REMOTE SENSING APPLICATIONS IN FORESTRY

CLOUD COVER INTERFERENCE WITH REMOTE SENSING OF FORESTED AREAS FROM EARTH-ORBITAL AND LOWER ALTITUDES

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By

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ABSTRACT

Most remote sensing devices do not adequately image the Earth's surface when separated from it by cloud cover. Since few weather stations are located in forested areas, little has been known about the potential limitations of cloud cover for the remoted sensing of forested areas. This study analyzes the cloud cover problem for selected forested areas in California, including the area in which the NASA Forestry Test Site (the Bucks Lake Test Site) is located.

Cloud cover information from several selected meteorological stations in California was interpreted in order to determine its influence on remote sensing applications over forested areas. The question of predicting percent cloud cover at various altitudes was examined by relating recorded ground station observations with representative Earth-orbital cloud imagery. A comprehensive bibliography of recent research on cloud cover conditions, including satellite applications, is included. AUTHOR

ACKNOWLEDGMENTS

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The author would like to thank Mr. Raymond Gosden for his diligent assistance in assembling the bibliographic citations included in this report. Appreciation is also directed to Miss Evelyn Hall who assisted in the data card keypunching.

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CLOUD COVER INTERFERENCE WITH REMOTE SENSING OF FORESTED AREAS FROM EARTH-ORBITAL AND LOWER ALTITUDES

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INTRODUCTION

The rate at which remote sensing applications have increased in recent years has highlighted certain limitations now coming under closer examination due to the need for rapid, precise interpretation of data that can be assembled and efficiently disseminated to the scientific world. This study is concerned with one of the major sources of remote sensing limitations - the very atmosphere through which information is sought. More specifically, this study is intended to examine the need for predicting cloudiness conditions over forested areas and the accuracy with which these predictions can be made.

Cloud-free skies provide both the viewer, and most remote sensing equipment, with an unobstructed view of the terrain. Unfortunately, the Earth's surface is 50 to 55 percent obscured by clouds (on the average) at any specified time. This would present an harassing problem for scientists requiring "the best" terrain imagery were it not for the following generalities:

a) Summer and fall seasons are less cloudy than winter and spring seasons (for the Northern Hemisphere).

b) Arctic and equatorial regions tend to be less cloudy than temperate regions.

c) Diurnal fluctuations in cloud amounts exist.

d) Water bodies tend to be less cloudy than land surfaces. (See figures 1 and 9a-o.)

Planning a flight mission, whether it be low altitude or Earth-orbital, requires accurate weather information in order to predict success in obtaining certain types of terrain imagery. Cloudiness over forested areas will usually delay a flight mission designed to inventory the wildland resources. In the case of forest fire detection and disease and insect control, timing of imagery is of the utmost importance. Remote sensing systems relying on conventional imagery (i.e., panchromatic and color photography) are hindered by clouds even when cloudiness is as low as two to four-tenths skycover. When such conditions prevail, flight missions must be rescheduled for a more favorable situation (though not necessarily a more favorable time) to retrieve optimum information. (See figs. 2 and 3.)

A brief examination of the electromagnetic spectrum reveals the requirements necessary to overcome or at least reduce atmospheric interference in obtaining specified imagery. Each film and/or recorder has a specified region of sensitivity and, with it, a compromise between resolution and attenuation due to atmosphere. Orthochromatic film is sensitive at short wavelengths and consequently has poor penetrating power through atmospheric haze. Panchromatic films extend to longer wavelengths but corrective filters are required to reduce the problem of haze; conventional color films have sensitivities beyond the panchromatic range (i.e., at longer wavelengths) and thus possess greater haze penetrating ability. As illustrated in figure 4, however, severe atmospheric haze ("smog") can seriously deteriorate the image. This emphasizes the fact that atmospheric particle size is directly related to the ease with which remote sensing can penetrate dust, smoke, and clouds. Figure 5 reveals a radar image taken with considerably longer wavelengths that essentially "see through" particles of the size that contribute to a cloud formation. Radar imagery also is capable of registering detail at night, as well as during the day, should the need arise. Since cloud particles are somewhat larger than smoke particles, this suggests that a sensing device for detecting forest fires (even under obscured skies) using the same wavelengths as are used in radar sensors, might prove superior to conventional methods of detection now in operation. However, at these radar wavelengths greater success for fire detection might be obtained through use of a "passive" microwave sensor rather than an "active" radar system.

Greater detail and image resolution is possible using panchromatic type films (see figure 6) than with radar or passive microwave sensors. For general, gross surveys and special applications, however, radar or passive microwave sensors may be more desirable whenever clouds are a problem.

JUSTIFICATION

The necessity for predicting cloudiness over either a specific region or a very large portion of the Earth has far-reaching implications. From a forestry standpoint, these implications can be expressed in terms of the ease with which land-use surveys are made, timber species and quantities delineated, management decisions formulated, forest protection practices intensified, and many other forestry applications developed.

METHODS AND PROCEDURES

In conducting this study of cloud amounts over forested areas, it was decided that California would provide suitable regions to investigate for the following reasons:

a) the diversity of forested and agricultural conditions

b) the well distributed weather station coverage

c) the complexity of meteorological conditions, and

d) the presence of NASA test sites for which cloudiness is an important concern in flight mission planning.

Cloudiness information for eight stations was obtained from the Weather Records Center, Asheville, North Carolina. This information consisted of magnetic tapes and punched cards. In addition, representative TIROS imagery was obtained as an aid in interpreting data on cloud amounts. (Refer to figs. 7-9.) The Reno weather station was included to indicate how cloudiness changes from the crest of the California Sierra Nevada Range to the Great Basin Plateau. This information is included in the "Results" section where Blue Canyon cloudiness is compared with that of the Reno station.

Where possible, each station was analyzed for a fifteen year period. Monthly summaries were made first and variations of cloudiness tested so that 95 and 90 percent confidence bands, respectively, were computed. Blue Canyon and Reno data are attached herein. Simply, the method of computing these confidence bands is:

Confidence level	Confidence band
95%	monthly average $\pm$ 1.96 (standard deviation of data in population)
90%	monthly average $\pm$ 1.64 (standard deviation of data in population)

The ninety-five percent (upper) confidence level was chosen because it was felt that, owing to the nature of weather data, a greater confidence requirement would result in too broad an interval for realistic cloudiness conditions in any given area. The ninety percent (lower) confidence level was chosen because it was felt that little significance could be ascribed to cloud-cover predictions based on a degree of confidence lower than this.

By applying the foregoing simple analysis to the weather stations incorporated in this study (see map, page 8), it was then possible to summarize in tabular form the levels of confidence associated with the specified time interval of cloudiness data. Cloudiness data for specified altitudes and times of day were available, but cursory examination of these suggested that less than meaningful information would result from the method selected for analysis. Consequently, monthly summaries are presented herein without regard to differences in cloud altitudes. It should be emphasized that long term records of cloudiness data are currently undergoing adaption to EDP files so that records longer than those employed in this study can be analyzed quickly in the future.

The generalization regarding cloudiness conditions over a forested region--which might result from a few, widely scattered weather station skycover reports--may prove entirely adequate for certain objectives; but, for the most part, these generalizations must be loosely interpreted. Meteorological variables have been shown to be complex in nature, and considerable "homogeneity" of terrain is required before wide-ranging extrapolations between observing stations are made; in mountainous, forested regions these extrapolations are confounded by a multitude of variables which make predictions of clouds a generalization at best.

DISCUSSION OF RESULTS

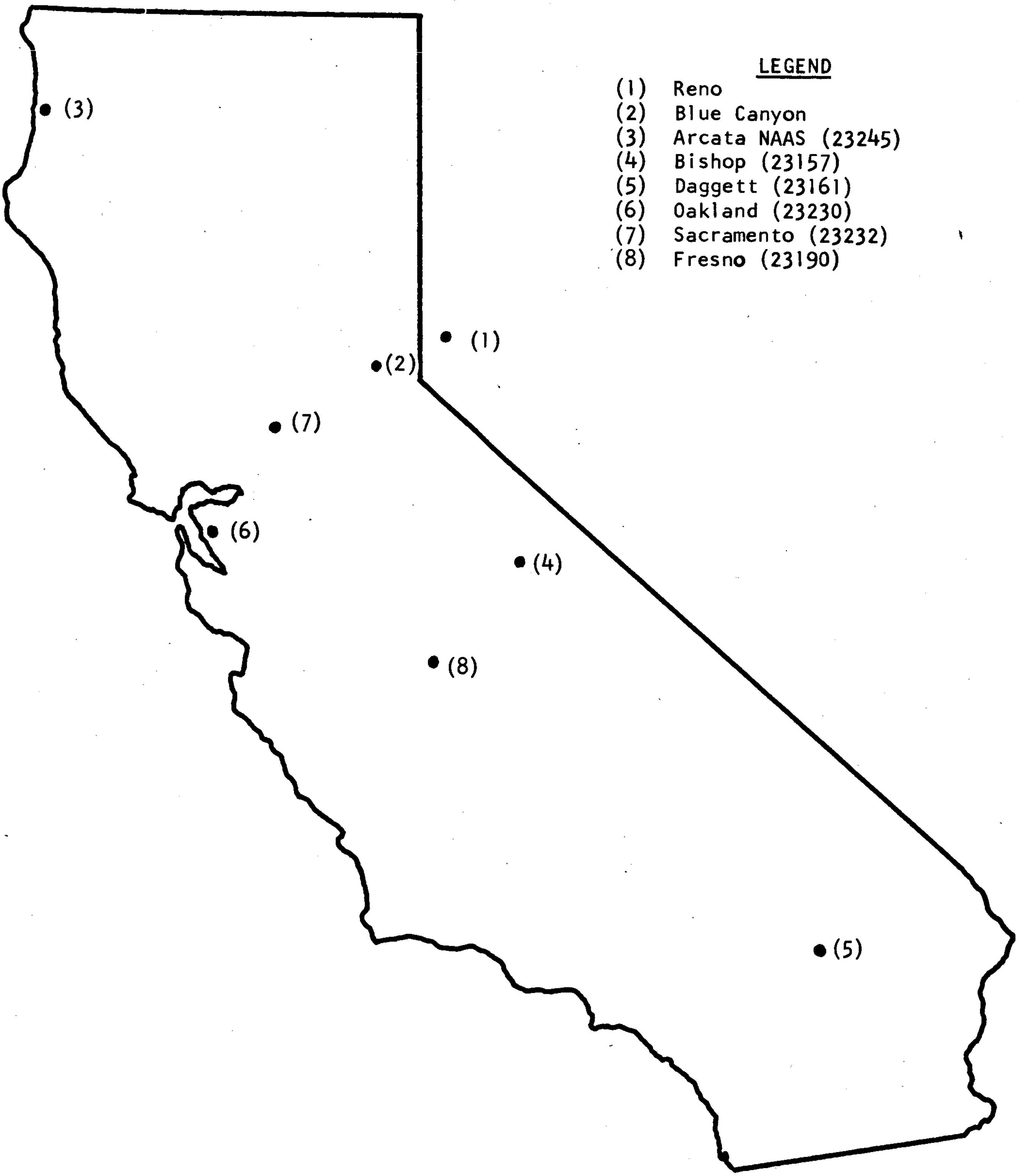
Two viewpoints of analysis commonly held by meteorologists--numerical analysis and synoptic analysis--have been incorporated in this study as an aid to deriving meaningful results.

The sparsity of weather stations so situated as to record cloud cover in remote forested areas presented problems, in this study, of extrapolating data between stations. A similar difficulty would likely exist with respect to most other forested areas of the world. In the absence of an adequate network of weather stations, the problems associated with predicting cloud amounts of a specified forested region are very complex. It is readily seen by noting figure 1 that present weather stations recording cloud cover are located in well established sites. The forested regions of the southeast United States, in fact, are sufficiently homogeneous in land features that a closer interpretation of data (vis., cloudiness at various altitudes and times of day) is possible with reliability for success greatly enhanced. Along the Pacific Coast Range and Rocky Mountain Range, however, this homogeneity deteriorates into a myriad of terrain characteristics such that forested regions remain relatively remote even by present standards. Many meteorological variables can contribute to cloudiness and the interplay of these variables is not completely understood at the present time. Promising factors for additional study include upper air wind patterns that contribute to changing weather conditions, precipitation records, and radiation measurements.

The use of weather satellite imagery is a proven application for instantaneous weather surveys throughout the world. The latest Nimbus series of weather satellites provides the Weather Bureau with the best available source of rapid world-wide weather data now known. Nephographs showing cloud type and distribution are drawn up, and when compared with long-term ground observations, show broad agreement. It should be mentioned that the resolution of such imagery is such that little extrapolation beyond meteorological aspects is commonly made. To the meteorologist, clouds become a "target" rather than an obstruction.

The following tables list summaries of cloudiness over a period of years for the stations included in this study: Blue Canyon, located at the crest of the central Sierra Nevada, and Reno, Nevada, some thirty miles away are especially interesting to compare. The Reno station is broken down into nighttime hours and daytime hours and it is seen that clouds are less frequent during the nighttime hours on the average. In comparing the two tables the difference between nighttime and daytime cloudiness for the Reno station must be considered. The most cloud-free periods for these two stations are July and August for Blue Canyon (averaging close to twenty cloud-free days a month) and August and September for Reno (averaging fifteen cloud-free days a month). Timing of ground observations is at six-hour intervals. Afternoon build-up in the Sierra Nevada during these summer months somewhat confuses the problem of recording cloud cover.

In conclusion, this author feels that useful generalizations presently can be made regarding the weather situation likely to exist at given times over a given forested area. When it appears probable from these generalizations that cloud cover will obscure forested areas of interest from aerial view, radar or passive microwave imagery may still provide very useful information despite its present limited resolution characteristics. Continuation of basic research of the type suggested and reported herein, including extensive use of data available from weather reconnaissance satellites, should steadily improve the accuracy with which these vital weather predictions can be made.



The above map of California depicts the location of weather stations used in assembling data on cloudiness for this study; the Bucks Lake Test Site is some 50 miles north of Blue Canyon (1); Pisgah Crater is only 11 miles from the Daggett station (5); the Davis agricultural Test Site is 20 miles west of the Sacramento station (7); the San Pablo Reservoir Test Area is only a few miles from the Oakland station.

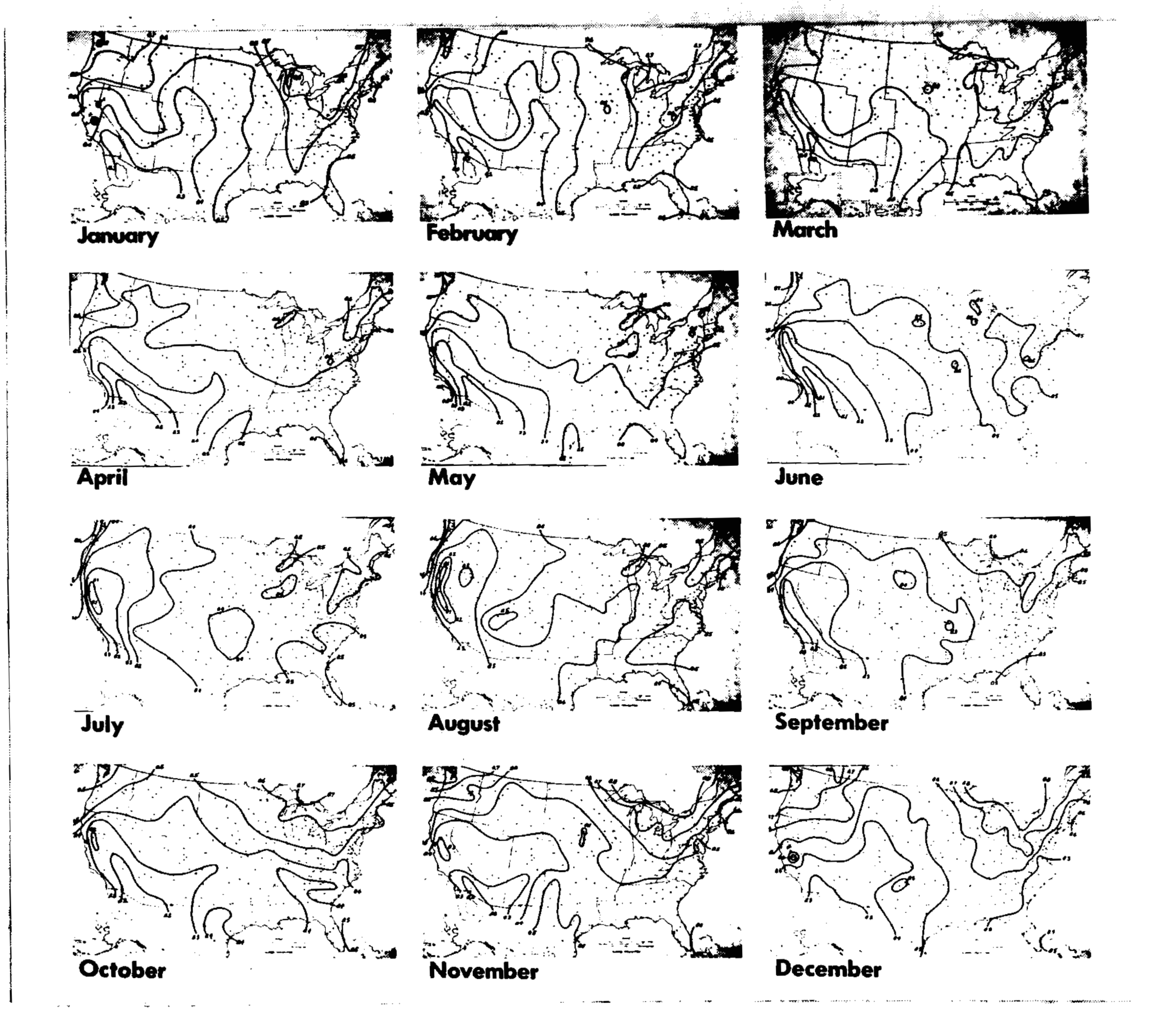
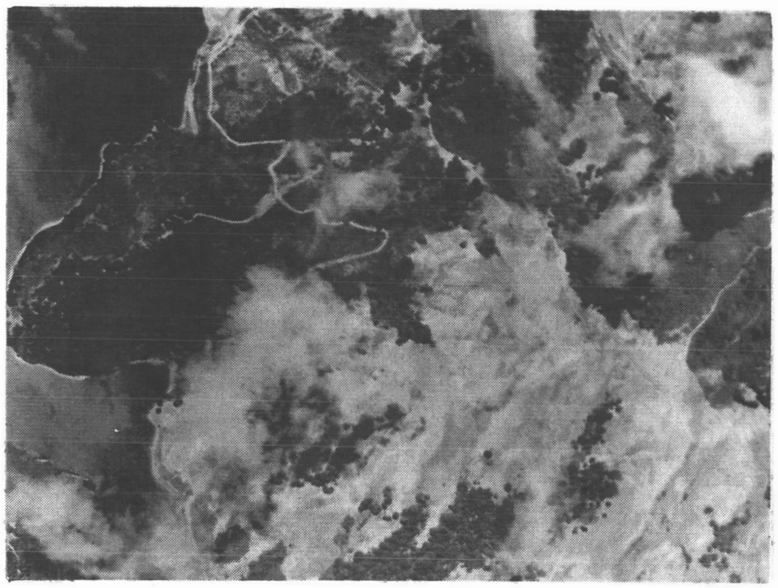


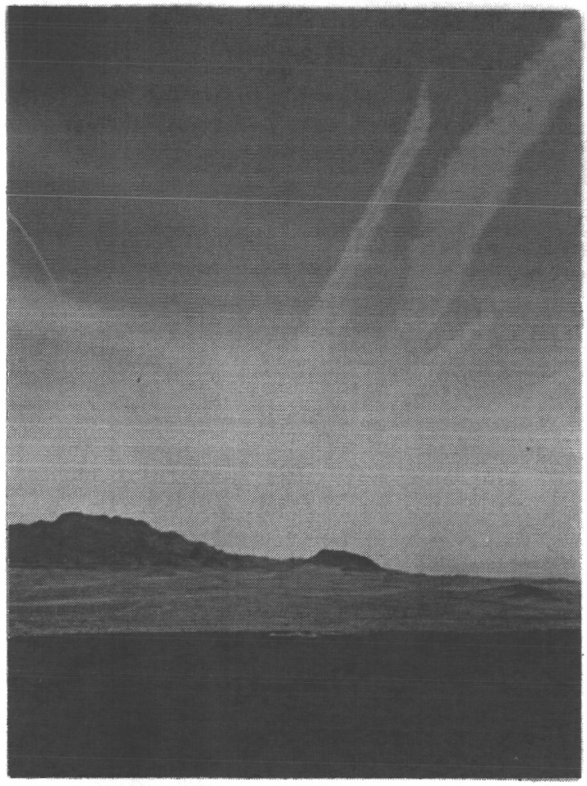
Figure 1: (Ref. No. 22, Bibliography Section) Long term cloudiness charts for the United States. These diagrams are constructed from weather station data listing "skycover" as a percent of total cloudiness. Weather stations denoting cloudiness are indicated by the "dots" shown above. The generalities regarding cloudiness as depicted by charts like those shown here are sufficiently detailed for most purposes.

a) Ekta Aero Infrared (oblique-30000ft. above terrain)

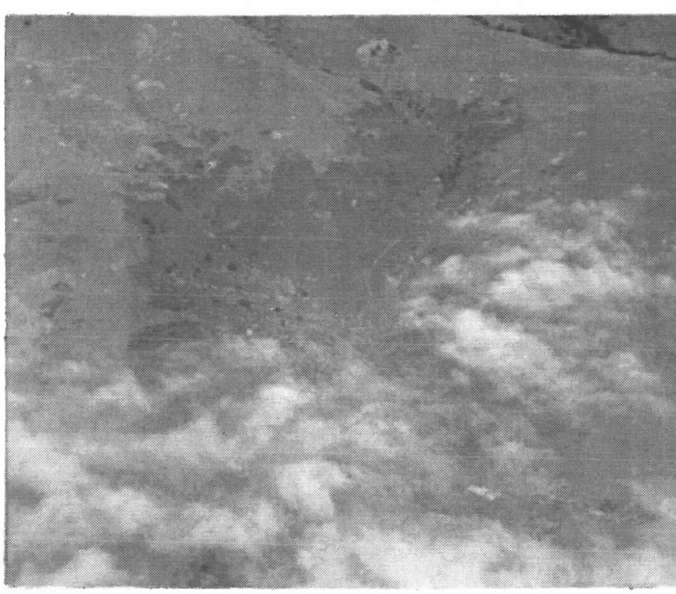


b) Ekta Aero Infrared (vertical-scale: 1/20,000)

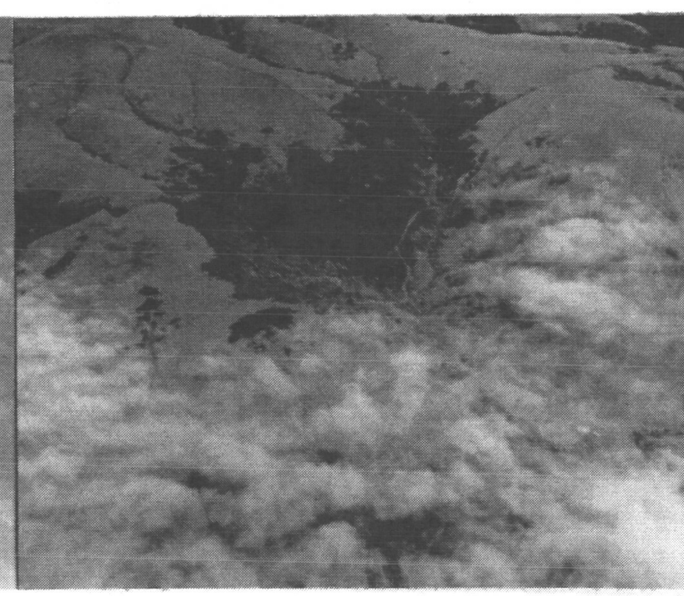
Figure 2: Proper selection of film type to meet a mission's objective can often be disrupted by atmospheric interference. In the above example illustrations, it is seen that clouds have obscured terrain features sufficiently to deplete information which might be obtained. The "bluish" cast in (a) above is due to the great depth of atmospheric penetration required for this photographic angle. In (b) the San Pablo Reservoir Test Site is shown which is subjected to dense fog banks at certain times of the year.



a) Kodachrome



b) Ektachrome



c) Ekta Aero Infrared

Figure 3: Many types of atmospheric interference are known. The above example illustrations are pertinent to several California NASA Test Sites. (a) illustrates a phenomenon especially peculiar to the Pisgah Crater Site -- high speed aircraft contrails from nearby airbases. (b) illustrates a fog bank near the San Pablo Reservoir Test Site filmed through emulsions sensitive to different parts of the Electromagnetic spectrum.

Figure 4: Severe atmospheric interference is becoming more common in lowland urban and suburban regions of the United States. The above example ground illustration shows a Southern California vineyard subjected to moderate "smog" conditions exposed through black and white infrared film. While this condition is relatively rare in regional forested areas, it is noted that local sawmill activity can generate conditions similar to those above under inversion atmospheres.

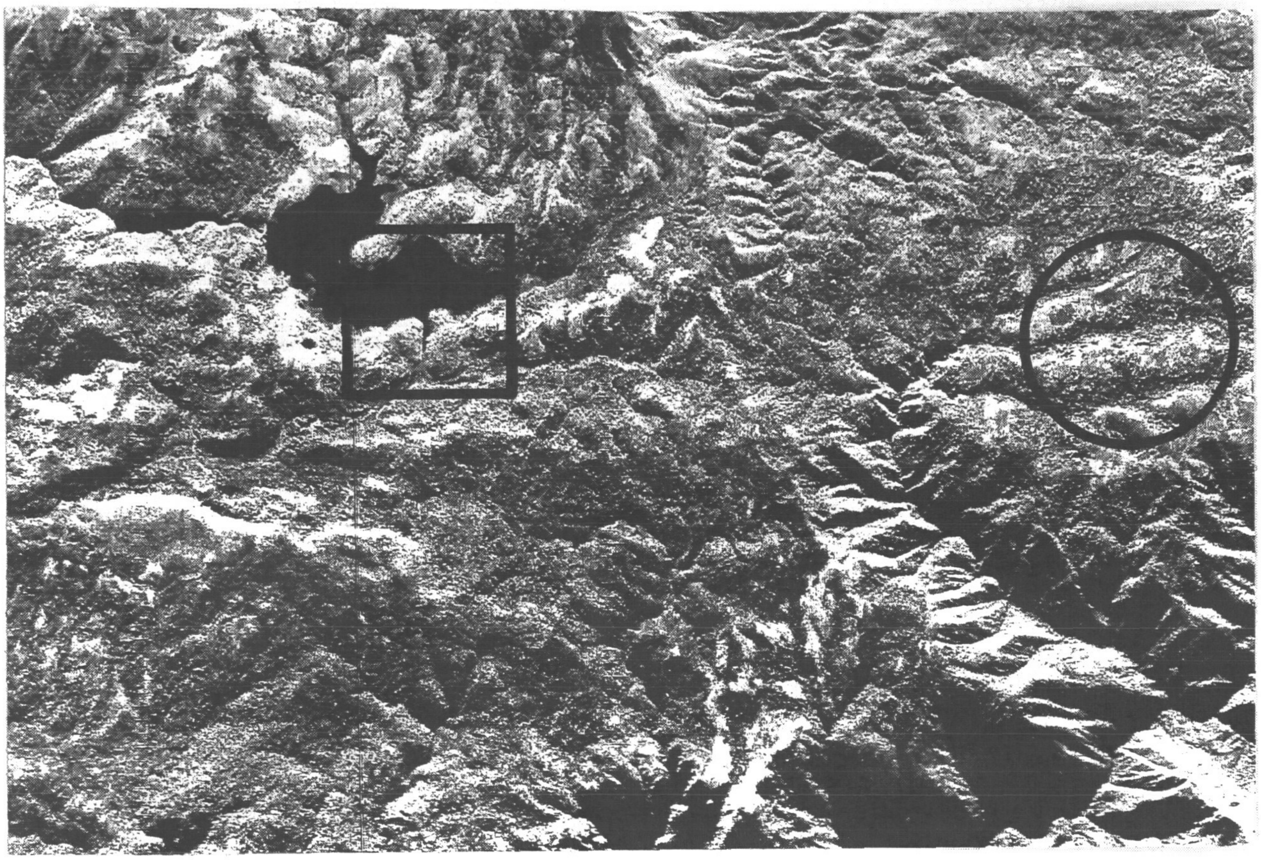


Figure 5: The application of remote sensing employing longer wavelengths than conventional imagery (i.e., panchromatic and near-infrared) is gaining support from many scientific disciplines. The example illustration shown here depicts a radar exposure of the Bucks Lake Test Site (California). Proper selection of radar or passive microwave sensors operating in the longer wavelengths prove invaluable aids to forestry applications when clouds obscure the terrain or when detection of forest fires is the objective. The reduced resolution inherent in present radar systems must be weighed against the ability to obtain imagery at a time when it is needed, irrespective of atmospheric interference. Texture and tone differences aid the interpreter in distinguishing brush from timber; large water bodies are readily distinguished by tone; even burned brushfields can be seen as darkened areas in the circled area above. (The square outline shows approximate area seen on Figure 6).

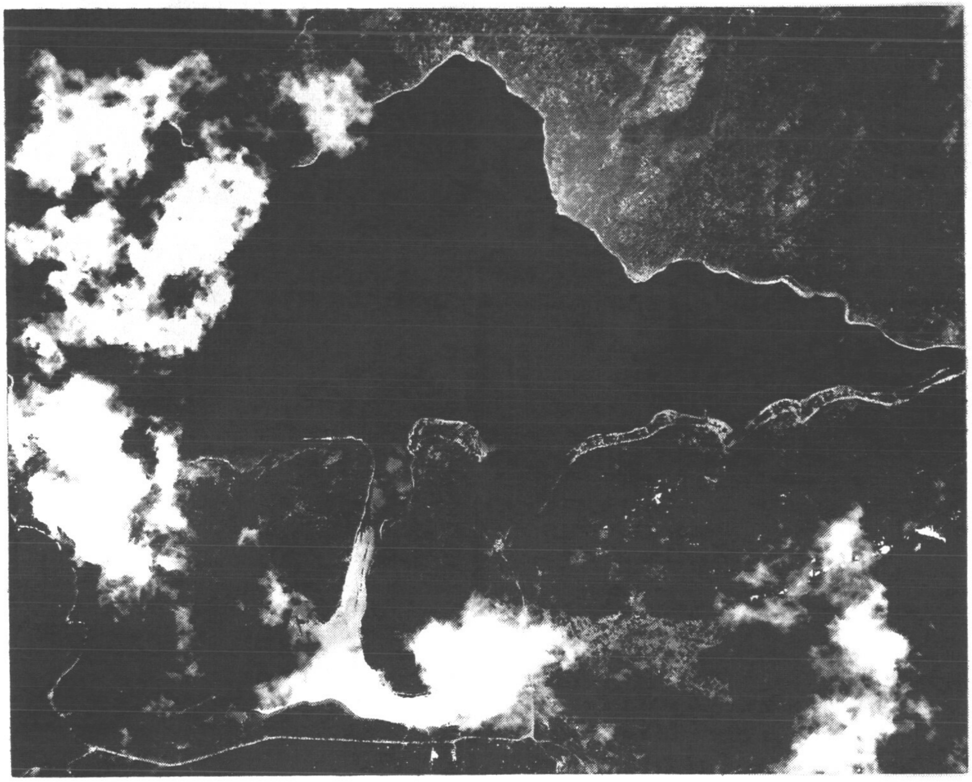
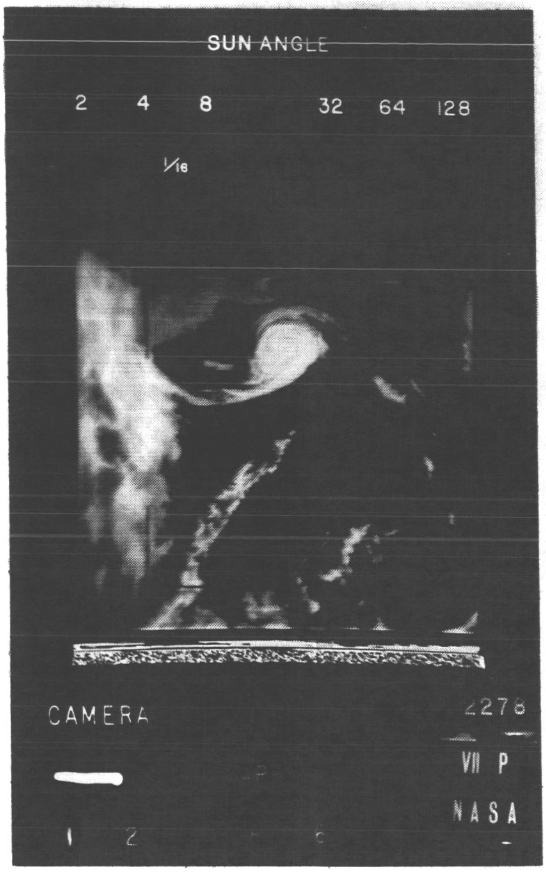
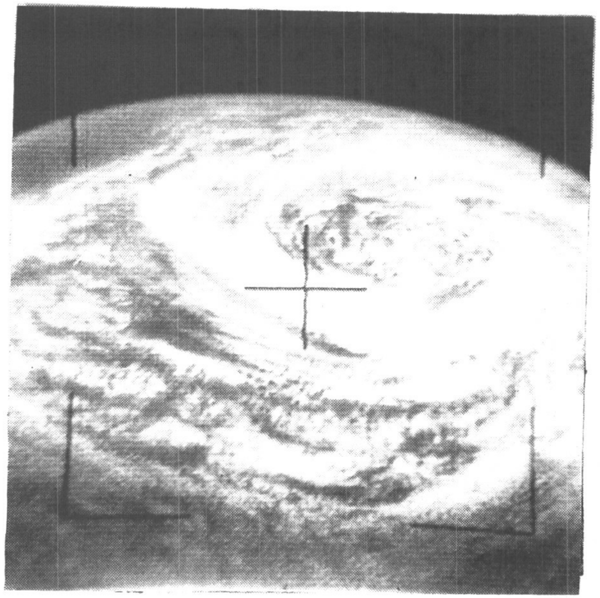


Figure 6: A portion of the area seen in Figure 5 is shown here in conventional panchromatic film. Greater detail is possible, but even here there is sufficient cloud obstruction to hinder accurate delineation of the waterline. Cloud shadows also reduce interpretability (see Figure 11).



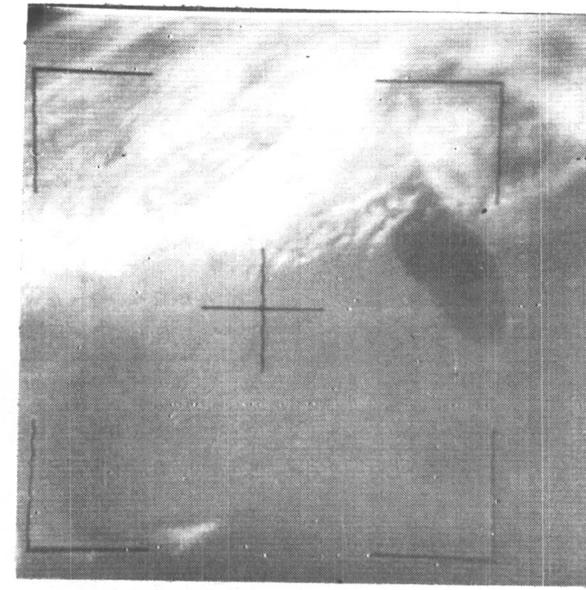
<u>Figure 7</u>: Example of TIROS imagery and accompanying reference data. Taped and Direct TV transmission are photographed on 35 mm black-and-white film.

<u>Figure 8</u>: Earth-orbital image of Grand Bahama Reef obtained from an early Gemini mission showing resolution and color advantages.



9a)

9b)



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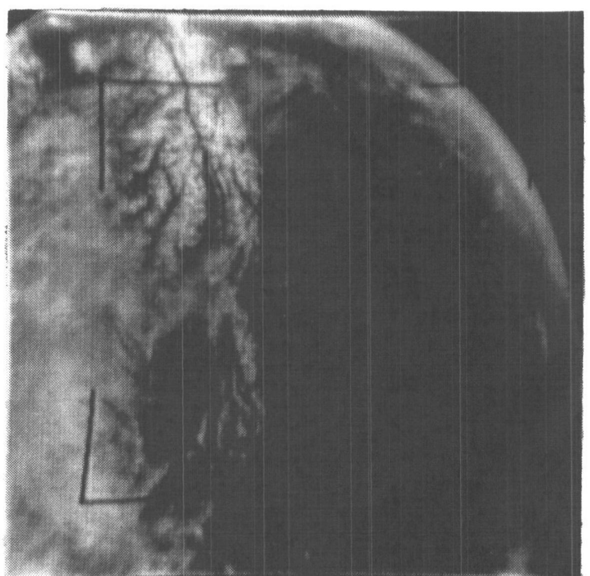

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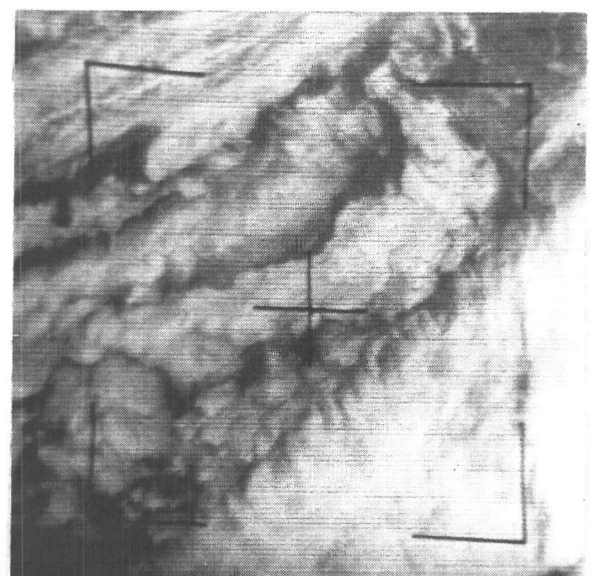

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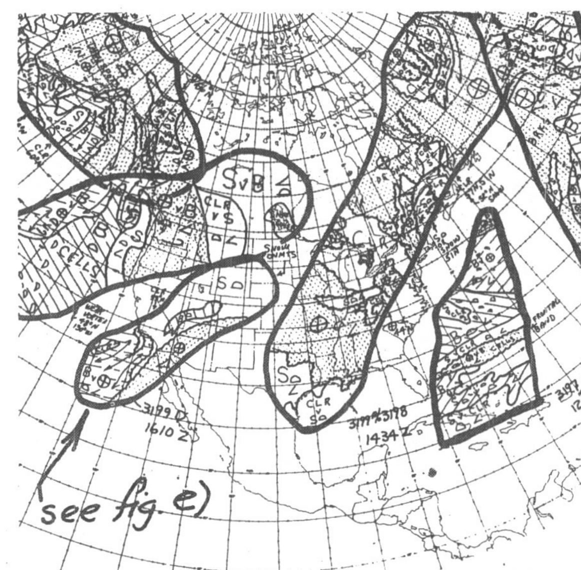

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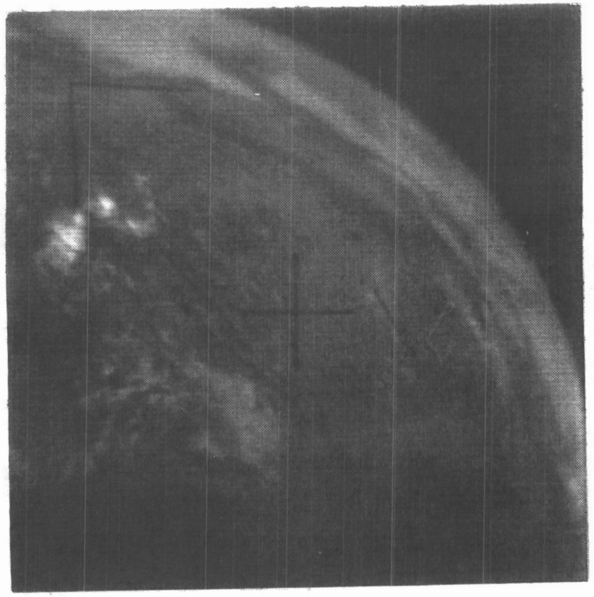

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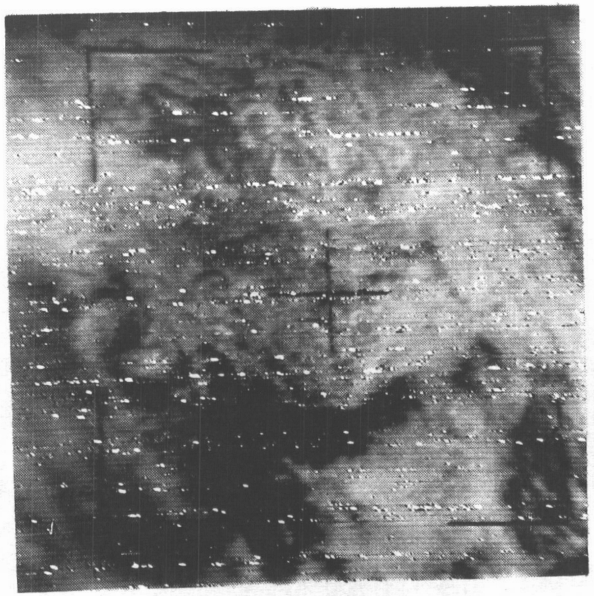

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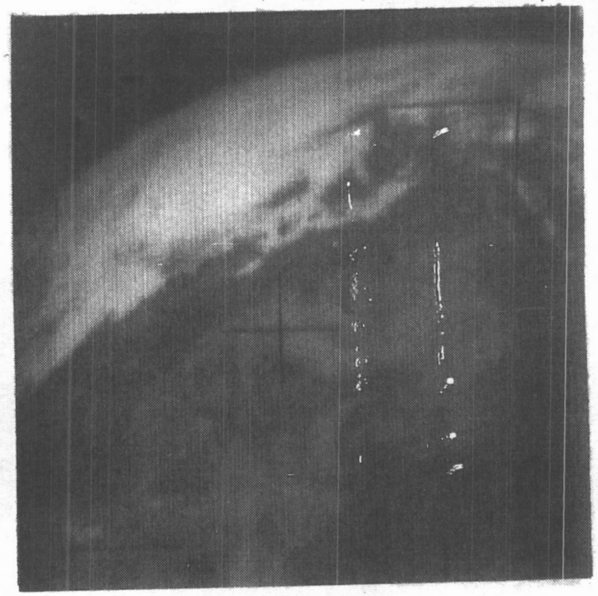

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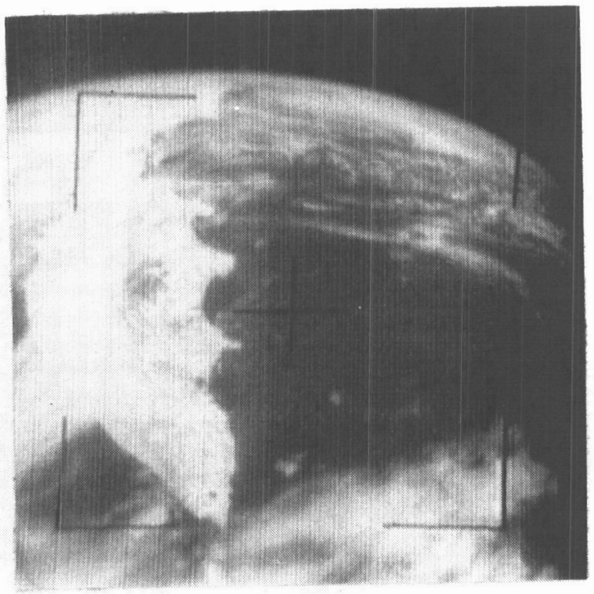

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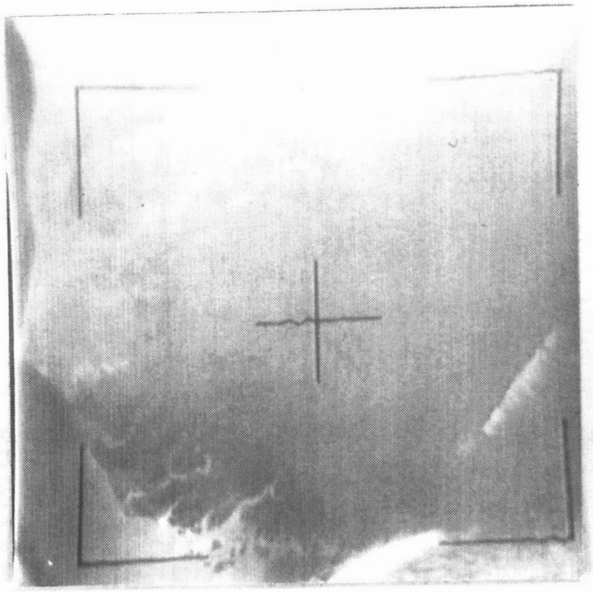

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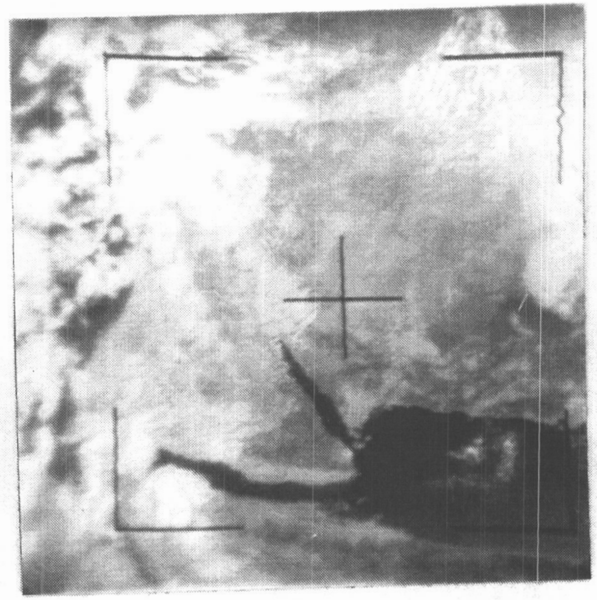

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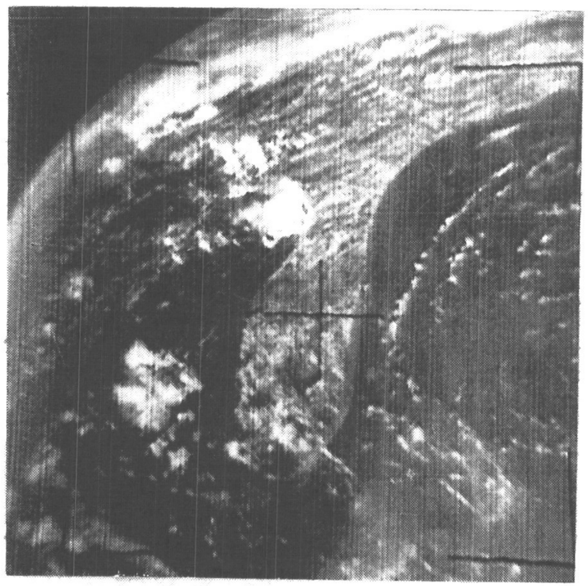

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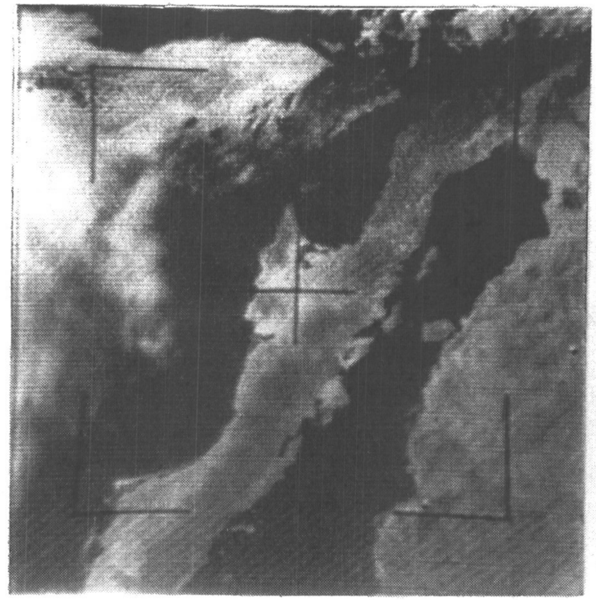

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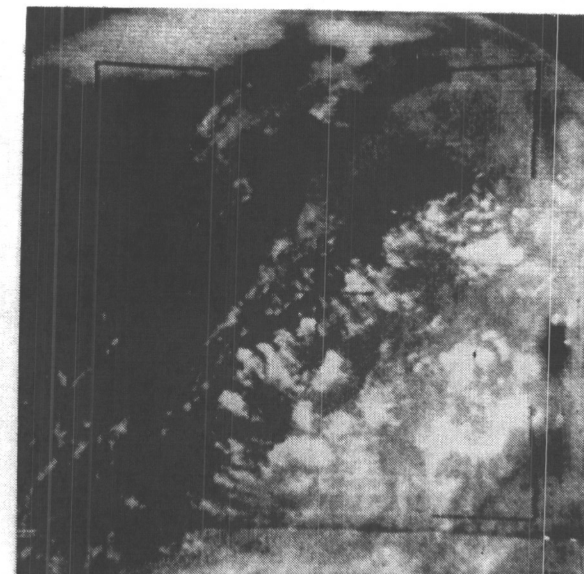

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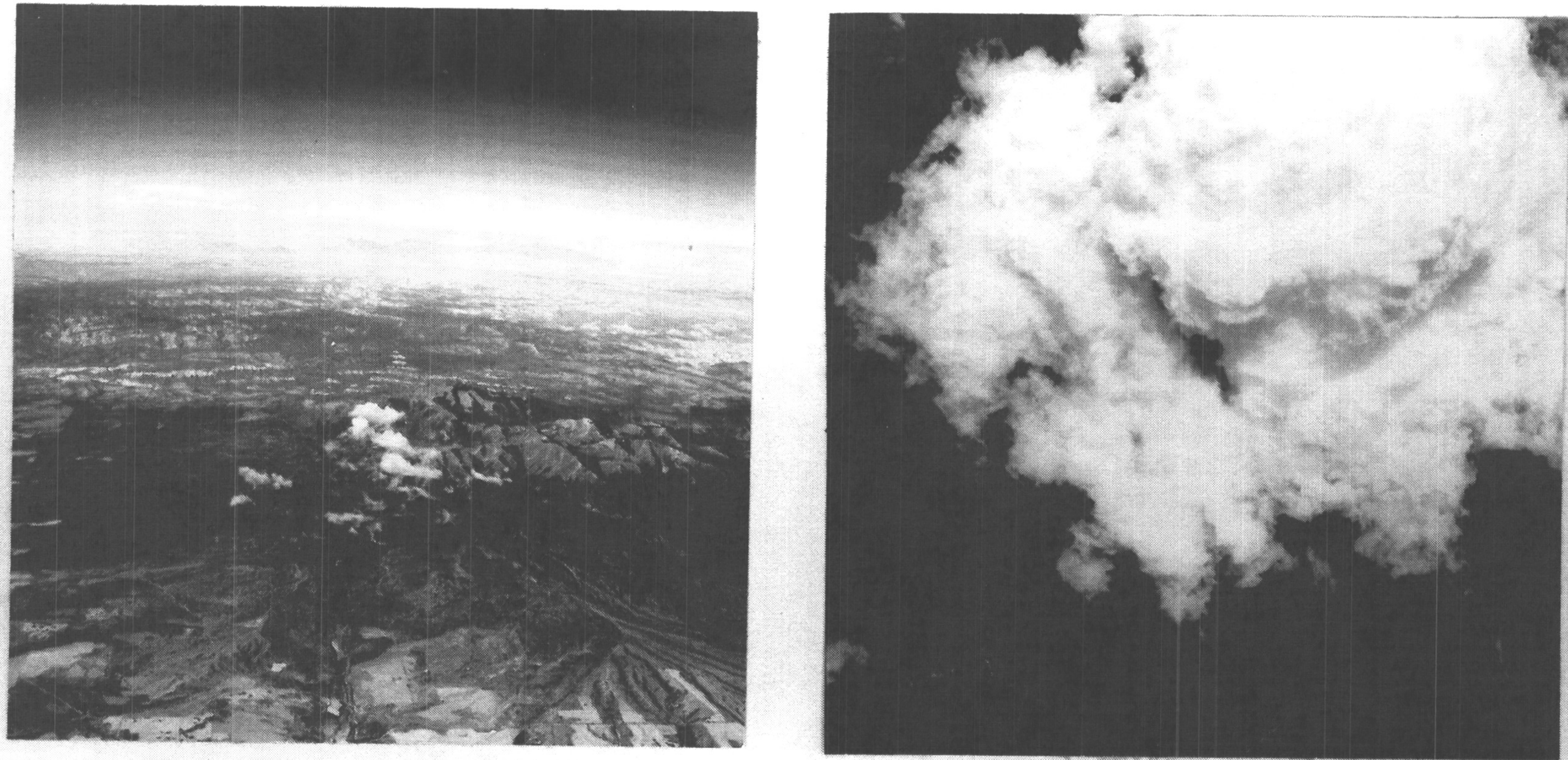
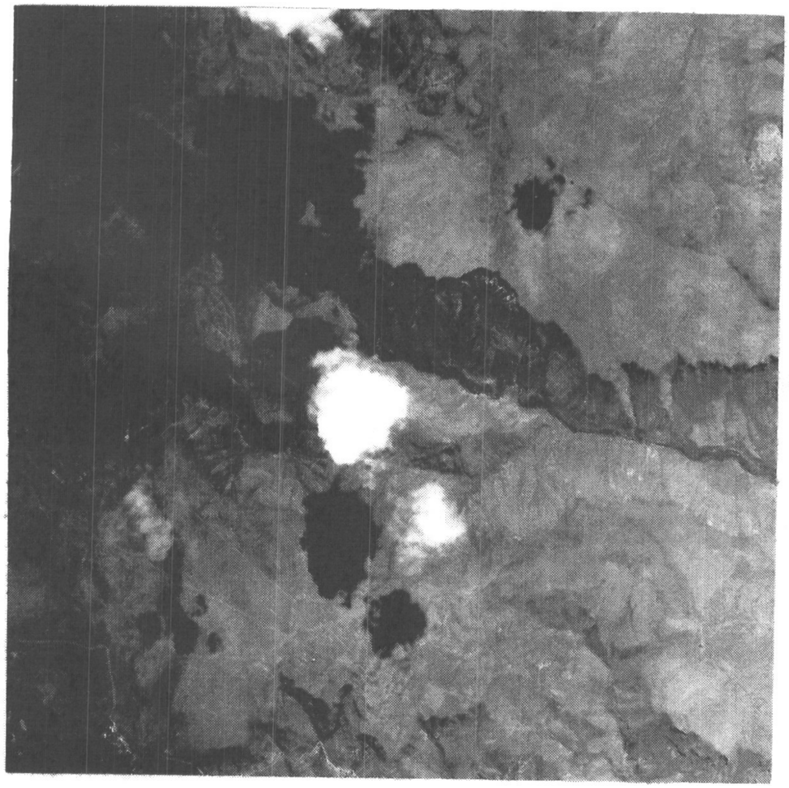


Figure 10: High altitude oblique and vertical images. Left illustration shows attenuating atmosphere on horizon and cloud development near mountain crests. Right illustration is developed in such a way to bring out cloud features, not terrain features, and reveals suitability of accurate height measurements using photogrammetric principles.



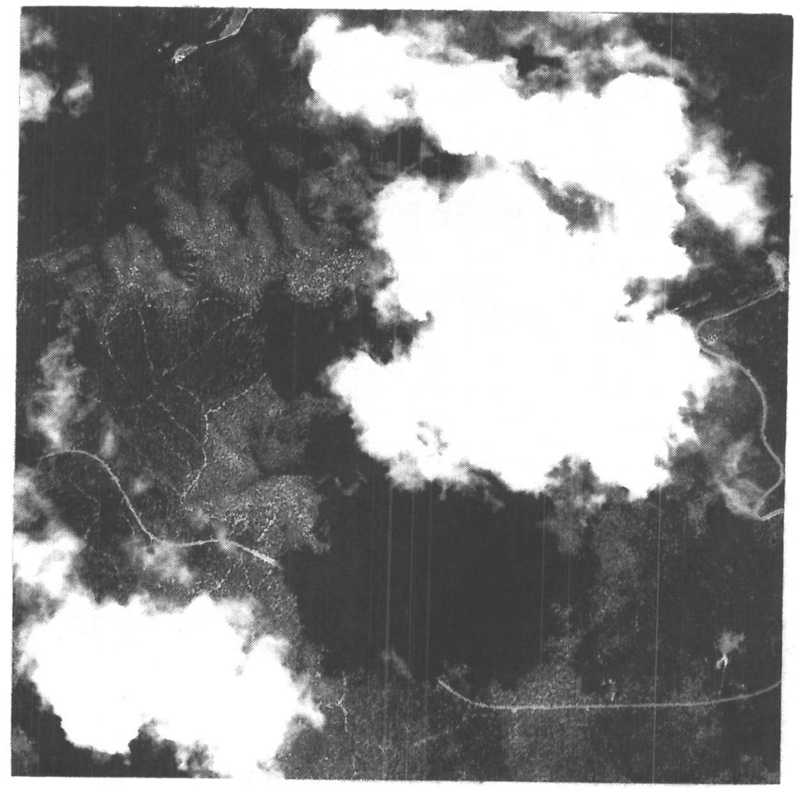


Figure 11: The above two illustrations point out the "double interference" usually associated with clouds during conventional photographic missions. Not only are the clouds obscuring important terrain detail, but their shadows are similarly obscuring the terrain. Exposure to compensate for cloud normally results in poorly degraded imagery where no clouds exist (see Figure 10).

Table 1. Blue Canyon, California
(length of record: 5 years)

Cloudiness data computed from 0 to 10 (clear to 100% sky cover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	5.4	9.0 - 1.8	9.7 - 1.1
February	6.4	9.2 - 3.6	9.7 - 3.1
March	6.7	8.0 - 5.4	8.3 - 5.1
April	6.6	9.8 - 3.4	10.0 - 2.8
May	6.0	8.0 - 4.0	8.4 - 3.6
June	3.6	5.7 - 1.5	6.1 - 1.1
July	0.8	1.7 - 0.0	1.8 - 0.0
August	2.4	4.4 - 0.4	4.8 - 0.0
September	2.4	4.0 - 0.8	4.4 - 0.4
October	3.9	6.1 - 1.7	6.5 - 1.3
November	6.3	7.5 - 5.1	7.7 - 4.9
December	6.3	8.4 - 4.1	8.8 - 3.8

*Interpreted as the percent that the true cloudiness condition will lie within the band specified.

Table 2 - Reno, Nevada

(length of record: 8 years)

Cloudiness data computed from 0 to 10 (clear to 100% skycover)

Confidence Bands for Cloudiness Dates*

	Daylight hours			Nighttime hours		
Month	Mean	90%	95%	Mean	90%	95%
J	6.1	9.1-3.1	9.6-2.6	5.4	7.7-3.1	8.6-2.2
F	6.2	9.5-2.9	10.0-2.3	5.6	8.7-2.5	9.3-1.9
M	6.0	7.4-4.6	7.7-4.3	5.4	7.1-3.7	7.4-3.4
A	5.6	7.1-4.1	7.3-3.9	4.9	6.5-3.3	6.8-3.0
M	5.2	7.0-3.4	7.4-3.0	4.8	6.6-3.0	6.9-2.7
J	3.6	5.4-1.8	5.8-1.4	3.4	5.1-1.7	5.5-1.3
J	2.3	4.0-0.6	4.3-0.3	2.1	3.7-0.5	4.0-0.2
A	2.5	4.1-0.9	4.2-0.8	2.3	4.1-0.5	4.4-0.2
S	2.5	4.2-0.8	4.6-0.4	2.1	3.6-0.6	3.9-0.3
O	3.8	5.5-2.1	5.8-1.8	3.0	4.5-1.5	4.8-1.2
N	5.5	8.2-2.8	8.7-2.3	4.7	7.1-2.3	7.6-1.8
D	5.8	10.0-1.4	10.0-0.5	4.9	6.6-3.2	6.9-2.9

*Interpreted as the percent that the true cloudiness condition will be within the band specified.

Table 3. Arcata NAAS, California
(length of record: 15 years)

Cloudiness data computed from 0 to 10 (clear to 100% sky cover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	6.5	8.0 - 5.0	8.3 - 4.7
February	6.2	8.1 - 4.3	8.9 - 3.5
March	6.1	8.1 - 4.1	9.0 - 3.2
April	5.9	8.2 - 3.6	8.5 - 3.3
May	5.6	7.6 - 3.6	7.9 - 3.3
June	5.4	7.3 - 3.5	7.7 - 3.1
July	5.0	7.0 - 3.0	7.2 - 2.8
August	4.7	6.9 - 2.5	7.2 - 2.2
September	4.9	7.4 - 2.4	7.9 - 1.9
October	5.1	8.4 - 1.8	8.7 - 1.5
November	5.8	9.2 - 2.4	9.4 - 2.2
December	6.6	8.5 - 4.7	8.7 - 4.5

*Intepreted as the percent that the true cloudiness condition will lie within the band specified.

Table 4 - Bishop, California
(length of record: 15 yrs)

Cloudiness data computed from 0 to 10 (clear to 100% skycover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	4.3	7.5 - 1.1	7.8 - 0.8
February	4.2	7.0 - 1.4	7.2 - 1.2
March	4.0	5.5 - 2.5	5.7 - 2.3
April	3.4	4.8 - 2.0	4.9 - 1.9
May	2.3	4.3 - 0.3	4.4 - 0.2
June	2.0	3.7 - 0.3	4.1 - 0.0
July	1.7	2.5 - 0.8	2.7 - 0.6
August	2.0	3.2 - 0.8	3.3 - 0.7
September	2.1	4.2 - 0.0	4.4 - 0.0
October	2.7	5.3 - 0.1	5.5 - 0.0
November	3.4	5.9 - 0.9	6.2 - 0.6
December	4.5	7.5 - 1.5	7.8 - 1.2

*Interpreted as the percent that the true cloudiness condition will lie within the band specified.

Table 5 - Daggett, California
(length of record: 15 yrs)

Cloudiness data computed from 0 to 10 (clear to 100% skycover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	3.0	3.3 - 2.7	3.4 - 2.6
February	3.1	3.6 - 2.6	3.8 - 2.4
March	3.3	3.9 - 2.7	4.1 - 2.5
April	2.5	3.1 - 1.9	3.2 - 1.8
May	2.0	2.4 - 1.6	2.5 - 1.5
June	1.6	1.9 - 1.3	2.0 - 1.4
July	1.5	2.0 - 1.0	2.2 - 0.8
August	1.8	2.1 - 1.5	2.3 - 1.3
September	1.9	2.2 - 1.6	2.5 - 1.3
October	2.2	2.6 - 1.8	2.9 - 1.5
November	2.3	3.0 - 1.6	3.4 - 1.2
December	2.8	3.6 - 2.0	4.0 - 1.6

*Interpreted as the percent that the true cloudiness condition will lie within the band specified.

Table 6 - Oakland, California
(length of record: 15 yrs)

Cloudiness data computed from 0 to 10 (clear to 100% skycover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	5.2	8.0 - 2.4	8.2 - 2.2
February	5.0	8.3 - 1.7	8.5 - 1.5
March	4.9	7.4 - 2.4	7.7 - 2.1
April	4.3	6.6 - 2.0	6.8 - 1.8
May	3.3	6.4 - 0.2	6.5 - 0.1
June	3.0	5.8 - 0.2	6.0 - 0.0
July	2.8	5.5 - 0.1	5.7 - 0.0
August	3.0	5.6 - 0.4	5.8 - 0.2
September	3.4	6.2 - 0.6	6.4 - 0.4
October	3.6	6.5 - 0.7	6.7 - 0.5
November	3.7	7.2 - 0.2	7.5 - 0.0
December	5.0	7.7 - 2.3	7.9 - 2.1

*Interpreted as the percent that the true cloudiness condition will lie within the band specifies.

Table 7 - Sacramento, California
(length of record: 15 yrs)

Cloudiness data computed from 0 to 10 (clear to 100% skycover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	4.8	7.9 - 1.7	8.0 - 1.6
February	4.0	6.6 - 1.4	6.8 - 1.2
March	3.8	6.1 - 1.5	6.2 - 1.4
April	3.7	5.6 - 1.8	5.8 - 1.6
May	3.1	4.4 - 1.9	4.5 - 1.8
June	2.6	3.6 - 1.6	3.8 - 1.4
July	1.7	2.2 - 1.2	2.2 - 1.1
August	0.8	1.2 - 0.4	1.2 - 0.4
September	1.5	2.0 - 1.0	2.1 - 0.8
October	1.8	2.8 - 0.9	2.9 - 0.7
November	2.9	4.2 - 1.6	4.4 - 1.4
December	4.4	7.2 - 1.6	7.4 - 1.4

*Interpreted as the percent that the true cloudiness condition will lie within the band specified.

Table 8 - Fresno, California
(length of record: 15 yrs)

Cloudiness data computed from 0 to 10 (clear to 100% skycover)

Confidence Bands for Cloudiness Data*

Month	Mean	90%	95%
January	3.7	6.4 - 1.0	6.6 - 0.8
February	3.9	6.4 - 1.4	6.7 - 1.1
March	3.8	5.6 - 2.0	5.8 - 1.8
April	3.1	4.4 - 1.8	4.7 - 1.5
May	2.4	3.5 - 1.4	3.5 - 1.5
June	1.8	2.6 - 1.0	2.8 - 0.8
July	1.4	1.8 - 1.0	1.8 - 0.9
August	0.8	1.1 - 0.5	1.3 - 0.4
September	1.5	2.1 - 0.9	2.4 - 0.6
October	2.3	3.4 - 1.1	3.6 - 0.9
November	3.2	5.4 - 1.0	5.8 - 0.6
December	6.0	10.0 - 1.2	10.0 - 0.4

*Interpeted as the percent that the true cloudiness condition will lie within the band specified.

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