NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL LETTER NASA-117

MAKING COLOR INFRARED FILM A MORE EFFECTIVE HIGH ALTITUDE SENSOR

By

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May 1968

Prepared by the U. S. Geological Survey for the
National Aeronautics and Space Administration (NASA)
under NASA Contract No. ~~R-14-08-0001-10674~~
R-09-020-024

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-117
May 1968

Mr. Robert Porter
Acting Program Chief
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith is one copy of:

INTERAGENCY REPORT NASA-117

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Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. R-14-08-0001-10674
**Department of Geography, University of California

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PLATE 1.

Color Infrared Enhancement

In this view of the Canadian River of Oklahoma, taken with color infrared film from an altitude of 40,000 feet, the false color blushes of newly sprouted winter wheat give a strong infrared record. The distant bend in the river floodplain is approximately 50 miles away, yet the red reflection is penetrating through this great thickness of atmosphere. This picture was taken from an airliner window with a 35 mm camera using a CC30B filter in addition to the basic minus-blue Wratten 12 recommended for the film.

Time: 3:45 pm in mid-October, 1967.

Preface

The following report by Dr. Robert W. Pease, University of California, Riverside, is the result of a continuing need to improve upon color infrared photography as a tool of remote sensing. Credit is due the Earth Resources Aircraft Program for its part in initiating the research described herein. During three overflights of Southern California test site 130 and one of Salton Sea test site 27 by both NASA 926 and 927, color infrared film was used. Despite the fact the camera crew followed recommended and standard exposure, shutter speed, and filter procedures--the resultant images were often less than satisfactory. Examination of camera logs, interviews with crew members, and evaluation of processing techniques indicated nothing amiss in flight operation or data handling. Yet the imagery was not interpretable for the kinds of resource information one expects available from color infrared film. Another impetus for a closer examination of the film was the disappointing results from the color infrared photographic experiment on Gemini VII. Even though many frames appeared properly exposed, oriented, and processed, very little infrared reflectance was recorded, nor were the images much different from those made with true color film.

Although it cannot be documented, there is some evidence that many researchers in the field of remote sensing have been prone to place color infrared in a category of "thoroughly examined and analyzed." It was becoming commonplace to say that color infrared was useful for specific targets, landscapes, and environmental conditions but was regimented by narrow time limits, critical exposure levels, and arduous handling. There is an indication, now, that what is reported here is an initial "break through" in the confines of color infrared in environmental remote sensing and advances the practicability of using such film at aircraft and spacecraft altitudes. One of the fascinating aspects of the inquiry is that the method used to improve the process is a relatively easy modification, yet the results are augmented many times.

The enhancement techniques used in the experiment modify the outlook for color infrared film as a data collector from which earth analysis can be better achieved. Further research, too preliminary to report here, indicates we have not reached the apex of total use for color infrared photography. Images taken with the filter combinations described on the following pages have produced a host of exciting but as yet undeciphered spectral records about urban spatial patterns, dawn and twilight infrared photography, near infrared reflectance at various temperature and moisture conditions, unexplained false color renditions of cultural and natural features, and more. Most exciting of all is the wide availability of film and filters, ease of modification, and potential for universal use that color infrared photography can provide. Probably no other single remote sensing device, available to the field scientist and spacecraft mapping camera alike, images and contains so much information about the earth's environment.

The authors would like to acknowledge the help and advice of Norman L. Fritz of Eastman Kodak Research Laboratories in the pursuit of this inquiry.

Leonard W. Bowden
Principal Investigator
Southern Calif. Test Site 130

MAKING COLOR INFRARED FILM A MORE EFFECTIVE HIGH ALTITUDE REMOTE SENSOR

In a single package, color infrared transparency film (Kodak Ektachrome Infrared Aero type 8443) has the potential for yielding a wide variety of multispectral information when used in remote sensing. Ability through color to recognize growing vegetation by recording near infrared reflection provides important clues for the analysis of both urban and nonurban environments. Because it does not sense the short-wave end of the visible spectrum, color infrared film (CIR) is far less susceptible to Rayleigh scattering than normal color film and thus is better for penetrating great thicknesses of atmosphere and certain forms of atmospheric haze (Plate 2). In brief, it has the haze-penetrating capabilities of filtered black and white film plus the capability to differentiate by color hue.

Although CIR appears to combine many of the best features of both color and monochromatic media, recent experimental use in high flying aircraft has not yielded the consistently good results that the potential would indicate. Frequently the image is predominantly blue with the infrared reflection barely discernible as a dark purplish brown (Plate 3,a). Critical exposure determinations must be made to try to preserve some of the infrared record. With underexposure, the red disappears. Overexposure degrades the rest of the image to the point where a great deal of valuable information is lost and difficulty is encountered in interpreting the meaning of the red components captured by the long exposure.

The potential of the film for high altitude imagery can be realized, however, by the use of a system of filters auxiliary to the basic minus-blue Wratten 12 or 15 filters recommended by the manufacturer. The record of infrared reflection is enhanced in such a manner with respect to the rest of the image that there is no problem in obtaining good reds from high altitudes which show the most subtle blushes of growing vegetation (Plates 1 and 3,b). Exposure is less critical since underexposure still retains red tones. Feasibility testing by a number of users with 35 mm cameras indicates a high degree of reliability when simple instructions are followed. With the exception of Plate 3,a, examples in this report are only a few of many tests taken from commercial airliners at altitudes ranging from 14,000 to 41,000 feet. Taken obliquely, they represent penetration by the reflection of considerably more than one atmospheric mass. When the suggested auxiliary filters are used, color infrared transparency film appears to be a thoroughly reliable remote sensing system for use at either high aircraft or spacecraft altitudes--a system that will yield a wider variety of information than normal multilayer color film and with better haze penetrating capabilities.

Problems related to high altitude use stem from the fact that in its present design the layer of the film that controls the appearance of red in the positive transparency (the cyan dye layer) purposely has been reduced in sensitivity in order that subtle differences in the infrared reflectance of nearby objects be recorded in contrasting colors. Operating close to its exposure threshold, the red-controlling layer simply fails to record low levels of reflected light and thus only strong infrared reflection records as red. Of value at low aircraft altitudes for camouflage detection (the original use of the film) or for assessing chlorotic decline in growing crops or forest, this property becomes the Achilles' heel of the utility of the film when reflected light must pass through considerable thicknesses of atmosphere. Water vapor in one atmospheric mass can attenuate penetrating light with wavelengths between 700 and 1,000 millimicrons or nanometers (nm.) as much as 20 percent (List, 1958).[1] This lowers exposure of an already weak infrared sensitivity close to its exposure threshold. Reducing exposure to combat haze luminance (Sorem, 1967) compounds the problem for then the camera further attenuates the surface infrared reflection. The cyan dye layer of the film may be so poorly exposed that in the development process little is removed. Reds from the combined yellow and magenta dye layers cannot show through. The cyan color remains to mask the infrared record and give an overall blue appearance to the image.

The attenuating effect of course will vary with the water vapor content of the air, the altitude at which the image is recorded, and the inclination of the optical path with respect to the earth's surface. Since water vapor content generally decreases rapidly with altitude, a vertical image taken at 40,000 feet (12,200 meters) may be subject to as much as 90 percent of the attenuation by one atmospheric mass of the

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[1] This assumes 40 mm of precipitable water in the air column, an amount frequently encountered in the humid tropics (Sellers, 1965) or mid-latitude humid regions in summer. An oblique view can increase the water vapor in the optical path to considerably more than 40 mm. Attenuation in the visible realm is related to Rayleigh scattering and contributes to exposure as air luminance.

near infrared.

As an alternative to the manufacturer's redesign of the film for high altitude use, the following procedures are suggested. Except for the record of the near infrared, the image of type 8443 film is the product of the visual wavelengths of light longer than about 520 nm. Shorter wavelengths have been removed by the basic minus-blue filtration used with the system with the exact cutoff point depending on the choice of a Wratten 12 or 15 filter. Wavelengths between 520 and 700 nm. produce the main body of the image or frame in which the infrared reflection is recorded. It then follows that relative enhancement of the infrared record can be achieved by selectively reducing the intensity of the visible wavelengths reaching the film and increasing the exposure to compensate for the reduction. If in the process wavelengths longer than 700 nm. have not been retarded, the near infrared will receive greater relative exposure.

This is readily achieved because many dye filters are more transparent to wavelengths longer than 700 nm. than to those that are shorter. In the example plotted in Figure 1, a transmittance of only 19 percent at 700 nm. becomes more than 90 percent at 800 nm. Filters can be chosen that will attenuate the visual wavelengths to various desired degrees without materially reducing the intensity of the light to the film in the near infrared. Thus the added exposure necessary to produce proper densities in the body of the image will better expose an infrared reflection that has become attenuated by the atmosphere or from other causes. This is tantamount to decreasing the sensitivities of dye layers in the film which control the visual image to better match that which yields the infrared, except that the sensitivity of the red-controlling layer is also reduced in the visual realm.

The most desirable infrared enhancement perhaps could be obtained with neutral density dye filters that increase their transmittance in the near infrared. These would provide the desired enhancement while disturbing the overall color balance the least. But such filters are not readily available. Fortunately, there are a variety of color compensation, light balancing, and photometric filters which will serve the purpose with only a moderate amount of general color shift. The effects of several of these are shown in Plates 4 and 5, views of ground targets in Southern California. Far from detracting, some of these color shifts improve the image. Excess cyan color is removed and neutral tones may appear more natural. It must be remembered that this is a film which purposely renders colors falsely in order to yield desired information. If the nature of the color shifts is understood, a variation in the false color rendition can be as, or more, useful than the results of standard exposure techniques.

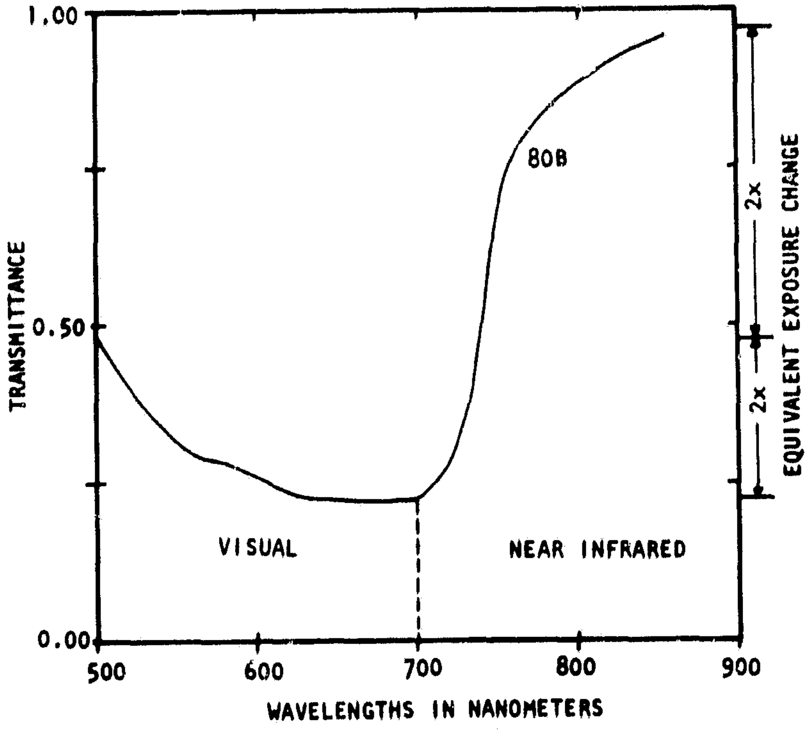
The nature and causes of these changes are illustrated by the sensitometric curves of Figure 3 and the spectrograms of Plate 6. The sensitometric curves give explanations in terms of the dye layer densities in the film image, but due to the reversed nature of the transparency these are not the apparent changes that take place in image color. The spectrograms, on the other hand, explain the changes in terms of apparent image color and may well be of more use in gaining a functional understanding of the effects of auxiliary filter enhancement. They were made in the course of

Figure 1. Transmittance versus wavelength for a Wratten 80B filter, an auxiliary that produces drastic enhancement of the infrared record. The rise toward transparency that is strong for wavelengths longer than 750 nm. shows clearly. In plotting, the values for transmittance have been kept linear, but the effect in changing exposure of the film is indicated on the right-hand side of the graph.

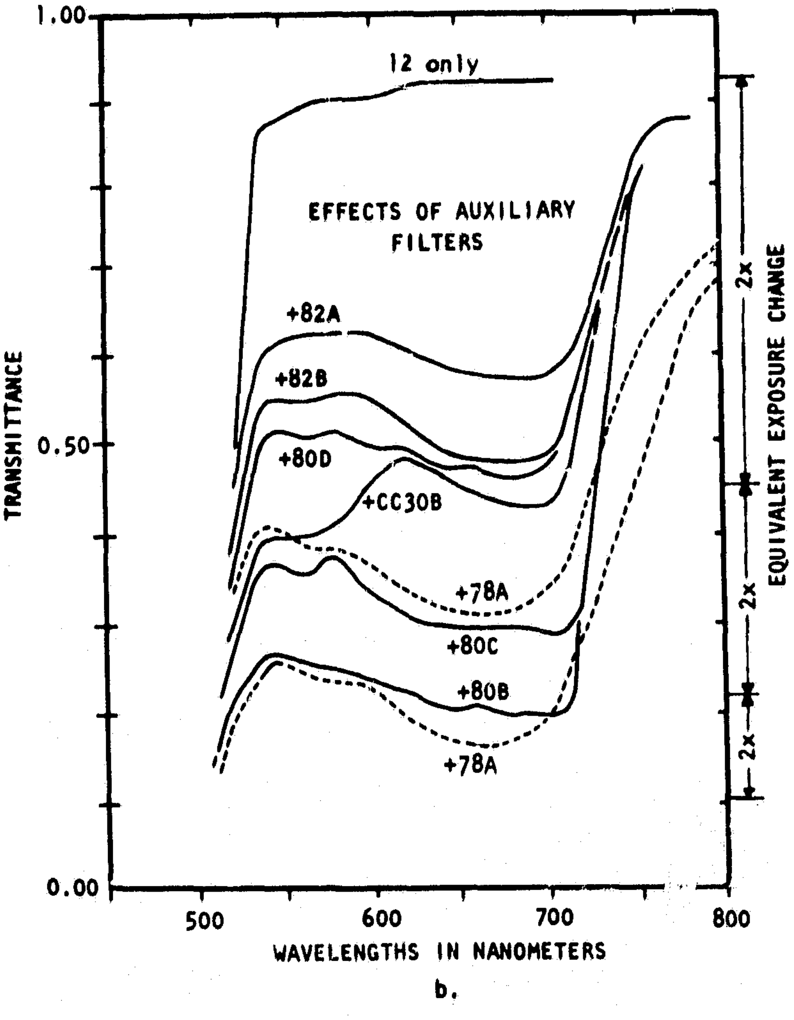
Source of data: Kodak (1966) <u>Wratten Filters</u>.

Figure 2. Plots showing the combined transmittances of some potentially useful infrared enhancing filters when used in combination with a minus-blue (Wratten 12) basic filter. The transmittances have been plotted in a linear manner in order to separate the curves. The relative effect on exposure, however, should be noted on the right-hand side of the graph. Near infrared transmittance characteristics of the blue (CC) color compensation filters is similar to that for the 80 & 82 series (Fritz interview, March 1968). The infrared characteristics for these filters were also estimated from performance tests and the spectrograms illustrated in Plate 6.

Source of data: Kodak (1966) <u>Wratten Filters</u>.


1.00
0.50
0.00
TRANSMITTANCE
80B
VISUAL
NEAR INFRARED
2x
2x
EQUIVALENT EXPOSURE CHANGE
500
600
700
800
900
WAVELENGTHS IN NANOMETERS

a.


1.00
0.50
0.00
TRANSMITTANCE
12 only
EFFECTS OF AUXILIARY FILTERS
+82A
+82B
+80D
+CC30B
+78A
+80C
+80B
+78A
2x
2x
2x
EQUIVALENT EXPOSURE CHANGE
500
600
700
800
WAVELENGTHS IN NANOMETERS

b.

Figure 3. Generalized sensitometric curves for type 8443 color infrared film that show the effects of auxiliary filters and changes in exposure. The curves plot the densities of the dye layers in the positive transparency image according to exposure. In the reversed transparency the absence of cyan dye permits red from the combined magenta and yellow dye layers to be transmitted and record the infrared. In a similar manner, magenta controls the transmittance of green and the absence of yellow yields blue when the other necessary dye colors are present. High cyan density reduces the infrared record. Curves are based on those given by Fritz (1967).

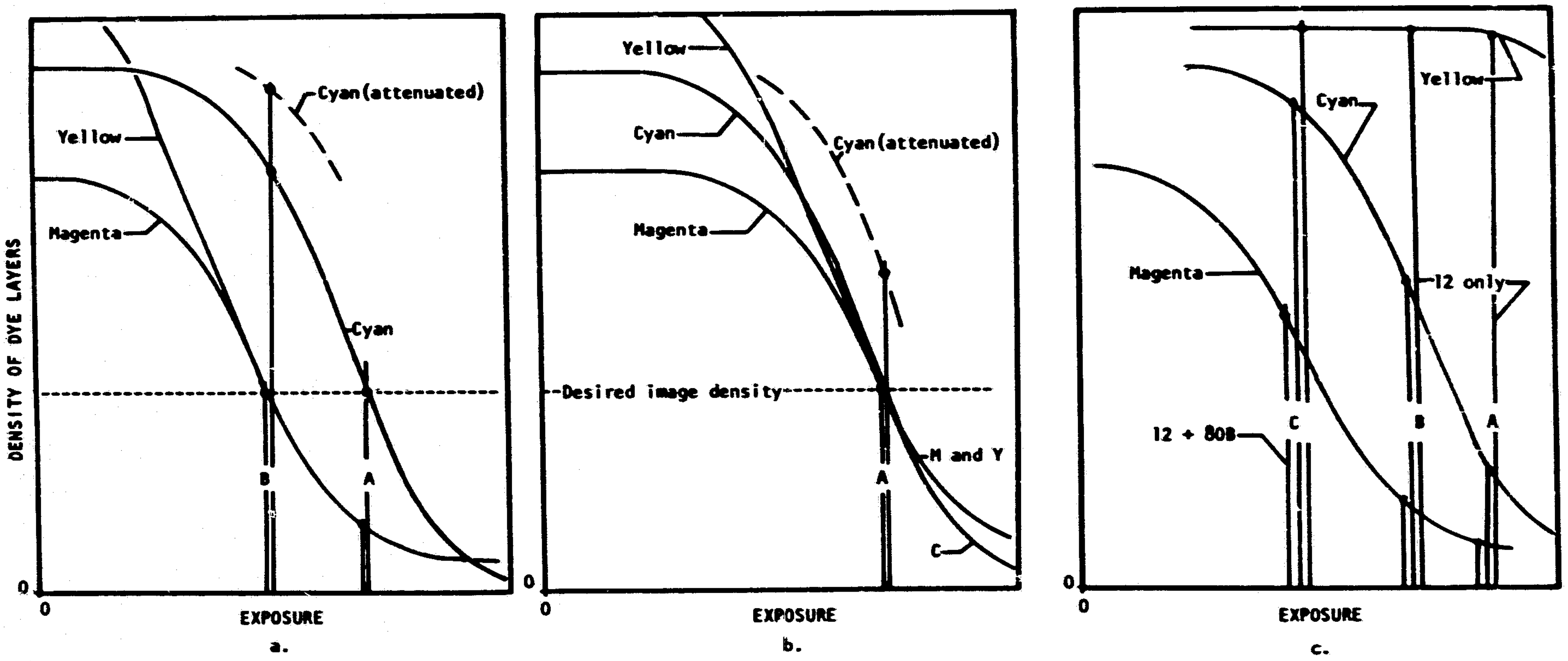
a. When only a minus-blue filter is used, the magenta and yellow dye-forming layers have approximately the same sensitivity, but that of the cyan layer is lower. Exposure A is sufficient to reduce cyan density to desired levels but in so doing reduces the magenta and yellow densities to the point where little color is left to yield red. If exposure is reduced to B in order to increase the magenta and yellow, the cyan density is increased to the point where little red can be transmitted. Effective reduction of cyan sensitivity by water vapor attenuation [cyan (attenuated)] increases the cyan density further. Because the cyan sensitivity affects the image in the visual wavelengths, changes in exposure also change the ratio of red to other colors and shift the color balance.

b. The minus-visual auxiliary filters in effect lower the sensitivities of the magenta and yellow dye-forming layers, in this case to approximately that of the cyan layer. This permits adequate image density and the necessary red-yielding colors without an excess of masking cyan,factors conducive to enhancement of the infrared record. With dye layer sensitivities more closely balanced, changes in exposure are less likely to cause color shifts. The attenuation of the infrared by water vapor is less serious in its cyan producing effect.

Graphs a and b assume a "white" light source that supplies all wavelengths between 520 and 900 nm.

c. Sensitometric curves for a narrow waveband (650-660 nm.) illustrate changes that occur in the "green realm" of the spectrograms of Plate 6. Due to its very low sensitivity to these wavelengths, yellow dye density remains high regardless of exposure, but magenta and cyan are markedly affected. With the long exposure at A, both cyan and magenta have low densities and yellow predominates as the image color. When exposure is reduced to B the cyan gains density rapidly and converts the yellow appearance to green. The magenta has changed but little. Further exposure reduction to C strengthens the magenta more rapidly than the cyan which both darkens the dye combination and shifts it toward a neutral balance.

By attenuating these wavelengths, an 808 filter produces the effects of reduced exposure: thus the dark band and neutral tones that lack yellow.


DENSITY OF DYE LAYERS
0
0
EXPOSURE
a.
Yellow
Magenta
Cyan(attenuated)
Cyan
B
A
0
0
EXPOSURE
b.
Yellow
Cyan
Magenta
Cyan(attenuated)
Desired image density
A
M and Y
C
0
0
EXPOSURE
c.
Yellow
Cyan
Magenta
12 only
12 + 80B
C
B
A

this inquiry through a diffraction grating onto type 8443 film. With the light source strongly wedged in intensity across the slit of the spectrograph, sensitivity curves for the various dye layers were obtained which closely match the spectral sensitivity curves given by Fritz (1967). Made with a variety of auxiliary filters and with different exposures, these curves of apparent image color show graphically effects upon the film.

The film layers which control the appearance of blue and green in the positive image (yellow and magenta dye layers, respectively) cut off sharply at their long wave ends. There is some overlap between them, but blue predominates between 520 and 580 nm. (spectral green to yellow) while green predominates between 580 and 680 nm. (spectral yellow to red). Both have strong sensitivities as is indicated by the widths of their images. On the other hand, the layer that controls the red at no discrete wavelength has the breadth of apparent sensitivity of either of the other two, but its sensitivity is spread over a much broader band of the spectrum. From a peak in the near infrared (750 to 900 nm.), the sensitivity of this layer wedges or declines into the visual bands, overlapping the wavelength domains of the other layers. Where it is strong in the green domain, yellow results and thus with full exposure contributes significantly to the visual as well as the infrared image. As exposure is decreased, however, the contribution of this layer retreats rapidly out of the visual bands, remaining only in the near infrared (Plate 6, e-g). The low sensitivity of the cyan or red-controlling layer causes it to be affected more by reduced exposure than those yielding blue or green. For this reason the color balance of the image will change noticeably with exposure, underexposure favoring a cyan appearance (Fig. 3,a). Reduced exposure causes a dark band to appear in the spectrum near 700 nm. In practice this means that the deep reds do not get recorded. Attenuation of the long wavelengths of light by water vapor in the atmosphere causes color shifts much like those that stem from underexposure since the effect is felt most by the cyan or red-controlling dye layer.

Color shifts produced by the most useful types of auxiliary filters are discussed in the following. Conclusions are based upon experience with the 35 mm version of the film and spectrograms, examples of which are included in Plate 6.

Blue color compensation filters: There should be initial understanding that blue color compensation filters do not add blue or a false color equivalent to the CIR image because wavelengths that are blue in nature do not enter into the exposure of the film. Rather, they should be considered as only mildly effective minus-yellow (spectral yellow) filters. Indeed, this type of filter was first tried as a means of reducing the cyan-producing effect of yellowish urban "smog," for which use there appears to be some merit. The chief value of blue color compensation lies in its ability to selectively reduce exposure in the visible parts of the spectrum. That the minus-yellow peak is not pronounced is to the good because this prevents severe color shifts when the filter type is used. For CIR enhancement, the blue color compensation filter comes close to possessing neutral density in the visual realm.

The transmittance curve when a CC30B is auxiliary to a Wratten 12 (Fig. 2) is low at 580 nm., has a minor peak at 620 nm., and only a moderate drop to 700 nm. where the rise toward transparency begins. With this pattern, the long visible wavelengths are less attenuated than with the light balancing filters mentioned below such as the 80B. With magenta density already low in the wave band between 600 and 700 nm., the reduction in cyan produced by the filter permits considerable yellow to be apparent in the image. For this reason, blue compensation filters tend to give a light orange cast to the body of the image which becomes more orange as filter density increases. A relatively early rise toward transparency (at the edge of the visible spectrum) resists the development of the dark bands and permits a color record of the long visible wavelengths.

Since compensation filters are made in many density increments, a wide variety of control is possible with their use. A CC30B appears as a good compromise between enhancement and an overly orange result. It should be particularly useful where there is a desire to give a color hue to such targets as reddish grain stubble, tropical soils, sandstone outcrops, or others which in nature often trend toward the red. Several of the oblique aerial views included in this report were made with a CC30B as an auxiliary filter.

<u>Blue light balancing and photometric filters</u>: Unlike the blue compensation filters, those in the Wratten 80, 82, and 78 series are essentially spectral wedges with transmittances that decrease steadily from the 520 nm. CIR threshold to the long wave end of the visible spectrum. Their rise

toward transparency occurs at a slightly longer wavelength (750 nm.) than with the blue CC types. This late rise combined with a low transmittance at 700 nm. attenuates the long visible wavelengths more than is the case with the blue compensation filters (Fig. 3,c). There is more chance that color hue will be lost in the dark bands and, with comparable exposures, for less yellow to occur in the body of the image. In the visible realm, peak transmittance for an 80B occurs at 540 nm. or close to the minus-blue cutoff wavelengths. Under proper exposure conditions this increases blue and reduces yellow to yield an image that is neutral to bluish in color balance. In Plate 4,d, light brown to gray off-season vegetation appears neutral, in contrast to the warmer tones when a CC30B is used. Soil and weathered tonalite appear neutral rather than green.

As can be noted in the spectrograms, much of the infrared enhancement that occurs with either an 80B or CC30B is produced by added exposure between 800 and 900 nm. Because the 80B required more exposure for proper densities in the body of the image than any other type tested, in this inquiry greatest infrared enhancement was achieved with its use and very low levels of infrared reflection were recorded. In Plate 4,d, coniferous forest on the 25-mile distant mountains is producing a strong record that barely shows when only basic minus-blue filtration is used (Plate 4,b). At ground target altitude, the intervening 25 miles of atmosphere contain many times the water vapor content of the atmospheric column that would be encountered in a near vertical spacecraft photo of the earth's surface.

The 80 series light balancing filters are available in only a few densities. An 80D will produce about one-half the enhancement of an 80B. An 82B will enhance about the same as an 80D, but will permit more yellow and green to be present. Mild enhancement is possible with an 82A.

Other filters: Any filter with good density in the visual bands but which becomes transparent in the near infrared logically would have potential as an enhancement filter. Transmittance to wavelengths shorter than 520 nm. will be of no consequence because light in this wavelength band does not enter into the exposure of the film. Most useful filters, however, appear to fall into the above two groups. Cyan color compensation, for example, enhances the blue in the image as much as the red, one masking the other. Magenta compensation filters have marked density peaks near 550 nm. but are quite transparent to much of the visual as well as the infrared bands of the spectrum. The result is an overly yellow image with little infrared enhancement. Sharp cutting filters would have only specialized use. They are virtually opaque to many desired wavelengths and produce monochromatic or at best bichromatic results.

Exposure considerations: Manipulation of the film sensitivity by means of auxiliary filters is done at the expense of effective film speed or shortness of exposure. Despite the added exposure that gives the enhancement, use of the CIR system is still quite feasible. An 80B filter which gives drastic enhancement opens the lens only 1-1/3 aperture stops (or an equivalent lengthening of exposure) from that used with a Wratten 12 or 15 filter alone. Moderate enhancement requires less exposure increase.

Typical exposures of 1/500 second at apertures smaller than f:4 leave the enhanced CIR film still comparable in speed to many other aerial photographic materials.

Determination of correct exposure when a specific auxiliary filter is used can be accomplished by filter factors or an adjusted ASA film speed rating. For ground targets, Eastman Kodak Company recommends a trial ASA speed of 100 for CIR type 8443. This does not yield consistent results because the average light photometer reacts to wavelengths shorter than the 520 nm. threshold of the film system. More consistent exposure determinations have been achieved by placing a minus-blue filter such as a Wratten 15 over the light sensor of the meter and using an ASA speed of 160 rather than 100. Table 1 suggests both filter factors and adjusted film speed for various auxiliary filters. One or the other should be used, not both. The adjusted film speed requires that minus-blue filtration be used with the meter.

When the camera employs a "behind-the-lens" automatic exposure calculating system, the film speed should be simply set at 160. The sensing system will then automatically compensate for all filtration and no other adjustment is necessary. Care should be taken, however, to check the accuracy of the exposure integrating system because if it is not working properly an alternate speed setting must be determined by trial.

For aerial exposures Eastman Kodak Company gives an index of 10 for type 8443 (Kodak, 1967). It would appear logical to adjust aerial exposures for specific auxiliary filters by applying the factors suggested

TABLE 1.

SUGGESTED EXPOSURE MODIFICATIONS FOR AUXILIARY ENHANCEMENT FILTERS

	Auxiliary filter	Filter factor	Adjusted ASA speed[b]
For mild enhancement	82A	1.3 (1/3 stop)	130
For moderate enhancement	82B, (80D,78C)[a]	1.6 (2/3 stop)	100
	CC30B, (78B)[a]	2.0 (1 stop)	80
For drastic enhancement	80B, 80C, (78A)[a]	2.7 (1-1/3 stops)	60
	CC50B	3.0 (1-1/2 stops)	50

[a] Filters in parentheses were not tested but adjustments were estimated from their positions on Figure 2.

[b] The suggested ASA film speeds assume a minus-blue Wratten 12 or 15 filter is used with the light photometer.

in Table 1 to this index or to settings determined by an aerial exposure calculator. Reduction of exposure with altitude to combat air luminance should not be the same as for normal color, however, because of the haze penetration of the CIR system. Haze will not reduce transparency density to the extent that occurs with normal color and underexposure can result if the same altitude adjustments are made (Plate 3,b). Trial exposures to determine exact auxiliary filter adjustments for high altitude use of CIR were not possible in the course of this inquiry.

SUMMARY

Although the enhancement of the record of near infrared reflection could be achieved by redesign of the film, minus-visual filtration as described in this report provides the investigator with an array of control that is immediately available to him with existing materials. There should be no thought, however, that the described enhancement is a panacea for all use of color infrared film. Where crop or forest vigor is to be determined by low level aerial or ground photography, such enhancement could remove desired subtle discriminations built into the film. There may be times, however, when a record of low levelsof infrared reflection is desired and auxiliary enhancement is in order. Where attenuation of the infrared reflection reduces the usefulness of the film, enhancement control may well be of project-saving significance.

Of the auxiliary filters tested, two stand out as particularly useful. The CC30B provides good enhancement with only a moderate sacrifice in effective film speed. Other than enhancing the infrared, it changes the basic color balance of the film system only slightly. The addition of yellow converts the cyan to a true green. The CC30B gives color rendition to the long wave end of the visible spectrum, but for the yellows and browns of nature this color is green to yellow-green (Plate 7,a). In contrast, the 80B as an auxiliary eliminates the green and in so doing frequently produces sharper contrasts between tone signatures. Greater enhancement of the infrared gives the 80B better haze-penetrating ability (Plate 7,b), particularly in the case of brown urban haze which forms a slight green obscuration when the CC30B is used. In the course of this inquiry, aerial photographs made with the 80B appeared to provide clearer information than those made with the CC30B. Where the infrared reflection is weak, the 80B is most apt to yield a record of it on the image.

The inquiry described in this report may well only touch upon control possibilities that give this potentially useful remote sensing material more successful and wider application without design change. The method is simple and an investigator can modify or improve upon it for his own purposes.

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PLATE 2.

Haze Penetration
by Color Infrared Film

a. A view of the Mississippi River taken from a commercial airliner flying at an altitude of 41,000 feet. Atmospheric luminance is strongly obscuring the surface in this image made on normal color (Kodachrome) film.

b. Taken on type 8443 color infrared film a few moments later, this image shows the surface clearly. Field patterns show well and some late season crops are producing the characteristic infrared reflection. Reelfoot Lake, a relic of the great New Madrid earthquake, lies at the edge of the floodplain near the dissected valley bluffs.

Although the utility of color infrared film has often been limited to the mid-hours of the day, this image was made at 4:30 pm in October--the long shadows attesting to the late hour. With a CC30B as the auxiliary enhancing filter, no exposure precautions were necessary other than the use of a standard CdS exposure meter.

PLATE 3.

The Need for Enhancement When Used at High Altitudes

a. This color infrared image of Malibu Canyon, California provides a good example of severe water vapor attenuation of the infrared record. Taken at 8,000 feet on Kodak Ektachrome Infrared Aero (type 8443) with an RC-8 camera, the image contains no record of infrared reflectance from either the verdant chaparral-covered slopes or riverine vegetation along the stream. This is typical of the problems encountered when only the basic minus-blue filtration is used--in this case a Wratten 15. Close to the ocean, the water vapor content of the lower atmosphere was high.

Image from NASA 926, Mission 30, Site 130, August 8, 1966.

b. In contrast, the red infrared record penetrates great thicknesses of atmosphere when the relative sensitivity of the red-yielding layer of the film is increased by auxiliary filter enhancement. From 38,000 feet the red of fall dairy pasture is clearly visible through this break in a cloud deck. The view also demonstrates the degree to which image density is lightened by the thickness of atmosphere penetrated. At Latrobe, Pennsylvania, 20 miles distant, the density is approximately half that in the sunlit areas of the foreground. There would be more than 100 mm of precipitable water in this thickness of air.

Time: 9:30 am. October, 1967. Auxiliary filter, CC30B. 35 mm camera.

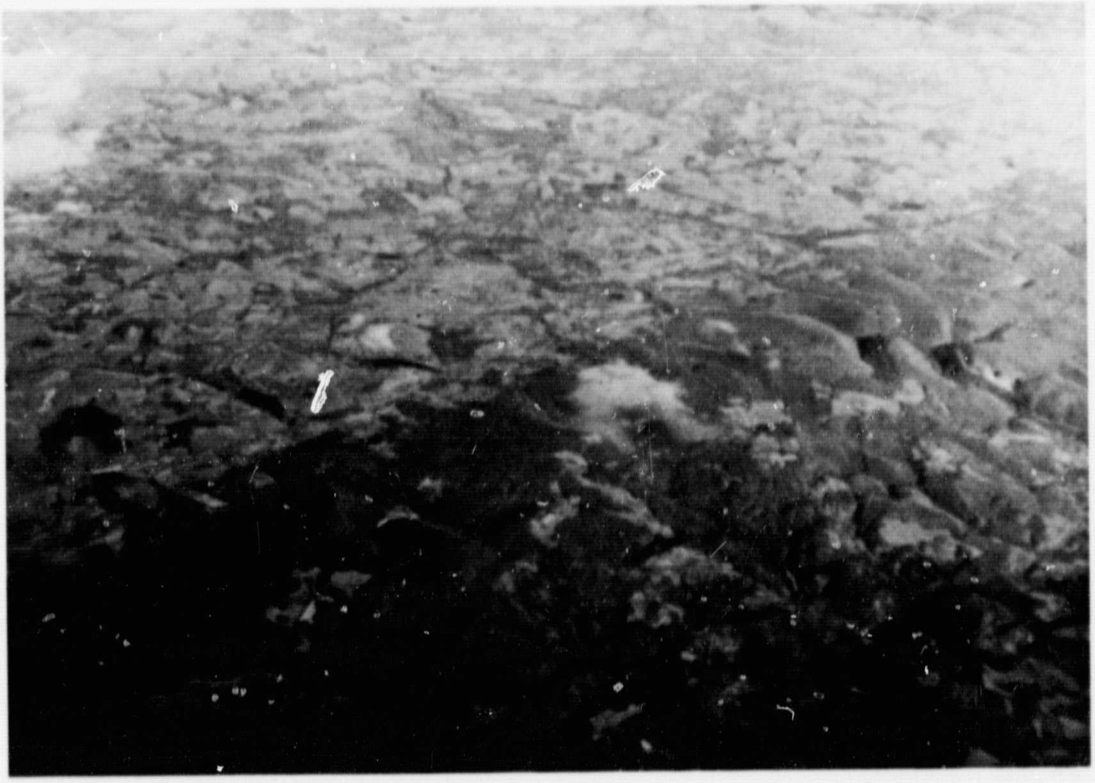


PLATE 4.

The Effects of Various Auxiliary Enhancement Filters

a. (upper left) A normal color view across the eastern end of the Los Angeles Basin on a moderately clear day. The San Gabriel Mountains are approximately 25 miles distant. The coastal sage vegetation cover in the foreground in this fall season is at a minimal level of vegetative growth.

b. (upper right) The effect when only minus-blue (Wratten 15) filtration is used. The orange groves in mid-distance are a deep red. Only a slight hint of color on the distant mountain slopes marks conifer forest. Nearby off-season vegetation shows no infrared reflection. Like all the views on this plate, this picture was taken within minutes of the others.

c. (lower left) The effect when a CC30B auxiliary enhancing filter is used. Mild infrared reflection shows on the distant mountains. The orange groves are brighter, more red--a characteristic of this enhancement. A little red shows in the nearby vegetation. The yellow to orange cast is typical of blue color compensation filters.

d. (lower right) The effect when an 80B is used as the auxiliary filter. The conifer forests on the distant mountains are now yielding a strong infrared record. The color reproduction fails to show how intense the red of the orange groves has become and considerable IR record occurs from the nearby off-season vegetation. Note that rock and soil have become neutral in tone.

Time: 1:30 pm in early October, 1967.

PLATE 5.

The Effects of Various Auxiliary Enhancing Filters

The effects of two additional auxiliary filters are compared in the plate with conventional filtration. The view is northward across San Gorgonio Pass toward the San Bernardino Mountains in Southern California. The town in the foreground is Banning. Time: 2:30 pm, December, 1967.

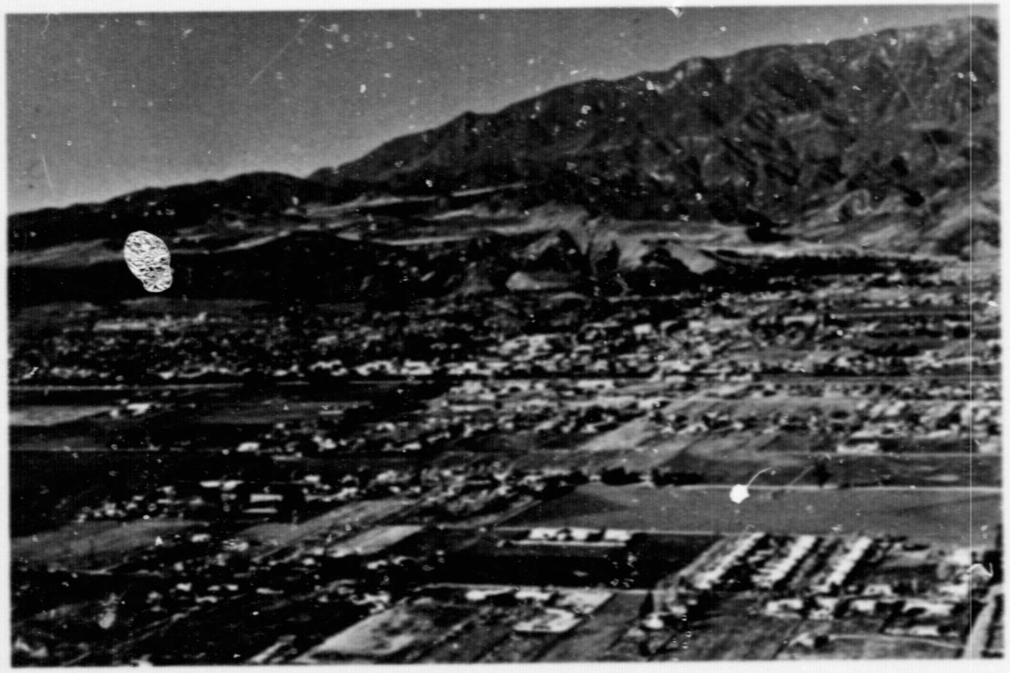
a. (upper left) Normal color. There are many green fields and trees in vegetative growth in Southern California at this season. On the distant mountains higher slopes are forested with conifers and lower slopes are covered with evergreen chaparral.

b. (upper right) Wratten 15 minus-blue filtration only. Record of the infrared reflection from the fields is minimal. Trees on the floor of the pass show some red, but there is little record from the distant mountain slopes.

c. (lower left) The effect of an 82B auxiliary filter. Moderate enhancement of the infrared record has occurred. More and brighter reds now show in the fields and trees on the pass floor. An orange-red tinge marks the location of conifer stands on the San Bernardino Mountains, and the IR record of the chaparral is brown in tone. The 82B gives moderate enhancement without the yellow cast of the blue color compensation filters.

d. (lower right) The effect of an 80C as an auxiliary filter. Results from this filter are difficult to distinguish from those of an 80B although the enhancement is slightly less. Fields have a bright red hue as do those trees that still have green foliage. The conifer forest yields a bright reflectance and the record from the chaparral is strong.

As with all auxiliary filters the reds tend to be more orange and lighter in tone than when no enhancing filter is used. This is due to removal of cyan from the image.



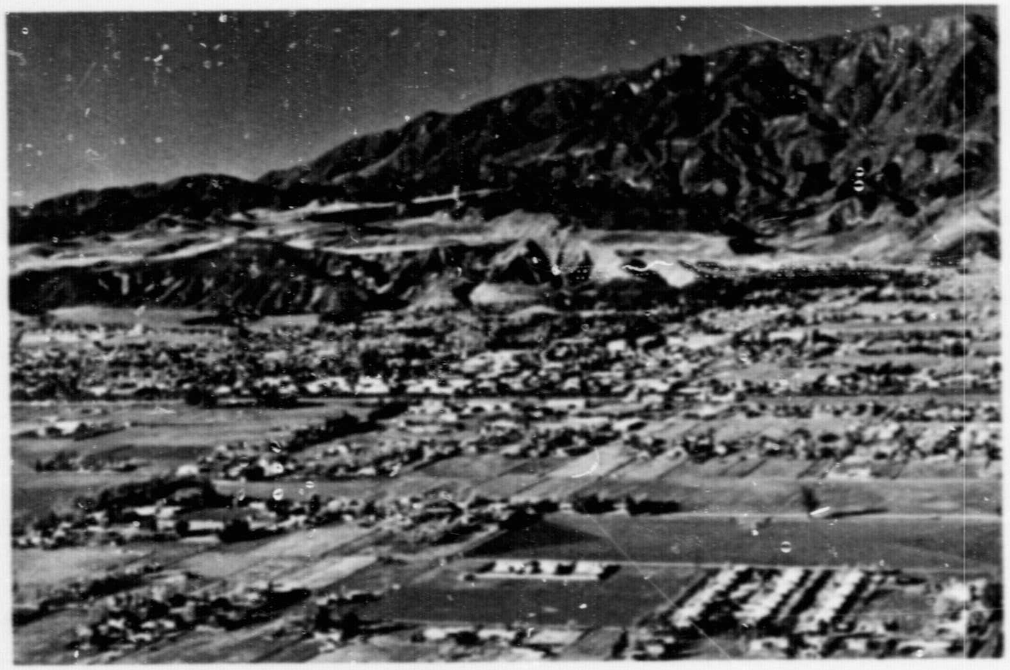


PLATE 6.

Spectrograms of Color Infrared Film Showing the Effects of Auxiliary Filters and Exposure

Spectrograms tell the story of the nature of color infrared transparency film and the effects of both auxiliary filters and exposure upon the apparent color response of its image. These spectrograms were made through a 13,000 lines per inch diffraction grating and with the exception of a. onto Kodak Ektachrome Infrared Aero film (type 8443). The spectrograph slit was opened to .025 inch to shorten exposure. Illumination from a tungsten source (3400°K) was wedged in intensity across the slit to achieve the spectral curves of the dye layers. The spectrograms are listed below in positions corresponding to their placements in the plate.

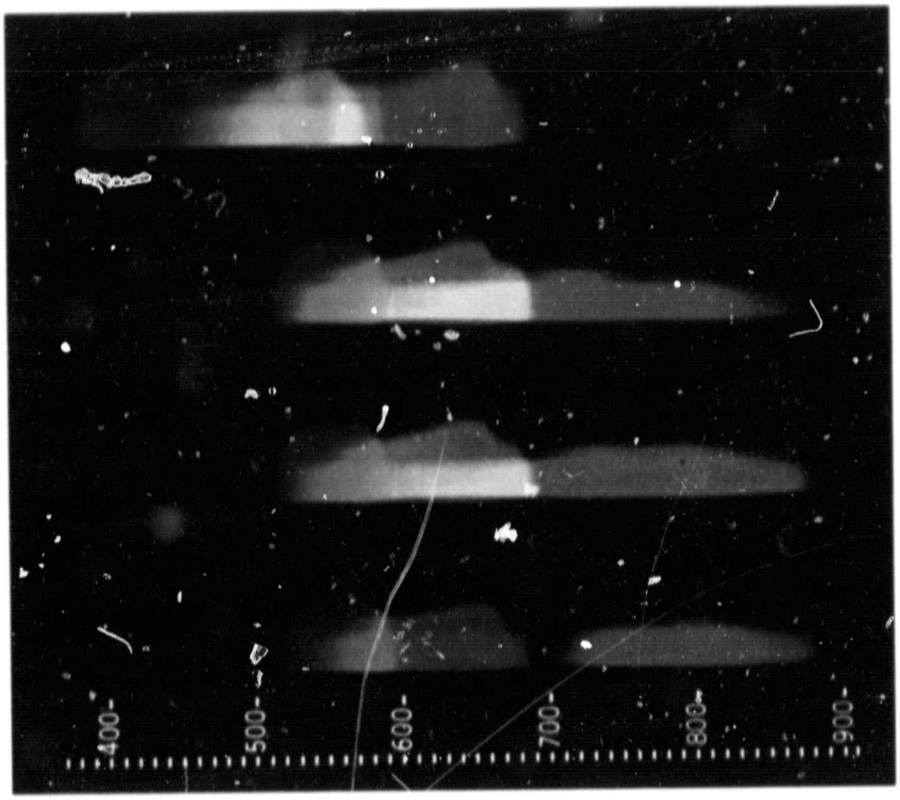
(upper group) a. Normal color (Kodak Ektachrome-X). Curves for the three dye layers occupy overlapping domains in the visible spectrum from 400 to 700 nm. The layers appear as approximately equal in sensitivity and therefore variations in exposure do not materially affect the color balance of the image. The colors yielded by the three dye layers are in their proper spectral positions and are "true colors."

b. CIR film with only minus-blue filtration (Wratten 15). Sensitivity extends from 520 to close to 900 nm. Colors do not appear in their proper spectral positions and are therefore "false colors." The red-yielding sensitivity is a narrower curve than the other two but extends over a broad band from 600 to 900 nm. Overlap with the green permits yellow to appear in those wavelengths which in nature are orange to red.

c. CIR film with a CC30B auxiliary filter. The red curve has been broadened between 750 and 850 nm. Although slightly reduced near 600 nm., the yellow remains strong which combined with the enhanced red gives the image produced by this filter its characteristic yellow to orange cast. There is only a slight tendency toward a dark band at 700 nm.

d. CIR film with an 80B auxiliary filter. Due to filter factors, this spectrogram has about 1/3 less exposure than those above. The withdrawal of the red-yielding sensitivity from the visible spectrum and the tendency toward a dark band show well. With equivalent exposure, enhancement is slightly greater than with the CC30B.

(lower group) e-g. This series of spectrograms shows the effect of reduced exposure on color balance in CIR film. Due to its lower sensitivity, the red-yielding layer retreats rapidly from the visible spectrum as exposure is reduced while the blue and green are less affected. This not only reduces the infrared record, but removes yellow from the image. Each spectrogram has one-half the exposure of that above it. All were made with a CC30B auxiliary filter.


400
500
600
700
800
900

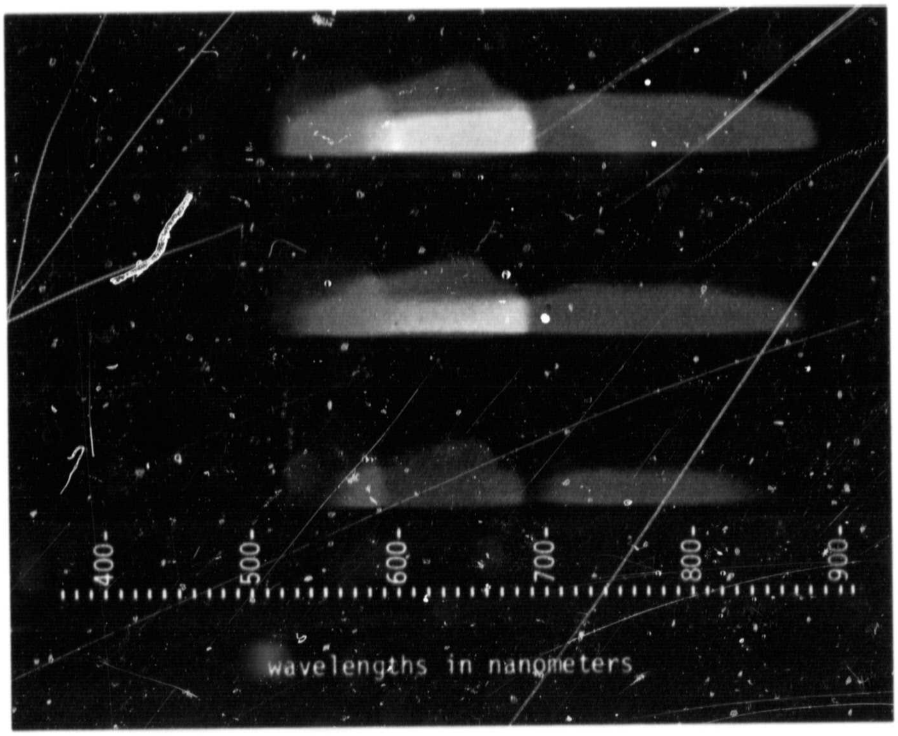

400
500
600
700
800
900
wavelengths in nanometers

PLATE 7.

Landscape Analysis

a. Stillwater, Oklahoma taken on 35 mm CIR film at 35,000 ft. with auxiliary CC30B filter through an airliner window in mid-October. Rural land use is indicated by red for winter wheat; light green for corn, alfalfa, and sorghum stubble; and dark green for fallow land. Riverine vegetation responds to the dark band due to possible seasonal decline in vigor. Close examination reveals the urban commercial core responding at about 600 nm. with outlying commercial-industrial areas slightly less in wavelength. Older residential areas respond nicely in the 700-850 nm. infrared because of abundant vegetation while the newer subdivisions are a mixture of blue-green (550 to 600 nm.) and infrared (700 to 850 nm.). The university complex corresponds in reflectance to the commercial center but has islands of infrared response. Preliminary studies indicate that useful rural and urban land use mapping is possible from this image at a scale larger than 1/250,000.

b. Pomona-Claremont area of Southern California taken on 35 mm CIR film at 17,000 ft. with auxiliary 80B filter through airliner window in late December. Ozone "smog" count was 18 ppm and a distinct inversion line is detected about mid-way up the slopes of the San Gabriel Mountains. Single family suburban housing patterns can be distinguished as well as vacant land, orange groves, vineyards, and grazing land. Distinct color differences of the various arteries differentiate freeways from streets and/or emply flood canals. Ribbon commercial developments, industrial sites, shopping centers, and recreation areas also have individual responses. There is a color change between the higher conifers and the upper boundary of chaparral. "Smog" which tends to be yellow in color is best penetrated by this filter combination. A matching Kodachrome-X with a Tiffen Haze 1 filter revealed little more than the top of the inversion with the mountain peaks showing through.