NPS-MR-94-003

NAVAL POSTGRADUATE SCHOOL
Monterey, California

DTIC
SELECTE
DEC 2 3 1994
F

THE EFFECT OF INFRARED SEA SURFACE TEMPERATURE MEASUREMENTS ON EVAPORATION DUCT HEIGHT ESTIMATION

by

P.A. Frederickson
K.L. Davidson
F.K. Jones

November 1994

Approved for public release; distribution is unlimited

Prepared for: Naval Oceanographic Office
                  Stennis Space Center, MS

19941219 067

Naval Postgraduate School
Monterey, California 93943-5000

Rear Admiral T. A. Mercer
Superintendent

This report was prepared for and funded by the Naval Oceanographic Office.

Reproduction of all or part of the report is authorized.

This report was prepared by:

Paul Frederickson

Paul A. Frederickson
Physical Scientist

Kenneth Davidson

Kenneth L. Davidson
Professor of Meteorology

F. Keith Jones

F. Keith Jones
Physical Scientist

Reviewed by:

Robert L. Haney

Robert L. Haney, Chairman
Department of Meteorology

Released by:

Paul J. Marto

Paul J. Marto,
Dean of Research

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 30 Nov 1994	3. REPORT TYPE AND DATES COVERED Technical Report

4. TITLE AND SUBTITLE The Effect of Infrared Sea Surface Temperature Measurements on Evaporation Duct Height Estimation	5. FUNDING NUMBERS N62306940B40001

6. AUTHOR(S)
P. A. Frederickson, K. L. Davidson, and
F. K. Jones

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Meteorology Naval Postgraduate School 589 Dyer Rd., Room 254 Monterey, CA 93943-5114	8. PERFORMING ORGANIZATION REPORT NUMBER NPS-MR-94-003

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Oceanographic Office 1002 Balch Blvd. Stennis Space Center, MS 39522-5001	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

In September 1994 personnel from the Naval Postgraduate School (NPS) and the Naval Oceanographic Office (NavO) conducted an experiment off the coast of Mississippi to determine the accuracy of infrared sea surface temperature (SST) measurements made from a small boat, and the effect of these measurements on estimating the evaporation duct height (z_*). It was found that infrared SST measurements are highly accurate, agreeing closely with SST measurements made by other methods, and that a small relative error in the SST measurements can lead to large errors in z_* estimates. However, it is difficult to predict the effect a given error in SST will have on the resulting z_* estimate, due to the complex relationship between SST and z_*.

14. SUBJECT TERMS Sea Surface Temperature Evaporation Duct			15. NUMBER OF PAGES 18
			16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

ABSTRACT

In September 1994 personnel from the Naval Postgraduate School (NPS) and the Naval Oceanographic Office (NavO) conducted an experiment off the coast of Mississippi to determine the accuracy of infrared sea surface temperature (SST) measurements made from a small boat, and the effect of these measurements on estimating the evaporation duct height (z_*). It was found that infrared SST measurements are highly accurate, agreeing closely with SST measurements made by other methods, and that a small relative error in the SST measurements can lead to large errors in z_* estimates. However, it is difficult to predict the effect a given error in SST will have on the resulting z_* estimate, due to the complex relationship between SST and z_*.

The Effect of Infrared Sea Surface Temperature Measurements on Evaporation Duct Height Estimation

P. A. Frederickson, K. L. Davidson and F. K. Jones
Department of Meteorology
Naval Postgraduate School
Monterey, California

1) Introduction

In September 1994 personnel from the Naval Postgraduate School (NPS) and the Naval Oceanographic Office (NavO) conducted an experiment off the coast of Gulfport, Mississippi, to determine the feasibility and accuracy of measuring the sea surface temperature from a small boat with infrared radiation thermometers. A major goal of this effort was to show how the accuracy of infrared sea temperature measurements effect the resulting evaporation duct height calculations. During two days, 21 and 22 September, atmospheric surface-layer wind, temperature, humidity and pressure and sea surface temperature measurements were made from a hydrographic survey launch to support these objectives. This report presents the data obtained during this experiment and an analysis of the effects of the infrared sea temperature measurements on evaporation duct height calculations.

2) Instrumentation and Measurements

2.1) Naval Postgraduate School (NPS)

A Coastal Climate WeatherPak was used to obtain mean vector wind (speed and direction), air temperature, relative humidity and atmospheric pressure measurements. The weatherpak also contains a magnetic compass which was used to determine the boat's heading. The WeatherPak was mounted on the starboard side of the aft cockpit of the HSL (see fig. 1), with the wind sensor 3.7 meters above the sea surface, and the temperature, humidity and pressure sensors 3.3 meters above the sea surface.

A Magnavox Global Positioning System (GPS) was used to obtain the HSL's location, as well as it's course and speed over ground. The boat's course and speed must be known in order to determine the true wind speed and direction, which is calculated by subtracting the boat's motion from the wind data actually measured by the moving wind sensor. The GPS device was not configured for differential GPS operation, therefore, at low boat speeds (< 1.5 m/s) the GPS course and speed data are not accurate, and should not be used to obtain the true wind. Therefore, when the HSL was dead in the water, or had little headway, the Coastal Climate Weatherpak compass data were used instead of the GPS course over ground for the boat's heading in the true wind calculations.

All meteorology and GPS data described above were sampled and stored at 30 second intervals. The true wind speed and direction were then calculated using 30 second averaged relative wind speed and direction and boat speed and heading data. The resulting data were then averaged over 10 minute intervals.

The sea surface temperature (SST) was measured using an Everest Interscience, Inc. Model 110AL hand-held infrared thermometer. This IR probe was used looking directly downward along the side of the aft cockpit of the HSL, at a height of approximately 1.5 meters above the water surface. The emissivity setting in the IR thermometer was 0.986. The SST was also measured with a mercury thermometer dipped into a bucket of seawater. The bucket contained sea water from roughly the top 0.3 m of the sea surface. Both the hand-held IR and the bucket measurements were made from the aft cockpit of the HSL when the boat was stopped or had very little headway. It was also planned to measure the SST with a floating thermistor, however this system was damaged in shipment and was rendered inoperable.

2.2) Naval Oceanographic Office (NavO)

The sea surface temperature was also measured by personnel from the Naval Oceanographic Office (NavO). The NavO system consisted of a Heimann KT19 radiation thermometer, with digital output being received and stored approximately every 15 seconds by a portable PC. Emissivity in the IR thermometer was set to 0.985. The Heimann sensor was enclosed inside a water-tight box custom designed by NavO and mounted on the bow of the HSL looking perpendicular to the water surface at a height of about 1.5 meters.

3) Measurement Platform and Boat Operations

The experiment was conducted on board a hydrographic survey launch (HSL) operated by the Boat Operations Branch of NavO in Gulfport, Mississippi. The HSL is 34 feet in length and has a beam of 10 feet. Due to the very shallow water off Gulfport, the HSL cruised only along the dredged harbor channel during this experiment. The HSL generally cruised at about 10-14 knots, except when the boat stopped in order for bucket and IR-gun sea temperature measurements to be made, when headway of less than one knot was maintained.

4) Evaporation Duct Calculations

The evaporation duct is a persistent feature over ocean areas because of the rapid decrease in moisture immediately above the water surface. A simplified depiction of the refraction and humidity correlation shows that the resulting duct, or "wave guide", is surface based because the humidity decreases from its

2

maximum at the surface where the relative humidity is 100%. Model predictions of the influence of the evaporation duct on C-band radar detection ranges have been examined by Patterson et al. (1987). This study showed a large variation in detection ranges over evaporation duct regimes that could exist simultaneously in a coastal region. It was also shown that ESM intercept ranges for surface-to-surface paths can be quite variable due to the evaporation duct mechanism. Therefore, proper measurements for an accurate estimation of the evaporation duct height are important.

The near-surface properties most important in determining the evaporation duct height are the humidity, the temperature difference between the water surface and the overlying air and the turbulent mixing. Turbulent mixing is a factor because it can alter the shape of the temperature and humidity profile for similar air-surface temperature and humidity differences. Increased turbulent mixing would lower $z*$ because the air-sea humidity difference is contained in a layer closer to the surface. Hence, information is required of the sea surface temperature, which also determines the surface humidity value since the sea surface is assumed to be at saturation, the temperature and humidity of the overlying air, and the turbulent mixing adjacent to the surface. Turbulent mixing is controlled by SST, as well as wind speed. The near-surface wind speed controls turbulent mixing through shear-induced mechanical turbulence, while the air-sea temperature difference determines the thermal stratification for either damping turbulent mixing in stable conditions or enhancing buoyant mixing in unstable conditions. In summary, the SST is very important in determining the evaporation duct height, since it determines the surface-layer temperature and humidity profile, as well as exerting a strong control on the near-surface turbulent mixing.

Multi-level measurements will never be routinely available to determine the evaporation duct height. Instead, wind speed, temperature and humidity measurements at a single level near the surface and the sea surface temperature are used with Monin-Obukhov (MO) surface-layer scaling methods to obtain reasonable estimates of $z*$ with the bulk method. The evaporation duct height can be calculated from the bulk MO surface-layer scaling parameters for momentum, temperature and humidity ($u*$, $T*$ and $q*$) and for stability, defined as z/L, where z is the measurement height above the sea surface and L is the MO length scale, to be defined below. We used the bulk surface layer formulations presented in Smith (1988) for these calculations, which are briefly summarized below. The MO surface-layer scaling parameters $u*$, $T*$ and $q*$ are given by

$$X* = (X_z - X_O)k/[\ln(z/z_{OX}) - \psi_x(z/L)] \qquad (1)$$

where $X* = u*$, $T*$ or $q*$, X_z = the value of u, T or q at measurement height, z, X_O = the value of u, T or q at the sea surface, k is Von Karman's constant with the value of 0.4, z_O is

a parameter called the roughness length which relates to the roughness of the sea surface and ψ_x is an empirical stability-dependent function. L is the Monin-Obukhov length scale defined by

$$L = Tu_*^2/kg(T_* + 0.61Tq_*) \qquad (2)$$

were T is the absolute air temperature, and g is the acceleration due to gravity (9.8 m/s^2). Since q_* is almost always negative, the sign of z/L is largely determined by the air-sea temperature difference. When the air is warmer than the sea surface, conditions are stable (z/L > 0), and when the sea is warmer than the air, conditions are unstable (z/L < 0).

The above equations represent a system of four equations and four unknowns (u_*, T_*, q_* and L) which are solved iteratively. This system of equations was solved for this experiment using 10 minute averaged NPS measurements of wind speed, air temperature and specific humidity and using the NavO IR SST measurements. The surface value of specific humidity is determined by assuming that the sea surface is saturated and by computing the saturation specific humidity for the measured sea surface temperature. The surface value of the wind speed is assumed to be zero.

Once T_*, q_* and L are known, the evaporation duct height can be calculated. The expression for the evaporation duct height, denoted by z_*, is as follows (Fairall et al., 1978):

$$z_* = -[7.2q_* - 1.3T_*] \, \phi_S(z_*/L)/k(0.125) \qquad (3)$$

where ϕ_S is an empirical scalar gradient function describing the dimensionless vertical profile of temperature and humidity as a function of stability, z/L. ϕ_S is given by

$$\phi_S(z/L) = \begin{cases} (1 - 16z/L)^{-1/2} & z/L < 0 \text{ (unstable)} \\ 1 & z/L = 0 \text{ (neutral)} \\ 1 + 7z/L & z/L > 0 \text{ (stable)} \end{cases} \qquad (4)$$

Since z_* appears on both sides of equation 3, it is solved iteratively.

An examination of the above equations shows the importance of the SST in determining the evaporation duct height. The three parameters which determine z_* (t_*, q_* and $\phi_S(z/L)$), are all dependent upon the SST. As seen in equation 2, T_* is largely determined by the air-sea temperature difference in the surface layer, q_* is largely determined by the air-sea specific humidity difference, which depends upon the SST because the surface is assumed to be saturated at the sea temperature.

The $\phi_S(z/L)$ function reflects the effect that stability conditions will have on changing the shape of the humidity and temperature profiles for the same air-sea humidity and temperature differences, due to turbulent mixing. The ϕ_S

4

function is plotted versus stability, z/L in fig. 3. Note that the function $\phi_S(z/L)$ is largest when the air is warmer than the water (stable stratification, z/L > 0) and smallest when the air is colder than the water (unstable stratification, z/L < 0). Note also the large increase in ϕ_S as conditions become more stable (z/L increasing). Since the stability is given by z/L, it can increase with decreases in wind speed (u_*), as well as increases in air-sea temperature difference (T_*).

5) Cruise Narrative and Results

5.1) 20 September 1994 cruise

The HSL departed the dock at 1215 Central Standard Time (CST) and proceeded out of the harbor, continuing outward along the harbor channel heading to the southeast. At about 1320 CST the HSL turned around and headed back to the harbor and docked at 1403 CST. The HSL stopped briefly for several periods during the cruise, in order to make SST measurements with a bucket dipped into the water and with hand-held infrared thermometers. Cloud conditions during this time were about 20% cumulus cloud coverage on the horizons and complete high level haze coverage. The seas were calm, with wave heights between 1 and 2 feet. Time series data for the 20 September 1994 cruise are shown in fig. 4. As seen in this figure, the winds were quite steady between 4.8 and 6.7 m/s from the east during the whole cruise. The relative humidity fluctuated between 84 and 88%, and atmospheric pressure was steady between 1014.6 and 1015.0 mb. The air temperature was lower than the sea surface temperature (using NavO IR data) by about 1 to 2 $^\circ$C, resulting in unstable conditions, with 10 m/L values ranging between -0.1 and -0.4. Near-surface atmospheric and sea surface temperature conditions resulted in evaporation duct heights of 11-13 meters.

5.2) 21 September 1994 cruise

The HSL departed the dock at 0849 Central Standard Time (CST) and proceeded southeast outward along the harbor channel. At about 1005 CST the HSL turned around and headed back to the harbor, docking at 1052 CST. Again, the HSL stopped briefly for several periods during the cruise in order for bucket SST measurements to be made. Cloud conditions at the beginning of the cruise were mostly cloudy, with broken cumulus coverage. The sky cleared continuously during the cruise and by the time the HSL returned to the dock the skies were clear, except for a thin level of haze. The seas were calm during this time, with wave heights between 1 and 2 feet. Time series data for the 21 September 1994 cruise are shown in fig. 5. The winds ranged between 4.6 and 7.4 m/s during the cruise and were from the northeast and east- northeast. The relative humidity fluctuated between 84 and 90%, and atmospheric pressure was steady between 1015.0 and 1015.5 mb. The air temperature was cooler than during the 20 September afternoon cruse, ranging between 21.6 $^\circ$C at the

beginning of the cruise and increasing to 23.5 °C by the time the boat returned to port. The cooler air temperatures resulted in larger magnitude negative air-sea temperature differences than on 20 September, ranging from -5 to -3 °C, which in turn created more unstable conditions, with 10 m/L values ranging between -0.3 and -0.6. Near-surface atmospheric and sea surface temperature conditions resulted in evaporation duct heights of 11-13 meters.

6) Comparison of Sea Surface Temperature Measurements

As discussed above, the SST was measured by several sensors during the experiment:

1) NavO Heimann bow-mounted IR thermometer,
2) NPS Everest hand-held IR thermometer,
3) Mercury thermometer measuring bucket of sea water.

In this section the sea temperatures measured by the different sensors are compared. Figure 6 shows a scatter plot between the NavO IR SST measurements and the bucket SST measurements for both days of the experiment. For the following comparisons, we used 1 minute averaged NavO sea temperatures. The NavO IR measurements, except for two points, were cooler than the bucket temperatures, with differences ranging from -0.6 °C to +0.1 °C. These small differences indicate that the NavO Heimann IR system measures the sea temperature to a high degree of accuracy. The bucket temperatures of 27 °C and lower all occurred on 21 September and during that day the differences between the NavO and bucket temperatures were smaller (-0.4 to +0.1 °C) than on the 20 September cruise (-0.2 to -0.6 °C). This may be due to the fact that a small component of the IR radiation sensed by the IR thermometers is due to reflection from the sky off the water surface. On 21 September the skies were cloudier than on the 20th, and therefore the NavO IR thermometer was sensing the reflection from a warmer sky, making the SST measurements slightly warmer.

Figure 7 shows a scatter plot of the NavO IR SST measurements versus the NPS IR SST data. The agreement between the two IR sensors is very good, with the exception of one outlying point where the NPS temperature was 1 °C lower than the NavO temperature. The large deviation of this point is unexplainable. Other than this one point, the differences between the NavO and NPS measurements ranged from -0.2 °C to +0.3 °C. The agreement between the two IR sensors is very good, despite the fact that the NPS IR thermometer was sensing the sea alongside the aft cockpit, where the water was probably more influenced by the presence of the boat due to the effect of the boat's wake mixing the near-surface water. Since the HSL had very little headway during these IR measurements, apparently any mixing caused by the boat's wake was minimal.

Both the NavO and NPS IR sensors measured generally cooler temperatures than obtained by the bucket method. The bucket method measures mixed water obtained from roughly the top 0.3 m of the sea. The IR sensors measure the radiation emanating from a very thin layer of the sea surface, which is typically less than 50 micrometers thick (Katsaros, 1980). Since the water temperature is warmer than the air temperature, there is a net heat loss by the ocean at the air-sea interface due to conduction and sensible and latent heat fluxes from turbulent exchanges. This results in a "cool skin" on the order of several millimeters thick forming on the sea surface, and it is this layer that is sensed by infrared thermometers. Since the IR sensed SST is more truly representative of the air-sea interface, we believe that IR measurements of SST are the proper quantity for determining air-sea temperature differences and sea surface saturation vapor pressure, which are very important parameters in air-sea interaction processes.

7) Effect of SST Errors on the Evaporation Duct Height

To examine the effect of errors in SST measurements on the resulting evaporation duct heights, we computed $z*$ assuming errors of $+-2$ $^{\circ}C$ in the NavO sea surface temperature data. The results of these computations are shown in figs. 4a and 5a. As can be seen in fig. 4a, the resulting errors in $z*$ were not too great when 2 $^{\circ}C$ was added to the NavO SST data of 20 September, being on the order of +1.5-2 meters (approximately 10-20% relative errors). The errors in $z*$ are much greater, however, when 2 $^{\circ}C$ was subtracted from the measured NavO SST data. For this case, the errors in $z*$ ranged from +0.5 to +18 m (5% to 170% relative errors). This is because when the sea temperature was assumed to be 2 $^{\circ}C$ cooler than the actual values, the sea temperature became slightly lower than the air temperature, which changed the stratification conditions from unstable to stable. The stability (z/L) has a large effect on the magnitude of $z*$, as can be seen in equation 3, since the $z*$ expression is multiplied by the $\phi_S(z/L)$ function in the right hand side. From fig. 3 we can see that the values of $\phi_S(z/L)$ change dramatically as conditions vary from unstable to stable, with the values of $\phi_S(z/L)$ increasing much more rapidly with z/L in stable conditions. These characteristics of the $\phi_S(z/L)$ function for different stability conditions therefore have a large influence on the resulting values of $z*$.

It is interesting to note that when we assumed errors of +2 $^{\circ}C$ and -2 $^{\circ}C$ in SST for the 20 September data, for both cases the resulting error led to larger values of $z*$. However, when both +2 $^{\circ}C$ and -2 $^{\circ}C$ errors were assumed on 21 September, as seen in fig. 5a, the resulting errors in $z*$ were of opposite sign, with the +2 $^{\circ}C$ error in SST resulting in smaller $z*$ values, and the -2 $^{\circ}C$ error in SST resulting in larger values of $z*$. The errors in $z*$ were not too large in the 21 September cases, being roughly 0.5 to 2 m or 10-20% relative errors, since the assumed errors in

SST did not change the stability. Because changes in SST effect the calculation of z* in several ways, it is difficult to predict the result an error in SST will have on z*. As discussed above, errors in sea temperature can have a great effect on the stability which can result in very large errors in z*. In addition, an error in SST will change the values, and possibly the signs as well, of the air-sea temperature and humidity differences, which both enter into the z* calculations. As the above examples illustrate, the greatest errors in z* are likely to result from errors in SST measurements in near-neutral conditions, when a small error in SST can change the stability.

8) Conclusions and Recommendations

This report has shown that the sea surface temperature can be measured operationally on a small boat with infrared radiation thermometers with a high degree of accuracy. Since the SST measured by IR thermometers is more truly representative of the actual air-sea interface, we believe that IR measurements of SST are the proper quantity for determining air-sea temperature differences and sea surface saturation vapor pressure, which are very important parameters in air-sea interaction studies, including the determination of the evaporation duct height. During this experiment the NavO SST sensing system was shown to be rugged to withstand rough operating conditions and is reliable so that it can be operated with little supervision. The NavO system also operates continuously, providing SST measurements approximately every 15 seconds.

The differences in SST between the NavO IR data and the NPS bucket measurements were in the range of -0.6 to +0.1 ^{O}C. The differences in SST between the NavO IR data and the NPS hand-held IR measurements, except for one outlying point, were in the range of -0.2 ^{O}C to +0.3 ^{O}C. We consider this agreement between the various sensors to be very good. As discussed above, both the NavO and NPS IR SST measurements were generally lower than the bucket measurements, since the IR sensors measure the "cool skin" of the sea surface, while the bucket method measures mixed water from approximately the top 0.3 m of the sea.

As shown in this report, accurate SST measurements are very important in determining the evaporation duct height. Small errors in SST can lead to large errors (over 100%) in evaporation duct height, especially in near-neutral conditions, where an error in SST can change the measured stability conditions which is a very important factor in determining z*. However, it is difficult to predict the effect errors in SST measurements will have on the resulting z* estimates, due to the complex relationship between SST and z*.

In the opinion of the authors, further studies to examine the accuracy of IR SST measurements and their influence on determining the evaporation duct height over a wider range of

sea, meteorological and hydrographic conditions and over a longer
period of time would be useful.

9) References

Fairall, C. W., K. L. Davidson, G. E. Schacher and T. M.
Houlihan, 1978: "Evaporation Duct Height Measurements in
the Mid-Atlantic," Naval Postgraduate School Report, NPS61-
78-005.

Katsaros, K., 1980: "Radiative Sensing of Sea Surface
Temperature," in *Air-Sea Interaction: Instruments and
Methods*, F. Dobson, L. Hasse and R. Davis, eds., Plenum
Press, New York, 293-317.

Patterson, W. L., C. P. Hattan, H. V. Hitney, R. A. Paulus, K. D.
Anderson, G. E. Lindem, 1987: "IREPS 3.0 User's Manual,"
Naval Ocean Systems Center, San Diego, CA, Technical
Document, NOSC TD 1151.

Smith, S. D., 1988: "Coefficients for Sea Surface Wind Stress,
Heat Flux, and Wind Profiles as a Function of Wind Speed and
Temperature," *J. Geophys. Res.*, 93, 15467-15472.

Coastal Climate
WeatherPak
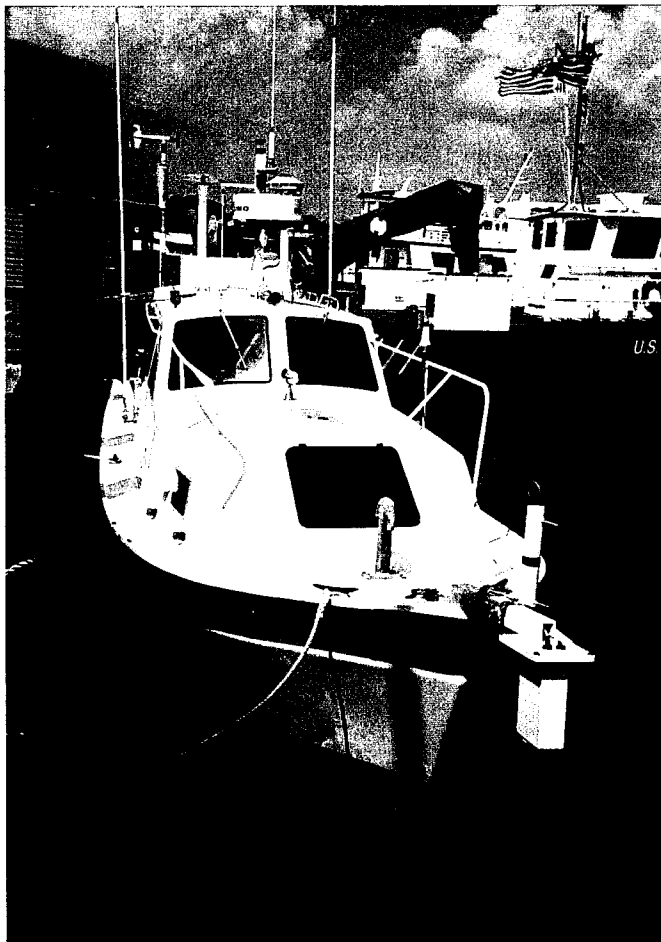
Heimann IR
Thermometer

Figure 1.   Photograph of the Hydrographic Survey Lauch
(HSL) used for the experiment, showing the locations of the
NPS Coastal Climate WeatherPak and NavO Heimann IR
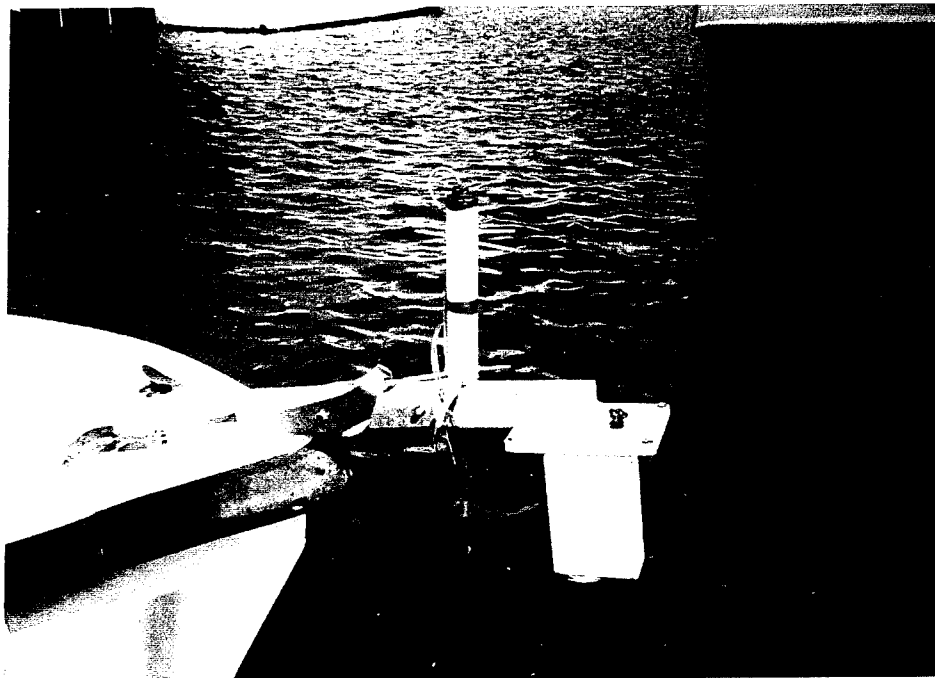thermometer.

10

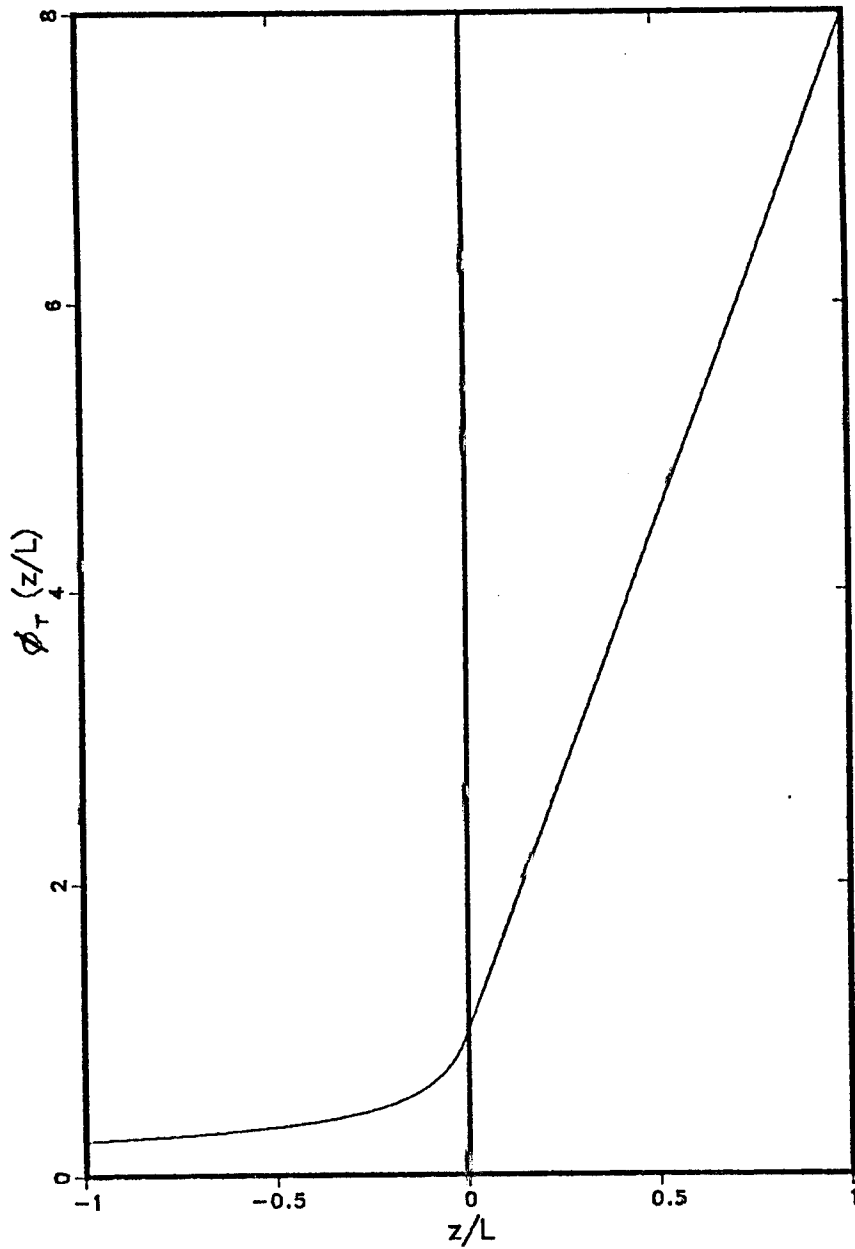Figure 2. Close-up photograph of the bow-mounted NavO
Heimann IR thermometer.

Figure 3. Plot of the dimensionless surface-layer
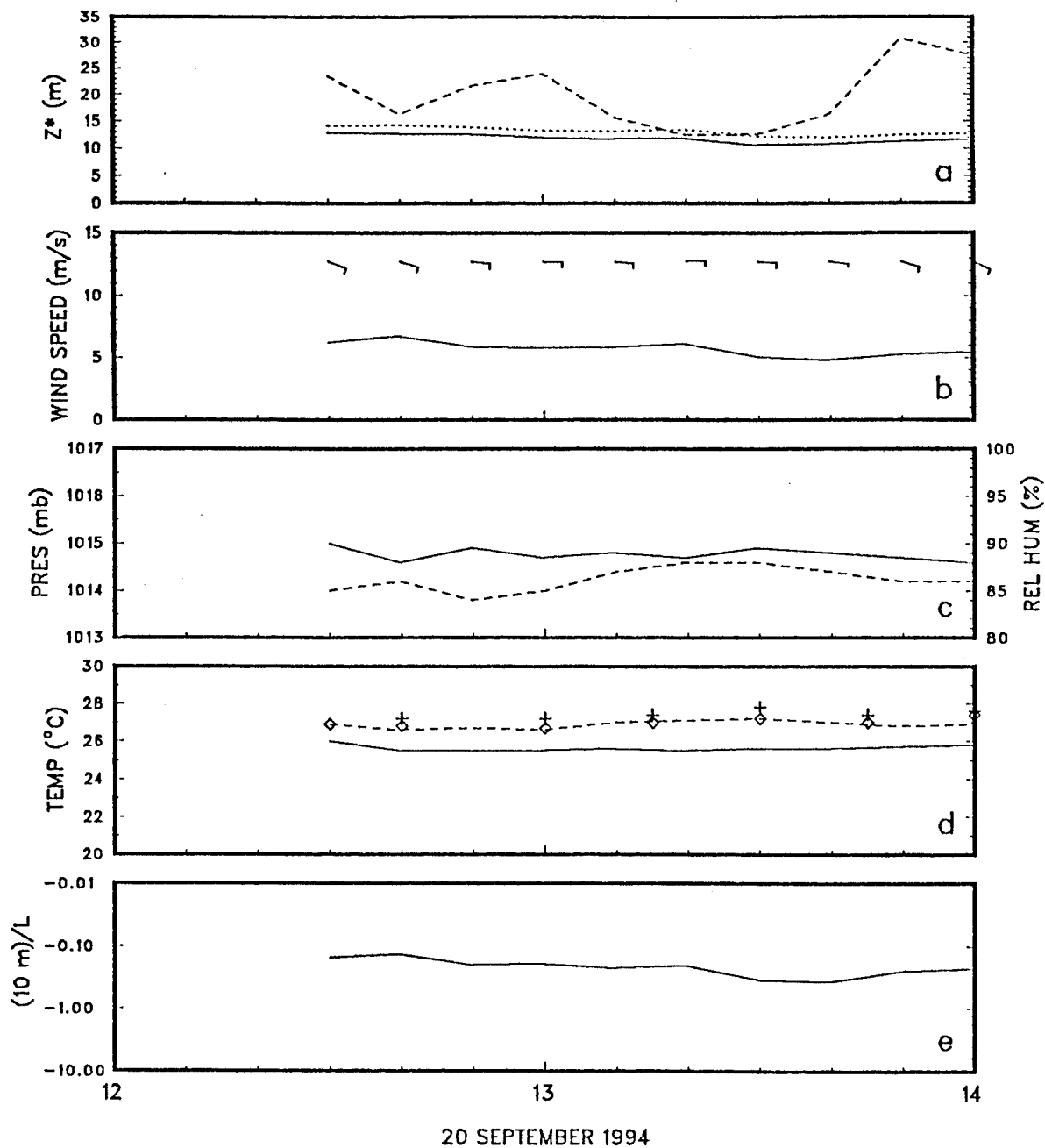profile function for temperature and humidity, $\phi_S(z/L)$,
versus stability, z/L.

Figure 4. Time series data for 20 September 1994, showing 10-minute averaged values of a) evaporation duct height, calculated with actual SST (solid line), calculated assuming a -2° C error in SST (dashed line), and assuming a +2 °C error in SST (dotted line); b) wind speed (solid line) and wind direction (barbs pointing toward direction wind is coming from); c) atmospheric pressure (solid line) and relative humidity (dashed line); d) air temperature (solid line) and sea surface temperature measured by NavO IR thermometer (dashed line), NPS IR thermometer (diamonds) and by bucket (crosses); e) stability, defined as 10 m/L, were L is the Monin-Obukhov length scale.
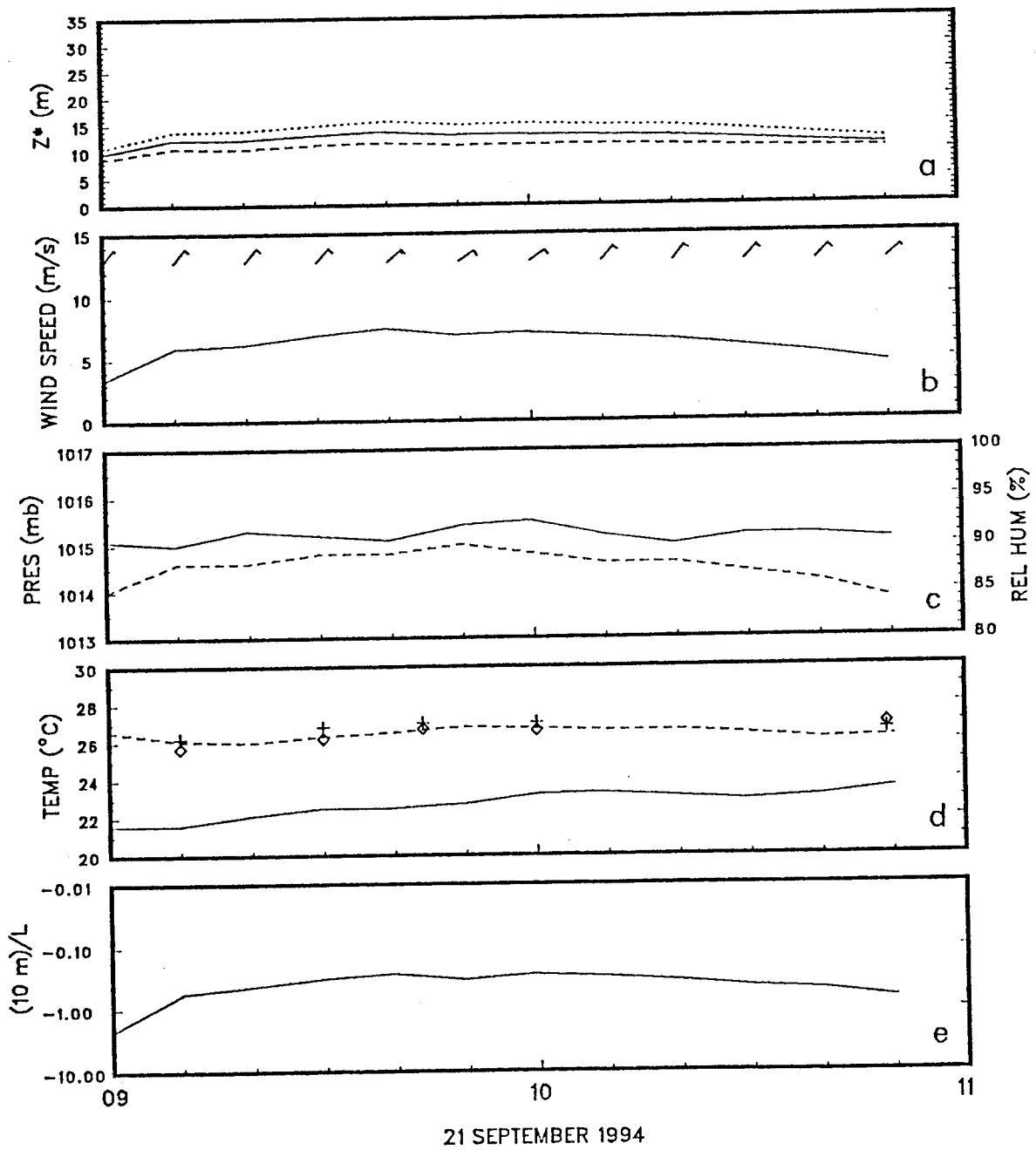
13

Figure 5. Same as figure 4, except for 21 September 1994.
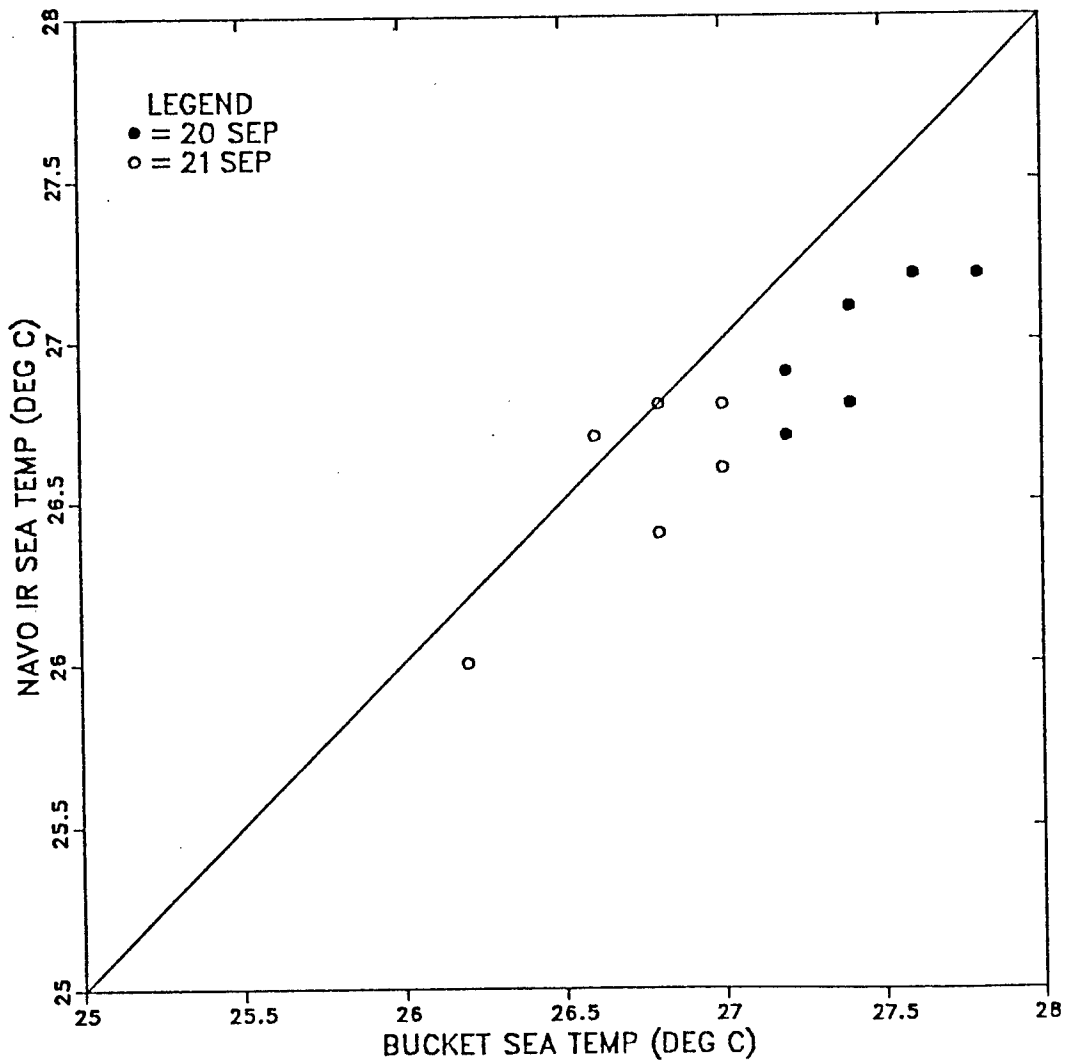
14

Figure 6. Scatter plot of NavO IR SST measurements versus bucket SST measurements. Data for 20 September are indicated with solid circles, data for 21 September are indicated with open circles.
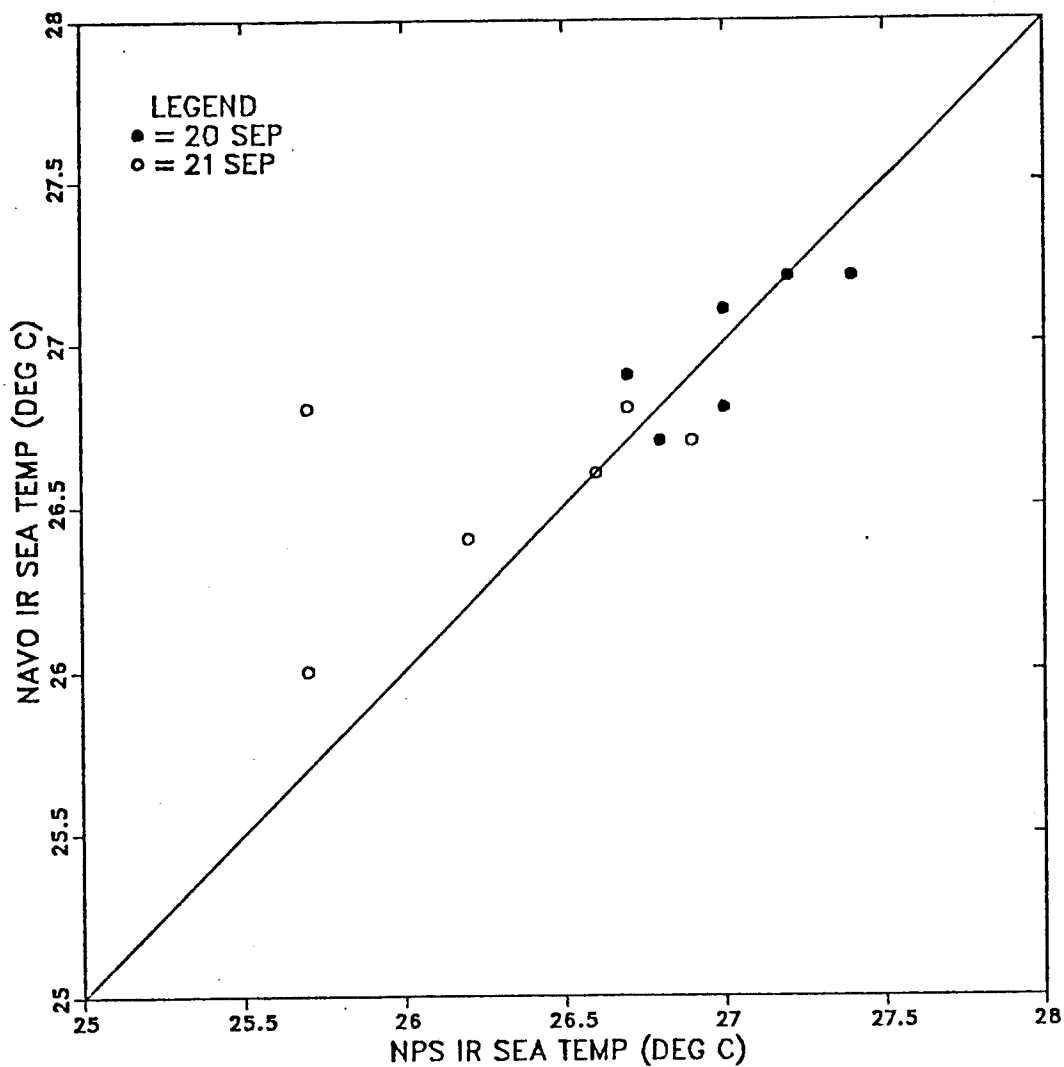
15

Figure 7.   Scatter plot of NavO IR SST measurements
versus NPS IR thermometer SST measurements.   Data for 20
September are indicated with solid circles, data for 21
September are indicated with open circles.

DISTRIBUTION LIST

No. Copies

Dr. Bernard Fogle (Code N512) 5
Naval Oceanographic Office
1002 Balch Blvd.
Stennis Space Center, MS 39529

Mr. Paul A. Frederickson (Code MR/Fd) 4
Department of Meteorology
Naval Postgraduate School
Monterey, CA 93943-5114

Dr. Andreas K. Goroch (Code 7542) 1
Naval Research Laboratory
Marine Meteorology Division
Forecast Support Branch
Monterey, CA 93943-5006

Library (Code 52) 2
Naval Postgraduate School
Monterey, CA 93943-5000

Research Administration (Code 08) 1
Naval Postgraduate School
Monterey, CA 93943-5000

Defense Technical Information Center 2
Cameron Station
Alexandria, VA 22304-6145