D. S. Ross*
International Imaging Systems
Mountain View, Calif. 94040

Atmospheric Effects in Multispectral Photographs

A simple method is offered for remotely determining gross effects on image densities.

Introduction

Sunlight incident on, and reflected by the scene toward the camera is subjected to spectral scattering and absorption. Scattering is the most serious effect, and arises primarily from aerosols—dust, moisture, pollen, salt nuclei and other airborne particles which vary with time and place in size, mixture, and concentration. These variables can seldom be predicted or measured in most operational situations. Scattering produces a luminosity in the atmosphere, variously called air light, haze, or non-image-forming light.

Abstract: *A simple method of estimating gross atmospheric effects on distorting multispectral image contrast is based on a graphical solution using image density measurements of bright and dark terrain reference areas of known (or estimated) spectral reflectances. The density data are normalized to the sensitometric spectral-response film curves in a way which compensates for variations in response-curve shape, film processing, filter factors, exposure, atmospheric radiance and spectral attenuation. The order of spectral reflectance in parts of the scene other than the reference areas may be assessed and a comparison of spectral response between bands can be made.*

The shorter blue wavelengths are most affected, but in some instances serious effects occur in the green and even red end of the spectrum. Light scattering and absorption is of consequence for all types of remote sensors; but because images are the product, the effects seem more prominent in multispectral photographs where the blue and green records have visibly less scene contrast than the red and infrared.

Haze light affects the recording of the lower scene radiance values more than the higher, resulting in a distorted reproduction curve, which can vary considerably between spectral bands. Other factors which affect the exposure-density relationship in photo recording further complicate matters, and are noted below.

In multispectral densitometric analysis it is frequently necessary to estimate the effects of the atmosphere on each image in the set in order to determine more closely the relative spectral reflectance values of the subjects under investigation. Unless quantitative data are known on the condition of the atmosphere at the time of photography, the investigator is obliged to apply complex mathematical corrections in a computer from one of the several models of the atmosphere; or he may even be reduced to educated guessing.

A simple alternative method (which automatically takes into account many variables in the photographic process) is offered for quickly estimating gross atmospheric effects on image densities. The method requires only spectral filter response curves for the films used, and known or estimated ground-level reflectance (or radiance) values for two or more subjects of types normally found in multispectral imagery.

At worst, the reduction method is capable of estimating *relative* percentages of subject

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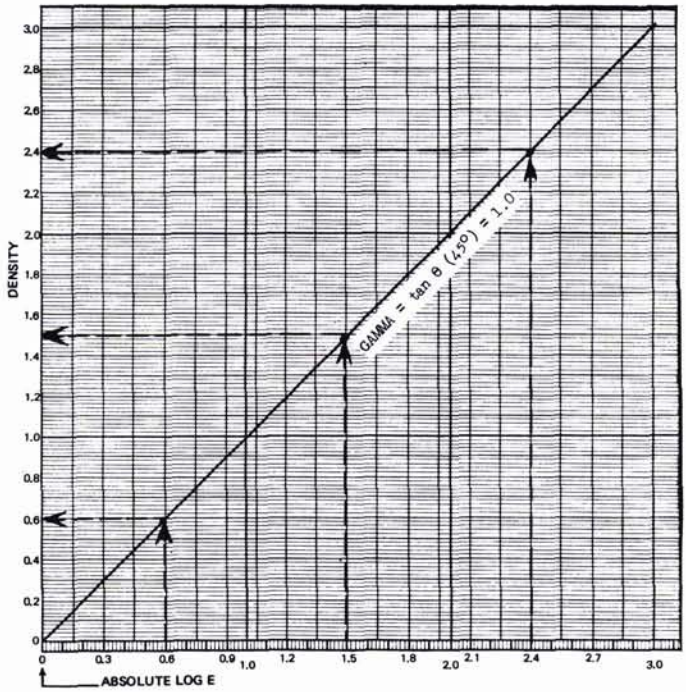

FIG. 1. Idealized linear photographic film response where the film density values are equal to the $\log_{10}$ exposure values.

reflectance values between spectral bands to a first approximation. At best, quantitative radiance values might be derived if enough scene radiance data and film-filter factors (response in ergs/cm^2) are known accurately.

THE PHOTOGRAPHIC SPECTRAL IMAGE

An understanding of the main factors affecting spectral image recording is helpful in explaining why data corrections are necessary, and how this can be done. A brief survey of some key elements follows.

SENSITOMETRIC RESPONSE

In a perfect recording system, image densities could be directly related to the exposing energy (scene radiances), if exposure is adjusted so all radiances are recorded on the linear part of the response curve, and the film is processed to gamma 1.0, as shown in Figure 1. Gamma 1.0 (*tan θ* of the 45° film response slope) represents a 1:1 ratio between film density and exposing energy; the latter in $\log_{10}$ units, and density as $\log_{10}$ of film opacity. Thus absolute *log E* radiance units represented by 0.6, 1.5 and 2.4 in the figure, would produce 0.6, 1.5 and 2.4 density units in the perfect system.

Gammas larger or smaller than 1.0 represent increases or decreases in the energy-density ratio; i.e., at gamma 2.0, the ratio of scene radiances recorded by film densities are amplified by a factor of two, and image *contrast* is twice as high as actually received at the camera station. Gammas higher than 1.0 are normal in aerial photography.

It is not operationally practicable to have a perfect photographic recording system. Small differences between film batches, filters, spectral response and curve shape, exposure, processing, and other factors produce a film response similar to that shown in Figure 2; *log E* units of 0.6, 1.5 and 2.4 are now represented by densities of .18, 1.3 and 2.65, respectively. This is not a criticism of the photographic process *per se;* other sensors exhibit similar non-linear characteristics which must be corrected also for data reduction.

SPECTRAL SENSITOMETRIC CONTROL

It is necessary to have spectral sensitometric control step tablets exposed on the original film(s) through each of the spectral filter types used, by a light source equivalent to daylight. The control exposures should be made as close as possible to the time of photography, to avoid latent image failure ef-

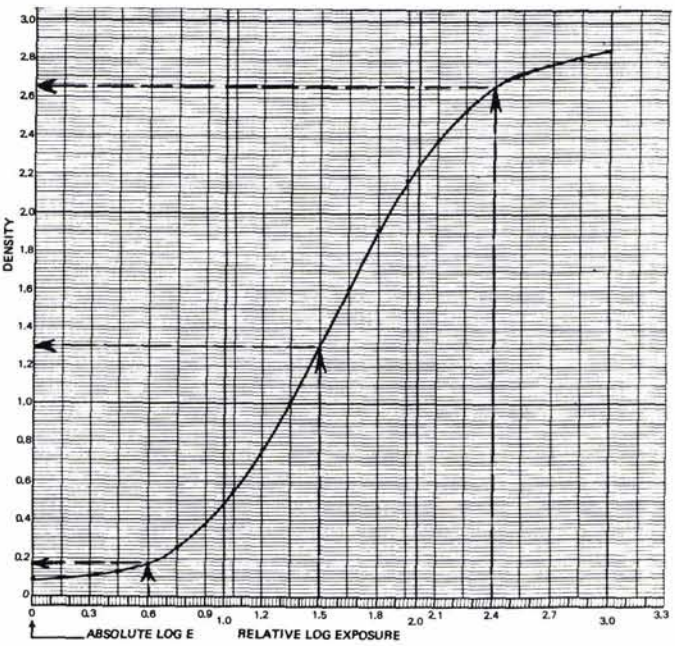

FIG. 2. Sensitometric film response curve for a typical film (Kodak Plus-X Aerographic 2402).

fects. Sensitometric exposure duration (by strobe or shutter) should be in the same order as camera shutter speed if reciprocity effects are likely to be of consequence[1].

These are standard control procedures in multispectral work where valid analyses are to be performed. The characteristic response curves for each spectral band should be plotted as in Figure 2, preparatory to data reduction.

FILM SPECTRAL RESPONSE THROUGH THE ATMOSPHERE

The unpredictable atmospheric haze effects differ between spectral bands according to the nature and concentration of the aerosols. It was noted that scene reflectance or radiance values are affected more in the lower values than the higher. Consider a spectral scene with a range of 5-percent reflectance at the low end and 50 percent at the high: If viewed through the veiling light of a 5-percent atmospheric haze, the low value will now appear to be 10 percent, or doubled in radiance, relative to the high of 55 percent, which has been only increased by one-tenth. All remote sensors are affected by this phenomena, which must be accounted for where relative or quantitative values are to be determined. The effect is to decrease the recorded contrast of the low reflectance or radiance values relative to the brighter objects. To complicate matters, different spectral bands will *see* different percentages of haze, the blue more than the green, the green more than the red, and red band more than the infrared.

GRAPHIC EXPRESSION OF HAZE EFFECTS

Tupper and Nelson,[2] in studying the effects of haze on the tonal reproduction of black-and-white aerial photographs, developed a graph showing the theoretical distorting effects of various amounts of haze on the tone reproduction cycle. Based on the analysis of samples, corrections were applied to account for atmospheric absorption. As haze increases, so does spectral absorption, and ground reflectance is reduced to some lesser value if seen through the atmosphere column. In plotting haze curves of different percentages against the exposure scale it is found they cross over at some intermediate point at the high end (high scene radiance or reflection percentage).

In an experiment where multispectral photographs were made of a large step tablet array on the ground from various altitudes, the same approach was adopted to derive the set of curves given in Figure 3. The point of origin of the curves was established at 63-

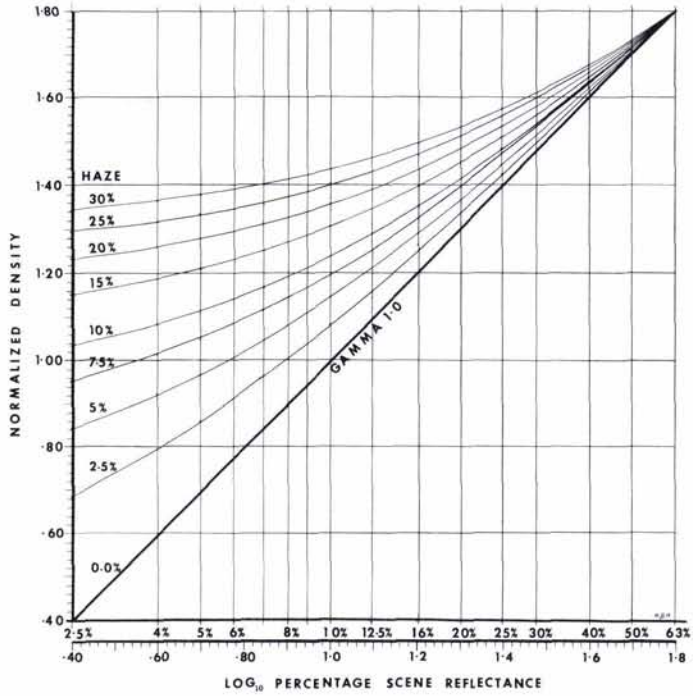

FIG. 3. Curves illustrating effects of different amounts of atmospheric haze in distorting the linear reproduction of scene radiances.

percent reflectance; this is empirical but is based on limited experimental data. Atmospheric light absorption will vary according to the spectral band and the types and concentrations of aerosols, displacing the set of curves to the left at higher absorption or to the right at lesser absorption. However, on the logarithmic scale for high-scene radiance percentages such displacements would be relatively small, and for practical purposes the origin is generally somewhere near this point within the range of visible and infrared photographic sensitivity.

SPECTRAL REFLECTANCE REFERENCES

Atmospheric effects on the image may be evaluated by including large gray-scale ground panels in the photography, from which film response curves are plotted from the recorded densities of the step images. The enormous size of panels which would be required for high-altitude and space imagery precludes this approach. Brock and others have pointed out that the more significant atmospheric effects can be inferred by comparing images of black-and-white areas; the contrast compression ratio indicating the effect of haze. Whether these be man-made or natural features is immaterial so long as something is known about their reflectance characteristics, in this instance, their spectral reflectance characteristics; and the image is large enough for densitometry.

In the ideal case, the experimenter has made spectral radiometric or reflectance measurements on subjects of interest in the scene, hopefully taken near the time of overflight. If these areas are not large enough to be imaged in the photographs at a size adequate for densitometry, larger areas in the vicinity, of the kinds discussed later, should also be measured for future reference.

The reference areas in the photographs should be near the nadir point at a scale minimizing adjacency effects[1]; that is, the non-linear density increase/decrease at area boundaries which would falsify density measurements. The image of the reference area should be not less than 1.2 mm in diameter if measured with a 1 mm densitometer aperture. Because of adjacency effects, microdensitometry of small areas is not advisable for this method of data reduction.

If ground truth is not available, data on orders of spectral reflectance for many subjects are found in the literature, as in References 4 through 8, and may be used for estimating reflectances.

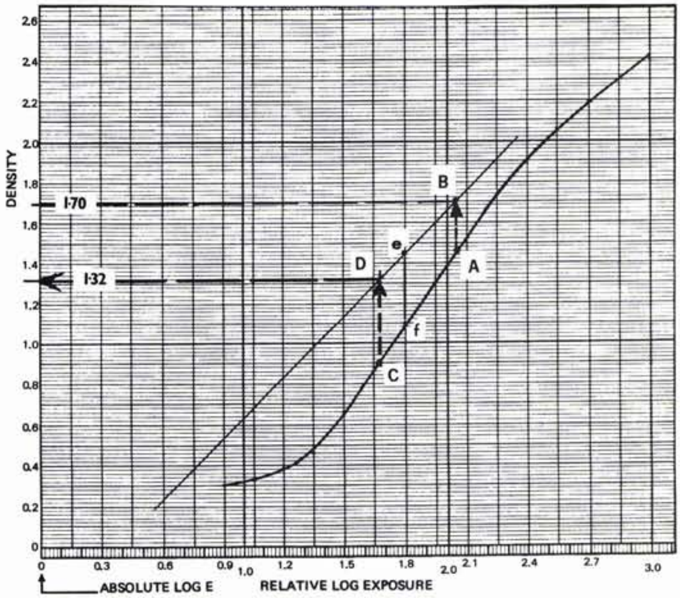

FIG. 4. Normalizing density data from areas of high and low reflectance (or radiance) for estimating the haze factor.

Reference areas of high- and low-spectral reflectance are required, preferably equally reflective in the spectral bands to be compared. Freshly plowed black soil, asphalt parking lots, and aircraft runways are suitable for low reflectance areas. White beach sand, fresh concrete, snow on flat surfaces (use with caution—new snow may be too highly reflective), areas where light-colored soils are exposed for construction work are examples of where reflectances in the order of 40 to 60 percent can be found.

These examples will suggest other possible reference subjects to experimenters specializing in forestry, agriculture, soil identification, geology and other sciences, who know from experience or measurement the probable orders of spectral reflectance expected from particular subjects.

ESTIMATING GROSS ATMOSPHERIC EFFECTS

DATA NORMALIZATION

The objective is to normalize image densities to the values they would have had, if it had been possible to make a perfect exposure on the linear portion of the film curve processed to gamma 1.0; that is, to determine relative but unknown reflectance values of significant areas by converting densities obtained in the typical response curve shown in Figure 2 to the form illustrated in Figure 1. Normalization is done as follows:

1. The density of the most highly reflective reference area (least affected by the atmosphere) is measured. Its known ground-level reflectance in the spectral band concerned should be in the order of 40 to 60 percent. The measured density is then marked on the film spectral response curve. Let us assume it is $D = 1.46$ at A in Figure 4, and is known to have 50-percent reflectance, or 1.70 in logarithmic units.
2. A vertical line is produced from A to B, at 1.70 measured on the density scale.
3. A gamma = 1.0 (45°) line is drawn through B.
4. The density of the least reflective reference area is measured and marked on the film response curve at C; assume it is $D = .90$.
5. Draw a vertical line from C to intersect the gamma = 1.0 line at D and note that the figure on the density scale at this point reads 1.32.
6. If the least reflective reference area was known to have 7-percent reflectance, its density on the perfect gamma = 1.0 reproduction curve, unaffected by the atmosphere, should be about .85 ($\log_{10}$ of 7 percent, Figure 3) instead of 1.32. The difference is attributable to effects of atmospheric light. On the haze diagram in Figure 3, read up from .85 on the reflectance scale to the point where 1.32 density intersects a haze curve. This is found at the 20-percent haze line.
7. The effect of a 20-percent haze on other scene reflectance-density relationships may

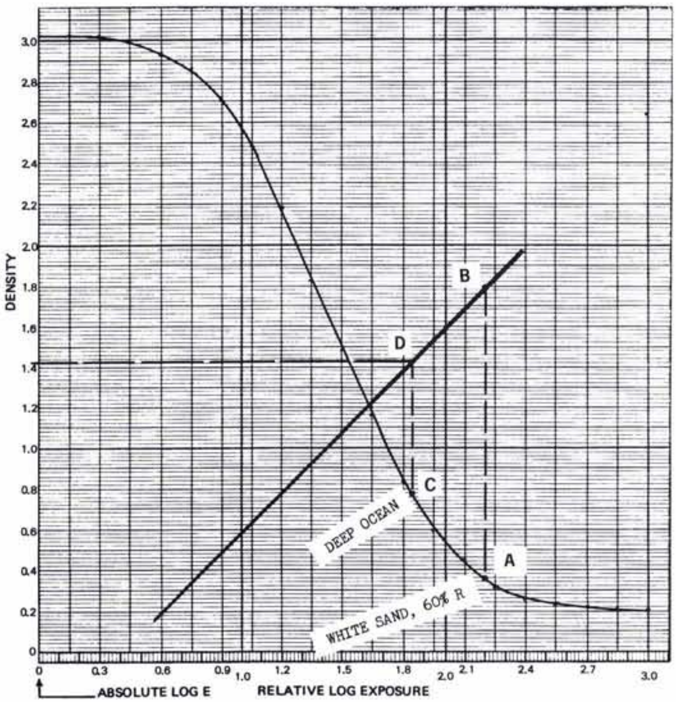

FIG. 5. Normalizing the density data on a positive film transparency.

now be found in Figure 3, by tracing along the 20-percent haze curve. For example, a surface reflecting 16 percent (1.2 on the gamma = 1.0 curve) would become 1.44 in the presence of 20 percent haze as shown in Figure 3 where 16 percent intersects the haze line. If this is transferred to Figure 4, a line dropped from 1.44 at (*e* to *f*) intersects the film curve at a density of 1.10. Other areas in the scene with densities of 1.10 will also have reflectances in the order of 16 percent.

In some applications the position of the high-reflectance density point on the film response curve may require the line to be dropped, rather than erected, as in the example. The gamma = 1.0 line is drawn as described, and may even cross the film curve, reference lines being drawn up or down, as the situation requires. The same graphic procedures apply to sensitometric curves for positive images, as shown in Figure 5.

CORRELATING SPECTRAL HAZE FACTORS

Gross atmospheric effects as they influence each spectral band may be plotted in the form shown in Figure 6, prepared from red, green and blue multispectral images taken from an altitude of 6,000 feet. The data points are normalized from density measurements on the images of a large step tablet recorded in each of the three bands. The *R*, *G*, *B* ordinate axes are measured spectral reflectances in the red, green and blue bands.

The red band has a 7- to 8-percent haze factor, the blue about 15 percent and the green, 20 percent. Incidentally, the reversal of haze conditions between the blue and green bands, although unusual, is not unknown; the types of aerosols, particle sizes relative to the spectral wavelengths concerned, and stratification of haze layers can produce such effects.

ERROR SOURCES

Accuracy depends on knowing as exactly as possible the reflectances of the selected high- and low-reflectance reference areas. For example, if the high-reference area was actually 40 percent rather than the 50 percent given in the example, the normalized low reference would read 1.21; a haze factor of 13 percent rather than 20 percent. Areas of 16 percent reflectance in this instance would appear to have a density of 1.17 rather than 1.10.

If it has not been possible to make ground

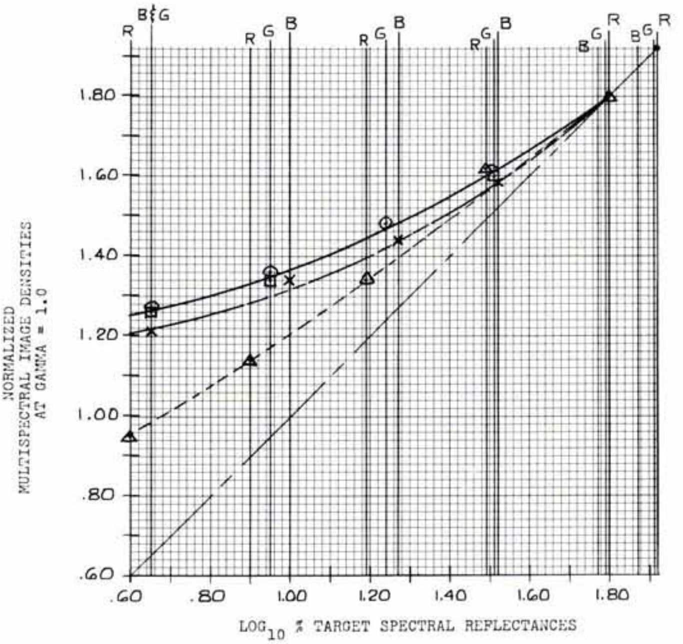

FIG. 6. Estimating the haze effects in the blue, green and red spectral bands as determined aerial photographic images of gray step tablet on the ground. Circled points indicated are for a 57A green filter, squares are for the I²S-G green, *X* for 47B blue, and triangles for the 25 red filter. Estimated haze factors: blue, 15 percent; green, 20 percent; and red, 7 to 8 percent.

measurements of the reference areas and estimates from reflectance tables are used, care must be taken to account for sun angles, flatness of terrain and seasonal factors if these apply. Error can be reduced by measuring the densities of as many areas as possible, where percentage reflectances are known, or can be estimated with some accuracy. These normalized data can be plotted at intermediate points as in Figure 5. This aids selection of the haze curve which best fits the data points with an improvement in accuracy commensurate with the number of measurements normalized.

Another possible error source lies in the choice of 63 percent as the crossover point for the haze curves. As noted, light energy is not absorbed equally through the spectrum, and the crossover will vary between spectral bands according to altitude and haze concentrations. Table 1 gives approximate percentages of light transmission in four filter spectral bands at two altitudes under fair photographic conditions, derived from Elterman's model atmosphere.[9]

The variations in spectral transmission are not so large that, inasmuch as lens absorption, camera flare and similar factors are included, the combination of effects would shift the haze cross-over point significantly from the 63-percent region used in the example. However, more experience with this data-reduction method, particularly with images taken from orbital altitudes, may require a separate set of curves for each spectral band to improve accuracy.

Finally, too much confidence must not be placed on data which show haze to be 5 percent or less if the photographs have been taken from above 4,500 or 5,000 feet. Hazes of 10 percent in the visible region represent

TABLE 1. APPROXIMATE PERCENTAGES OF SPECTRAL ATMOSPHERIC TRANSMISSION FOR WRATTEN FILTER BANDS
(for 7-nautical-mile meteorological ground visibility, derived from Ref. 9.

Filter Region	*13,000 ft. ASL*	*50,000 ft. ASL*
Blue—47B	62%	55%
Green—57A	68%	63%
Red—25	73%	70%
Infrared—88A	79%	76%

excellent photographic conditions, which are rather rare.

In conclusion, the procedures described permit rapid estimates of the gross effects of the atmosphere on multispectral images, and relative effects on individual spectral records. Where sufficient and accurate spectral radiometric data on ground areas are available, where absolute spectral film response is known, and where the photometric qualities of the camera system are calibrated, the procedures offer a means of measuring atmospheric effects in radiometric terms. Further refinement of these procedures is desirable.

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