SECTION 35

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MULTISPECTRAL IMAGING RADAR

by

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ABSTRACT

During calendar year 1971 a University of Michigan fine-resolution sidelooking radar, installed in a C-46 aircraft, was modified to provide it with an initial multispectral imaging capability. The radar is capable of radiating at either of two wavelengths, these being approximately 3 cm and 30 cm, with either horizontal or vertical polarization on each wavelength. Both the horizontally- and vertically-polarized components of the reflected signal can be observed for each wavelength/polarization transmitter configuration. At present, two-wavelength observation of a terrain region can be accomplished within the same day, but not with truly simultaneous observation on both wavelengths. A multiplex circuit to permit this simultaneous observation has been designed. A brief description of the modified radar system and its operating parameters is presented. Emphasis is then placed on initial flight test data and preliminary interpretation. Some considerations pertinent to the calibration of such radars are presented in passing.

INTRODUCTION

In this report, we describe results achieved by the Radar and Optics Division of The University of Michigan's Willow Run

Laboratories under a NASA-supported* multispectral radar program. A fine-resolution airborne synthetic-aperture radar system, originally designed to operate at a wavelength of 3 cm (X-band), was modified such that, on any pass of the aircraft, the radar could be operated either at 3 cm or at 26 cm wavelength (L-band). Although funding did not permit provisions to be made for simultaneous two-wavelength operation, duplication of flight paths on successive passes was adequate to permit images generated at each of the two wavelengths to be examined in reasonable geometric registration. At each wavelength, it was possible to transmit one linear polarization — either horizontal or vertical — and to receive both the parallel-polarized and the cross-polarized components of the reflected signal. Because the two operating wavelengths differ by almost an order of magnitude, the roughness scales to which the radar is sensitive in its two operating modes likewise differ by a like amount. This feature, coupled with the greater transparency of vegetation at the longer wavelength provides us with a "two-color", two-polarization view of overflown terrain which is a potentially significant step in the direction of a multispectral microwave remote sensor.

After completion and checkout of the hardware, this simple multispectral system was then operated at Garden City, Kansas, and in the Lavic Lake/Pisgah Crater region of California. In this paper, we describe the radar system itself, and include some preliminary samples of multispectral radar imagery. The agricultural and geologic interpretation of the Garden City and Pisgah data respectively are the responsibility of University of Kansas investigators and are not treated formally in this paper.

SYSTEM DESCRIPTION

The multispectral radar consists of a synthetic-aperture radar (SAR) system which, in its basic form, operates at 3 cm wavelength. The 26-cm capability is provided by means of a down-converter inserted between the transmitter and antenna, and an up-converter inserted between the antenna and receiver. The basic 3-cm radar

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*Contract NAS 9-11036

has the following key properties:

Type:	Focused synthetic aperture
Pulse:	Dispersed, linear FM
Antenna:	Dual-polarization slotted guide array with 6 in. × 60 in. aperture, and 25 db isolation between polarization
Data storage:	CRT/film recorder
Data processor:	Coherent optical correlator

The system is operated in a C-46 aircraft (Fig. 1). For the purpose of this program, the overall system, including the data processor, yields imagery with slant-range and along-track resolutions both equal to 30 feet. Since the system is a focused synthetic-aperture radar, both values of resolution are independent of slant range at the ranges of interest to this program.

When 26-cm operation is required, the down-converter/up-converter circuitry is inserted into the radar signal chain. The RF bandwidth of the radar is not altered, although the radiated nominal center frequency is translated from 9.4 GHz to 1.265 GHz. Therefore, the range resolution of 30 feet is preserved. The 30 foot along-track resolution is likewise preserved, since synthetic-aperture systems have a theoretical resolving capability which is λ-independent. The motion-compensation circuitry which frequently is employed in SAR systems must be rescaled when λ is changed, since the inertial sensing subsystem is sensitive to aircraft translation or its derivatives, and a given translation inserts a phase error which varies as λ^{-1}. The required rescaling is provided by a gain change in an amplifier. The conversion of the system from 3-cm to 26-cm or vice versa can be accomplished in the air between passes since it was feasible to mount both the 3-cm and the 26-cm dual polarization antennas within the C-46 radome. (Figure 2) Changeover time for the RF circuitry and motion compensation scaling is about 30 minutes, considerably shorter than one day changeover time initially specified by MSC. Once the conversion from X-band to L-band is complete, the basic performance parameters are as listed earlier for the 3-cm case.

A comment is in order on the reasons why a heterodyne approach was employed to provide the multispectral capability. One fundamental reason was cost. The operating X-band system, prior to modification, contained nearly all the expensive and technically difficult components which a SAR system requires; i.e.,

Phase coherence circuitry
Broad-band pulse generation circuitry
Motion sensing and compensation
Broad-band receivers and video gain
Optical data recorders

The only new components which were required were the up/down converters, the L-band transmitter and the antennas. In addition to minimizing cost, this approach provided high probability of success, since the basic X-band system had been well proven.

PRELIMINARY RESULTS

The two-frequency radar was operated in Kansas and in California during the latter half of 1971. Figure 3 shows comparative X/L band images of a portion of the Garden City Agricultural Test Site, Kansas, generated July 23, 1971. As mentioned above, University of Kansas investigators will provide detailed interpretation of this imagery and thus only comments based on brief inspection of the data and no ground truth are presented here. The two fields called out by arrows in the four images provide an interesting illustration of the reflectivity differences to be expected at the two wavelengths and polarizations. The X-band images show some fine structure in the ground cover, possibly related to water content, while the normal polarized L-band energy probably penetrated the vegetative cover and was reflected by the residual cultivation furrows which are perpendicular to the radar line-of-sight and was reflected relatively less by the furrows parallel to the line-of-sight.

Figure 4 shows comparative X/L band images of Pisgah Crater, California, generated in October 1971. An interesting feature of these images is the relative reflectivity of the lava area left (west northwest) of the crater. This demonstrates the multifrequency radar's ability to differentiate surface roughness changes from slope changes as the relative reflectivity would remain approximately constant from wavelength to wavelength if the higher return in this area were due to slope effects.

Figure 5 shows comparative X/L band imagery of Lavic Lake, California, generated in October 1971. Once again surface roughness effects are evident with particular emphasis in the left (southwest) portion of the image.

CONCLUDING REMARKS

The radar described above satisfies the basic program objective of providing a capability for imaging terrain, with fine resolution, in two spectral regions separated by approximately one order of magnitude in wavelength. However, this system, as implemented, has several glaring weaknesses:

a) It cannot observe on both wavelengths simultaneously. Therefore, even if flight lines are repeated precisely, other natural changes may occur between observations which alter the apparent reflection properties of the surface. As one example, enough rain fell on the surface at Lavic Lake between two of the passes so that the lake surface was dry on one pass and liquid on the other (these are not the passes illustrated in Fig. 5).

b) Differences in flight path for the 3-cm and 26-cm observations result in changes of aspect and depression angle of the observation for flat terrain and differential errors in ground range/slant range transformations over hilly or mountainous terrain. As a result, λ-dependences are mixed with viewing angle dependences, and this complicates the interpretation/recognition process.

c) The two-wavelength radar is not amplitude-calibrated on either operating wavelength.

Many of the multispectral recognition concepts now being developed and applied in the IR and visible portions of the electromagnetic spectrum show promise, if suitably modified, in the microwave portion of the spectrum. A full assessment of the applicability of these techniques to radar imaging is very difficult without a calibrated and simultaneous observation system. The Michigan X/L band SAR system, while not adequate for this larger assessment, does provide a good start toward establishment of a data base which is a necessary step in the direction of multispectral radar sensing.

Figure 1. - C-46 radar testbed.

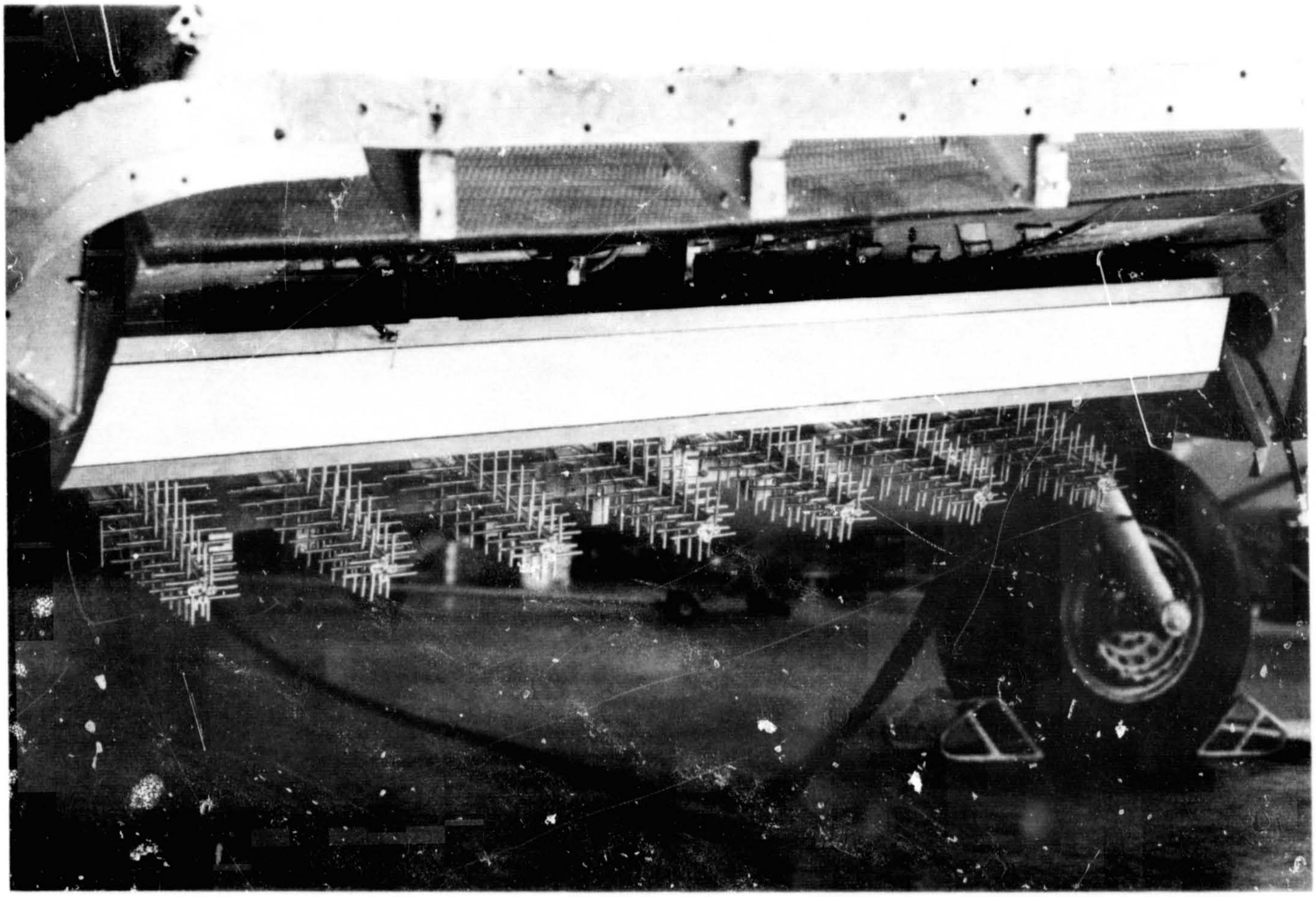
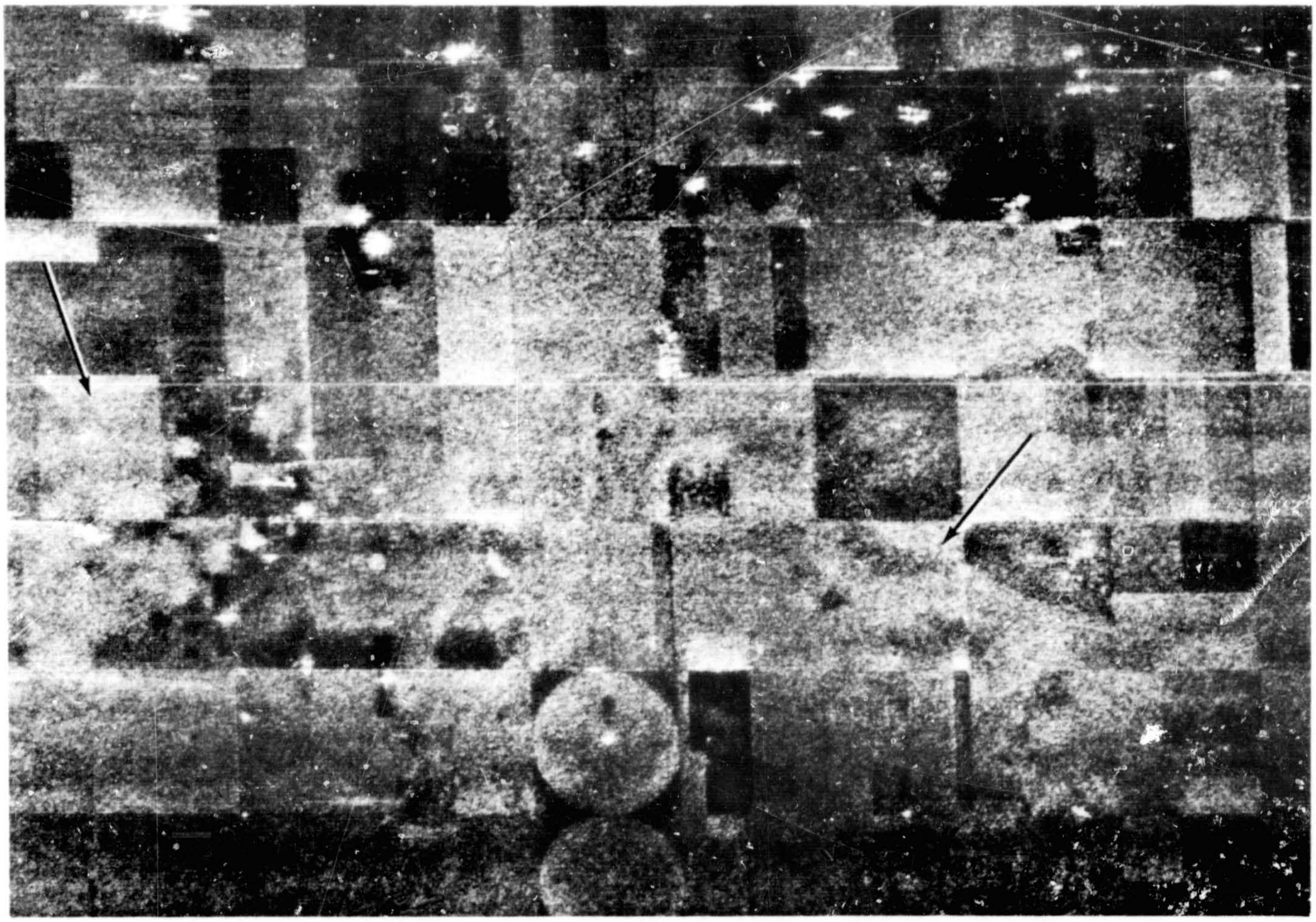


Figure 2. - X-band (above) and L-band (below) antenna installation on C-46 aircraft (radome removed).



AGRICULTURAL TEST SITE

GARDEN CITY, KANSAS

JULY, 1971

X-BAND 30' x 30'

HORIZONTAL - HORIZONTAL

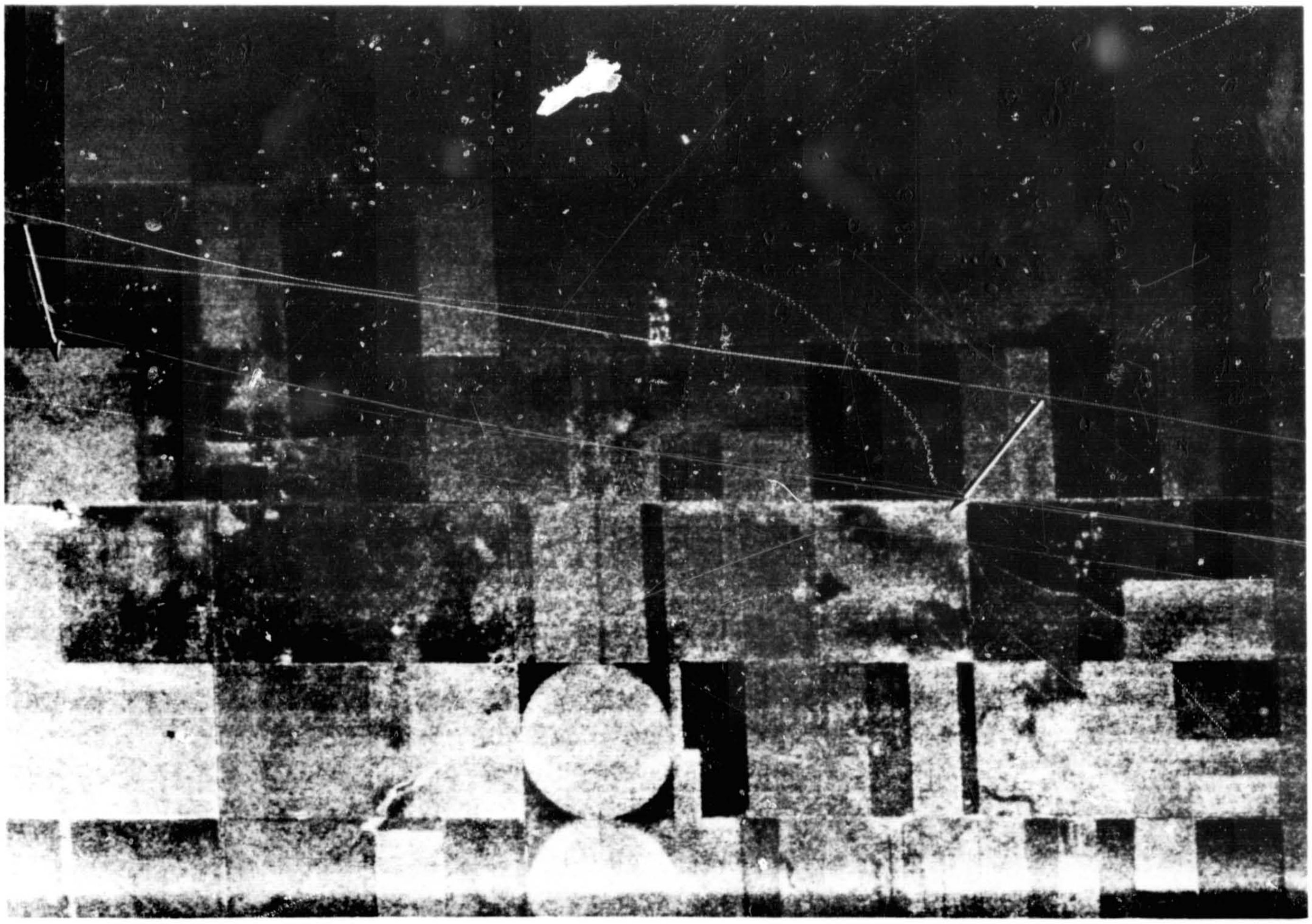
PRELIMINARY COPY

← NORTH ——

← DIRECTION OF FLIGHT ——

Figure 3. - Multifrequency, multipolarization imagery of agricultural test site.

AGRICULTURAL TEST SITE
GARDEN CITY, KANSAS
JULY, 1971



X-BAND - 30' x 30'
HORIZONTAL - VERTICAL

PRELIMINARY COPY

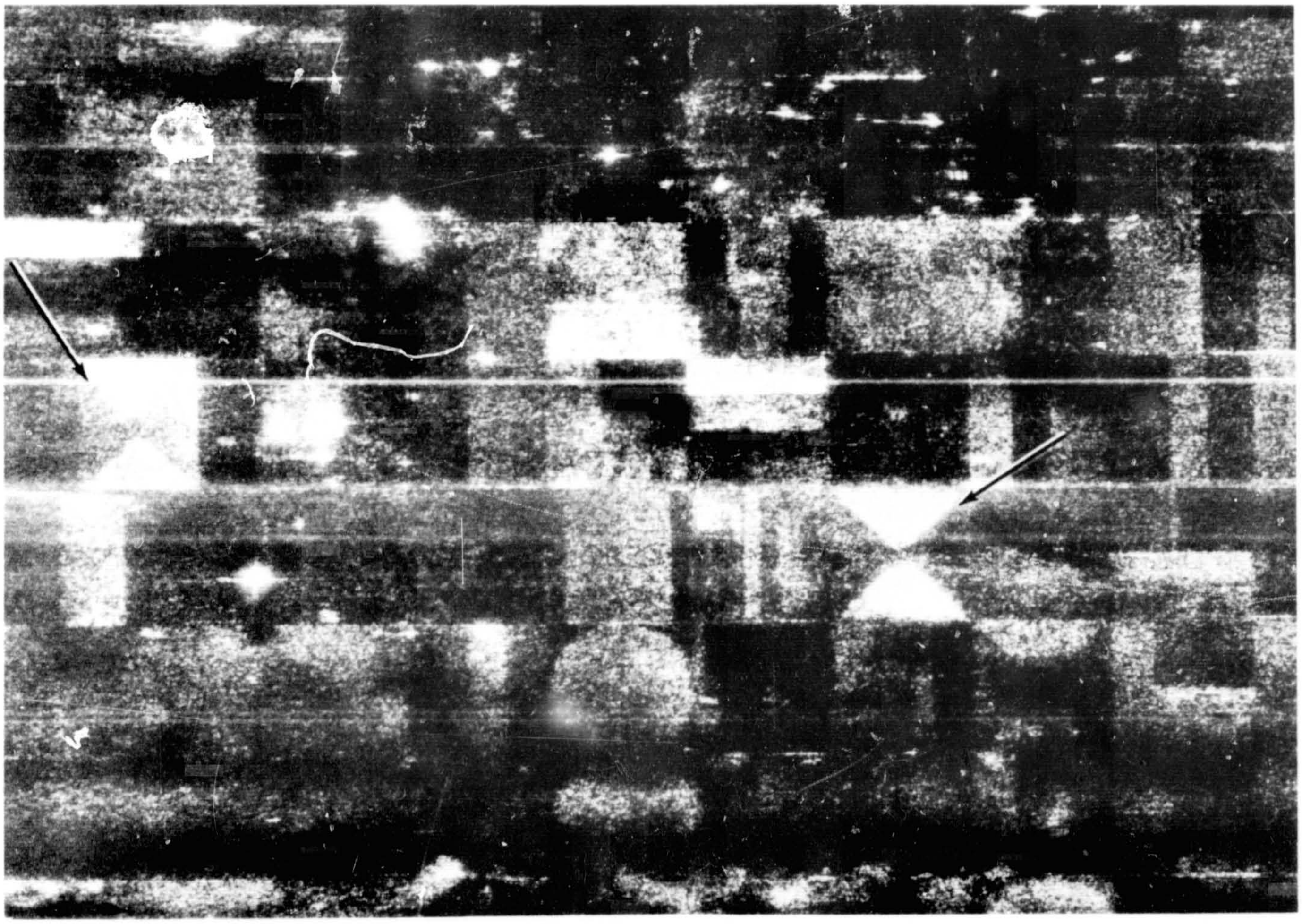
← NORTH ——— ← DIRECTION OF FLIGHT ———

Figure 3. - Multifrequency, multipolarization imagery of agricultural test site (continued).

AGRICULTURAL TEST SITE

GARDEN CITY, KANSAS

JULY, 1971



L-BAND 30' x 30'

HORIZONTAL – HORIZONTAL

PRELIMINARY COPY

←NORTH——

←DIRECTION OF FLIGHT—

Figure 3. - Multifrequency, multipolarization imagery of agricultural test site (continued).

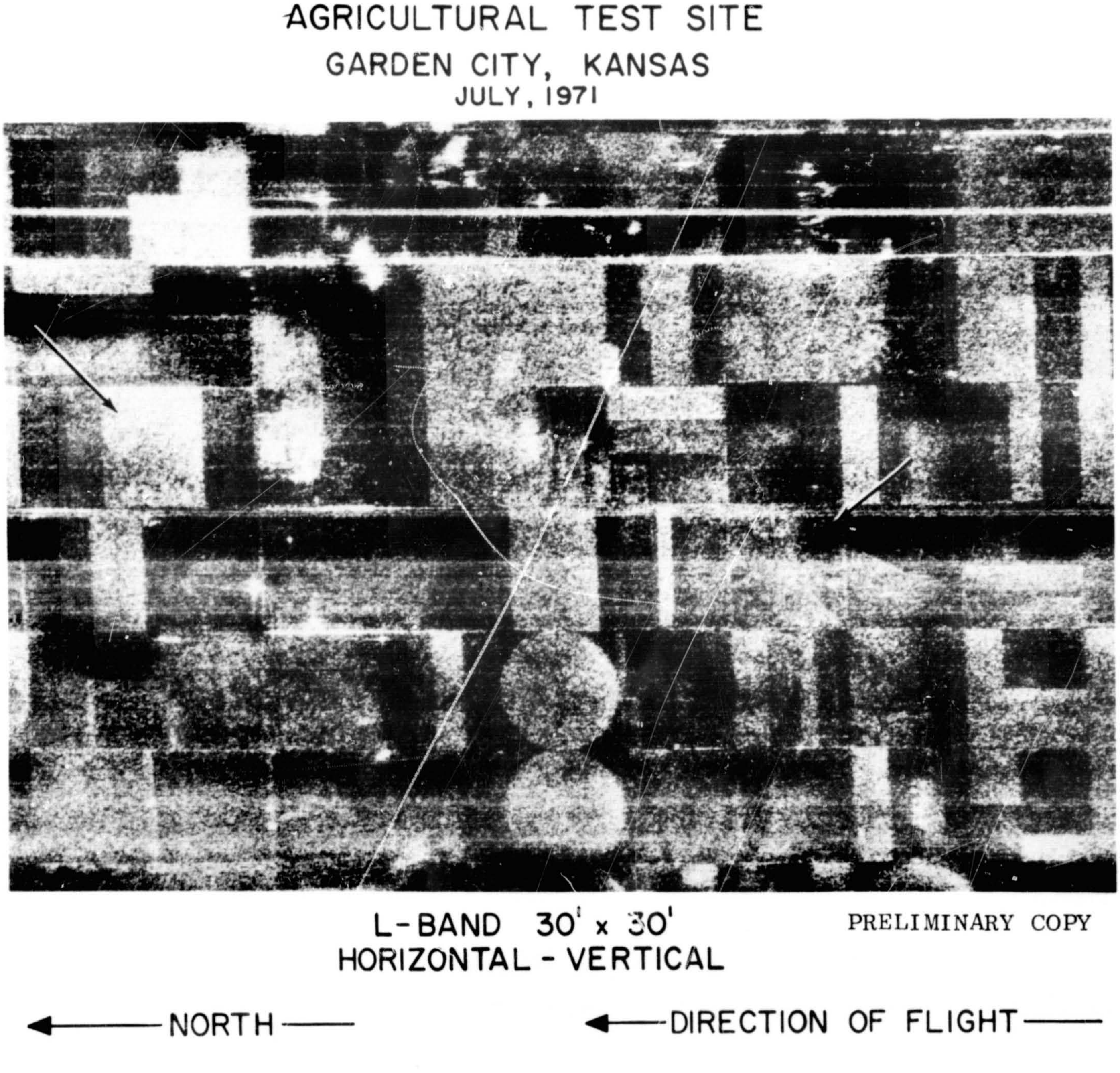


Figure 3. - Multifrequency, multipolarization imagery of agricultural test site (concluded).

PRELIMINARY COPY

Figure 4. - Multifrequency, multipolarization imagery of Pisgah Crater area.

Figure 4. - Multifrequency, multipolarization imagery of Pisgah Crater area (continued).

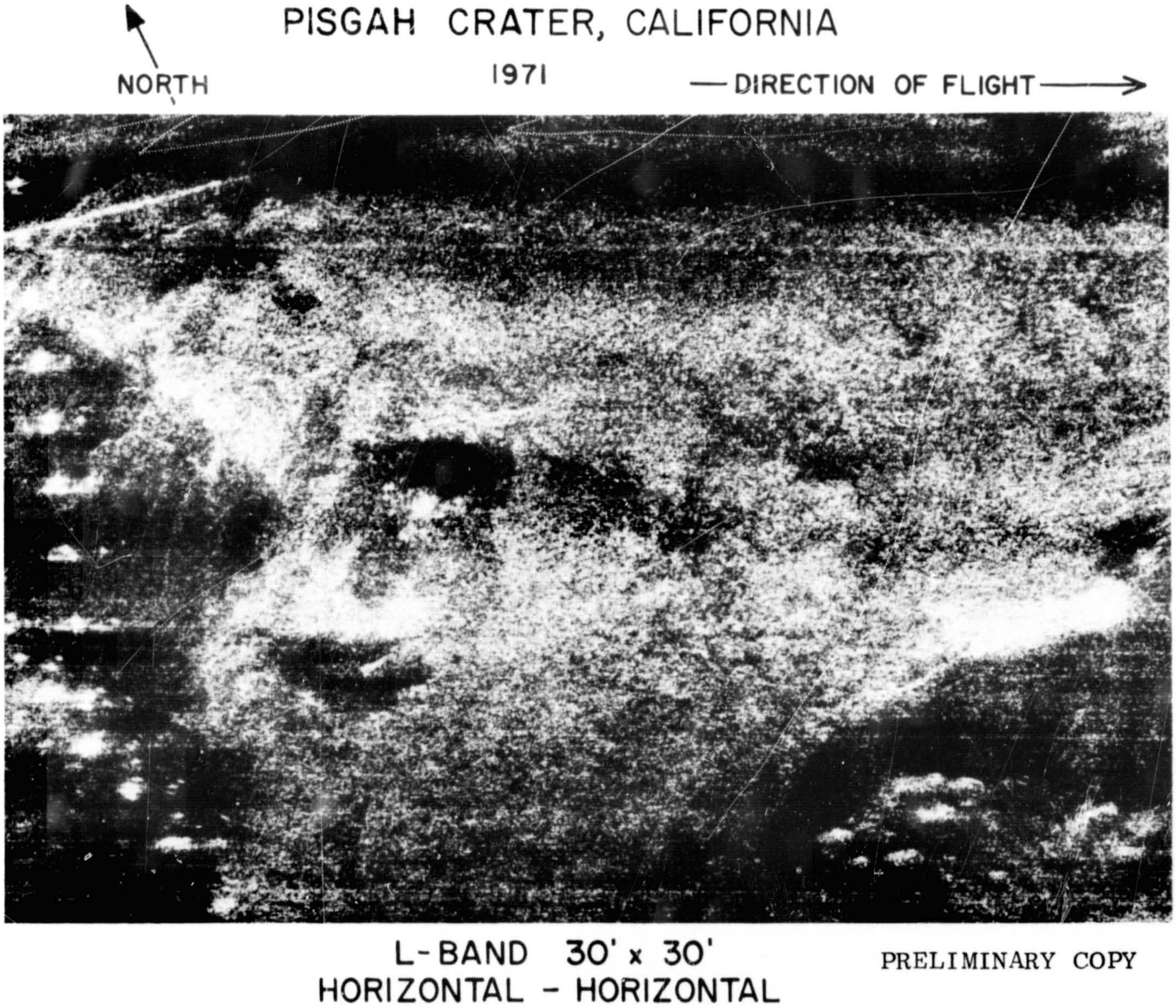


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Figure 4. - Multifrequency, multipolarization imagery of Pisgah Crater area (continued).

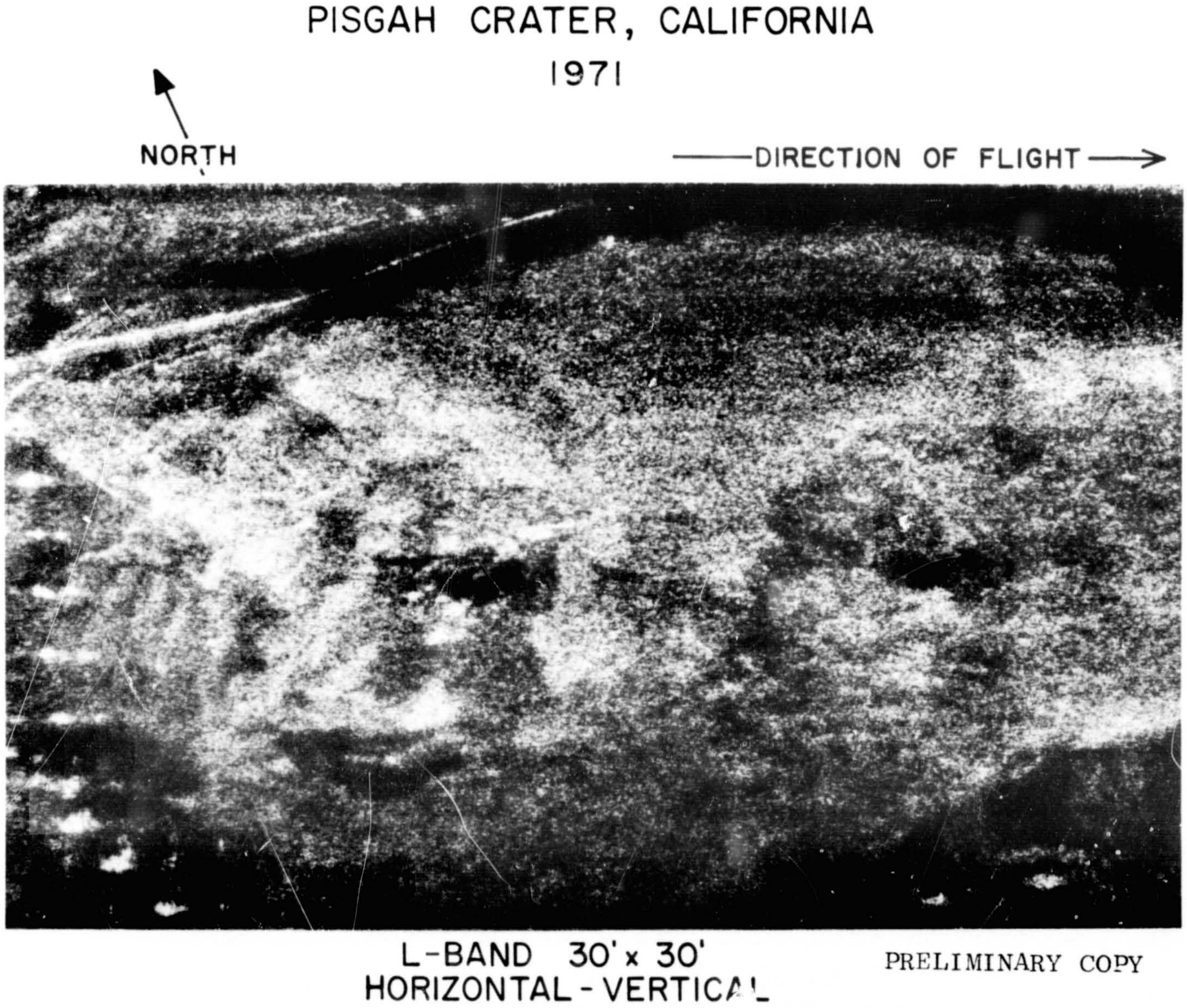

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Figure 4. - Multifrequency, multipolarization imagery of Pisgah Crater area (concluded).

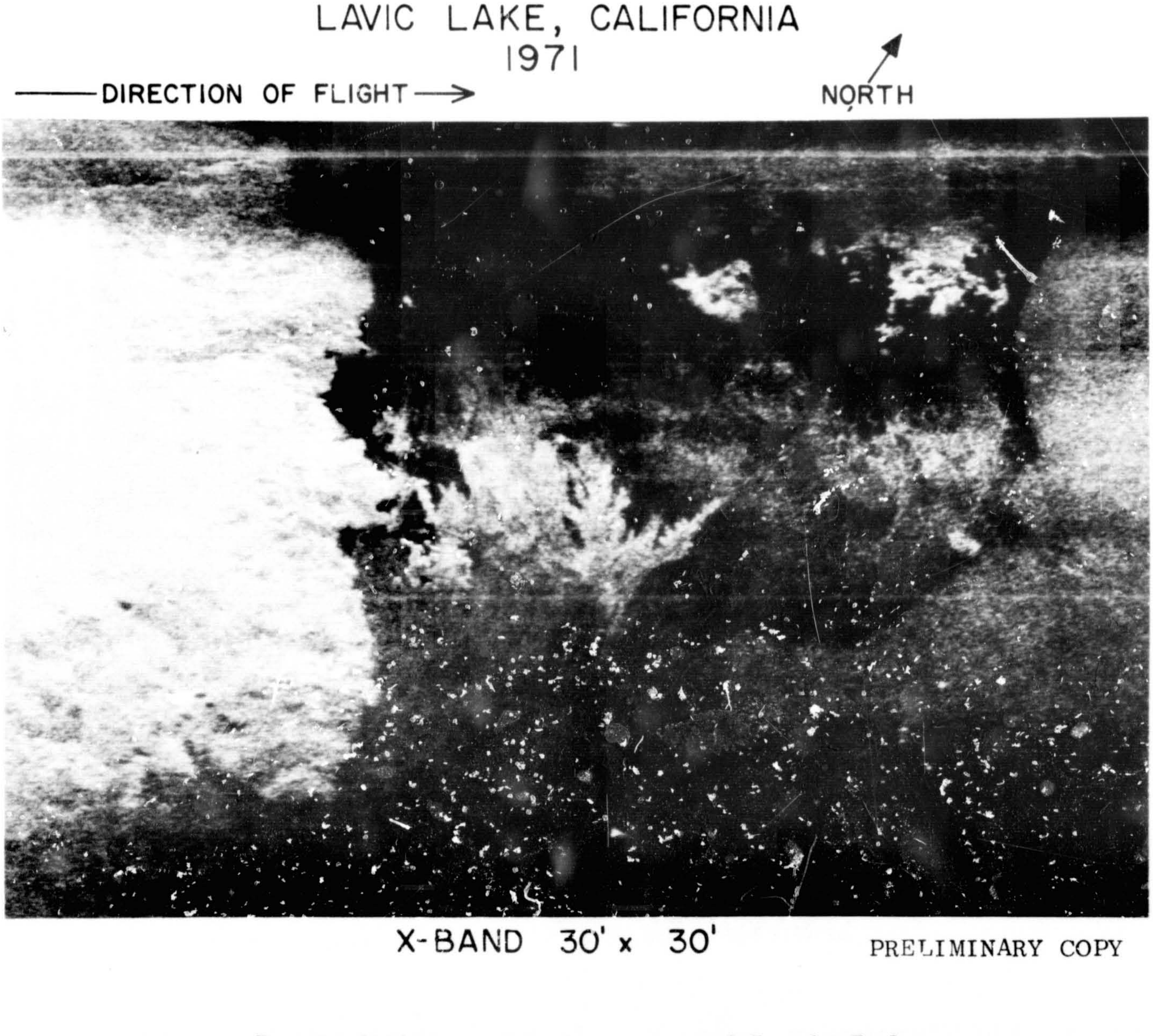

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Figure 5. Multifrequency imagery of Lavic Lake.

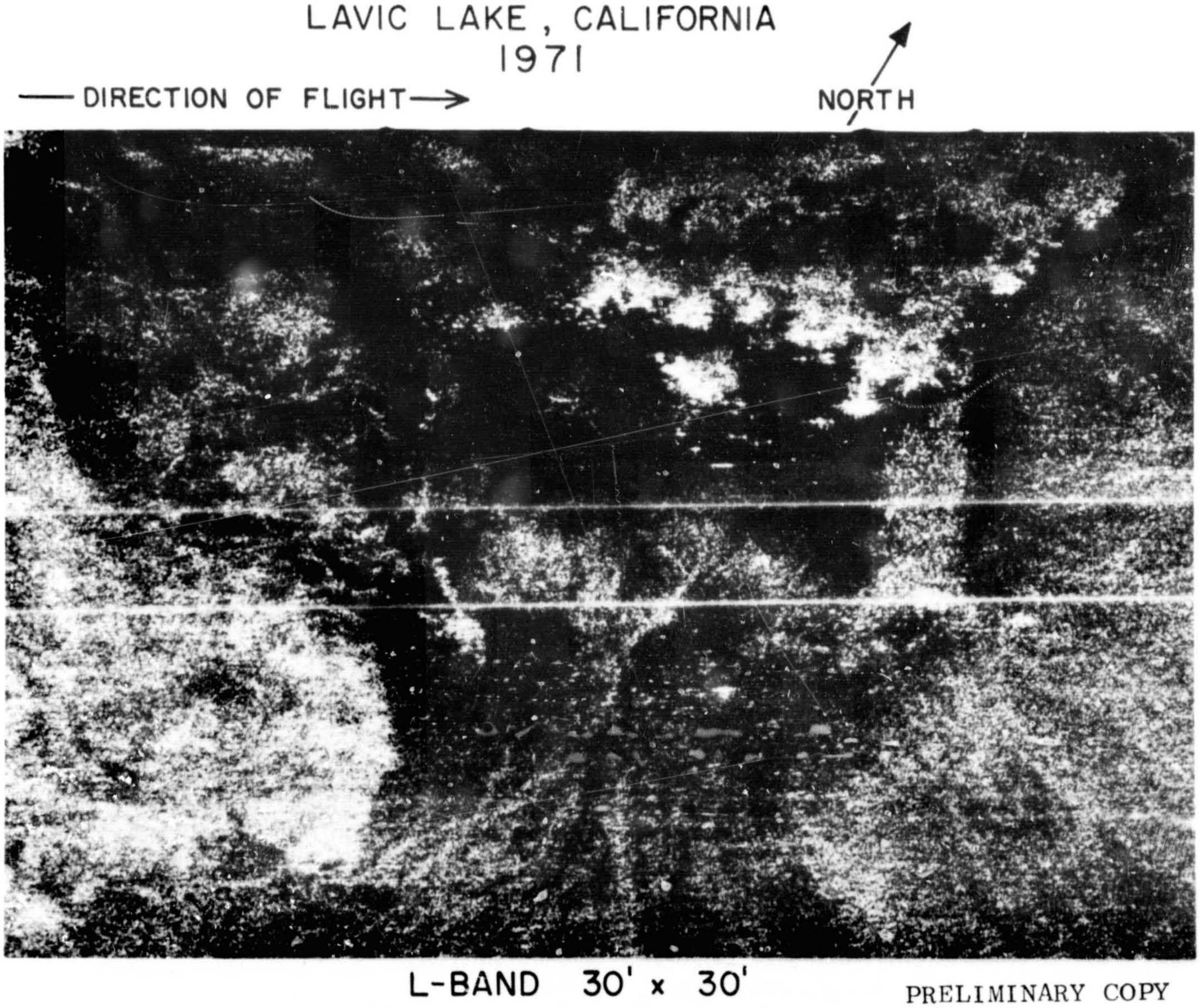

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Figure 5. Multifrequency imagery of Lavic Lake (concluded).