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PASTURE/WHEAT SURFACE TEMPERATURE DIFFERENCES: INDICATOR OF RELATIVE SOIL MOISTURE DIFFERENCES

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I. INTRODUCTION

Thermal infrared data can potentially improve crop yield estimates through detection of different crop stress levels. Jackson, et al. (1977) have used thermal data in detecting different levels of moisture stress. An accumulated sum of the crop-air temperature difference through the growing season is indicative of different moisture stress levels and, consequently, wheat yields. Various other studies on different crops have arrived at similar results (Reginato, 1978).

Little work has been conducted relating satellite thermal data to moisture stress conditions. One important reason is that the spatial resolution of present satellite thermal data is quite large. For example, one pixel from HCMM (Heat Capacity Mapping Mission) would correspond to 25 hectares (62 acres), and HCMM has the best spatial resolution of the present sensors. Therefore, to evaluate moisture conditions in small commercial fields, relationships need to be determined between moisture conditions in the smaller, nearby commercial cultivated fields. To do this the thermal IR-soil moisture relationship in pasture and wheat is being studied from three different levels--ground, aircraft, and satellite-- in a region where both wheat and pasture are common. Prior to this study there has been little effort to use thermal infrared systems over rangeland. Most studies of rangeland growing conditions have been conducted using the visible/near infrared sensors (Deering, et al. 1976).

II. OBJECTIVE

The objective of our study was to relate surface temperature of pasture and wheat to corresponding soil moisture data. This experiment was to be conducted at three different levels on one date during a period when moisture stress would have a significant effect on yield. The aircraft thermal data was collected from channel 11 on the NASA M^2S system (8.0-11.0 μm). The satellite data was collected from the thermal channel aboard HCMM (10.5-12.5 μm).

III. METHOD

The area selected for this study was the Southern Great Plains Watershed Study area near Chickasha, Oklahoma--where pasture and wheat are common. The area also has an extensive network of rain gauges set up by USDA SEA-AR. This allows determination of moisture conditions prior to, and during, data collection periods from precipitation records.

During the month of May, wheat is usually in the heading to flowering stage, a biophase sensitive to moisture stress (Robins and Domingo, 1962). Aircraft flights were therefore scheduled during this period. About one month before the scheduled flight, commercial fields were selected for measurement. To eliminate drastic soil type differences from affecting the analysis, as many adjacent pasture and wheat fields were selected as was possible. Permission was granted by farm operators to sample in 16 fields. These fields can be divided up into two general soil types--clay and loam-- corresponding to the two flight lines. One representative site within each of the fields was selected for intensive measurement. Each site area was approximately 50 feet in diameter.

To compare aircraft thermal data between pasture and wheat, three types of ground level measurements were collec-

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ted: (1) gravimetric soil moisture at each site; (2) surface temperature of an area lake and (3) thermal emissivity data at each site. Six to eight gravimetric samples were collected for the two 15 cm thick increments (0-15 cm and 15-30 cm) down to 30 cm. This technique is the most accurate method available, within the limitations of time available and the number of samples needed. Utilizing the high thermal emissivity and heat capacity of water, lake surface temperatures were used to calibrate the M²S thermal data. The lake temperatures were collected in conjunction with the aircraft overpass. Emissivity measurements were collected at each site to determine the influence emissivity differences between pasture and wheat have on surface temperature differences. One measurement was collected at an area representative of the vegetative cover at a given site. The technique is similar to that used by Fuchs and Tanner (1966) and is given in the following section.

A. EMISSITY MEASURMENT PROCEDURE

The procedure to determine emissivity of a surface is divided into five basic measurements using a radiation thermometer (in this case a Barnes Instatherm): (1) the temperature of a known-emissivity panel exposed to the air; (2) the temperature of the panel covered by a large can lined with aluminum foil; (3) the temperature of the vegetated surface; (4) the temperature of the surface after shading from the sun; and (5) the temperature of the surface covered by the foil-lined can.

After placing the panel horizontally on the ground, and allowing the panel temperature to equilibrate, panel temperatures were taken. By standing far from the panel, the portion of the sky blocked by the operator and instrument is minimized. In any case, the operator and instrument should be in the same position relative to the target and sun during all measurements. The response measured by the thermometer (R_{panel}) is given by equation (1):

$$R_{panel} = F(T)[\sigma T^4 \varepsilon_{panel} + (1-\varepsilon_{panel}) B_s]. \quad (1)$$

Where F(T) is the integrated spectral response of the instrument over all wavelengths, B_s is the background thermal radiation, ε is thermal emissivity, and T is the radiative temperature.

Immediately after this measurement, the foil-lined can, with the thermometer mounted on it, is placed over the plate. The plate temperature must be read immediately, before the temperature begins to decrease. This reading is given by the equation

$$R_{cp} = F(T)\sigma T^4_{panel} \quad (2)$$

where R_{cp} is the radiation received by the instrument with the can placed over the panel.

Comparing these two results, we can determine $F(T)B_s$. These measurements should be taken once at each site--more frequently if the sky is partly cloudy, as background radiation is a function of water vapor concentration and cloud over.

Next, a large representative area of the surface is shaded using the panel or other large opaque object. The temperature of the shaded area is monitored until the surface temperature stabilizes with the surroundings (this will take 3-5 minutes). By shading this area, direct solar radiation is eliminated and temperature will be stablized for the can measurement. The shaded surface temperature $(T)_{surface}$ as measured by the instrument will be related to the instrument response by

$$R_{surface} = F(T)[\sigma\varepsilon T^4_{surface} + (1-\varepsilon)B'_s] \quad (3)$$

where B'_s is approximately equal to B_s. Any difference between B_s and B'_s is due to the thermal radiation emitted from the shade.

While keeping the area shaded, the can with the thermometer mounted on it is placed over the area and the temperature is recorded immediately. It is important that this measurement be taken within 10 seconds of applying the can because the shaded canopy temperature is likely to change. The response from the thermometer is a direct function of the actual surface temperature:

$$R_{cs} = F(T)\sigma T^4_{surface} \quad (4)$$

where R_{cs} is the radiation received by the thermometer when the can is placed over the surface.

Since we are given $F(T)B_s$, T, and $R_{surface}$ from the previous measurements, we can calculate ε of the given surface using the equation

$$\varepsilon = \frac{R_{surface} - F(T)B_s}{R_{cs} - F(T)B_s} \qquad (5)$$

The calcualted ε from equation 5 is the actual ε because F(T) is a factor in $R_{surface}$, R_{cs}, and $F(T)B_s$ and consequently canels out.

IV. RESULTS

A. GROUND DATA RESULTS

The aircraft flew at 5,000 feet over the selected fields on May 8 and 9; ground data was collected on May 9. Rains during the previous week supplied the soil with adequate moisture. No moisture stress symptoms were observable. Wheat at this time of the year was approximately 75 cm tall and heading. Most of the pasture fields had vegetation less than 15 cm tall. All of the fields, except for one bare field and one grazed wheat field, had greater than 50% ground cover.

The volumetric moisture content within the top 30 cm at each site is shown in Table 1. One notices that:

(1) fields tend to be drier along the west than east flight line, and
(2) several pasture fields are wetter than dryland winter wheat fields.

The soil moisture difference between the flight lines is partly due to water-holding capacity differences of the two soil types, one along each flight line. Fields along the east flight line are in clay; along the west flight line in a sandy loam, which holds less moisture.

Due to differences in the amount of green material, the pastures are wetter than the wheat fields. Most of the pastures average from 50-80% green material, while wheat averages from 90-100% green material. A large amount of green material transpires more water and depletes the soil water content faster than dead vegetation.

The emissivity data for each of the sites are given in Table 2. There is no significant difference between pasture and wheat thermal emissivity. The reason for this is that thermal emissivity appears to be based primarily on the amount of vegetative-cover within the scene rather than the type of cover. Consequently, no correction is needed in comparing wheat to pasture thermal data.

Lake surface temperatures as measured on the ground were 20°C at the pre-dawn time (3 a.m. CDT), and 21°C during the afternoon (2 p.m. CDT). This reflects the small diurnal variation in lake temperature due to its high heat capacity.

V. M^2S THERMAL DATA PROCESSING AND RESULTS

Upon arrival of the M^2S data, the digital thermal data was converted to surface temperatures, scaled, and transferred to a magnetic tape (CCT). The range of digital data on the magnetic tape was 0-255(0-25.5°C). An additional scaling factor easily allows extraction of actual surface temperatures. The range of temperatures on a given file were then divided into 8 regions. These regions were assigned a greytone and printed out as a greymap. One pixel corresponded to an area on the ground approximately 11 feet in diameter. An example of a greymap of an area flown during the day is shown in Figure 1. Each grey tone corresponds to approximately 1°C range. From the greymap average surface temperatures and within-field variability can be determined at each site.

Day/night temperature from the M^2S CCT data are shown in Table 3. One notes the temperatures for pastures are warmer than wheat during the day, and cooler at night. Site temperatures were compared to surface temperatures throughout the rest of the field by analyzing the greymaps and the digital color display (DCD) from an interactive minicomputer processor system. The DCD works on the same principle as the greymap, however it displays a color image of the data where each color represents a given temperature range. Through this analysis we can see that site surface temperatures are fairly representative of temperatures throughout the rest of the field. In most cases, the site temperature is within 2°C of temperatures throughout the rest of the field.

Comparing lake temperatures as measured on the ground and by the M^2S, it is seen that the two are within 1°C of each other, implying that minimal correction is needed for the aircraft data. Lake temperatures may be used as surfaces to calibrate satellite thermal data.

Comparing results from Tables 1 and 3, one can see that several pasture sites have high moisture contents, but warmer day and cooler night surface temperatures than winter wheat fields. The physical explanation for the thermal and soil moisture difference between pasture and wheat is the differing amounts of green material between them. Pasture, as previously mentioned, has a larger percentage of dead material with different thermal properties than live vegetation, and surface temperature is primarily dependent on insolation. Dead vegetation heats and cools more quickly than live. The dead material is transpiring less, but is warming up faster than live wheat, resulting in higher daytime surface temperatures and moisture contents as well.

The timing of the green-up period for pasture is related to growing conditions of wheat. Theoretically, a wet, warm spring would hasten green-up and decrease the thermal and soil moisture difference between pasture and wheat. The opposite would be true for a dry, cold spring.

VI. HCMM PROCESSING AND RESULTS

The May 14, 1978 nighttime HCMM data for the Chickasha area was received in CCT form. Greymaps were produced at a scale close to 1:250,000. At this scale, the greymap can be overlaid onto a USGS topographic map and facilitate in locating field sites. The data were not geometrically corrected. The data output and color displays of the area were analyzed, and the measurement sites were located. The temperature range over the entire area was 2°C, similar to the evening temperature range on May 9. An example of the HCMM greymap is shown in Figure 2. Pasture and wheat temperature differences during the evening correspond to less than 2°C difference. The nighttime data does not prove to be enough for analyzing temperature and soil moisture differences. Consecutive day/night data is needed. This is the major limitation in using this technique to evaluate soil moisture condition.

VII. SUMMARY AND CONCLUSIONS

The objective of this study was to relate surface temperatures of pasture and wheat to corresponding soil moisture data. Data were collected and correlated at two levels: ground and aircraft. Aircraft thermal data was calibrated to ground thermal data by equating lake surface temperatures as collected on the ground and from the aircraft.

Two significant conclusions have been reached after analyzing the thermal and soil moisture data: (1) day/night pasture surface temperature differences indicate relative soil moisture differences on a given date, and (2) lake surface temperatures may be used as calibration surfaces for aircraft and satellite thermal data.

The aircraft thermal and soil moisture data show that day/night pasture temperature differences can indicate relative soil moisture differences on a given date. An 18°C day/night temperature difference is noted in fields along the west flightline (sandy soil); a 16°C difference along the east flightline (clay soil). The sandy soil had soil moisture tensions around -300 to -400 kPa; the clay had around -33 kPa. Wheat fields had significant temperatures differences as well, though not as large (6-8°C difference). Additional data is needed to determine this relationship through the growing season. Once these relationships have been developed, soil moisture conditions can be evaluated over large areas with greater precision.

Lake surfaces, with their emissivity near 1.0, can be utilized as calibration targets for aircraft and satellite thermal data when the lake surface temperature is known. Using the lakes the absolute surface temperature will be known for that point in the imagery, and atmospheric attenuation does not have be to handled separately. For other surfaces in the imagery the apparent radiative temperature, corrected for atmospheric attenuation (if one assumes the attenuation to be the same everywhere as it is over the lake), is obtained by determining the difference of that surface's temperature from the lake's. Further, knowing the land surface emissivity, as we do here, allows determination of the absolute surface temperature by applying the correction for emissivity.

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Table 1: Soil Moisture Data Collected at Chickasha on 5/9/78

East Flight Line Site	Depth (cm)	Moisture (% by weight)	West Flight Line Site	Depth (cm)	Moisture (% by weight)
E-1	0-15	19.1	W-1	0-15	19.1
(wheat)	15-30	17.5	(pasture)	75-30	19.3
				30-45	19.3
E-2	0-15	17.5	W-2	0-15	19.3
(wheat)	15-30	14.1	(pasture)	15-30	14.0
				30-45	15.0
E-3	0-15	17.0	W-3	0-15	10.2
(pasture)	15-30	15.5	(wheat)	15-30	9.3
	30-45	13.6			
	45-60	13.4			
E-4	0-15	13.1	W-4	0-15	11.8
(wheat)	15-30	11.6	(pasture)	15-30	11.9
	30-45	8.6		30-45	10.5
E-5	0-15	25.0	W-5	0-15	8.8
(wheat)	15-30	23.8	(wheat)	15-30	8.4
	30-45	22.7			
E-6	0-15	15.3			
(pasture)	15-30	14.4			
	30-45	16.5			
E-7	0-15	17.5			
(wheat)	15-30	15.4			
	30-45	17.1			
E-8	0-15	15.0			
(wheat)	15-30	14.7			

Table 1: Soil Moisture Data Collected at Chickasha on 5/9/78 Continued

East Flight Line Site	Depth (cm)	Moisture (% by weight)	West Flight Line Site	Depth (cm)	Moisture (% by weight)
E-9	0-15	18.7			
(bare soil)	15-30	19.5			
	30-45	23.3			
E-10	0-15	19.2			
(pasture)	15-30	21.5			
	30-45	22.8			
E-11	0-15	19.3			
(wheat)	15-30	18.7			

Table 2: Emissivity of Oklahoma Sites

East Flight Line			West Flight Line		
E - 1	(wht.)	.99	W - 1	(past.)	.97
- 2	(past.)	.99	- 2	(past.)	.98
- 3	(past.)	.97	- 3	(wht.)	.97
- 4	(wht.)	.97	- 4	(past.)	.96
- 5	(wht.)	.99	- 5	(wht.)	.97
- 6	(past.)	.91			
- 7	(wht.)	.99			
- 8	(wht.)	.92			
- 9	(bare soil)	.92			
-10	(past.)	.99			
-11	(wht.)	.97			

Table 3: Day/Night Surface Temperature Data

Site		Day Temp.	Night Temp.	Day-Night Diff.
E-1	(wheat)	25.06°C	17.32°C	7.74°C
E-2	(oats-pasture)	27.96°C	15.98°C	11.98°C
E-3	(pasture)	30.31°C	16.12°C	14.19°C
E-4	(wheat)	25.52°C	16.96°C	8.56°C
E-5	(irr. wheat)	24.33°C	15.77°C	8.56°C
E-6	(pasture)	30.49°C	16.68°C	13.81°C
E-7	(wheat)	23.33°C	17.25°C	6.08°C
E-8	(wheat-graze)	27.26°C	16.46°C	10.80°C
E-9	(bare)	32.06°C	15.11°C	16.95°C
E-10	(pasture)	32.90°C	16.05°C	16.85°C
E-11	(wheat)	27.82°C	17.11°C	10.71°C
W-1	(pasture)	31.81°C	15.57°C	16.24°C
W-2	(pasture)	34.01°C	15.44°C	18.57°C
W-3	(wheat)	24.92°C	16.31°C	8.61°C
W-4	(pasture)	33.26°C	15.74°C	17.52°C
W-5	(wheat)	25.64°C	16.04°C	9.60°C
Lake		20.61°C	22.42°C	-1.81°C

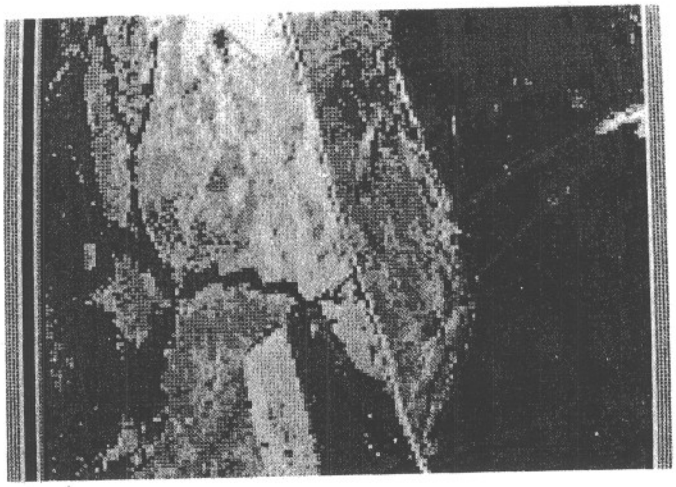

Figure 1. Computer greymap of the afternoon flight over several pasture (light tones) and wheat fields (dark tones).

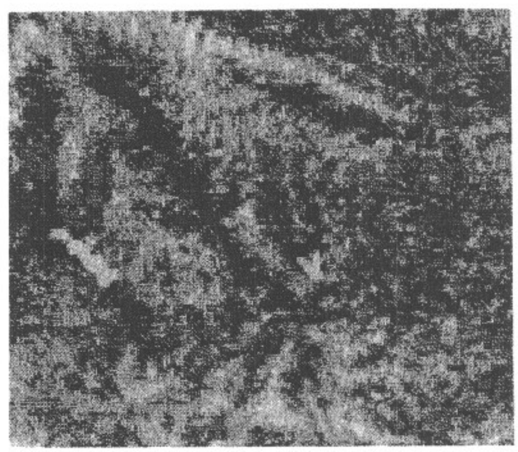

Figure 2. Computer greymap (1:250,000 scale) of a night HCMM - IR data obtained over Chickasha on May 14, 1978.

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