MODIS/VIIRS Sea-Surface Temperatures

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Algorithm continuity – MODIS to VIIRS

- The ROSES objective is to demonstrate compatibility between MODIS (Terra and Aqua) SST retrievals and those of S-NPP VIIRS to lead to the production of a Consistent Data Record, and then to a Climate Data Record.
- Consistency can be achieved by using, over multiple missions, comparable cloud-screening and atmospheric correction algorithms, and using same approaches to estimate errors and uncertainties.

C(onsistent)DRs to C(limate)DRs

- Temperature Climate Data Records are more demanding, requiring traceabilty of calibration history to SI standards, and this requires ship-board radiometers with calibration referenced to NIST, or NPL, standards.
- SST accuracy requirements are very stringent: absolute accuracy of 0.1K, and decadal stability of 0.04K

(Ohring, G., Wielicki, B., Spencer, R., Emery, B., & Datla, R., 2005. Satellite Instrument Calibration for Measuring Global Climate Change: Report of a Workshop. *Bulletin of the American Meteorological Society, 86*, 1303-1313)

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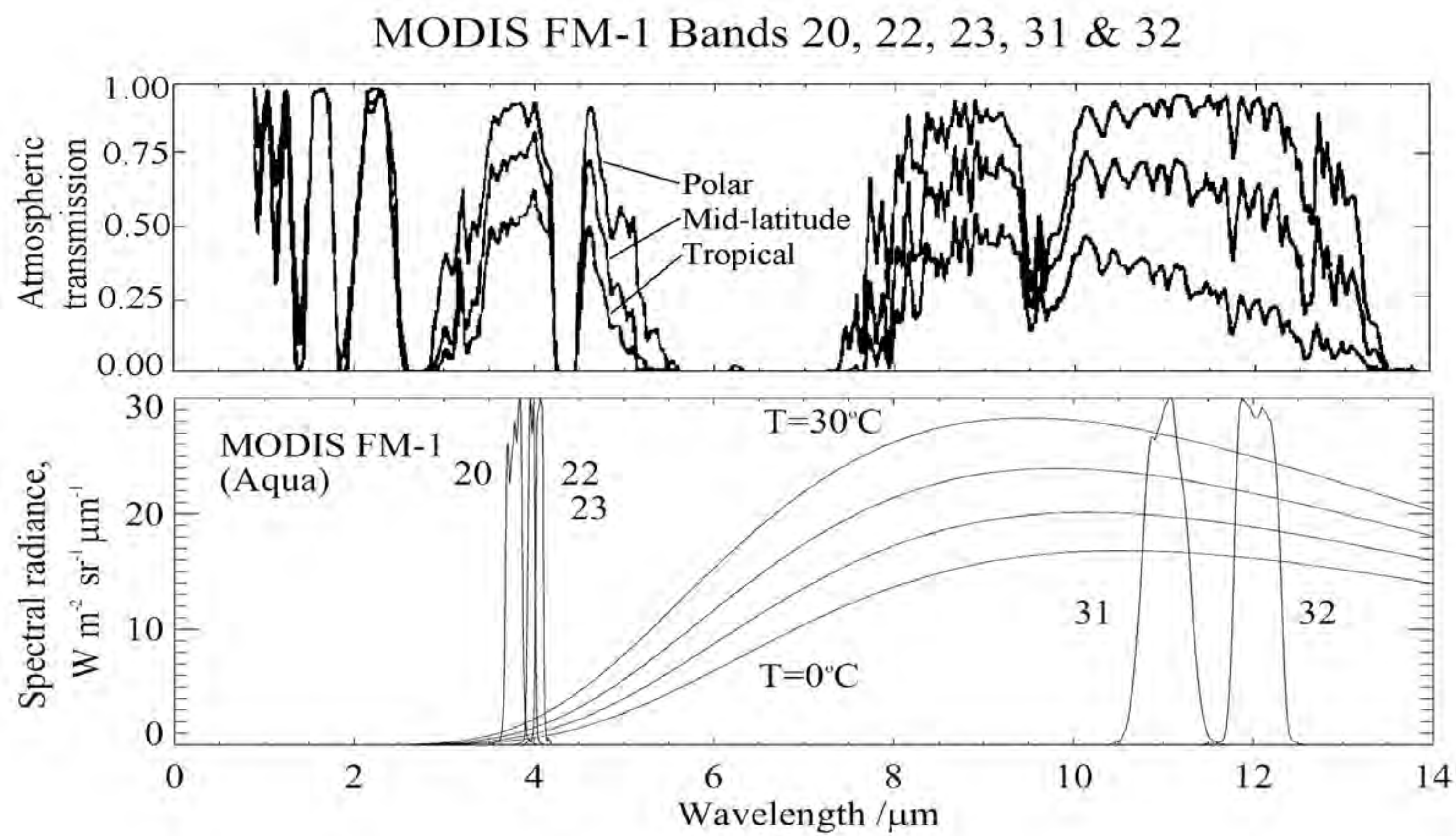
Atmospheric transmissivity in the infrared



Spectral dependence of the atmospheric transmission for wavelengths of electro-magnetic radiation from about 1 to 14 µm, for three characteristic atmospheres (above), and (below) the black-body emission for temperatures of 0, 10, 20 and 30ºC, and the relative spectral response functions of the bands MODIS (Flight Model 1) on *Aqua* used to derive SST.

NLSST Retrieval Equation

Non-Linear SST algorithm (day and night, cloud and aerosol free):

$$SST = c_1 + c_2 * T_{11} + c_3 * (T_{11} - T_{12}) * T_{sfc} + c_4 * (\sec(\theta) - 1) * (T_{11} - T_{12})$$

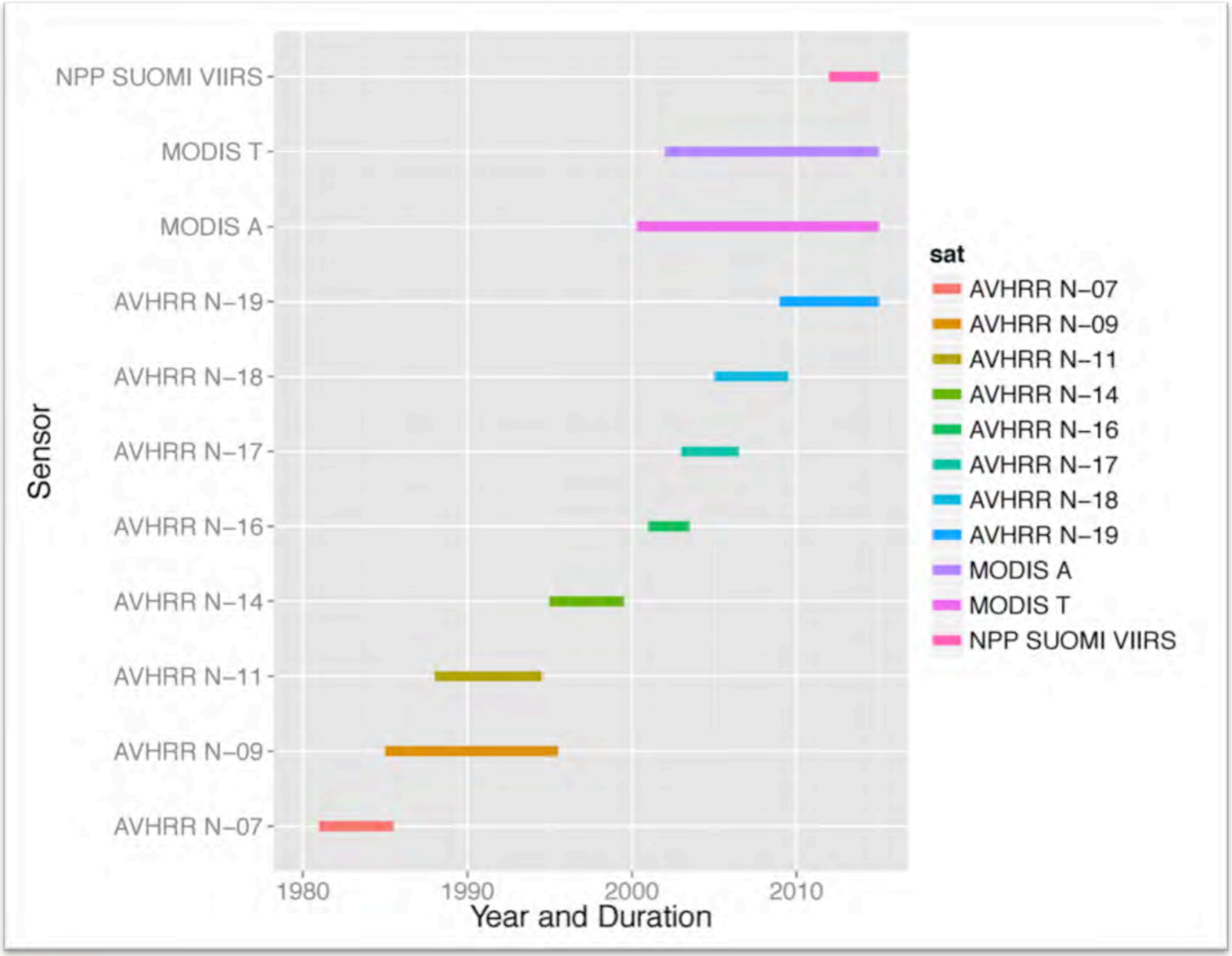
where T_n are brightness temperatures measured in the channels at n μm wavelength, T_{sfc} is a 'climatological' estimate of the SST in the area, and θ is the satellite zenith angle. For MODIS, T_{11} from Band 31, T_{12} from Band 32.

c_i are coefficients, not necessarily constant. There are uncertainties associated with their derivation – both for rte and matchups.

Applicable to cloud-free conditions only; residual effects from cloud screening and aerosol radiances add uncertainties….

(Walton et al, (1998). The development and operational application of nonlinear algorithms for the measurement of sea surface temperatures with the NOAA polar-orbiting environmental satellites. *Journal of Geophysical Research* **103** 27,999-28,012.)

Time Series of Satellites



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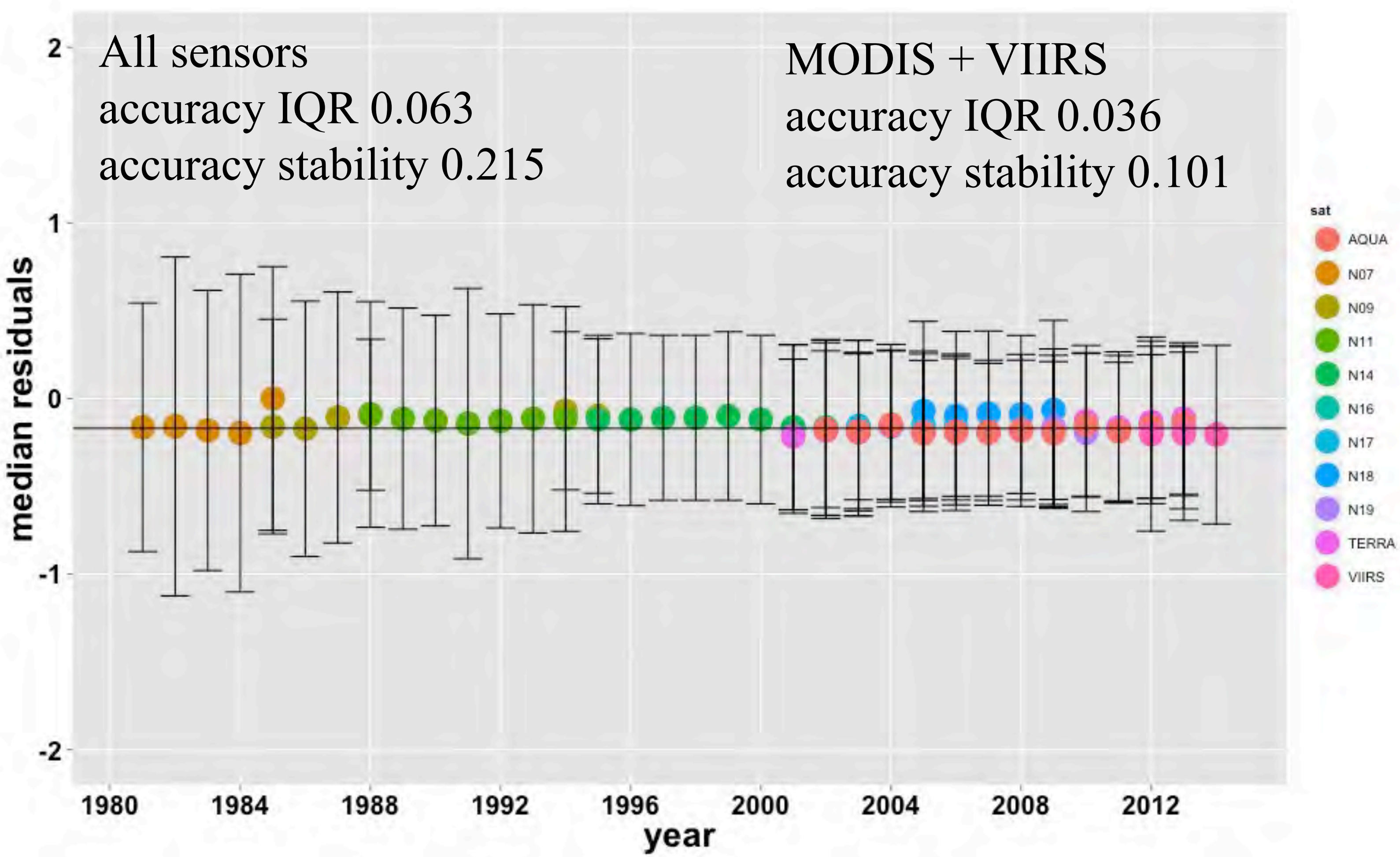
Consistent Data Record



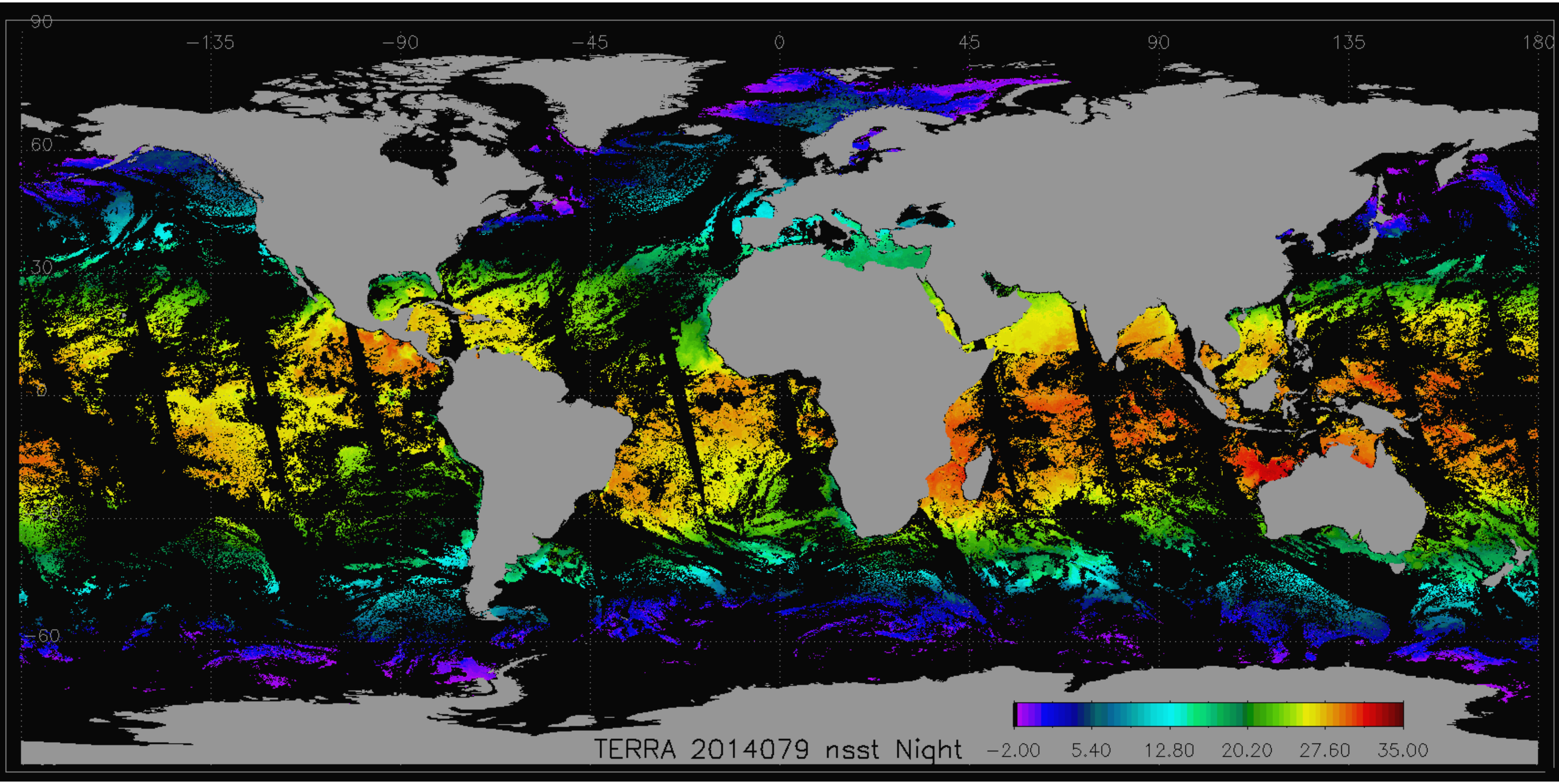
MODIS SST4

Measurements in mid-IR atmospheric transmission window have potential to provide better SSTs

$$SST4 = c_1 + c_2 * T_{3.9} + c_3 * (T_{3.9} - T_{4.0}) + c_4 * (\sec(\theta) - 1)$$

But can only be used confidently at night, due to reflection of solar radiation at the sea surface, and scattering from the atmosphere.

Terra MODIS night SST



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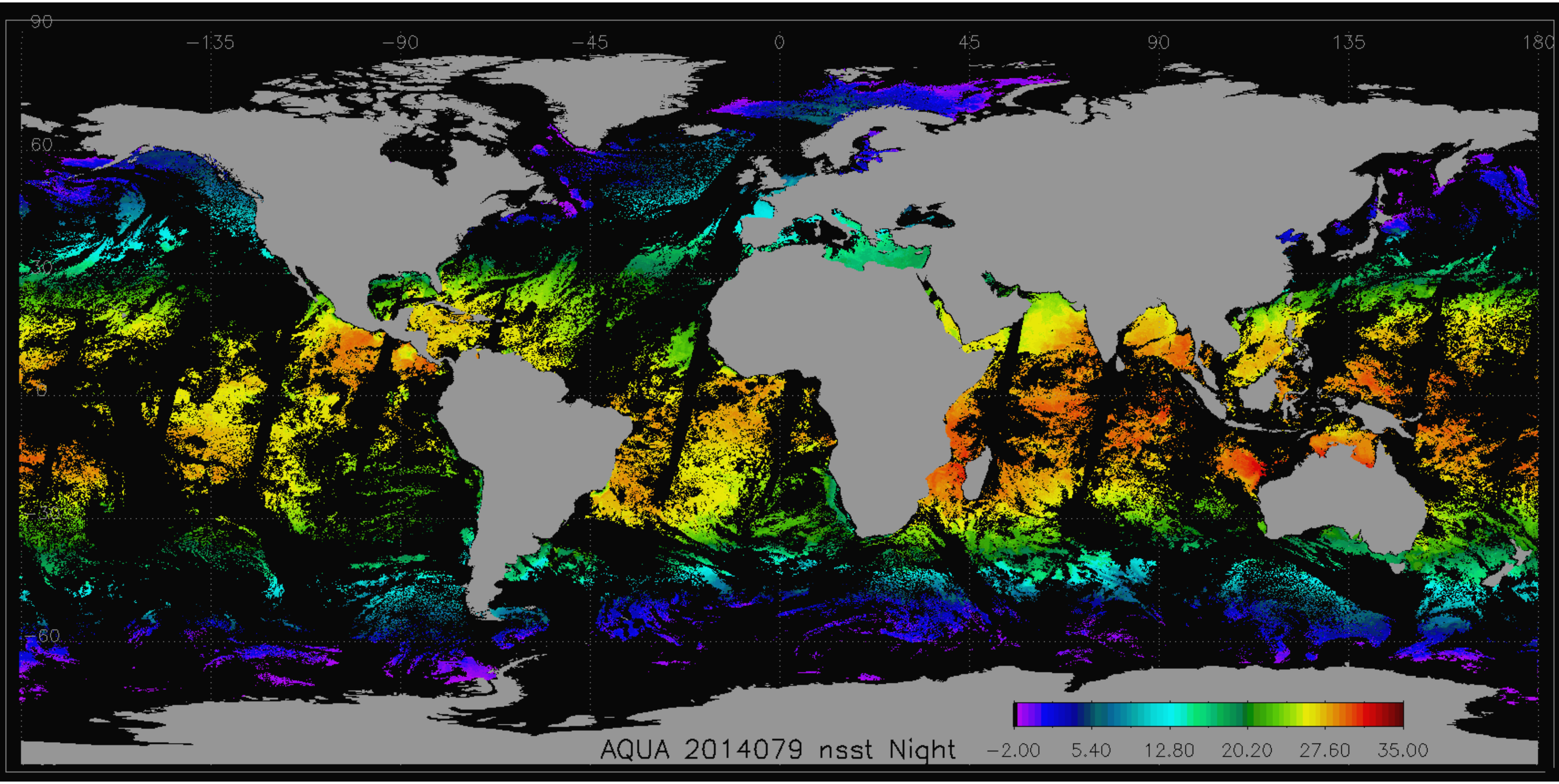
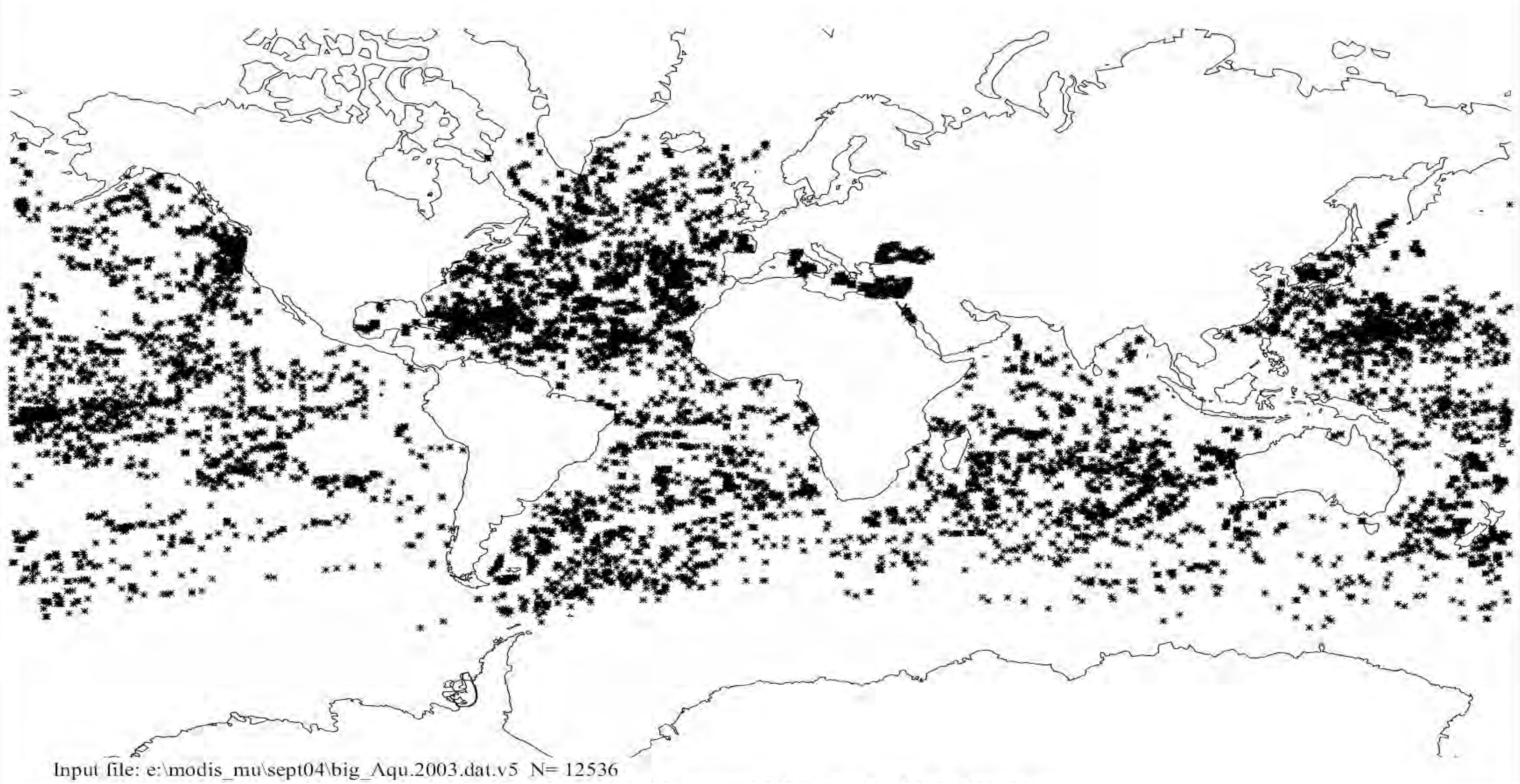
MODIS/VIIRS Science Team Meeting
21 May 2015

Aqua MODIS night SST

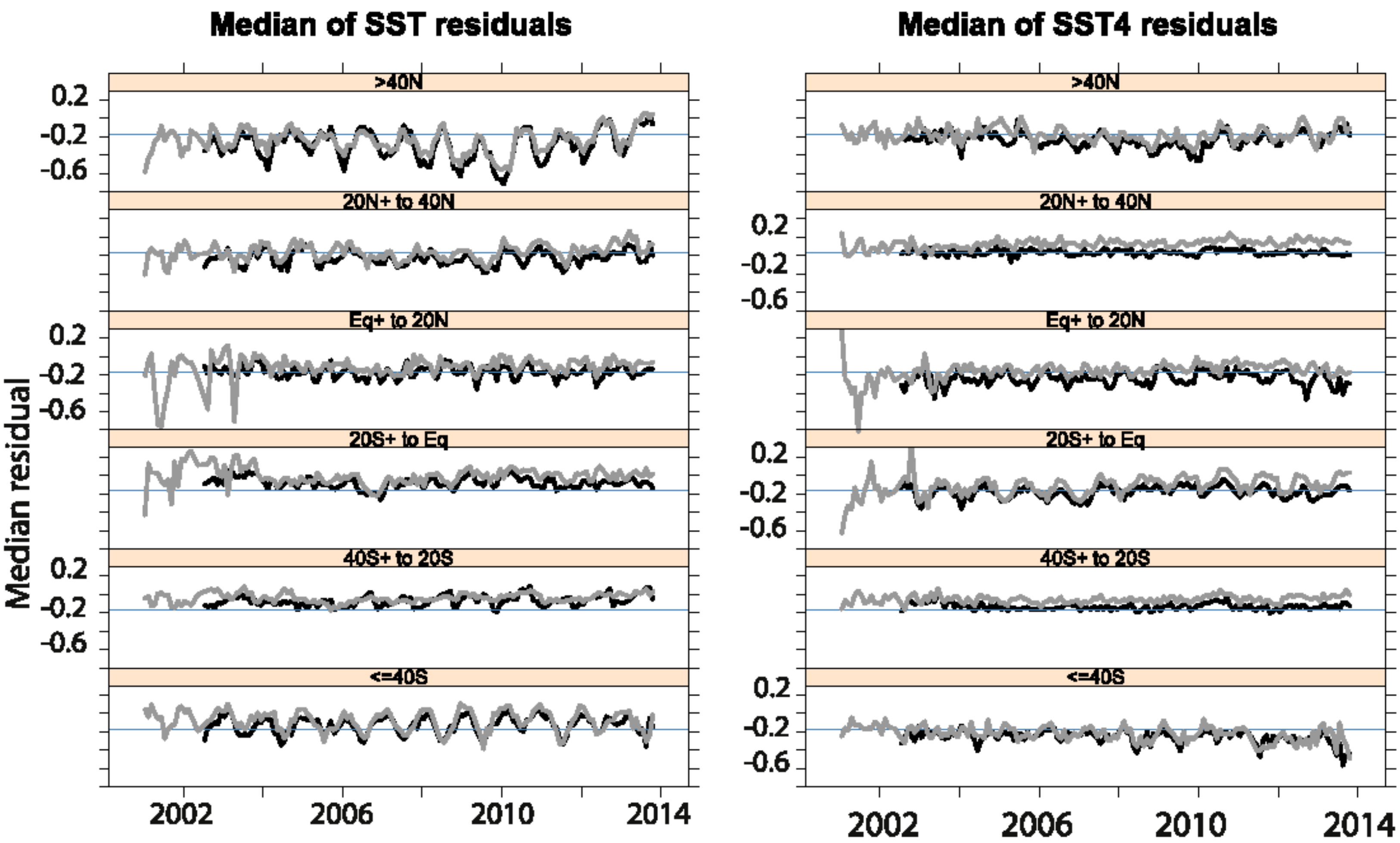


Validation with buoys



C5 Aqua MODIS ql=0 matchup with buoys. 2003. N=12536.

C5 MODIS median errors



From Kilpatrick et al., 2015. A decade of sea surface temperature from MODIS. *Remote Sensing of Environment*, **165**, 27-41

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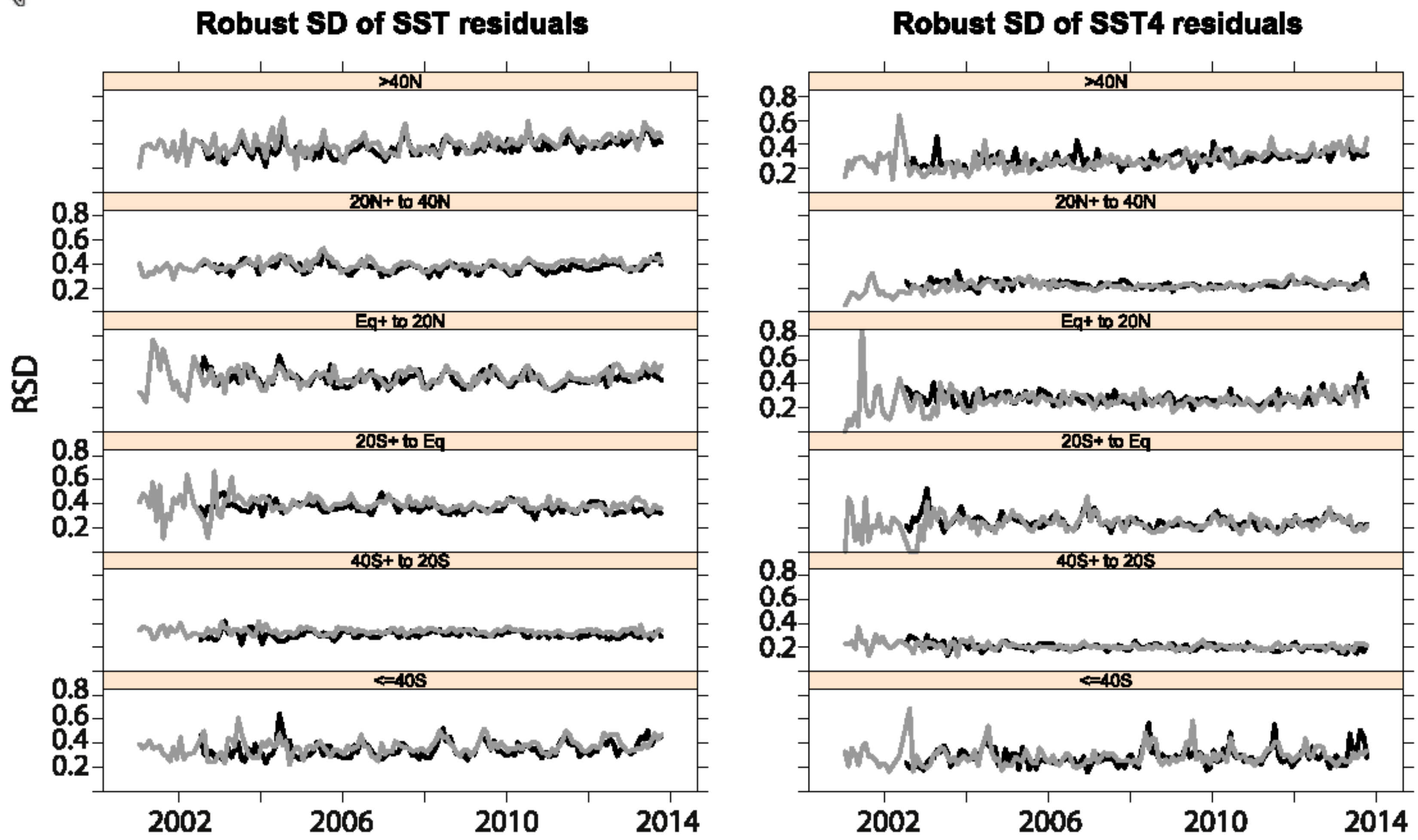
C5 MODIS uncertainties



From Kilpatrick et al., 2015. A decade of sea surface temperature from MODIS. *Remote Sensing of Environment*, **165**, 27-41

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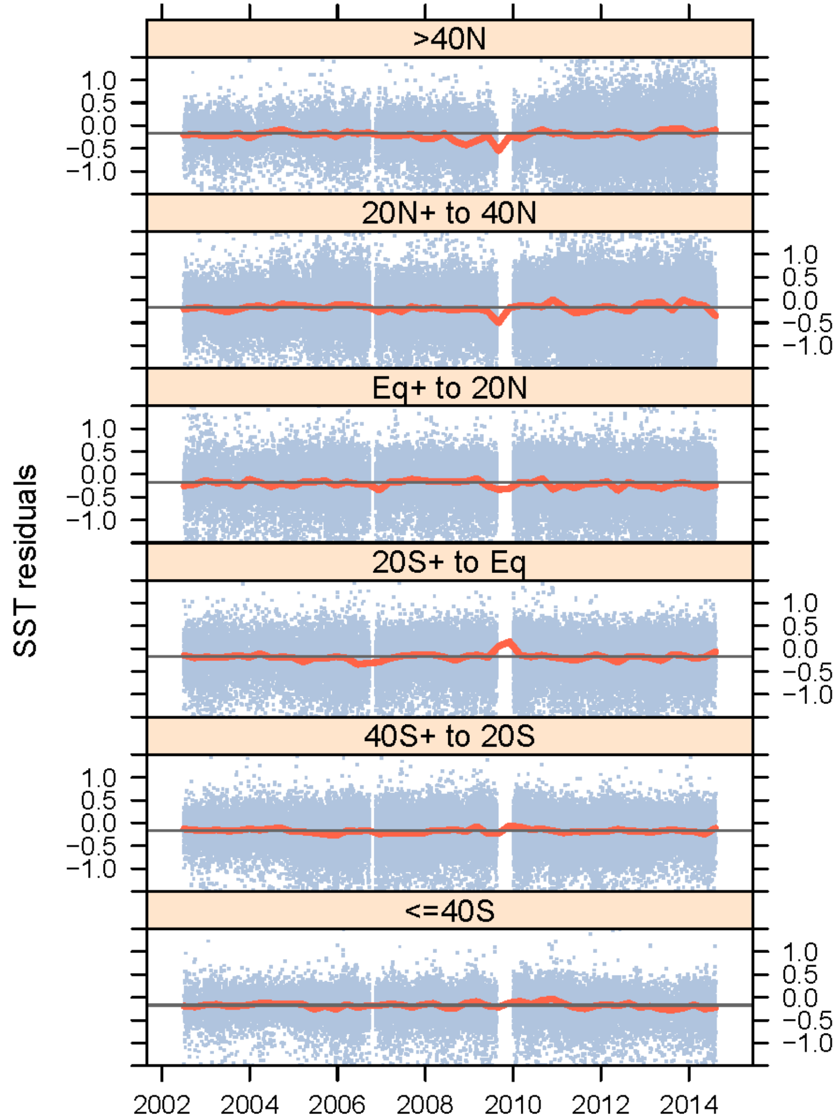
Aqua MODIS SST C6 - night



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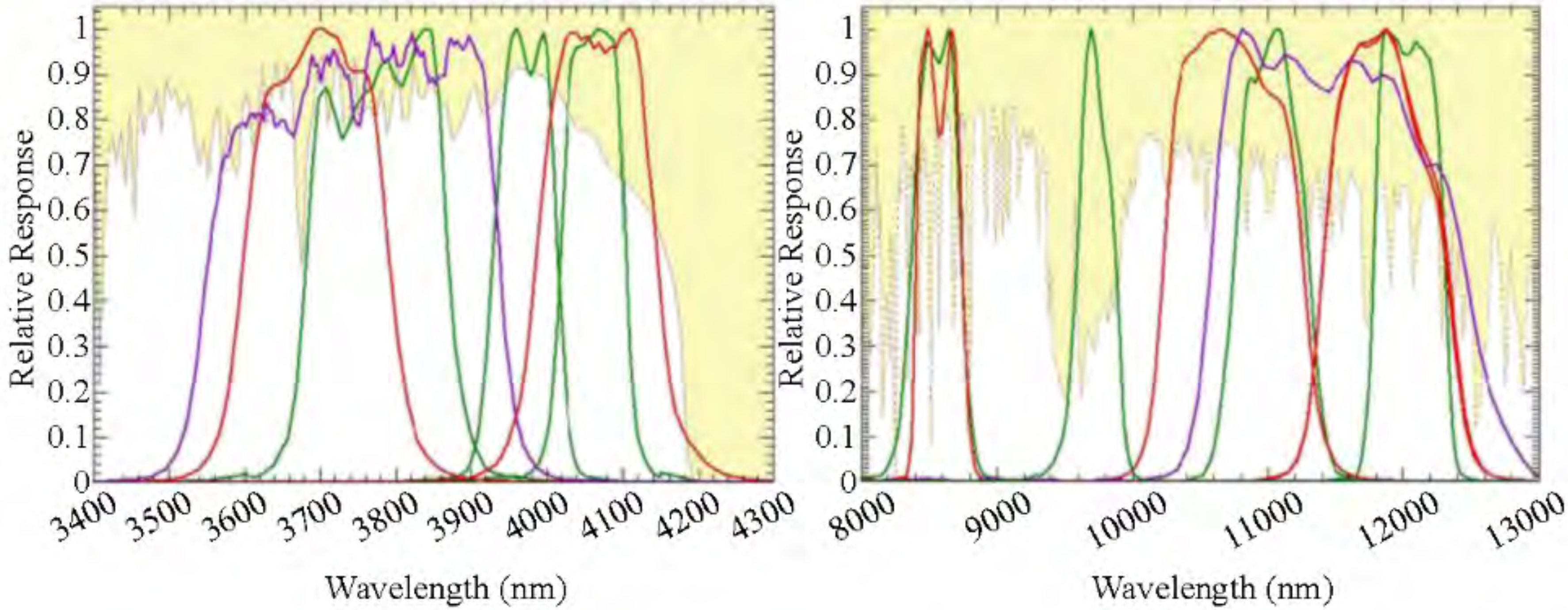
GSFC Matchups C6 2015 reprocessing

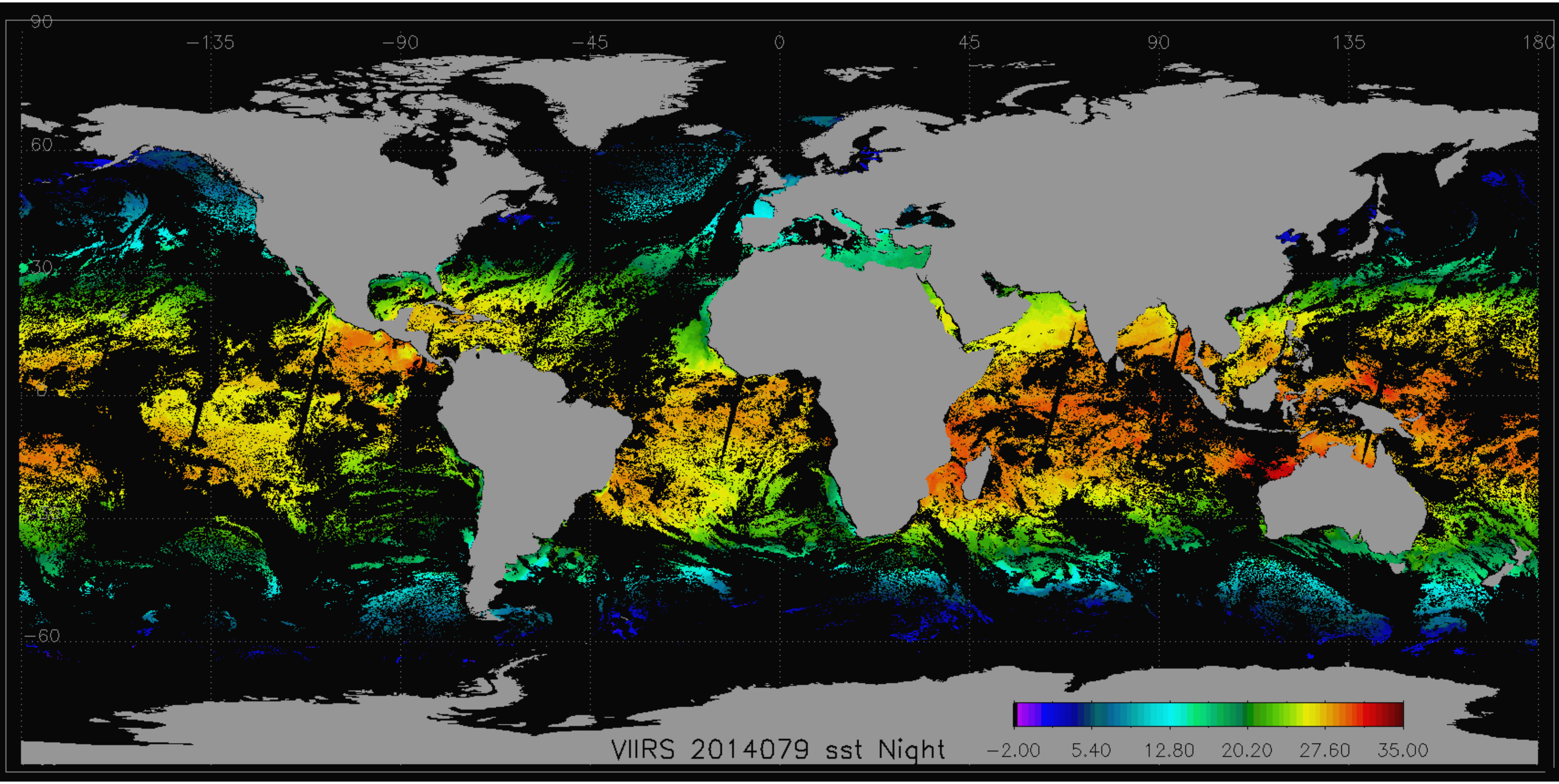
Sensor	quality	mean	median	SD	RSD	Count
Residuals MODIS SST – buoy SST						
TERRA SST	ql 0	-0.171	-0.155	0.445	0.353	428,374
TERRA SST	ql 1	-0.451	-0.405	0.659	0.533	154,228
AQUA SST	ql 0	-0.121	-0.141	0.477	0.346	307,558
AQUA SST	ql 1	-0.265	-0.19	0.752	0.468	164,949
TERRA SST4	ql 0	-0.166	-0.145	0.331	0.209	427,768
TERRA SST4	ql 1	-0.419	-0.385	0.632	0.523	139,254
AQUA SST4	ql 0	-0.210	-0.18	0.448	0.331	420671
AQUA SST4	ql 1	-0.489	-0.405	0.677	0.515	223929

Continuity to VIIRS



After C. Moeller, J. McIntire, T. Schwarting, et al., VIIRS F1 "best" relative spectral response characterization by the government team, in: J.J. Butler, X. Xiong, X. Gu (Eds.), SPIE 8153, Earth Observing Systems XVI, 81530K, San Diego, California, USA. September 13, 2011. http://dx.doi.org/10.1117/12.894552.

S-NPP VIIRS night SST



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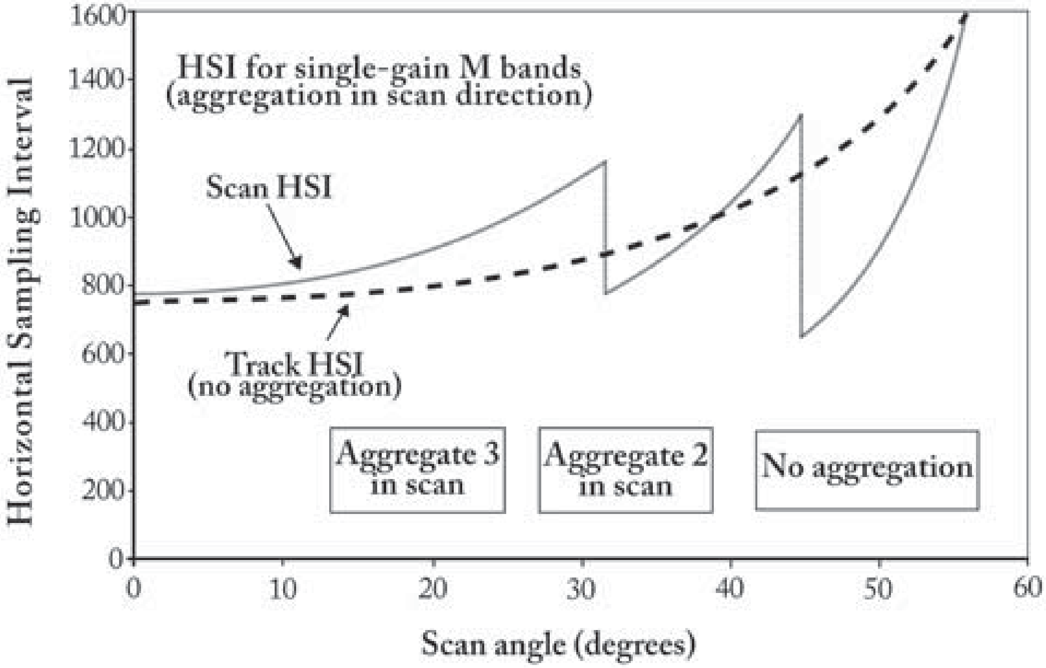
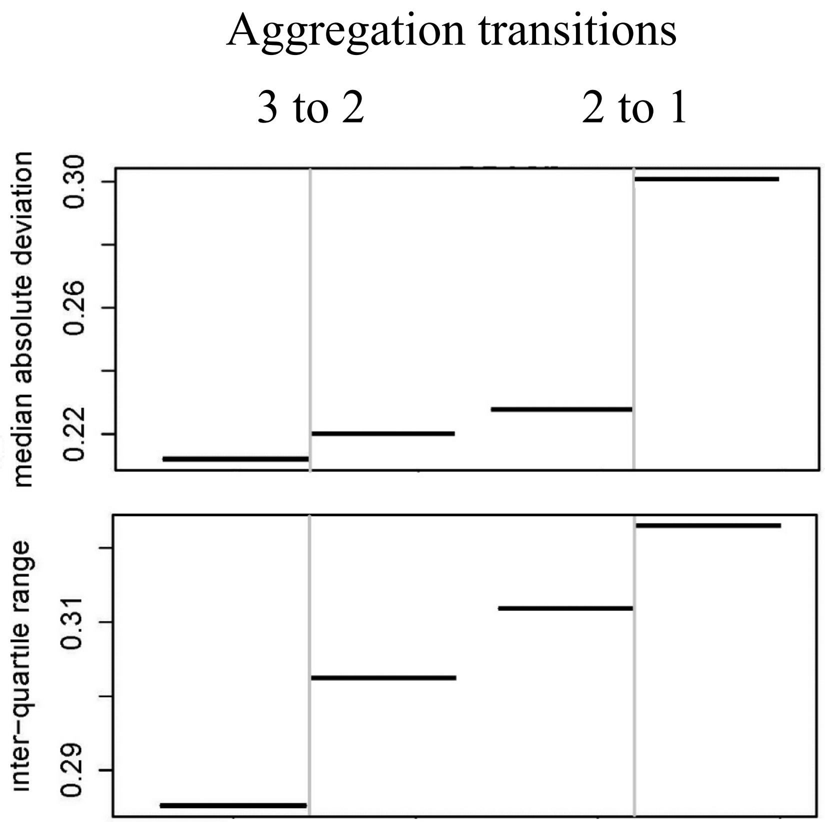
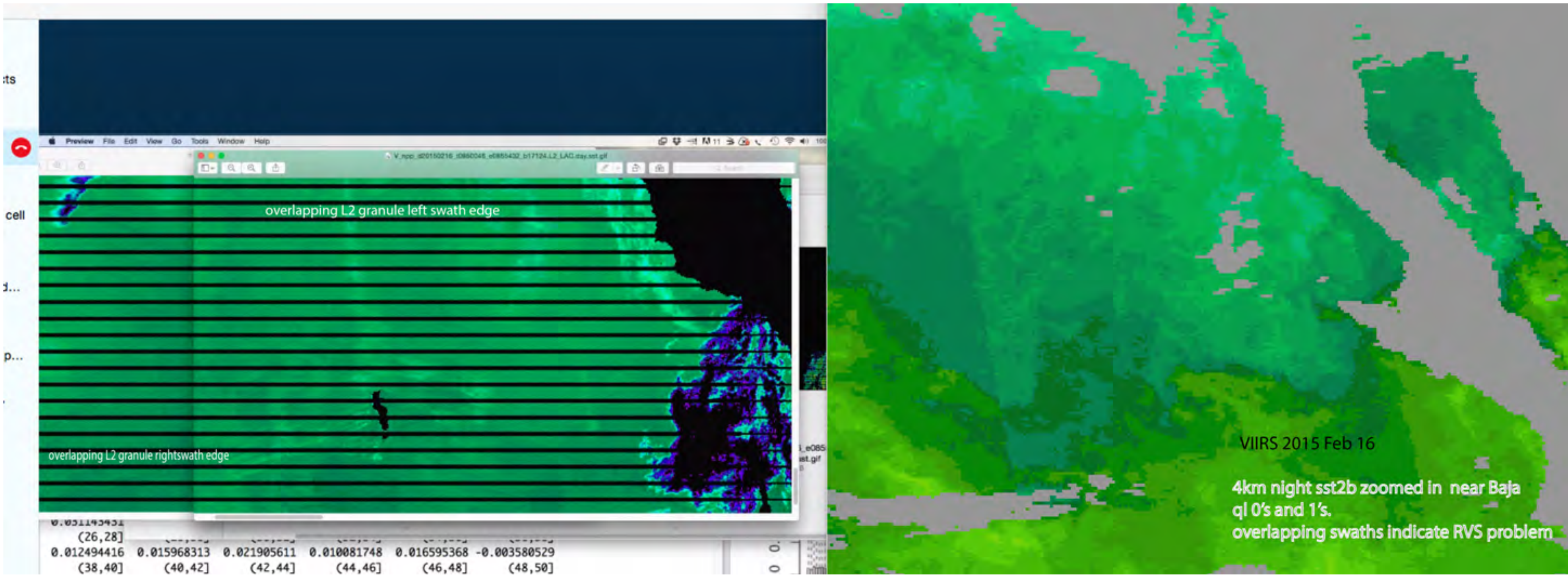
Effects of VIIRS pixel aggregation

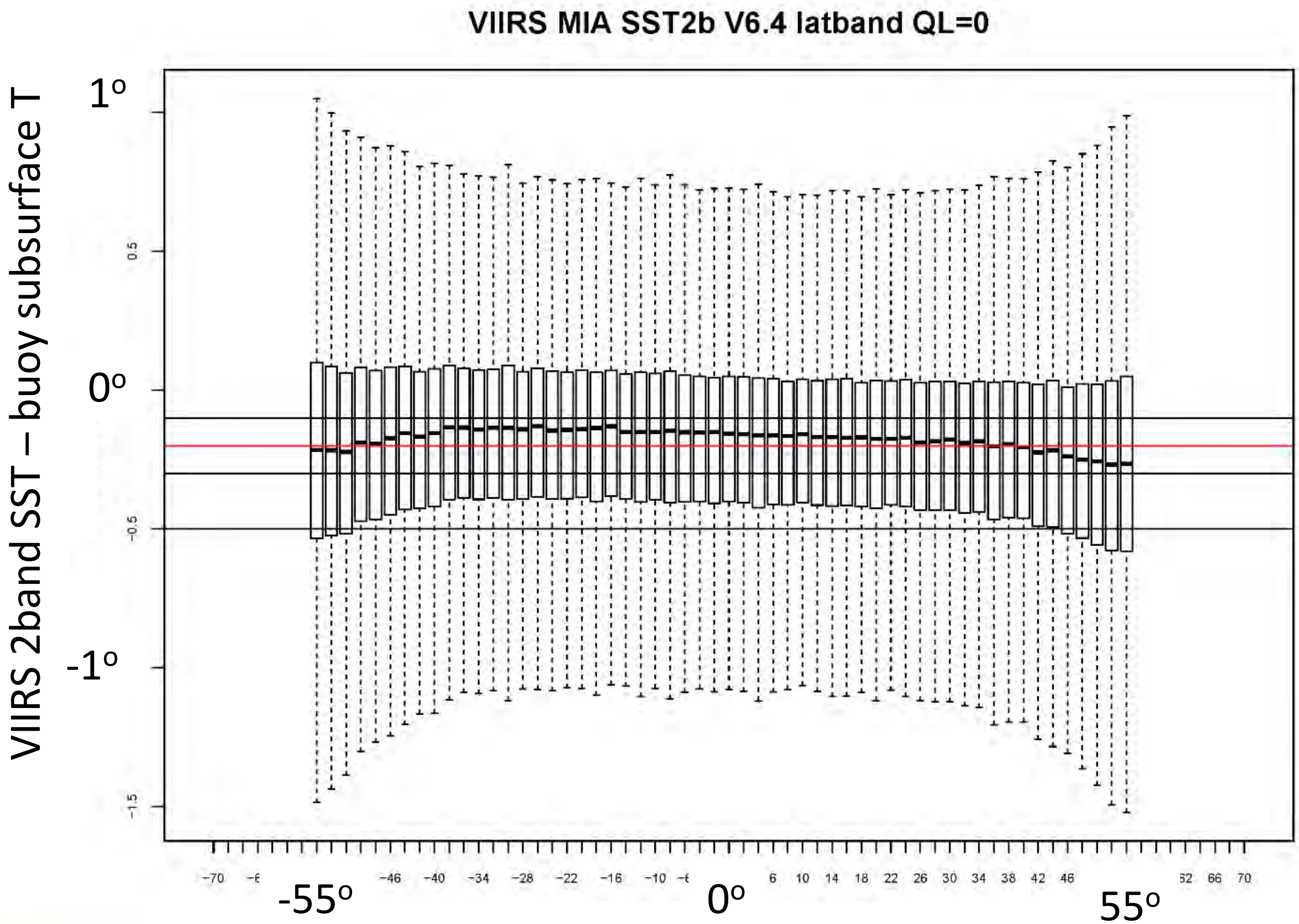




VIIRS RVS issue at 10-12μm?



SST uncertainties as f(satellite zenith angle). QL=0



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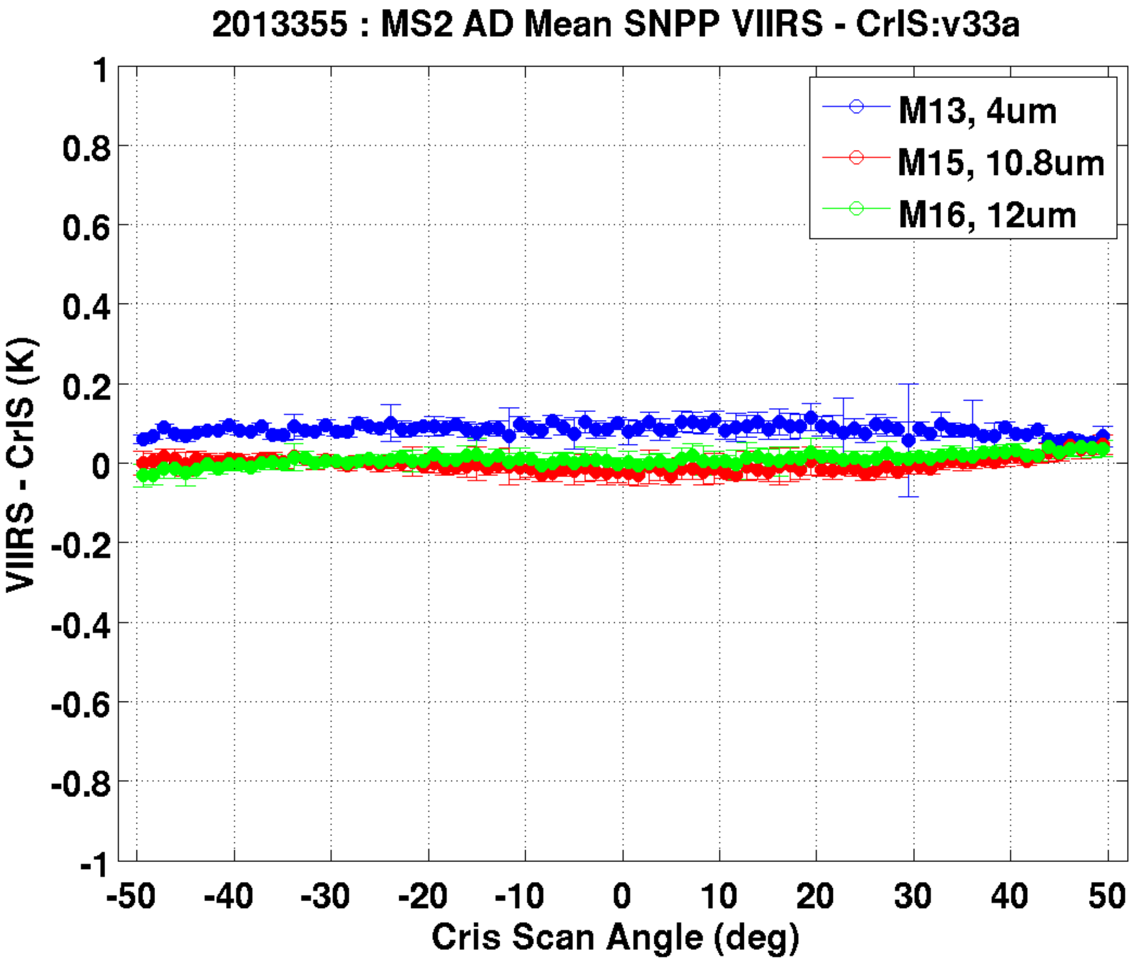
VIIRS *vs* CrIS



Provided by Chris Moeller

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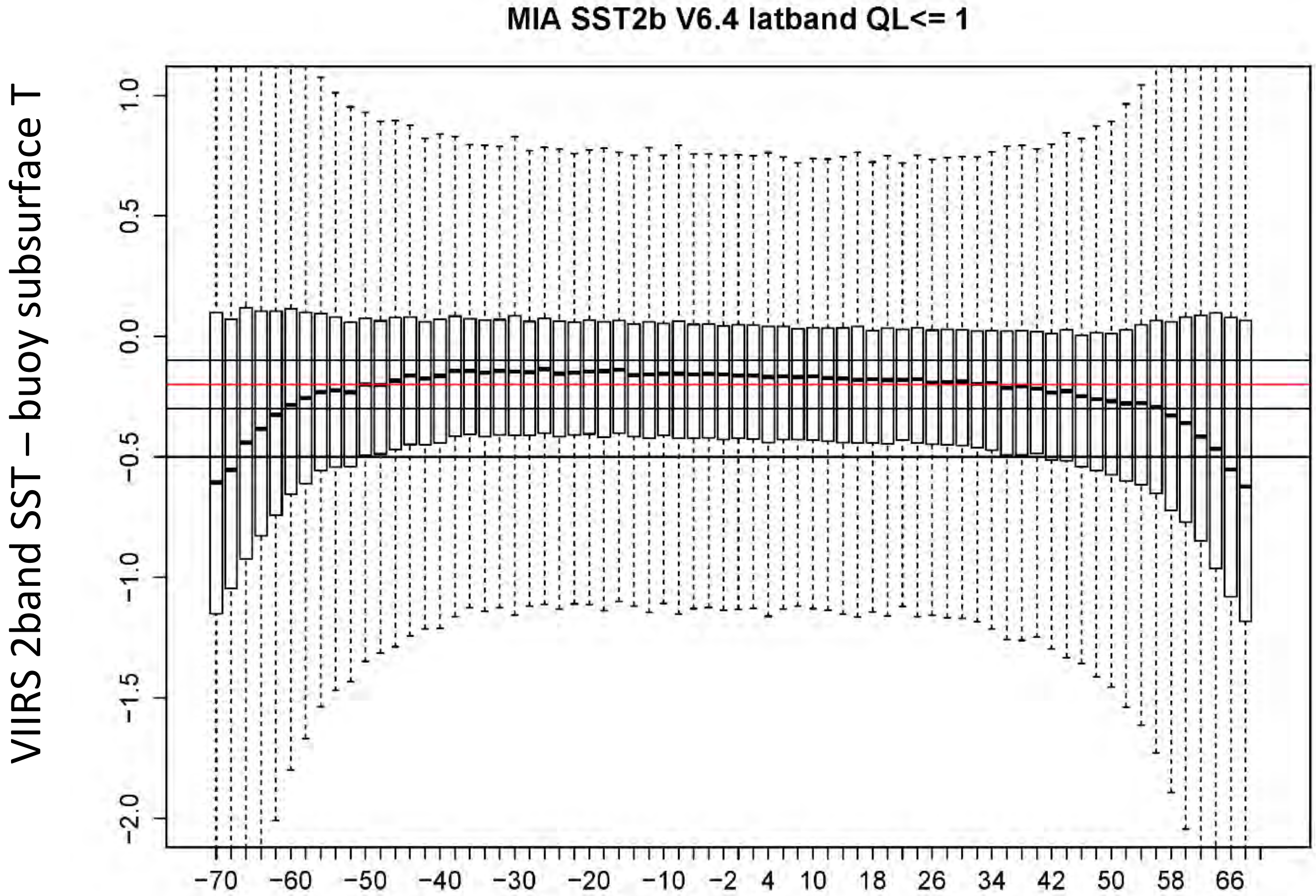
SST uncertainties as f(satellite zenith angle). QL=0,1



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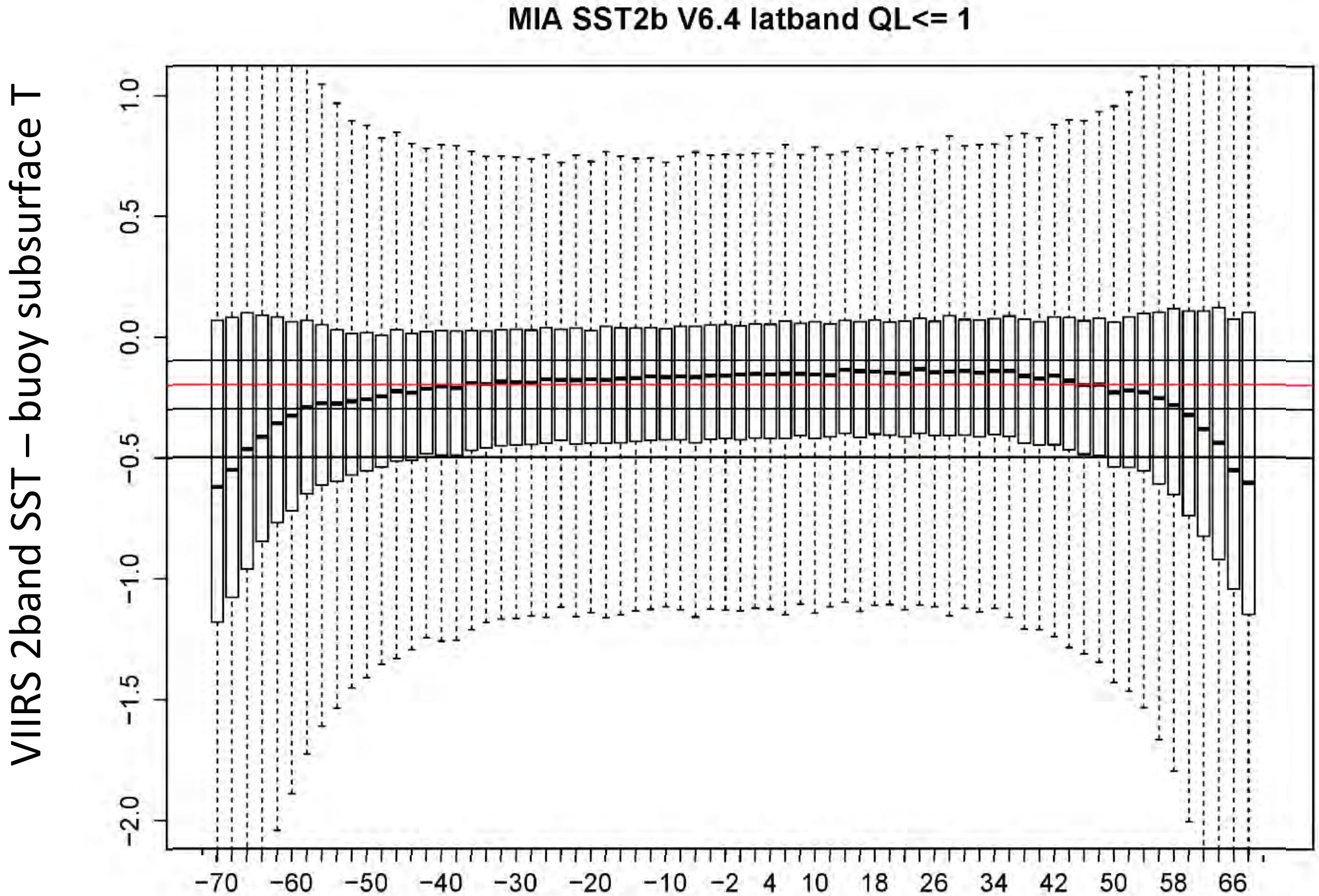
SST uncertainties as f(satellite zenith angle). QL=0,1



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Algorithm innovations

Objective to extend retrievals towards edge of VIIRS & MODIS swaths

$$
\begin{aligned}
SST_{sat} = {} & a_0 + \\
& a_1 T_{11} + \\
& a_2 (T_{11} - T_{12}) T_{sfc} + \\
& a_3 (\sec(\theta) - 1)(T_{11\mu m} - T_{12\mu m}) + \\
& a_4 (\text{mirror.side}) + \\
& a_5 (\theta) + \\
& a_6 (\theta^2)
\end{aligned}
$$

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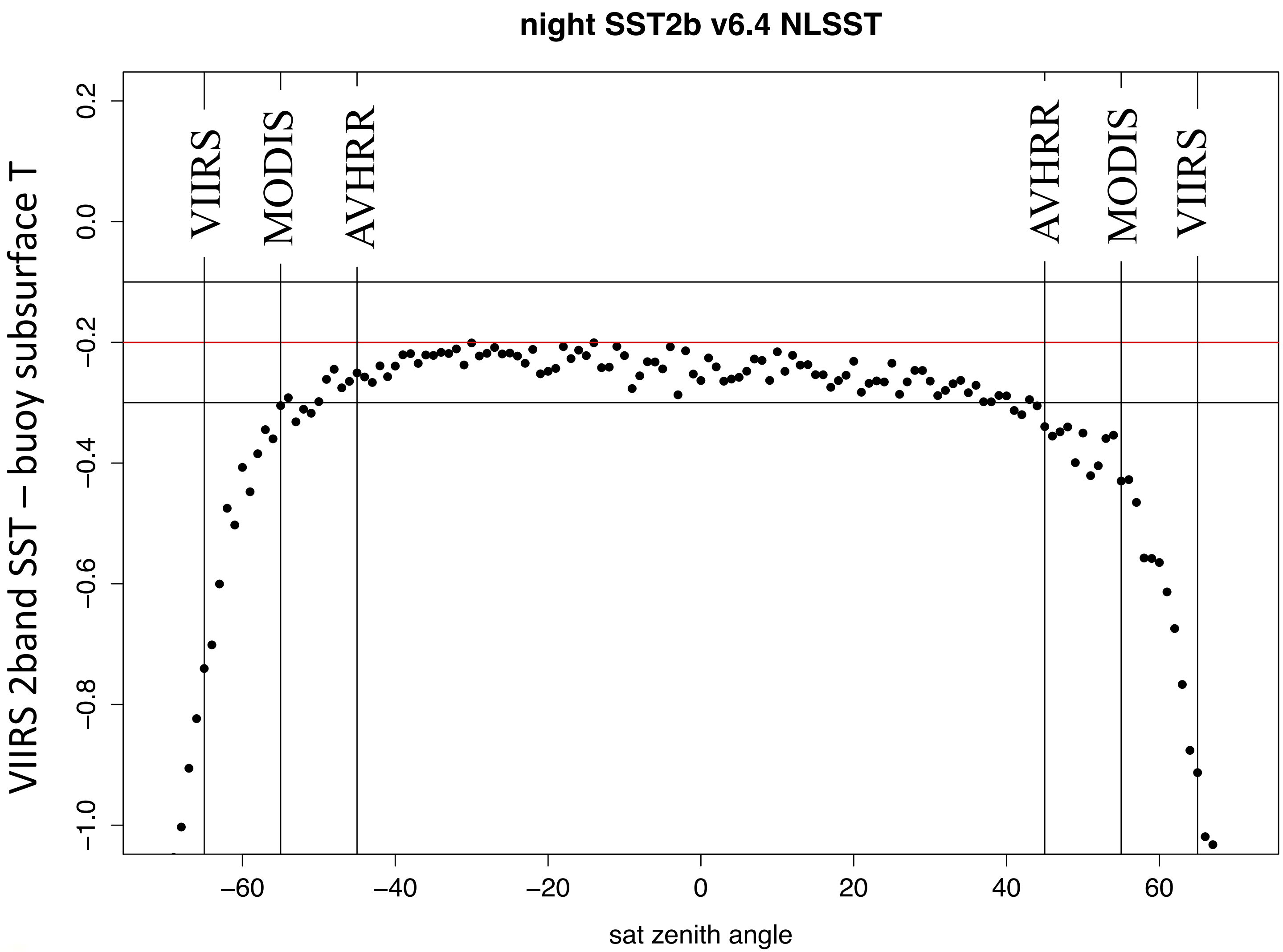

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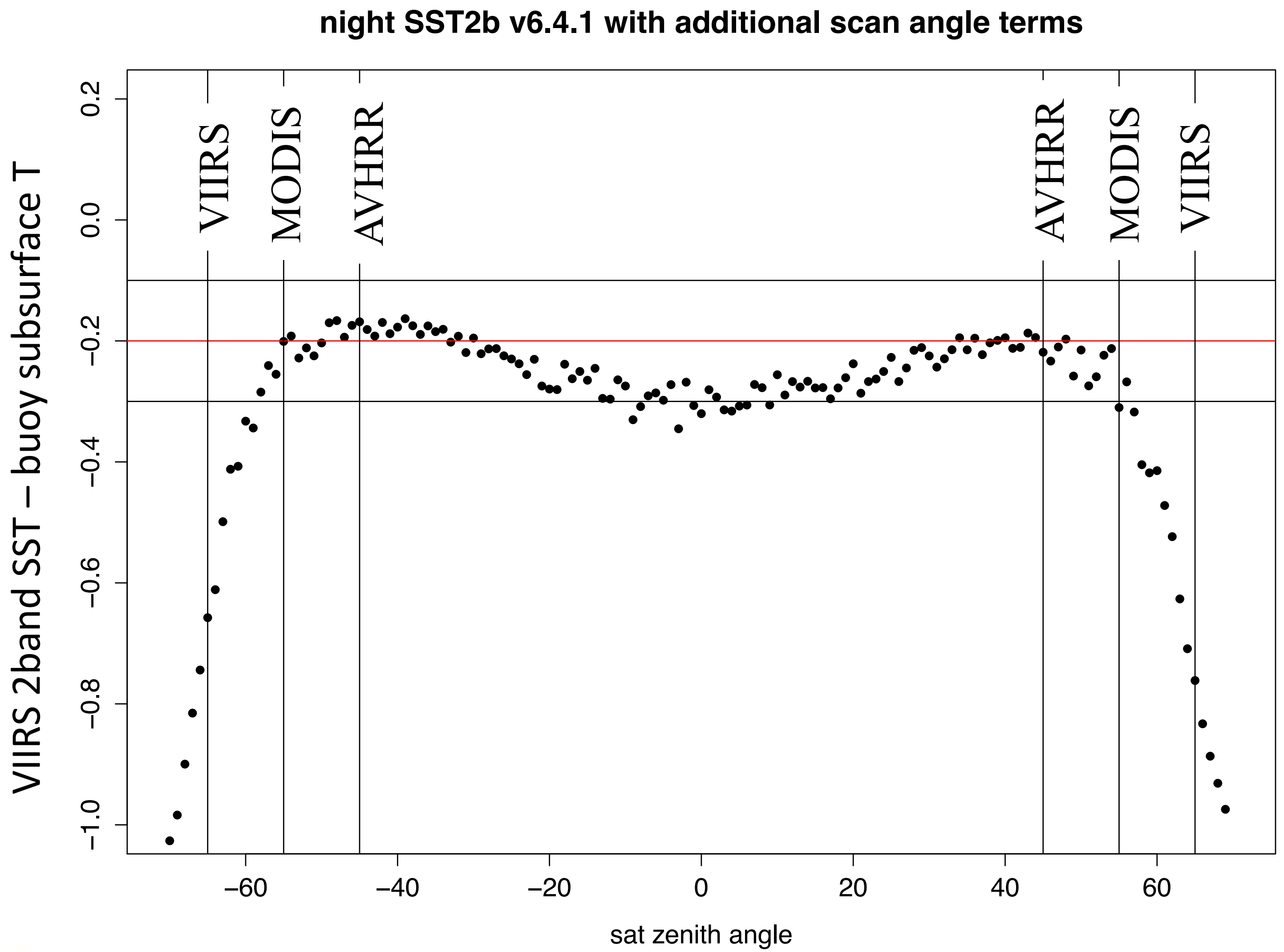

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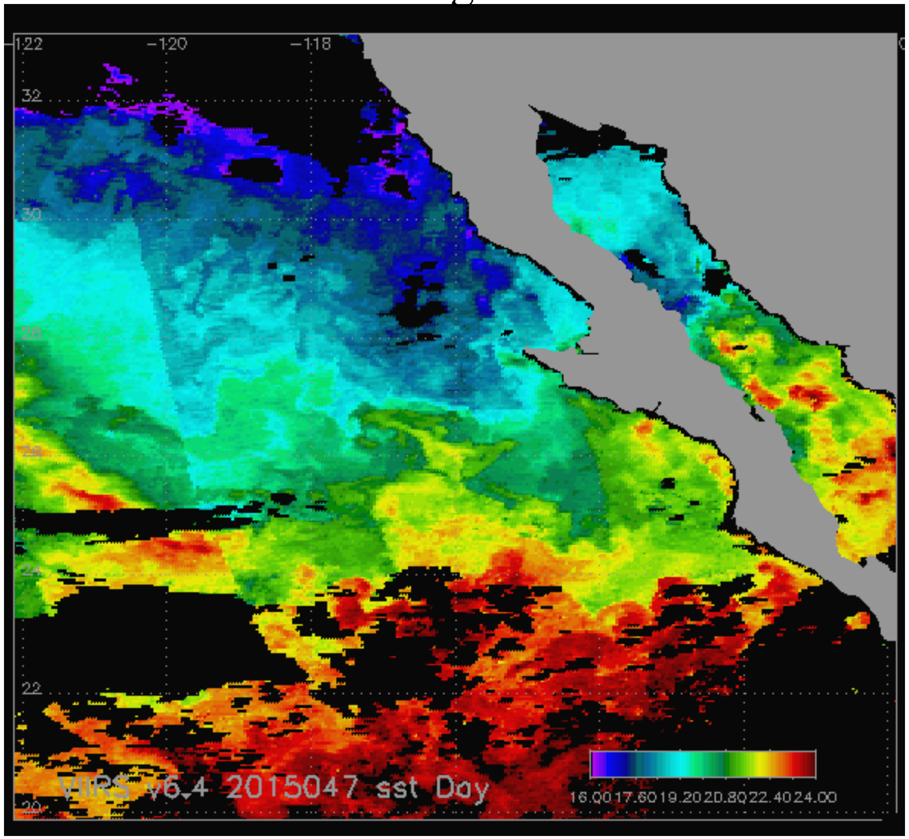
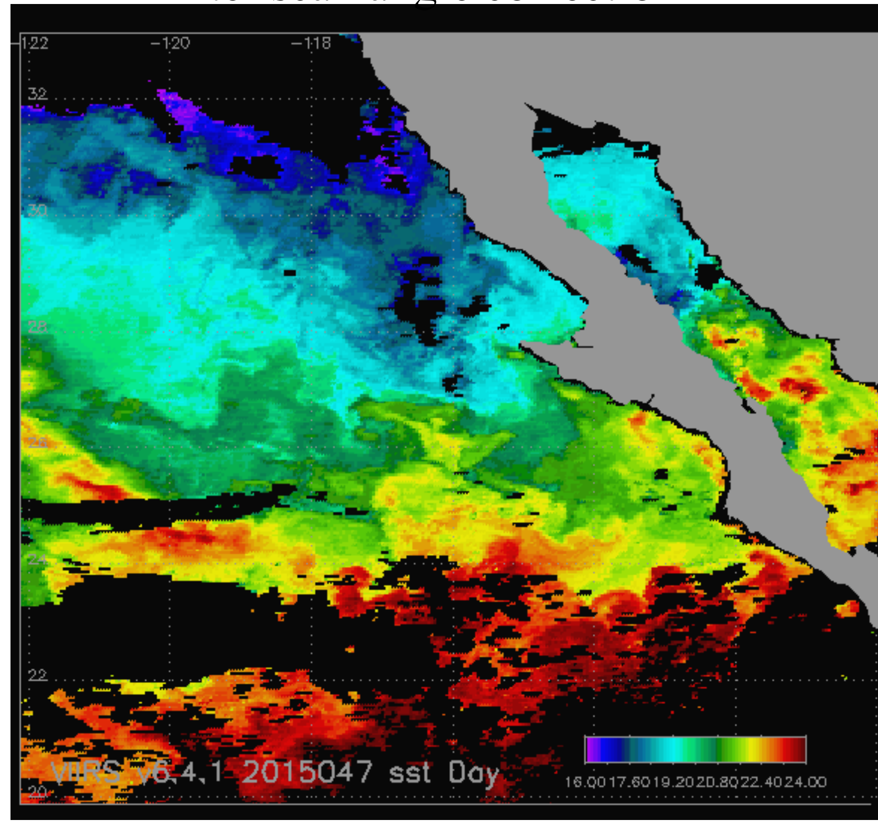
VIIRS Day SST Feb 16 2015

4km map image

Before scan angle correction



After scan angle correction



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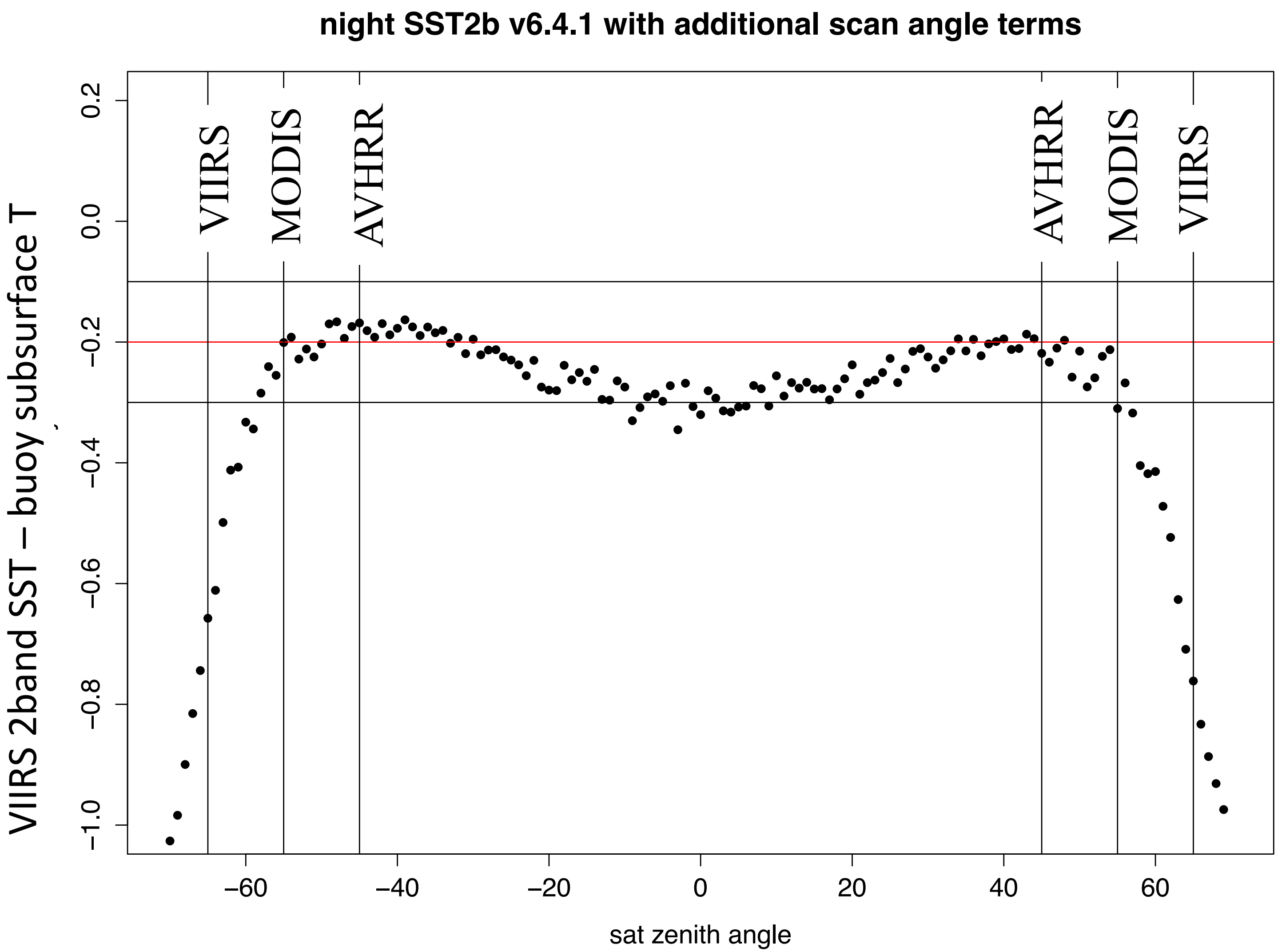

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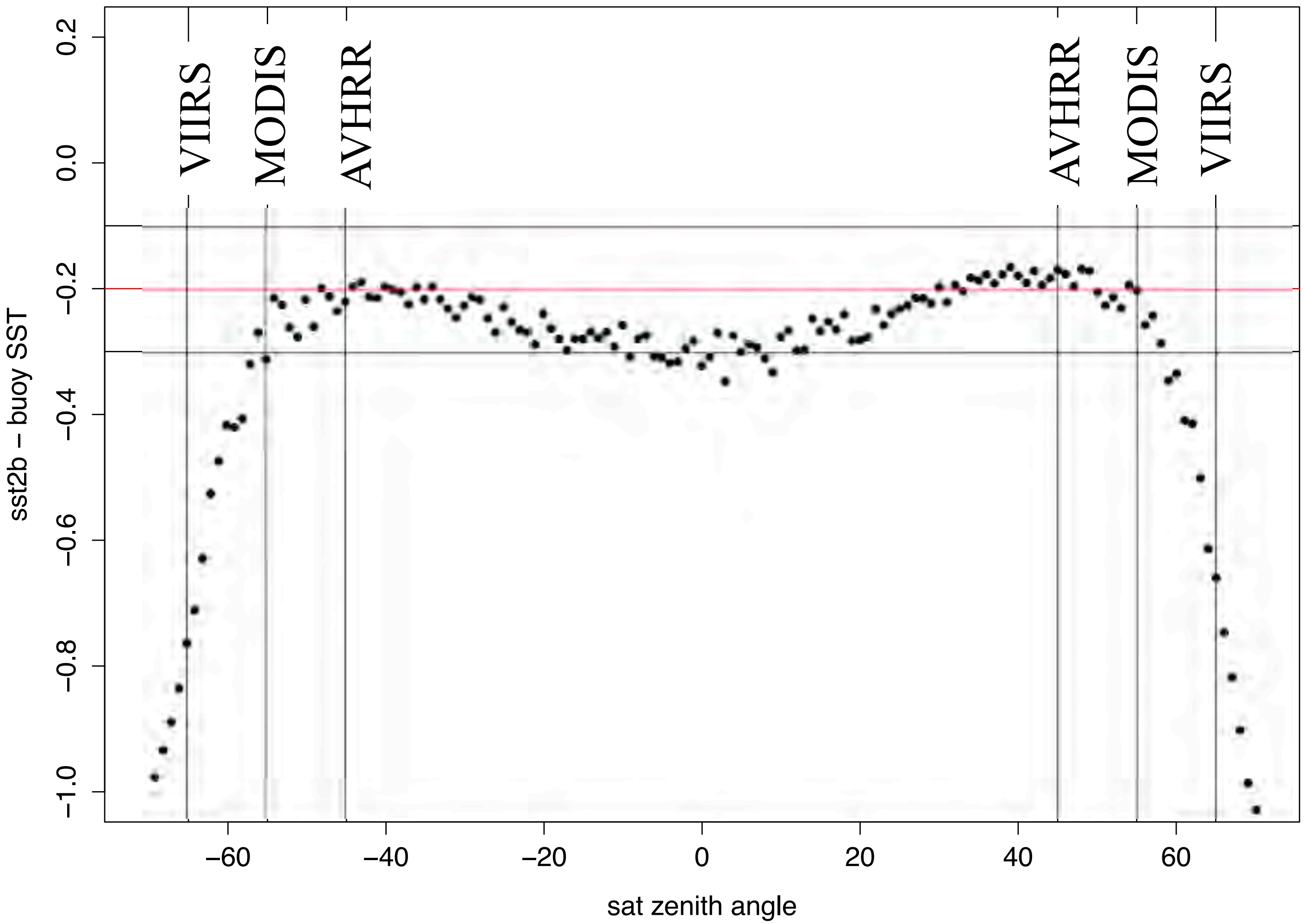
21 May 2015

night SST2b v6.4.1 with additional scan angle terms



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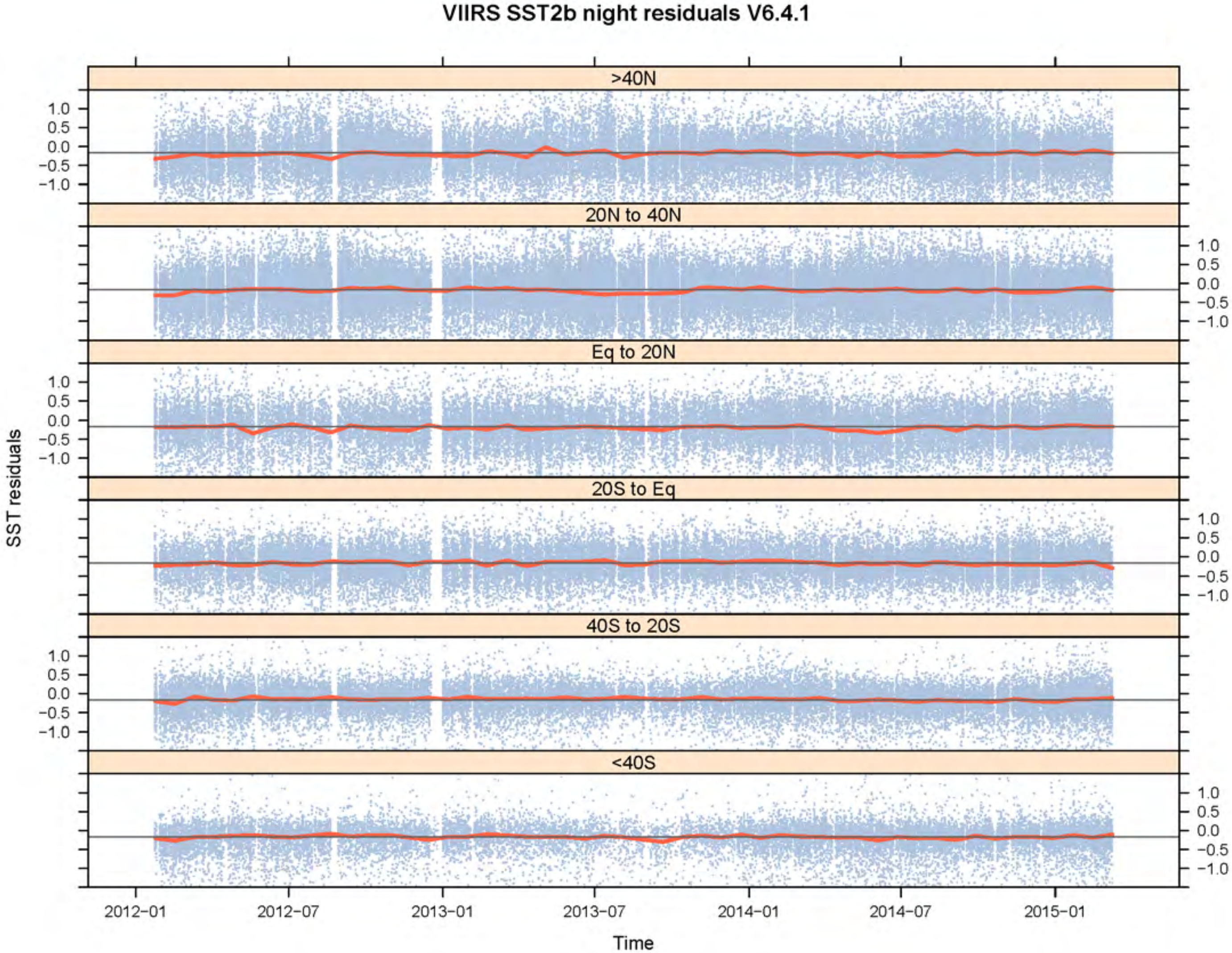
VIIRS SST stability



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And so to Climate Data Records… using shipboard radiometry.

Groups deploying filter radiometers on ships:

- Werenfrid Wimmer, University of Southampton, UK
- Tim Nightingale, Rutherford Appleton Laboratory, UK
- Lei Guan, Ocean University, Qingdao, China
- Helen Beggs, Bureau of Meteorology, Australia
- Carol Anne Clayson, WHOI, USA
- Jacob Høyer, Danish Meteorology Institute, Denmark
- Simon Hook, JPL, USA (on moorings)

Marine-Atmospheric Emitted Radiance Interferometer

- M-AERI is a very well-calibrated and stable sea-going Fourier Transform Infrared Interferometer.
- At sea calibration by two internal blackbody cavities with thermometers with NIST-traceable calibration.
- Calibration sequence before and after each cycle of ocean and atmospheric measurements.
- Calibration before and after deployments using NIST-designed water-bath blackbody calibration target at RSMAS. Uses NIST-traceable thermometers at mK accuracy.
- Periodic radiometric characterization of RSMAS water-bath blackbody calibration target by NIST TXR.

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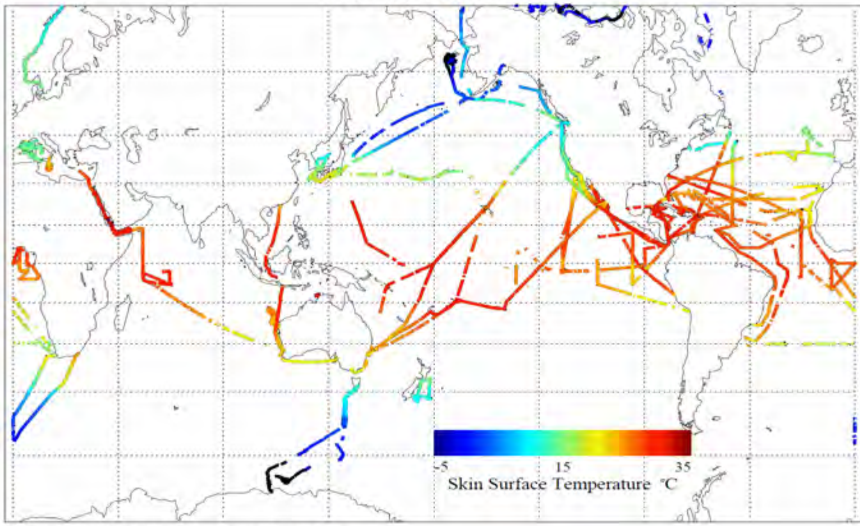
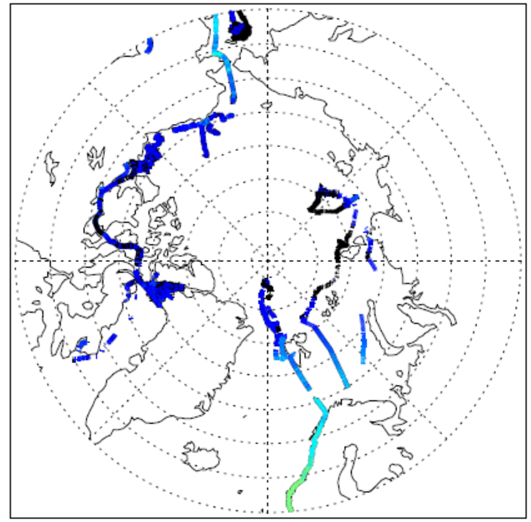
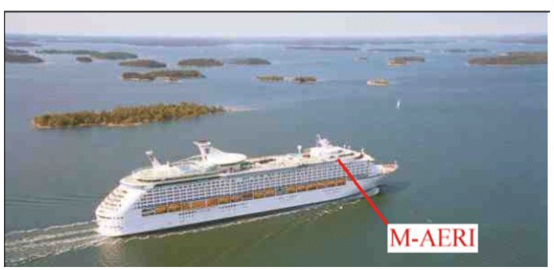
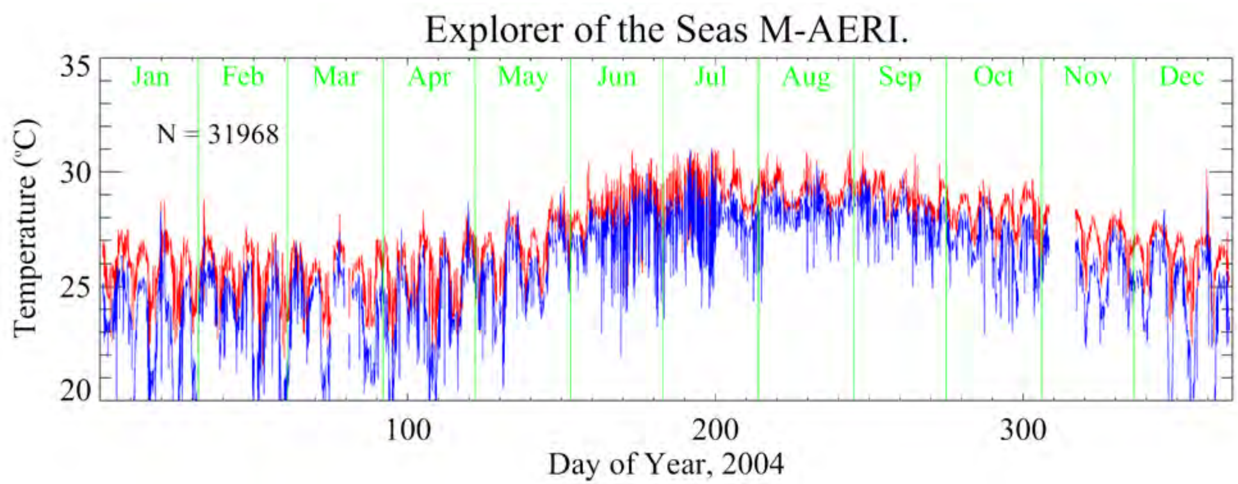
M-AERI Deployments





Skin SST (red) and near-surface air temperature (blue) measurement for 2004.





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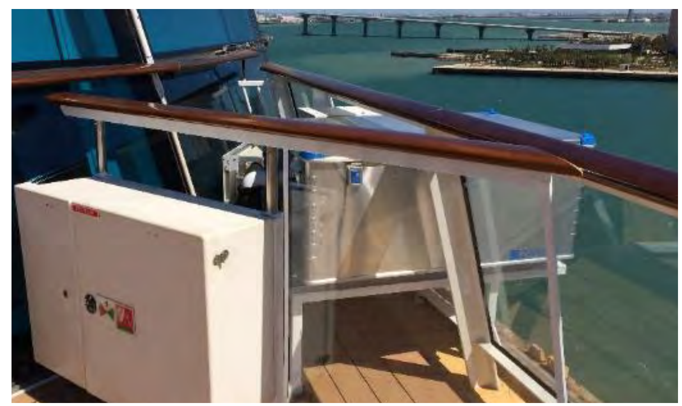
Current VOS deployments

Collaboration with Royal Caribbean Cruise Lines


Allure of the Seas

Celebrity Equinox



3rd ship being negotiated

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Summary

- Both MODIS's are very stable.
  - Algorithm developments are improving accuracy
- VIIRS is a very "clean sensor"
  - SSTs are of good quality
  - Recent evidence of a possible rvs (HAM) issue
- Methodology for generating SST Climate Data Records is understood…. (we think).

(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)

Data availability

- MODIS (C5) SSTs from NASA OBPG at GSFC website:

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

- MODIS (C5) 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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- Support of OBPG at NASA GSFC.
- Support of MCST & VCST.
- Input from many students and colleagues.

Thank you.