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Measuring and Modeling Near Surface Reflected and
Emitted Radiation Fluxes at the FIFE Site

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Introduction

Research was conducted during the four Intensive Field Campaigns (IFC) of the FIFE project in 1987. This research was done on a tallgrass prairie with specific measurement sites on and near the Konza Prairie in Kansas. Measurements were made to help meet the following objectives: (1) determination of the variability in reflected and emitted radiation fluxes in selected spectral wavebands as a function of topography and vegetative community; (2) development of techniques to account for slope and sun angle effects on the radiation fluxes; (3) estimation of shortwave albedo and net radiation fluxes using the reflected and emitted spectral measurements described above; (4) estimation of leaf and canopy spectral properties from calculated normalized differences coupled with off-nadir measurements using inversion techniques; (5) estimation of plant water status at several locations with indices utilizing plant temperatures and other environmental parameters; and (6) determination of relationships between estimated plant water status and measured soil water content.

Data Collected During 1987 FIFE

A research team composed of eleven members collected data during each IFC as well as before and/or after some IFC's. The primary instrument used in our study was a Barnes model 12-1000 Modular Multiband Radiometer (MMR). The MMR measures reflected shortwave radiation in the following wavebands: 0.45-0.52 µm, 0.52-0.60 µm, 0.63-0.69 µm, 0.76-0.90 µm, 1.15-1.30 µm, 1.55-1.75 µm, and 2.08-2.35 µm and emitted radiation in the 10.4-12.5 µm waveband. We used the 15° FOV setting for our measurements. The instrument was mounted on a portable mast to maintain it approximately 3.4 m above the soil surface. Measurements were made from seven different view angles located in or near the

principal plane of the sun. These angles were nadir and 20°, 35°, and 50° to either side of nadir. In a few cases, the same measurements were made perpendicular to the principal plane. Occasionally, readings were made with the principal plane aligned to the view angle of the SPOT satellite. In those cases, view angles were changed to collect data at the same view angle as SPOT. Due to a malfunction of our MMR, we used one borrowed from Goddard during IFC 1, 2 and used our own during IFC 3, 4. All data were collected on an Omnidata Polycorder and then dumped in the field to a lap top microcomputer during IFC 2, 3, and 4. (During IFC 1, we experienced long delays in dumping data into a KSU microcomputer when the Polycorder memory banks became full. This resulted in unacceptably long delays and loss of data collecting opportunities. Therefore, we purchased and used a lap top portable microcomputer following IFC 1.) The lap top computer also made it possible for us to change our data collecting procedure from taking a single reading at each angle to taking 3 readings at each angle during IFC 2, 3, and 4.

We also measured surface temperature of the MMR viewed area with an Everest infrared thermometer (IRT) mounted at a 30° view angle on top of a 2.5 m pole. Three replications were taken at each of four stops--one facing the sun, one with the sun at the back, the other two perpendicular to the principal plane. A hand-held Scheduler IRT was also used to measure surface temperature at the same four directions. It was held at a height of about 1.5 m and at an angle of about 20°. Net radiation of the same viewing area was made with a Micromet net radiometer. Incoming and reflected solar radiation were made with an Eppley Precision Spectral Pyranometer. These instruments were mounted on an A-frame made from black painted conduit with the height adjusted to make the readings about 0.3 m above the top of the vegetation.

We collected data primarily from eight sites near selected super automated meteorological stations (AMS) or flux stations. In addition, special

studies were done at two other sites. At each site data were collected from eight to eleven different locations surrounding the AMS or flux stations. Incident radiation was estimated from measurements made with the MMR over a painted $BaSO_4$ panel approximately every 30 minutes. Incident radiation was also collected on an almost continuous basis by Kansas State with an MMR located over a $BaSO_4$ panel located at site 16 during data collection periods.

Most MMR data were collected to coincide with a satellite overpass and with concurrent coverage by the C-130 and the NASA helicopter. On two separate occasions we collected data in conjunction with bidirectional radiation measurements made by Don Deering and his crew. We collected MMR and other supporting radiation data on a total of 30 days. Sky quality conditions ranged from excellent to marginal on these days. Acceptable data were obtained during part or all of 24 days.

We collected plant samples from a 0.1 m^2 area near each location where radiation readings were taken to determine phytomass dry weight and leaf area. Measurements made with a LiCor LI-1915B line quantum sensor will be used to estimate leaf area index (LAI) values nondestructively using inversion techniques developed by Norman, et al (1983). Radiation reflected and transmitted from individual leaves of the dominant species was measured at a few sites during IFC 1 using a prototype radiometer and an LI-1800 integrating sphere. Unfortunately, this instrument malfunctioned and was not available during the remaining IFC's. An integrating sphere attached to a Spectron Engineering SE 590 was used to obtain some additional leaf reflectance and transmittance data before and during IFC 4. Measurements of soil water content were also made using a Time Domain Refractometer at a few sites. For the most part, however, we will rely on soil moisture measurements made by the Science Support Group. We made estimates of percent cover, plant height and

species composition at each measurement location during each IFC, but we will also use similar data collected by others at the same sites. We determined the surface emissivity at each measurement location using a technique similar to that of Fuchs and Tanner (1966). We need the surface emissitivities and the longwave sky radiation, which we also measured, to calculate true surface temperatures. The northings, eastings, degree of slope, and the slope aspect for each measurement location were determined once during the year.

All MMR's used in the study were calibrated before IFC 1 and after IFC 4. Facilities at NASA Goddard Space Flight Center were used to calibrate the instruments in the reflective wavebands and facilities at the USDA Water Conservation Laboratory in Phoenix, Arizona, were used to calibrate the thermal channel. All infrared thermometers were also calibrated in Phoenix. The painted $BaSO_4$ panels used to estimate incoming solar radiation in the MMR wavebands were calibrated by Dr. Ray Jackson at the Water Conservation Laboratory in July 1987, following the method of Jackson et al. (1987).

Current Status of Data Reduction and Analysis

Calibration equations for the MMR's were received in January 1988. Since that time we have processed the data on the so-called "golden days," i.e. June 6, July 11, August 15 and October 10 and on a few additional days and have begun to analyze these data.

One of the first goals of our study is to use the spectral data collected with the MMR to estimate the albedo of the surface. The albedo is defined as the ratio of the reflected solar beam (0.3-4.0 μm) from a surface to the total shortwave radiation impinging on the surface (Rosenberg et al, 1983). Accurate estimates of albedo are required to determine radiation and energy balances on, among other things, vegetative surfaces, buildings, the

atmosphere and on energy collecting devices (Igbal, 1983; Kriebel, 1979; Brest and Goward, 1987).

Albedoes are commonly determined by measuring incoming and reflected radiation with pyranometers. These point measurements may be extended to larger areas, but only if the reflecting surface is homogeneous with the larger area. This is generally not the case for land surfaces which exhibit considerable variation in surface conditions from one point to another. Remotely sensed data offers the potential for estimating albedo from large areas; therefore, we and others (e.g. Brest and Goward, 1987) are evaluating the use of remotely sensed spectral data for albedo determination.

We are currently evaluating the following equation for estimating albedo (ρ) from MMR data:

$$\rho = \sum_{i=1}^{7} W_i RH_i \tag{1}$$

where W_i = weighting coefficient for MMR channel i and

RH_i = hemispherical reflectance for channel i.

We use a simple solar irradiance model (SPCTRAL 2, Bird and Riordan, 1986) to calculate W_i. SPCTRAL2 produces global, direct and diffuse solar irradiance values at given wavelengths for selected sky conditions. MMR wavebands were extended to account for all energy under the global irradiance curve. The ratio of the energy determined for the portion of the curve assigned to each channel to the total energy under the entire solar irradiance curve is W_i. Values of RH_i were determined using the model of Walthall et al. (1985).

We have calculated albedo values for several measurement locations using equation 1. Calculated albedo values have been about 6% higher than measured

values in absolute terms, (about 30% relative error). We are uncertain at this point as to the reason(s) for these unacceptably large differences but we are evaluating each component of equation 1 as well as the MMR data for possible errors in our calculation procedure.

After we have developed an acceptable procedure for calculating the albedo, we will calculate the surface radiation balance - the so-called net radiation. This will require knowledge of the longwave radiation emitted by the surface ($R_{LW\uparrow}$). The equation for describing this longwave emitted radiation is given by the Stefan-Boltzmann law where:

$$R_{LW\uparrow} = \varepsilon_s \sigma T_s^4 + (1-\varepsilon_s) R_{LW\downarrow}$$

where ε_s = the emissivity of the surface,

σ = Stefan-Boltzmann constant (5.67×10^{-8} $Wm^{-2}{}^{\circ}K^{-4}$),

T_s = the surface temperature in $^{\circ}K$,

and $R_{LW\downarrow}$ = longwave sky radiation.

Surface temperature can also be used to infer the water status of vegetation when used in conjunction with air temperature and vapor pressure deficit data (Jackson, 1982). Our measurements of the surface emissivity at the various sites show ε_s values in the range of 0.95 to 0.99.

We have begun to analyze the surface temperature data. Preliminary analysis of surface temperature measurements indicate some differences between the Everest IRT (held at a 30° angle) and the Scheduler (held at an angle of 20°) (Figs. 1-4). As shown in Fig. 1 the surface temperatures (averages of readings made from the four directions) measured with the Scheduler were consistently 4 to 5° C cooler than the temperature measured with the IRT and both temperatures were several °C warmer than the air temperature on 5 June 1987. Some, and perhaps all, of the surface temperature differences measured by the

two instruments can be ascribed to differences in the surfaces viewed by the two instruments because of differences in the view angles. Site 32 was quite heavily grazed so more of the warm soil surface would be viewed by the IRT than by the Scheduler. Temperature measurements of a blackbody source made before and after each data collection period show differences due to instruments should not be more than 0.5°C.

On 5 June surface temperature measurements were also made at site 18 (Fig. 2). Temperature differences for the two instruments were slightly less than at site 32. More vegetation was present at site 18 but plant cover was still incomplete on this early date. On 11 July 1987, at site 18 temperature differences were much smaller than on 5 June (Fig. 3). This is attributed to an increase in plant cover. On this date the IRT viewed temperature was about 0.5 to 1.5°C warmer than that measured by the Scheduler. Temperature differences were less than 0.5°C and readings taken with one instrument were not consistently higher or lower than the other on 15 August 1988. By that date vegetative cover was essentially complete. Temperature patterns measured by both instruments were very similar for all dates and sites. We have not yet analyzed any of the surface temperature data collected with the thermal channels on the MMR. It will be interesting to see how the surface temperature measured from the seven different angles compare with the IRT and Scheduler data.

Future Work

The majority of the data collected in 1987 still need to be processed and analyzed. A major effort will be devoted to these tasks in 1988 and 1989. We will conduct a series of experiments during the spring and summer of 1988 at the FIFE site to investigate diurnal and temporal effects. We will confine

our data collection to 2 or 3 sites. In addition to the radiation measurements, we will collect more ancillary data such as soil water content, plant water potential, stomatal diffusion resistance and leaf transmittance and reflectance than it was possible to do in 1987.

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COMPARISON OF SCHEDULER AND IRT AT SITE 32 ON 5 JUNE, 1987

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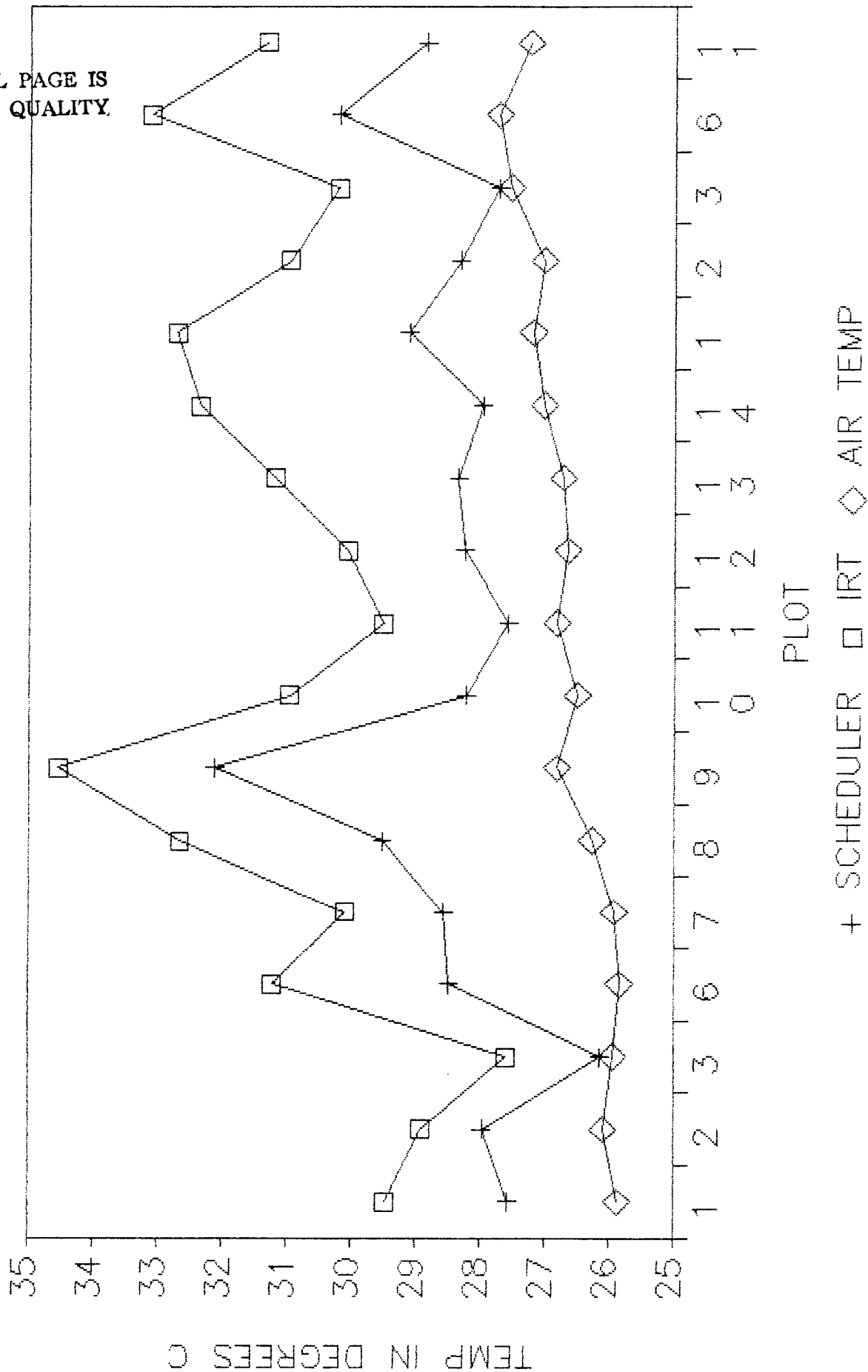
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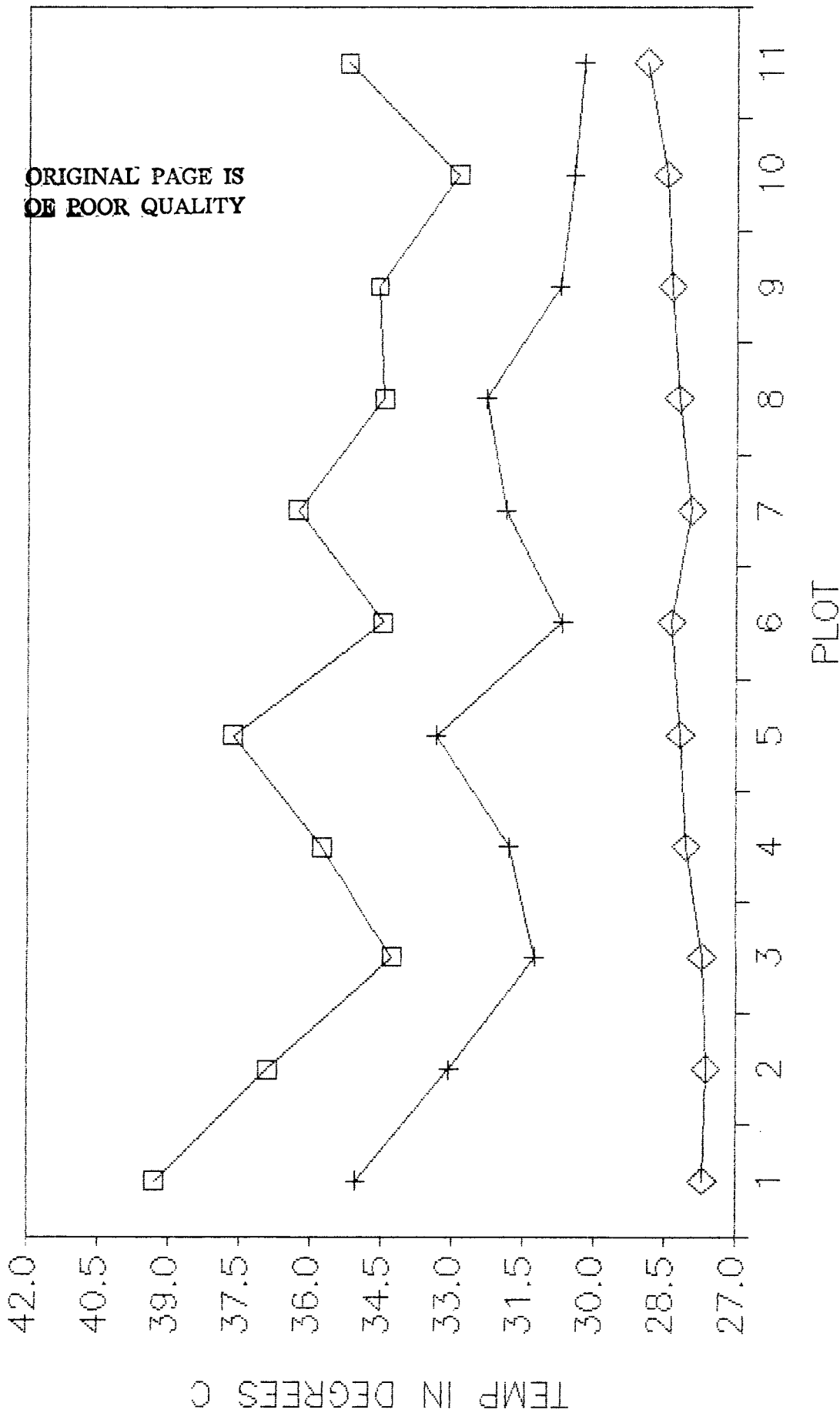
PLOT

+ SCHEDULER □ IRT ◇ AIR TEMP

Fig. 1. Average surface temperatures measured with an Everest IRT and the Scheduler IRT on 5 June 1987 for the eleven plots located at site 32. Air temperature data are included for comparison purposes.
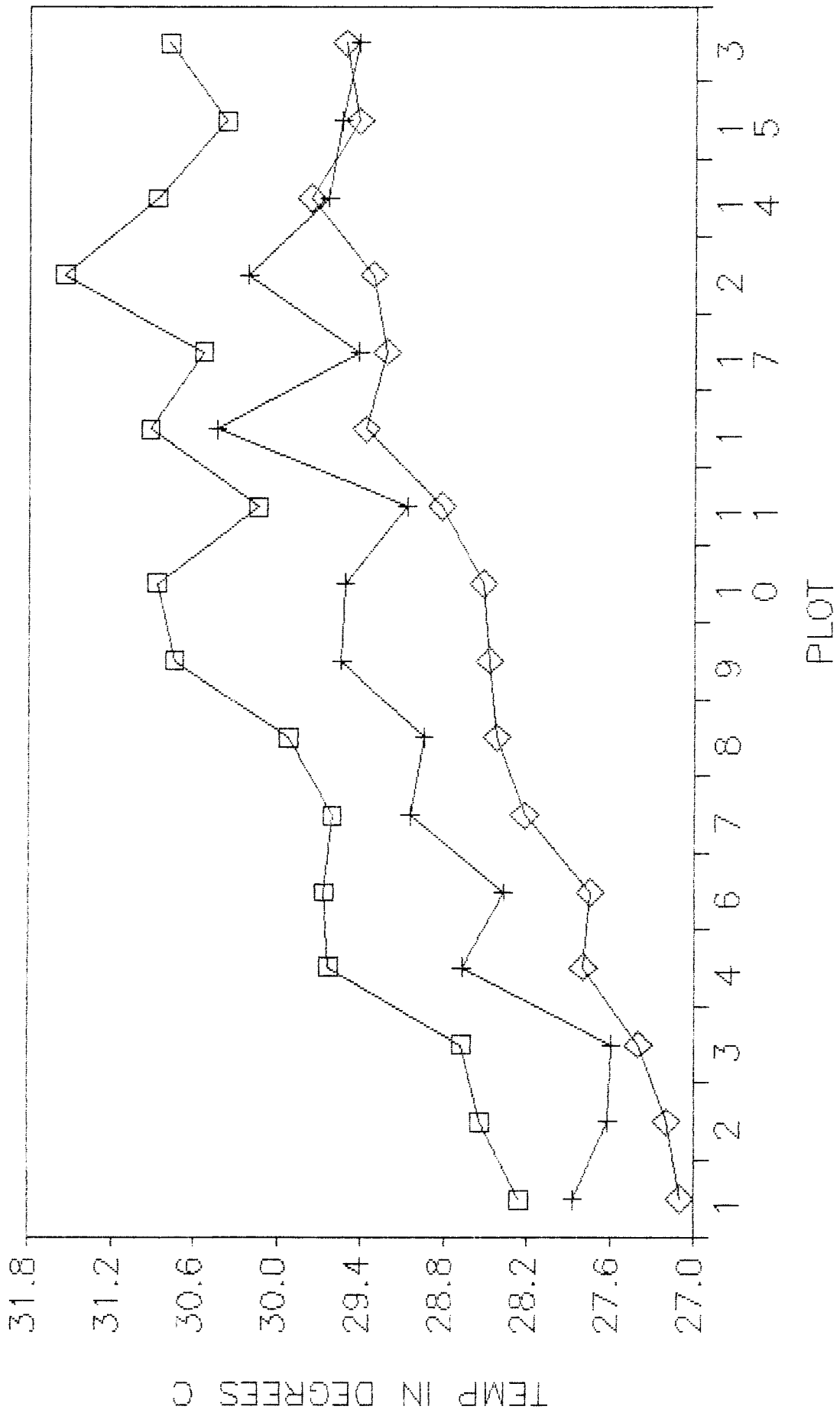
Readings taken between 2040 and 2117 GMT

COMPARISON OF SCHEDULER AND IRT AT
SITE 18 ON 5 JUNE, 1987

TEMP IN DEGREES C

PLOT

+ SCHEDULER □ IRT ◇ AIR TEMP

Fig. 2. As in Fig. 1 for site 18.

Readings taken between 1641 and 1835 GMT

COMPARISON ON SCHEDULER AND IRT AT SITE 18 ON 11 JULY, 1987

Readings taken between 1424 and 1609 GMT   Fig. 3.   As in Fig. 1 for site 18 on 11 July 1987.

COMPARISON OF SCHEDULER AND IRT AT
SITE 18 ON 15 AUGUST, 1987

TEMP IN DEGREES C

PLOT

+ SCHEDULER □ IRT ◇ AIR TEMP

Fig. 4.   As in Fig. 1 for site 18 on 15 August 1987.
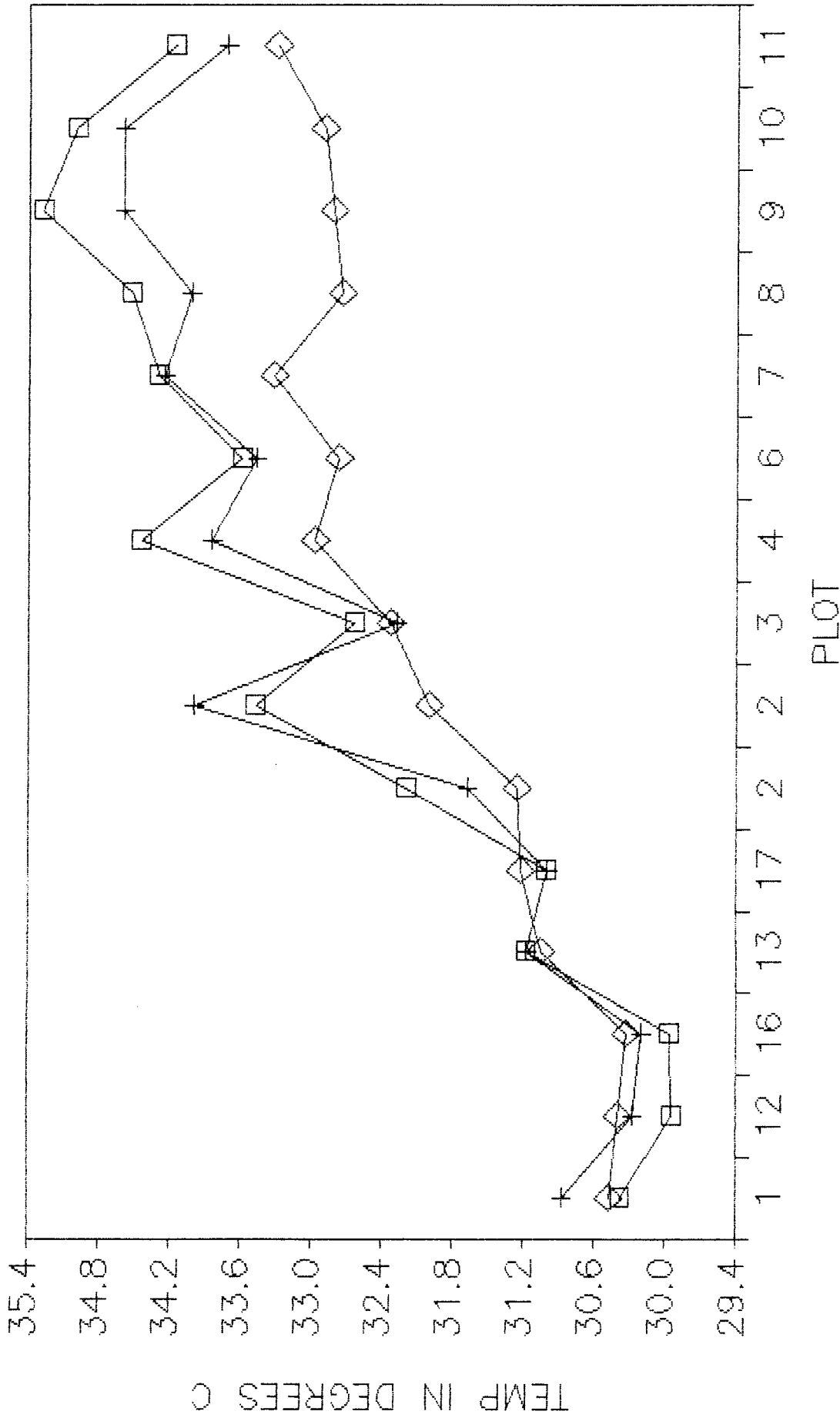
Readings taken between 1450 and 1714 GMT