J. L. Hatfield
Land, Air and Water Resources
University of California
Davis, CA 95616
J. P. Millard
NASA/Ames Research Center
Moffett Field, CA 94035
R. C. Goettelman
LFE Corporation
Richmond, CA 94035

Variability of Surface Temperature in Agricultural Fields of Central California

Variability within fields was larger for bare, dry fields than for vegetatively covered fields.

Abstract: *In an attempt to evaluate the relationship between hand-held infrared thermometers and aircraft thermal scanners in near-level terrain and to quantify the variability of surface temperatures within individual fields, ground-based and aircraft thermal sensor measurements were made along a 50-km transect on 3 May 1979 and a 20-km transect on 7 August 1980. These comparisons were made on fields near Davis, California.*

Agreement was within 1°C for fields covered with vegetation and 3.6°C for bare, dry fields. The variability within fields was larger for bare, dry fields than for vegetatively covered fileds. In 1980, with improvements in the collection of ground truth data, the agreement was within 1°C for a variety of fields.

To evaluate the variability within a field, detailed measurements of surface temperature were made at metre intervals and every five metres for soil moisture in the 0-2 cm surface layer. The transects were run in a north-south and east-west direction across a cultivated field 340 m in the north-south and 180 m in the east-west direction. These data showed that there is large variability and that a random sampling would be as efficient as a grid sampling. Further research is needed to evaluate the variability of spectral reflectances and thermal emission within fields throughout a growing season.

Introduction

Recent research has shown the utility of using surface temperature in yield models and evapotranspiration estimates (Idso *et al.*, 1977; Jackson *et al.*, 1977). Idso *et al.* (1977) proposed that stress-degree-day be used as an indicator of wheat yield. Walker and Hatfield (1979) also showed this concept to be valid for kidney bean yield when radiation balance, wind, and humidity are considered. Data and results have been obtained on small plots using hand-held infrared thermometers. Obtaining the same results on large areas would require aircraft or satellite platforms. Millard *et al.* (1979) found that, for level terrain, the agreement between an airborne scanner and a hand-held infrared thermometer held in a nadir orientation was within 1°C over an entire growing season of wheat. Millard *et al.* (1981) showed that temperature varies more in bare fields than in crop-covered ones.

Most comparisons between aircraft and hand-held data have been made between data obtained on small plots. In general, few data exist on the variability in commercial agricultural fields. The objective of this study was to survey near-level-terrain agricultural fields in California to quantify the relationship between hand-held and aircraft infrared thermometers and to quantify the variability of temperature within fields.

Photogrammetric Engineering and Remote Sensing,
Vol. 48, No. 8, August 1982, pp. 1319-1325.
0099-1112/82/4808-1319$02.25/0

Materials and Methods

On 3 May 1979, an overflight was made at 3050 m over a 50-km transect from Winters to Dunnigan, California. The flight was made about 1200 P.S.T. from north to south over the transect. Data were collected with a Texas Instruments RS-25 Scanner* that had a 10.5 to 12.5 μm filter and a color-infrared camera. Pixel ground resolution of the scanner was 5 by 5 m square at this altitude.

Ground-based measurements of the surface temperature were collected at five sites in selected fields along the transect with a Barnes PRT-5* infrared thermometer that had a 10.5 to 12.5 μm filter and a 20° field-of-view (FOV) lens. Within each field the five measurements were made in a corner of the field accessible by the road and with the infrared thermometer looking down at an angle of 45°C from the horizon. At each site within the field, each individual reading was made on the immediate field of view of the infrared thermometer. This area would be approximately 0.2 m^2. Ancillary data identified ground cover, if any, in each field and surface-soil moisture content in bare fields. These fields were randomly chosen along the transect during the flight. During the time of the overflight the skies were clear with a temperature of 20°C, relative humidity of 50 percent and wind from the south at 4 ms^{-1}. The environmental data were collected at the Climatological Station at the University of California-Davis, located approximately 25 km from the transect.

In 1980, flights were made over a 900 ha area located northeast of Davis. The thermal scanner was a Daedalus Model DEI1260 that had a 10.5 to 12.5 μm filter and a 2.5 milliradians FOV. These data were collected at 5000 m in an east-west pass over the area. At this altitude, each pixel measured 12.5 m per side at the ground. Simultaneously, ground-based surface temperature was measured within eight fields along the transect with a Telatemp Model AG-42* with an 8 to 14 μm filter and 4° field of view held in a nadir angle 1.5 m above the surface; ten measurements were made in each field. Surface temperature measurements were made with the infrared thermometer held at one metre above the surface at an angle of 45° from the horizon. In each field with row crops, a site consisted of the average temperatures obtained from measurements perpendicular to either direction to the row.

All data collected with the airborne scanner were corrected for atmospheric temperature and water vapor between the ground and the aircraft. This was done by utilizing a temperature and relative humidity sensor mounted on the aircraft and sampling both parameters at selected altitudes beginning at 170 m above the ground and continuing up until the flight altitude of the transect. These corrections were then incorporated into the scanner data to obtain a surface temperature. Concommitant with the airborne scanner data, pictures were made with an infrared film camera. Images from this camera were used to locate to within the nearest pixel the area of the ground-based measurements. This procedure was utilized on both the 1979 and 1980 comparisons.

In 1980, following the analysis of the differences between aircraft and ground-based measurements, an additional study was conducted to evaluate the variability within a bare, dry field. This study was conducted on the Davis campus on a bare field that had been recently cultivated. After cultivation, the field was marked with stakes, one metre between stakes, in a north-south transect for 340 m and in an east-west direction for 180 m. On 25 November 1980, surface temperature was measured with the Telatemp model AG-42 infrared thermometer. At each stake, surface temperature was measured by moving the infrared thermometer in an arc of 10° either side of nadir. The infrared thermometer was held about 1 m above the surface, and this movement allowed for an average to be obtained from an area rather than a small spot. Soil moisture in the 0 to 2 cm depth was sampled along both transects. These measurements were made between 1300-1400 P.S.T. with the ambient temperatures between 17-18C with the wind from the north at less than 2 ms^{-1}.

* Mention of a specific product name does not imply endorsement or preferential treatment by NASA or the University of California.

Results and Discussion

Surface temperatures along the 3 May 1979 transect ranged from less than 20C to more than 40C. The variability between fields was large, as shown in Plate 1. Field identification revealed that bare, dry fields were warmer than cropped or recently irrigated fields. The large variability within the fields and along the transect was surprising. This aspect was common to all fields. In general, however, the temperature appears to vary more in the bare, dry fields than in cropped or bare, irrigated fields.

The patterns of variability were not consistent within the fields. Temperatures of some fields were very uniform, whereas others varied as much as 6°C. Some of the variability at the northern end of the transect is attributed to topographic differences. In the more level fields in the Central Valley, the variability in surface temperature was due to soil water variability within fields caused by irrigation differences. This indicates that thermal infrared measurements might be used to assess the efficiency of irrigation practices. At this time of the season the fields were either cropped with alfalfa or small grains, wheat or barley, or were bare in the process of being prepared for planting. There

PLATE 1. Thermal infrared temperatures and color infrared for a 3050-m altitude transect from Winters to Dunnigan, California on 3 May 1979.

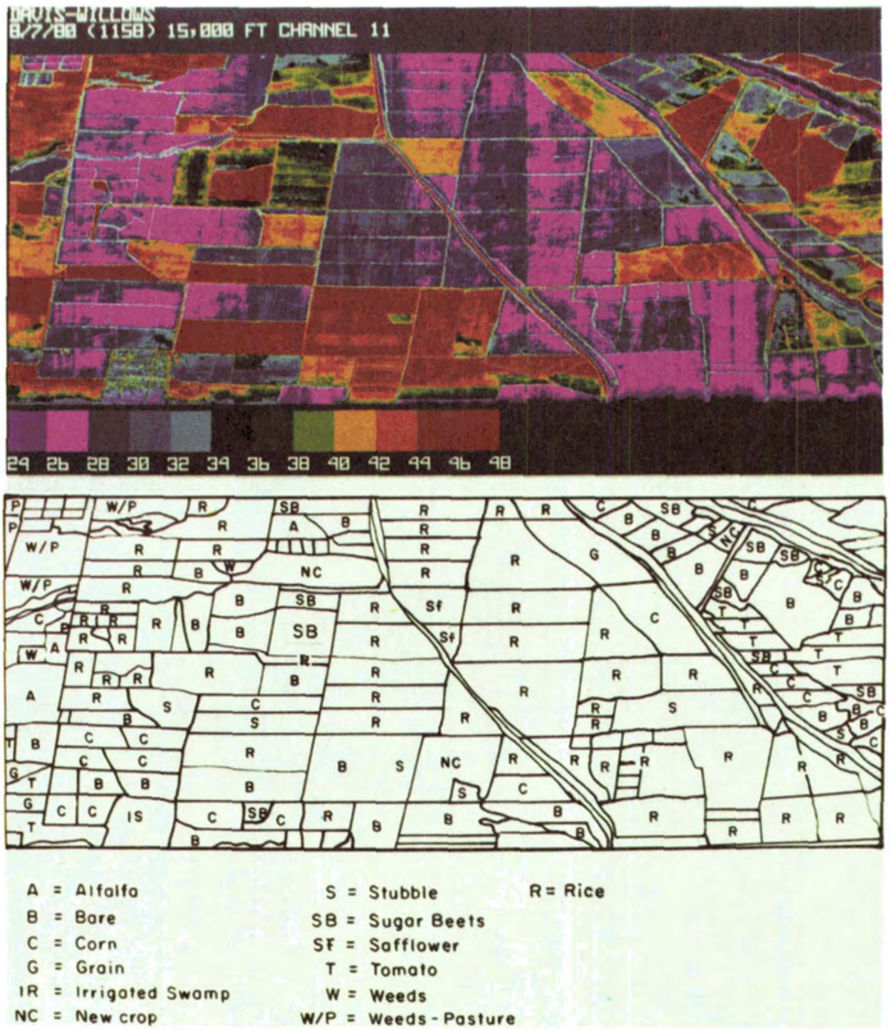

PLATE 2. Thermal infrared temperatures and field identification for a 5000-m-altitude transect northeast of Davis, California on 7 Aug 1980 at 1200 P.S.T.

TABLE 1. COMPARISON OF GROUND-BASED AND AIRCRAFT SURFACE-TEMPERATURE DATA FOR THE 3 MAY 1979 WINTERS TO DUNNIGAN TRANSECT

	Surface Temperature (C)		
Field-Type	Ground-based	Aircraft	Difference
Barley	24.0	25.0	1.0
Barley	26.8	27.0	0.2
Wheat	23.0	24.0	1.0
Wheat	22.0	24.0	2.0
Alfalfa	26.0	26.0	0.0
Bare, dry soil	42.5	36.0	5.5
Bare, dry soil	43.0	39.0	4.0
Bare, dry soil	47.0	46.0	1.0
Bare, dry soil	43.0	37.0	6.0
Bare, dry soil	42.5	41.0	1.5

were few fields which were of partial ground cover and none in the area of ground-based sampling.

The ground-based measurements of surface temperatures differed with the aircraft measurements, as shown in Table 1. In this comparison, the ground-based measurements were compared with aircraft measurements in the area of the field where the data were collected by hand. The average of the ground-based measurements was compared with the aircraft data for the pixels surrounding the measurement on the ground. In all cases, the variation in the ground-based readings was less than 1.0°C. The average temperature difference between ground-based and airborne data was 0.5C for the fields covered with vegetation and 3.6C for bare, dry fields. Because of the length of time needed to take ground-based measurements, only ten fields were measured during the aircraft overpass. However, the ground-based measurements were completed within 40 minutes and were centered about the aircraft overpass and, given the conditions, did not significantly affect the results.

Twelve fields were selected to further evaluate the variability within the fields along the transect. Six fields were the same as those involved in the comparison of ground-based and aircraft measurements and the other six were randomly chosen. The digital airborne-acquired data were extracted from the magnetic tapes for each of these fields and then analyzed separately. Results from these analyses showed that the variance was larger in the bare, dry fields but that the coefficient of variability was the same for cropped versus bare fields. The largest variance was 5.4°C² and this was in a bare, irrigated field and is largely the result of an uneven distribution of water across the field; another irrigated field also had the smallest variance, which suggests a very uniform water application (Table 2), thus reinforcing the concept that remote sensing imagery could be utilized for evaluating the efficiency of the irrigation method.

Plate 2 shows data for a 7 August 1980 overflight at 1200 P.S.T. As in the 1979 overflight, there was considerable variability within each field. However, at this date there was no more variability in one particular field than another. These patterns, as well as those from 1979, suggest that care has to be taken in collecting ground truth to compare to aircraft data.

Comparisons between the ground-based and aircraft data of that flight showed agreement within 1°C for all fields, except the sugar beets and one rice field (Table 3). In all cases, the standard deviation of the ground-based measurements bracketing the airborne data suggested that the agreement in sampling and between methods to be very good. The discrepancy between the readings in the sugar beet field is attributed to less-than-full ground cover, because a computed

TABLE 2. MEAN AND VARIANCE WITHIN SELECTED FIELDS DERIVED FROM AIRCRAFT SURFACE-TEMPERATURE DATA FOR THE 3 MAY 1979 OVERFLIGHT

Field Type	Number of pixels	Surface Temperature (C)		Coefficient of Variability
		Mean	Variance	
Alfalfa	80,600	23.6	0.4	2.66
Alfalfa	35,700	25.7	1.8	5.20
Wheat	246,400	25.3	1.3	4.45
Wheat	18,700	24.5	0.3	2.18
Bare, dry	20,000	42.4	0.3	1.34
Bare, dry	76,840	37.2	1.3	3.12
Bare, dry	154,000	37.7	2.9	4.52
Bare, dry	50,000	38.0	1.7	3.46
Bare, dry	52,200	37.9	0.2	1.25
Bare, irrigated	82,000	28.8	5.4	8.07
Bare, irrigated	81,000	25.5	0.5	2.84
Bare, irrigated	35,200	25.0	0.15	1.54

TABLE 3. COMPARISONS OF GROUND-BASED AND AIRCRAFT THERMAL INFRARED MEASUREMENTS OF SURFACE TEMPERATURE ON 7 AUG 1980 AT 1200 P.S.T.

Field	Ground-based (c)		Aircraft (c)
	Mean	*s.d.*	
Rice	27.4	0.5	27
Corn	28	0.6	28
Rice	25.3	0.6	26
Safflower	41	2.0	40
Sugar beets	30(32)*	1.0	34
Rice	24.5	0.8	28
Corn	28.5	0.5	28
Bare soil	48.1	2.5	48

* Value adjusted for 75% ground cover.

surface-temperature value weighted by the percentage of ground cover adjusted the differences to within 2°C. The only other large difference was in the rice field (No. 3), in which all ground measurements were made at a grazing angle with the infrared thermometer because of a canal on the one side of the field, which limited access. This field was also extremely weedy, so it was impossible to obtain a good ground-based measurement.

Upon completion of these analyses, the question arose as to how sampling should be conducted when comparing ground-based data with aircraft data, particularly if ground cover is zero or incomplete. Surface temperature and 0.2-cm soil moisture in the dry field at Davis were collected and analyzed for variability within each transect using statistical procedures described by Davis (1973). These data are given in Figure 1 for the north-south transect and Figure 2 for the east-west transect. For both transects the data were collected in less than 20 minutes, hence, elapsed time would not significantly influence the variability of temperature along the transects. The environmental conditions, i.e., temperature and windspeed, did not change appreciably during this time period. In each figure two details are significant: first, the variability was large in both directions, and second, the relationship between data points is random, as shown by the variograms. Even though the variograms exhibit what would appear to be a pattern in the variance, the values of the surface temperature are distributed randomly about the means in both transects (Figures 1 and 2). The soil was rough at that time because of recent cultivation, and the overall variance was 9.2°C^2 for the east-west transect and 8.1°C^2 for the north-south transect. This variance was larger than any we found in the 3 May 1979 transect and could be attributed to the extremely rough surface that was cultivated three days before; hence, it would probably represent one case of the upper limit of surface-temperature variability. The other case would be partial canopy cover, which has not been

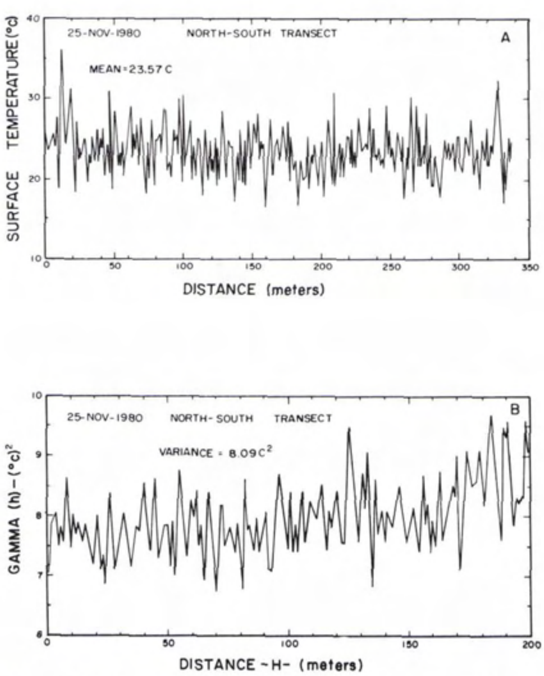

FIG. 1. Surface temperature (A) and variogram (B) for a 1-m spacing on a north-south transect of surface temperature measured on 25 November 1980 at 1300-1315 P.S.T.

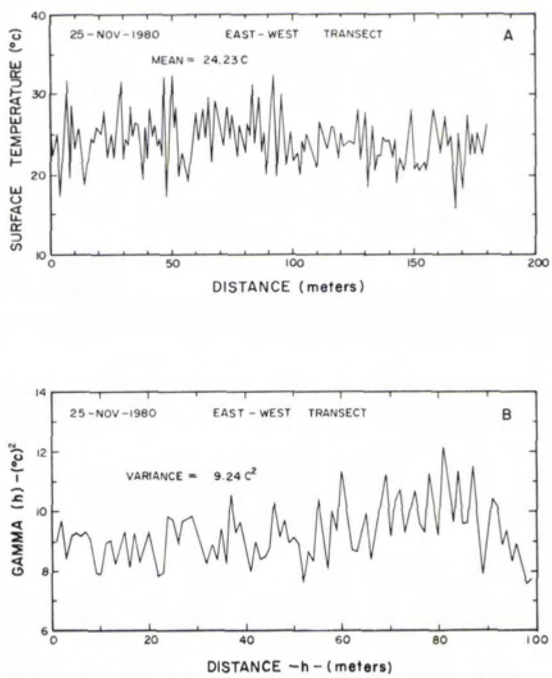

FIG. 2. Surface temperature (A) and variogram (B) for a 1-m spacing on an east-west transect of surface temperature measured on 25 November 1980 at 1320-1335 P.S.T.

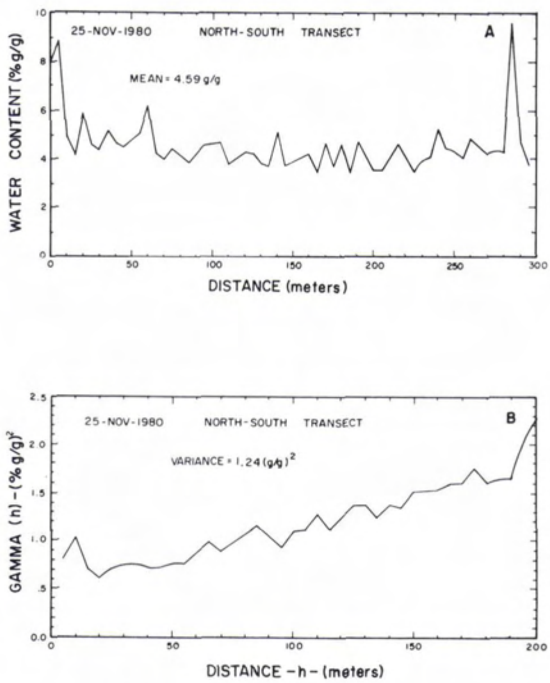

FIG. 3. Surface soil moisture (0-2 cm) (A) and variogram (B) for a 5-m spacing on a north-south transect of soil moisture measured on 25 November 1980 at 1100-1200 P.S.T.

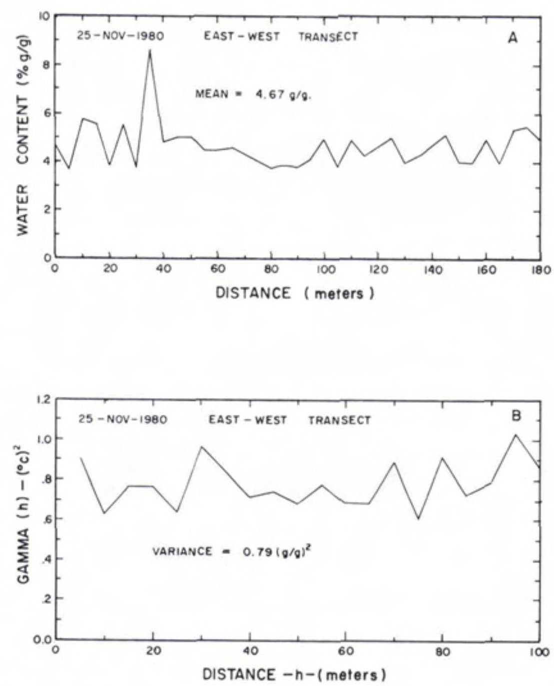

FIG. 4. Surface soil moisture (0-2 cm) (A) and variogram (B) for a 5-m spacing on an east-west transect of soil moisture measured on 25 November 1980 at 1100-1200 P.S.T.

studied in sufficient detail and was not possible in this data set. To evaluate any possible difference between the transects, a comparison of each transect was made with a simple t-test. It was found that the north-south and east-west were significantly different at the 0.05 level but not at the 0.01 level. Both transects were normally distributed about the mean.

Surface soil moisture from the 0 to 2 cm depth along these same transects also varied greatly. These data are given in Figure 3 for the north-south transect and in Figure 4 for the east-west transect. Gravimetric soil-moisture contents ranged from 3.5 to 9.5 g g^{-1} (expressed as a percent) along the transects and exhibited a variance of 1.2 and 0.8 $(g\ g^{-1})^2$ for the north-south and east-west directions, respectively. Again, there was no structure in the variogram of soil moisture, which indicates that a random sampling within the field could give the same result as a sampling along a specified transect. The north-south transect was significantly drier than the east-west transect at the 0.01 level. As in the surface temperature, the soil moisture data were normally distributed about the mean.

Both surface temperature and surface soil moisture in this transect study exhibited a random behavior. Since aircraft and ground-based data differed most on bare, dry fields, these transect data were an attempt to understand why the disagreement occurred. Partial ground cover would probably represent the worst situation between aircraft and ground-based data, but these situations were not encountered during this study. Based on these results, random sampling appears to be sufficient for comparing aircraft and ground-based data provided, however, that a large enough area were covered in the sample. This would appear to be feasible because in the 1980 studies a random sampling pattern was followed and an improvement over the 1979 results between ground-based and aircraft was achieved. Further studies are needed, however, to assess the changes of variability within agricultural fields as a function of spectral wavelength, time of year, crop type, stage of crop development, weed or pest incidence, and irrigation practices.

ACKNOWLEDGMENTS

This report is a contribution from the California Agricultural Experiment Station Project No. 3963 and NASA/Ames Research Center. It was partially supported by California Space Institue Grant CS-79-3 and CS-80-41 and NASA Consortium Agreement NCA-2-OR180-901.

REFERENCES

Davis, J. C., 1973. *Statistics and Data Analysis in Geology*. John Wiley and Sons, New York. 550 p.

Idso, S. B., R. D. Jackson, and R. J. Reginato, 1977. Remote sensing of crop yields. *Science* 196:19-25.

Jackson, R. D., S. B. Idso, and R. J. Reginato, 1977. Wheat canopy temperatures. A practical tool for crop water requirements. *Water Resources Research* 13:651-656.

Millard, J. P., J. L. Hatfield, and R. C. Goettelman, 1979. Equivalence of airborne and ground-acquired wheat canopy temperatures. *Remote Sensing of Environment* 8:273-275.

Millard, J. P., R. C. Goettelman, and M. J. LeRoy, 1981. Infrared-temperature variability in a large agricultural field. *International Journal of Remote Sensing* 2:201-211.

Walker, G. K., and J. L. Hatfield, 1979. A test of the stress-degree-day concept utilizing multiple planting dates of kidney beans. *Agronomy Journal* 71: 967-971.

(Received 28 May 1981; accepted 15 January 1982; revised 23 March 1982)

CALL FOR PAPERS

Third Asian Conference on Remote Sensing

Dacca, Bangladesh
4-7 December 1982

The objectives of the conference—sponsored by the Bangladesh Space Research and Remote Sensing Organization (SPARRSO), the Japan Association of Remote Sensing, the Japan Society of Photogrammetry and Remote Sensing, the Remote Sensing Technical Center (Japan), the Tokai Research and Information Center (Tokai University, Japan), and the International Society for Photogrammetry and Remote Sensing—are to discuss Asian problems in remote sensing, to exchange academic and technical information, and to promote operational applications.

Those wishing to attend the Conference, or to submit an abstract of a paper for presentation at the Conference, should no later than 31 August 1982 contact

Dr. Shunji Murai
Institute of Industrial Science
University of Tokyo
7-22, Roppongi, Minatoku
Tokyo, Japan