Technical Report 1639
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An At-Sea Evaluation of an Infrared/Resistance Temperature Device for Air/Sea-Surface Temperature Measurements

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MA

SUMMARY

OBJECTIVE

To evaluate the shipboard use of the infrared/resistance temperature device (IR/RTD) to obtain at-sea temperatures for evaporation duct height calculations.

RESULTS

In comparing data collected by the USS *Kitty Hawk* with data collected by the USS *Ranger* during their deployments, it came clear the IR/RTD shows no distinct advantage over traditional methods in measuring the environment. In fact, for EM propagation assessment purposes, using the hand-held psychrometer for air temperature and the engine intake temperature to represent the sea-surface temperature show equal results between the two measurement techniques.

The IR/RTD suffered mechanical and electrical failures during both the USS *Kitty Hawk* and USS *Ranger* measurement periods.

Since repair and recalibration must be done at the manufacturer's facility, the device is inappropriate for shipboard use. Also, the design of the battery-recharging unit does not conform to shipboard requirements for electrical grounding.

CONCLUSIONS AND RECOMMENDATIONS

Borne out by both the comments of the USS *Kitty Hawk's* oceanographer and a large number of highly suspicious readings, additional training for observers is warranted. Thus, training on the proper use and care of temperature-measuring devices could be made part of the Aerographer's Mate course curriculum and shipboard performance factors.

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BACKGROUND

For general meteorological and climatological purposes, the elements of air and sea-surface temperatures measured by transiting ships have been sufficiently accurate. Measurement errors in air and sea-surface temperatures are made however, and these errors may occur in a number of ways. For example, air temperatures reported by ships in the tropics appear to be consistently high under sunny conditions due to poor instrument exposure and heat radiation from adjacent metal surfaces. Sea-surface temperatures have typically been determined by measuring the seawater intake for engine cooling with readings taken by engine room personnel from analog gauges located in the power plant spaces. Calibration and reading errors are common. These water inlets do not measure surface temperature because they are located well below the surface and are also subject to thermal contamination.

Compounding the problem of differences in air and sea-surface temperature measurements is the fact that these measurements are typically made using two different sensors that are most likely not calibrated together.

A critical component of the calculation of evaporation duct height is the difference between air and sea-surface temperatures. Measurement errors are, therefore, reflected in the evaporation duct height (Paulus, 1984).

To address these measurement errors, a 2-week experiment was conducted during the period 12 to 24 July 1991 (Patterson, 1992). Two noncontact infrared, resistance temperature devices (IR/RTD) were placed aboard the USS *Ranger* (CV–61). The IR/RTD measures air temperature with a gold-foil-covered thermistor that protrudes from the IR/RTD, and the sea-surface temperature is measured with an infrared sensor. A separate infrared sensor located on top of the device is used to remove sky and cloud radiance and cloud reflection contributions from the sea-surface temperature. Air and sea-surface temperature data were collected by the ship's meteorological personnel using the IR/RTD. In addition, temperature data were also collected using the traditional psychrometer and engine-room seawater intake methods.

From these data, evaporation duct heights statistics were compiled. The evaporation duct heights were used in turn as environment inputs to the radio physical optics (RPO) electromagnetic propagation model. The RPO model outputs were used with the Engineer's Refractive Effects Prediction System (EREPS) to produce radar performance predictions.

From this experiment, it was concluded there was no significant difference in the statistical distribution of evaporation duct height calculated from these two measurement systems. It was postulated the distributions were invariant because all measurements were taken within a single homogeneous air mass. The frequency-dependent nature of the evaporation duct effect upon electromagnetic (EM) propagation was observed in the radar performance predictions. With lower frequencies (approximately 3 GHz), the radar performance was insensitive to the duct height variations between the two measurement systems. At higher frequencies (15 GHz), the radar performance was very sensitive to duct height variations between the two measurement systems.

A question of the IR/RTD's reliability also arose as IR temperature display on one of the devices ceased to operate early in the measurement period. At the time of failure, the device was located in close proximity to a large radio frequency source. In addition, the air temperature thermistor probe on the second device failed to deploy properly. Following the experiment period, both IR/RTD were returned to the manufacturer for repair and recalibration. It was determined that the IR failure was unrelated to any external influence. The failure of the thermistor probe was due to rough handling.

In an attempt to resolve the questions of equal statistical evaporation height distributions and device reliability raised during the USS *Ranger* measurement period, a second measurement period was proposed. In a letter from Commander, Space and Naval Warfare Systems Command (Ser PMW 165-32/822 of 28 October 1992) to Commander, Naval Air Forces, U.S. Pacific Fleet (COMNAVAIRPAC), a second experiment period was requested. The intent of the second data-collection period was to verify the utility of the IR/RTD and to determine the effect on electromagnetic propagation calculations based on the improved measurements. The Naval Oceanography Command Facility (NOCF), San Diego was to coordinate the experiment.

EXPERIMENTAL TECHNIQUE

On 14 October 1992, two IR/RTDs, a bucket thermometer, a complete test plan with data collection sheets, operation and maintenance instructions for the IR/RTD and bucket thermometer, and training in the device's use, were provided to the NOCF. These instruments and instructions were provided by the NOCF to the oceanographer onboard the USS *Kitty Hawk* (CV 63) for use during her normal 6-month deployment period. Training of the ship's meterological personnel in the data-collection requirements and in the use of the IR/RTD was provided by NOCF personnel.

Figures 1 through 8 display the recorded air and sea-surface temperature data from the two measurement systems together with the frequency of observation. From these data, evaporation duct heights were calculated.

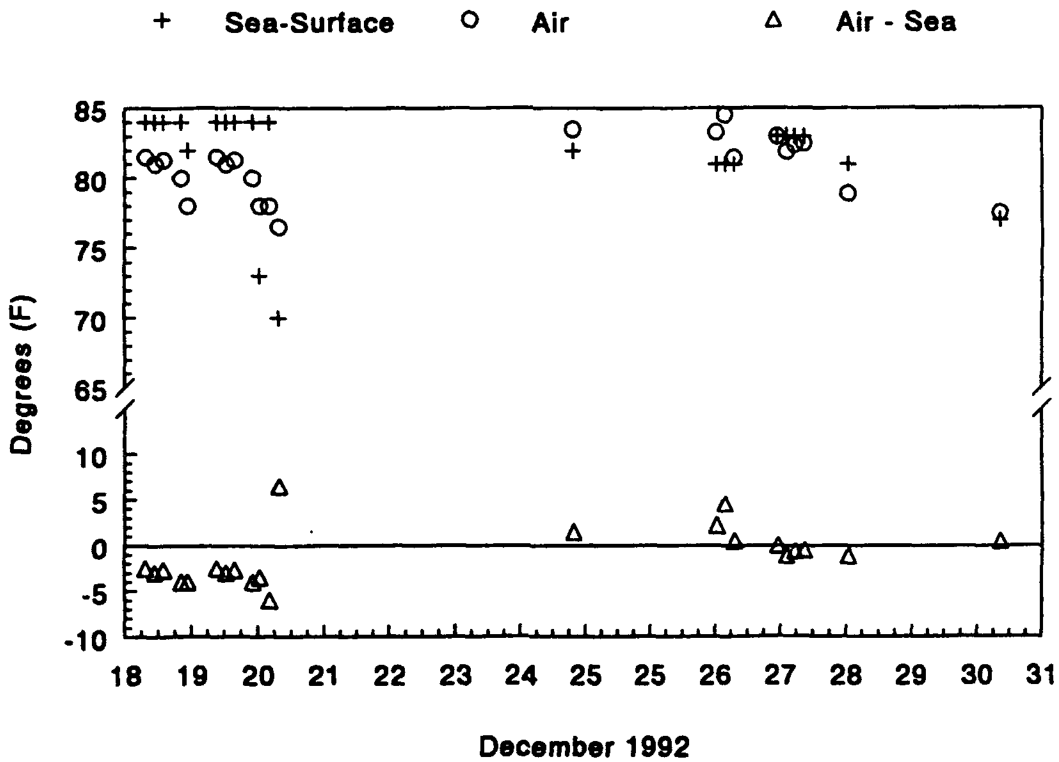

Figure 1. Air and sea-surface temperatures (psychrometer-engine injection) measured during December.

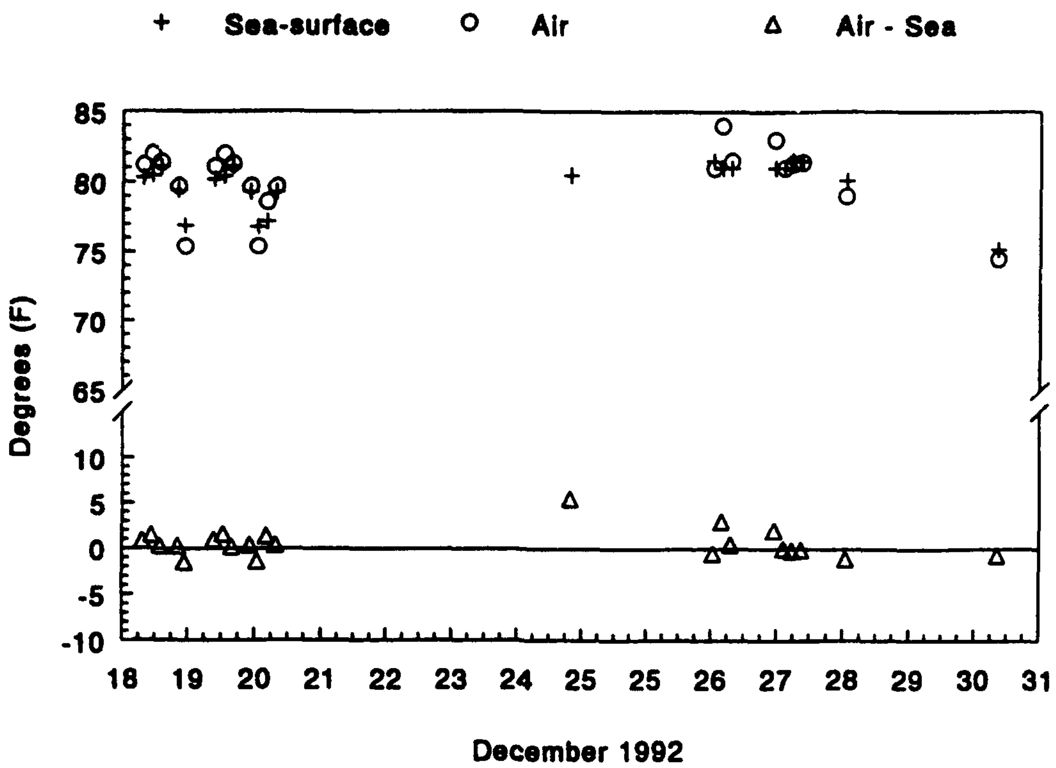

Figure 2. Air and sea-surface temperatures (IR/RTD) measured during December.

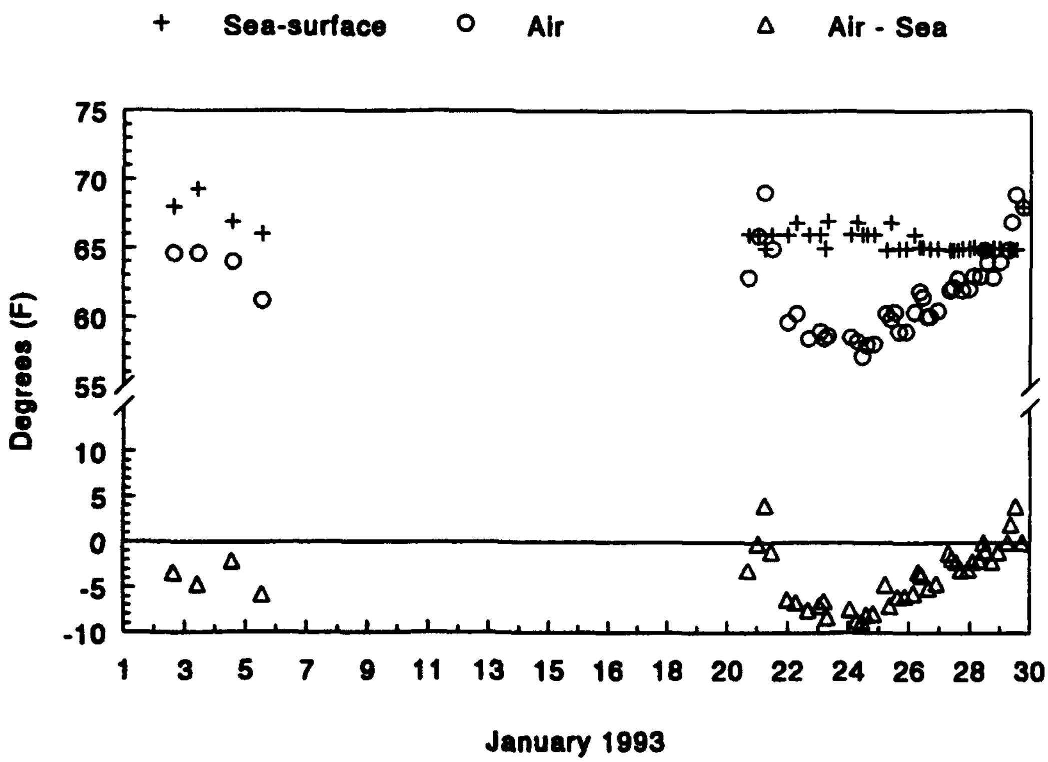

Figure 3. Air and sea-surface temperatures (psychrometer-engine injection) measured during January.

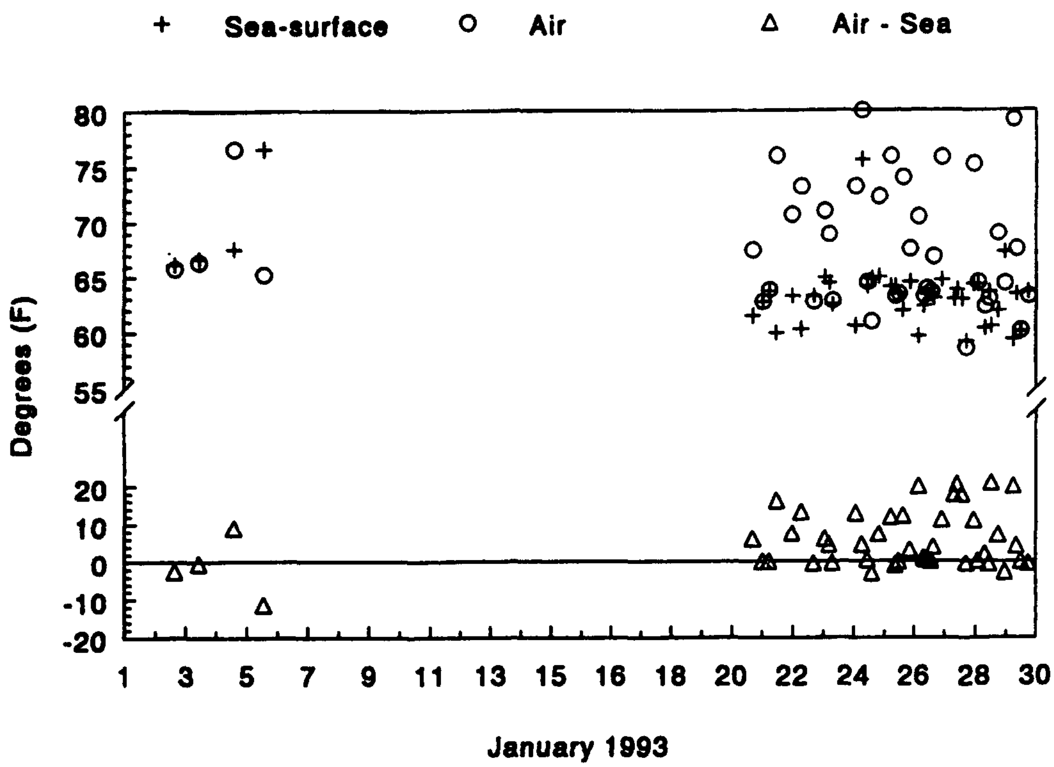

Figure 4. Air and sea-surface temperatures (IR/RTD) measured during January.

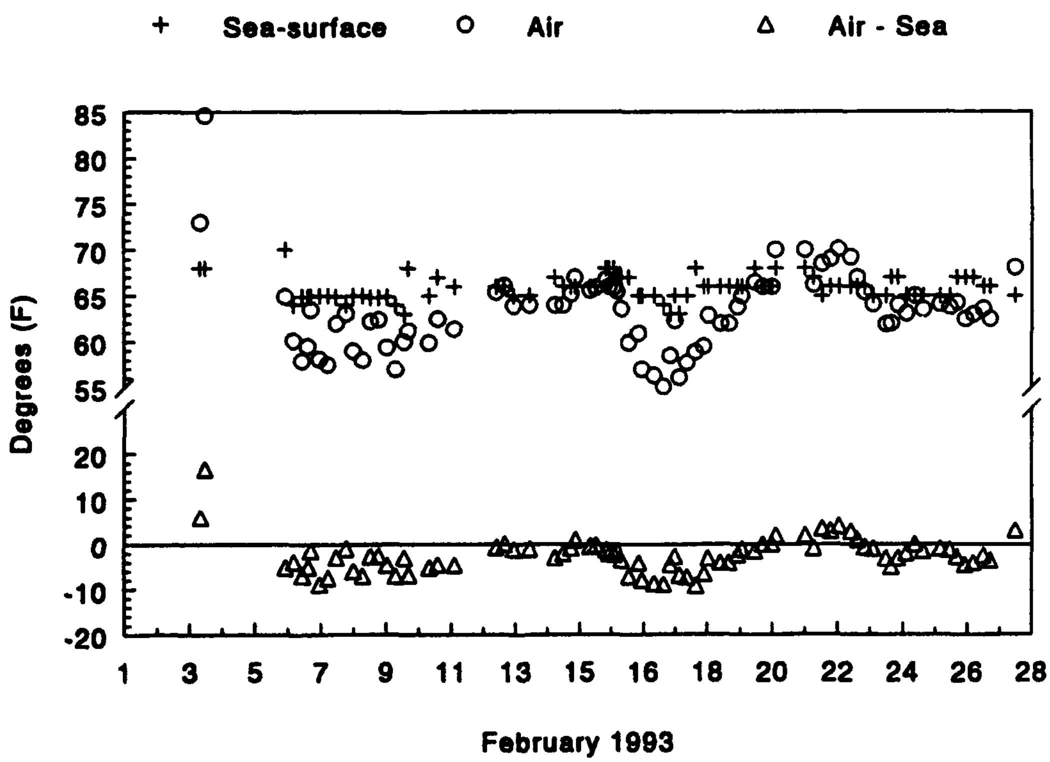

Figure 5. Air and sea-surface temperatures (psychrometer-engine injection) measured during February.

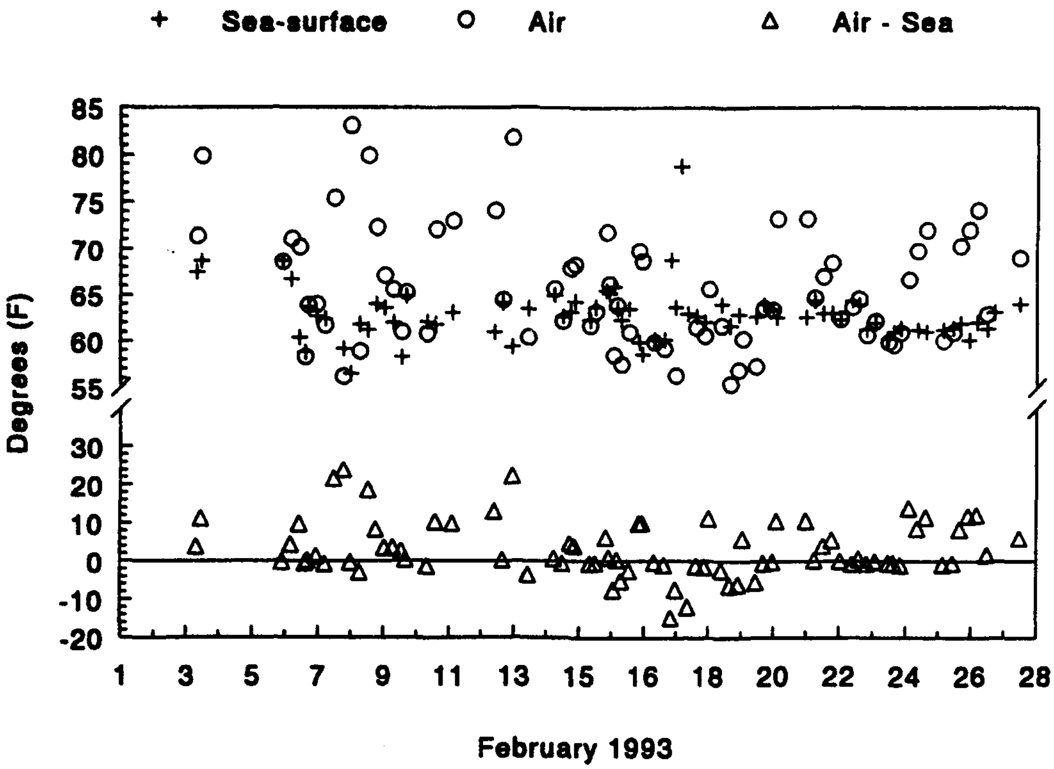

Figure 6. Air and sea-surface temperatures (IR/RTD) measured during February.

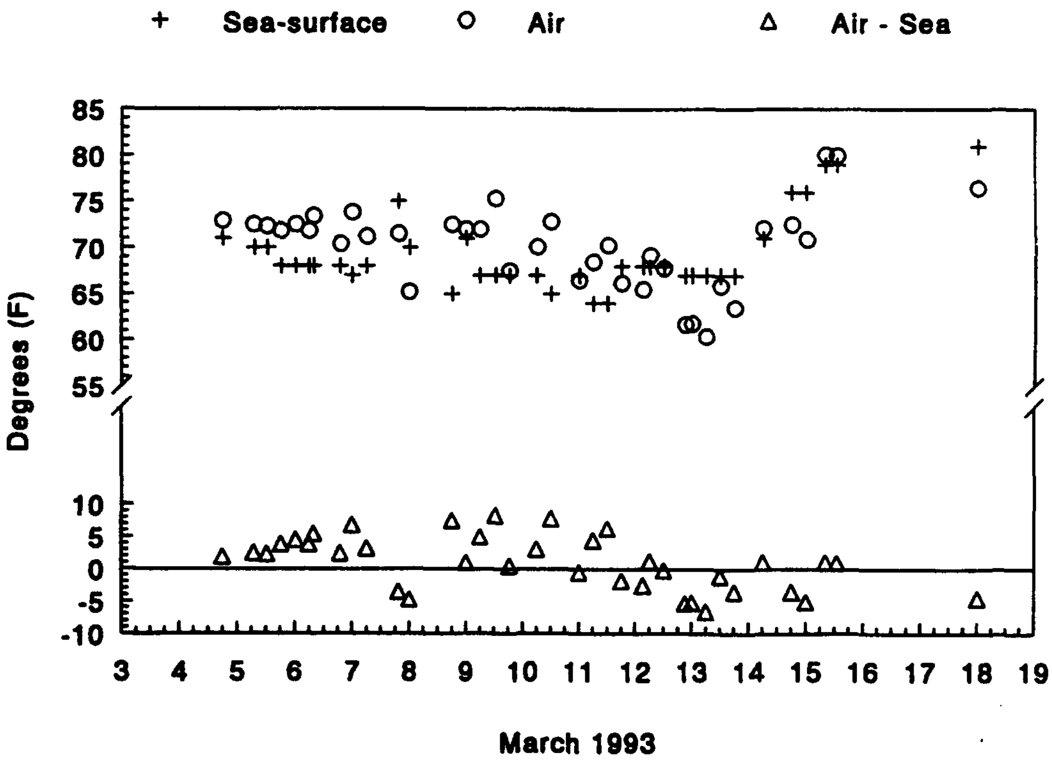

Figure 7. Air and sea-surface temperatures (psychrometer-engine injection) measured during March.

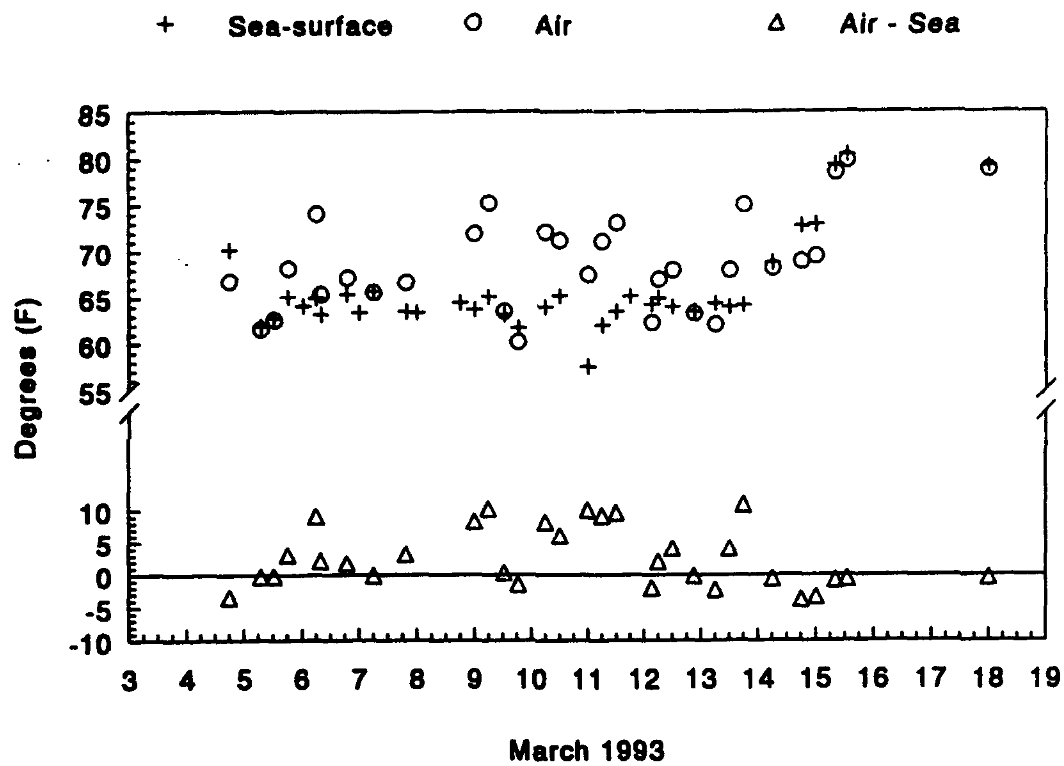

Figure 8. Air and sea-surface temperatures (IR/RTD) measured during March.

DATA QUANTITY, QUALITY, AND EVALUATION

The following observations, results, and conclusions were reached.

(a) While the USS *Kitty Hawk*'s deployment period was 6 months in length, data were collected sporadically over 4 months by the ship's meteorological personnel. In some cases, only one observation was recorded for an entire 24-hour period. The maximum number of observations in any one 24-hour period was five. The data-collection instructions called for hourly observations of temperature, in addition to the inclusion of aviation hourly, special observations, and surface-synoptic weather observations for the entire period of deployment.

Figure 9 illustrates the data-collection periods and the ship's location. Because data were not collected during the transit of the oceans, questions of varying air masses raised during the USS *Ranger* measurement period cannot be resolved. When questioned about the quantity of data, the oceanographer stated his observation that personnel were incapable of using the IR/RTD without close supervision. No explanation was given for lack of data during the ocean transits.

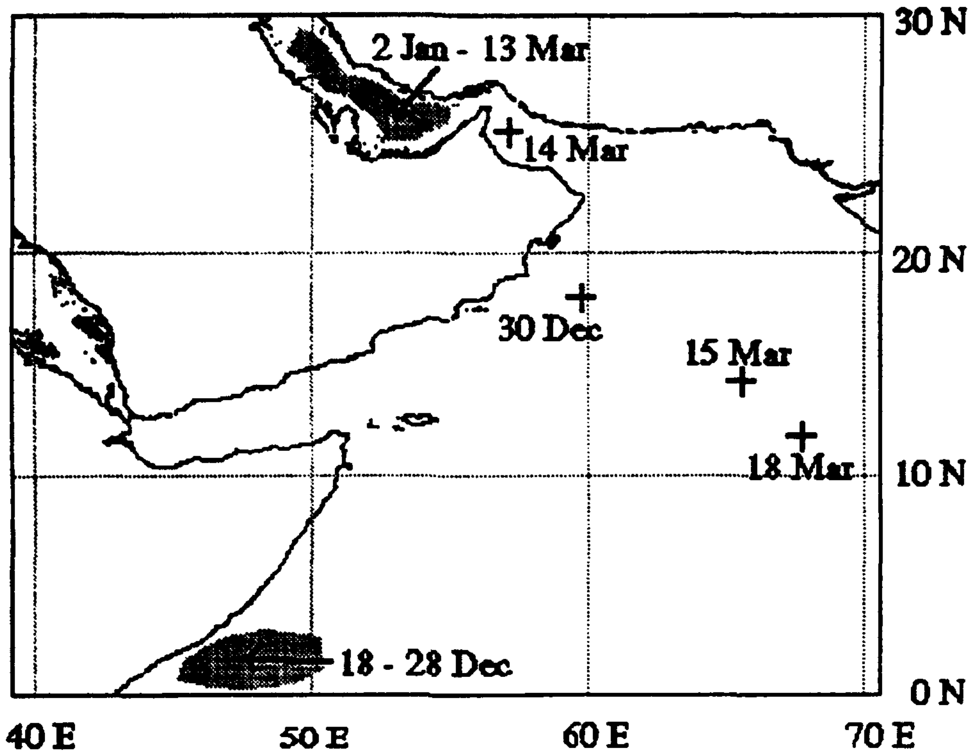

Figure 9. Observation areas and times.

(b) Except for 24 observations taken during the month of December, sea-surface temperatures measured with the bucket thermometer are unavailable for comparison with the IR/RTD and the engine injection temperature, as the bucket thermometer was lost over the side of the ship.

Figure 10 illustrates the correlation between the engine intake, IR/RTD, and bucket thermometer temperature measurements of the sea-surface. The constancy of the engine injection temperature over time noted in the previous USS *Ranger* collection period is still evident. Also of note is that the IR/RTD reported sea-surface temperatures below that of the bucket thermometer while the engine injection measurement reported sea-surface temperatures higher than the bucket thermometer.

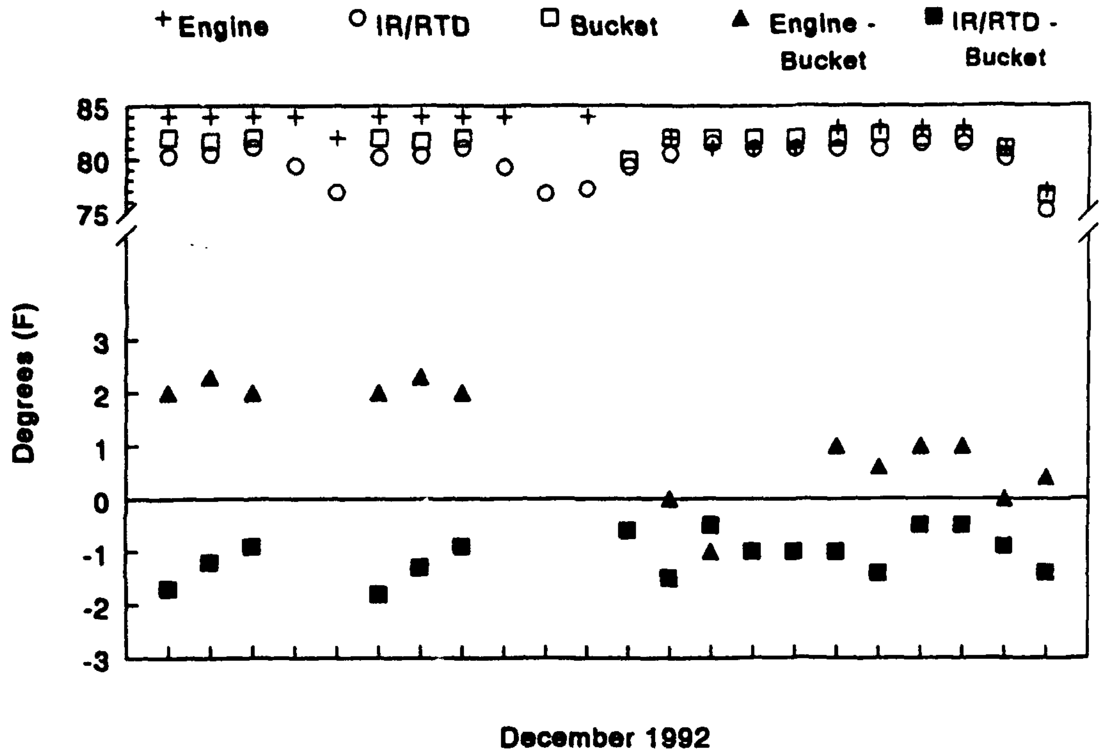

Figure 10. Sea-surface temperatures.

Liu and Businger (1975), describe a surface renewal process as related to sea-surface temperature in turbulent water. Sensible and latent heat fluxes and outgoing infrared radiation combine to remove heat from the water's surface, establishing a cool layer of water at the surface known as a "cool skin." On the open sea, the surface is typically colder than lower layers by a few tenths of a degree Kelvin. Since a bucket thermometer will capture both surface water and warmer water from below this cool skin, it is not surprising to observe the IR/RTD recording cooler surface temperatures than the bucket thermometer. In addition, it is not surprising to see the engine injection temperature warmer than the bucket temperature since the intake is located below the surface of the water. Additionally, heat contamination from the engineering spaces is also expected. The mean wind speed for the December time period was 15.6 knots. What is surprising is that the mean temperature difference for the engine injection and bucket thermometer is only 0.8 degree. For many years, it was assumed the engine injection temperature was several degrees warmer than the sea-surface and thus, the use of a bucket thermometer was recommended for all sea-surface temperature observations.

(c) Additional supplemental data necessary to answer questions of varying environmental conditions were requested, but were not provided. It is not possible, therefore, to distinguish true temperature measurements resulting from frontal passages, littoral processes, or mesoscale circulations, from temperature measurements resulting from instrument failure or operator error.

An objective of this measurement effort is to evaluate the EM system performance. To do so, surface-based ducting must be considered in conjunction with evaporation ducting. Although requested in the data collection plan, no Tactical Environmental Support System (TESS) or Integrated Refractive Effects Prediction System (IREPS) environmental condition summaries or data lists were provided. It is not possible, therefore, to reconstruct EM propagation conditions. Thus, it is unknown if surface-based ducts were present. Climatology for the measurement areas (Somali coast and Persian Gulf) indicate surface-based ducts occur 10 and 30 percent of the time respectively. In the presence of a surface-based duct, EM propagation is dominated by its effect. An evaporation ducting in the presence of a surface-based duct will tend to enhance the EM signal strength within the "skip zone" of the surface-based duct. For short-range detection of surface or low-flying targets, the evaporation duct will have an effect. For long-range detection, however, no matter how accurate the evaporation duct calculation is, any possible gain by using the IR/RTD is lost to other effects. Thus, the need to use an IR/RTD may be irrelevant for long-range tactical applications.

(d) Numerous data-logging errors are evident in the data set. For example, the data collection sheets requested temperatures in degrees Celsius. While most temperatures were recorded in Fahrenheit, an attempt to convert some to Celsius was made. A number of conversion errors are observed on the data collection sheets.

(e) During the months of January and February, unusually high (as compared with climatology, figures 11 and 12), air and sea-surface temperature differences were measured with the IR/RTD. These temperature differences were not evident in the psychrometer and engine injection temperature measurements. It would appear that an IR/RTD failure had occurred. Upon closer inspection of the data log sheets, however, the anomalous temperatures were occurring at consistent times (or by a particular watch section) and the entries were made in the same handwriting. Observations in other handwritings at these times do not show such anomalous temperatures. It is suspected that a particular observer was making an error in the use of the IR/RTD.

Even with anomalous observations, the calculated evaporation duct height distributions shown in figures 13 and 14 are in line with climatology. This is particularly evident in the February distribution. This is due to the application of the Paulus (1984) technique to modify evaporation duct heights under stable conditions (resulting from possible observation errors).

It should be noted that stable conditions are still being recorded in significant numbers. This is to be expected as the USS *Kitty Hawk* was in the Persian Gulf at the time of observation. The prevailing winds were from the northwest, which would produce strong offshore influence.

(f) Figures 15 through 18 illustrate the evaporation duct height calculations during the data-collection period. During the month of December, the mean duct height difference between the two measurement techniques is 0.7 meter. The maximum (psychrometer/injection minus the IR/RTD) difference is 1.9 meters and the minimum difference is –0.02 meter. The standard deviation is 0.6 meter. The prevailing wind during the 18th to 19th time period was from the west or from the land. The prevailing wind during the 25th to 30th time period was from the northeast or from the ocean. It is clear that even under the influence of the offshore flow, the IR/RTD measurement did not produce any significant increase in accuracy over the psychrometer/engine intake measurement method.

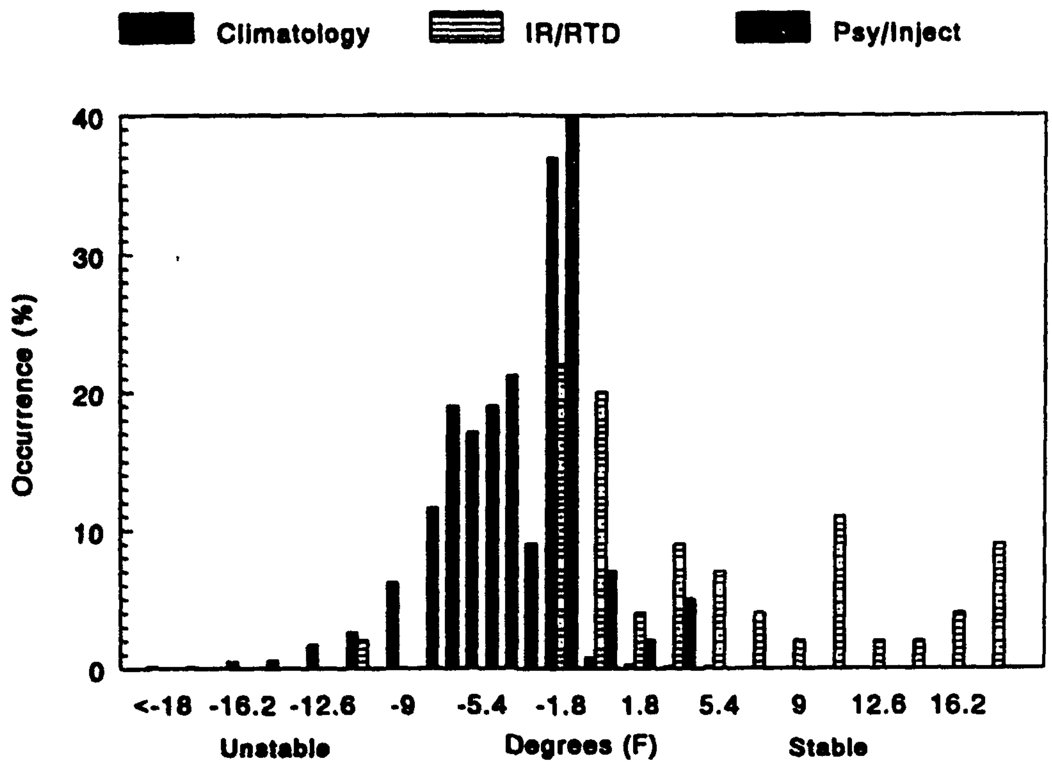

Figure 11. Air and sea-surface temperature differences during January.

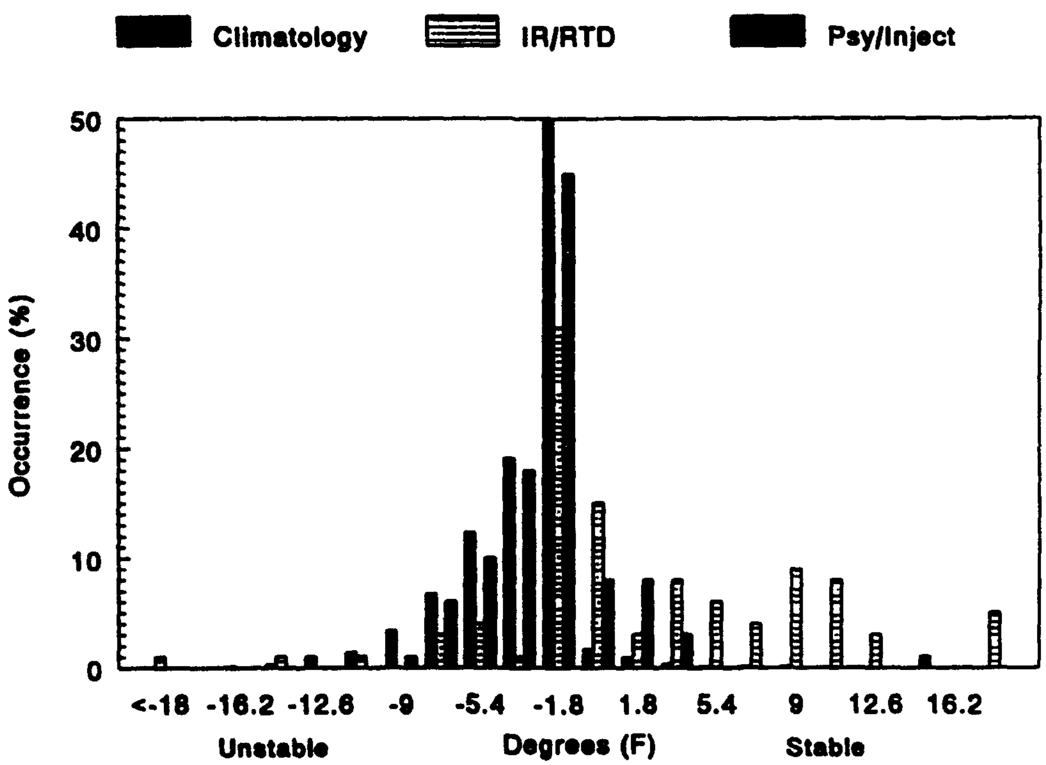

Figure 12. Air and sea-surface temperature differences during February.

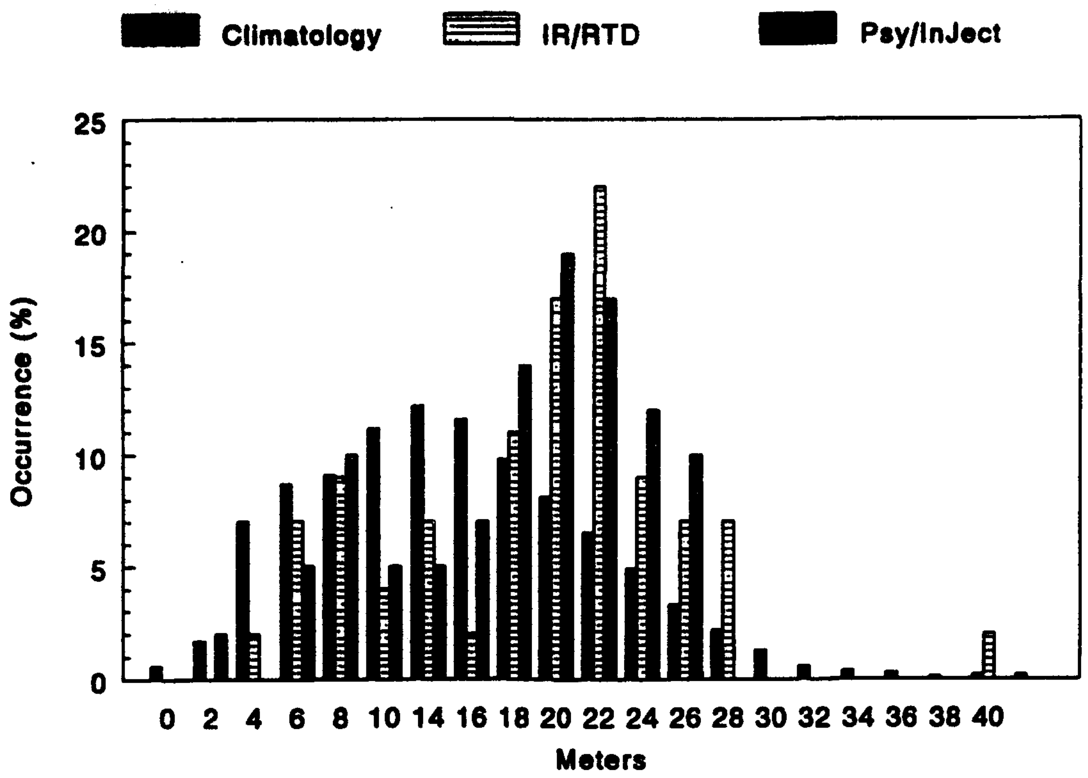

Figure 13. Evaporation duct height distributions during January.

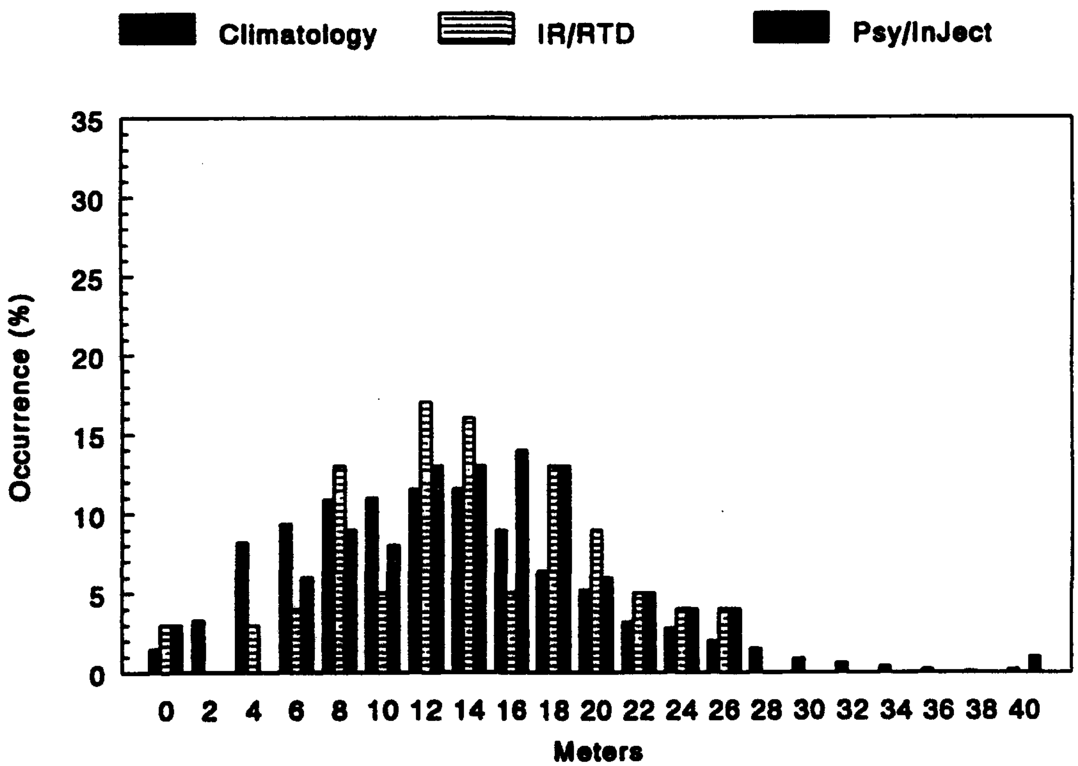

Figure 14. Evaporation duct height distributions during February.

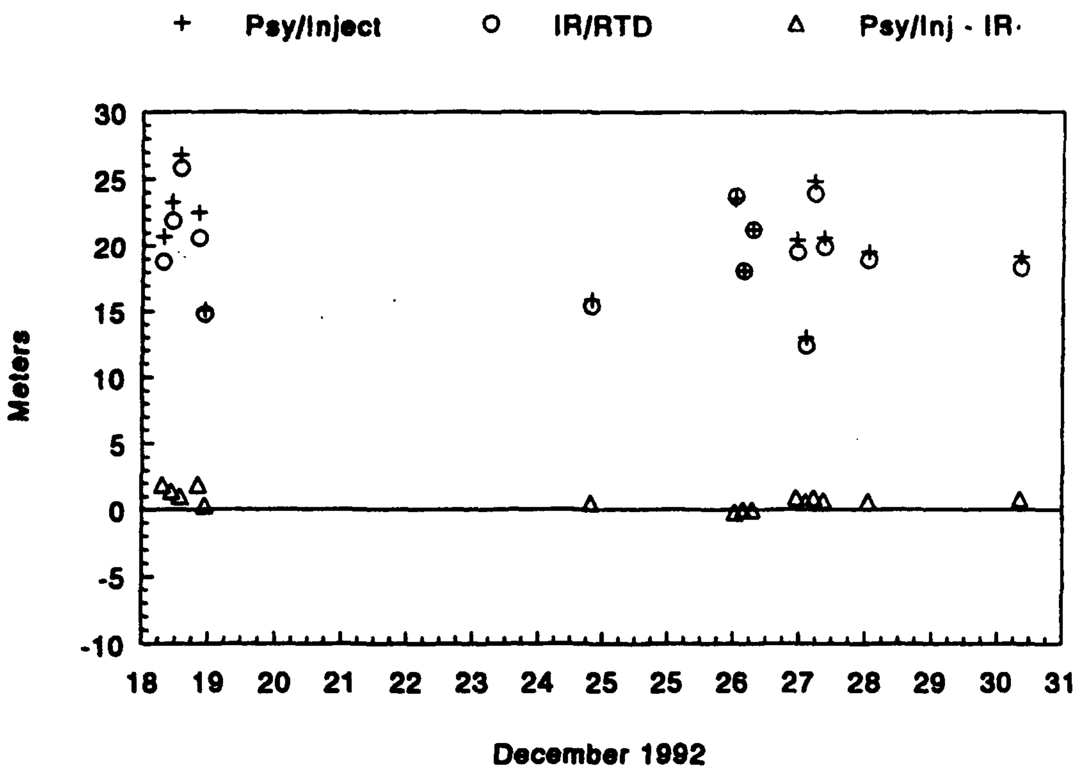

Figure 15. Evaporation duct heights and differences during December.

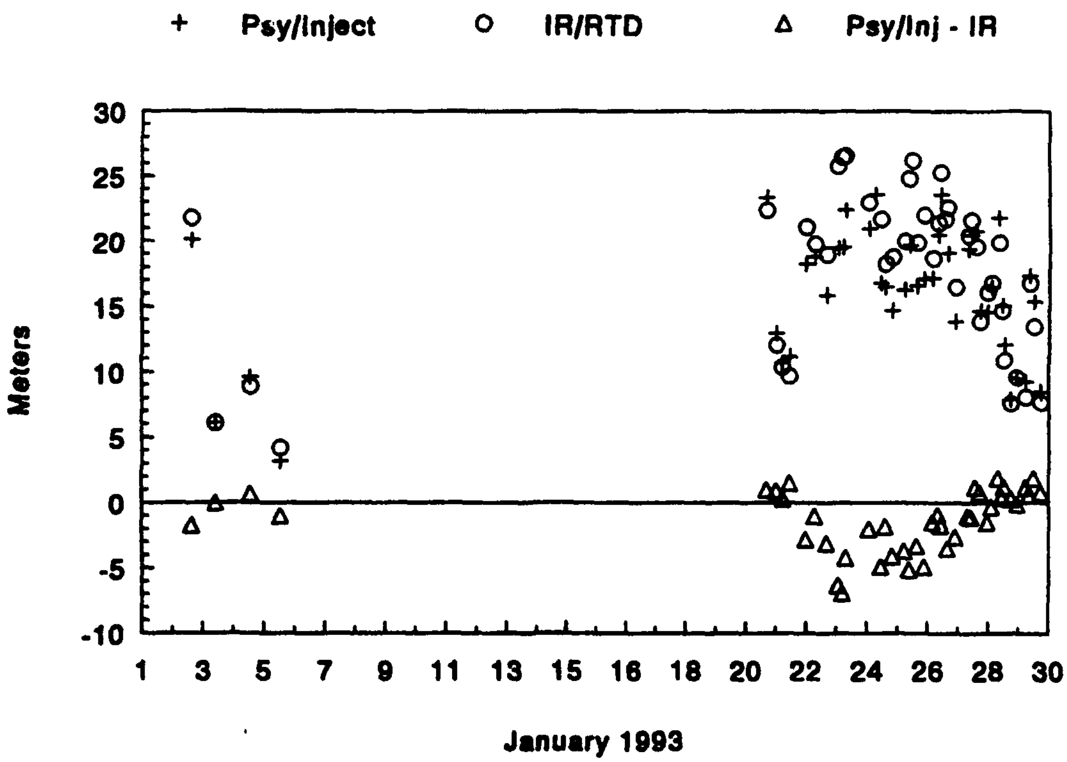

Figure 16. Evaporation duct heights and differences during January.

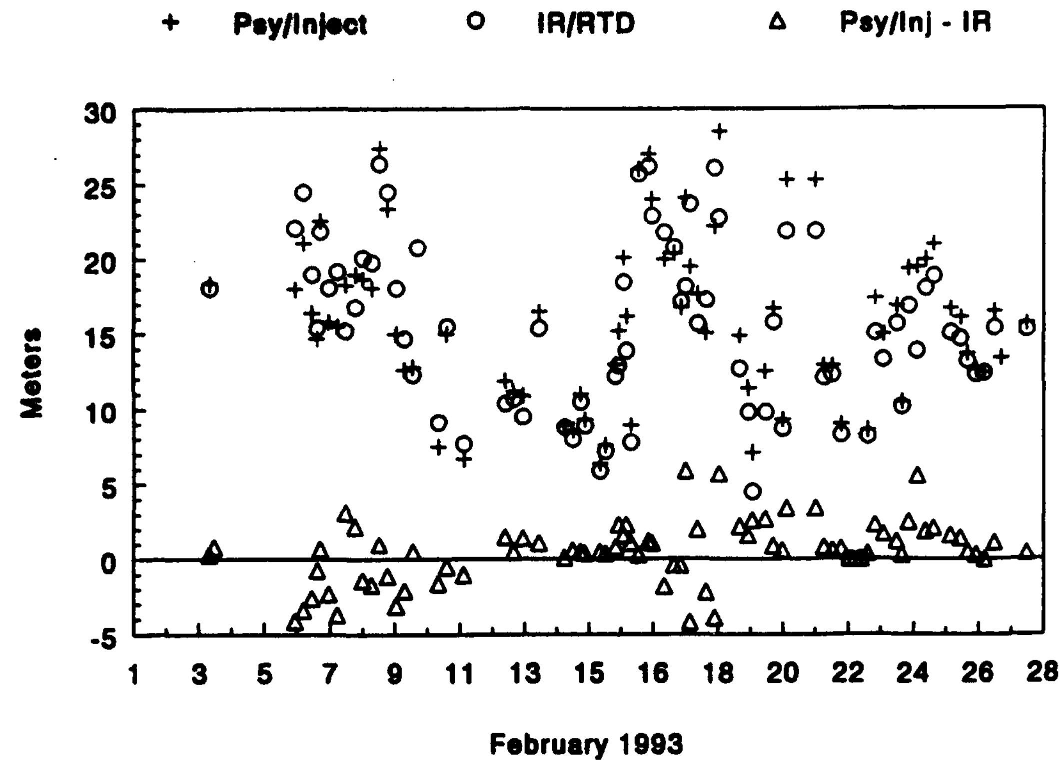

Figure 17. Evaporation duct heights and differences during February.

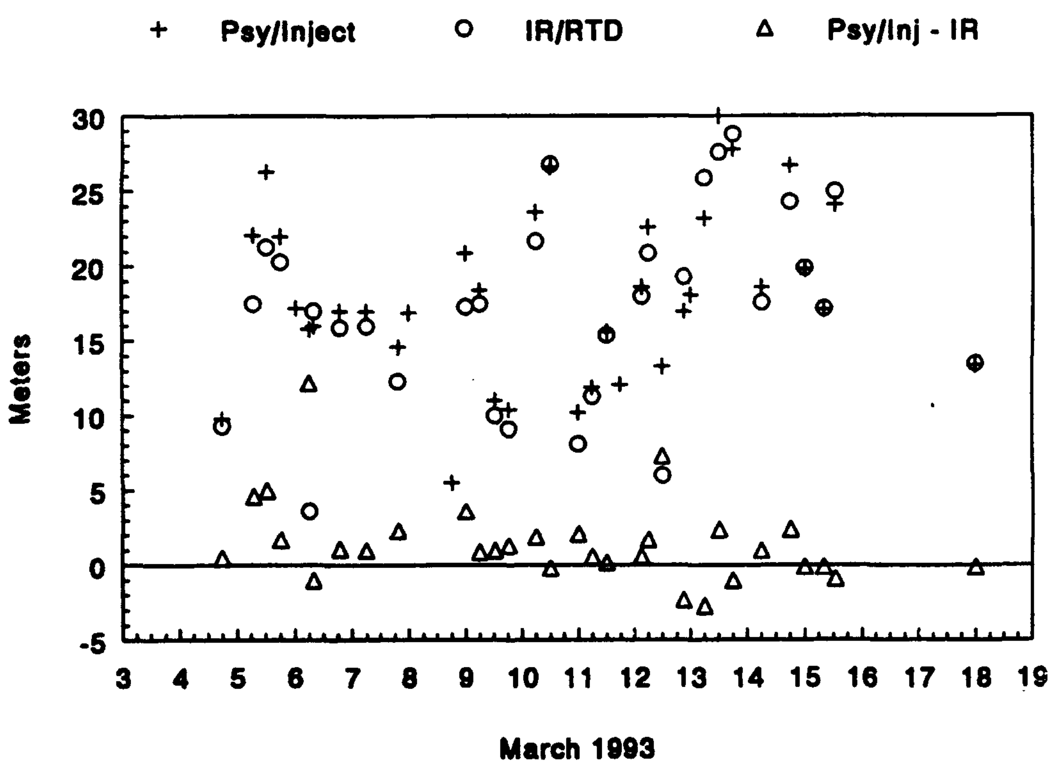

Figure 18. Evaporation duct heights and differences during March.

In January, even with the questionable data related to the unskilled observer, the mean duct height difference between the two measurement techniques was −1.6 meters. The maximum difference was 1.9 meters and the minimum difference was −13.9 meters. The standard deviation was 2.9 meters. The low minimum of −13.9 meters occurred on 24 January at 1057 local time when the observer, using the IR/RTD, recorded a sea-surface temperature 15 degrees higher than that measured at 0607 and 1505 local times. In addition, the air temperature measured with the IR/RTD at 1057 was 22 degrees higher than that measured with the psychrometer. No change in wind speed, direction, or relative humidity was observed over the 0607 to 1505 time period.

The mean duct height difference between the two measurement techniques for February was 0.5 meter. The maximum was 5.9 meters and the minimum was −4.2 meters. The standard deviation was 2.0 meters.

For March, the mean duct height difference between the two measurement techniques was 1.5 meters. The maximum was 12.2 meters and the minimum was −2.7 meters. The standard deviation was 2.8 meters. The high maximum of 12.2 meters occurred on 6 March at 0600 local time when the observer, using the IR/RTD, recorded an air temperature 10 degrees warmer than the sea-surface temperature. This high air temperature is not supported by the psychrometer measurement taken at 0600 nor with the air temperatures measured with the IR/RTD at 0000 (prior to) and 0800 (after) this time. In addition, the wind speed, wind direction, and relative humidity remained constant from the previous to the latter observation. Disregarding this observation and another single observation of 7.3 meters made by the same observer under equally questionable circumstances, the maximum duct height difference is reduced to 4.6 meters for the entire month of March.

The accuracy of the IR/RTD device itself has been verified under laboratory conditions and is not in dispute (Olson 1989). From the USS *Kitty Hawk* observed data, however, it is evident that using the device is not error free. The IR/RTD-measured sea-surface temperatures are consistently lower than those measured with a bucket thermometer, while the engine intake temperatures are consistently higher than the bucket temperatures. If the bucket temperature is accepted as the "ground truth" for sea-surface temperature, the question is raised, "Which measurement technique should be used?"

One of the two purposes for this measurement experiment is to determine the effect on EM propagation calculations based upon an improved measurement technique. In an attempt to answer the question of which measurement technique should be used, two height versus M-unit profiles were created using observations from both measurement techniques. Because of possible operator errors, rather than use an extreme duct height difference, the observation taken at 1700 local time on 2 January was selected. This observation represents the mean difference for January. It also falls outside of the questionable time interval discussed earlier and is recorded in a handwriting different than that of the questionable observer. Both evaporation duct height profiles were processed with the RPO propagation model, with the RPO output used for input to EREPS for EM propagation assessment. Figure 19 illustrates the EREPS evaluation. It is apparent that for one specific tactical application, i.e., the detection of a small, low-flying target using a surface-search radar, it does not matter which measurement system produced the evaporation duct height calculation. Detection ranges for both evaporation duct heights are the same. From the perspective of another tactical application, however, i.e., the detection of a moderate-size, low-flying target using the same surface-search radar, it appears at first glance that it does matter. However, it has been shown by Dockery (1987) that EM signal fluctuations of ± 10 dB from the mean are common. These fluctuations emphasize the probabilistic nature of detection. In the mean, relative performance is reasonably predictable (Patterson, 1984; Hitney & Vieth, 1990); but a single detection event is not likely to exactly verify the predicted range, even with perfect environmental data. Taking into account the ±10-dB variation in detection threshold, it may be seen from figure 19 that it does not matter which measurement system produced the evaporation duct height calculation. In light of the probabilistic nature of detection, the question still remains: which measurement is the "best?" The answer has to be, it can not be determined. The measured data do not support accepting one measurement technique over another.

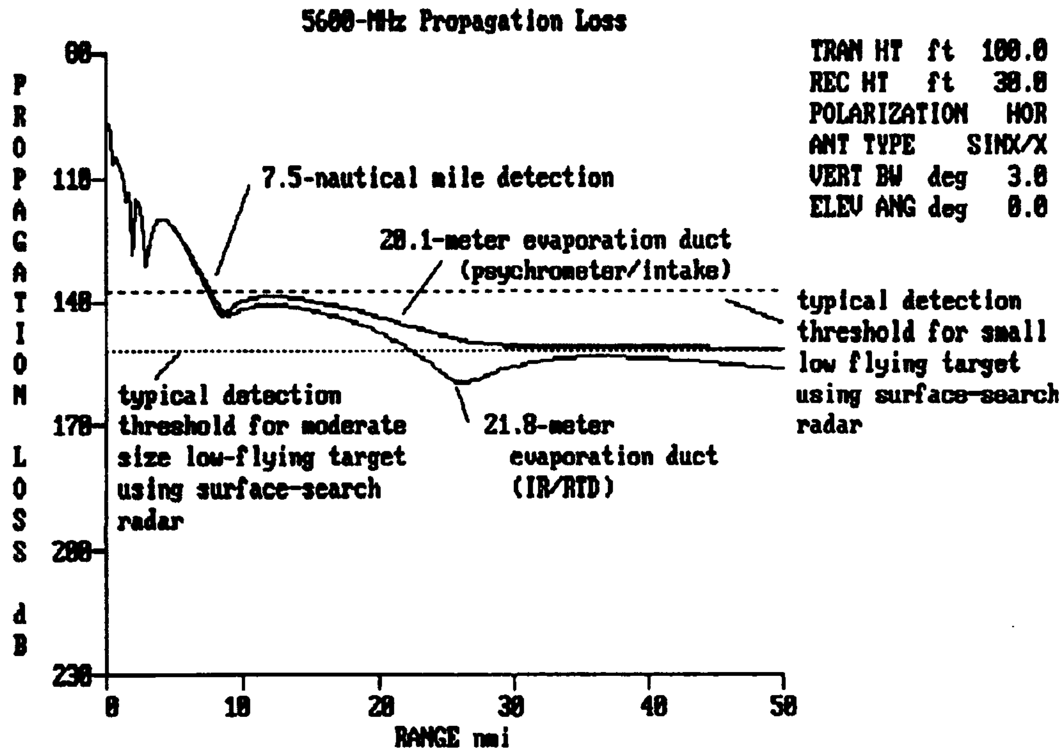

Figure 19. EM propagation assessment using RPO model and EREPS display.

IR/RTD RELIABILITY

(a) Both devices suffered mechanical failures during the collection period. For one device, the air temperature thermistor probe was pushed into the device and could not be retrieved. For the second device, the battery recharging cable was torn from its pin connector. For both devices, the battery was unable to hold a charge beyond a few minutes. Because of these failures, the devices could not be transferred to the NOCF mobile environmental support teams for additional data-collection efforts. Both devices were returned to the manufacturer for repair and recalibration.

It was noted by the oceanographer that the battery charging unit did not conform to the three-prong grounding standards required by ship's regulations for personal electronic equipment. This delayed the use of the IR/RTD for several days until a special dispensation was granted by the Electronic Materials Officer.

(b) Unexplained, extreme swings in the air temperature over short time intervals were recorded by the IR/RTD. For example, in one 5-hour period, the air temperature rose and fell by 15 degrees.

No corresponding temperature change was noted from the dry bulb thermometer in the psychrometer. A 9-degree sea-surface temperature swing in a 3-hour period was recorded by the IR/RTD. As no supplemental information was provided, it is not possible to tell if this temperature swing was a recording error, an error in reading the device, or a device failure. As discussed earlier, it is suspected that a recording error or an observational error occurred rather than a device failure.

CONCLUSIONS AND RECOMMENDATIONS

(a) Justification does not exist for shipboard use of the IR/RTD to measure sea-surface or air temperatures. In comparing the data collected by the USS *Kitty Hawk* with that collected by the USS *Ranger*, it is apparent the IR/RTD shows no advantage in measuring the environment for evaporation duct height calculations. In fact, for EM propagation assessment purposes, the traditional method of using a hand-held psychrometer for the air temperature and the engine intake temperature to represent the sea-surface temperature show equal results between the two measurement techniques.

(b) In both the USS *Kitty Hawk* and the USS *Ranger* measurement periods, all IR/RTD suffered mechanical or electrical failures. Since repair and recalibration must be done at the manufacturer's facility, the device is inappropriate for shipboard use. In addition, the design of the battery recharging unit does not conform to shipboard requirements for electrical grounding.

(c) While measuring a surface's temperature only requires pointing the device at the surface and reading the LED display, obtaining an air temperature by pressing a menu button on the device appears too complicated for some observers. This conclusion is borne out by both the comments of the USS *Kitty Hawk* oceanographer and the large number of highly suspicious readings. Thus, training on the proper use and care of temperature-measuring devices could be made part of the Aerographer's Mate course curriculum and shipboard performance factors.

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13. ABSTRACT *(Maximum 200 words)*

Air and sea-surface temperatures were measured and recorded by the USS *Kitty Hawk*'s meteorological personnel during a 6-month deployment period. Using infrared/resistance temperature devices (IR/RTD) and hand-held psychrometers, air and sea-surface temperature data were compiled. In comparing these data with data collected earlier by the USS *Ranger*, it became apparent that the shipboard use of the IR/RTD to measure sea-surface and air temperatures was not warranted.

The IR/RTD suffered mechanical and electrical failures during both the USS *Kitty Hawk* and USS *Ranger* measurement periods. Since repair and recalibration must be done at the manufacturer's facility, the device is inappropriate for shipboard use. In addition, the design of the battery-recharging unit does not conform to shipboard requirements for electrical grounding.

Borne out by both the comments of the USS *Kitty Hawk* oceanographer and the large number of highly suspicious readings, additional training for observers is justified. Thus, training on the proper use and care of temperature-measuring devices could be made part of the Aerographer's Mate course curriculum and shipboard performance factors.

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