Microwave Sea Surface Temperatures for Climate

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1. INTRODUCTION

Sea surface temperature is a key climate and weather measurement routinely made each day by satellite infrared (IR) and passive microwave (PMW) radiometers, in situ moored and drifting buoys, and ships of opportunity. These measurements are used to create daily spatially-complete global maps of SST that are then used for weather prediction, ocean forecasts, and in coastal applications such as fisheries forecasts, pollution monitoring, and tourism. They are also widely used by oceanography, meteorology, and climate scientists for research.

Prior to 2002, SSTs were only available globally from IR satellite retrievals, but with the launch of AMSR-E, PMW retrievals became possible. While IR SSTs have a higher resolution than PMW SSTs (1 – 4 km as compared to 25 km), their retrieval is prevented by clouds giving the thru-cloud PMW SSTs better coverage (Figure 1).

Between 4 and 11 GHz the vertically polarized TB of the sea-surface has an appreciable sensitivity to SST. In addition to SST, TB depends on the sea-surface roughness and on the atmospheric temperature and moisture profile. Fortunately, the spectral and polarimetric signatures of the surface-roughness and the atmosphere are quite distinct from the SST signature, and the influence of these effects can be removed given simultaneous measurements at multiple frequencies and polarizations.

AMSR-E, and WindSAT measure multiple frequencies that are more than sufficient to remove the surface-roughness and atmospheric effects. Sea-surface roughness, which is tightly correlated with the local wind, is usually parameterized in terms of the near-surface wind speed and direction. The additional 7 GHz channel present on AMSR-E and WindSAT, but not earlier radiometers, provides improved estimates of sea-surface roughness and improved accuracy for SSTs less than 12°C (Gentemann et al., 2010). All channels are used to simultaneously retrieve SST, wind speed, columnar water vapor, cloud liquid water, and rain rate (Wentz and Meissner, 2000). SST retrieval is prevented only in regions with sun-glitter, rain, and near land. Since only a small number of retrievals are unsuccessful, almost complete global coverage is achieved daily. Any errors in retrieved wind speed, water vapor, cloud liquid water can result in errors in retrieved SST.

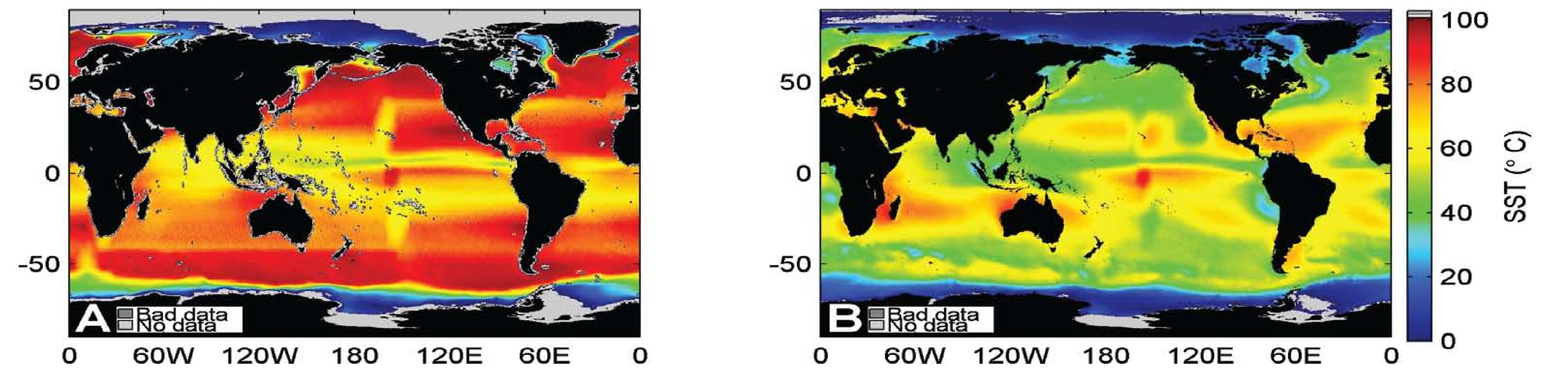

Figure 1. Percentage of successful daily retrievals for A) AMSR-E and B) MODIS. This comparison was for the AQUA AMSR-E and AQUA MODIS, from 2003 through 2010. The global average successful daily retrieval is 70% for AMSR-E and 44% for MODIS.

2. SATELLITE PASSIVE MICROWAVE RADIOMETERS

NASA's AQUA satellite carries the JAXA's Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E). The AQUA satellite was launched in May 2002 into a polar, sun-synchronous orbit at an altitude of 705 km, with a LECT of 1:30 AM/PM. AMSR-E has 12 channels corresponding to 6 frequencies: 6.9, 10.7, 18.7, 23.8, 36.5, and 89.0 GHz, all except 23.8 measure both vertical and horizontal polarizations (Parkinson, 2003). The calibration is completed similar to previous passive MW radiometers, using a cold reflector and hot absorber with 8 thermistors. At 6.9 GHz the 3-dB footprint size is approximately 56 km, setting the resolution of the SST retrievals. A day of AMSR-E SST retrievals is shown in Figure 2 (A and B).

WindSat is a polarimetric radiometer developed by the Naval Research Laboratory (NRL) to measure wind speed and direction. The instrument was launched on 2003 January 6 on the Department of Defense Coriolis satellite with a local time of the ascending node (LTAN) at 17:59. Data begins on 2003 February 3. Calibration of retrievals is completed using measurements of a hot load and cold space mirror, similar to the AMSR calibration methodology. WindSAT measures V- and H- polarization at 6.8, 10.7, 18.7, 23.8, and 37.0 GHz. The polarimetric measurements at 10.7, 18.7, and 37.0 GHz are not utilized in the SST retrieval. At 6.8 GHz the 3-dB footprint size is 40 km x 60 km, setting the resolution of the SST retrievals. Figure 2 (C and D) show daily WindSAT SSTs.

Future global PMW radiometers include JAXA's Global Change Observation Mission – Water (GCOM-W) AMSR2 and the National Polar Orbiting Earth observing System of Systems (NPOESS) C2 satellite will carry the Microwave Imager Sounder (MIS). GCOM-W is to be launched in February 2012 into NASA's A-Train satellite formation in a sun-synchronous orbit with an altitude of 700 km and a LECT of 1:30 AM/PM. AMSR2 is similar to AMSR-E but has an improved hot absorber and an additional channel at 7.3 GHz to minimize Radio Frequency Interference (RFI).

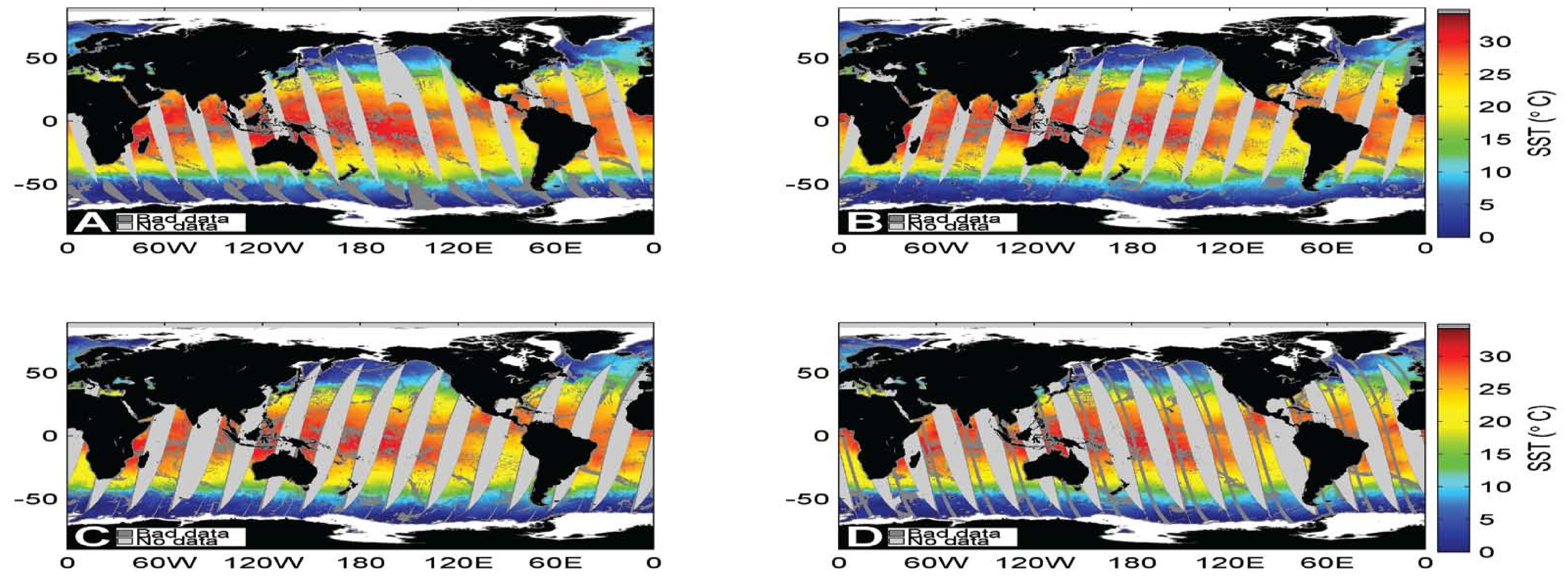

Figure 2. AMSR-E SSTs on 1 Jan 2010 (A and B). WindSAT SSTs on 1 Jan 2010 (C and D).

3. VALIDATION OF MICROWAVE SST

The primary source of validation data in this study will be in-situ measurements collected from the existing network of fixed buoys, drifting buoys, and ship measurements available via the Global Telecommunication System (GTS). These data are available in NRT from the US Global Ocean Data Assimilation Experiment (USGODAE) server in Monterey. Additional delayed-mode quality-controlled calibrated fixed buoy SSTs (the US National Data Buoy Center (NDBC), the Tropical Atmosphere Ocean (TAO) TRITON, and the PIRATA arrays) are further quality controlled and available through Remote Sensing Systems (RSS).

The AMSR-E and WindSAT data were individually collocated with the GTS buoy data. A valid collocation required a maximum of 25 km spatial difference between satellite and buoy location and 3 hours in time of observation. Table 1 shows the results, separted by in situ data type. The drifting buoys which have global sampling, show a mean bias and standard deviation of 0.02 and 0.52 C, respectively, when compared to the 6 AM WindSat data. The moored buoys show a larger bias and standard deviation. Since the moored buoys are generally more accurate , the increase in error is likely due to sampling location.

Table 1. Comparison of in situ to satellite v7 data from 2/2003 – 12/2010 (WindSAT) and 6/2002 – 12/2010 (AMSR-E).

WindSAT v7

	Descending – 6 AM			Ascending – 6 PM		
	#	Mean	STD	#	Mean	STD
ship engine intake	12962	0.28	1.14	15404	0.17	0.96
Moored buoy	61682	0.04	0.68	79442	0.08	0.61
Drifting buoy	337095	-0.05	0.55	416284	0.02	0.52
ship bucket	1395	0.09	0.78	1242	0.19	0.83
ship hull sensor	4139	0.16	0.84	4477	0.06	0.78

AMSR-E v7

	Ascending – 2 PM			Descending – 2 AM		
	#	Mean	STD	#	Mean	STD
ship engine intake	25789	0.29	1.04	22478	-0.06	0.79
Moored buoy	118490	0.03	0.59	105908	-0.04	0.56
Drifting buoy	398417	0.00	0.52	505715	-0.04	0.51
ship bucket	2126	0.34	1.14	1767	0.07	0.69
ship hull sensor	6165	0.17	0.86	5267	-0.04	0.77

Table 2 shows the moored buoy mean bias and standard deviation separated by moored buoy type. Each buoy was identified using the list at the PMEL website. The TAO/TRITON and PIRATA buoys both have significantly lower standard deviations than 'other' moored buoys (mostly NDBC buoys). In Table 1, the STD is about 0.25 C higher for all moored buoys because of the NDBC buoys. NDBC buoys have a higher STD for two reasons: first the buoy measurement of SST is less accurate than the TAO and PIRATA, and second, the NDBC buoys are located mostly along the US coast where there is high spatial/temporal variability that will not be well represented the by the 50 km footprint of the microwave radiometers.

Table 2. Nighttime satellite minus buoy SST errors, bias and standard deviation (STD).

Satellite	TOGA TAO/TRITON			PIRATA		
	#	Bias	STD	#	Bias	STD
AMSR-E	41771	-0.11	0.34	4976	-0.06	0.32
WindSAT	27403	-0.07	0.34	3219	0.01	.032

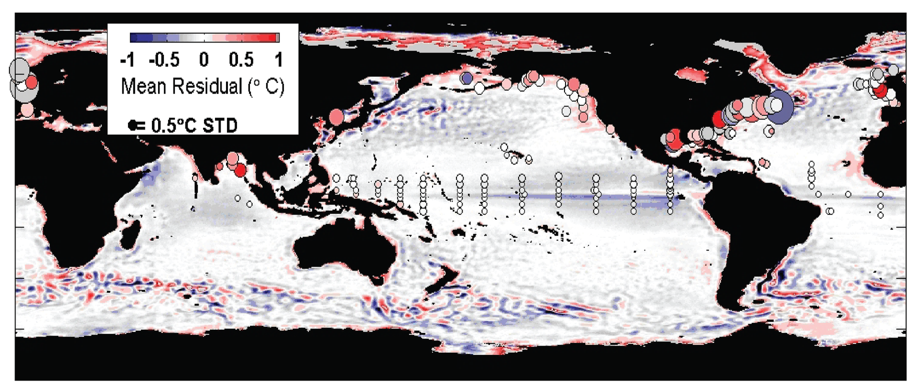

Figure 3. Global map of moored buoy mean bias (color) and STD (size). Background is the mean difference for WindsSAT – Reynolds OI SST

For WindSAT, all the moored buoys are plotted in Figure 3, to illustrate where the TAO/TRITON, PIRATA, and other buoys are located. The color of the circle indicates the bias at that buoy location while the size indicates the standard deviation. The tropical arrays, TAO and PIRATA, are uniformly low in bias and standard deviation. The largest errors are seen along the US East Coast, and these buoys are the source of the increase in the standard deviation. The background color is the mean difference, 2003-2010, of WindSAT minus Reynolds v2 weekly OI SST. Generally the difference is small, but in areas of high variability the WindSAT does a better job of measuring the temporal/spatial variability than the 100 km weekly Reynolds analysis.

4. RESULTS AND CONCLUSIONS

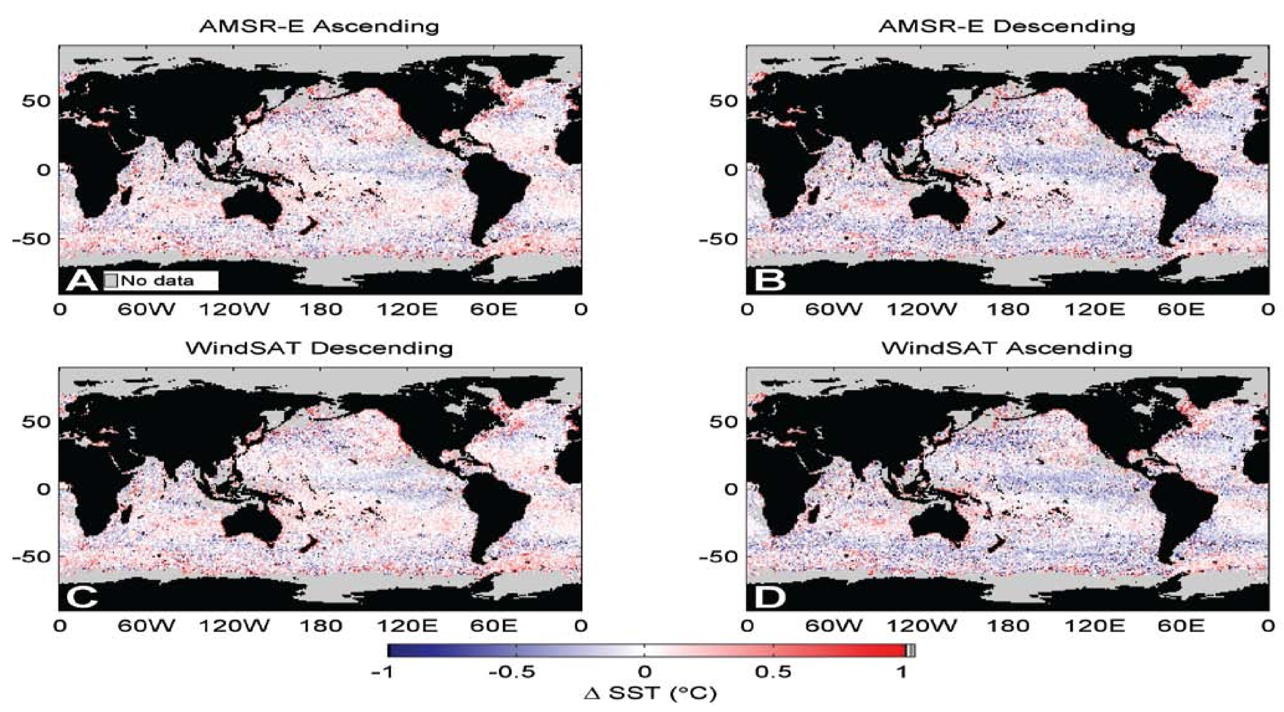

Figure 4. The mean difference, AMSR-E (A and B subpanels) and WindSAT (C and D subpanels) minus drifting buoy SSTs.

Figure 4. The mean difference, AMSR-E (A and B subpanels) and WindSAT (C and D sub-panels) minus drifting buoy SSTs. There are no obvious patterns to the differences, except a small cool bias in the tropical Pacific. The AMSR-E and WindSAT subpanels show remarckable agreement, partly due to the careful processing of both data streams to ensure compatability and inter-calibration.

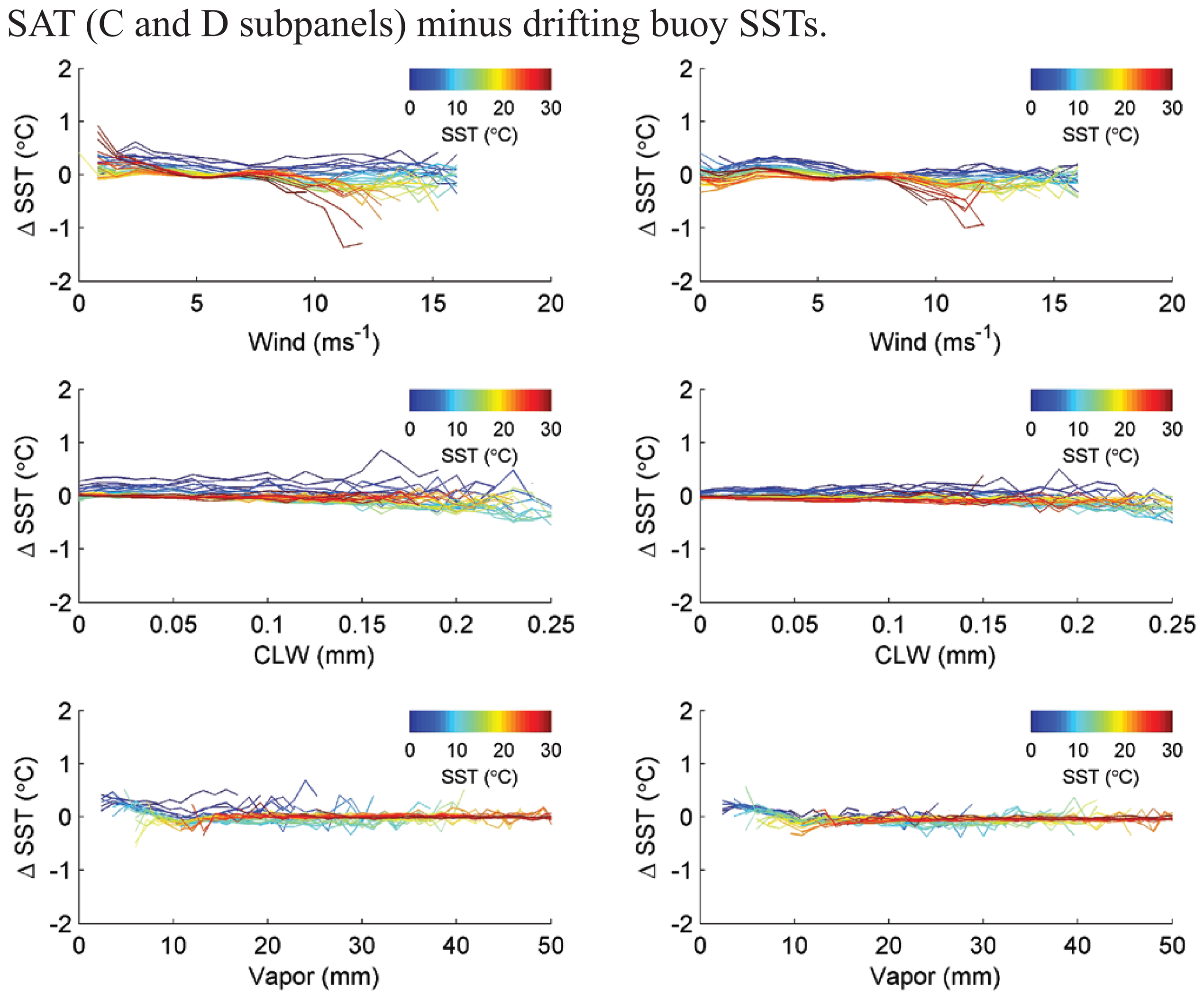

Figure 5. Mean difference AMSR-E v7 SSTs minus drifting buoys as a function of SST (color of line) and AMSR-E v7 retrievals of surface wind speed, cloud liquid water, and columnar water vapor (x-axis).

Microwave SST errors are not correlated to water vapor, wind speed, or cloud liquid water as shown in Figure 5. The top left panel in Figure 5 shows the mean difference as function of wind speed and there is a small positive bias at low wind speeds that is due to diurnal warming in the satellite observation. The buoys measure SST at approximately 1 m and often contain diurnal warming effects, although smaller. At the lower wind speeds there is less surface mixing and the warming often is contained in a layer less than 1 m, resulting in a warmer satellite measurement of SST than the buoy measurement at 1 m.

The microwave SSTs errors are not correlated to water vapor and are also unaffected by atmospheric aerosols such as volcanic eruptions. These properties encourage their use for climate studies, since water vapor is a green house gas and volcanic eruptions can bias infrared retrievals unless carefully screened.

The AMSR-E and WindSAT version 7 SSTs are freely availalbe at www.remss.com.