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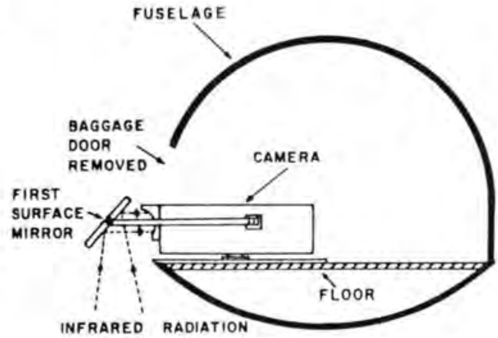

FIG. 1. Cross-section of Apache aircraft at baggage door looking aft (not to scale).

Coastal and Urban Surveys with IR

The AGA Thermovision system proved to be a practical, real-time, remote sensing device for fresh-water studies along coastal areas in Hawaii.

ABSTRACT: *This report describes remote-sensing research at the University of Hawaii involving real-time imagery of thermal anomalies with an air-borne scanner. The main effort was directed to a study and development of techniques in geophysical exploration for water-resources research utilizing the 3 to 5.5-micrometer band of infrared real-time imagery. An infrared scanner covering the 2 to 5-micrometer wavelength region was flown over the coastline of the Puna and Kau Districts on the island of Hawaii. Only a 5°×5° lens (narrow-angle) was available, hence the flight line had to be at an altitude of 11,000 feet in order to make each image about 1100 feet on a side. A few areas were mosaicked and mounted on aerial photographs to facilitate interpretation. Thermal anomalies were easily identifiable on early morning images, but not during midday hours, as no filter was used.*

INTRODUCTION

THE AGA THERMAL SCANNING system, tradenamed *Thermovision* and described by Myers and Allen (1968), was applied as an airborne remote sensor to map coastal thermal anomalies, possible correlated with ground-eater outflows into ocean water.

Previous field studies to evaluate the water-development potential along many miles of remote coastline of the island of Hawaii indicated that an improved reconnaissance technique was desirable. Attempts to obtain information by hiking along the coastline on the shoreside or by approaching the shoreline from a boat require much time, many persons, extensive support equipment, and the risks of working in remote areas.

Previous applications of infrared imagery have been directed to the ocean (Stommel, 1963) or land. A study by the U. S. Geological Survey has been directed to coastlines of the island of Hawaii (Fischer, *et al.*, 1966), conducted in conjunction with a study of infrared radiation from volcanic terrain. In 1967 efforts to verify the existence of all the thermal anomalies reported in the 1963 field work were only partially successful. This may be due to the difference in the season between the USGS and those efforts. The USGS records were taken in January and February while the University of Hawaii (UH) field work was conducted in June of a different year.

INSTRUMENTATION: AGA THERMOVISION SYSTEM

The AGA Thermovision system has been described by Myers and Allen (1968). Briefly,

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The article was submitted under the title "Coastal and Urban Surveying in Hawaii with Infrared Thermovision."

it consists of two components: the heat-sensing camera and the display unit. The camera is a self-contained unit and usually requires no adjustments. The display unit, a greatly modified bench oscilloscope, has many adjustments but only two are commonly used. The image presented by the display unit is an image similar to that of an ordinary television and may be adjusted for brightness, width, vertical position, and so on. A permanent record of the image is made by placing a camera on the display unit and photographing the image directly.

INSTALLATION OF THE INSTRUMENTS IN THE AIRCRAFT

The University's Piper Apache aircraft was modified to accommodate the AGA Thermovision system. AGA provided a front-surface mirror (required for infrared uses) for attachment to the forward-facing camera unit as a 45° angle to obtain a downward view, reversing the image on the screen. The mirror had to be placed to project out of the side baggage doorway (Figure 1). This required the construction of a portable door which could be replaced from the inside. When the aircraft reached an altitude of 11,000 feet the portable door was removed and the camera extended out of the doorway. When scanning was completed, the portable door was replaced.

As the field of view of the 5°×5° AGA is very narrow, the scanner is operated from as high an altitude as possible: 11,000 feet was generally used. The AGA system requires at least an additional one-half hour to become stable enough for accurate use after the initial adjustments, which required 15 to 20 minutes, were made.

Because the aircraft was neither pressurized nor heated, it was extremely difficult to work at the 11,000-foot altitude. In addition, there was no possible way for the person operating the equipment to see the ground below accurately. Hence, the actual process of taking photographs of infrared images depended on the speed and coordination of the operator who had to be simultaneously aware of his relative position and the image quality. The operator sat on the floor of the plane (Figure 2), opposite the baggage door, with the display unit in front of him and the camera 45° to the right. He operated the photographic camera with his left hand. With his right hand, he made the constant mechanical tilting adjustments necessary for the infrared camera to follow the indentations of the coastline in a sweep perpendicular to the straight flight path.

The Sensitivity was set to the 5°C range. In the normal tones, the cold springs of water would appear as dark shadows emerging from the coastline into the ocean.

OPERATIONAL METHODS

The copilot-navigator sat beside the pilot, instructed him as to the exact flight path, and acted as the communicator between the camera operator and the pilot. He was the only member of the research team who was able to see the approximate area being photographed. He also plotted the flight track on a map which would serve as the only available source for later identification. The camera operator was able to view only the infrared imagery, and he was unable to see below the plane. With a field of view of only 5°×5°, the camera operator was required to track the passing coastline constantly. During a run, the camera operator also had to adjust continuously the display unit to overcome reflection and atmospheric changes.

In taking photographs both the 16-mm (Bolex) and the 35-mm (Minolta) formats had advantages and disadvantages in data evaluation. Both films had to be printed in reverse to compensate for the inversion by the 45° mirror. The 16-mm film had the advantage of continuous picture overlap but the Bolex movie camera could not be reloaded in flight. The 35-mm film proved to be the most useful size. An 8×10-inch contact print

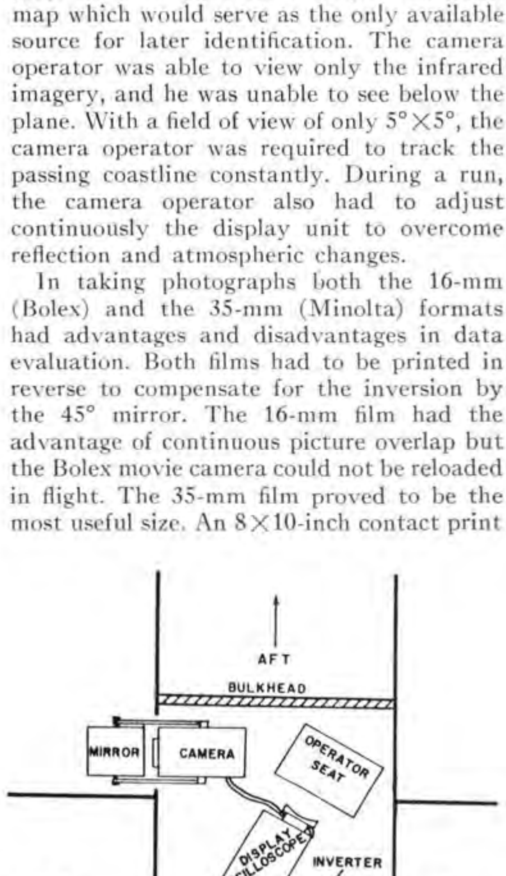

FIG. 2. Layout of equipment and personnel within the Apache aircraft (not to scale).

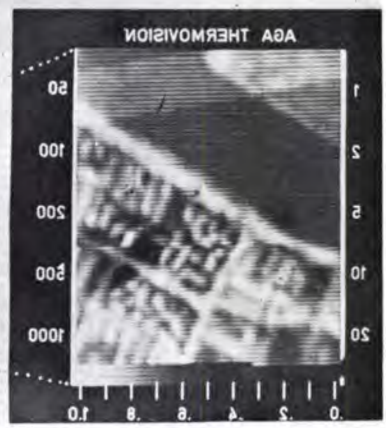

FIG. 3a (Left). Airphoto of the Ala Wai Canal in the Waikiki Area of Honolulu. (Photo courtesy of R. M. Towill Corp.) FIG. 3b (Right). Thermal image taken at 11,000 feet.

was made of the entire roll so that the exposures of each roll could be examined simultaneously. These contact prints were then cut and put together to make uncontrolled mosaics.

Even at 11,000 feet the screen displayed a linear view of only 1100 feet. Compared to ordinary aerial photos, this area is the size of a postage stamp. Figures 3a and 3b further illustrate the narrow field of view. Figure 3a is an ordinary airphoto showing the Ala Wai Canal in the Waikiki area of Honolulu. This photo was taken by R. M. Towill Corporation at 3000 feet with a 6-inch focal-length camera. Because of the low altitude, Figure 3a would normally be considered to have only limited area coverage. The outlined area on the Towill photo shows the coverage of the indicated thermal image taken at 11,000 feet (Figure 3b).

For flight lines at 11,000 feet, the scale of imagery on the AGA screen is 1:2640 (11 feet per inch) and on the negative of the 35-mm film it is 1:22,000. The scale of the 35-mm film is almost ideal for use with the 1:24,000 USGS topographic sheets. The 16-mm film is too small to be used for contact printing.

Where one is looking for cold water springs, which are only a few degrees below the general sea-water temperature, a useful sensitivity scale is five (at 11,000 feet). This means that between white and black, as represented on the screen, there will be a difference of 5°C. All objects having temperatures greater than the selected 5°C range will appear as solid white, whereas all temperatures below it will be solid black. The various temperatures within the range selected will appear as shades of grey. In Figures 4a to 4c, the sensitivity varies from 50°C to 20°C to 10°C, respectively. These images of Oahu were taken at 11,000 feet. In the 50°C image, the areas appearing solid white are more than 50°C hotter than the solid black areas.

The effect of altitude is similar to the effect of changing sensitivity and is illustrated in Figures 5a and 5b which were taken at 3100 feet with a sensitivity of 20°. The intensive heat of the driveways, as well as the temperature variations in the water (thermal pollu-

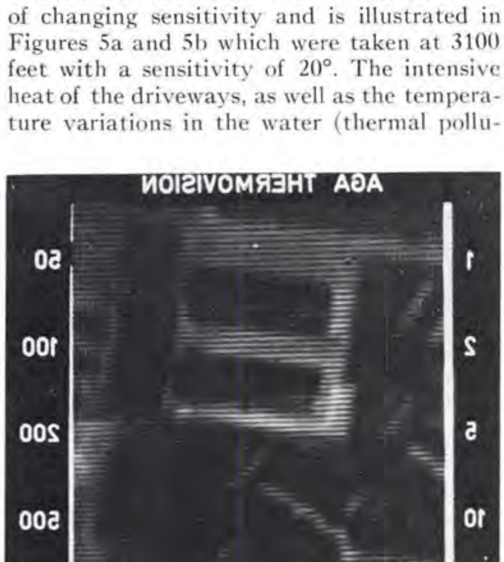

FIG. 4a. Sensitivity of image at 50° C.

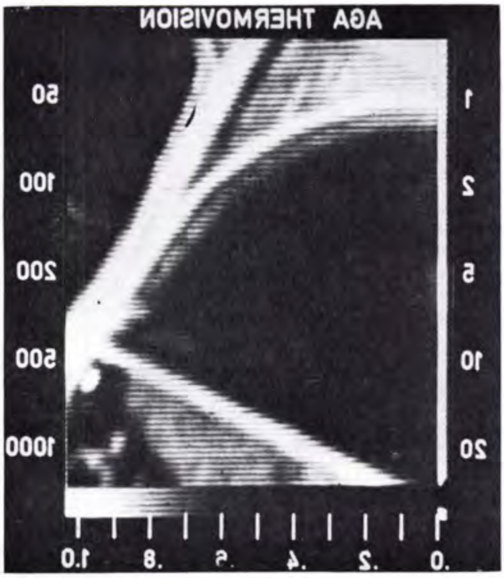

FIG. 4b. Sensitivity of image at 20° C.

tion), are much more noticeable in Figures 5a and 5b than in Figure 4c. All of these images were obtained on 35-mm film in a late afternoon in July, 1968.

Discussion of the Results

SAMPLE MOSAICS

Interpretation of the infrared imagery is greatly facilitated by printing the frames at some convenient size and mosaicking them to produce a replica of the shoreline corresponding to a topographic map or aerial photograph. Such a mosaic is shown in Figure 6. This is a montage of the Ninole Springs area, a location near Punaluu, which has been widely mentioned in the literature (Stearns and Macdonald, 1949) as producing over ten million gallons of brackish water per day. This water is recorded to have a temperature as low as 64°F and is the most extreme infrared anomaly recorded along this coastline. The

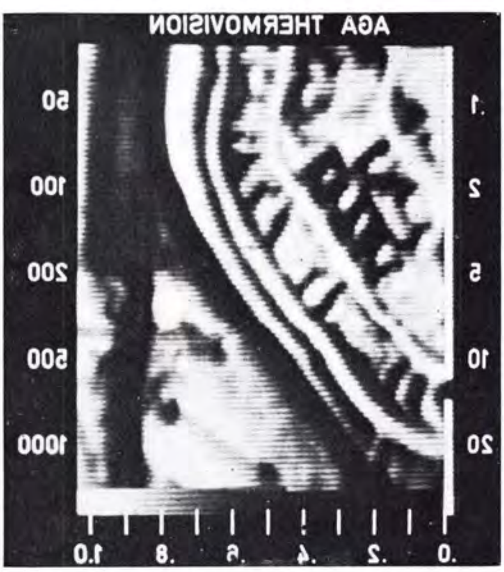

FIG. 4c. Sensitivity of image at 10° C.

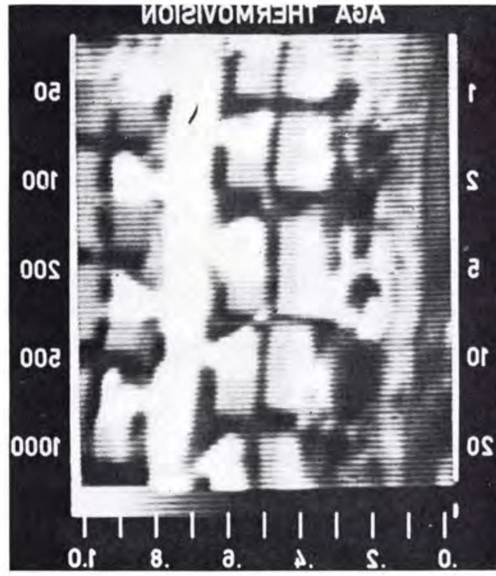

FIG. 5a. Image taken at an altitude of 3100 feet with a sensitivity of 20° C over a driveway.

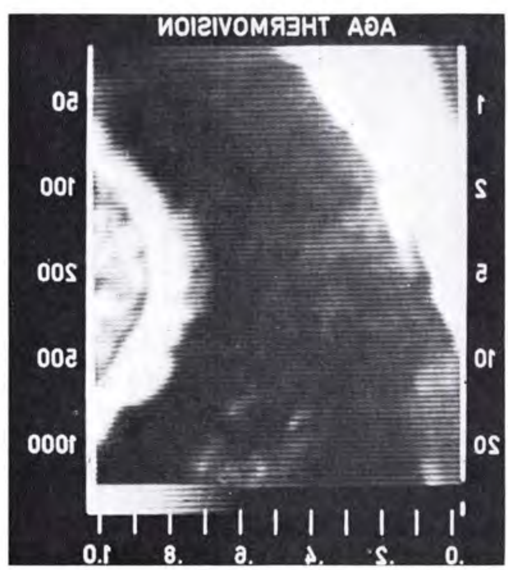

FIG. 5b. Image taken at an altitude of 3100 feet at a sensitivity of 20° C over water.

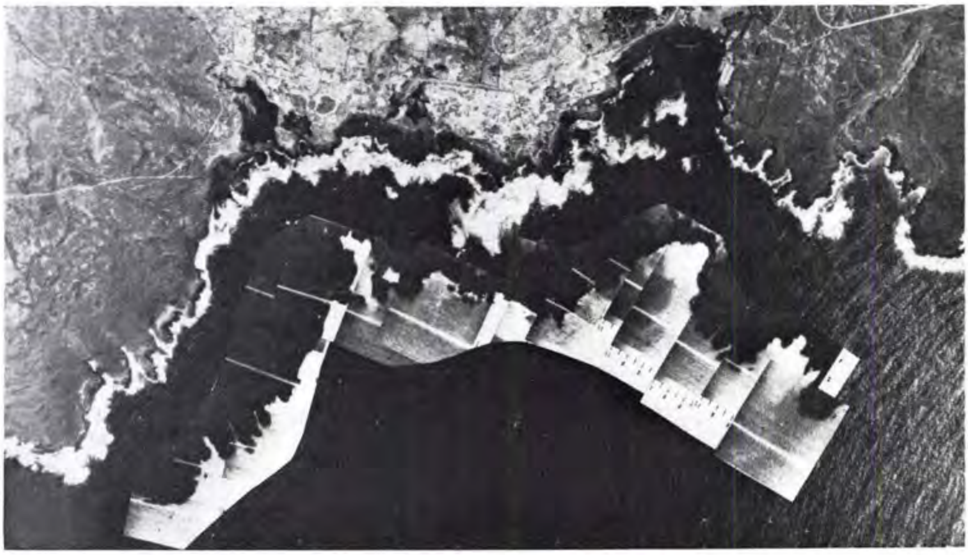

FIG. 6. Montage of Ninole Springs.

white areas along the west coast are due to instrumentation.

Figure 7 is a montage showing an urban area of Honolulu on a late afternoon in July. Identification and alignment of these inland images is easier than with coastline imagery. In the top mosaic, the aircraft was in a descent so that the series begins on the right at 8000 feet and ends at 7000 feet. The images in the lower mosaic were taken at 11,000 feet.

FIG. 7. Montage of urban area of Honolulu.

COASTAL FRESH WATER SPRINGS

The use of the AGA Thermovision for locating and determining the extent of fresh water is based on the expected anomalous temperature of such water. Usually the water which is discharged from land at or near the coastline is colder than the exposed ocean. The Thermovision can ideally detect temperature differences down to 0.2°C. Its usefulness as a reconaissance is based on the idea that the knowledge of discharge zones will aid in determining the locations and presence of water inland.

The flights were conducted in early morning between 5:30 and 9:30 in order to avoid flashing solar heat reflection from the ocean surface. On the southeast shore of Hawaii at this time of day, the sunlight is from the east, often leaving unheated water in the cool shadows of cliffs above little gorges and inlets. Consequently, where the anomaly only occurs westward of a jutting point of land, it is anticipated this may be due to lack of solar heating because of the shadows. Comparison, therefore should be made to adjacent gorges. Hence, it is evident that *not all thermal anomalies are spring water*. Consequently, any aerial infrared survey should be accompanied by a field effort. Otherwise, all thermal anomalies cannot be considered as fresh-water springs.

The main value of using the AGA Thermovision for locating thermal anomalies associated with fresh water is its convenience as a reconnaissance tool. Infrared Thermovision provides a real-time display of the thermal dynamics of a coastal region and large areas of coastline may be surveyed in a matter of hours.

URBAN AREAS

One of the uses of urban infrared scanning is to locate hot air or gas leaks from underground pipelines. Other possible uses include scanning golf courses and parks to determine drainage and vegetation requirements. In colder regions, the AGA Thermovision can be used to measure the insulative characteristics of building structural materials. In warmer regions, building roof tops may be scanned to check temperatures of the structural materials after years of erosion. It is also possible to estimate easily water-main breaks, transportation patterns, and land use patterns in real-time.

AGRICULTURE

Much work has been done in the field of forestry and agriculture with infrared technology (Colwell, 1967; Myers and Allen, 1968; Blythe and Kurath, 1968). In Hawaii,

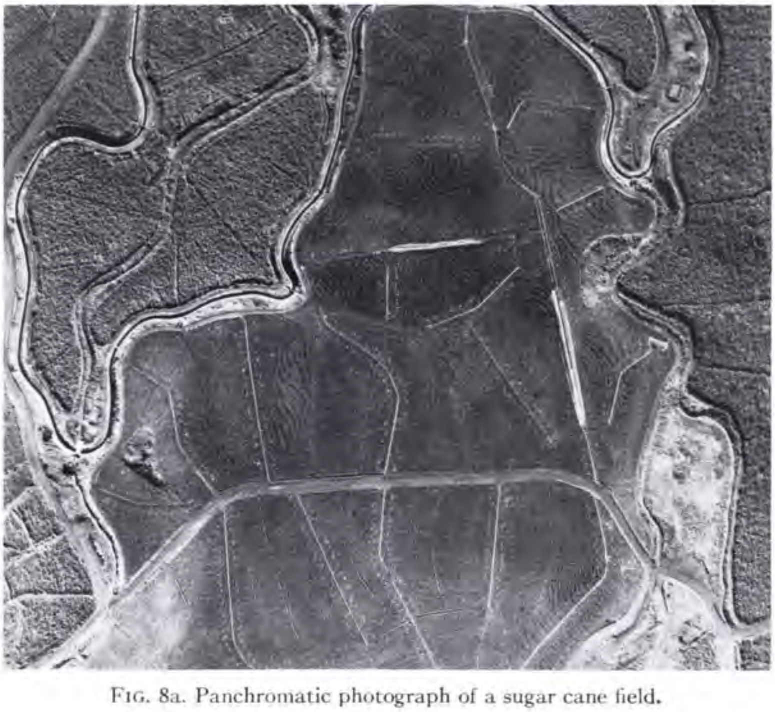

FIG. 8a. Panchromatic photograph of a sugar cane field.

infrared scanning is found to be especially useful for determining the distribution of irrigation water. The greatest advantage of the Thermovision is the real-time image. If the vegetation of an area on a plantation was found to be particularly hot and thus dry, irrigation water may be diverted to that area and the results of the diversion checked immediately so that the necessary corrections may be made promptly.

Sugar-cane fields are shown in Figures 8a, 8b, and 8c. Figure 8a is a panchromatic photo showing both recently plowed and mature sugar-cane fields. It is a section of a 9×9-inch panchromatic aerial photograph which has been taken at 7200 feet and enlarged 4.5 times. Figures 8b and 8c show infrared images of a relatively mature sugar-cane field and a recently plowed field, respectively. They were taken at 2300 feet north of Pearl City, Oahu in late afternoon. Note on the infrared images that very cool areas, usually due to moisture, still exist.

Examples of the use of the isotherm function in agriculture are shown in Figure 9. The image was taken at 11,000 feet over Oahu. It is in the inverted mode with cold temperatures shown as the white and lighter areas. The sensitivity selected is at a range of 10°. These images are particularly good for showing cool areas in a field and irrigation ditch.

Conclusions

Although the AGA Thermovision's usefulness was restricted by the 5°×5° view, as a temperature sensing device it possesses usefulness for various applications. The value of the Thermovision as a practical remote-sensing device to provide fresh-water reconnaissance along coastal areas has been demonstrated. General applications of Thermovision in urban and agricultural environments have been illustrated. The most valuable asset of the AGA Thermovision system is its ability to provide real-time images.

It is anticipated that future real-time

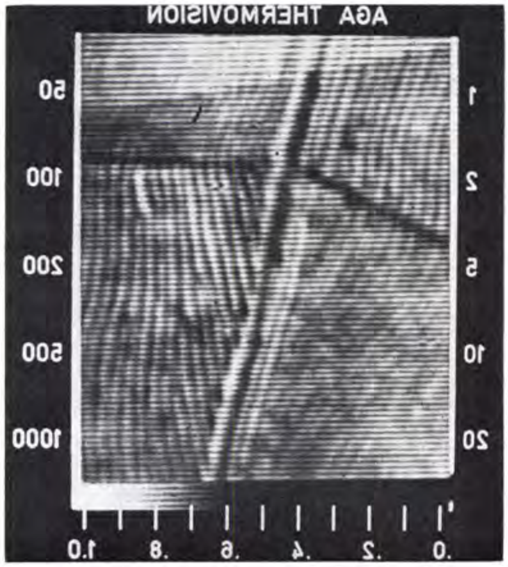

FIG. 8c. Infrared image of a recently plowed sugar cane field.

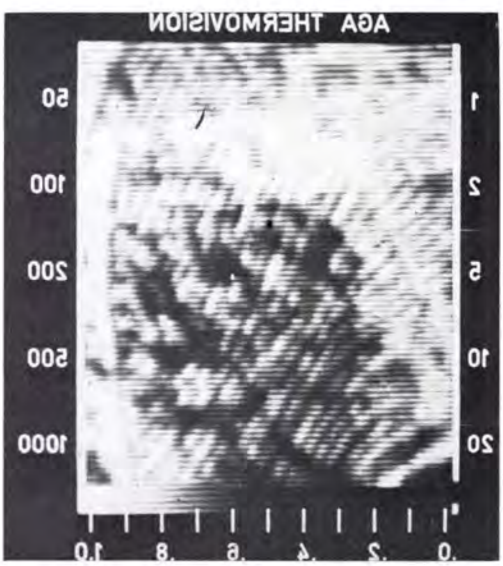

FIG. 8b. Infrared image of a mature sugar cane field.

FIG. 9. Isothermal function in an agricultural field.

remote sensing will be directed to longer wavelengths, on either side of 3 centimeters, as indicated by a recent study (Lepley and Adams, 1968). In the case of fresh water springs, however, the greatest need is now considered to be the development of a method and appropriate field procedures and instrumentation for estimating the *quantity* of outflow, once such an outflow has been indicated on an infrared image.

ACKNOWLEDGEMENTS

Much of the success of this reconnaissance effort was due to the efforts of Steven Langford, field operator, who constructed instrument mountings and carried out the dark-room processing.

The pilot on all flights was Joseph Shad. The aircraft was made available by Dr. G. P. Woollard; and the lease arrangements for the scanner were administered by Dr. D. C. Cox. The cataloguing and mosaicking were by Roy Araki.

The tolerance and continuous cooperation of the AGA representative, Jack Patterson, helped avoid many operational difficulties and hazards.

BIBLIOGRAPHY

Anonymous. 1966. *Proceedings of the 4th Symposium on Remote Sensing of Environment* (12–14 April 1966). University of Michigan.

Blythe, R. and E. Kurath. September 1968. Infrared Images of Natural Subjects. *Applied Optics*.

Colwell, R. N. 1967. Agricultural and Forestry Uses of Thermal Infrared Data Obtained by Remote Sensing. *AIAA Thermophysics Specialist Conference*. American Institute of Aeronautics and Astronautics. New York.

Colwell, R. N. January 1968. Remote Sensing of Natural Resources. *Scientific American*.

Fischer, W. A., D. A. Davis, and T. M. Sousa. 1966. "Fresh Water Springs of Hawaii from Infrared Images." *U. S. Geological Survey Hydrology Atlas*. HA-218.

Lepley, L. K. and W. M. Adams. 1968. *Reflectivity of Electromagnetic Waves at an Air-Water Interface for Pure and Sea Water*. Technical Report No. 25. Water Resources Research Center. University of Hawaii. Honolulu, Hawaii.

Lepley, L. K. and L. A. Palmer. 1967. *Remote Sensing of Hawaiian Coastal Springs Using Multispectral and Infrared Techniques*. Technical Report No. 18. Water Resources Research Center. University of Hawaii. Honolulu, Hawaii.

Myers, V. I. and W. A. Allen. September 1968. Electro-optical Remote Sensing Methods as Nondestructive Testing and Measuring Techniques in Agriculture. *Applied Optics*.

Simon, I. 1966. *Infrared Radiation*. D. Van-Nostrand Co., Inc. Princeton, New Jersey. 117 p.

Stearns, H. T. and G. A. Macdonald. *1946 Geology and Ground Water Resources of the Island of Hawaii*. Hawaii Division of Hydrography. Bull. 9. 363 p.

Stommel, H. 1963. Rapid Aerial Survey of the Gulf Stream with Camera and Radiation Thermometer. *Science*. Vol. 117. pp. 639–640.

Wolfe, W. L., Ed. 1965. *Handbook of Military Infrared Technology*. Office of Naval Research. Superintendent of Documents. G. P. B. 906 p.