Columbia University in the City of New York

LAMONT GEOLOGICAL OBSERVATORY

PALISADES, NEW YORK

CALIBRATION AND FIELD TEST OF IRT

by

Takashi Ichiye and Noel B. Plutchak

Technical Report No. CU-19-65
Atomic Energy Commission
Contract AT [30-1] 2663

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INTRODUCTION

Our interest in using IRT lies mostly in determining the fine structure of the surface water temperature concurrently with some field experiments of dye diffusion in the upper layer of the ocean. In such experiments, five to fifteen gallons of rhodamine "B" dye are dumped from a small boat and for several hours a light plane is used to take aerial photographs of dye patches. In many cases, dye patches indicate striations with spacings of furrows from several tens to hundreds of meters dimension. It is speculated that such striations are caused by cellular convective currents near the surface due either to turbulent structure of surface winds or internal waves (Ichiye, Iida and Plutchak, 1964; Ichiye, 1964). In any case, if there are cellular currents, surface water temperature may indicate alternative cold and warm bands as schematically indicated in Fig. 1. In order to determine such a fine structure in the surface temperature, IRT seems to be ideal if it has enough accuracy since the sensor of the IRT need not be immersed in the water and thus will not disturb the temperature pattern.

This report shows results of some preliminary experiments to determine the accuracy and operational capacity of the instrument. These results seem to indicate that there are so many factors influencing the readings that great precaution must be taken in order to obtain accurate data.

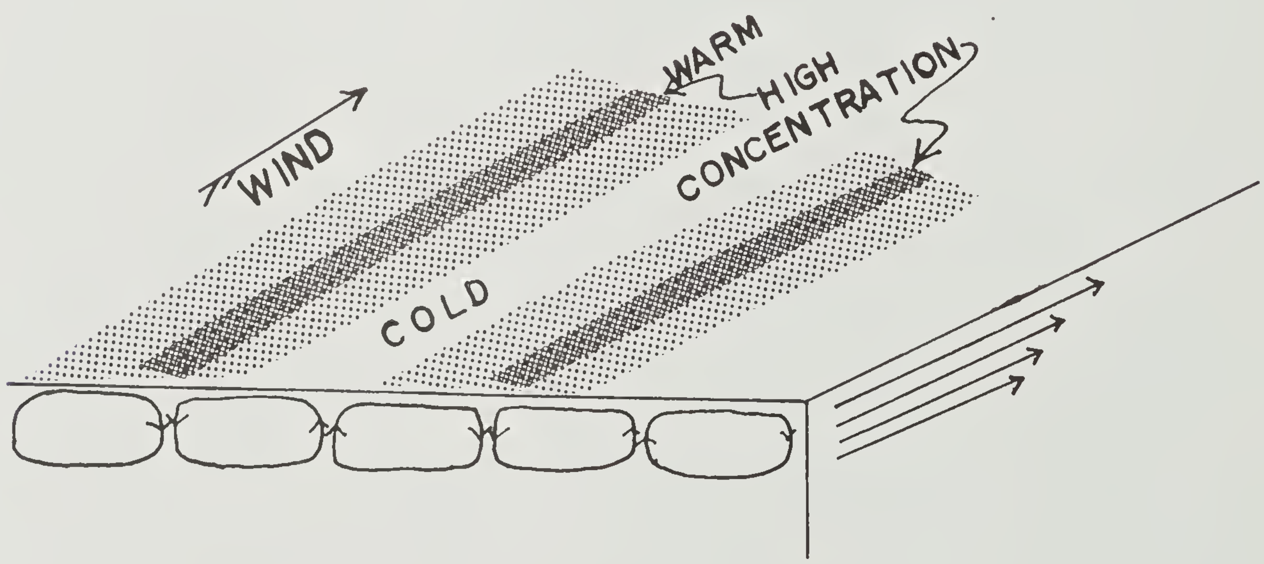

Figure 1. Schematic representation of alternative cold and warm bands thought to be caused by cellular convective currents

CALIBRATION OF IRT

We are using the IRT Barnes Model IT-2. The first calibration was made indoors, using a water bath of 15 cm. diameter and 50 cm. depth agitated by a small motor-driven propeller. The room temperature was almost constant from 75.8° to 77.0°F. The IRT sensor was mounted on a tripod about one meter above the water surface. Water temperature was measured with a mercury thermometer recently calibrated by the Bureau of Standards. The comparison of the readings of IRT and water temperature measured by this thermometer for a range of water temperature from 32.0° to 88.0°F is shown in curves A and B of Figure 2. It is noted that the IRT readings are higher than the true temperature by almost 2.0°F for lower temperatures but the difference becomes very small as the water temperature becomes close to air temperature. This suggests that the air temperature between the sensor and the water has some influence on the IRT readings. The second calibration was made at the rooftop using the same set-up. The air temperature changes from 31.5° to 33.0°F. Curve C of Fig. 2 indicates that the effect of the air temperature caused IRT readings lower than the true values by 4.0°F in the range of 90.0° to 100.0°F and by 2.0°F in the range of 60.0° to 80.0°F and has 1.0° to 2.0°F in the range of 40.0° to 50.0°F water temperature. It was also recognized in this experiment that the wind gusts changed the readings of the IRT by 1.0° to 2.0°F.

In order to study further the effect of the air between the sensor and the water, a series of experiments were made by changing the vertical distance between the sensor and the water surface. A basin of 1.2 meters diameter was filled with hot water about 10 cm. deep. The water temperature was changed by melting snow. It was kept almost constant

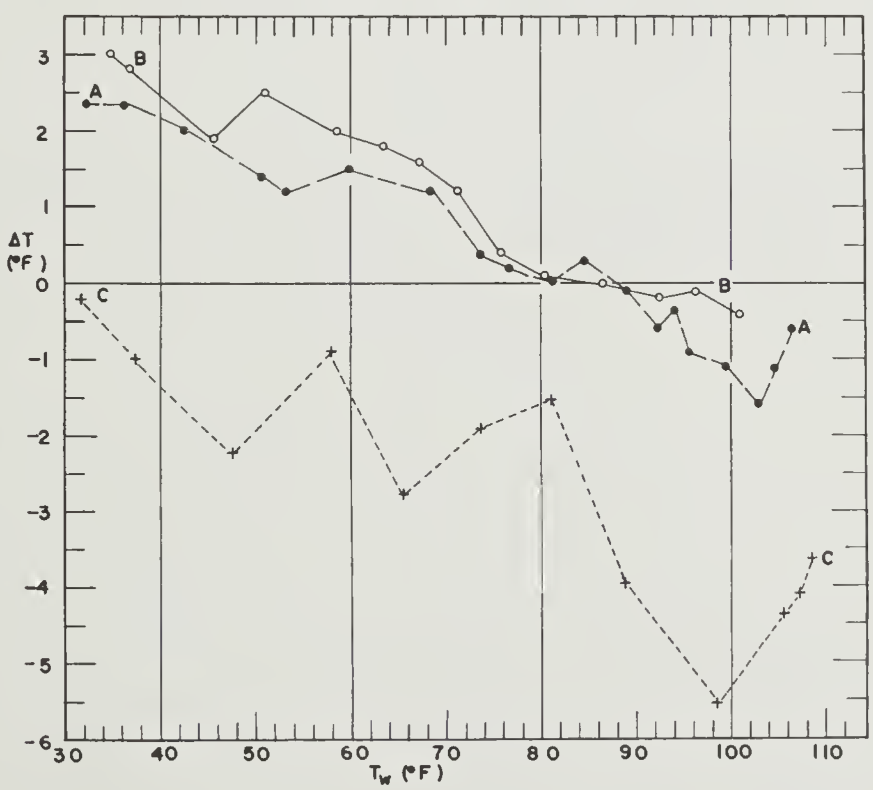

Figure 2. Calibration of IRT with water temperatures ranging from 32.0°F to 88°F; A and B, indoor tests; C, outdoor test

by agitating the water with the propeller mentioned above. The basin was put outside our three-storied Oceanography Building and the sensor was mounted at the rooftop, the third and second floor window, and on the tripod at ground level. The result is shown in Figure 3. Air temperature changed from 38.0°F for the rooftop mount to 33.0°F for the tripod mount. This figure indicates that the IRT readings again are lower than the true values and the difference becomes large as the distance increases and as the water-air temperature difference increases. However, there is an indication that the effect of the distance might be diminished as the distance increases further.

The third series of experiments were made to determine the effect of angle of the sensor window from the vertical. The sensor was mounted on a rod at two meters above the water surface. Then the rod was rotated to about ten degrees from the hroizontal while the sensor was always pointed at the same point on the water surface at the constant distance away. Each curve in Figure 4 represents a different situation, which includes both indoor and outdoor experiments. The outdoor experiments were made on a sunny day with snow on the ground and on an overcast day with snow falling. On each day the differences between the IRT and a mercury thermometer reading were varied according to the directions pointed by the sensor, that is, toward the building, the sky or the shade of a large tree. The effect of falling snow on the overcast day was so large in lowering the IRT readings that the effect of angles of the sensor seemed to be obscured. However, in all these situations angles of the sensor from the vertical less than 40° do not seriously influence the IRT readings.

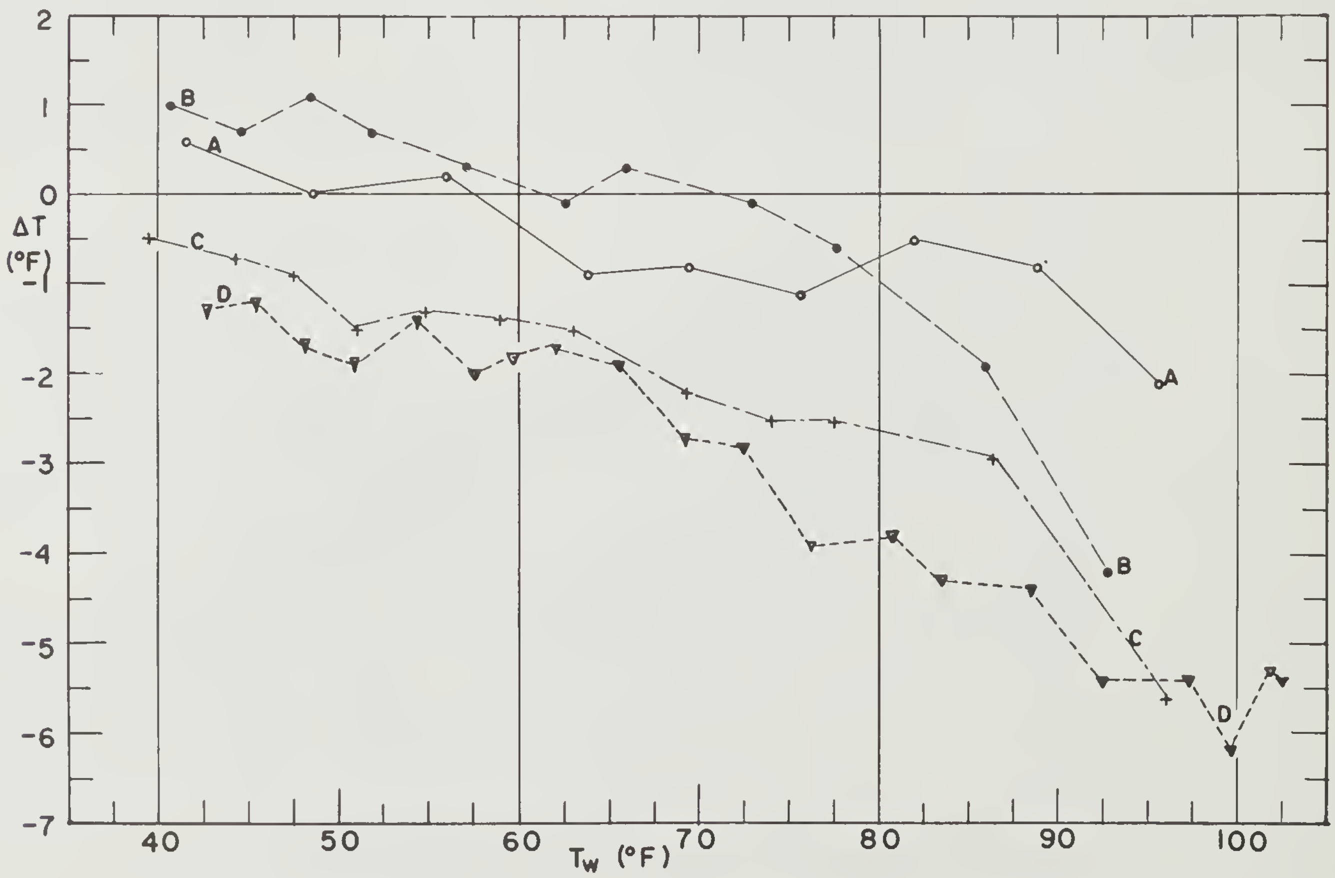

Figure 3. Results of tests with varying distance between IRT sensor and target; A - rooftop, B - third floor, C - second floor, D - ground level. See text for details

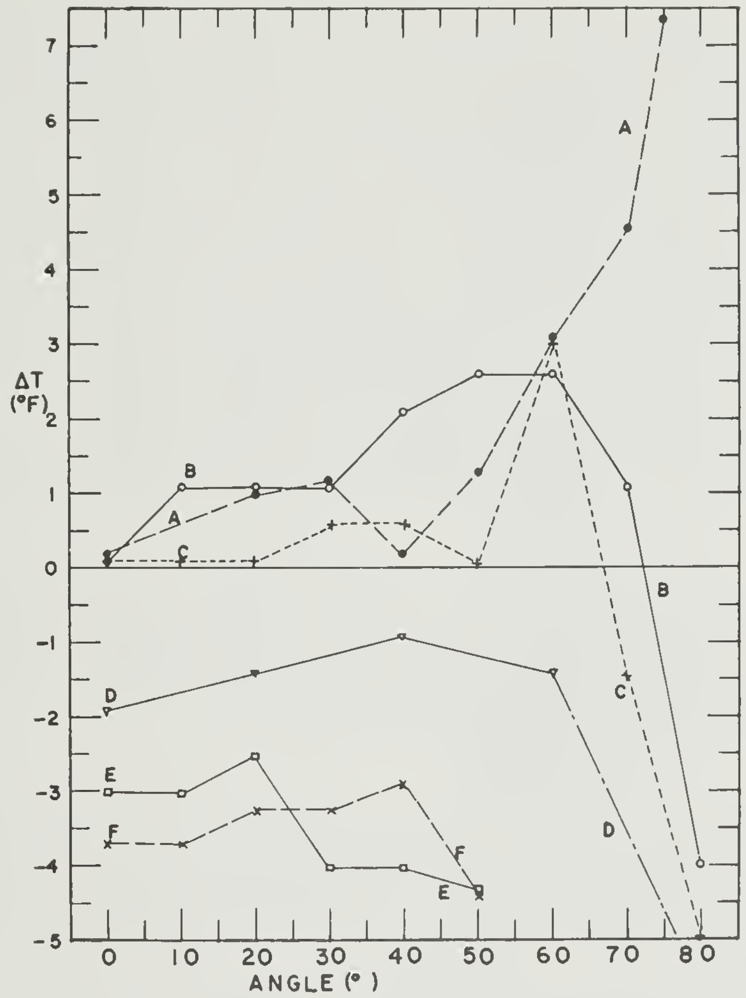

Figure 4. Results of tests with varying angle of view of IRT sensor. See text for details.

FIELD TESTS

The first field test was made on February 4, 1964, on a flight off Narragansett Bay by a Coast Guard Albatross used by Sandy Hook Marine Laboratory (Clark and Stone, 1964) with the intention of inter-calibrating our instrument with his. Our instrument was hand-held side by side with Clark's over a period of nearly two hours. The two instruments produced almost similar data except ours showed on degree (F) higher than his.

The second field test was done on a Cessna off Sandy Hook on February 12th. This test was scheduled to coincide with the course and passage time of the VEMA so that the IRT record might be compared with the record from the ship-borne sensor (thermistor). However, the ship left two hours earlier than the scheduled time and the rendezvous failed. Also, it turned out that the fluctuations in the power source of this kind of plane and the effect of wind on the instrument in such a small plane were so great that the records showed the temperature fluctuating across a range of 10.0° to 15.0°F. when the sensor was exposed to the air. Since the window in such a small plane is small, the effect of radiation from a body of a plane might be serious if we install the sensor inside the window. We should develop some device which may be used in a small plane to shield the effect of both wind and body radiation to the sensor.

The third field test was made on the occasion of dye diffusion experiments done in the middle of March off Panama City, Florida. On March 12th we mounted the instrument on a Navy tower 12 miles off shore. The height of the platform above the sea surface is about 100 feet. (Gaul, 1963) In this field test, two bits of evidence were found to demonstrate the usefulness of the IRT to detect a fine temperature structure. Figure 5 indicates the record of the IRT in the case of passage of a tide line. The BT data are also shown in this figure. The mercury thermometer readings show the increase of 0.6°F after the passage. The sharp rise in the record corresponds to this increase. Figure 6 shows the change of IRT readings in the wake of a boat with a draft of about 7 feet. On this day, air temperature is colder than the sea surface temperature and thus the temperature of the surface film seems to be much lower than the bucket temperature. This decrease of surface film temperature could not be detected by BT. However, the increase of IRT readings by about 0.6°F suggests the existence of such a film.

In concurrent use of the IRT with dye experiments, it was found that both the fluorescein dye and rhodamine "B" dye seem to raise the IRT readings. The actual traces of the IRT on board a ship and on the stage are shown in Figure 7. The former indicates the rise of IRT readings at the edge of the rhodamine "B" dye patch.

It is interesting that the subsequent main part of the dye patch did not show any change in the IRT record although the patch was clearly visible on board the ship and from an airplane. This is consistent with other observations that dye is close to the surface of the leading edge of dye patches but is found deeper in the trailing part (Ichiye, 1964). The latter shows also a jump of about 1.0 to 2.0°F when the dye patch was passing. Later laboratory experiment indicates that the rhodamine "B" dye increased the IRT readings by 1.5°F immediately when the powdered dye was added and by 2.5°F after the surface film was formed in water of 66.0°F.

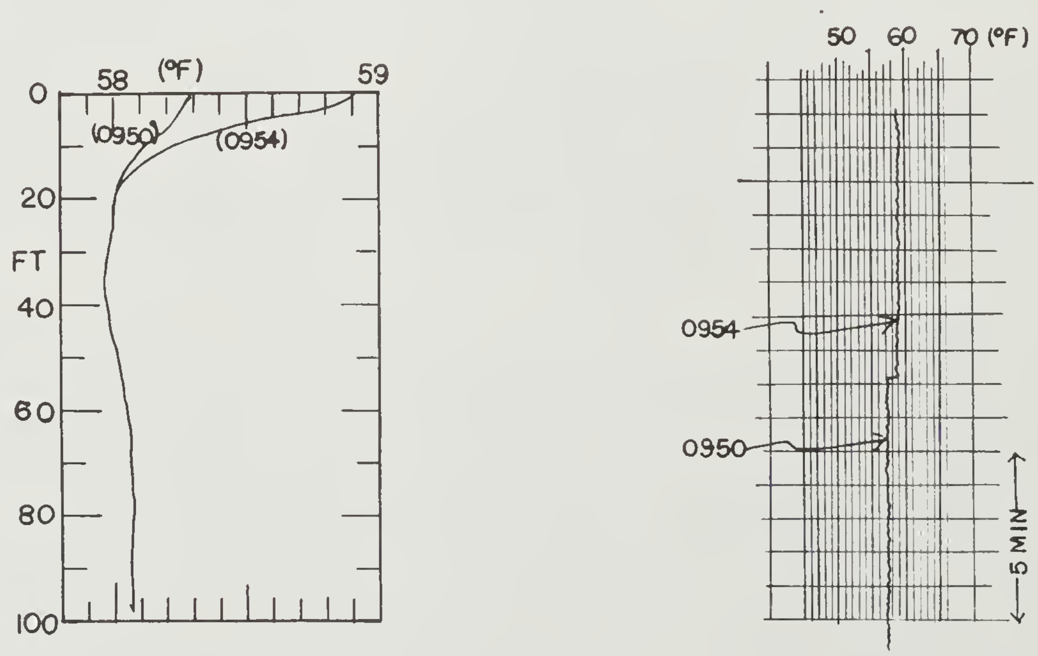

Figure 5. Effect of a tide line passing IRT fixed on Panama City Tower. Bathythermogram shown at left for same time and place

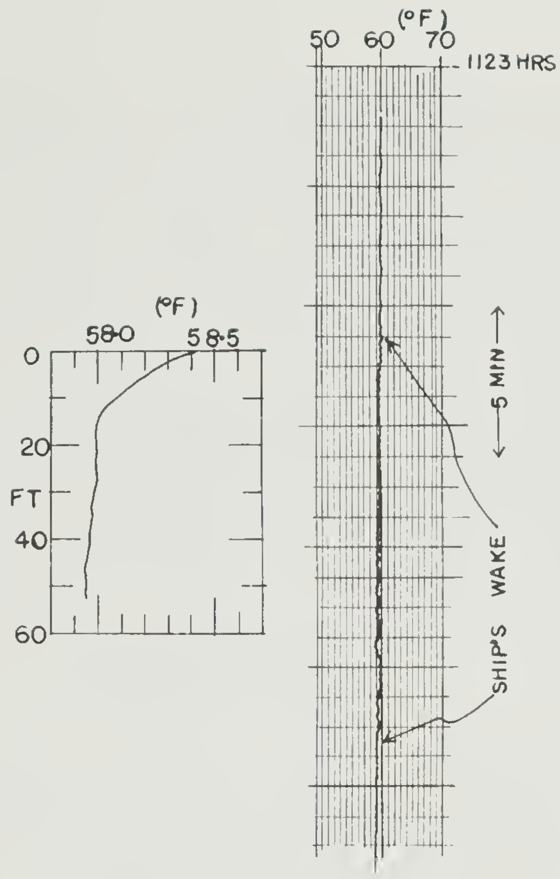

Figure 6. Effect of a ship passing IRT fixed on Panama City Tower
Bathythermogram shown at left

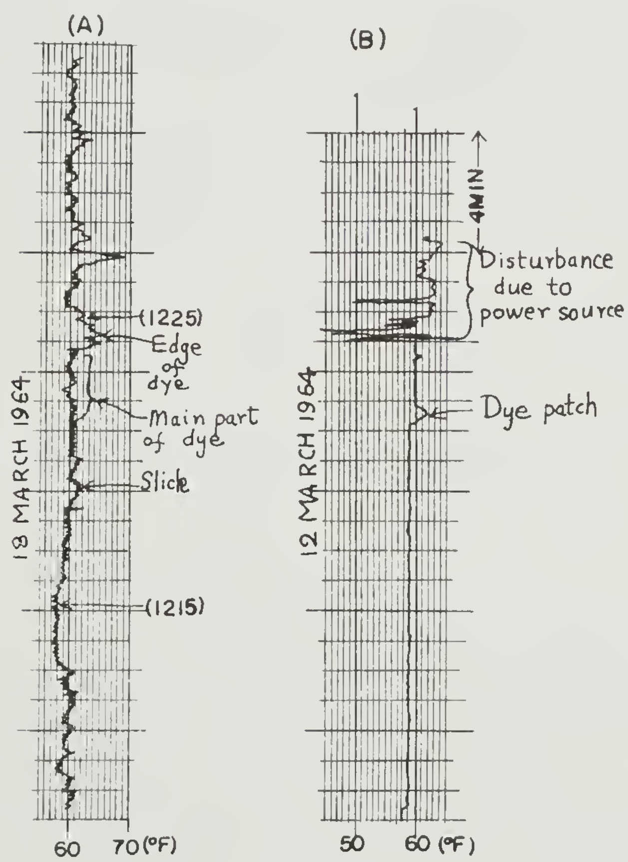

Figure 7. Effect of dye at surface on IRT readings. See text for details

DISCUSSION

It was very surprising and rather annoying to us that the differences between the IRT and mercury thermometer readings ΔT were so large both in indoor and outdoor calibrations, as indicated in Figures 2 and 3. These differences are much larger than those reported by other studies (Pirart, 1961; Richardson and Wilkins, 1957) although the calibrations in these studies were made in the situation of much smaller air-water temperature differences than the extreme cases of the present calibrations. The results of Figure 2 clearly indicate that the IRT at the constant distance from the water surface gives higher readings than mercury thermometers when the air is warmer than the water and vice versa. Those of Figure 3 indicate that these differences between IRT and mercury thermometers increase with the air path between the sensor and the water if the air-water temperature differences are constant.

The relation between the absolute temperatures of the ocean, and atmosphere T_w and T_a and those obtained by the IRT readings T_i is expressed approximately by

$$T_i^4 = Et\,T_w^4 + (1 - Et)\,T_a^4$$

where E is emissivity of the ocean; t is the transmissivity of the atmosphere (Frank, 1964). E is almost constant and equals to 0.98 but t is dependent on the radiative characteristics of the air column between the sensor and the sea surface. In ordinary meteorological situations without actual precipitations, the most important factor affecting t is the amount of water vapor in the air path. The values of t in percentage as a function of the precipitable water in cm were determined by Yates and Taylor (1960). However, the calculation based on these results gives much smaller values of ΔT than those in Figures 2 and 3. Instead, t_i is determined from equation (1) by using the observed values of T_i (with the IRT), T_w (with the mercury thermometer) and T_a. For the averaged values of T_z of the curves C and D of Figure 3, the computed values of t are as follows:

t (%)	95, 93, 94, 92, 92	for $T_a = 30°F$
T_w (°F)	60, 70, 80, 90, 100	

For the change of T_a from 33°F to 38°F, as observed in this calibration experiment, the variation of t is 1% at the most. The value of t estimated from the results of Yates and Taylor (1960) equals to 99.8% for the saturated air of 8.5 m deep with temperature 36°F. This estimation is based on the assumption that the water vapor is in a gaseous form. However, evidently there was a layer of steam close to the water surface in the outdoor experiment of Figure 3, particularly when the water temperature was higher than 80°F. When water-droplet radius is near the wave length of radiation, Mie-scattering becomes effective and the absorption is much larger than in the gaseous form of water vapor (McDonald, 1960). Therefore, the large values of t obtained from the experiments seem to be due to this effect.

Since sea steam which is much thinner than sea fog is a rather common phenomenon, particularly in cold seasons (Von Arx, 1962), caution should be taken for the use of IRT in such occasions. Also, accurate measurements of the transmissivity t in the presence of sea fog or sea steam will give us information on congregate structures of water droplets.

It is notable that the effect of air temperature is negligible when the air is much warmer than the water as indicated in later calibration (Aug. 6, 1964), in which the entire experimental set-up was the same as in that of Figure 3. The results indicate that the ΔT (=Ti - Tw) is -0.4° to 0.9°F for the range of Tw from 51° to 78° F with the air temperature 82° to 86° F at the air path of 9.9 meters. There is almost no correlation between the values of ΔT and Tw and thus the differences ΔT seem to be caused by other effects than those of water vapor. Since in this experiment the air temperature was higher than the water temperature, the air layer close to the water surface was stable and evaporation was also very small.

CONCLUSIONS

(1) Effect of the temperature of the air column between the sensor and the water becomes important when the air-sea temperature difference exceeds 10.0°F.

(2) The distance between the sensor and the water also influences the IRT readings.

(3) The effect of angle of the sensor becomes serious when the angle exceeds 40°.

(4) The snow or rain might substantially affect the IRT values.

(5) The IRT is useful to detect tide lines or ship's wake.

(6) The rhodamine "B" or fluorescein dye causes an increase in IRT readings.

ACKNOWLEDGMENT

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A number of tests were made to determine whether an infrared thermometer had sufficient accuracy to be useful for determining the fine structure of surface water temperature concurrently with field experiments of dye diffusion. A simple calibration was made by mounting the sensor at 33 feet, 13 feet, and 4 feet from the water surface of a basin 4 feet in diameter. Corrections of I R T readings for the airpath of 33 feet reach 2°F for water-air temperature differences (water warmer than air), of 20°F, 40°F and 60°F, respectively. These corrections seem to increase with the length of the airpath. The angle of attack of the sensor appeared to cause problems only when the angle exceeds 40° from normal. With I R T mounted on the tower at Panama City (at 100 feet from the sea surface) the instrument was able to detect tide lines, ship wakes, and dye patches.

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