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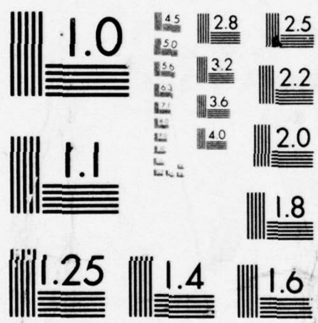

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
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VISIBILITY AS AN ESTIMATOR OF INFRARED TRANSMITTANCE

By

J. Mason
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July 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

To assess the utility of visibility as an indicator of transmittance in the infrared, models depicting haze, fog, smoke, and dust were constructed such that all yielded identical transmittances at 0.55μm (micrometers) (center of the visible spectrum), and transmittances at several infrared wavelengths (due to scattering only) were calculated. Results show that significant errors occur if visibility is relied upon.

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PREFACE

The authors wish to thank Dr. George Goedecke for assistance in adapting the ASL single scattering code to this problem and Dr. Richard Gomez for helpful discussions during preparation of this report.

CONTENTS

INTRODUCTION

With the growing emphasis on electro-optical systems in the Army's tactical arsenal, it is becoming more important to understand the atmosphere's effect on light transmission in the battlefield environment. One element of concern is the effect of suspended particulate material, and this especially in the infrared (1-15μm) region of the spectrum. At the present time, the Army has no field-hardened transmissometer for application in the battlefield environment, and where it is necessary to predict the performance of an aiming device or target designator, there is a tendency to apply what information is available - namely, the met observer's estimate of visual range. Empirical relations between visual range and IR transmittance have been devised and used [1,2]. Is visual range really indicative of transmittance in the near infrared?

Some examples of calculated effects due only to particulate light scatter using model aerosols of varying composition are presented. The purpose is to suggest the degree to which transmission in the IR can be affected by changes in the particulate content alone and how accurately (or inaccurately) an estimate of propagation in the visible region indicates those effects.

To establish a basis for comparison, we assume that visual range (defined below) is inversely proportional to the logarithm of monochromatic transmittance at 0.55μm, the center wavelength for human visual perception. All calculations are then normalized to a transmittance of 0.45 over a 1 km path at this wavelength which corresponds to a visual range of 5 km. That is, an observer would estimate the same visual range in every case.

PARTICULATE MODELS

The ASL single scattering transmission code (PGAUSS) [3] is used for the calculations and gaseous absorption effects are not included. The particulate model supposes a two-component aerosol in the combinations:

Dry Haze + Smoke	Wet Haze + Smoke	Fog + Smoke
Dry Haze + Dust	Wet Haze + Dust	Fog + Dust

with one component predominant in varying degrees. Clearly, other aerosol conditions can obtain. These were chosen as being representative of the environment encountered during Target Signature Model Validation Tests [4] conducted at Fort Knox, KY, in August 1974 by the Army Materiel Command. The size distributions pertaining to each component are given in Table 1 and the optical constants are given in Table 2.

TABLE 1

ATMOSPHERIC PARTICULATES AT FORT KNOX, KY

Designation	Composition	Size Distribution: Type	Size Distribution: Representation	Size Distribution: Constants	Radius (r) Range (μm)
Dry haze	Soil	Deirmendjian haze C	$n(r) = 0$	-	$r < 0.03$
			$n(r) = c \times 10^4$	-	$0.03 \leq r \leq 0.1$
			$n(r) = cr^{-4}$	-	$0.1 < r \leq 1.0$
Wet haze	Water		$n(r) = 0$	-	$r < 1.0$
Dust	Soil	Power Law (Junge)	$n(r) = cr^{-\beta}$	$\beta = 3.0$	$0.1 < r < 10$
Smoke	Carbon	Log-normal	$\left\{ n(r) = \frac{1}{r \ln(\sigma_g \sqrt{2\pi})} \exp \left\{ -\frac{1}{2} \left[\frac{\ln(r/r_g)}{\ln \sigma_g} \right] \right\}^2 \right\}$	$\sigma_g = 0.30$ $r_g = 0.25$	$0.1 < r < 0.4$
Fog	Water			$\sigma_g = 0.30$ $r_g = 5.0$	$4.85 < r < 5.15$

TABLE 2

OPTICAL CONSTANTS OF DRY HAZE, DUST, SMOKE, WET HAZE, AND FOG IN THE 0.34 TO 10.6 μm RANGE

λ(μm)	Dry Haze, Dust [5]		Smoke [6, 7, 8]		Wet Haze, Fog [9]	
	n	k	n	k	n	k
0.34	1.65	0.005	1.6	-	1.345	0.0
0.40	1.65	0.005	1.6	0.5	1.339	1.86 E-9
0.47	1.65	0.005	1.6	0.5	1.336	9.52 E-10
0.55	1.65	0.005	1.6	0.5	1.330	1.96 E-9
0.66	1.65	0.005	1.6	0.5	1.330	1.88 E-8
0.75	1.65	0.005	1.6	0.5	1.330	1.56 E-7
0.90	1.65	0.005	1.7	0.5	1.328	4.86 E-7
1.06	1.65	0.005	1.7	0.7	1.326	5.0 E-6
1.25	1.65	0.005	1.7	0.7	1.323	4.2 E-5
1.5	1.65	0.007	1.7	0.7	1.319	1.1 E-4
1.75	1.64	0.009	1.7	0.7	1.313	1.1 E-4
2.0	1.64	0.010	2.1	0.8	1.306	1.1 E-3
2.4	1.64	0.014	2.0	0.8	1.279	9.56 E-4
2.8	1.61	0.044	2.2	0.8	1.142	1.15 E-1
3.4	1.68	0.021	2.3	0.8	1.420	1.95 E-2
4.0	1.64	0.018	2.4	0.8	1.351	4.6 E-3
4.7	1.61	0.018	2.1	0.8	1.330	1.57 E-2
5.5	1.56	0.018	2.4	0.8	1.298	1.16 E-2
6.6	1.41	0.071	2.4	0.8	1.334	3.56 E-2
7.5	1.56	0.071	2.4	0.8	1.304	3.26 E-2
9.0	1.65	1.240	2.3	0.8	1.260	3.99 E-2
10.6	1.87	0.079	2.4	2.5	1.179	7.23 E-2

n = real component of the complex refractive index

k = imaginary component of the complex refractive index

Dry Haze-Wet Haze

The term dry haze refers to the natural background of particulates present in the air under low humidity conditions, i.e., when the relative humidity is less than 70 percent. Wet haze refers to the natural background of particulates when the relative humidity is greater than 70 percent. Both the dry haze and the wet haze are represented by the Deirmendjian Haze C size distribution [10]. The optical constants for wet haze are assumed to be those of water, while the optical constants for dry haze are assumed to be those of soil particles. Thus, no allowance is made for solid cores or dissolved material in the droplets.

A more extensive treatment of the effect of relative humidity dependent particulates upon transmission (e.g., Hänel [11]) was considered. However, for the purpose of demonstrating the unreliability of visibility estimates for inferring IR transmittances, the models selected proved adequate.

Dust

Dust refers to the larger soil particles injected into the air as a result of vehicular traffic, primarily over ungraveled dirt roads and unconsolidated natural terrain. The size distribution is represented by a power law selected to reflect higher concentrations of particles than for dry haze. The optical constants are the same as for dry haze, although the composition of the two categories is likely to differ.

Smoke

Smoke refers mainly to vehicle exhaust which is assumed to consist of carbon particles. The smoke is represented by a log-normal size distribution. The values of the optical constants were based on the works of Dalzell and Sarofim [6], Twitty and Weinman [7], and Foster and Howarth [8].

Fog

Fog refers to water droplets. The individual droplets are of a much larger size than wet haze and the size distribution is log-normal in contrast to the Haze C model for wet haze.

TRANSMITTANCE

The ASL scattering model used for this analysis included only single scattering, and all calculations were normalized to a 5 km visibility at a wavelength of 0.55μm using the relation [12]

$$V = \frac{1}{\sigma_{0.55}} \ln(\frac{1}{\varepsilon})$$

where V is the visual range in kilometers and $\sigma_{0.55}$ is the extinction coefficient at a wavelength of 0.55μm, and $\varepsilon = 0.02$. Thus, the total particulate concentration was adjusted to yield this condition. Six sets of two-component particulate conditions were simulated. In each, either dry haze, wet haze, or fog was regarded as the major constituent with either dust or smoke as the minor constituent. The relative composition of each set was varied through the number concentrations of each component.

Dry Haze + Smoke

Figure 1 shows the transmittance in the visible and IR for three combinations of background dry haze and the locally generated smoke. The decrease in transmittance at 9μm was attributed to energy absorption by the dry haze [13]. The number concentrations represent the total number of particles within the applicable size range and appropriate to a 5 km visual range.

Dry Haze + Dust

In this case the minor constituent smoke was replaced by the dust, thus simulating effects of vehicular traffic. Figure 2 shows that the effect with dust at 9μm was more pronounced than with smoke as the minor constituent.

Wet Haze + Smoke

The transmittances for three combinations of wet haze and smoke are depicted in Figure 3. The decrease in transmittance at 1.5μm is attributed to smoke. In the 2.5 to 3.0μm region, the effect of water absorption is evident.

Wet Haze + Dust

Figure 4 shows the relative effects of replacing the "battlefield smoke" with "battlefield dust." The effect of dust absorption at 9μm is noticeable.

Fog + Smoke

The last background to be considered is fog. Figure 5 illustrates the effects of the addition of four different percentages of smoke. The transmittance patterns are in marked contrast to the previous combinations. Note that for the four cases presented, the visibility appears to be a good estimator of transmittance out to 2μm. For cases 3 and 4 the transmittance actually decreases with increasing wavelength in the range from 3 to 6μm.

Fog + Dust

In this case dust was superposed on the background fog. Figure 6 reveals that the effect of the dust is much less pronounced than that of the smoke. The notable difference in transmittance over the 4 to 10μm range for fog, as opposed to dry and wet haze, is attributed to differences in size distribution and size range.

CONCLUSIONS

These results, based on scattering effects alone, show clearly that any estimate of near infrared atmospheric transmittance based on observations in the visible region (i.e., visual range) is subject to error and is probably quite wrong. It is noted that the story is not complete until gaseous absorption effects are included (e.g., water vapor and CO_2) and that these are likely to further enhance the error.

It is also noted, however, that if the composition of the suspended particulates is known the results presented here suggest that a more accurate estimate of IR transmittance might be obtained from a two-wavelength visual range observation since the slope of the transmittance curve would then be established. It is emphasized that gaseous absorption must be included before this is seriously considered. Thus, in the case of water vapor for example, one might anticipate a set of curves for varying water vapor content - meaning that a transmittance prediction would require as inputs both absolute humidity and dual wavelength visual range data. Similar adjustments might also be required for some other minor gaseous constituents.

It is clear, nevertheless, that if prediction of IR transmittance is desirable on the battlefield, more in-situ information than is currently available will certainly be required. In addition, the simpler the method for obtaining this information the more useful it will be.

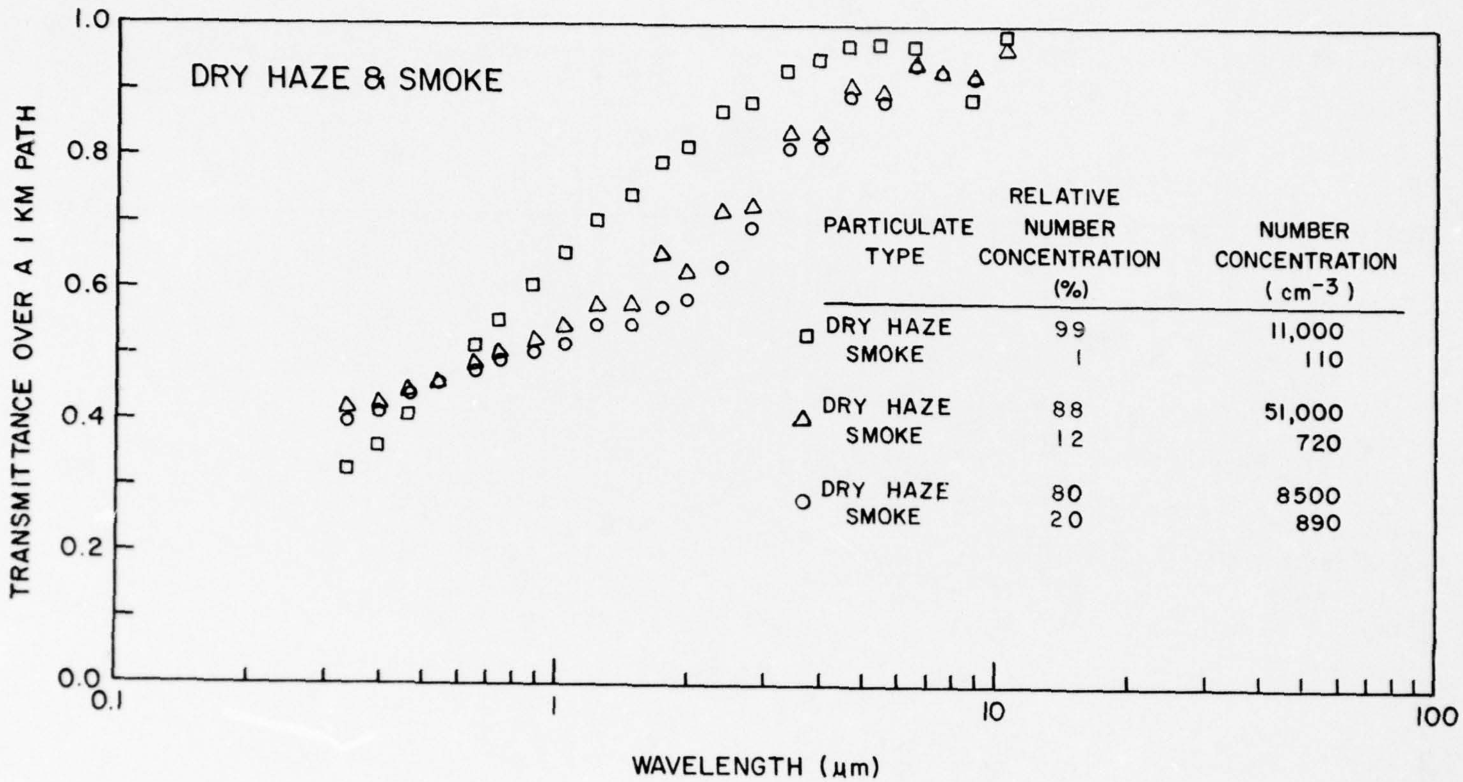

Figure 1. Calculations of transmittance over a 1 km path for various combinations of dry haze and smoke in the spectral range from 0.34 to 10.6μm. Total concentration is such that visibility as defined on page 6 is 5 km.

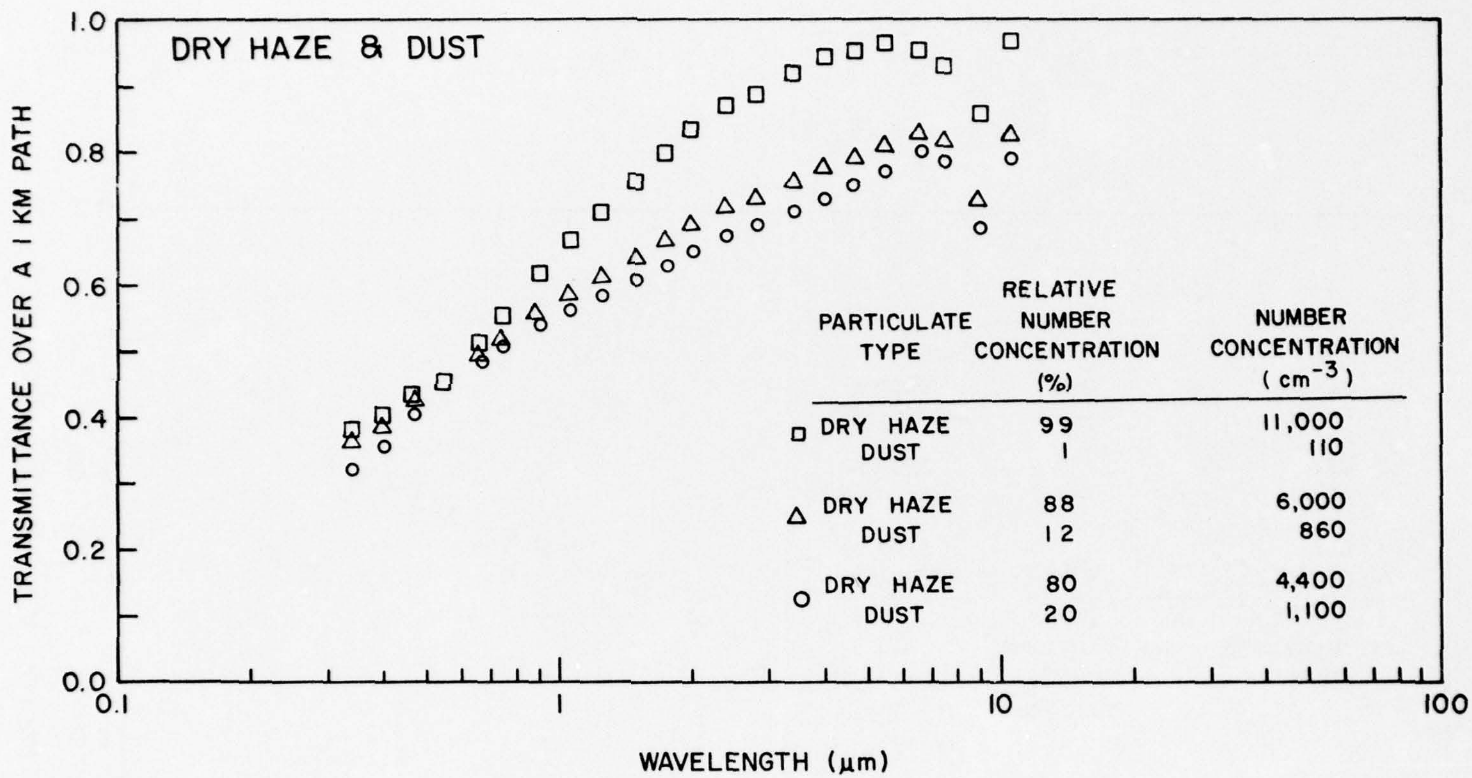

Figure 2. Calculations of transmittance over a 1 km path for various combinations of dry haze and dust in the spectral range from 0.34 to 10.6μm. (visibility = 5 km)

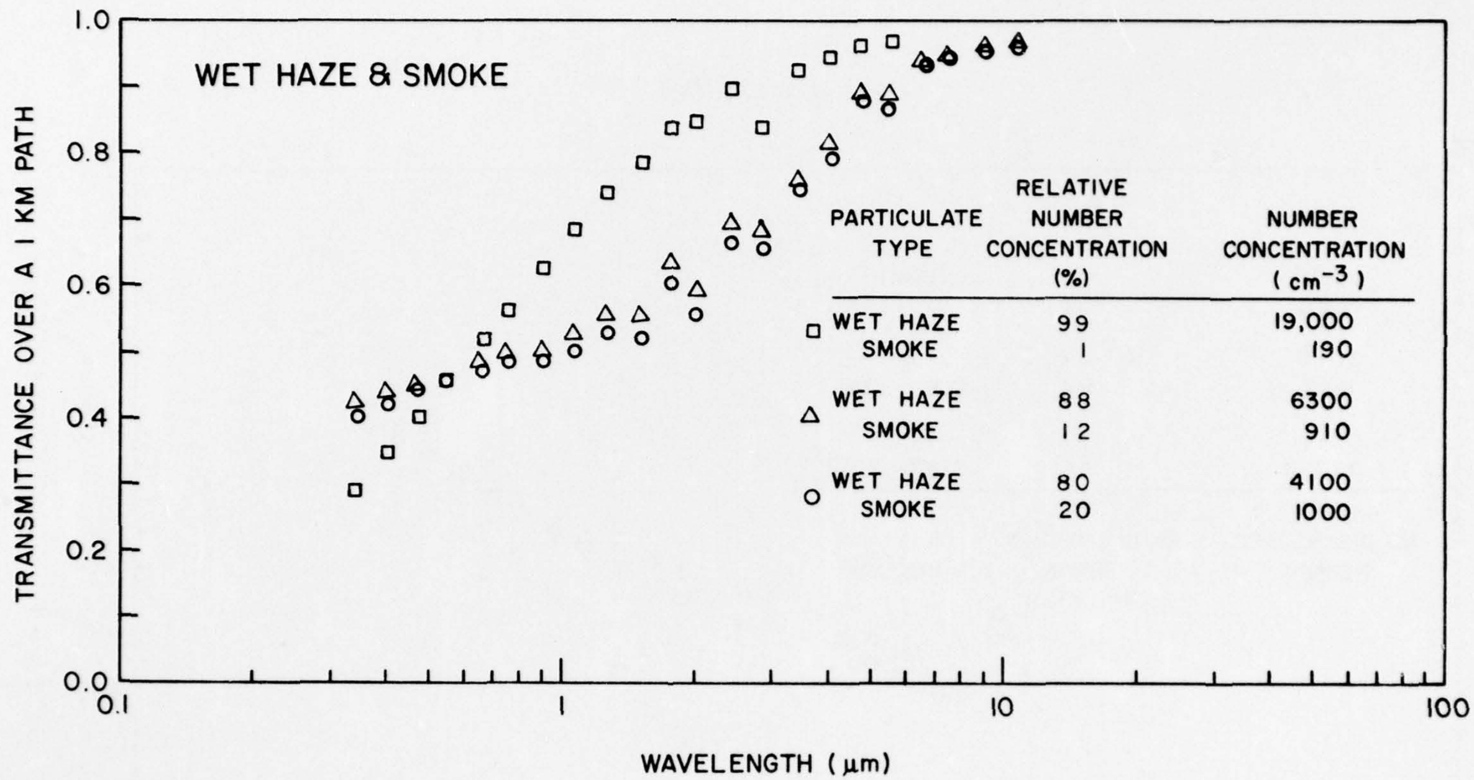

Figure 3. Calculations of transmittance over a 1 km path for various combinations of wet haze and smoke in the spectral range from 0.34 to 10.6μm. (visibility = 5 km)

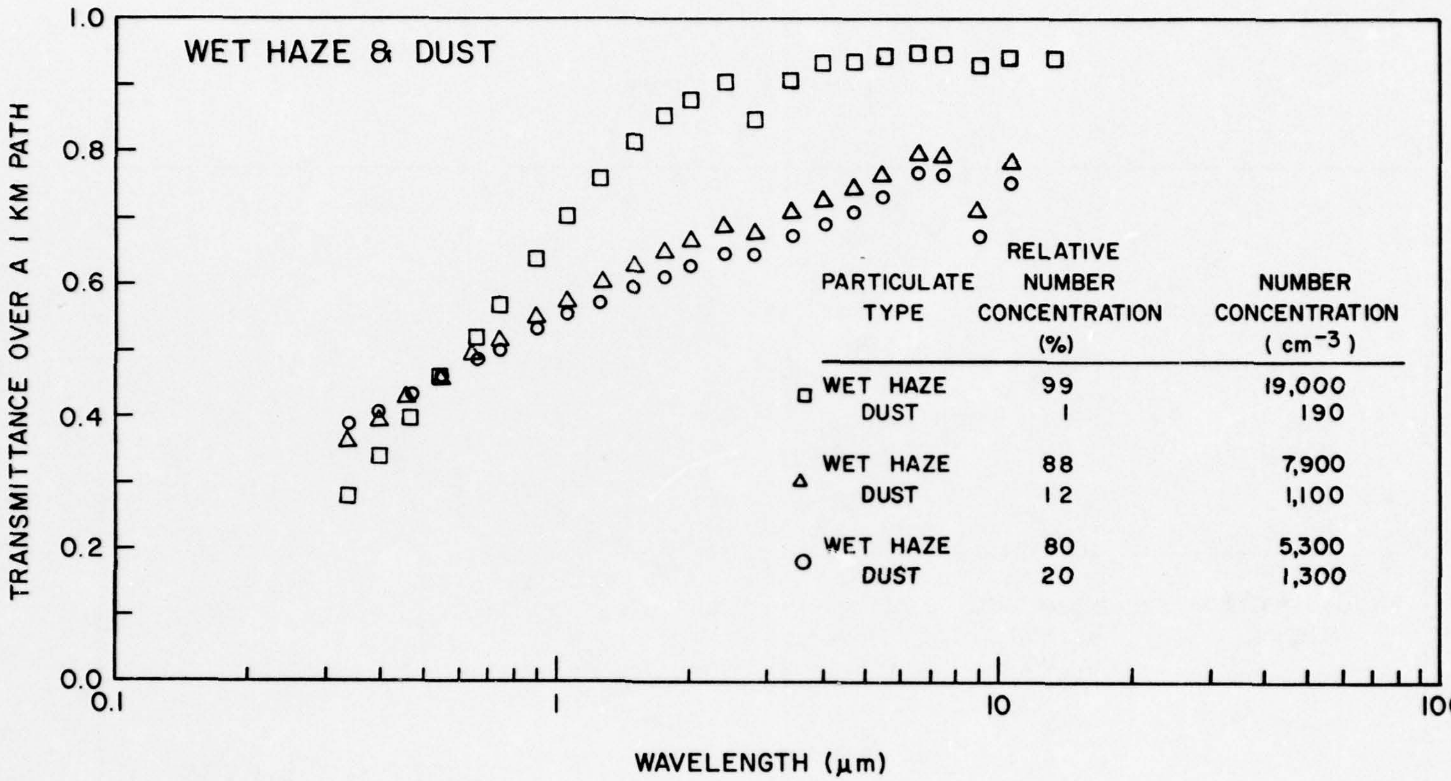

Figure 4. Calculations of transmittance over a 1 km path for various combinations of wet haze and dust in the spectral range from 0.34 to 10.6μm. (visibility = 5 km)

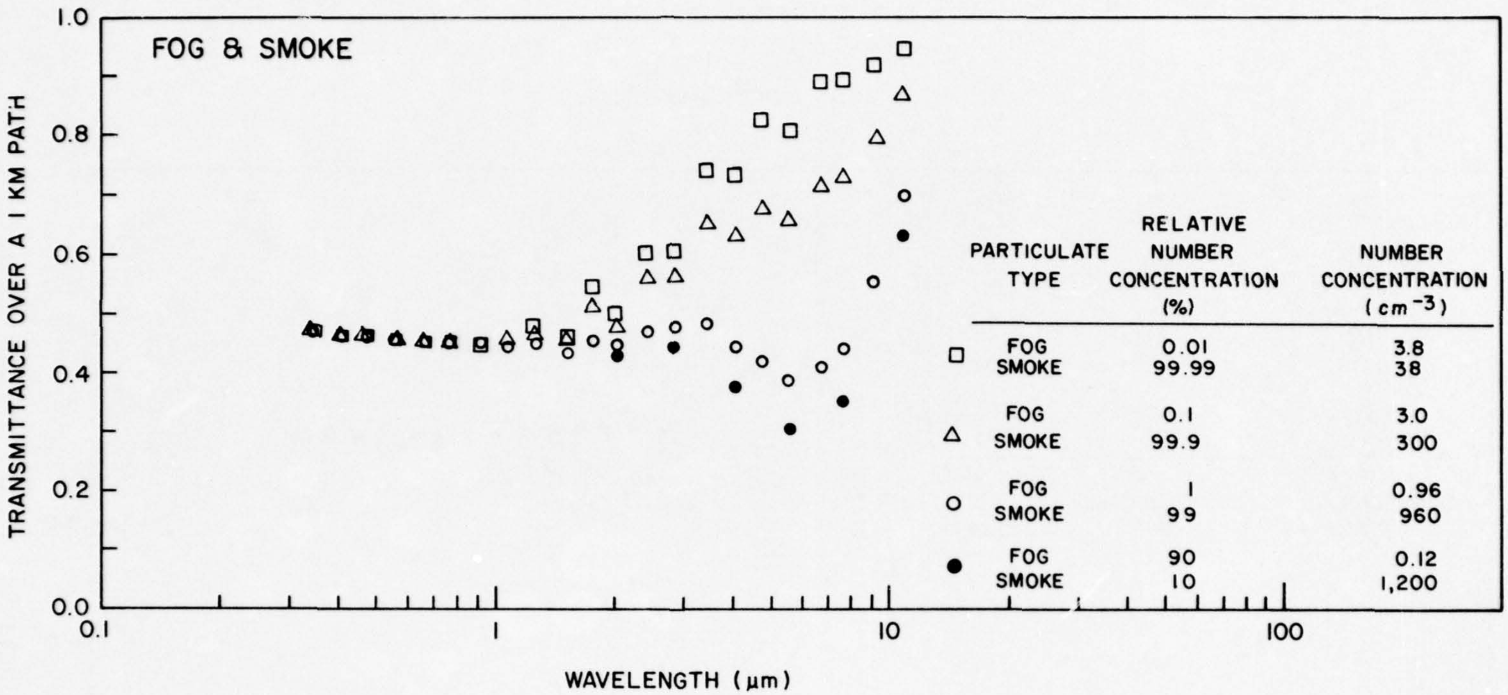

Figure 5. Calculations of transmittance over a 1 km path for various combinations of fog and smoke in the spectral range from 0.34 to 10.6μm. (visibility = 5 km)

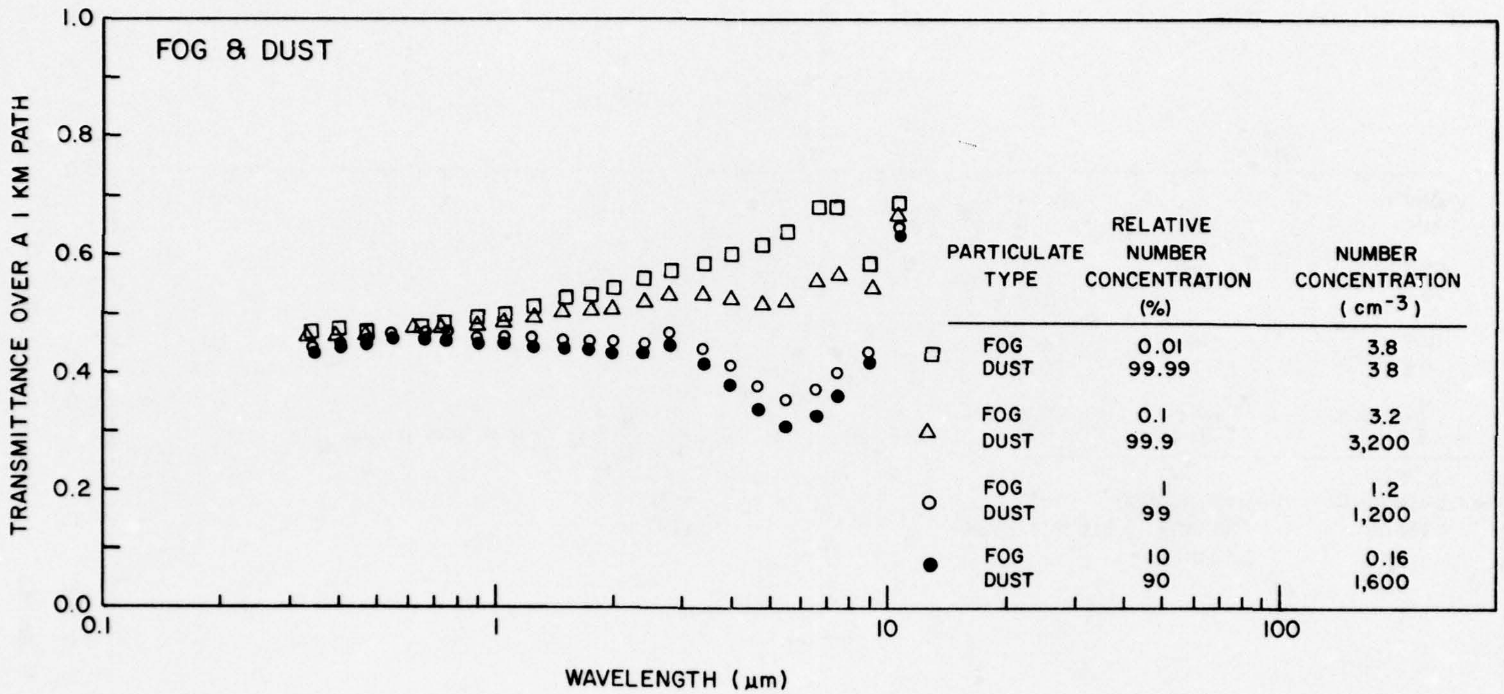

Figure 6. Calculations of transmittance over a 1 km path for various combinations of fog and dust in the spectral range from 0.34 to 10.6μm. (visibility = 5 km)

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