MODIS Science Team Meeting. March 23, 2005

MODIS Sea-Surface Temperature Algorithm Development and Maintenance

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SST Algorithm maintenance

- SST has a long track record – nearly 20 years of AVHRR Pathfinder data
- Has the attributes of a Climate Data Record – NAS report defines the attributes of a CDR
- Has real-time applications: NOAA, Navy & GHRSST-PP
- Primary variable for VIIRS
- For MODIS:
  - improve performance of algorithm – reduce residual uncertainties
  - provide determination of error characteristics

Atmospheric correction algorithms

The form of the daytime and night-time algorithm is:

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

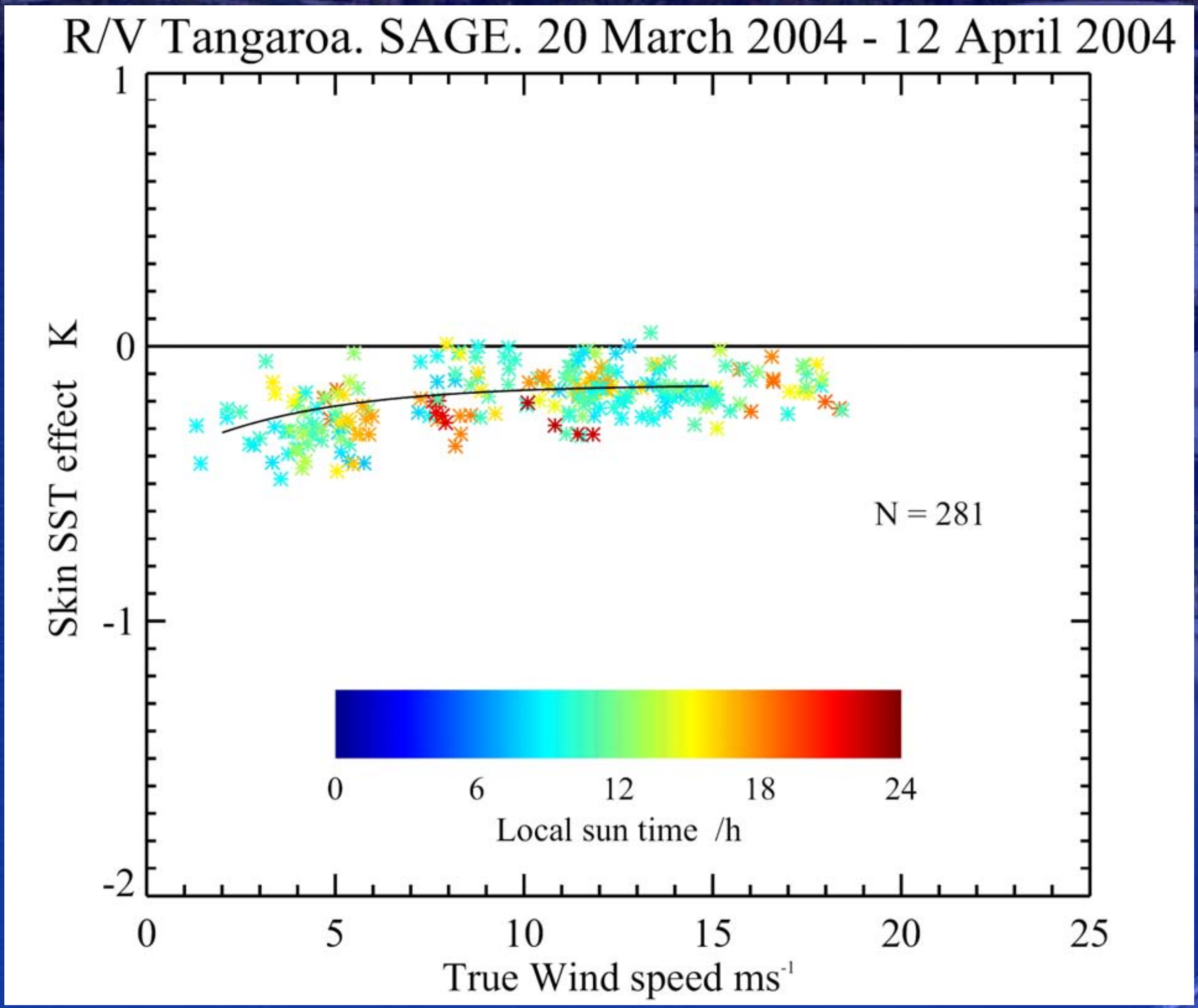
where T_n are brightness temperatures measured in the channels at n µm wavelength, T_{sfc} is a 'climatological' estimate of the SST in the area, and θ is the satellite zenith angle. This is based on the Non-Linear SST algorithm. (See Walton, C. C., W. G. Pichel, J. F. Sapper and D. A. May,1998, "The 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.)

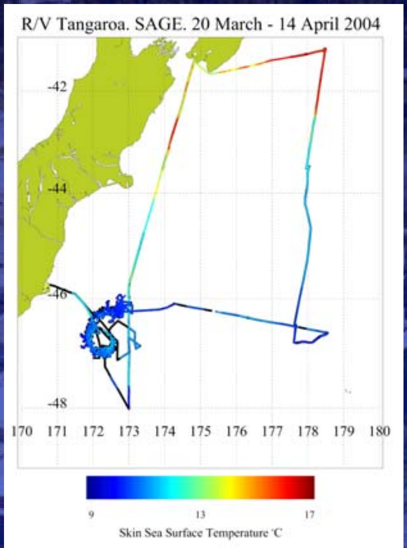
The night-time algorithm, using two bands in the 4µm atmospheric window is:

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

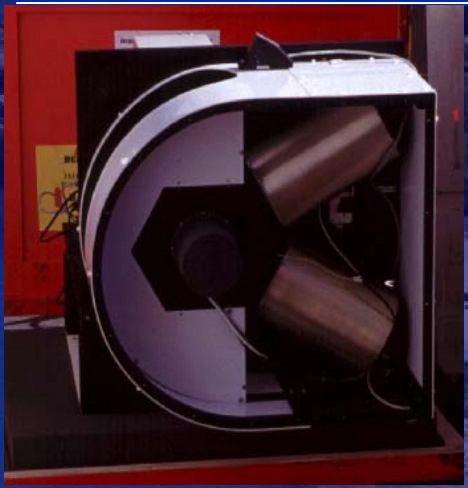
Note: the coefficients in each expression are different.

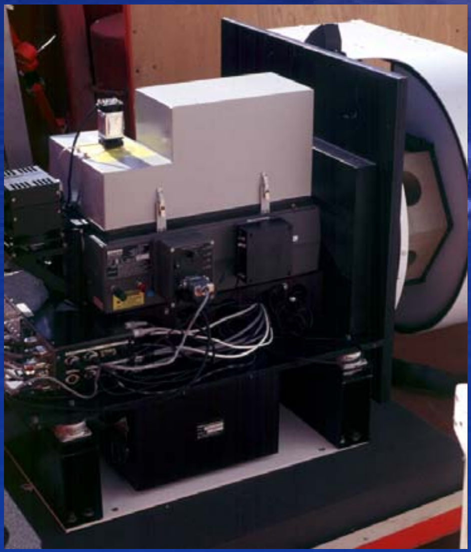
Thermal Skin Effects





Marine-Atmosphere Emitted Radiance Interferometer





Laboratory tests of M-AERI accuracy

Target Temp.	LW (980-985 cm^{-1})	SW (2510-2515 cm^{-1})
20^{o}C	+0.013 K	+0.010 K
30^{o}C	-0.024 K	-0.030 K
60^{o}C	-0.122 K	-0.086 K

The mean discrepancies in the M-AERI 02 measurements of the NIST – characterized water bath blackbody calibration target in two spectral intervals where the atmosphere absorption and emission are low. Discrepancies are M-AERI minus NIST temperatures.

Specifications	
Spectral interval	~3 to ~18µm
Spectral resolution	0.5 cm^{-1}
Interferogram rate	1Hz
Aperture	2.5 cm
Detectors	InSb, HgCdTe
Detector temperature	78^{o}K
Calibration	Two black-body cavities
SST retrieval uncertainty	<<0.1K (absolute)

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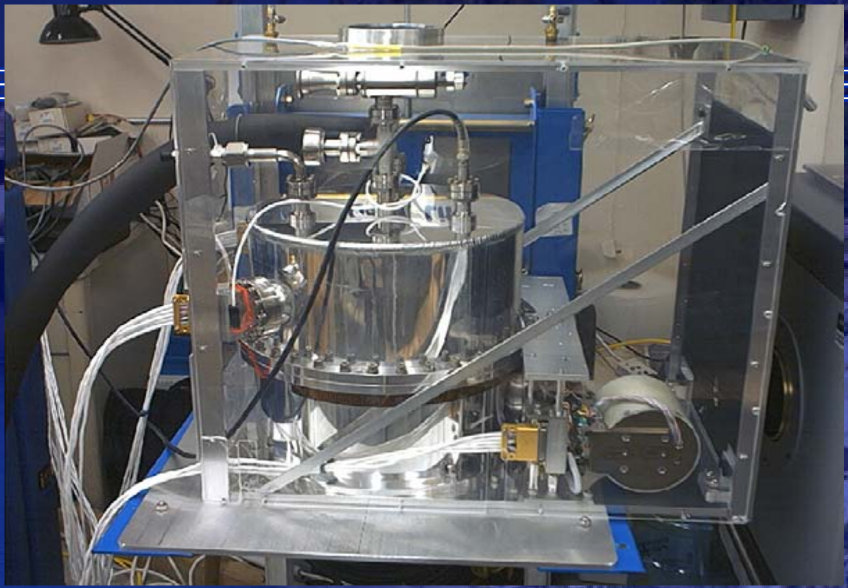
The NIST EOS TXR

Unique EOS Standard
Cryogenic detectors (liquid N_2)
λ= 5 & 10µm



Rice, J. P. and B. C. Johnson, 1998. The NIST EOS Thermal-Infrared Transfer Radiometer, *Metrologia*, 35, 505-509.

Rice, J. P., J. J. Butler, B. C. Johnson, P. J. Minnett, K. A. Maillet, T. J. Nightingale, S. J. Hook, A. Abtahi, C. J. Donlon, and I. J. Barton, 2004: The Miami2001 Infrared Radiometer Calibration and Intercomparison: 1. Laboratory Characterization of Blackbody Targets. *Journal of Atmospheric and Oceanic Technology*, 21, 258-267.

Barton, I. J., P. J. Minnett, C. J. Donlon, S. J. Hook, A. T. Jessup, K. A. Maillet, and T. J. Nightingale, 2004: The Miami2001 infrared radiometer calibration and inter-comparison: 2. Ship comparisons. *Journal of Atmospheric and Oceanic Technology*, 21, 268-283.

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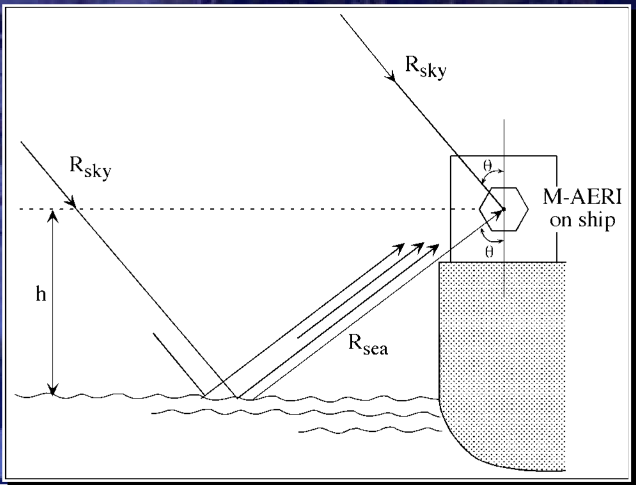
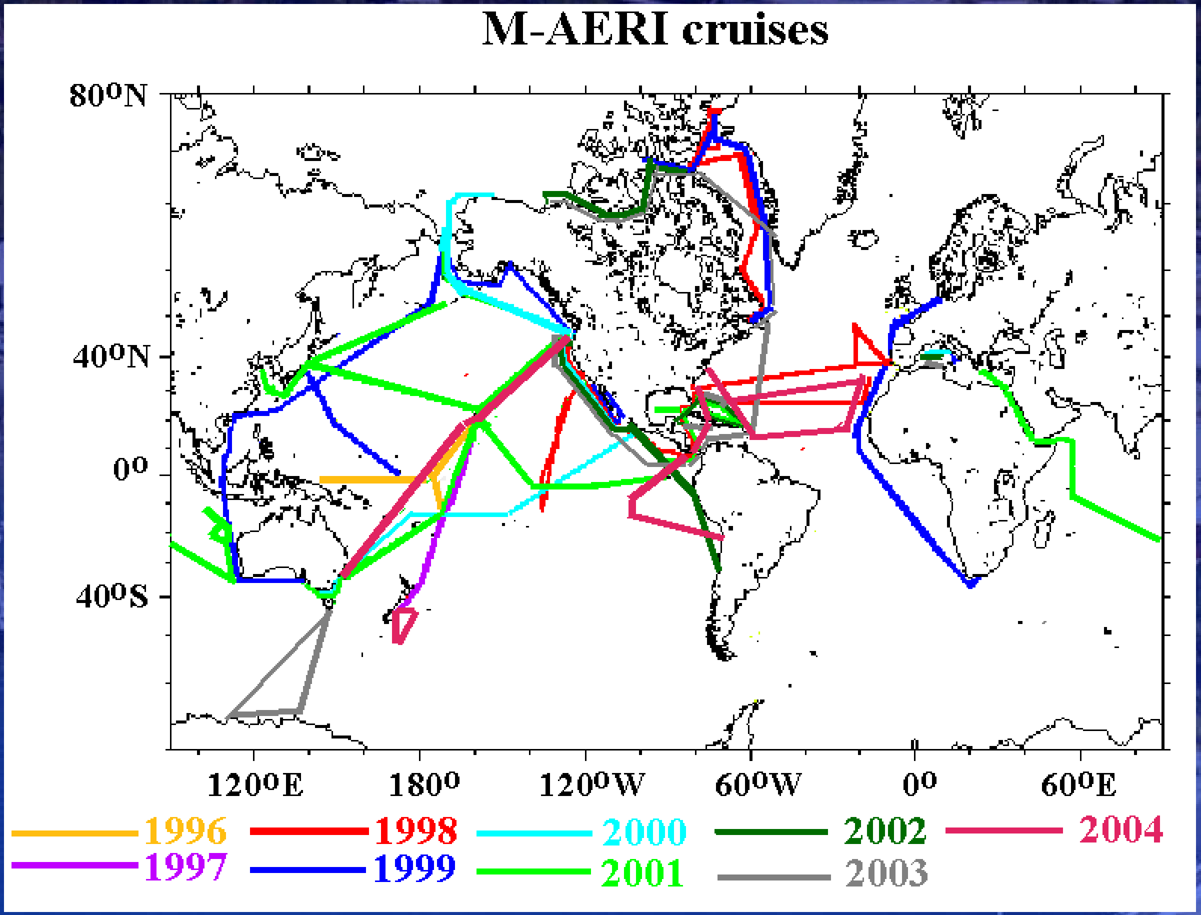
M-AERI at sea



M-AERI cruises for MODIS validation



2564 days of data to December 31 , 2004.

All with no ship costs charged to NASA.

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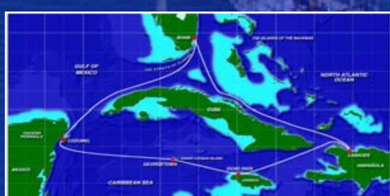
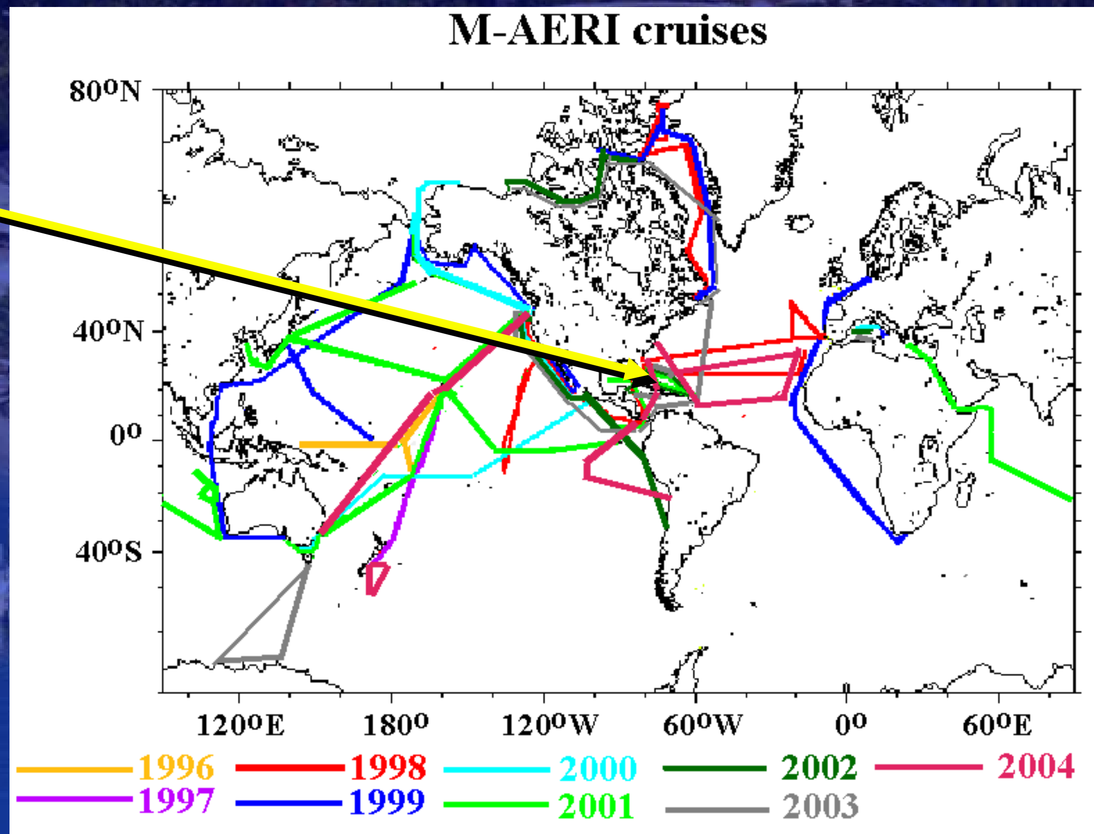
M-AERI cruises for MODIS validation

Explorer of the Seas





2564 days of data to December 31 , 2004.

All with no ship costs charged to NASA.

Future Validation Cruises

- ***Explorer of the Seas*** **will continue for at least 6 months**
- **Research ships cruises* will focus on poorly-sampled areas and where there are known challenges…**
  - **Aerosol outbreaks - Eastern Tropical Atlantic (*Ronald H. Brown*)**
  - **Arctic (*Amundsen, Kapitan Dranitsyn, Oden*)**
  - **Southern Ocean (*Aurora Australis*)**
  - **Tropical Western Pacific (*Southern Surveyor*)**
  - **Equatorial Indian Ocean (*L'Atalante*)**
  - **Trans-Pacific *NE-SW* (*Polar Star*)**
  - **Trans-Atlantic & Trans-Pacific *E-W* (*Falstaff*)**

(*Uncertain – pending funding and/or agreements with ship operators)

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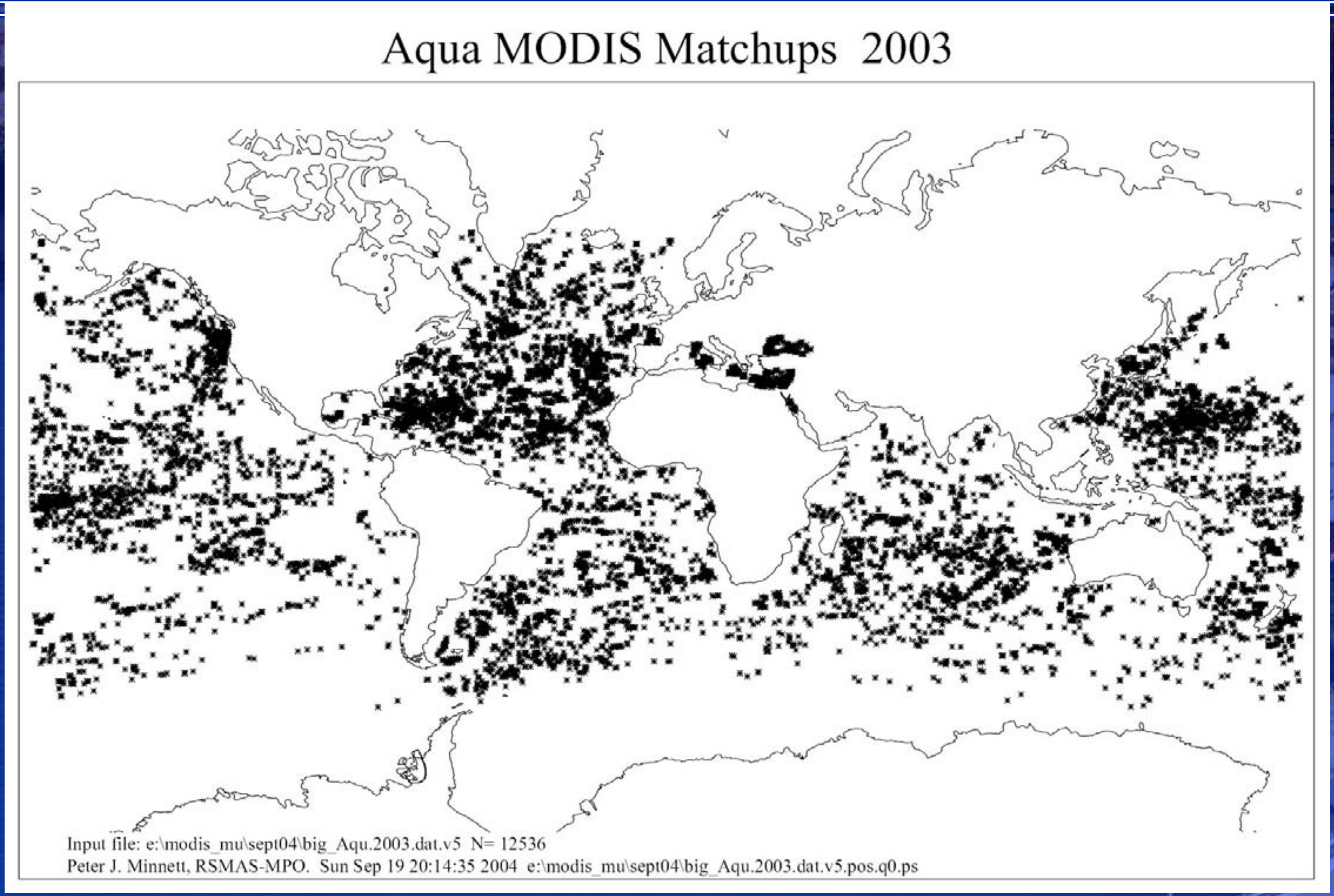
Buoy measurements



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Terra MODIS SST accuracies (V.4)

Terra	Buoy + M-AERI			Buoy (bulk)			M-AERI (skin)		
	$\overline{\Delta T}$	$\Delta T'$	n	$\overline{\Delta T}$	$\Delta T'$	n	$\overline{\Delta T}$	$\Delta T'$	n
SST (day+night)	-0.160	0.490	30488	-0.165	0.488	29284	-0.025	0.527	1196
SST (night)	-0.190	0.481	15398	-0.196	0.477	14579	-0.082	0.524	816
SST (day)	-0.129	0.498	15090	-0.135	0.497	14705	0.096	0.513	380
SST4 (night)	-0.080	0.363	14634	-0.083	0.361	13846	-0.026	0.400	785

- Few M-AERI SSTs compared with buoy SSTs (but many M-AERI cruise data are still in the processing pipeline)
- Biases w.r.t. buoys generally more negative than w.r.t. M-AERI – Skin effect
- Scatter at night smaller than during the day (diurnal thermocline effects)
- Scatter of SST4 uncertainties are smaller than SST uncertainties

Aqua MODIS accuracies (V.4)

Aqua	Buoy + M-AERI			Buoy (bulk)			M-AERI (skin)		
	$\overline{\Delta T}$	$\Delta T'$	n	$\overline{\Delta T}$	$\Delta T'$	n	$\overline{\Delta T}$	$\Delta T'$	n
SST (day+night)	-0.008	0.503	29259	-0.009	0.502	28737	0.037	0.559	522
SST (night)	-0.030	0.500	14155	-0.033	0.498	13744	0.038	0.550	411
SST (day)	0.012	0.505	15104	0.012	0.504	14993	0.036	0.595	111
SST4 (night)	0.175	0.465	12040	-0.107	0.397	5258	0.263	0.477	332

- Same characteristics as Terra MODIS
- Residual errors greater for Aqua than for MODIS

Characteristics of SST uncertainties

Uncertainties in SST have contributions from:

- **Residual instrumental effects –**
  - **Response *vs* scan angle**
  - **Mirror-sides**
  - **Multiple detectors**
  - **Others….**
- **Residual atmospheric effects:**
  - **Undetected clouds**
  - **Aerosols**

GHRSST – merging SST fields

Objective of the GHRSST-PP is to:

- ***Ensure the provision of rapidly and regularly diffused, high-quality sea surface temperature products at a fine spatial and temporal resolution that meet the diverse needs of GODAE, the scientific community, operational users and climate applications at a global scale.***
- **Theme I:** Specification and delivery mechanism of sea surface temperature products required by different users and diverse.
- **Theme II:** Characterization and identification of differences between SST fields derived from existing satellite and in situ data sources.
- **Theme III:** Targeted research and development for SST data integration.
- **Theme IV:** Generation of improved, multi-sensor, demonstration SST products through integration and assimilation.

GHRSST-PP

GODAE High Resolution Sea Surface Temperature Pilot Project

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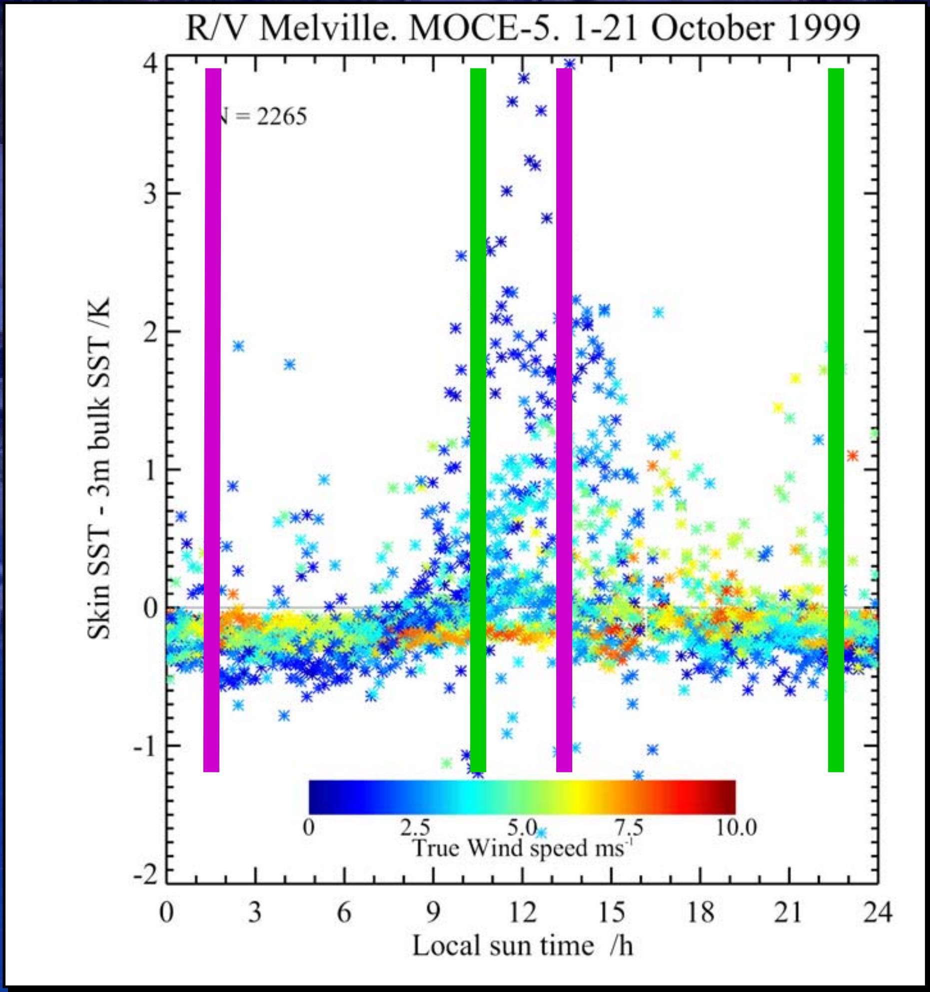
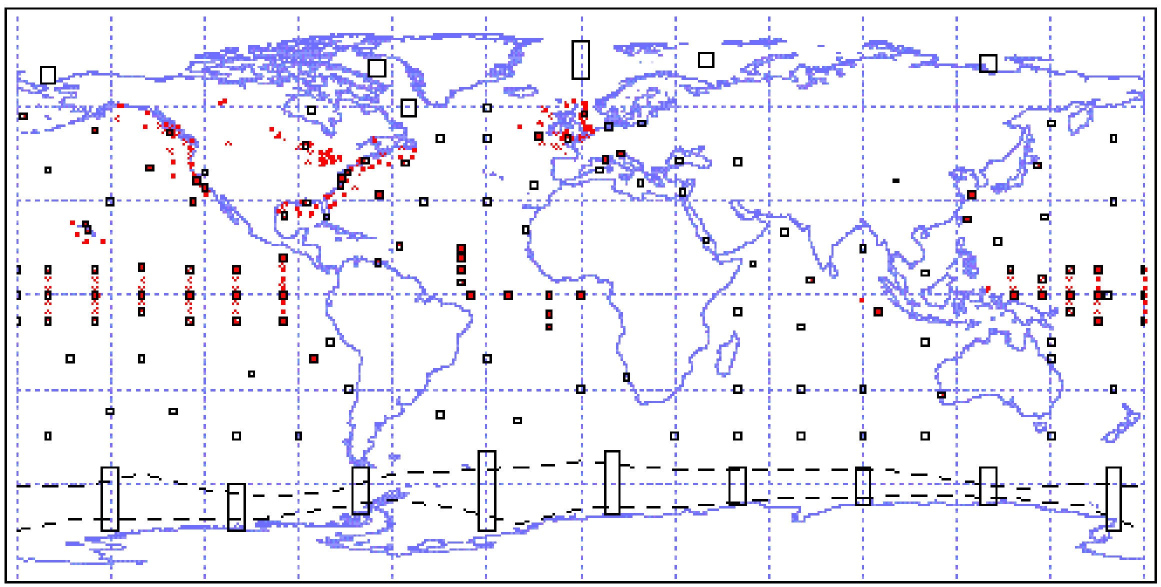
Diurnal heating effects

Skin SST measured by M-AERI, bulk SST by ship’s thermo-salinograph at a depth of ~3m



Terra and Aqua overpass times.

GHRSST diagnostic data set



Synergistic activities

- GHRSST
  - MISST – US component of GHRSST
- NOPP – Skin SST radiometer for VOS applications
- NSF funded research into effects of skin layer on CO_2 air-sea transfer (SOLAS)
- M-AERI being used for AIRS validation (NASA)
- M-AERI being used for AATSR validation (ESA)
- M-AERI being used for TRMM validation (NASA)
- M-AERI being used for AMSR-E validation (NASA)

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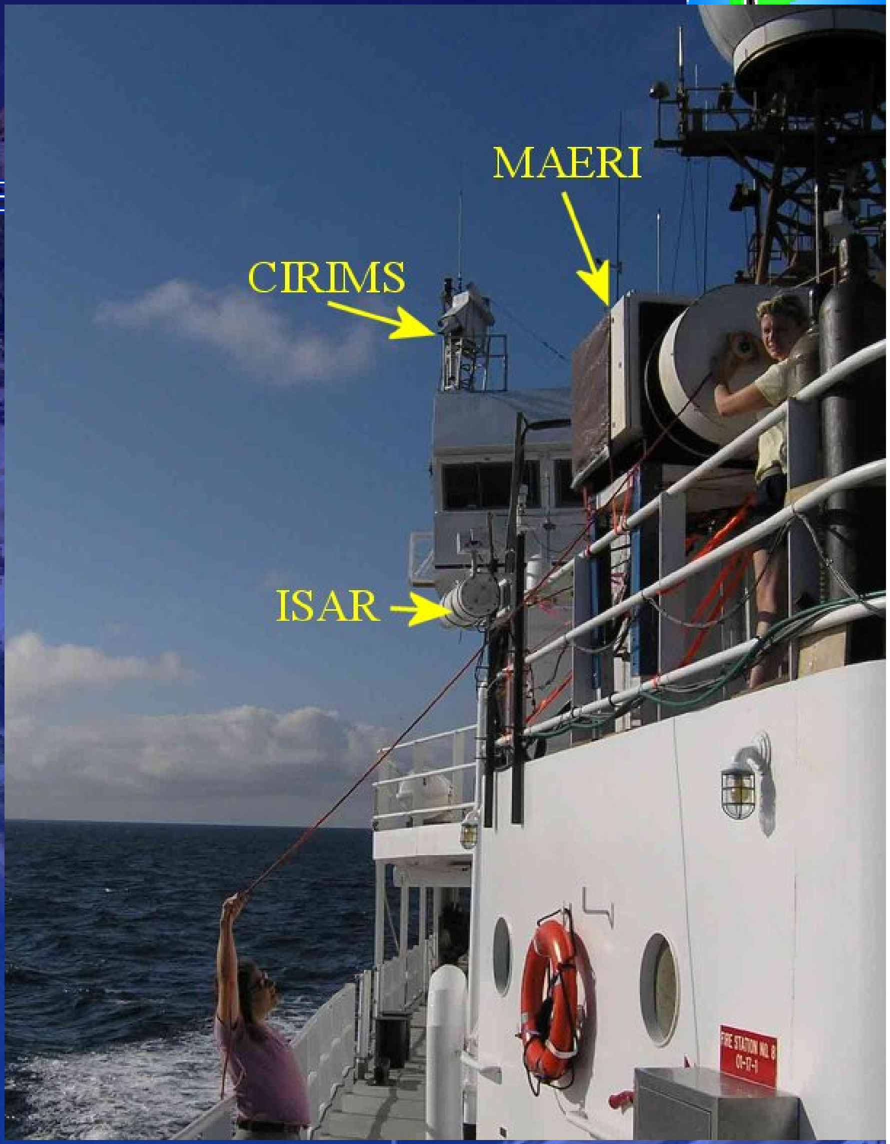
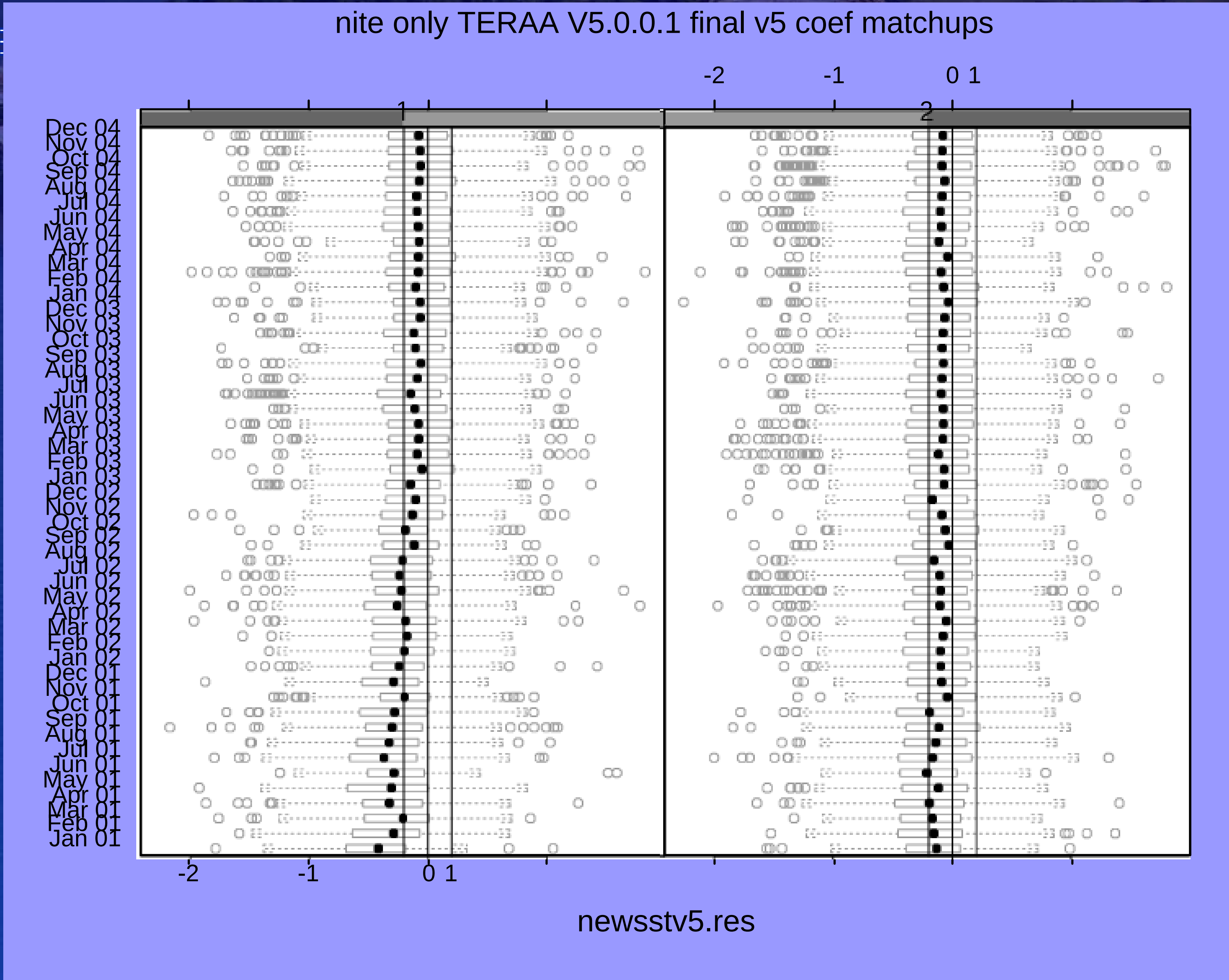
NOPP SST projects

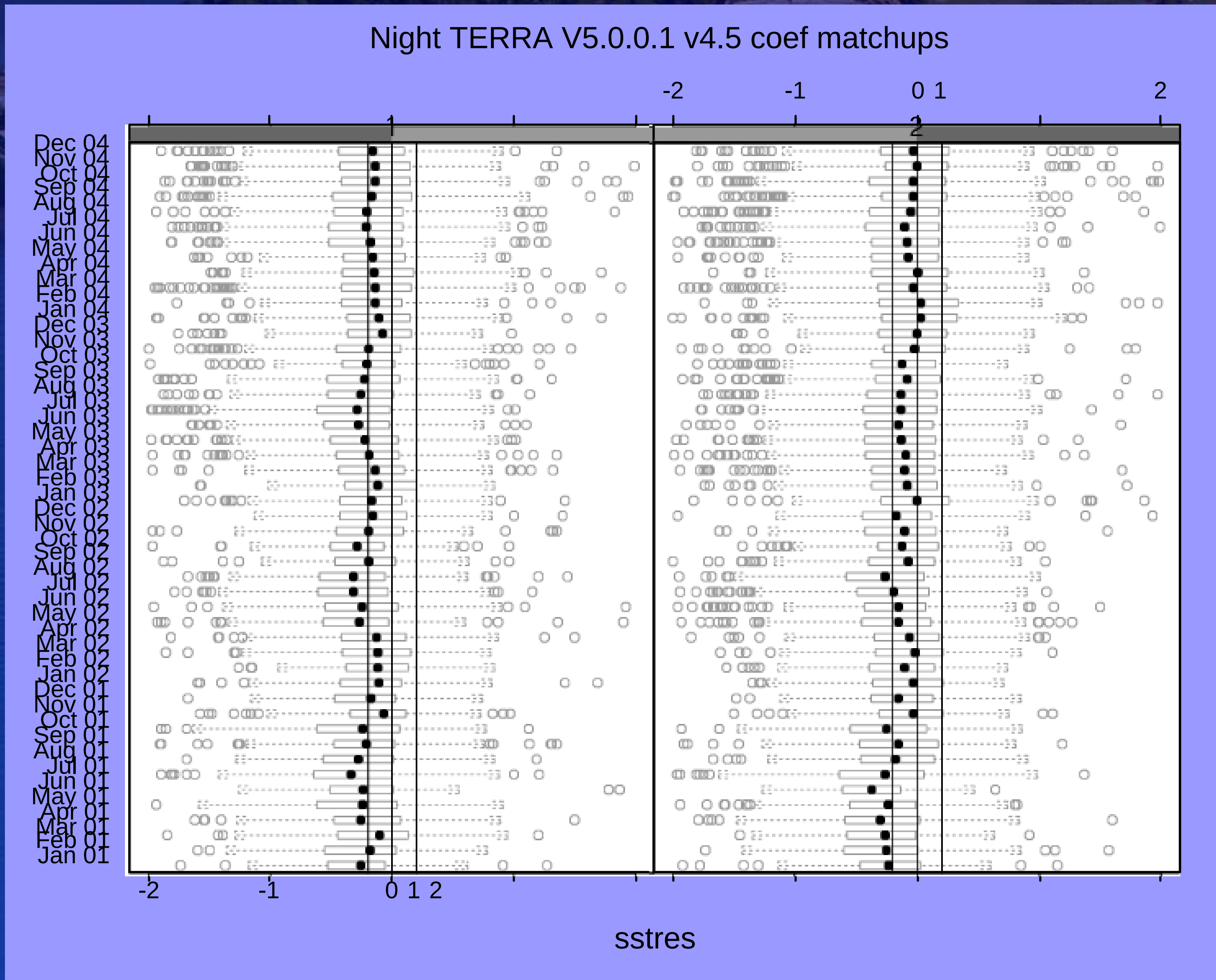
- Multi-sensor Improved SST (MISST) is US contribution to GODAE
- Skin SST measurements



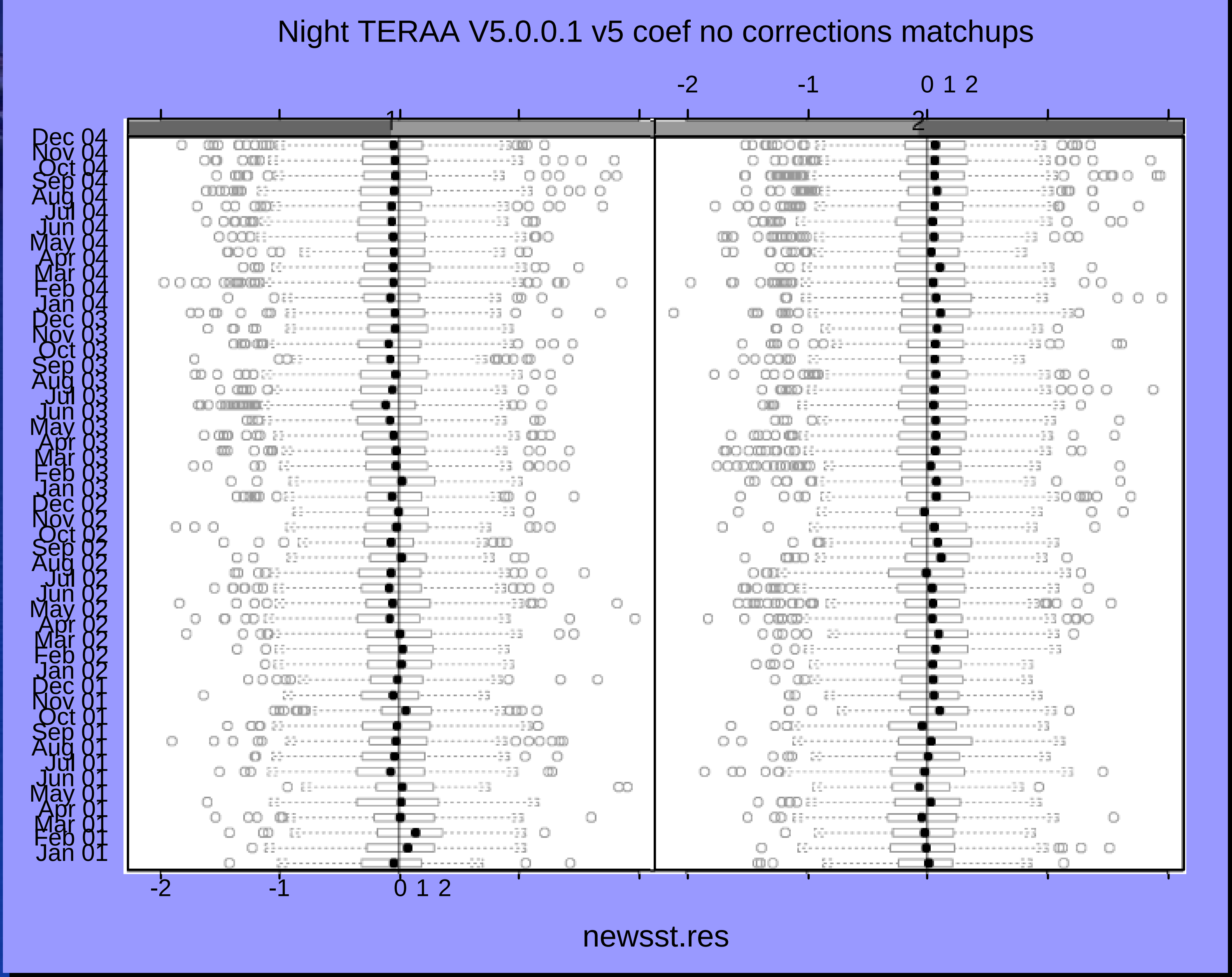
Night TERRA V4.3.0.21 LUT V4.5 Coeff SST matchups



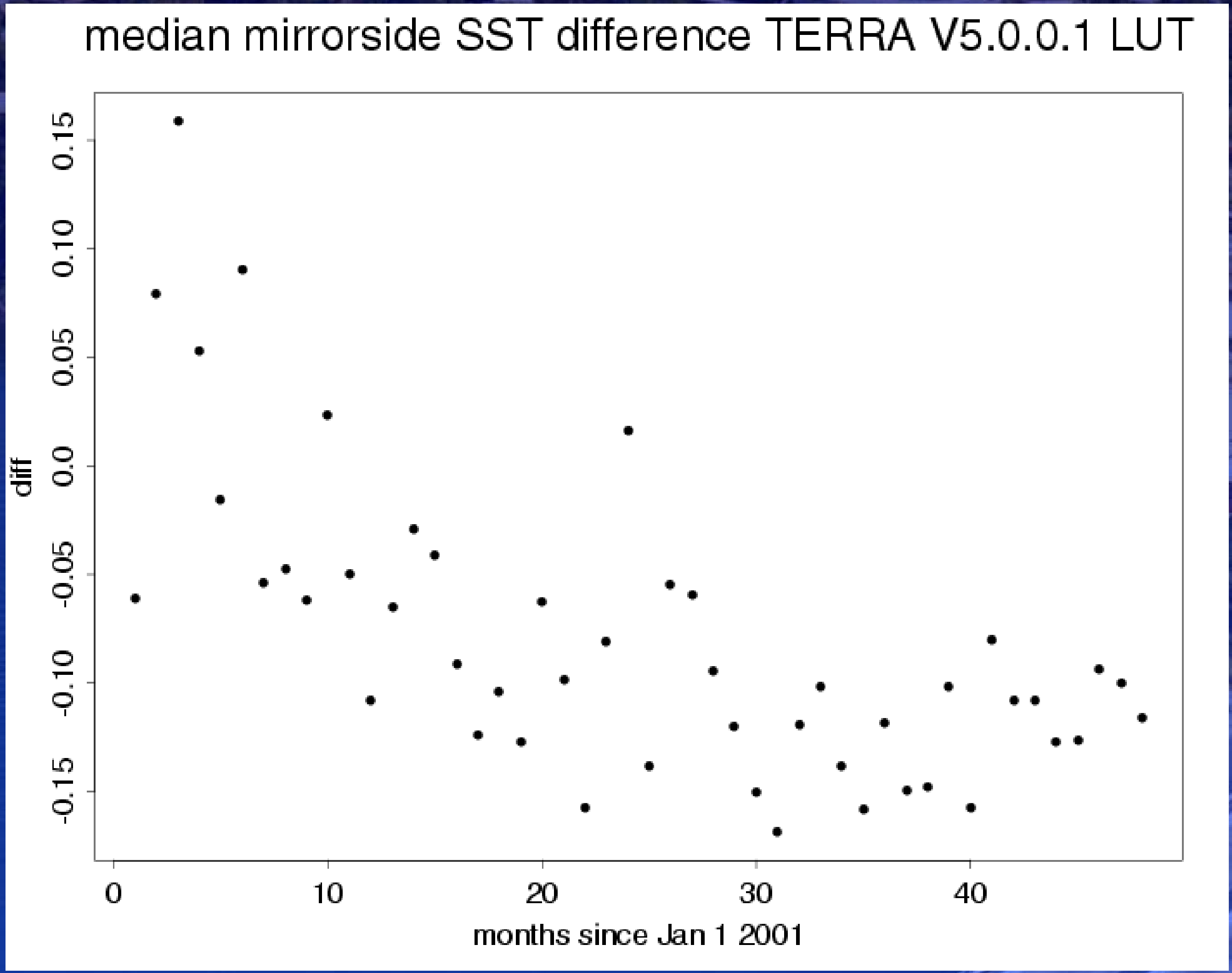
Night TERRA V5.0.0.1 LUT V4.5 Coeff SST matchups



Night TERRA V5.0.0.1 LUT V5.0 Coeff SST matchups
No mirror side correction



TERRA mirror side difference, 2001-2004



TERRA Collection V
Night time Validation Statistics

SST 11-12um Night time
Satellite-buoy residuals

Year	2001	2002	2003	2004
median	-0.147	-0.088	-0.082	-0.080
RMS	0.43	0.426	0.431	0.439
N	4388	6077	8417	11502

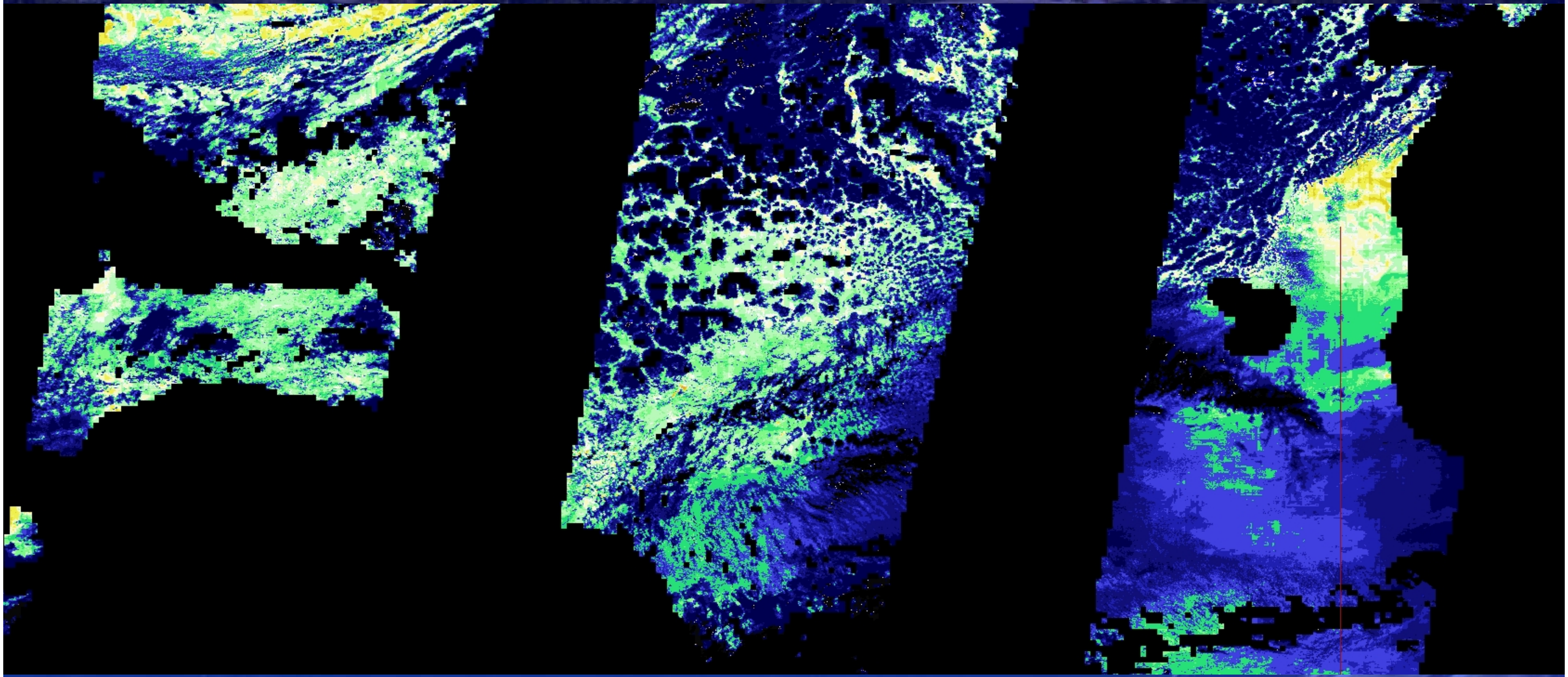
SST4 4um Night time
Satellite-buoy residuals

Year	2001	2002	2003	2004
median	-0.119	0.118	-0.114	-0.119
RMS	0.351	0.349	0.354	0.366
N	4239	5894	8023	10874

Search for Dust Aerosols

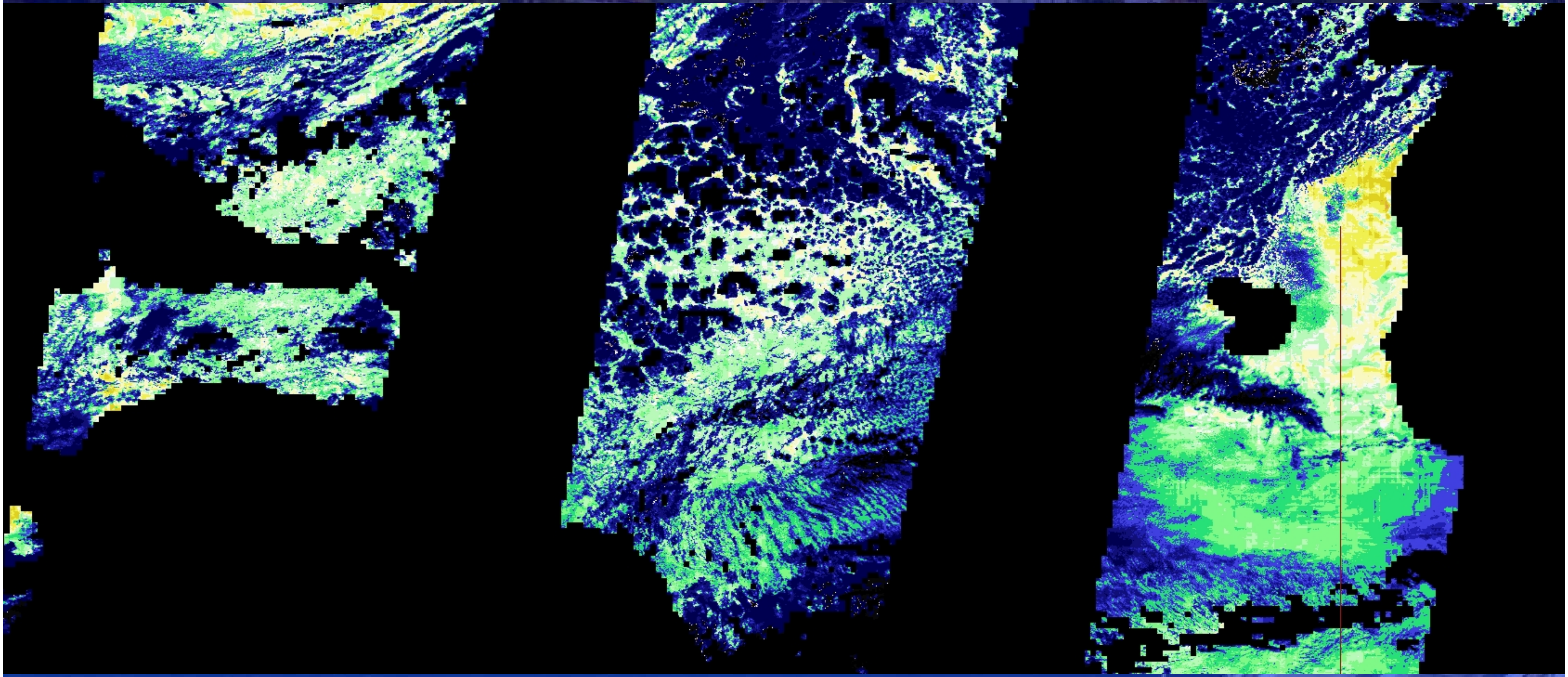
The ability to identify and possibly correct satellite infrared measurements for the presence of dust aerosols at night is limited due to only having access to wavebands in the emitted part of the spectrum. We have utilized the microwave measurement of SST observed by the AMSR instrument on board the Aqua spacecraft as a source of co-spatial and contemporaneous SST unaffected by the presence of dust aerosols to examine the relative impact of the aerosols on the 4 μm (SST4) and 11 μm (SST) MODIS Aqua SSTs. March 14, 2004 (day 2004074) was selected since a significant portion of the tropical eastern Atlantic is covered by dust. A trackline (the red line seen in the far eastern pass) was extracted from the SST(day)-AMSR, SST(night)-AMSR and SST4(night)-AMSR fields. The extractions show good agreement between the respective SST fields at the beginning of the track where no dust aerosol is present. However both the day and night SST fields show significant (order 3K) cold bias within the dust plume seen as the blue region in the eastern tropical Atlantic. The SST4 field is impacted to a lesser extent, showing a decrease of order 1K. The increased sensitivity of the SST to the dust aerosol relative to SST4 provides an opportunity to detect the presence of aerosol in the nighttime fields. Future work will explore the possibility to correct the SST4 for aerosols.

11 µm SST night, 2004074

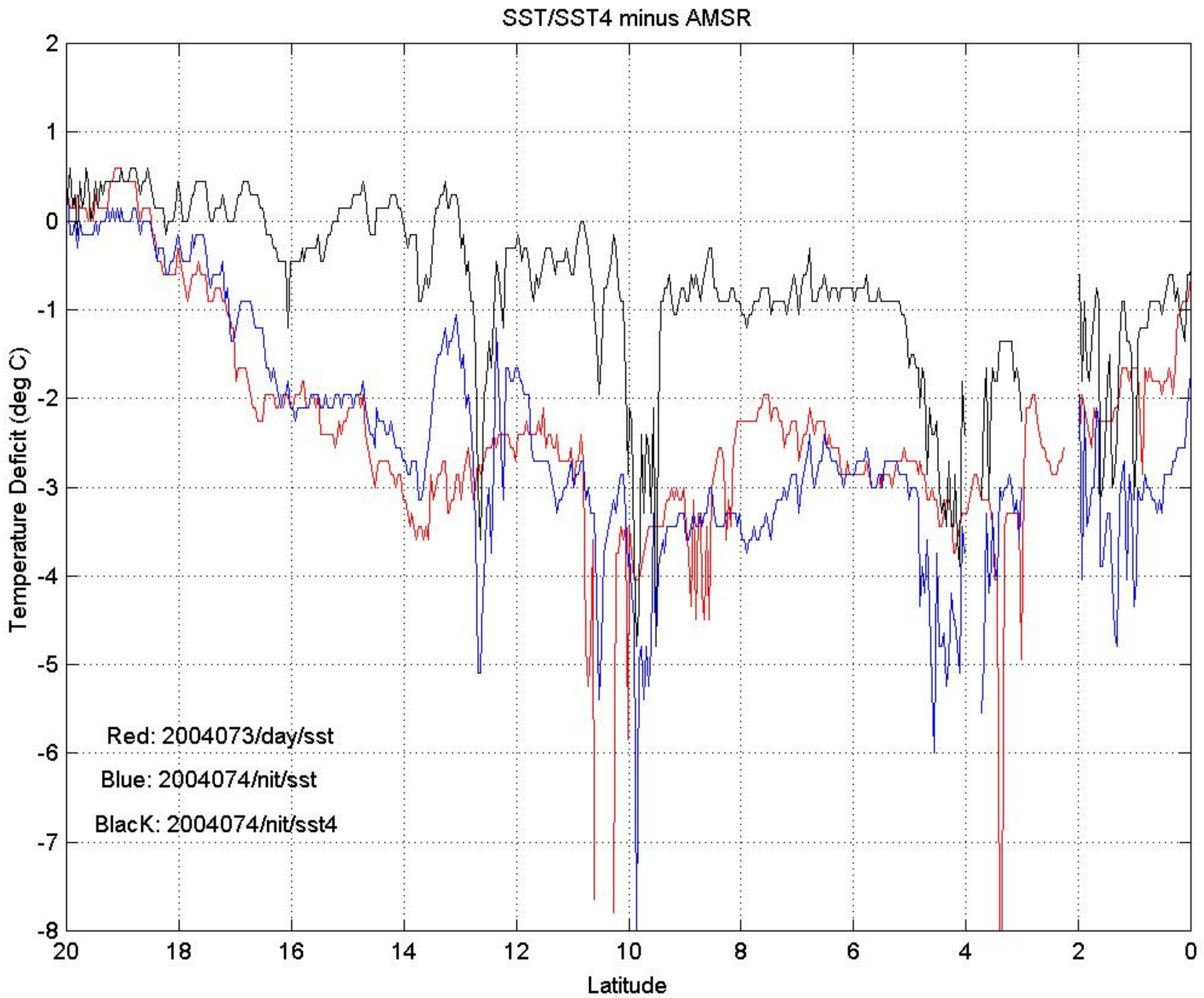


To show dust plume well, no cloud screening has been applied.

4 µm SST4 night, 2004074



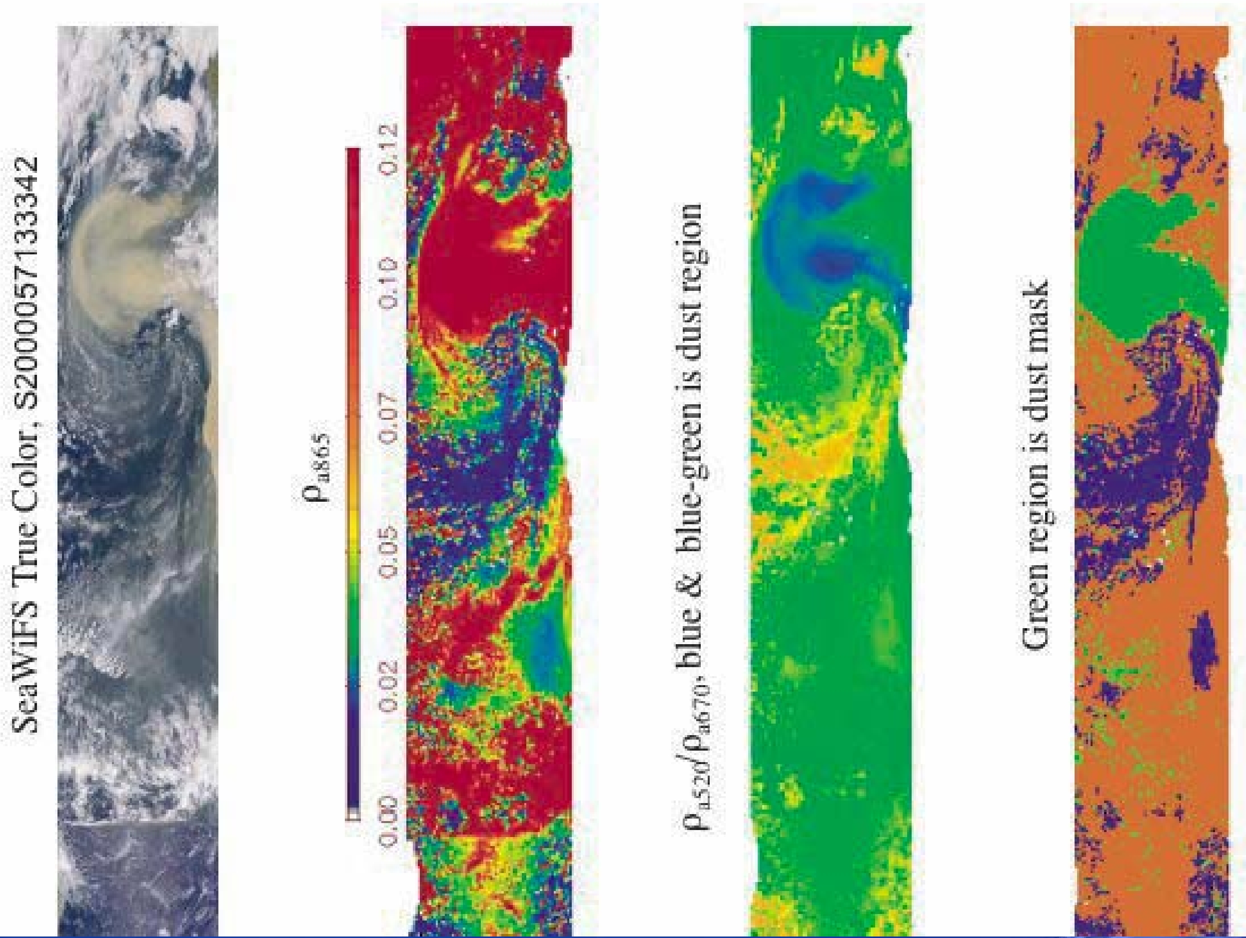
Day and night SST-AMSR residuals



Aerosol effects

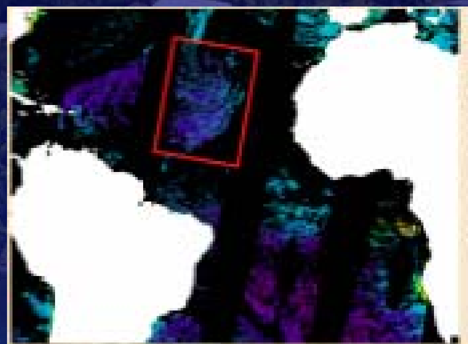
Determination of absorbing aerosol location to enable switching between standard and spectral matching atmospheric correction

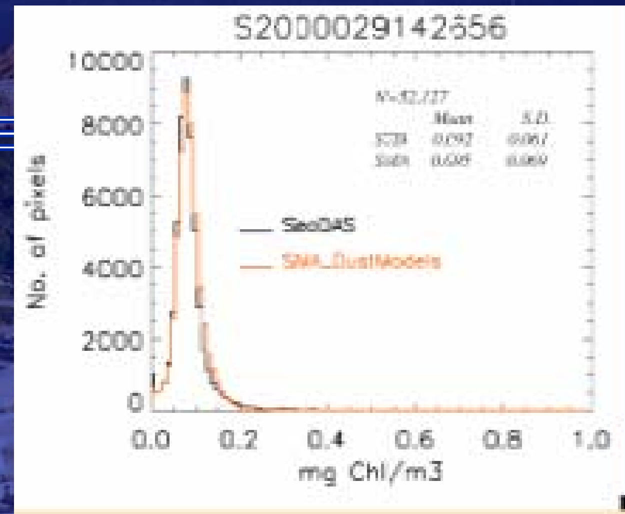
$\rho_{t} - \rho_{r}$ as proxie for ρ_{a}, new cloud mask required due to elevated τ_{a865}

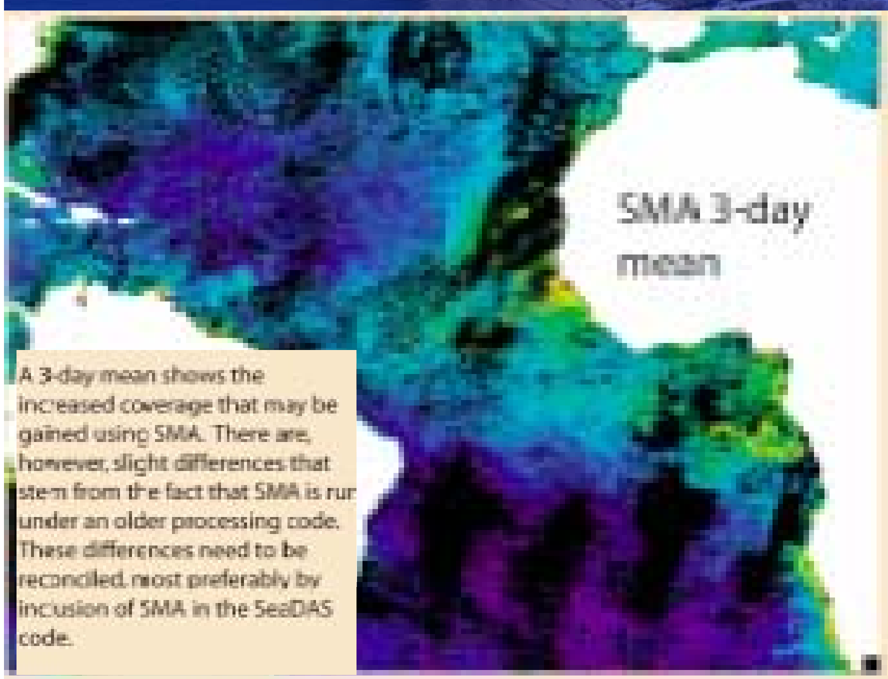


Chl retrieval in non-dusty conditions

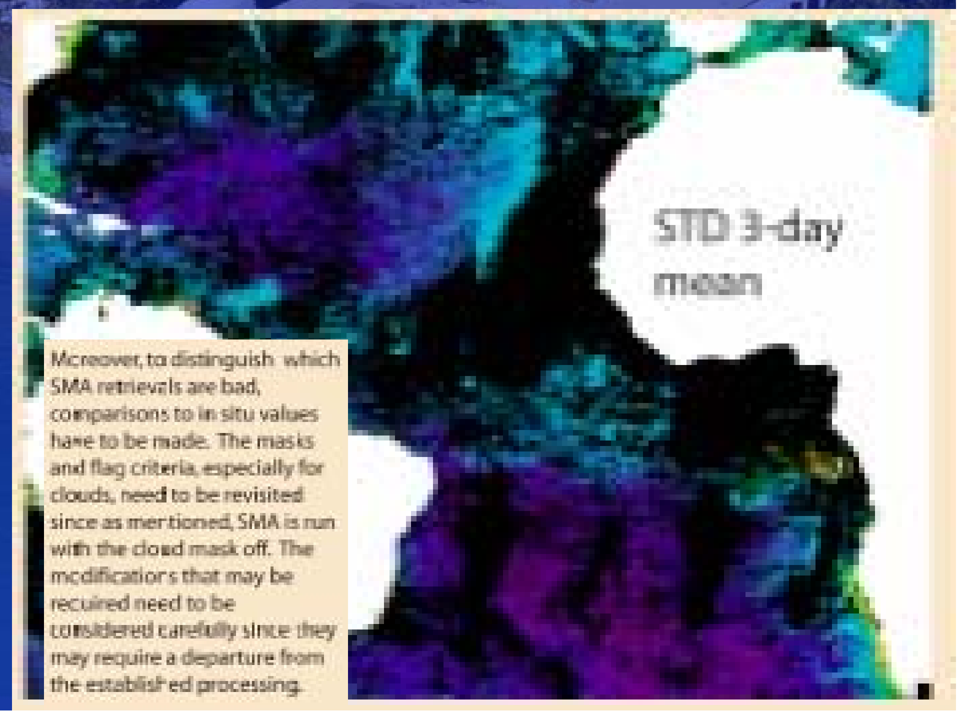
Comparison of the distribution of chlorophyll (common pixels only) in an oligotrophic region (red box) in the absence of dust aerosols shows that SMA yields statistically comparable values to the standard method, albeit requiring a longer computation time







A 3-day mean shows the increased coverage that may be gained using SMA. There are, however, slight differences that stem from the fact that SMA is run under an older processing code. These differences need to be reconciled, most preferably by inclusion of SMA in the SeaDAS code.



Moreover, to distinguish which SMA retrievals are bad, comparisons to in situ values have to be made. The masks and flag criteria, especially for clouds, need to be revisited since as mentioned, SMA is run with the cloud mask off. The modifications that may be required need to be considered carefully since they may require a departure from the established processing.

Summary

- Residual errors (V.5) are comparable to those from heritage instrument (AVHRR under best conditions), and close to the best available – AASTR on ENVISAT
- Error characteristics are reasonably well-understood
- Constant vigilance is required to sustain accuracies
- Aerosol contamination becoming tractable
- Synergistic projects widen the scope of MODIS SST applications