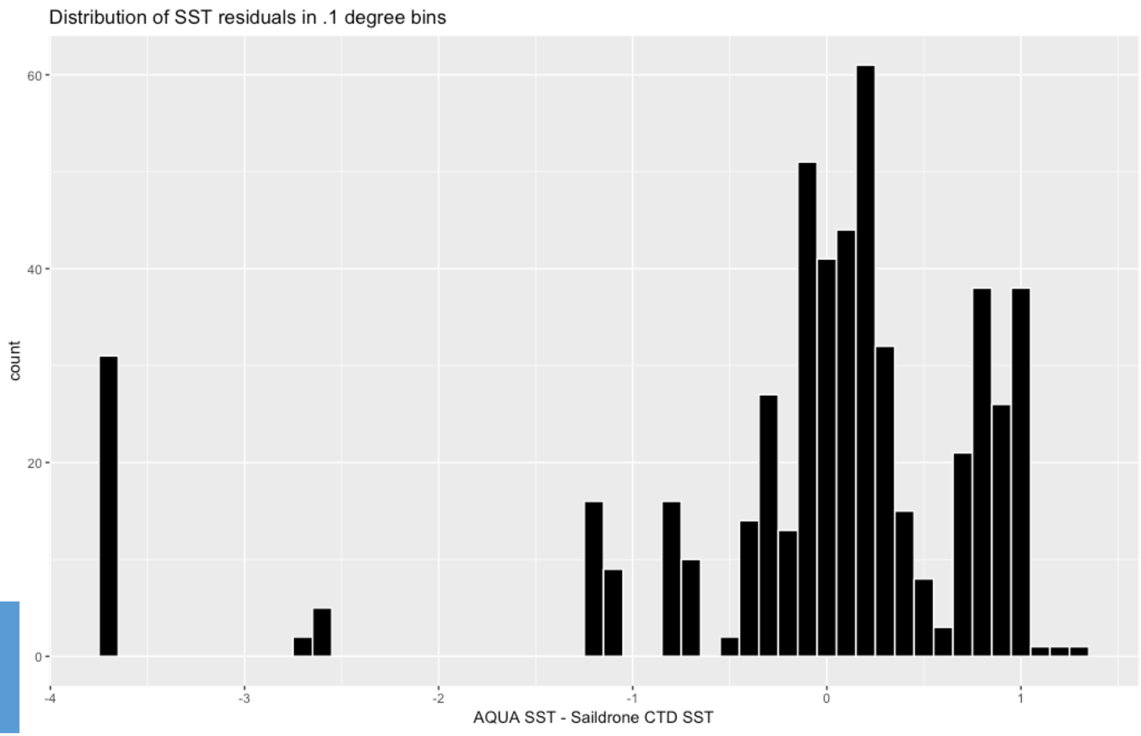
- In the NOPP MISST-3* (Multi-sensor Improved SST) project, we will deploy Saildrones in the ice-free summer Arctic to provide data for improving SSTs from IR radiometers on satellites.
- Although Saildrones have a simple IR radiometer, its absolute accuracy is questionable and the reflected sky radiance correction is not feasible.
- In a pilot project we deployed a Saildrone off the West Coast, 11 April – 10 June 2018, we

* PI: Chelle Gentemann, Earth & Space Research
CoIs: Mike Steele, APL, U Washington
Peter Minnett, RSMAS, U. Miami

Saildrone: Aqua MODIS comparisons



Positions of Match-Ups.



Histogram of Aqua MODIS SST_{skin}–Saildrone CTD SST .

Night best quality all records – multiple Saildrone temperatures in MODIS pixel			
Median	St Dev	RSD	N
0.092	1.096	0.399	526
Night best quality unique – closest Saildrone temperature in MODIS pixel.			
0.154	0.87	0.248	39

Preliminary results

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Summary

- Both MODIS's are very stable instruments, in the IR.
  - Algorithm developments are improving accuracy.
  - Coefficients in algorithms need updating.
- VIIRS is also a very good (better?) sensor.
  - ditto
- Methodology for generating SST Climate Data Records is understood….
  (Minnett, P.J., & Corlett, G.K. (2012). A pathway to generating Climate Data Records of sea-surface temperature from satellite measurements. *Deep Sea Research Part II: Topical Studies in Oceanography, 77–80*, 44-51)
- Focus on improving high latitude SSTs (MISST-3).
- Attempts to characterize stability of drifter temperatures.
- Working to understand potential of Saildrone data in assessment of satellite SST accuracies.

Funding status

- Now funded through Senior Review for SST from MODIS on both Aqua and Terra.
- Funded through NASA PO to combine OESST and NLSST for MODIS.
- Funded through USPI (NASA PO) for SLSTR (ESA) and METimage (EUMETSAT) SST accuracies.
- Funded through NOPP (NASA PO) for MISST-3: High Latitude SST.
- **Not** funded for S-NPP VIIRS SST, so continuity SST now an orphaned product.

Data availability

MODIS & VIIRS (C6) SSTs from NASA OBPG at OB.DAAC website:

http://oceancolor.gsfc.nasa.gov/

MODIS & VIIRS MUDBs from NASA OBPG at OB.DAAC website:

https://seabass.gsfc.nasa.gov/archive/SSTVAL

MODIS (C6) SSTs in GHRSST L2P format from the NASA PO.DAAC at JPL:

https://podaac.jpl.nasa.gov/dataset/JPL-L2P-MODIS_A

https://podaac.jpl.nasa.gov/dataset/JPL-L2P-MODIS_T

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- Luca Centurioni (SIO) & Rick Lumpkin (NOAA-AOML): drifters and telemetry.
- Saildrone Inc. & The Schmidt Family Foundation: funding Saildrone pilot project.

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Thank you.