

**Progress Report: NAG5-6463**  
**BROADBAND IR MEASUREMENTS FOR MODIS VALIDATION**  
**Reporting Period: 10/1/98 – 9/30/99**  
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## **REPORT OVERVIEW**

The goal of this research is to provide *in situ* calibrated IR measurements of SST to augment the pre- and post-launch validation plan for the MODIS SST algorithm. The instrument system we are developing is called the Calibrated InfraRed In situ Measurement System, or CIRIMS.

In early summer 1998, we deployed the CIRIMS prototype *A* on the R/V Ron Brown during the GAS EX 98 cruise in the North Atlantic. The purpose of this deployment was to evaluate a design for protecting the sensors using an IR transparent window and to compare our measurements to those of the M-AERI, which is the primary MODIS validation instrument. The results of the data analysis will be reported by *Wick and Jessup* [1999] at IGARSS '99.

During the current reporting period, we developed the CIRIMS prototype *B* and performed extensive laboratory and outdoor testing in order to evaluate the design. The results of this testing will be presented by *Jessup* [1999] at IGARSS '99 and are summarized below. Based on the progress over the past year, we refined the design and are now manufacturing CIRIMS production units #1 and #2 that will be deployed at sea during the post-launch period for Terra.

At the end of June 1999, the two sea-going units will be ready for local testing, which will include laboratory, rooftop, and sea trials on an Applied Physics Laboratory (APL) vessel in Puget Sound. The first open ocean deployment in the post-launch period will be a 30-day cruise in November 1999 on the R/V Ron Brown from Seattle to the equatorial Pacific, returning to San Diego. The time period for this deployment was chosen to obtain a significant amount of early data for MODIS calibration and validation. After this first at-sea deployment, we will coordinate with Peter Minnett of MOCEAN (University of Miami) to routinely deploy the CIRIMS with the M-AERI.

The CIRIMS homepage URL is **<http://www.apl.washington.edu/programs/cirims/cirims.html>**

The remainder of this report summarizes the current design and results of recent testing. We conclude that the measurements made with the CIRIMS versions to be deployed in the post-launch period will likely meet the design goal of an SST measurement accuracy of  $\pm 0.10$  °C.

## **CIRIMS DESIGN SUMMARY**

The CIRIMS is designed to be an autonomous instrument with an absolute accuracy of  $\pm 0.1$ °C that can be deployed on an ocean-going vessel for a period of 3 months without maintenance. The primary design principles are (1) Interval calibration of the infrared sensor using a precision blackbody, (2) Measurement of the sky temperature to correct for reflection effects, (3) Control of housing

temperature to minimize instrument drift, and (4) Complete protection of the sensor and calibration blackbody from the marine environment. In this brief report, we outline the general features of the system and the laboratory and field testing to determine the overall accuracy. Current efforts are focussed on evaluating the use of an IR transparent window to provide environmental protection.

The CIRIMS uses two Heitronics model KT-11.K6 infrared radiation pyrometers, which have non-linear output (proportional to radiance), small size, and modest cost. A down-looking radiometer used to measure ocean radiance is calibrated at 20-minute intervals using a computer-controlled external blackbody reference. An up-looking radiometer is used to measure the sky radiance in the direction from which it is reflected into the down-looking instrument. The external blackbody reference is used to account for instrument and electronic drift and the sky radiance measurement is used to directly correct for reflection effects.

Fig. 1 is a block diagram showing the system components comprising the electronics package and sensor housing. The sensor housing is designed to be mounted along the side of a ship to view the sea surface at an incidence angle between  $40^\circ$  and  $50^\circ$ . The electronics package is rack-mountable and can be separated from the sensor housing by up to 100'.

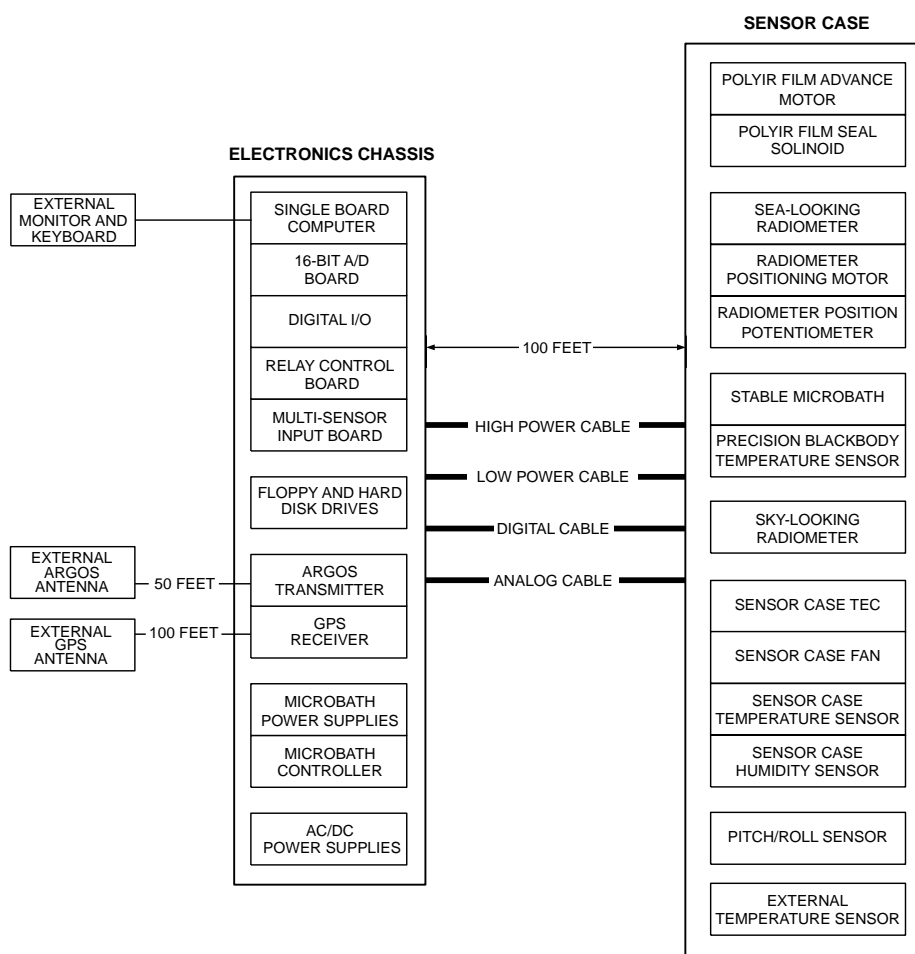


Fig. 1. Block diagram of CIRIMS components in Electronics Chassis and Sensor Housing.

### Electronics Package

The electronics are housed in a standard 19-inch rack chassis 22" deep and 18" wide. The CPU is a single board PC and performs all control and data acquisition functions. The system has 16 single-ended analog inputs, 6 serial communication interface ports, 4 digital I/O lines, and 8 relay control lines. A GPS module provides time and location and an Argos transmitter is used for sending data via satellite for monitoring in near real-time. Additional measurements include pitch and roll to monitor the effects of ship motion and external air temperature.

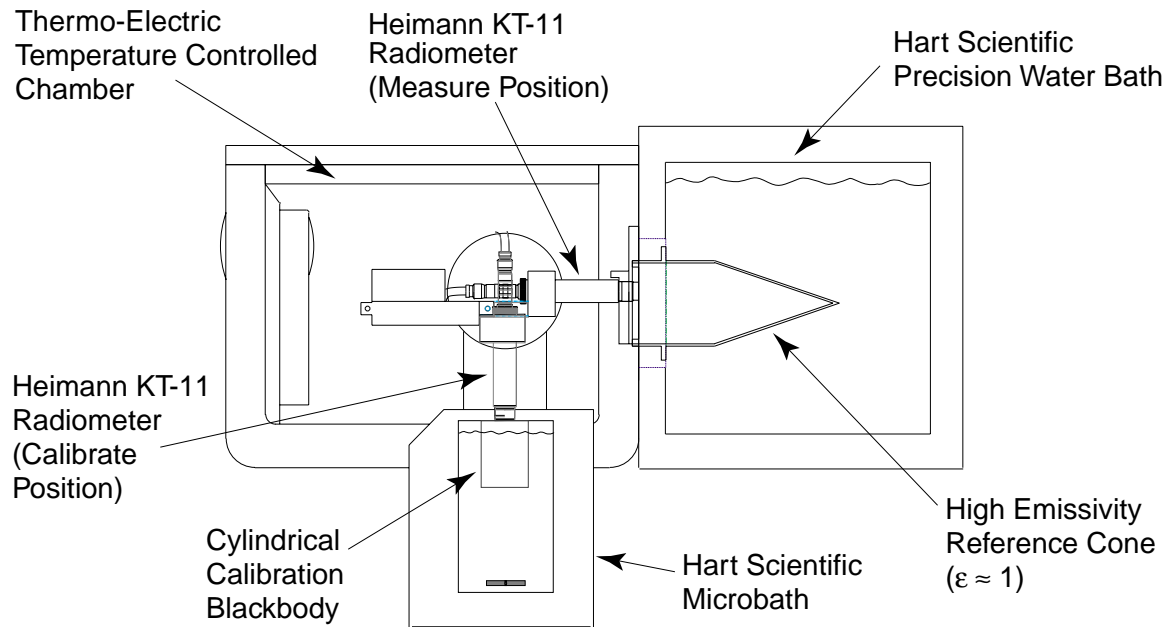


Fig. 2 CIRIMS prototype *B* configured to measure laboratory calibration reference target.

### Sensor Housing

The sensor housing contains the sea-looking radiometer and blackbody calibration unit. Fig. 2 shows a line drawing of the CIRIMS prototype *B* measuring the temperature of a precision reference blackbody in the laboratory. The housing is insulated and kept at a constant temperature of  $35 \pm 0.5^\circ\text{C}$  by means of an integrated thermo-electric heater/cooler (TEC) unit and circulation fan. The sea-looking radiometer alternately views the sea surface (measure cycle) and the blackbody (calibrate cycle). The housing is instrumented with an internal air temperature sensor and a humidity sensor. It is sealed with dry air and a reservoir of desiccant is used to maintain low humidity to avoid condensation on the blackbody and optics.

### Calibration Blackbody

A common approach for providing a two-point calibration is to use a constant temperature hot target and an ambient (cold) temperature target. This approach simplifies the engineering complexity since only one target must be temperature controlled, which is done by heating. The temperature of the hot and cold targets can be significantly different than the temperature of the external target to be measured. Thus the transfer function for the IR sensor must be well-characterized by two-points that

may be relatively far apart and significantly different than the temperature to be measured. Furthermore, the transfer function must not change over the duration of the intended deployment.

Because of the requirement of deployment for up to 3 months and associated uncertainty in stability of the sensor transfer function, we have chosen to implement a different scheme that we call a dynamic two-point calibration. In this approach, the hot and cold calibration temperatures follow the temperature to be measured, bracketing it above and below by a few degrees. The ability to implement this technique is provided by using a single blackbody calibration target immersed in a precision temperature-controlled bath. The design is similar to that described by *Geist and Fowler* [1986] but uses a miniature bath incorporating TEC units for both heating and cooling instead of an electric heater and compressor-based refrigerator. The bath is a Hart Scientific Microbath model 7102 equipped with a supplemental high-accuracy thermistor to measure the temperature of the blackbody.

### IR Transparent Window

We have concluded that the only way to ensure the environmental integrity of the sensor and the blackbody calibration is to use a sealed housing with an IR transparent window. This approach limits the problem of contamination to a small, well-defined area. The main disadvantages of using an IR transparent window are that the effect of the window depends on ambient temperature and that contamination of the window can affect the accuracy of the measurement. Our design uses an IR transparent window made of inexpensive plastic sheet that is periodically renewed. We are currently testing the material PolyIR2 manufactured by Fresnel Technologies, Inc. The material is 0.005" thick and has a transmission coefficient of 0.85.

## **LABORATORY AND FIELD TESTING**

Current testing and evaluation of the CIRIMS design has been separated into three major tasks:

- 1) Validate the radiometer calibration method by measuring a laboratory reference blackbody (see Fig. 2).
- 2) Evaluate the use of the IR transparent window by comparing brightness temperatures of an external reference measured with and without the window by using:
  - empirical approach (linear regression)
  - computational approach (radiative transfer analysis).
- 3) Evaluate overall measurement accuracy by comparison of brightness temperatures of an outdoor water surface obtained with and without the window

### Validation of Calibration Procedure

Fig. 3 shows results of the laboratory testing of the calibration procedure. Measurements were made with the housing temperature dynamically set to the target temperature and also set to a constant temperature of 35°C. When the housing temperature is equal to the target temperature, the correction for non-unity emissivity of the internal calibration target is negligible. For the case of a constant housing temperature, the non-unity emissivity effect is significant and a correction is applied. For both methods, we conclude that the calibration procedure is adequate to meet the accuracy specification of  $\pm 0.10^\circ\text{C}$ .

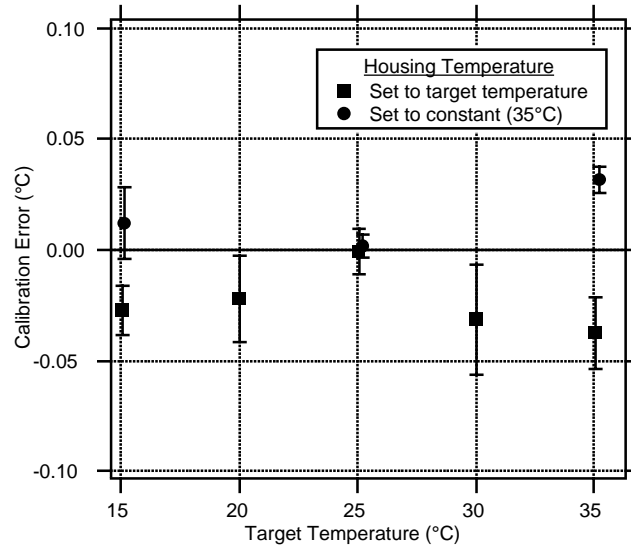


Fig. 3 Results of laboratory tests of calibration accuracy in test configuration shown in Fig. 2. The measurements show that the calibration method used exceeds the accuracy specification of  $\pm 0.10$  °C for a wide range of target temperatures.

*Evaluation of IR transparent window effect*

Fig. 4 shows the CIRIMS prototype *B* as it was deployed on the roof of the Applied Physics Laboratory (APL) to measure the skin temperature of a water-filled tank. The prototype has been configured so that continuous measurements are made alternately with and without the IR transparent window.

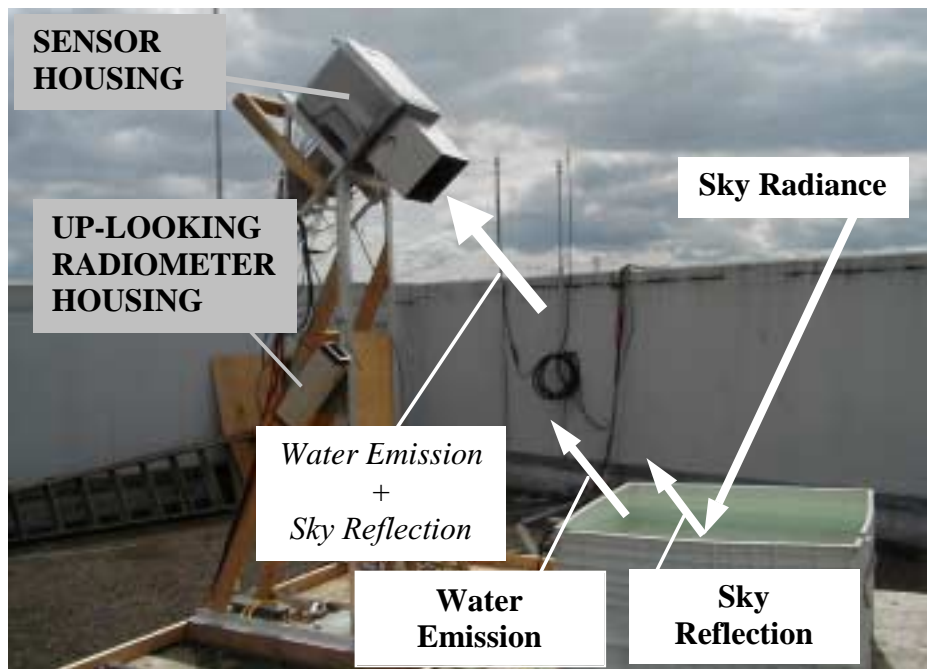


Fig. 4 Photo of rooftop testing showing housings, watertank, and antennas (background).

Fig. 5 shows a roughly 18 hour time series of rooftop measurements made using an external blackbody cycled between 10 and 60 °C every hour. The air temperature in the top trace in Fig. 5 shows the diurnal variation due to solar heating. The attenuating effect of the IR transparent window is removed by regressing the measurements with the window against those without it. The resulting (first) residual shown in the second panel of Fig. 5 is clearly correlated with the air temperature, indicating the remaining window effect of self-emission. The second residual is that which results from a linear regression of the first residual against air temperature. The bottom panel compares the final error in temperature from the linear regression with that from a radiative transfer analysis. The mean error using linear regression is zero and the variation about the mean is within  $\pm 0.1^\circ\text{C}$ . The mean error using radiative transfer analysis is roughly  $0.20^\circ\text{C}$  and the variation is within a band of  $\pm 0.10^\circ\text{C}$ .

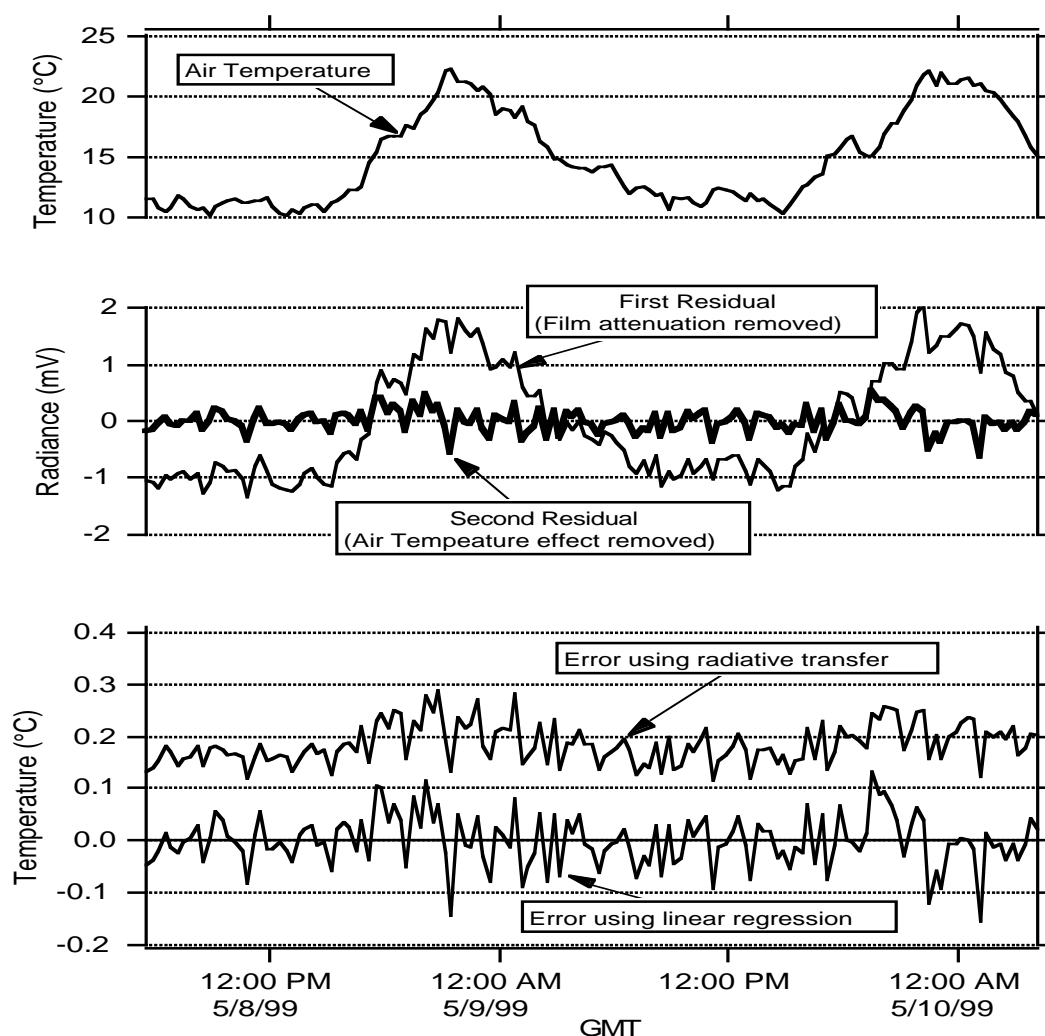


Fig 5. Time series of rooftop measurement of external blackbody target with and without the IR transparent film. Top: Air temperature. Middle: Residuals of linear regressions, shown in units of radiometer voltage, which is proportional to radiance. Bottom: Final temperature error using linear regression (empirical method) and radiative transfer analysis (computational method to explicitly account for attenuation and self-emission by window ).

Evaluation of error due to IR window viewing water surface outdoors

Fig. 6 illustrates the performance of the CIRIMS while viewing the water surface shown in Fig. 4 during a period when the sky conditions changed from overcast to partly cloudy. The results demonstrate the combined effectiveness of the corrections for the IR transparent window and sky reflection. Under overcast conditions, the temperature error variation is within  $\pm 0.2^{\circ}\text{C}$  of a mean offset of roughly  $0.2^{\circ}\text{C}$ . Under partly cloudy conditions, the error increases due to the temporal variability of the sky temperature, but remains within roughly  $\pm 0.5^{\circ}\text{C}$ . These results illustrate the difficulty of making accurate IR SST measurements under partly cloudy conditions.

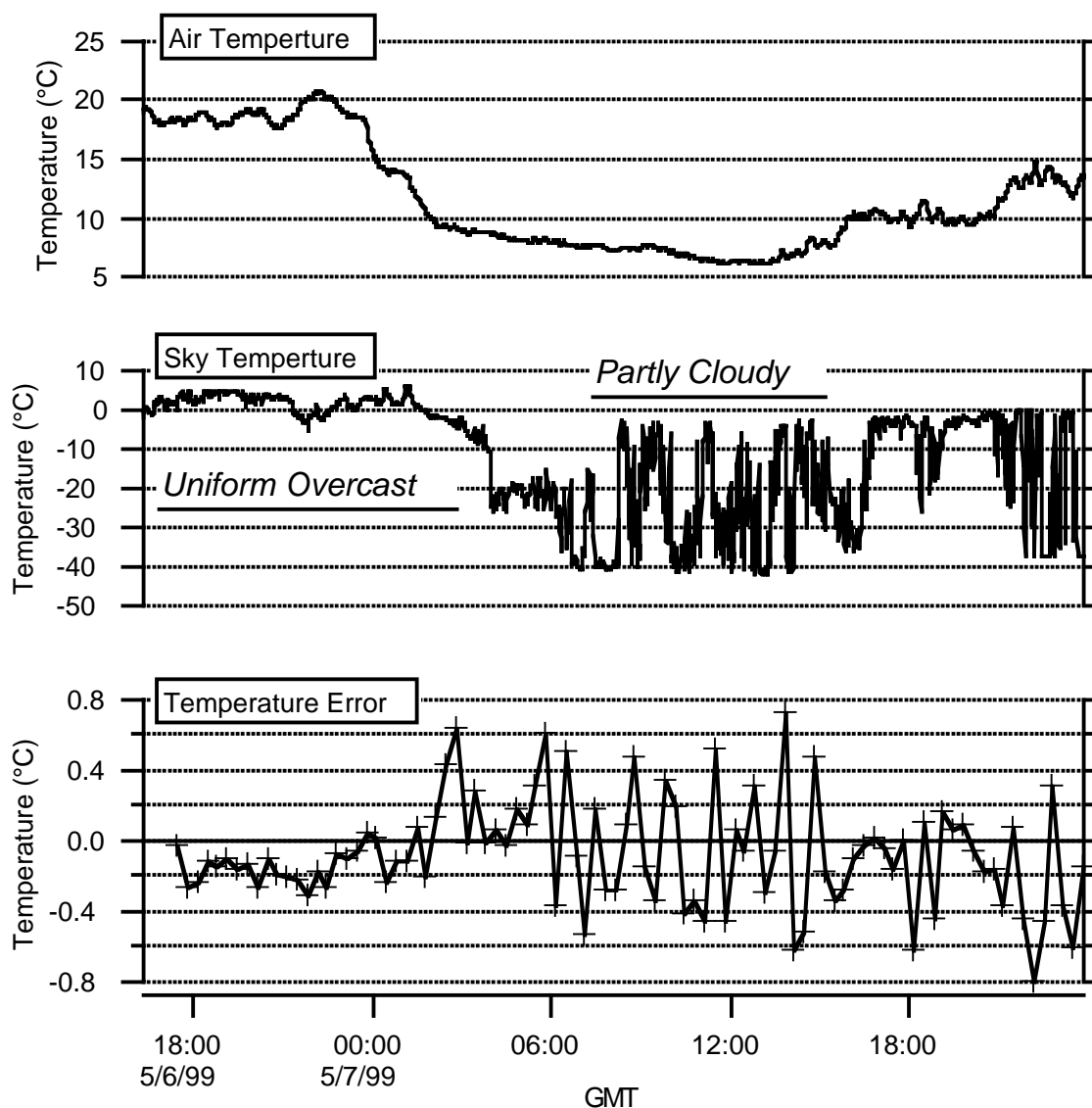


Fig. 6 Time series of rooftop measurements view the surface of the water tank shown in Fig. 4. Top: air temperature, Middle: sky temperature measured by uplooking IR radiometer, Bottom: error in brightness temperature using IR transparent window using radiative transfer analysis. Note that when the sky temperature is uniform, the error is small and stable.

### Summary of laboratory and rooftop testing

The testing to date indicates that the basic design of the CIRIMS is viable. We are now manufacturing two units with improved design features suitable for open ocean deployment. Fig. 7 is a cut-away drawing of the sensor housing that is currently being constructed for the ocean deployment. Enhancements to the ocean-going system include a higher-emissivity calibration blackbody and improved characterization of the window material. With these additions, I expect that the final accuracy of the system will achieve the design goal of  $\pm 0.10^{\circ}\text{C}$ . Field trials will begin in August 1999 in Lake Washington and Puget Sound. The first ocean deployment is scheduled for November 1999 during a cruise on the R/V Ron Brown from Seattle to the equatorial Pacific.

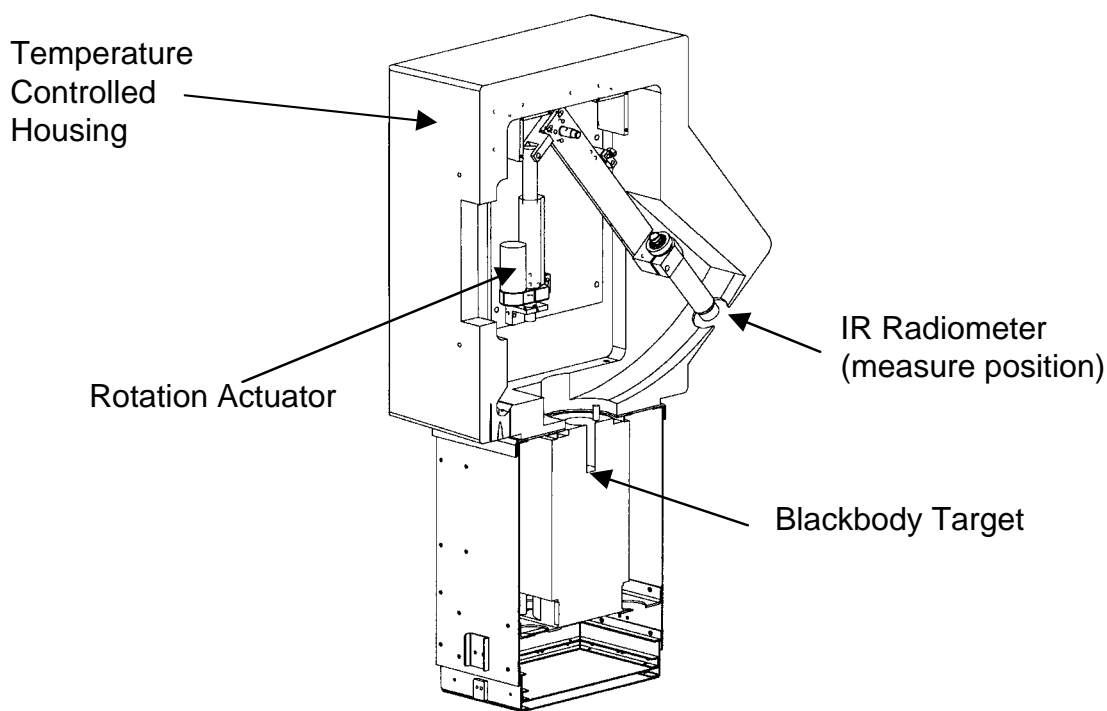


Fig. 7 Line drawing of CIRIMS sensor housing being manufactured for open ocean deployment. The overall dimensions are 34" H x 27" W x 13" D.

### **FUTURE DEVELOPMENT AND DEPLOYMENT**

In the third year of the grant, we will produce the CIRIMS unit #3 and make it available for dedicated deployment with the M-AERI. Unit #2 will be dedicated to regular deployment on a ship of opportunity. Unit #1 will be deployed on an oil platform in order to obtain an extended record of IR SST in conjunction with supporting environmental measurements.

### **REFERENCES**

- Geist, J. and J. B. Fowler, A water bath blackbody for the 5 to 60°C temperature range: Performance goal, design concept, and test results, NIST Technical Report, 1986.
- Jessup, A. T., CIRIMS: Calibrated In situ Infrared Measurement System, IGARSS 99, Hamburg, 1999.
- Wick, G. A., and A. T. Jessup, Evaluation of oceanic cool skin and warm layer models using recent measurements of improved accuracy, IGARSS 99 Hamburg, 1999.