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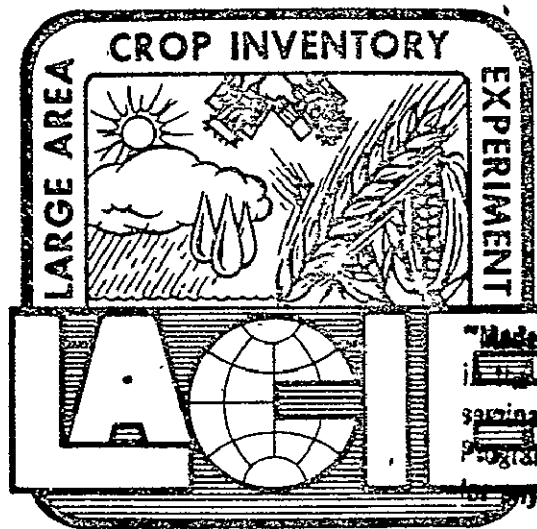
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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

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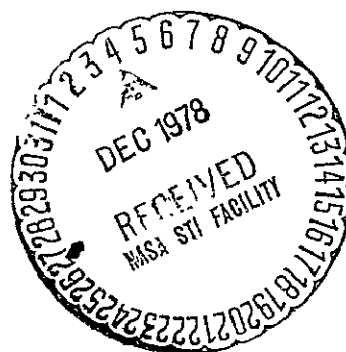
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DETECTION OF EPISODIC PHENOMENA
ON LANDSAT IMAGERY



National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER

Houston, Texas
MAY 1976

DETECTION OF EPISODIC PHENOMENA ON LANDSAT IMAGERY

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**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

MAY 7, 1976

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1. INTRODUCTION

While examining several full-frame Landsat color images of central and western Kansas for examples of landscape similarities, numerous instances were noted where extensive areas appeared much darker in color on some data passes than on other passes. It could be seen from the distribution patterns of these darkened surfaces that these changes resulted from short-term episodic phenomena rather than from changes in vegetative growth or differences in normal soil colors. After plotting daily precipitation data for the weather observation stations located within the areas covered by the imagery, it became evident that rainfall occurring a short time prior to the data pass was a major cause of widespread change in spectral reflectivities of these surfaces from pass to pass. Other episodic phenomena (thin translucent clouds, cloud shadows, aircraft condensation trails and their shadow, ... etc.) were also found to be responsible, to a much lesser extent, for changes in the spectral reflectivities of some surfaces.

2. PROCEDURES

Daily precipitation data for 1973 and 1974 for the state of Kansas were examined for all Landsat data passes over the wheat growing areas where full-frame Landsat color images were readily available. Goddard-produced full-frame color images were obtained from local files for a few passes where rainfall had occurred, either immediately before the data pass, or within approximately 1 week prior to the data pass. The location of weather observation stations were plotted on overlays for those full-frame images in which suspected rainfall patterns appeared. The total amounts of rainfall for spells of daily precipitation immediately before a cloud-free data pass were plotted on these full-frame image overlays. Isohyets were first drawn to show the rainfall patterns according to the distribution of observation stations.

Then the isohyets were adjusted to correspond more accurately to the probable actual distribution of rainfall as determined by the pattern of darkened surfaces observed on the full-frame images. Amounts of rainfall for the same periods of time were also plotted, and isohyets drawn for the surrounding areas of Kansas, so that an overall picture of rainfall patterns could be perceived for a much larger area.

Two small agricultural areas near the Finney County Intensive Test Site were selected for the purpose of determining how radiance values of surfaces exposed to recent heavy rainfall differed from those of similar surfaces in two nearby areas where very little rainfall had occurred. Radiance values for these four areas were plotted for three successive data passes (May 8, May 26, and May 27) so that changes in spectral reflectivities of rain-soaked surfaces could be observed more quantitatively than were subjectively evident from the darkened colors on the full-frame color images.

Radiance values for selected individual surfaces were also obtained in an area which had received moderate-to-heavy rainfall prior to the May 26 data pass, and also in an area where little or no rain had occurred prior to the same data pass. The mean radiance values from several samples of similar individual surfaces were averaged and then plotted on graphs.

3. OBSERVATIONS

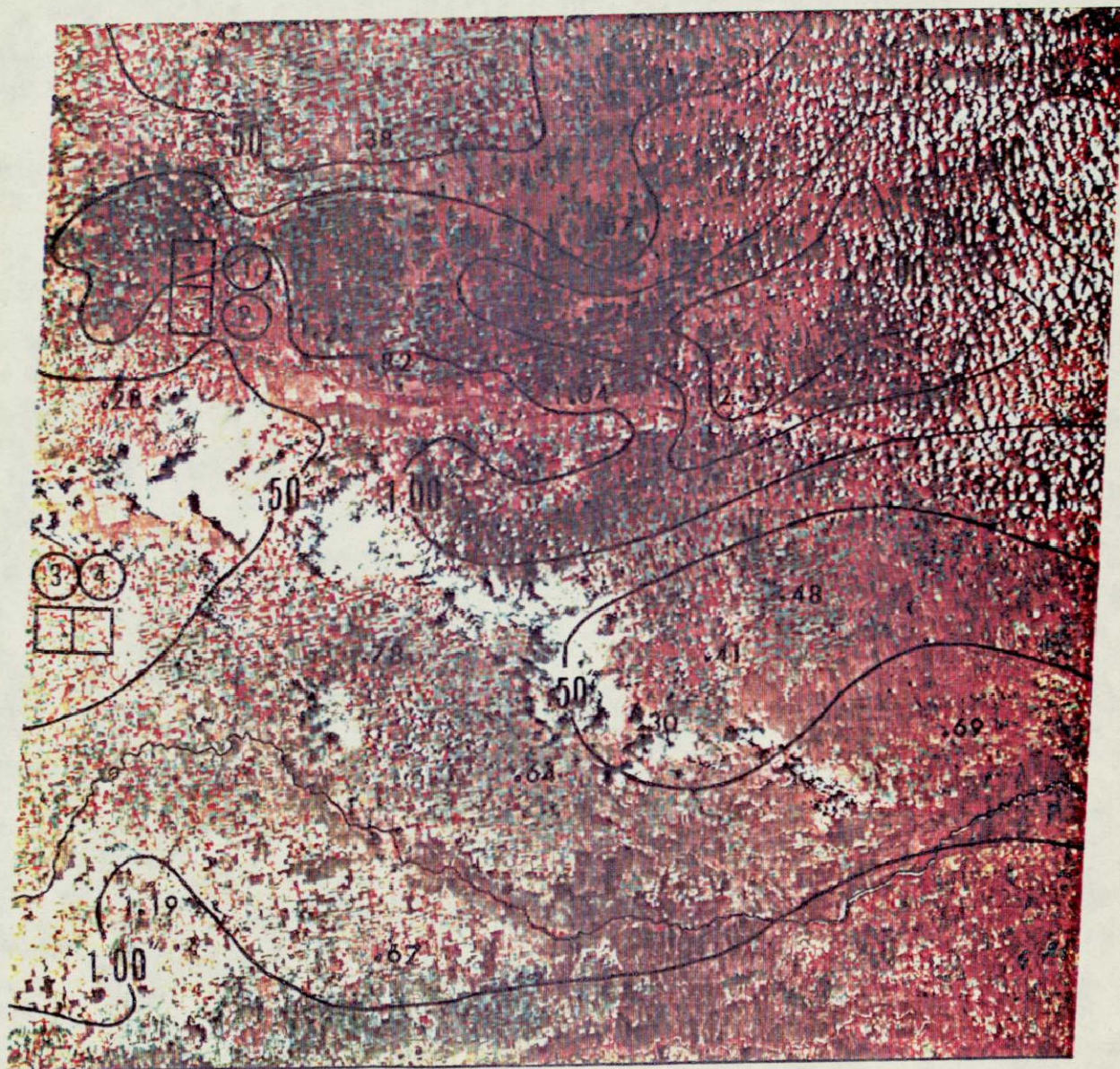
After comparing the distribution patterns of darkened surfaces on the full-frame color images with the rainfall patterns as depicted by the isohyets on the full-frame image overlays, it became evident that these darkened surfaces were in areas where sufficient precipitation had fallen to cause the soil surfaces to become water-soaked. It was also noted that the actual delineation of

isohyets based on proportional distances between observing stations frequently did not coincide with the areal extent of the darkened surfaces as seen on the full-frame color imagery. This meant that a more accurate representation of the areal distribution of rainfall could be obtained by adjusting the isohyets according to the delineations of the darkened surfaces seen on the full-frame color imagery. This would be particularly true over areas where the rainfall was in the form of scattered convection showers rather than the more uniform frontal-type rainfall. Numerous instances were observed where small scattered patches of darkened surfaces indicated that rain showers had occurred between observation stations where little or no rainfall was reported.

Figure 1 is a scene in southwestern Kansas where rainfall had occurred each day for 2 to 4 days prior to the May 26 data pass. Some of the weather observation stations in this scene had not had any measurable amount of precipitation for at least 27 hours or more prior to the data pass. The overlay for figure 1 shows the isohyets of total rainfall adjusted to portray the probable distribution of rain between observation stations.

Figure 2 shows the same geographic area 18 days earlier (May 8) when no precipitation had fallen for almost 2 weeks prior to the data pass. By comparing these two figures one can readily detect those areas where recent rainfall had caused significant decreases in spectral reflectivities of the surfaces. Within another 24 hours most of the water-soaked soils had dried out and returned almost to their normal brightness. Figure 3 shows a portion of the same scene as shown in figure 1, that was recorded the next day (May 27) when the Landsat orbit overlapped a portion of the previous day orbit. Only a small area of subtle darkening of surfaces remains on May 27 (figure 3). More detailed examination

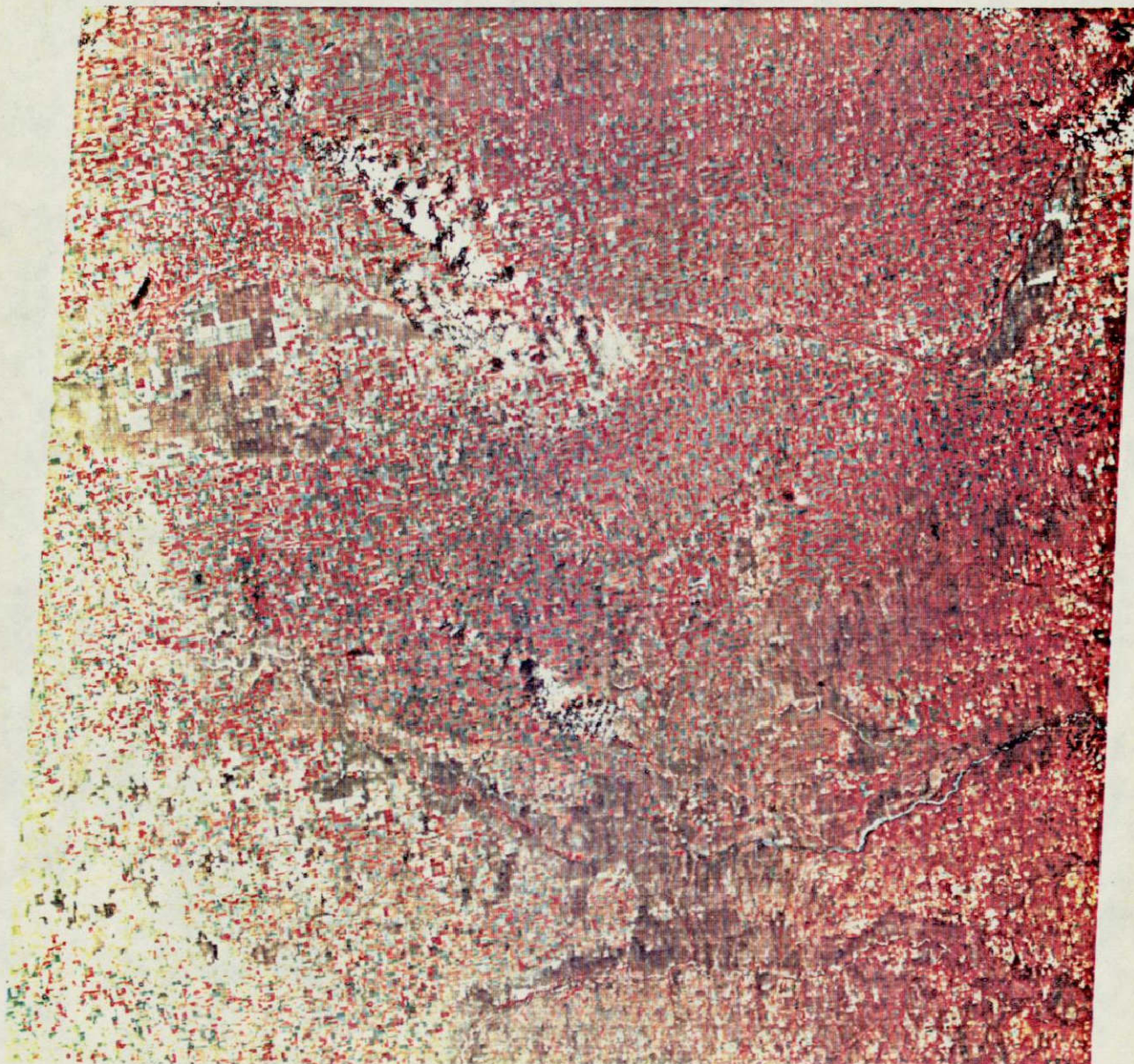
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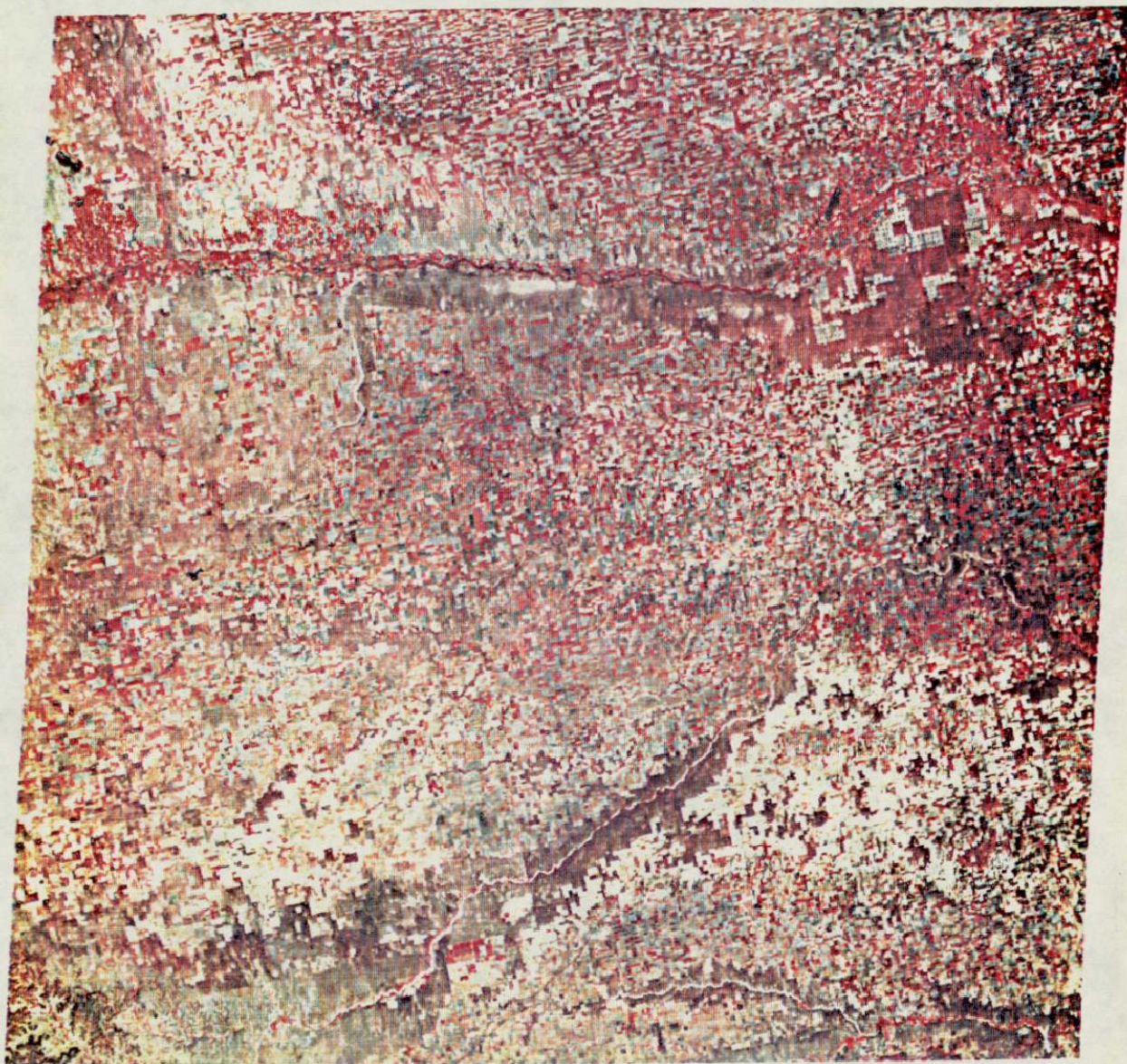
Figure 1. - Landsat image of southwestern Kansas, 26 May 1974
(with overlay of total precipitation for 23-26 May 1974).

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Figure 2. — Landsat image of southwestern Kansas, 8 May 1974.



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 27MAY74 C N37-33/W101-52 N N37-32/W101-44 MSS S 7 D SUN EL60 AZ115 190-9384-G-1-N-D-2L NASA ERTS E-1673-16505-3 01

Figure 3. — Landsat image of southwestern Kansas, 27 May 1974.

of figures 1, 2, and 3, using enlarged images, made it possible to detect some fields where poor drainage conditions caused field flooding.

An attempt was made to correlate the amount of rainfall with the degree of darkening of surfaces as seen on the Landsat imagery. There was a general agreement in that the very darkest areas appeared most often to be those areas which had experienced the heaviest rainfalls. However, the time that had elapsed between the end of the rainfall period and the data pass appeared to effect the degree of darkening much more than the actual amount of rainfall. Difficulty was encountered in attempting to ascertain the time of the end of the rainfall period because of the lack of any uniformity of observation times among the reporting stations. The first-order stations record the total amount of rainfall which occurs within the 24 hours prior to the observation time of midnight. While most of the other reporting stations record the amount of rainfall which occurs within 24 hours prior to 7 a.m., there were also some stations which make their observations at 6 a.m., 5 p.m., or 6 p.m. Since most of the data passes for the area of Kansas under study occurred a few minutes before 11 a.m., it would have been possible to have had rainfall as much as 29 hours before the data pass to 13 hours after the data pass and still be recorded as having occurred on the same day as the data pass. For this reason, the rainfall amounts shown on figure 1 overlay are the totals that fell anytime between May 23 and May 26. In this particular instance, most of the rainfall must have occurred almost 2 days prior to the data pass. Assuming the rainfall was of the afternoon convective shower type, then most of the rainfall must have occurred during the afternoon of May 24 because the majority of the stations recorded this rain as occurring 24 hours prior to 7 a.m. on May 25. Only a few stations reported very small amounts of rain occurring 24 hours prior to 7 a.m. on May 26, the day of the data pass.

Maximum temperatures just prior to the start of this brief rainy spell were in the mid 80's. During the rainy spell they dropped to the low and mid 70's. Within 2 days after the end of the rainy spell, the maximum temperatures climbed to the mid 90's and the low 100's. These high temperatures would account for some of the rapid return to normal brightness of the soil surfaces as seen the next day after the May 26 data pass (figures 1 and 3).

The drastic change in surface brightness which can occur even with very light amounts of rainfall is illustrated in figure 4. In this particular case, the month of March 1973 in Kansas was a very rainy month with rains occurring every day from March 1 to March 14. Only sporadic traces of rain occurred at a few stations between March 15 and March 19. On March 19 and 20, light-to-moderate rains occurred in eastern Kansas (figure 5), with only scattered light rains falling in portions of central and western Kansas. Figure 4 shows how one small wave of very light rainfall, mostly of only 1 day's duration, was sufficient to darken the soil surfaces which had been previously darkened by daily rains for a 2-week period until just 5 days prior to the data pass. This figure also serves to illustrate how Landsat imagery could be used to delineate fairly extensive areas of rain which had fallen between reporting stations where little or no rain was reported.

For the purpose of quantifying the changes in spectral reflectivities which occur over areas where rain had fallen recently, several histograms of radiance values were plotted for four areas which were covered by the May 8, May 26, and May 27 data passes. The location of these areas, comprising 11,000 pixels (picture elements) each, are outlined on figure 1. Area 1 borders the Finney County Intensive Test Site on its northern edge, while Area 2 is a portion of the test site itself. Areas 3 and 4 were arbitrarily selected to represent agricultural areas outside of the regions which had experienced the heavier rainfall shown in

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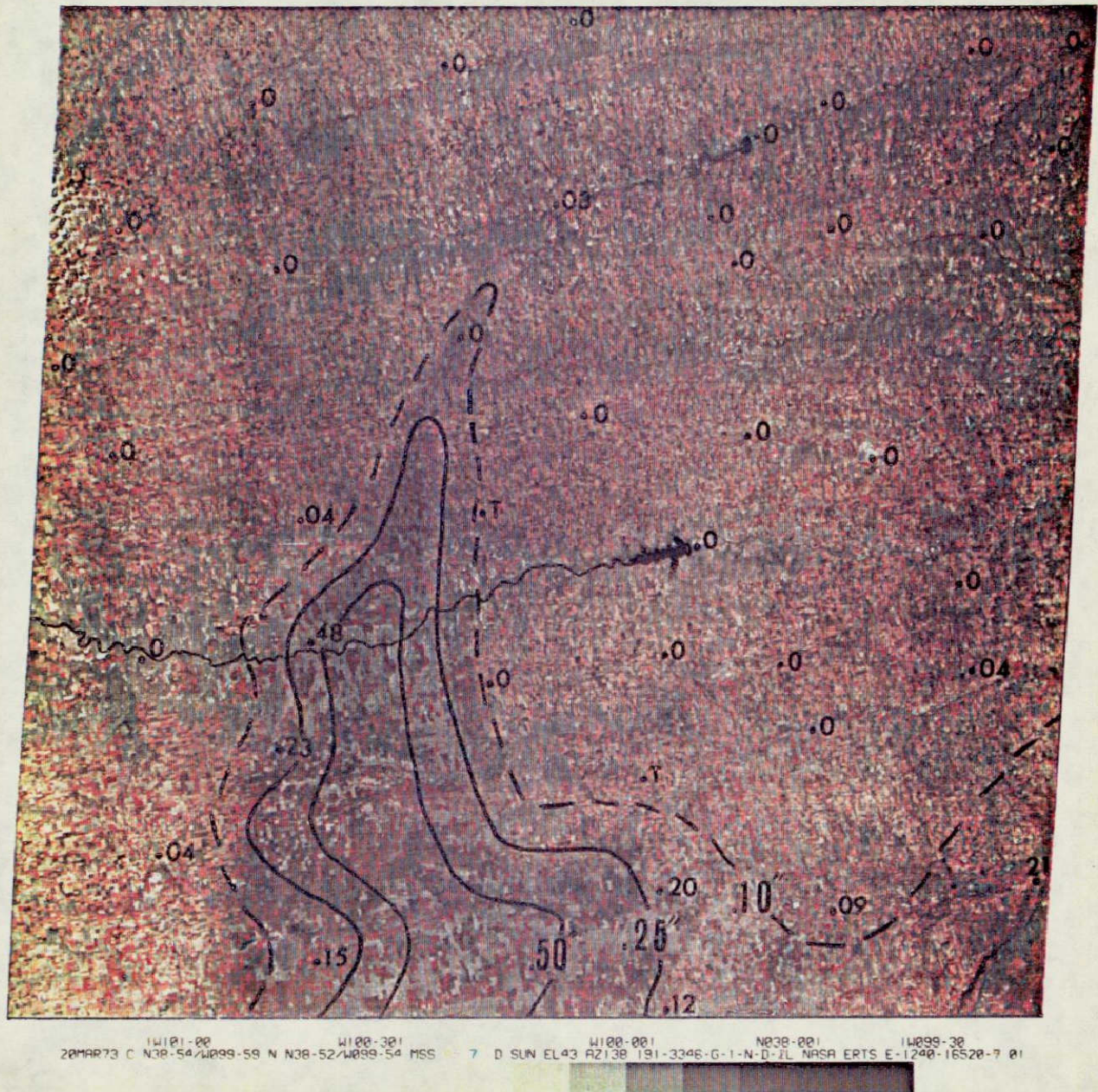


Figure 4. - Surface darkening from light rainfall of short duration
(with overlay of total precipitation for 19-20 March 1973).

figure 1. The mean, maximum and minimum radiance values for each Multispectral Scanner (MSS) channel for the four areas during the three data passes are plotted in figure 6. To eliminate the spurious maximum and minimum radiance values which often occur in the original data, the recorded values were truncated so that the calculated maximum and minimum values represent the values at which one-half of one percent (0.5%) of the total pixels in the scene were above or below the actual recorded maximum or minimum values. The radiance values of Channel 7 are plotted at double the value recorded on the Computer Compatible Tape (CCT) in order to compensate for the compression factor used in recording this channel from the original sensor data.

It is evident from the graphs in figure 6 that the mean radiance values for all four MSS channels decreased significantly in Areas 1 and 2 where the heaviest rainfall occurred shortly before the May 26 data pass. By the next day (May 27) these mean radiance values had increased almost to the level of the May 8 levels, which in this case are considered as depicting the more normal levels of scene brightness. It is believed that the May 27 radiance values normally should have been slightly higher than the May 8 radiance values because of the increase in leaf area index of most of the vegetation. The fact that the May 27 radiance values are not quite as high as the May 8 radiance values would indicate that a small amount of residual moisture still remains in the soil surfaces. A detailed comparison of figures 2 and 3 appears to confirm this premise. A qualitative estimate of the total amount of precipitation may be inferred by noting the magnitude of change in mean radiance values in Areas 1 and 2, and by referring to the general appearance of the outlined areas on figure 1. It appears that Area 1 had heavier rainfall than Area 2. Unfortunately, detailed ground truth is not available to confirm this premise.

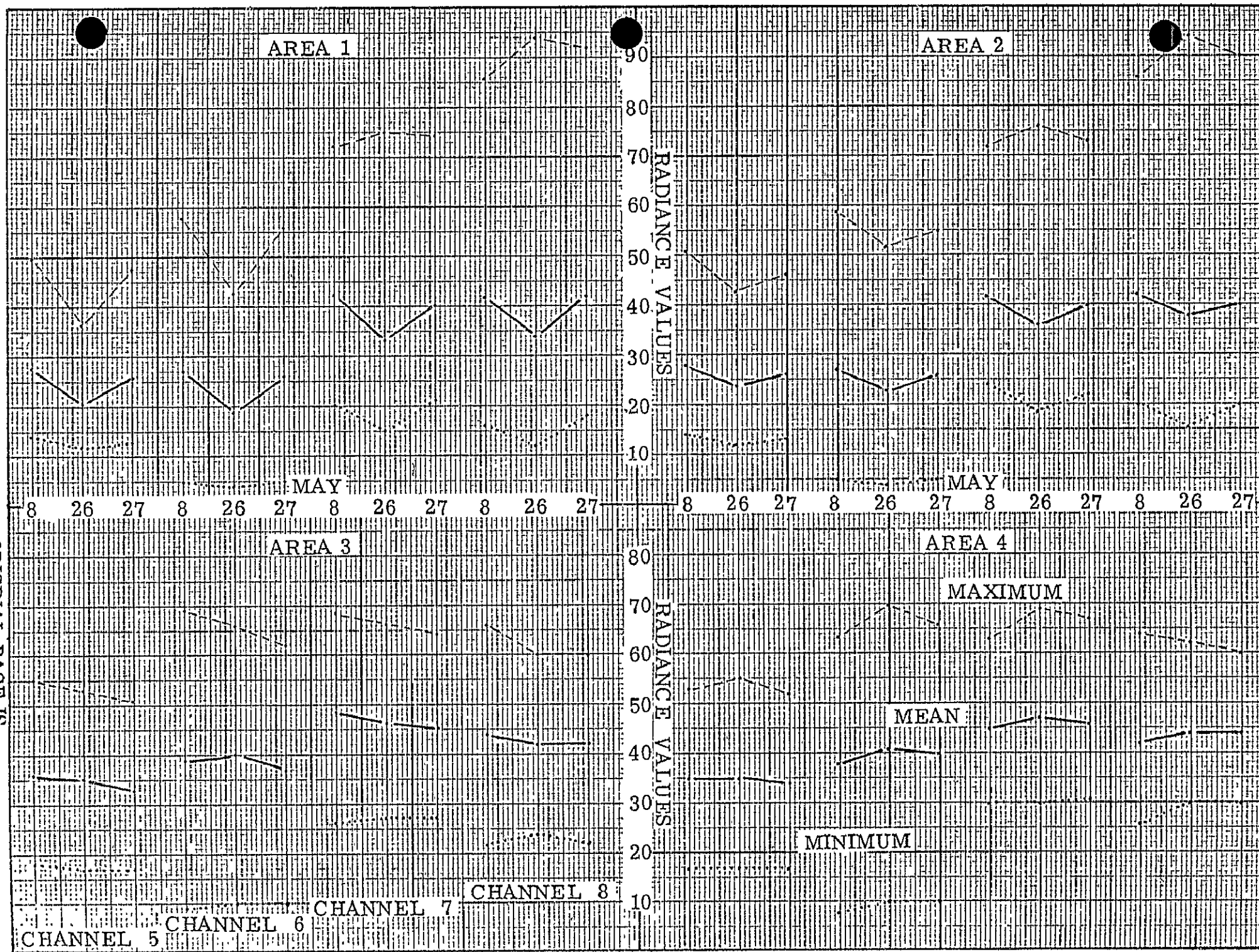
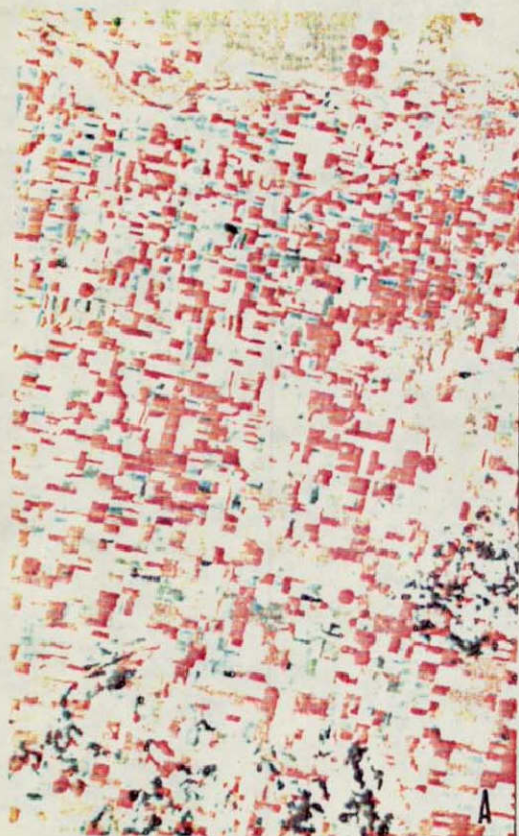


Figure 6. - Radiance values of selected agricultural areas.

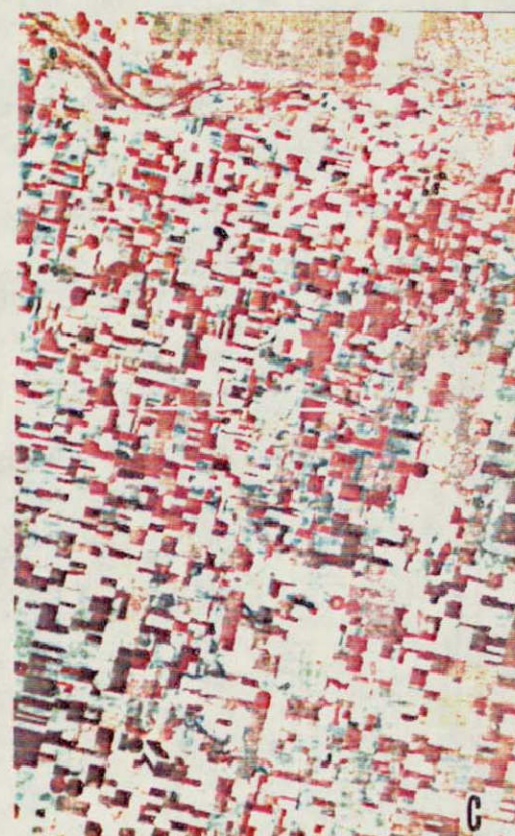
The mean radiance values of Areas 3 and 4, where very little rain had fallen prior to May 26, remain relatively constant for the three data passes. The differences in the trends of the maximum and minimum radiance values for the four areas should be noted. The minimum values remain fairly constant throughout the three data passes, whereas the maximum values change considerably. In the two visible channels (4 and 5) the maximum values decrease drastically in the two areas (1 and 2) where heavy rains had occurred before the May 26 data pass. In contrast to this, the maximum values increased in the two infrared channels (6 and 7) in the same areas. This would indicate that a considerable increase in scene contrast occurred in the infrared channels in scenes where the rain had occurred. If either of the infrared channels were used to generate simulated color infrared images, the increase in maximum radiance values after a rain would tend to make some heavily vegetated fields (alfalfa, for example) to appear even brighter red despite the overall darkening of the entire rain area as indicated by the decrease in mean radiance values in all four channels.. This increase in scene contrast (winter wheat becomes darker, alfalfa becomes brighter) is illustrated in several images which were generated from the computer compatible tapes obtained from the May 8, May 26, and May 27 data passes. A constant gain and bias input, as calculated from the radiance values of the entire scene of Area 1 for May 8 (no rain), was used in generating figures 7A, 7B, and 7C. No explanation can be offered for the more pinkish color of the grass/pasture lands in the May 26 scene when compared with the other two scenes. The three scenes were generated from the same registered computer compatible tape and were processed at the same time on the same roll of film. The histograms for several sample fields of grass for the three dates did not reveal any pronounced differences in radiance values (figure 8).



(A.) 8 May 1974



(B.) 26 May 1974



(C.) 27 May 1974

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Figure 7. - Comparison of different date images generated from May 8 histogram values.

The apparent increase in some maximum radiance values after rain had occurred was confirmed when histograms of individual fields were obtained. The selected areas for which histograms were obtained were arbitrarily limited to 5 x 5 pixel (25 pixels) areas near the center of fields of winter wheat, alfalfa, and grass or pasture. Approximately one-half dozen fields of each of the three types of vegetated surfaces were selected in both the rainfall and the drier areas. The mean radiance values for each sample of vegetation were averaged together, and plotted as an average mean radiance value for winter wheat, alfalfa, or grass. For comparison purposes one sample of 25 pixels was histogrammed for each of two different bodies of water.

Figure 8 shows that the average mean radiance values for winter wheat in the rainfall area follows a distinctly different trend for the three data passes than do the values for alfalfa and grass. Apparently, the mean radiance values for wheat in the rainfall area decreases on May 26 in both the visible channels (4 and 5) and the infrared channels (6 and 7). This is probably due to the preponderance of wet soil background in the integrated wheat signature. In contrast to this, the mean radiance values of the wheat from the drier area remain relatively constant for the three data passes, and bear some resemblance to the trend of the values for grass in both the rainfall and drier areas. Alfalfa, on the other hand, apparently increased considerably in vigor during the rainfall period as evidenced by the sharp increase in infrared radiance values for the May 26 pass. This increased vigor appeared to be temporary, since the mean radiance values had already declined by the next day (May 27). The visible color of the alfalfa seemed to remain fairly constant for the three data passes.

No ground truth was available for the water bodies, except that it was reported that the body of water in the rainfall area was a low lying area into which excess irrigation water and rain water accumulated. The decrease in mean radiance values for May 26 for this shallow body of water is probably due to the increase in depth of the water following a spell of rainfall. The trend of the mean radiance values for the other body of water is probably more representative, since this body of water is a large, deep permanent lake. The very slight rise in mean radiance values for this lake from May 8 to May 27 may be due to the slight increase in Sun elevation and/or to the increased atmospheric transparency following the spell of rain.

A cursory study of detailed soil maps for this particular part of Kansas (Finney County and Lane County) did not reveal any close correlation between the areal extent of the surface darkening after a rain and the boundaries of any particular types of soils. The boundaries of the darkened areas appeared to cut across various soil regions. Only in a few small areas where the soils were described as sandy or with very rapid drainage characteristics did the surface darkening appear to be less pronounced. Whether this lighter color was due to the actual color of the soil, the more rapid drying of the surface, or to a smaller amount of rain falling in these areas could not be determined without much more detailed ground truth. The network of weather reporting stations in these particular areas was too sparse to provide the microclimate type data that would be necessary for a more conclusive analysis of the relationship of soils, rainfall amounts, and surface darkening seen on Landsat imagery.

A review of additional full-frame Landsat color images of Kansas provided examples of other episodic phenomena which could greatly influence the accuracy of field identification and wheat classifications. Figure 9 shows an example of a high, thin cloud which

was translucent enough to allow field patterns to be observed almost as though the cloud did not exist. Although the fields were readily visible through this cloud, it is suspected that classification difficulties would be encountered if only a small segment were selected from either the cloud or cloud shadow portion of the full frame imagery. The density of the cloud shadow would indicate that some fields would be obscured more than might be suspected from the translucent appearance of the cloud as it appears on figure 9.

Figure 10 demonstrates the type of imagery which would be generated if only a small cloud or cloud shadow segment (comparable to a LACIE operational segment) were used to obtain the histogram values for input to the film recorder. Figure 11 shows the type of imagery resulting from a histogram of an area which included radiance values from both the cloud area and the cloud shadow area in its calculation. Although this image can be considered a reasonable compromise between cloud and shadow, it is evident from a comparison with figures 10(A) and 10(D) that less difficulty could be expected in interpreting colors if the images were generated from histograms which covered only the area of the specific images to be studied.

Another episodic phenomenon, which could effect the accuracy of field classifications, was observed on several different frames of Kansas imagery. On several occasions multiple condensation trails (contrails) from high flying jet aircraft were detected on images which, otherwise, were cloud-free. While the contrails, themselves, were usually barely visible, the linear configuration of the shadows from the contrails were very noticeable. The shadows, in some instances, darkened a swath of the Earth's surface as much as 1.0 km wide and 80 km long. Although this extent of shadow appears minor in respect to the size of a sample segment, it does have the potential of affecting the subsequent

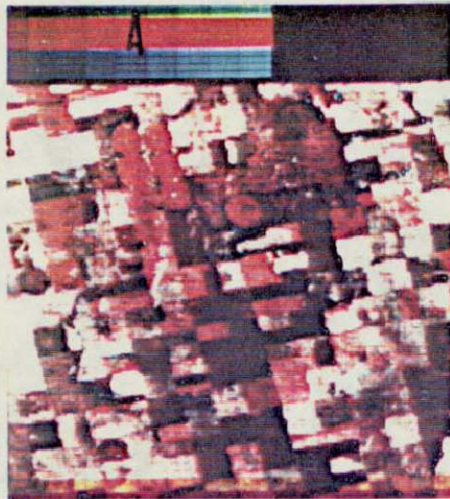
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Figure 9. - Landsat image with thin, translucent cloud
and cloud shadow.

- A. Shadow Area Image Generated with Histogram Values from Shadow Area
- B. Shadow Area Image Generated with Histogram Values from Cloud Area
- C. Same Area as Shadow Area (B) on a Clear Day (2/26/74)



- D. Cloud Area Image Generated with Histogram Values from Cloud Area
- E. Cloud Area Image Generated with Histogram Values from Shadow Area
- F. Same Area as Cloud Area (E) on a Clear Day (2/26/74)

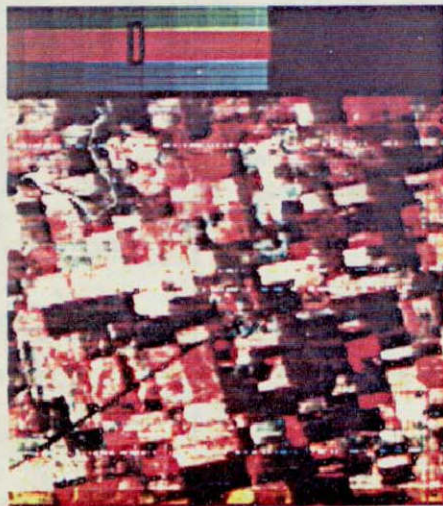


Figure 10. - Enlarged images generated with histograms of separate cloud and cloud shadow areas.

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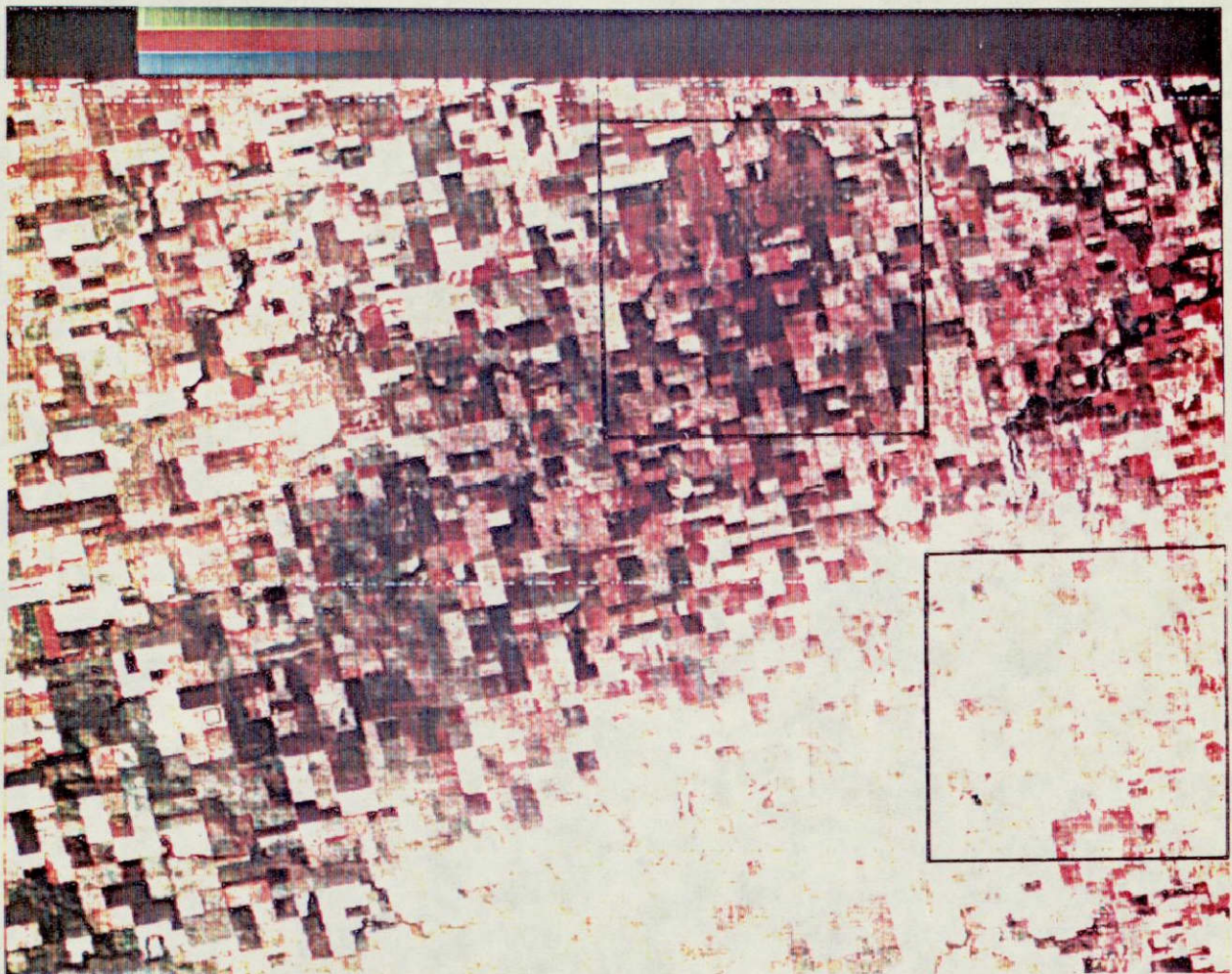


Figure 11. — Enlarged images generated with histograms of combined cloud and cloud shadow areas.

classifications of fields which may have been selected as training fields on previous data passes. It is quite possible that this phenomenon may be so uncommon (except in the vicinity of commercial or military airways) that it may be discounted in the overall classification procedures. The experienced image analyst should have no difficulty recognizing contrails if he has access to full-frame imagery on which they are easily detected.

The occurrence of an infrequent, but potentially devastating, episodic phenomenon was also detected on a few frames of Landsat imagery of Kansas. This occurred along some river bottoms where flooding resulted from 2 days of heavy precipitation. Figure 12 shows an area of east, central Kansas where very heavy rains had occurred 9 to 10 days prior to the data pass. Evidences of flooding (darkened soils) are still visible after this elapse of time. The locations of two sample segments are outlined in figure 12 to show the potential difficulties in field classifications which could occur in sample segments which happen to be in river bottom locations. No attempt was made to obtain histograms of radiance values for flooded areas. It was suspected that the flood-darkened areas would have classification anomalies similar to those in areas where heavy rains had fallen shortly before a data pass, such as the example cited earlier in this report.

4. CONCLUSIONS

It was concluded from this study that various episodic phenomena could be readily detected on Landsat full-frame color imagery. The regular use of full-frame color imagery should enable the image analyst to monitor the existence of episodic phenomena during specific data passes, and thereby increase the efficiency and accuracy of the selection and classification of training fields.

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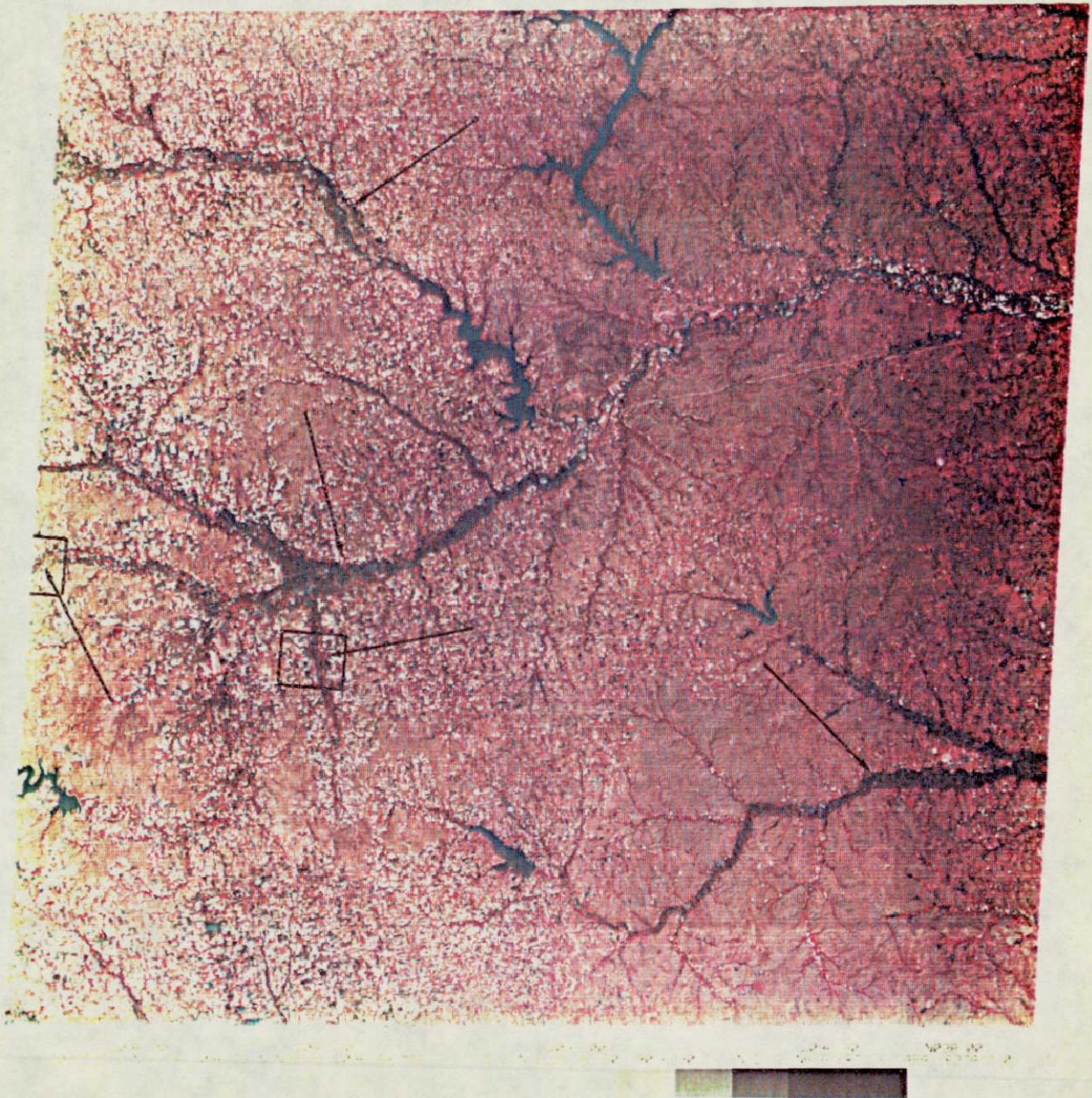


Figure 12. - Areas of severe flooding on Landsat imagery.

The very limited scope of this study (southwestern Kansas only) was dictated by the availability of full-frame color imagery and accompanying daily precipitation data for several years in the local LACIE files. Although a very cursory screening was made of a few full-frame images of limited areas in the northern Great Plains, and a few examples of rain-darkened areas were noted, the lack of necessary precipitation data prevented the extension of this study to those areas. Consequently, caution is suggested in applying the findings of this study to other LACIE areas until imagery from more diversified agricultural areas can be examined, and the rain-effected spectral signatures tested by LACIE automated data processing procedures.

