MODIS Science Team Meeting
MCST Session
November 1, 2006

Validation of Sea-Surface Temperatures from MODIS

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with

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Objective and Background

- To establish the residual uncertainties in MODIS SSTs, as functions of the 'governing' parameters
- MODIS SSTs derived from measurements in the 10-13 μm atmospheric window (SST) and in the 3.5-4.1 μm atmospheric window (SST4) at night
- Residual errors result from imperfections in the instrument measurements of top of atmosphere radiances, and imperfections in atmospheric correction and cloud & aerosol identification algorithms.
- The validation of the geophysical retrievals is accomplished by comparison with accurate surface-based measurements of SST – data are archived and distributed in "Match-Up Data Bases"

Measure of satellite retrieval uncertainty

MODIS - GHRSST (GODAE High Resolution Sea Surface Temperature Pilot Project) approach:

- **To provide a statistical estimate of expected bias and standard deviation for each satellite-retrieved SST**
- **Partition satellite - in situ match-up database along 7 dimensions (environmental conditions and observing geometry)**
- **The "uncertainty hypercube" has been implemented for MODIS SST and SST4 products and applied to the *AQUA* and *TERRA* instruments**

MODIS

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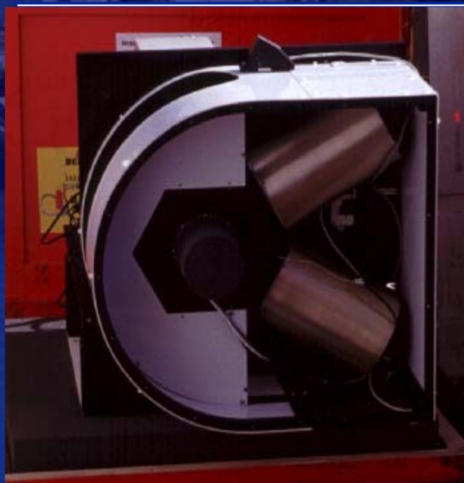
Marine-Atmospheric Emitted Radiance Interferometer (M-AERI)



M-AERI Characteristics	
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)

Laboratory confirmation 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.

Constructed by SSEC, U. Wisconsin - Madison

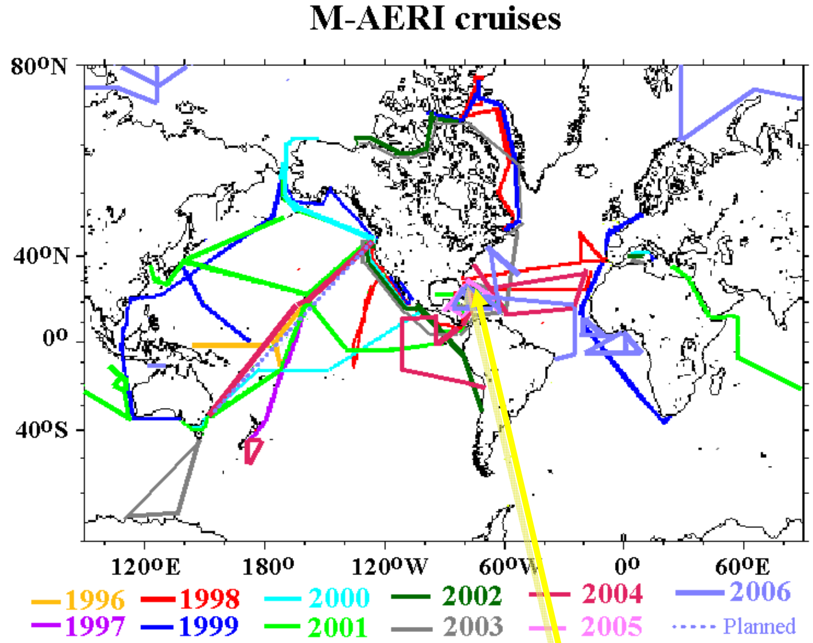
Traceable to National Standards: NIST EOS TXR

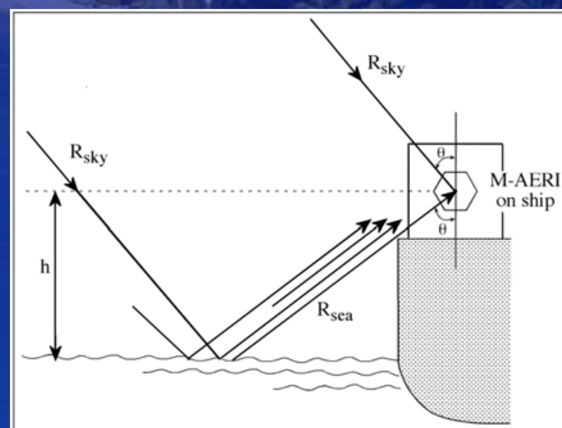
Unique EOS Standard
Cryogenic detectors (liquid N_2)
λ= 5 & 10μm

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

Surface radiometry

- Use ship-based radiometers, e.g. M-AERI, ISAR, CIRIMS and others.
- M-AERI is the reference standard for satellite SST retrievals (AVHRR, AATSR, as well as MODIS), and for other ship-board radiometers.
- M-AERI also being used for AMSR-E & AIRS SST validation.





M-AERI cruises	
Number of deployments	40
Number of ships	23
Number of days	3353

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M-AERI on Explorer of the Seas

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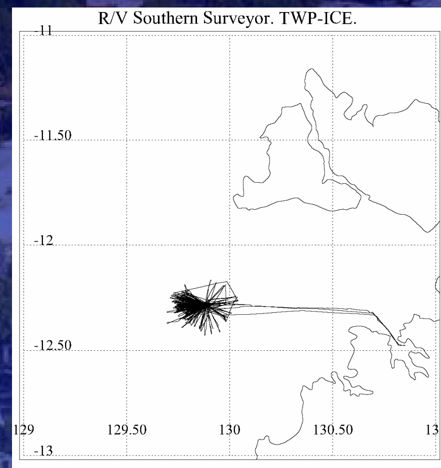
Satellite skin SST accuracies

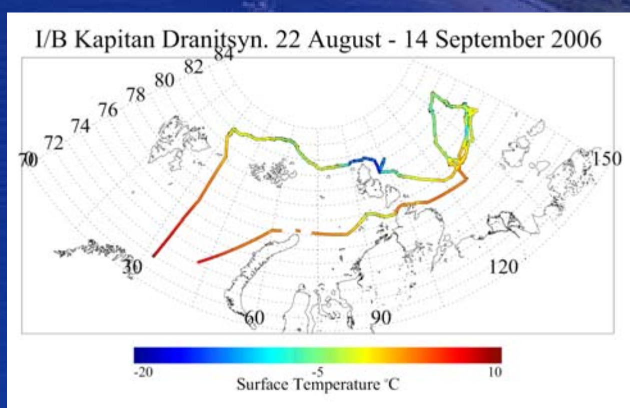
Statistics of M-AERI validation of MODIS and AMSR-E SST validation. *Explorer of the Seas* data from July 2002 to July 2005.

	Spectral interval	Diurnal characteristic	Bias K	St. Dev K	N
MODIS – M-AERI	11,12 µm	Night + Day	-0.025	0.48	1393
		Day	0.028	0.52	502
		Night	-0.055	0.45	891
	4 µm	Night	-0.093	0.45	1003
AMSR-E – M-AERI		Night + Day	0.182	0.59	139

Validating sensor must contribute <<0.1K to the error budget of the comparison

M-AERI at Sea – some issues…..





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ISAR – an autonomous IR radiometer

- **ISAR – Infrared SST Autonomous Radiometer**
- **Filter radiometer, internal calibration**
- **Deployed on *Jingu Maru*, Atlantic crossings**
- **Currently on *Mirai* in Indian Ocean**

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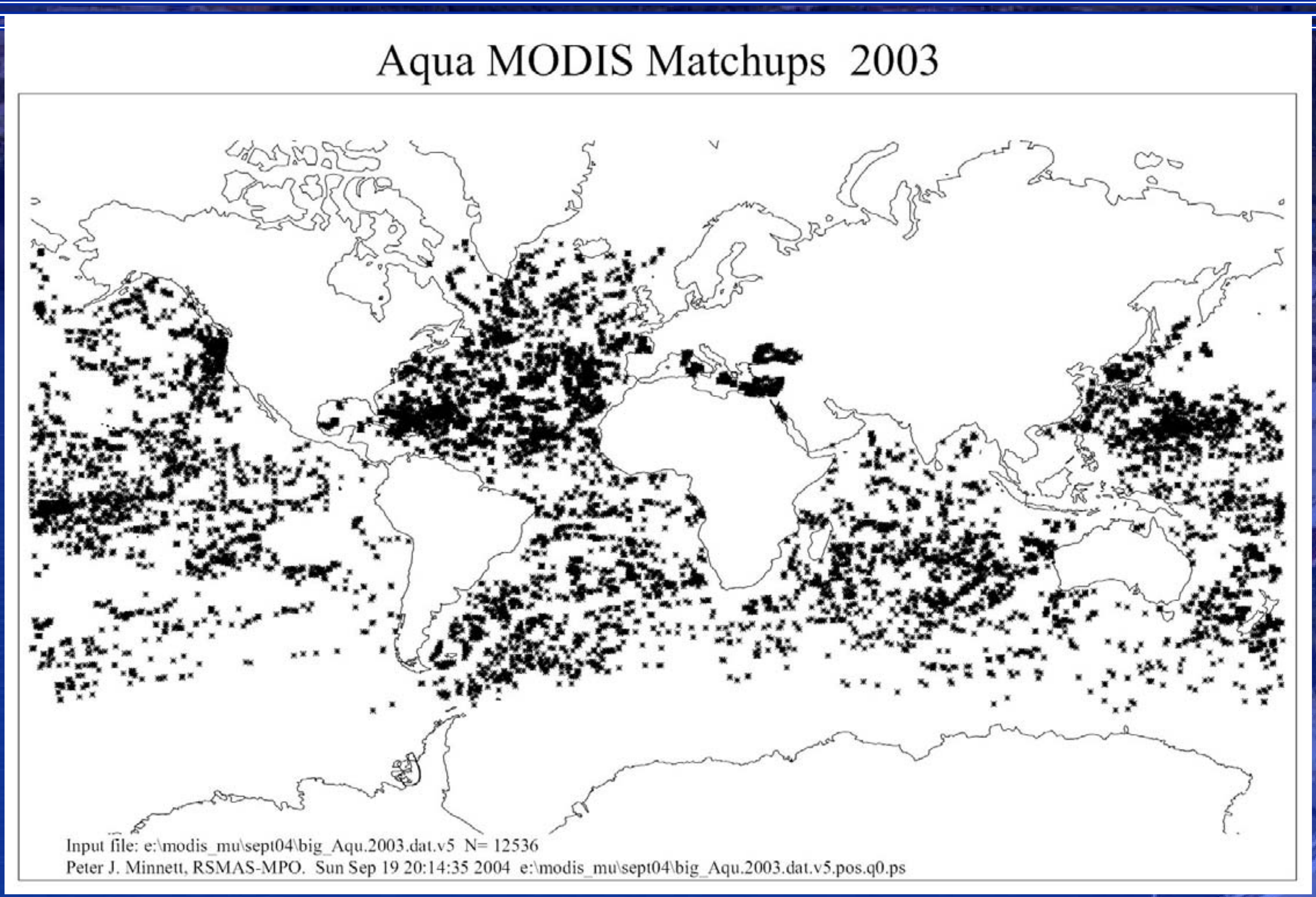
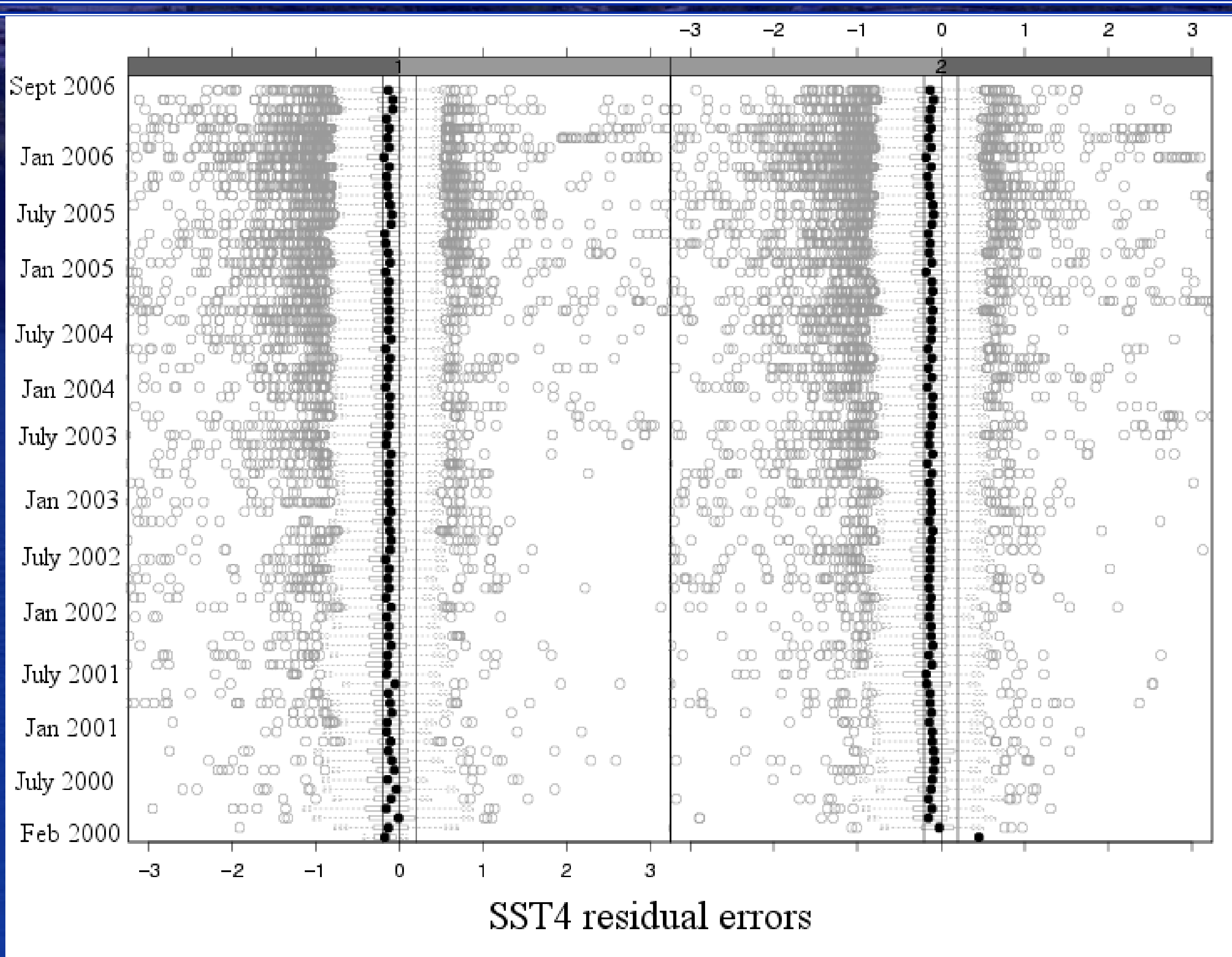
Buoy measurements



N = 12536
@ qf = 0

MODIS SST4 - Buoy Residuals Feb 2000 - Aug 2006



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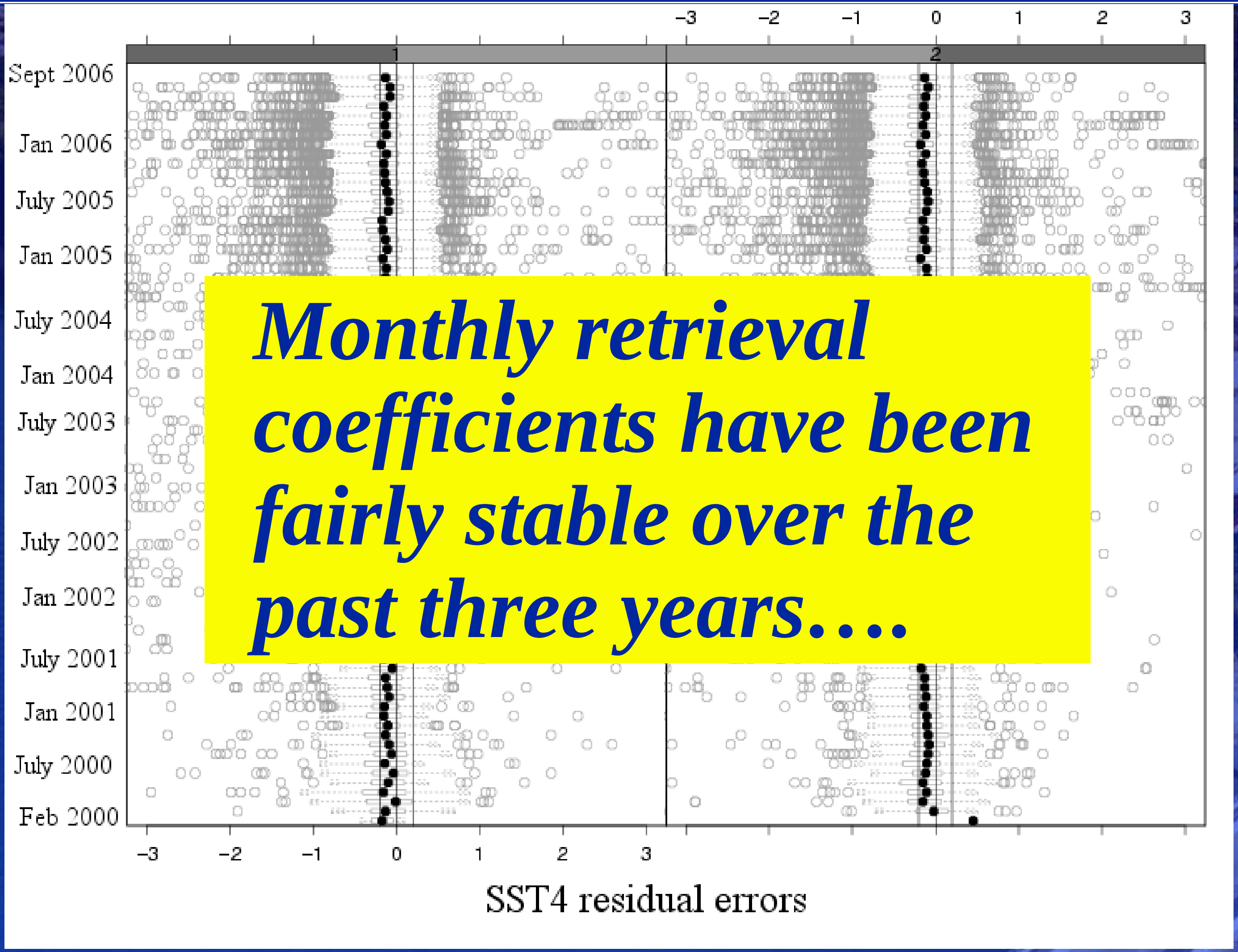
MODIS SST4 - Buoy Residuals Feb 2000 - Aug 2006



Monthly retrieval coefficients have been fairly stable over the past three years….

MODIS v5 global error statistics (buoys)

SST 11-12 µm	TERRA					
	day			night		
Year	mean	RMS	Count	mean	RMS	Count
2000	-0.139	0.797	3091	-0.186	0.794	1800
2001	-0.262	1.430	6321	-0.228	0.707	4935
2002	-0.135	0.621	9244	-0.204	0.580	6935
2003	-0.086	0.607	15685	-0.190	0.558	11058
2004	-0.068	0.579	24964	-0.167	0.559	16943
2005	-0.110	0.549	39826	-0.213	0.519	28460
2006	-0.105	0.574	32495	-0.208	0.524	23149
all years	-0.108	0.650	131626	-0.200	0.555	93280

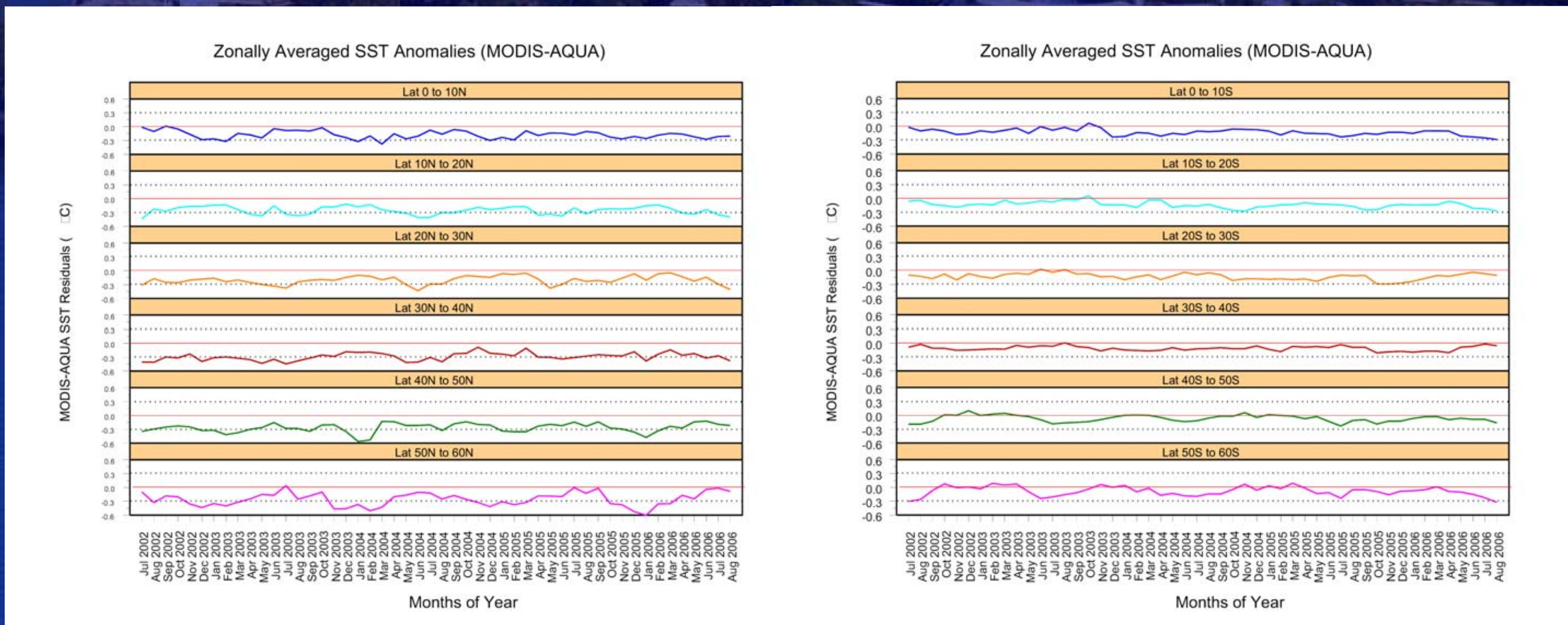
SST 11-12 µm	AQUA					
	day			night		
Year	mean	RMS	Count	mean	RMS	Count
2002	-0.153	0.538	10293	-0.235	0.499	5906
2003	-0.133	0.577	22988	-0.224	0.508	12977
2004	-0.137	0.562	26415	-0.219	-0.484	15471
2005	-0.152	0.539	40941	-0.235	0.461	25083
2006	-0.135	0.550	34687	-0.205	0.452	22187
all years	-0.142	0.553	135324	-0.222	0.475	81624

SST 4µm	TERRA			AQUA		
Year	night			night		
	mean	RMS	Count	mean	RMS	Count
2000	-0.161	0.829	1993			
2001	-0.220	0.663	5397			
2002	-0.191	0.528	7580	-0.224	0.449	6429
2003	-0.176	0.500	12006	-0.217	0.455	14095
2004	-0.178	0.493	18452	-0.214	0.426	16765
2005	-0.178	0.471	31130	-0.223	0.414	27280
2006	-0.174	0.473	25294	-0.208	0.404	24140
all years	-0.179	0.505	101852	-0.216	0.423	88709

MODIS v5 global error statistics (M-AERI)

SST 11-12µm	TERRA					
	day			night		
Year	mean	RMS	Count	mean	RMS	Count
2000	-0.015	0.613	116	-0.035	0.493	102
2001	0.115	0.557	510	-0.036	0.475	651
2002	0.174	0.448	236	0.020	0.502	362
2003	0.016	0.513	382	-0.060	0.453	417
2004	0.155	0.687	364	0.086	0.510	544
2005	0.121	0.723	176	0.092	0.466	296
2006	-0.032	0.515	164	-0.041	0.430	302
all years	0.090	0.584	1948	0.006	0.408	2372
SST 11-12µm	AQUA					
	day			night		
Year	mean	RMS	Count	mean	RMS	Count
2002	0.079	0.544	134	-0.061	0.440	80
2003	-0.087	0.621	323	-0.262	0.473	284
2004	0.087	0.615	249	0.034	0.534	465
2005	0.171	0.578	113	0.061	0.469	258
2006	-0.176	0.459	75	0.008	0.510	105
all years	0.037	0.593	803	-0.039	0.513	1192
SST 4µm	TERRA			AQUA		
Year	night			night		
	mean	RMS	Count	mean	RMS	Count
2000	-0.055	0.462	115			
2001	-0.046	0.387	714			
2002	0.004	0.390	397	-0.158	0.384	95
2003	-0.123	0.358	453	-0.213	0.389	328
2004	0.010	0.407	597	-0.019	0.486	509
2005	0.008	0.458	350	-0.038	0.382	281
2006	-0.017	0.373	316	0.007	0.432	110
all years	-0.030	0.400	2942	0.063	0.442	1323

But bias & rms alone do not tell the whole story…



Systematic patterns in residual uncertainties indicate shortcomings in the atmospheric correction algorithms, and indicate how they can be improved……

MODIS Single Sensor Error Statistics Approach
Bias and Standard Deviation Hypercube

Hypercube dimensions (partitioning of Match-up database):

- Time- quarter of year (4)
- Latitude band (5):
  "60S to 40S" "40S to 20S" "20S to 20N" "20N to 40N" "40N to 60N"
- Sat Zenith angle intervals (4):
  "0 to 30 deg" "30+ to 40 deg" "40+ to 50 deg" "50+ deg"
- Surface temperature intervals (8): **5 degree intervals**
- Channel difference intervals:SST(3), SST4(4)
  ch31-32 (SST): 0.7<, 0.7->2.0, >2.0
  ch22-23 (SST4) 0.5 degree intervals: -0.5<, -0.5->0, >0 ->0.5, >0.5

-Quality level (2)

cube created only for ql=0 and 1

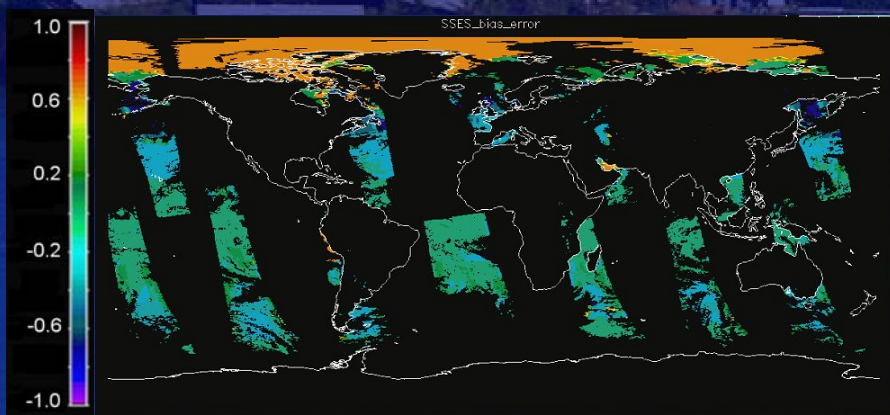
Note for ql2 and 3 the bias and standard deviation are each fixed to a single value

-Day/Night

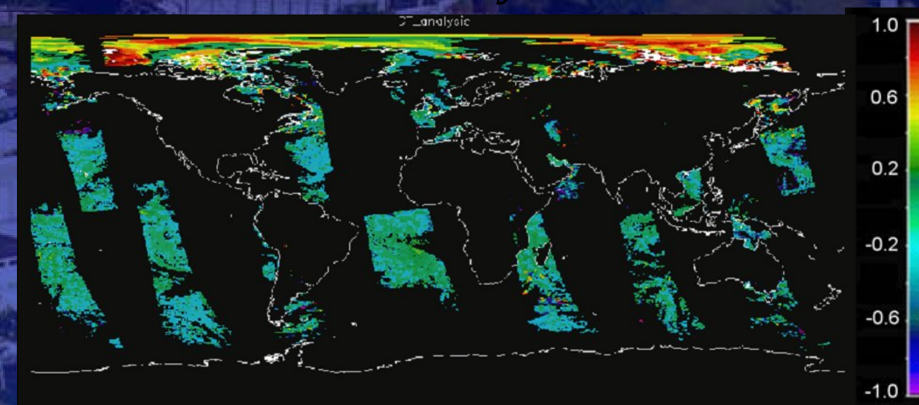
No interpolation between adjacent cells in Hypercube

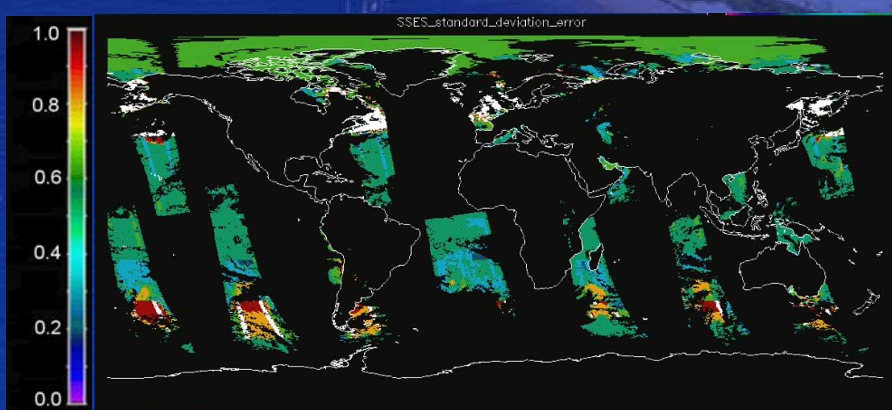
SSES for August 1

SSES Bias wrt In Situ

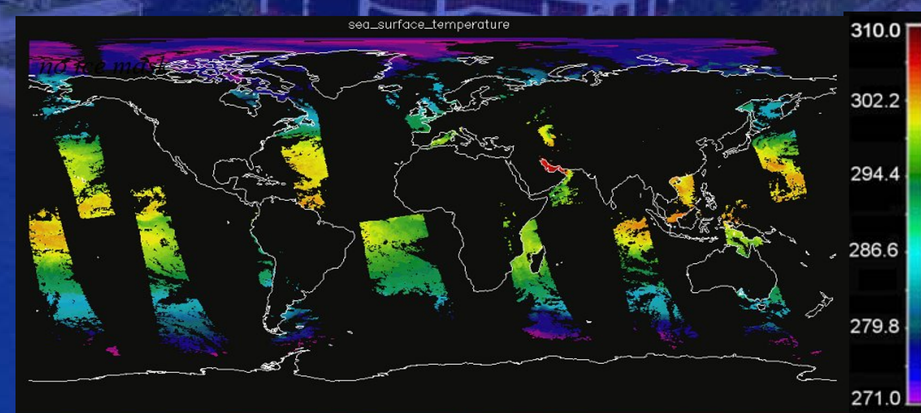


MODIS SST – Reynolds OI SST





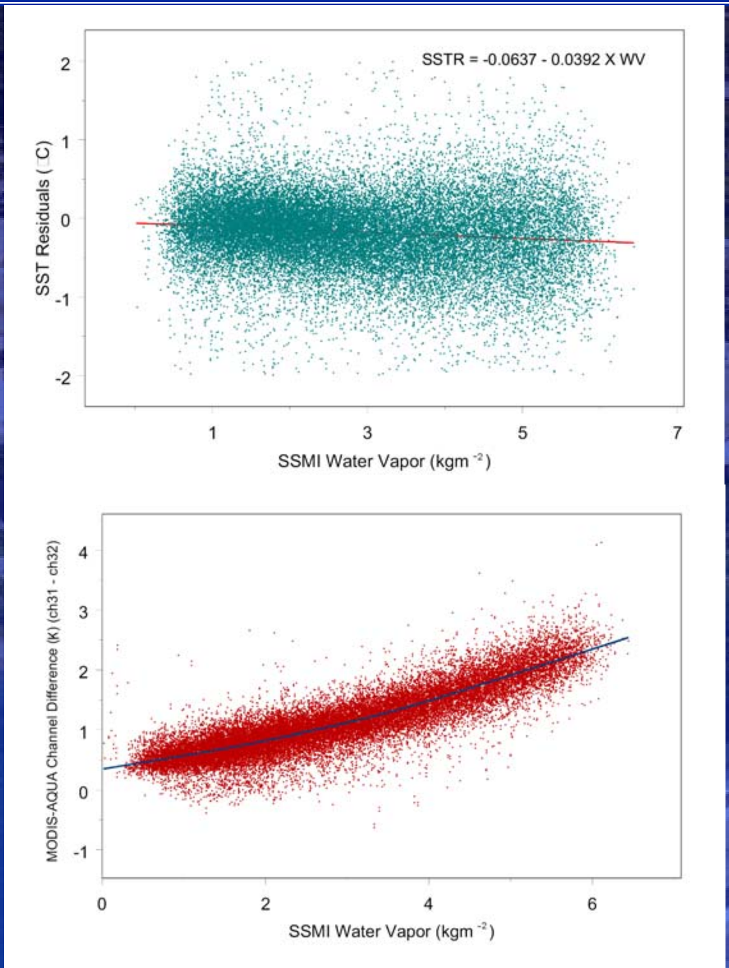
SSES St. Dev wrt In Situ



MODIS SST

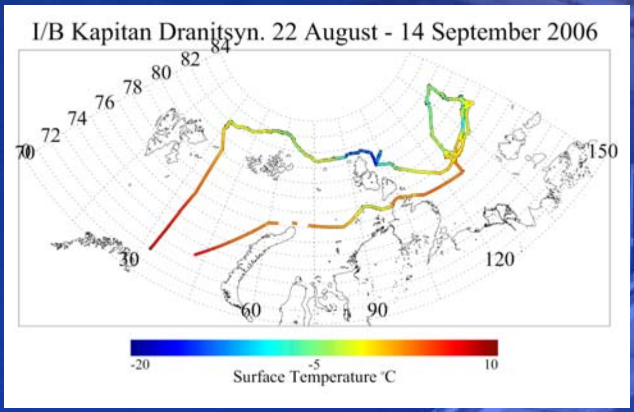
Water-vapor dependence…

- Water vapor is one of the main atmospheric constituents that contribute to the atmospheric effect in the infrared.
- Water vapor is not an independent variable in the atmospheric correction algorithm, but is represented by a proxy (brightness temperature difference).
- Shortcoming in the current algorithm results in a systematic dependence, that should be correctible.



Indirect validation

In cloudy areas, such as high latitudes & regions of extensive marine stratus, the best approach for validating infrared SSTs (e.g. from *Aqua* MODIS) is to validate microwave SSTs (e.g. from *Aqua* ASMR-E), and compare the two.

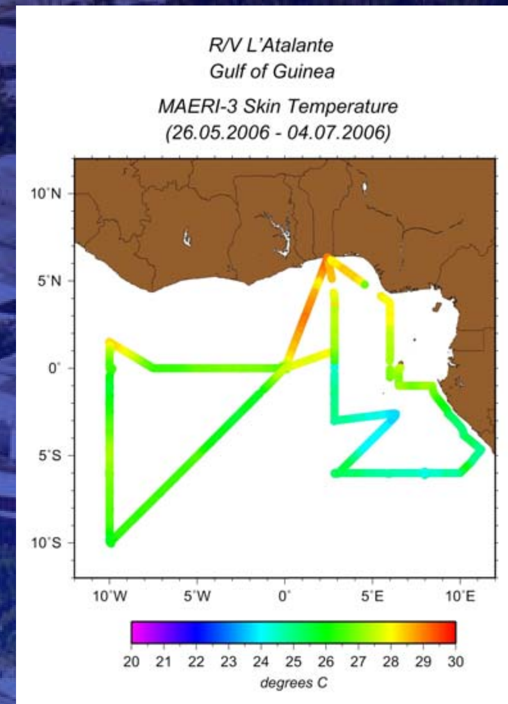


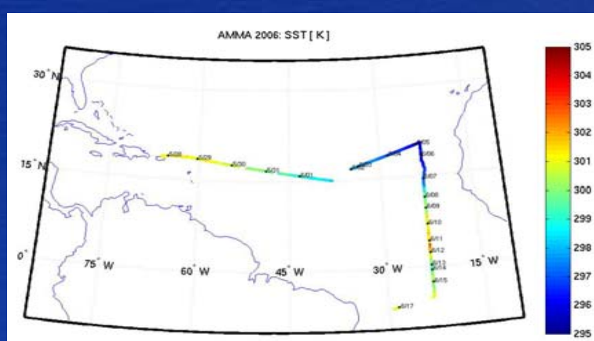
Microwave SST accuracies

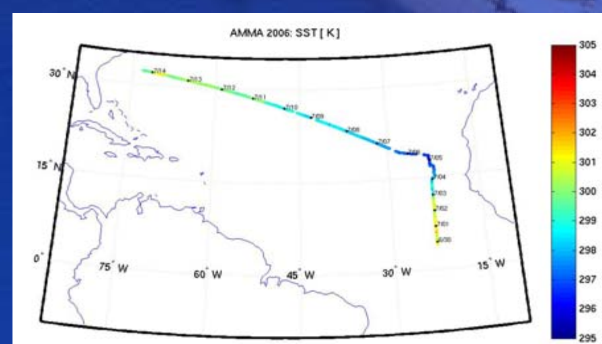
AMSR-E M-AERI comparisons during AMMA, May-July 2006.

Parts of the cruise tracks under clouds of ITCZ

	Mean K	St. Dev. K	N
N/O L'Atalante			
Ascending arc (daytime)	0.033	0.478	18
Descending arc (night)	0.143	0.350	18
Both	0.088	0.421	36
NOAA S Ronald H Brown			
Ascending arc (daytime)	0.105	0.439	15
Descending arc (night)	0.081	0.281	17
Both	0.092	0.358	32
Both Ships			
Ascending arc (daytime)	0.065	0.455	33
Descending arc (night)	0.113	0.321	35
All	0.090	0.390	68



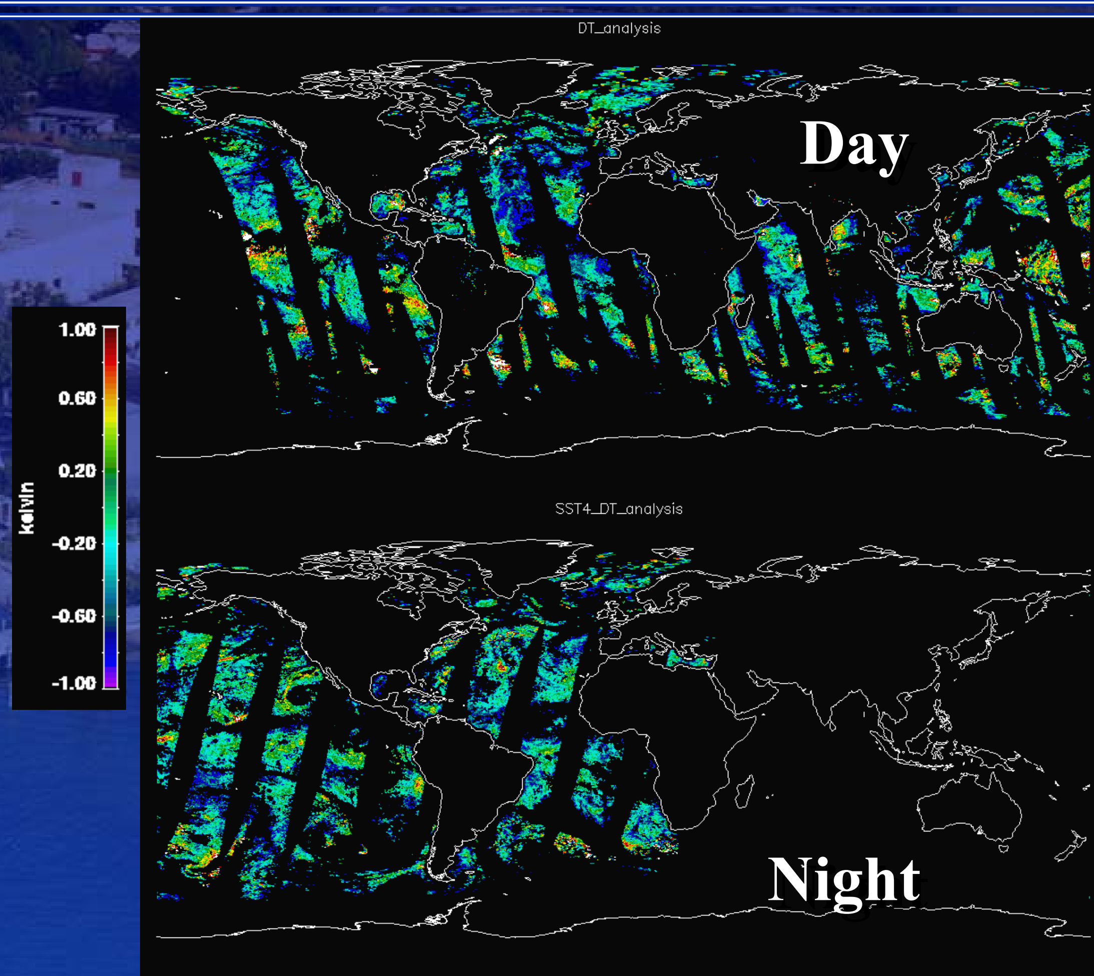




MODIS to AMSR-E SST comparisons

Differences in MODIS and AMSR-E SSTs have spatial patterns, indicating geophysical causes.

Some of the discrepancies are due to AMSR-E, some to MODIS



24 August 2004

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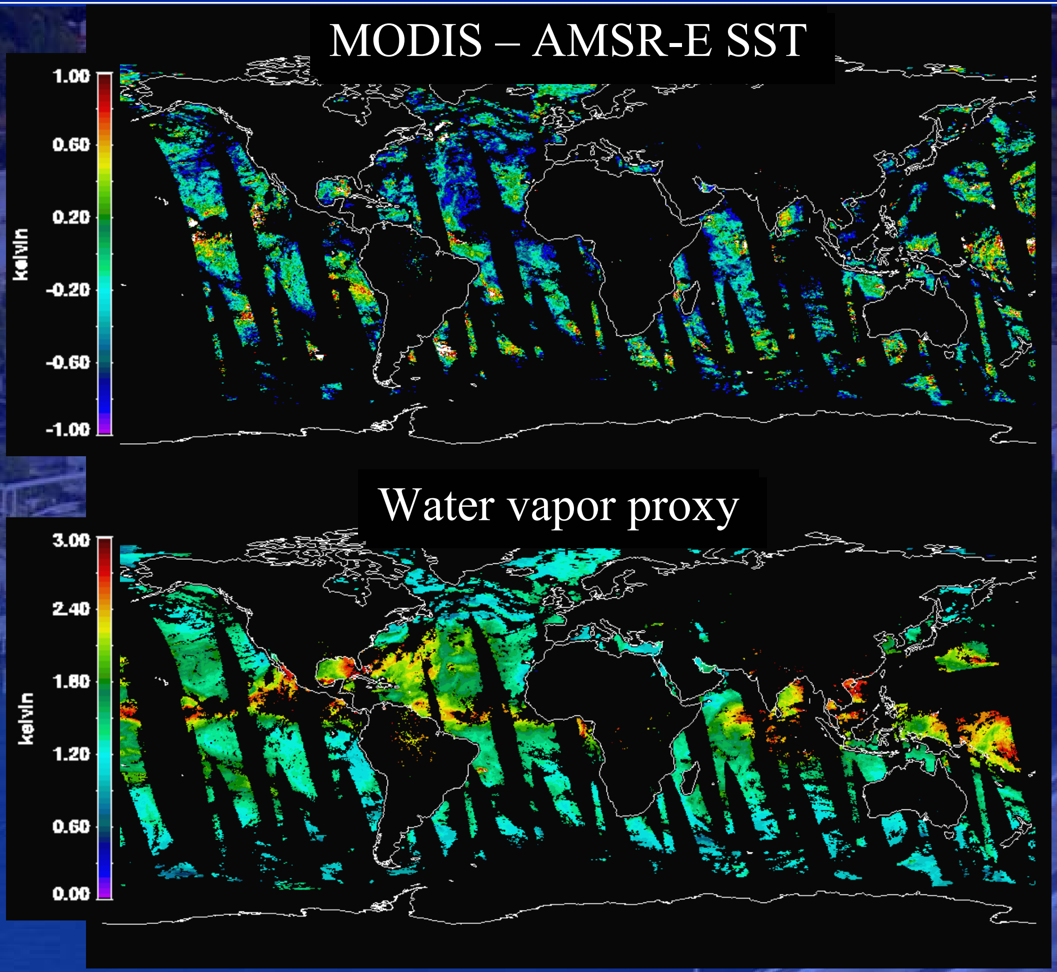
MODIS to AMSR-E SST comparisons

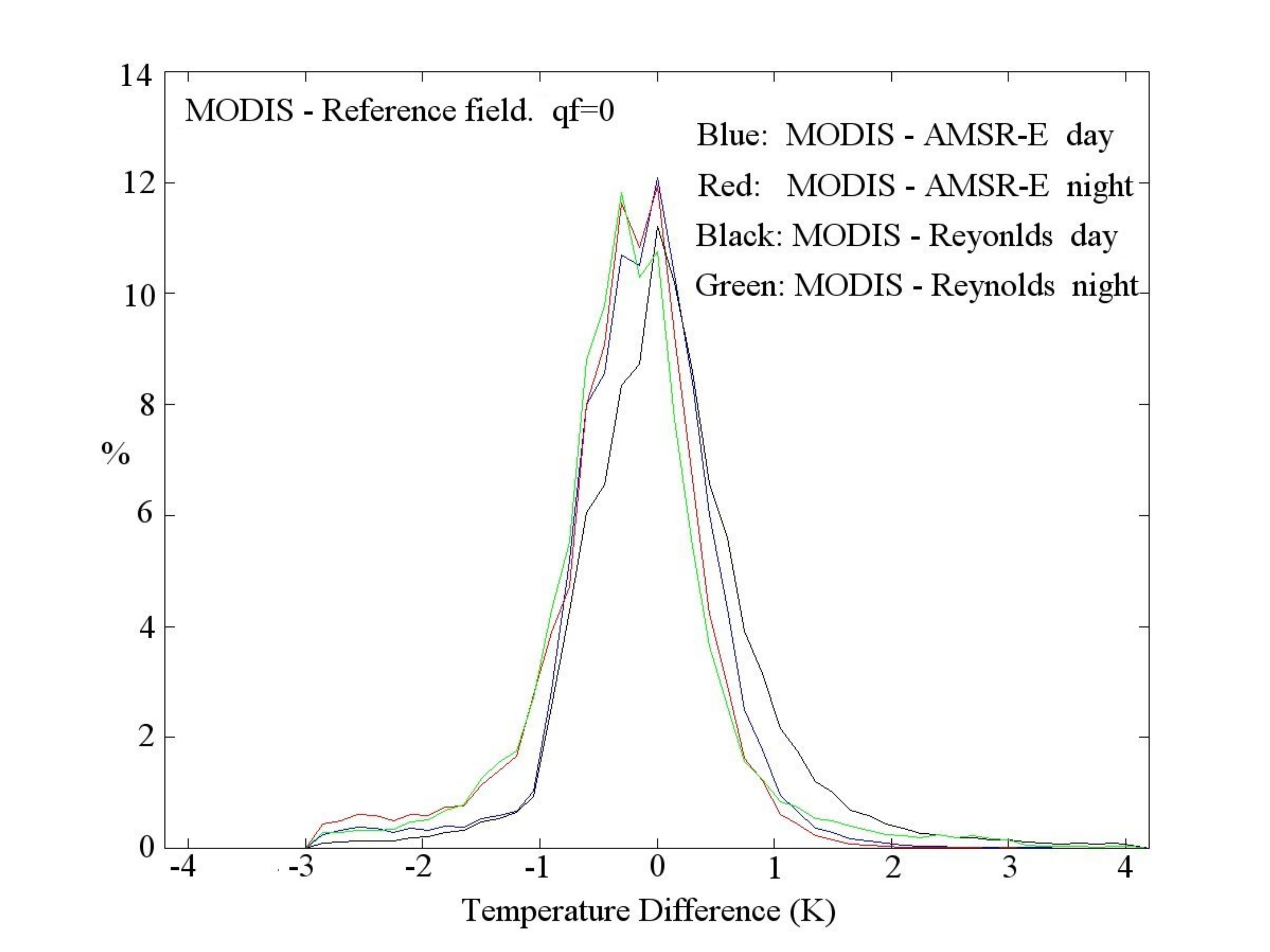
Differences in MODIS and AMSR-E SSTs have spatial patterns, that do not correlate with the water vapor proxy.

Other geophysical parameters also involved.



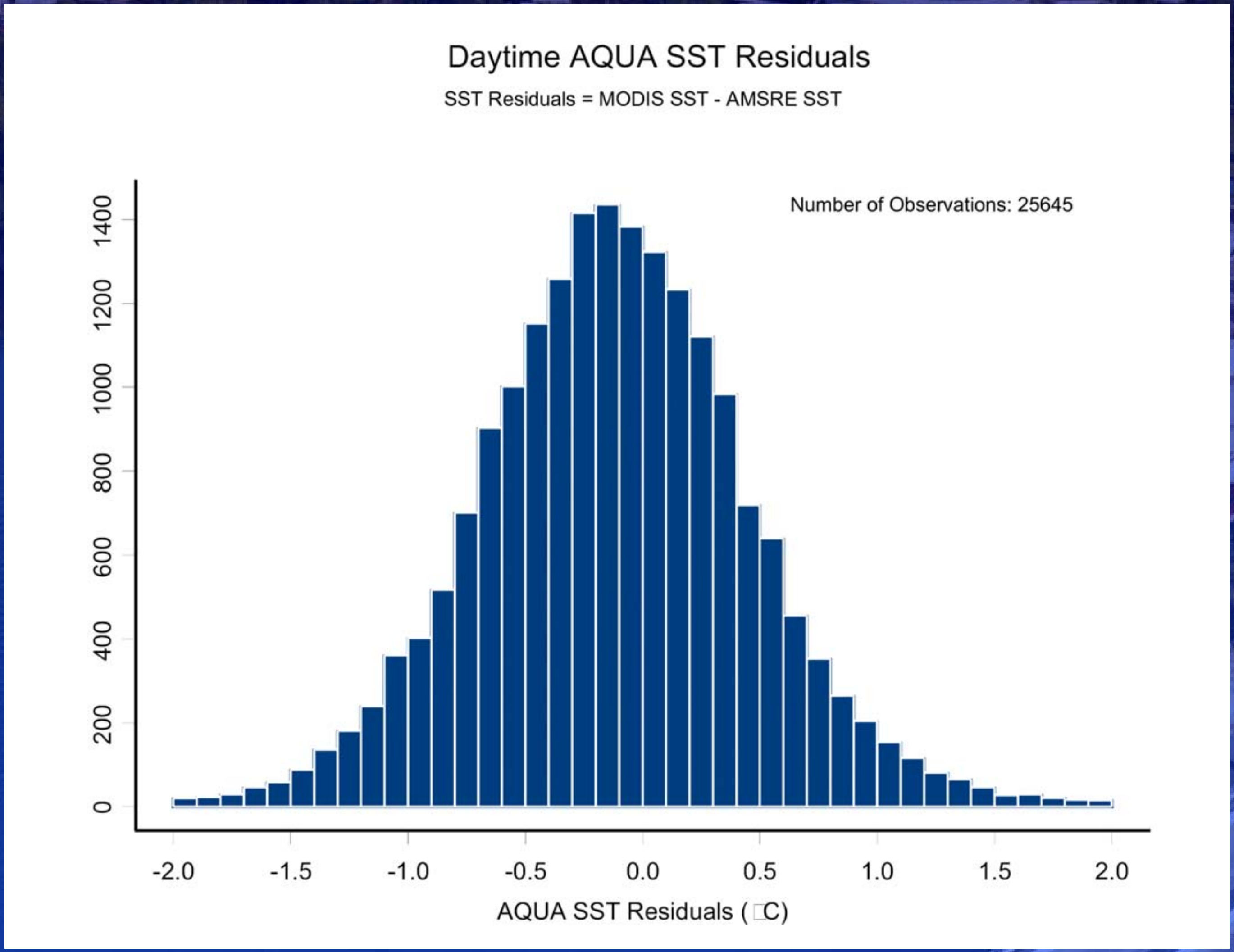
11-12µm brightness temperature differences
24 August 2004

MODIS, AMSR-E, Reynolds SST differences



24 August 2004

MODIS – AMSR-E SST differences



Summary

- V5 monthly coefficients removed seasonal bias trends, *Terra* mirror side trends

- SST4 rms order 0.4K, SST order 0.5K

- SST4 less affected by dust aerosols, water vapor

- Improved quality filtering removed most cold clouds and significant dust aerosol concentrations

- Hypercube developed and tested for *Terra* and *Aqua*

- Introduction of SSES hypercube provides insight into bias and standard deviation trends as a function of time, latitude, temperature, satellite zenith angle, brightness temperature difference as a proxy for water vapor and retrieval quality level

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Conclusions

- MODIS SSTs of "climate record" quality, having extensive error characterization, and traceability to NIST standards

- Current status is a tribute to efforts of MCST in characterizing the instrumental artifacts

- No evidence that *Terra* SSTs are of poorer quality than *Aqua* SSTs

- MODIS SSTs are an important component of GHRSST-PP

- An important focus of GHRSST-PP is quantifying effects of diurnal heating… benefits from *Terra* AND *Aqua*

- Hypercube provides insight leading to improved retrieval equation coefficient generation

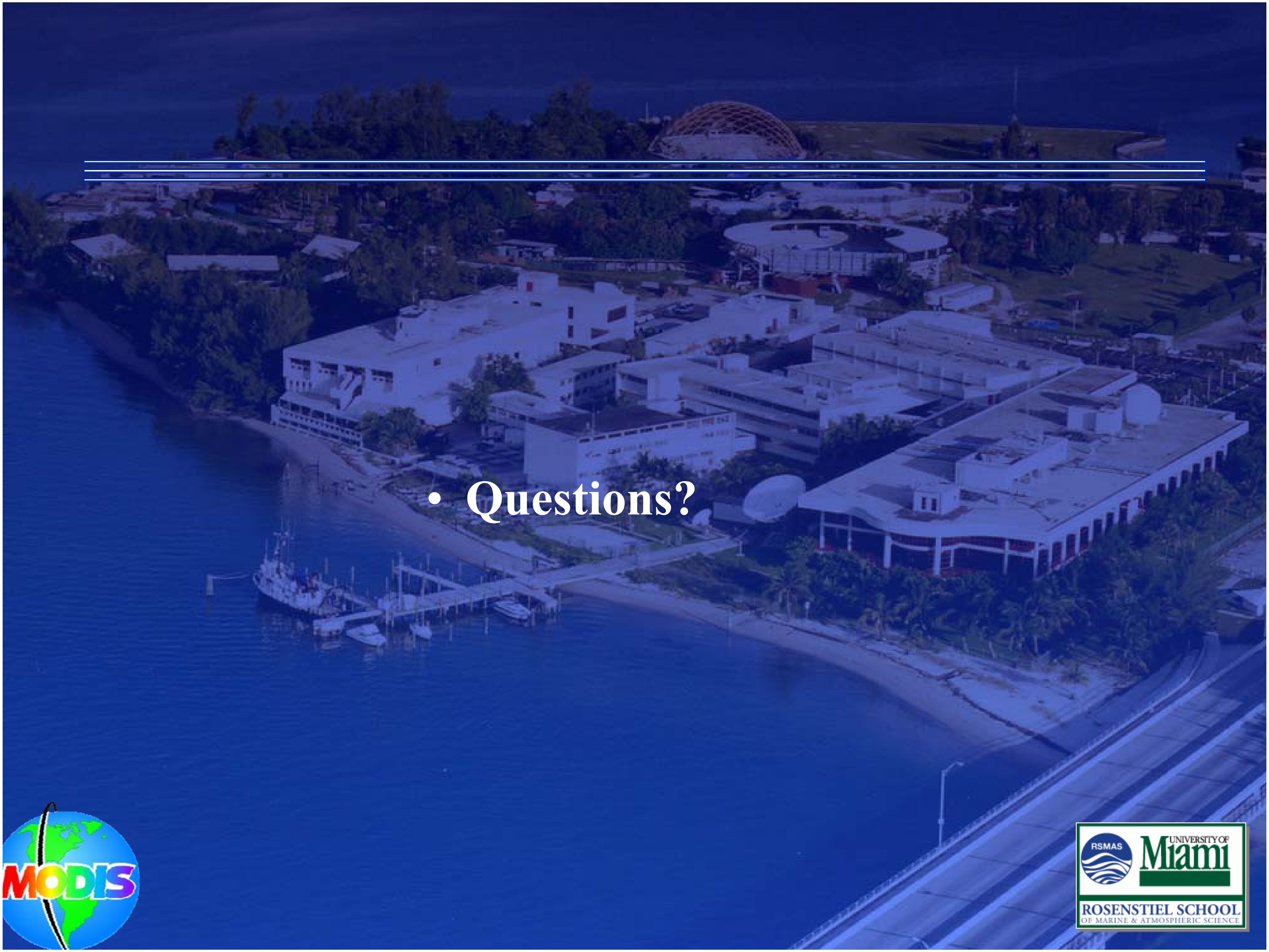
Challenges:

- Many areas of climate interest are very cloudy – approach to follow is to use AMSR-E SSTs as a "transfer standard"

- M-AERIs are still the best source of validation data, but are "showing their age…."

Looking forward…..

- MODIS on *Terra* and *Aqua* making contributions to GHRSST-PP pre-operational products. These are very likely to become operational data streams for NWP.
- MODIS's provide the best heritage data for VIIRS algorithm testing.
- There is a distinct risk that MODIS's will not be operating during NPP VIIRS mission to provide overlap – the best mechanism for continuing the integrity of the SST climate record will be high quality reference sensors with NIST traceability.
- M-AERI on *Explorer of the Seas* and research vessels, and ISAR on VOS's provide a valuable resource for continuing validation.



- **Questions?**