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Final MTI Data Report: Dahlgren Naval Surface Warfare Center (U)

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Savannah River Technology Center
SRTC
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INTRODUCTION

During the period from February 2001 to August 2002, paved-surface (tarmac) temperatures were collected at the Dahlgren Naval Surface Warfare Center (Figure 1). This effort was led by the Savannah River Technology Center (SRTC), with the assistance of base personnel, as part of Savannah River Technology Center's (SRTC) ground truth mission for the US Department of Energy's Multispectral Thermal Imager (MTI) satellite (Garrett, et al, 1999). Data described in this report are available from the authors (contact information provided at the end of report).

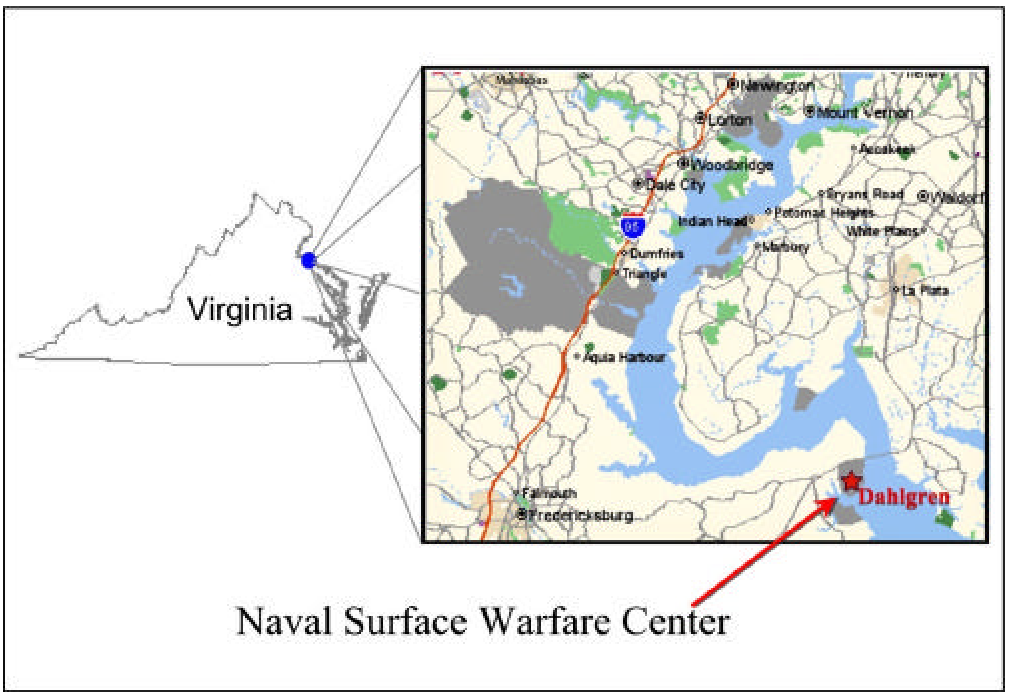

Figure 1. Location of the Dahlgren Naval Surface Warfare Center.

PAVED SURFACE TEMPERATURE MEASUREMENTS

SRTC's intent was to measure tarmac temperatures during MTI image times. Since image times were not known in advance, a continuous monitoring system was installed for long-term data collection. Surface temperatures can be measured either by direct means with an imbedded sensor or indirectly with a "remote," or non-contact sensor. For the Dahlgren site, both methods were used with the presumption that the non-contact sensor would be superior since a larger portion of the surface would be measured to obtain a representative reading.

Data described in this report are available from the authors.

However, the imbedded sensor, a “point” measurement, would prove to be a worthwhile “sanity” check and source of data when the remote sensor(s) was not operating properly.

Paved surface temperature measurements were made with inexpensive infrared sensors manufactured by Omega® and a buried copper-constantin thermocouple. The infrared sensors mimic a Type T thermocouple and have a field of view of 2 to 1. For example, a sensor 0.5 m above ground would sense over a 1m-diameter area directly below the sensor. Sensors were selected according to measurement ranges (Table I) that were expected to occur over the course of a given year.

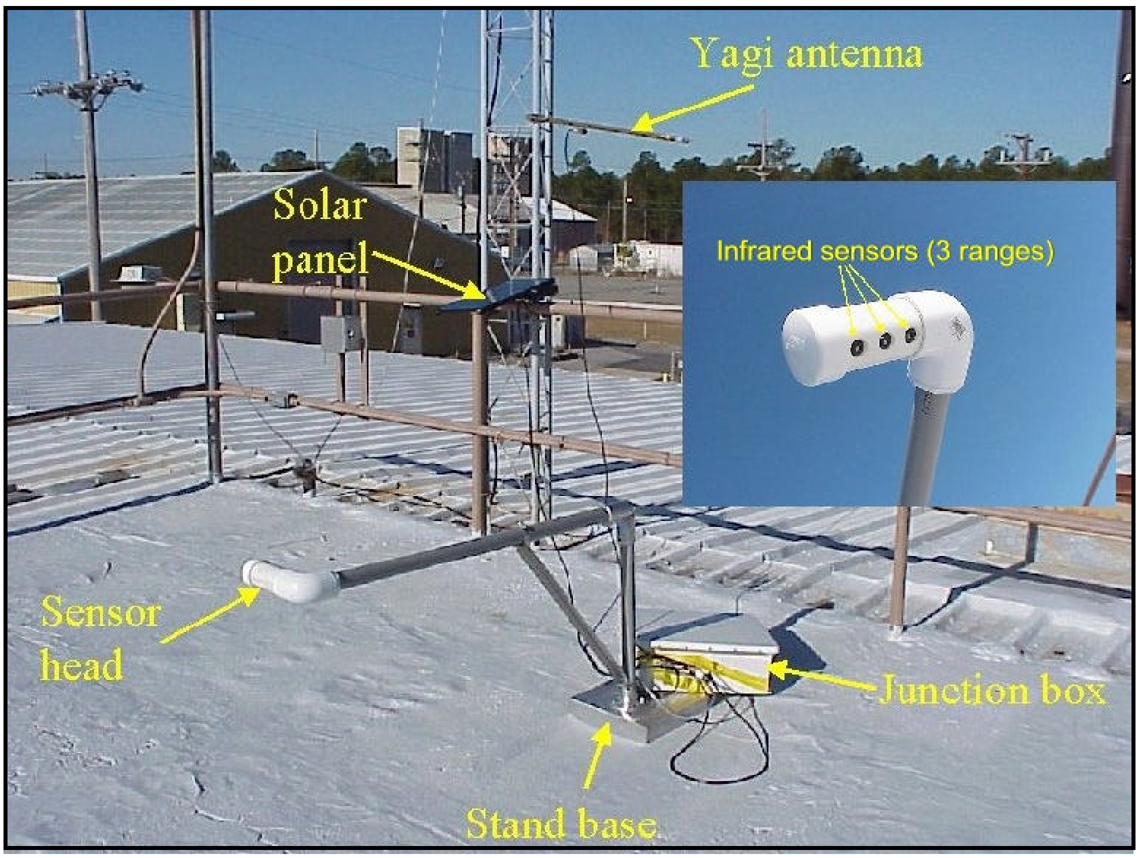

Figure 2. The portable temperature apparatus with its various components including the sensor head shown in the inset image. The Yagi antenna is used for cellular phone communications and remote data downloading. The junction box houses the datalogger, battery, and cellular phone.

An apparatus was built to house the sensors so that measurements were not influenced by solar reflections (Figure 2). Three infrared sensors were mounted inside the sensor head (Figure 2 [inset]). An additional thermistor (not shown) was installed inside the

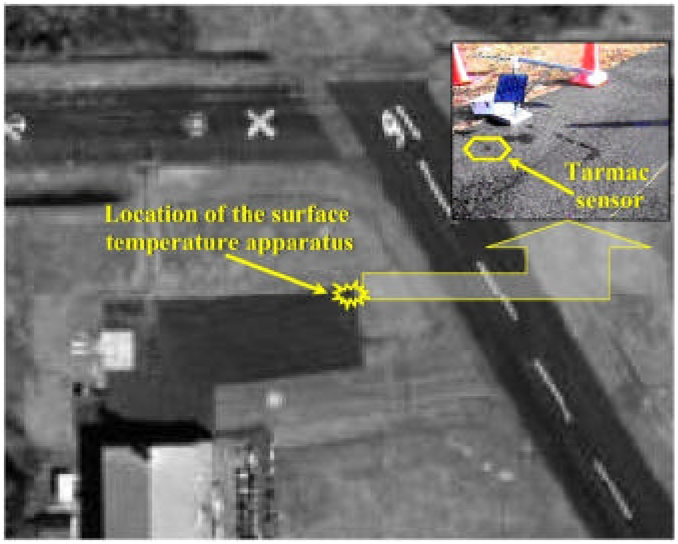

Figure 3. The location of the temperature sensor apparatus at the edge of the tarmac (inset). See cover image for an overview of the entire Dahlgren Naval Surface Warfare Center site.

sensor head and the copper-constantin thermocouple was buried in a small crevice in the tarmac (Figure 3). The apparatus was installed at the edge of an airstrip (Figure 3) and was grounded to avoid damaging lightning induced electrical surges. Data were logged with a Campbell Scientific® datalogger and were polled remotely via cellular phone. Power was supplied with a 12 volt DC battery and solar panel battery charger.

Table I

Paved Surface Temperature Measurement Apparatus Data

Location (based on WGS 84 datum) N38.336844°, W77.041053°

Name	*Type (Manufacturer)*	*Range*
Low	Infrared(Omega)	(-18°C) to 27°C
Medium	Infrared(Omega)	10°C to 49°C
High	Infrared(Omega)	25°C to 80°C
Tarmac	Copper-Constantine Thermocouple(Omega)	(-60°C) to 100°C
Sensor head	Thermistor (Campbell Scientific)	(-35°C) to 50°C

INFRARED SENSOR ACCURACY

The low, medium, and high range infrared sensors were compared to a National Institute for Standards and Testing (NIST) traceable blackbody standard in laboratory conditions. Figure 4 shows the relative accuracy of each sensor (note that two of each type were tested) against the blackbody. Errors of approximately 0.1°C or less in the mid-range of the sensors were observed with higher errors near the endpoints of the sensing ranges.

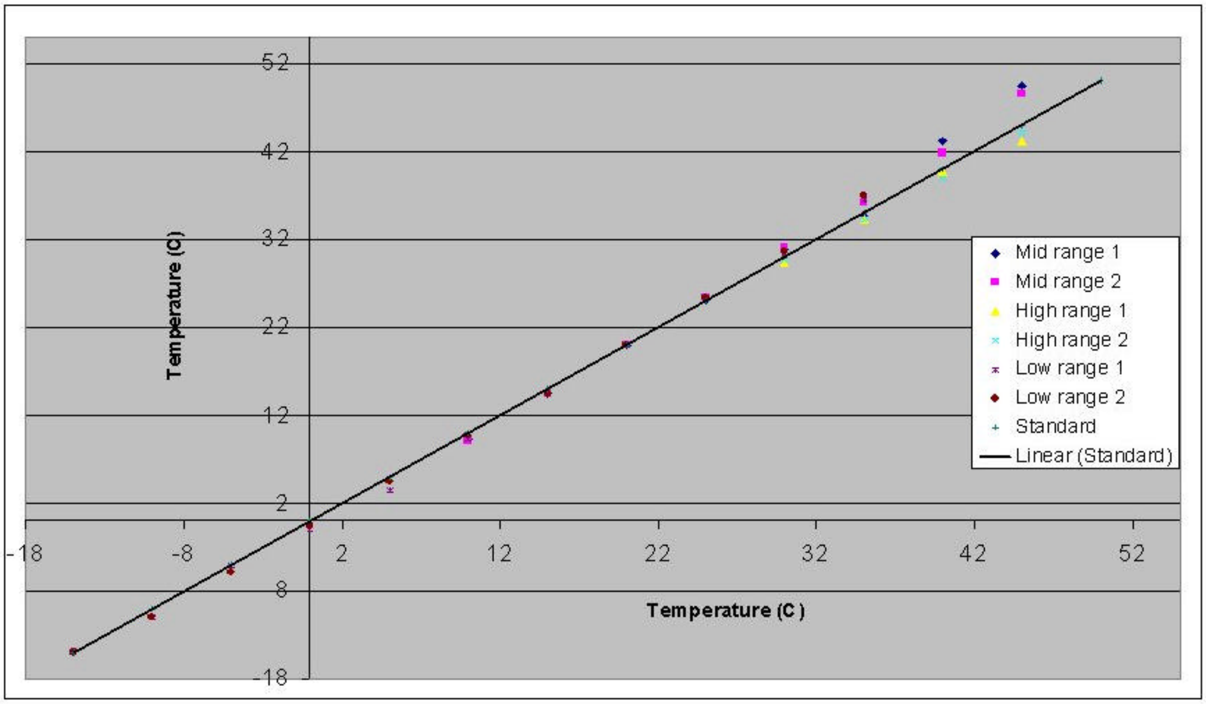

Figure 4. Comparison of blackbody (standard) temperatures and infrared sensors of differing ranges. The solid line ("Linear (Standard)") indicates the best fit for the blackbody data.

The actual accuracy during field deployment is lessened by two main factors including cleanliness and misalignment of the optics. As will be shown in sections entitled, "Quality Assurance" and "Example Data Plots", the degradation of measurements became quite obvious as the sensor lenses became dirty. After cleaning, measurements improved dramatically. Misalignment of the sensors can cause the field of view to be altered such that too much reflected light enters the sensor. This can cause erroneous measurements that are not totally representative of the actual target surface. Based on these factors, the actual measured tarmac temperatures are probably within ±1°C of the actual temperature. Additionally, the imbedded copper-constantin thermocouple probably has a similar accuracy of ±1°C based on errors associated with non-representativeness of the actual measurement location (i.e. not on the surface, but slightly under the surface). At night, the infrared (barring unclean optics) and copper-constantin measurements should be more accurate due to a lack of detrimental effects of incoming solar radiation.

EMISSIVITY MEASUREMENTS

The temperature measurements made with the infrared sensors must be adjusted according to the emissivity (ratio of the total radiant energy per unit area emitted to an ideal or "blackbody" radiator) of the surface being measured. After the temperature apparatus was installed, a Heiman® KT-19 radiometer with an attached cone reflector was used to characterize the emissivity of the tarmac in the vicinity of the apparatus and nearby taxiway and runway. A hand-held GPS device was used to determine approximate position and pictures were obtained with a low-resolution digital camera. Table II shows the data gathered and collected by and during this analysis, and Figure 5 shows a close-up of the tarmac under the temperature sensor.

At selected way points, measurements were made of: 1) the ground surface temperature (T_h) with the radiometer held at about a 1 m height, and 2) ground surface temperature (T_c) with the cone on the ground surface, and 3) the sky temperature (T_{sky}) at about 45° elevation away from the Sun. These data were used to calculate a value, which is an approximation to the surface emissivity from the following equation.

$$\text{Emissivity} = (T_h^4 - T_{sky}^4) / (T_c^4 - T_{sky}^4)$$

As an example, a measured temperature of 30°C, with a sky temperature of (-40°C) and a surface emissivity of 0.95 would yield an actual ground surface temperature of 29.1°C.

Table II

Emissivity Data

Way Point	E	N	Date	Time (GMT	AE	Comments
1	321620	4245154	7-Feb-01	20:25		Location of Temp apparatus
2	321617	4245143	7-Feb-01	20:34	0.958	
3	321620	4245143	7-Feb-01	20:34	0.953	
4	321610	4245130	7-Feb-01	20:36	0.95	
5	321589	4245121	7-Feb-01	20:37	0.946	
6	321561	4245120	7-Feb-01	20:39	0.949	
7	321543	4245112	7-Feb-01	20:41	0.959	
8	321513	4245136	7-Feb-01	20:45	0.977	dark,damp?
9	321543	4245144	7-Feb-01	20:48	0.954	
10	321602	4245149	7-Feb-01	20:50	0.955	
11	321618	4245155	7-Feb-01	20:53	0.955	Near Temp apparatus
12	321622	4245108	8-Feb-01	14:09	0.931	
13	321601	4245099	8-Feb-01	14:12	0.932	
14	321559	4245096	8-Feb-01	14:14	0.931	
15	321539	4245111	8-Feb-01	14:15	0.946	
16	321563	4245135	8-Feb-01	14:17	0.963	
17	321607	4245155	8-Feb-01	14:19	0.953	
18	321580	4245097	8-Feb-01	14:41		Parking place for plane
19	321627	4245097	8-Feb-01	14:42	0.924	
20	321715	4245117	8-Feb-01	14:45	0.948	
21	321730	4245123	8-Feb-01	14:47	0.955	
22	321699	4245174	8-Feb-01	14:49	0.953	
23	321664	4245233	8-Feb-01	14:52	0.952	white paint
24	321659	4245201	8-Feb-01	14:54	0.952	
25	321713	4245115	8-Feb-01	14:57	0.955	
26	321601	4245125	8-Feb-01	15:00	0.96	battery died/replaced
27	321510	4245141	8-Feb-01	15:04	0.981	drainage area, damp,sediment
28	321488	4245123	8-Feb-01	15:06	0.971	
29	321540	4245131	8-Feb-01	15:09	0.954	
30	321615	4245161	8-Feb-01	15:13	0.943	Near Temp apparatus
31	321613	4245144	8-Feb-01	15:14	0.955	
32	321600	4245134	8-Feb-01	15:16		
E=	UTM East Datum=NAD 1983 in meters					
N=	UTM North Datum=NAD 1983 in meters					
AE=	Effective emmisivity of tarmac from Heiman Radiometer					

Figure 5. Close-up of the tarmac where the temperature apparatus was installed.

DATA DESCRIPTION

Table III contains a description of the structure of the data files, <enddate>.dat, which contains paved surface temperatures collected during this campaign. Time stamps are in Eastern Standard Time and are not adjusted for Daylight Savings Time.

Table III

Description of Dahlgren Temperature Measurements

Name	*Description (All temperatures are in degrees Celsius)*
Sensor head	Temperature inside the sensor head that mimics ambient air temperature
Tarmac	Temperature measured with a probe buried just under the tarmac surface
Low	Temperature measured with a “low” range infrared sensor
Med	Temperature measured with a “medium” range infrared sensor
High	Temperature measured with a “high” range infrared sensor

Note about the structure of the data file, which could be used for data parsing and analysis. The first column contains the number "127" except at 10:00 ("103") and 14:00 ("112") when different numbers are shown. At 10:00, the port settings of the datalogger ("2" means the setting is "high"), battery voltage (VDC), and panel temperature are shown. At 14:00, a blank location ("0"), port settings, and battery voltage are shown.

QUALITY ASSURANCE

Data were compiled and reviewed for accuracy for the entire period of collection. Table IV shows the quality assurance condition of each measurement value during each month of the collection campaign.

Table IV

Data Quality Assurance Matrix

G – (Good) - Data are good to use as-is. When using IR sensors, care should be taken to correctly match the range to condition.
Y – (Yellow) - Caution should be exercised when using data. Significant biases may be present and comparisons to the other IR sensors and Tarmac sensor should be made to determine suitability for use.
R – (Red) - Data are unusable. Another IR sensor or the Tarmac sensor must be used.

YEAR	MONTH	SENSOR HEAD	TARMAC	LOW RANGE IR	MEDIUM RANGE IR	HIGH RANGE IR
2001	March	G	G	G	G	G
	April	G	G	G	G	G-Mid month Y-After mid month
	May	G	G	G	G	Y
	June	G	G	G-Mid month Y-After mid month	G-Mid month Y-After mid month	R
	July	G	G	Y	Y	R
	August	G	G	Y-Mid month R-After mid month	R	R
	September	G	G	R G-After 9/27	R G-After 9/27	R G-After 9/27

	October	G	G	Y-Day G-Night	Y	Y
	November	G	G	Y-Day G-Night	Y-Day G-Night	Y
	December	G	G	G	G	G
2002	January	G	G	G-Mid month Y-Daytime after mid month	G-Mid month Y-After mid month	G-Mid month Y-After mid month
	February	G	G	G	Y	Y
	March	G	G	G	G-Except during warm days	Y
	April	G	G	G	G	Y
	May	G	G	G-Mid month Y-After mid month	Y-Mid month R -After mid month	R
	June	G	G	Y-Mid month R-After mid month	R	R
	July	G	G	R	R	R

EXAMPLE DATA PLOTS

The following plots show examples of paved surface temperature data collected in 2001. The captions provide information on the relative accuracies of the data shown.

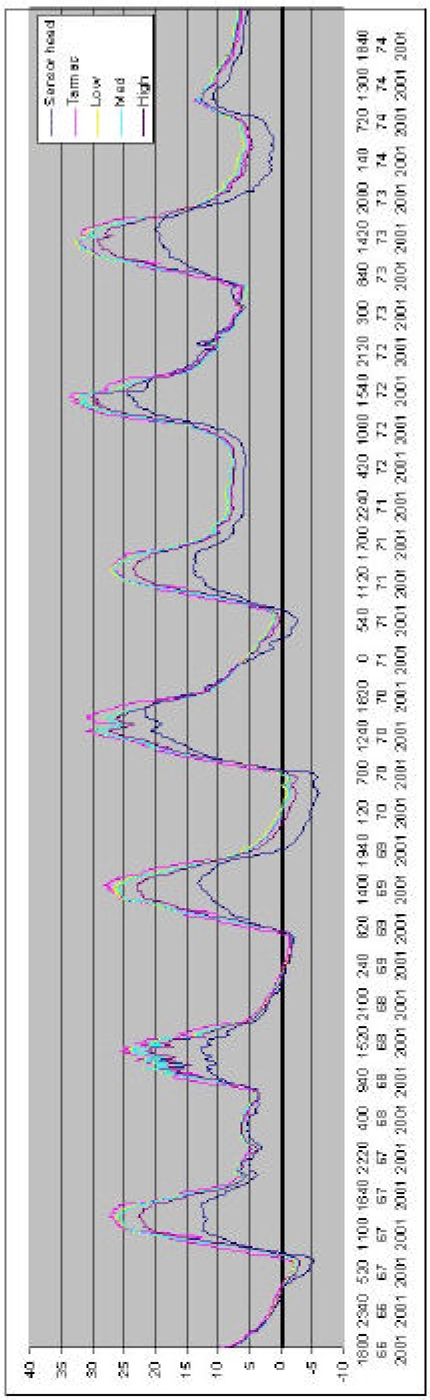

Figure 6. Temperature time series in March 2001. Note the relative closeness of measurements especially at night.

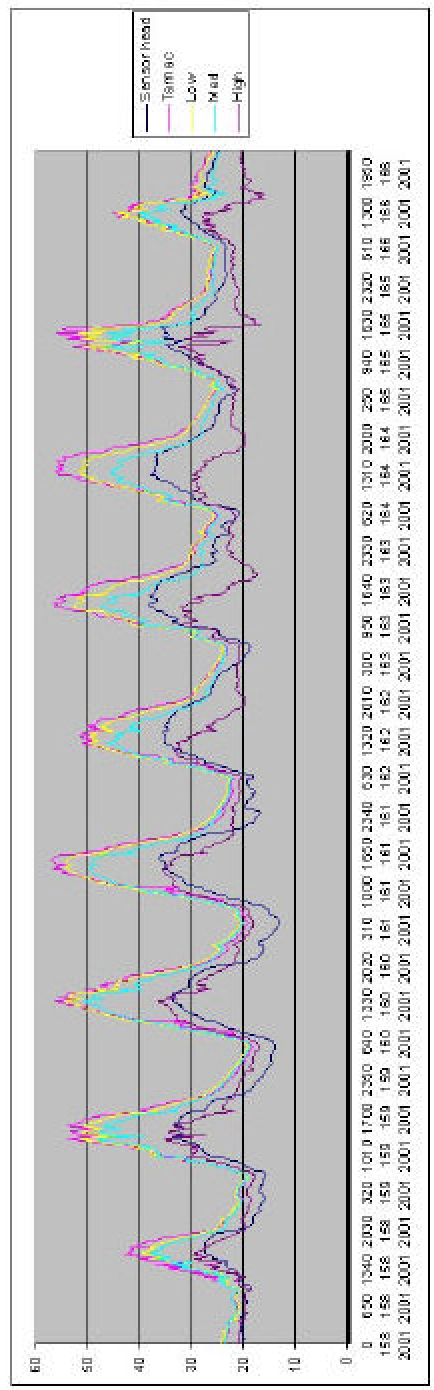

Figure 7. Temperature time series in June 2001. Large relative differences in temperature measurements are especially prevalent during daylight hours.

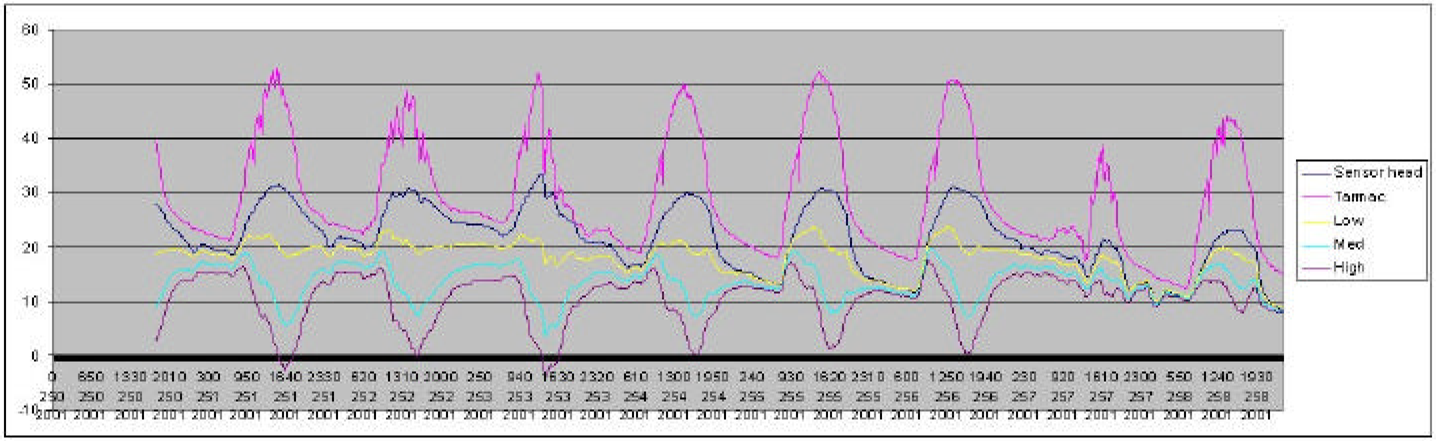

Figure 8. Temperature time series in September 2001. The infrared sensor measurements are massively inaccurate due to unclean lenses. Only the tarmac and sensor head measurements are useable during this period.

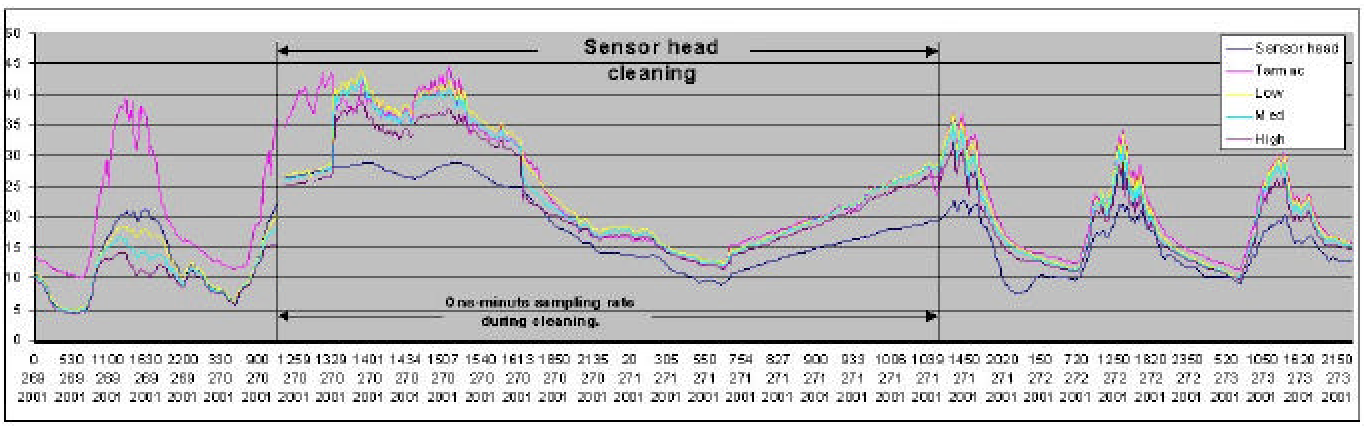

Figure 9. Temperature time series before, during, and after sensor cleaning. Note the relative closeness of measurements after the cleaning is completed.

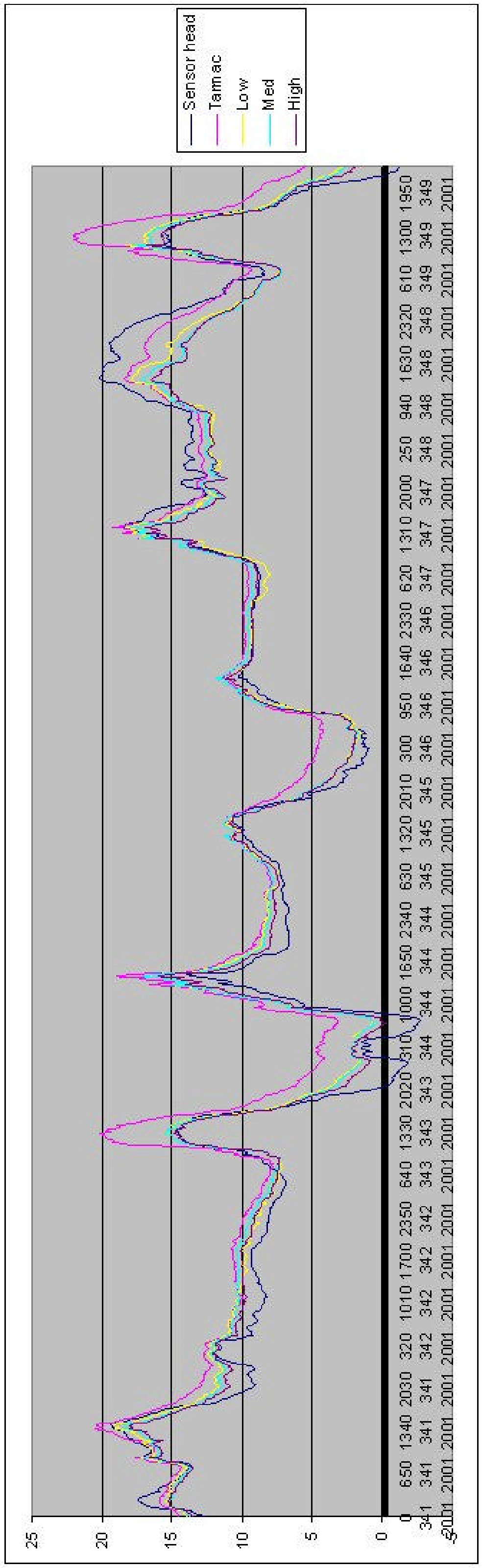

Figure 10. Temperature time series in December 2001. Note the lack of a consistent diurnal pattern and the relative closeness of the measurements. On day 348, the sensor head temperature is warmer than the paved surface temperatures, which is a departure from a typical daytime trace.

ACKNOWLEDGEMENTS

A special thanks goes to Ron Copeland at the Dahlgren Naval Surface Warfare Center for supporting the deployment and operation of the paved surface temperature apparatus.

REFERENCES

Garrett, A. J., R. J. Kurzeja, B. L. O'Steen, M. J. Parker, M. M. Pendergast, and E. Villa-Aleman, 1999: Ground-Truth Measurements Plan for the Multispectal Thermal Imager (MTI) Satellite. WSRC-TR-99-00455. Westinghouse Savannah River Company, Aiken, SC.