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16. Abstract

This study was designed to provide a preliminary evaluation of the possible effects of haze in plastic lenses of headlamps on the performance of low-beam headlamps. The approach was to simulate the effects of haze by applying Gaussian (normal) spread functions to each point of a beam pattern. The simulation used actual photometry from a U.S. headlamp and a European headlamp. The measure of interest was the percentage change, at each point in the beam pattern, of the luminous intensity with haze compared to the luminous intensity without haze. Seven levels of haze were simulated: 1, 3, 5, 7, 10, 20, and 30%.

The results of the simulation suggest that even the smallest amount of haze tested may produce major changes in both the visibility and glare illumination provided by low-beam headlamps. However, these are tentative findings that need to be interpreted with caution. There are two main reasons for the caution: First, the assumption that the effects of haze follow Gaussian distribution needs to be validated. Second, the potential contribution of the optics in the lenses was disregarded in the present simulation. The influence of the optics would need to be assessed before accepting the present results as generally applicable. Because of these concerns, no quantitative recommendation can be made from the present research for a maximum level of haze.

The main conclusion of this study is that haze of considerably less than 30% has the potential to be a major factor in the performance of headlamps with plastic lenses. Further research is needed to clarify the haze effects of actual headlamps.

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Introduction

What is haze?

A good, general description of haze is provided by Weidner and Hsia (1979).

> Haze is a word used in the general sense to describe light scattering by particles suspended in an otherwise nonscattering or transparent medium. The medium may be gas, liquid, or solid. In determining haze, the measured value is given in terms of a collimated light beam which is scattered when the light beam passes through the specified medium. Only that portion of the scattered light that is scattered in the forward direction, as the beam exits from the specimen, is considered in measuring the percentage haze. Backscattering is not included, nor is the angular distribution of the scattered light derived from haze measurements. Haze, or light scattering, degrades image quality and therefore affects visual perception (Weidner and Hsia, 1979, p. 1619)

The above description of haze lists scattering by particles within the medium only. On the other hand, SAE (1991) includes scattering from the surface as well, when it defines haze as "the cloudy or turbid appearance of an otherwise transparent specimen caused by light scattered from within the specimen or from its surface" (p. 1).

Measurement of haze

ASTM (1992) defines haze as "the percent of total transmitted light, which, in passing through the specimen, deviates from the incident beam through forward scatter by more than 0.044 rad (2.5°) on the average" (p. 1). There are two major problems with the ASTM definition of haze. First, as pointed out above by Weidner and Hsia (1979), this definition does not describe the angular distribution of the scattered light. Second, the definition disregards the amount of light that is either backscattered or absorbed. Consequently, a given percentage of haze, as defined by ASTM, does not uniquely describe what will happen to the emitted light.

Relevance to headlighting

Haze is relevant for headlighting because of possible changes over time in the transparency of headlamp lenses. While glass is not completely immune to changes, plastic materials are generally more susceptible to changes, including those induced by ultraviolet light. The greater concern with plastic materials in vehicle lighting is recognized in the current federal regulations by the imposition of an upper limit for haze in outer plastic lenses. The regulation states that "after the outdoor exposure test, the haze and loss of surface luster of plastic materials (other than those incorporating reflex reflectors) used for outer lenses shall not be greater than 30 percent haze" (FMVSS, 1995, p. 223) using the method of ASTM (1992).

It is generally acknowledged that 30% haze is likely to produce unacceptable changes in the headlamp beam pattern, including major reductions in the seeing light directed toward the roadway, and major increases in the glare light directed toward oncoming drivers. On the other hand, the SAE (1991) recommendation that "plastic materials used for forward road illumination devices, excluding cornering lamps, shall show no deterioration" (p. 1) is unrealistic if taken literally, implying 0% haze. However, we are not aware of any published evaluation of the consequences of different levels of haze on headlamp performance that would provide guidance for establishing a performance-based upper limit of haze.

Present study

This preliminary study was designed to estimate the likely magnitudes of changes in headlamp low-beam patterns caused by different levels of haze. An analytical approach was used, in which the effects of haze were modeled by Gaussian (normal) spread functions applied to each individual point in the beam pattern. The results of this simulation need to be interpreted with caution until a validation is performed.

Method

Approach

Gaussian spread functions, corresponding to particular levels of haze, were applied to each individual point in the beam pattern. Of interest was how these spread functions influence the amount of light directed to different parts of the beam pattern. The dependent variable was the percentage change, at each point in the beam pattern, of the luminous intensity with haze compared to the luminous intensity without haze.

Given the assumption that the effect of haze is Gaussian, the haze values defined by ASTM (1992) completely specify the effects of haze on the distribution of the transmitted light. For example, if haze is specified as 30%, there will be a unique corresponding Gaussian function with 30% of its area beyond ±2.5°. (This is the case because haze is defined as the percentage of the transmitted light that is scattered more than 2.5° from the intended direction.) Similarly, there will be a unique corresponding function for 10% haze with 10% of its area beyond ±2.5°.

In this manner, a unique function was derived for each level of haze. In addition to being Gaussian, these functions were further constrained as follows:

(1) The width of the spread was set at ± 5°. Thus, the effects of haze were truncated at ±5°. This constraint is unlikely to affect the results noticeably, because for the functions of interest the area outside of ±5° was relatively small, especially for the low levels of simulated haze.

(2) The sum of the values for all points of the function (i.e., from -5° to +5°) was set equal to 1. (The step size was 0.5°; see below.)

These Gaussian haze functions were then used as multiplicative functions at each point of the beam pattern: Each original (without haze) value of luminous intensity was thus distributed within ±5°, according to the particular haze function under consideration. (The same Gaussian function was applied to each original luminous intensity, and thus each luminous intensity was distributed within ±5° of its original location.) After the same Gaussian function was applied to each original luminous intensity, a sum of all luminous intensities at each point produced the after-haze luminous intensity pattern. This sum consisted of a reduction of the original value, with additions from the neighboring points.

Haze levels

The following haze levels were simulated: 1, 3, 5, 7, 10, 20, and 30%.

Beam patterns studied

Two low-beam headlighting patterns were used, one from a lamp manufactured for sale in the U.S., and one for sale in Europe (see Figure 1). The original photometry for each lamp was in 0.5° steps from 9.5° down to 9.5° up, and from 25° left to 25° right. However, the results will be presented only from 4.5° down to 4.5° up, and from 20° left to 20° right. This is because in our simulation the effects on the outlying 5° in each direction of the original photometric matrix from even more peripheral parts of the beam pattern could not be calculated. For example, the haze effects for a location at 24° left should be simulated by considering the influence from points located between 19° left and 29° left, but we did not have the photometry for the area extending beyond 25° left.

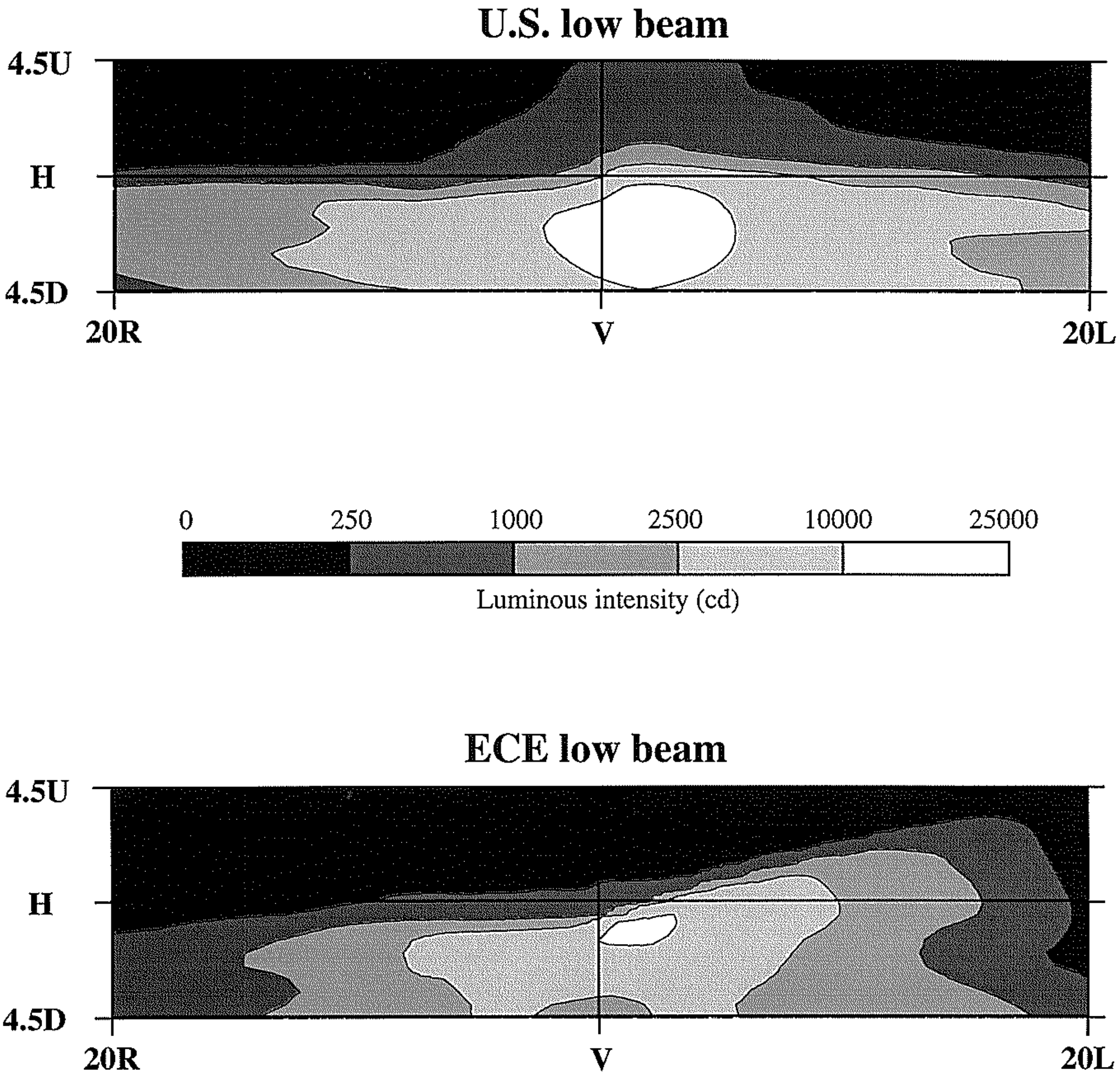

Figure 1. Photometry of the U.S. and European low-beams tested. The maxima were 24,702 cd at 2° down, 1.5° right for the U.S. lamp, and 18,722 cd at 1° down, 1.5° right for the European lamp.

Results

Figures 2 through 8 present the percentage changes in luminous intensities for the two lamps tested. In these figures the changes up to +25% and down to -25% are shown using the same shadings. The selection of ±25% was based on research of Huey, Decker, and Lyons (1994) showing that differences of less than 25% are not noticeable.

Figure 9 shows the changes in luminous intensities at selected points of interest for all simulated levels of haze. The selected points are the major current visibility test points (0.5° down, 1.5° right in the U.S., and 0.5° down, 1° right in Europe), the major current glare test points (0.5° up, 1.5° left in the U.S., and 0.5° up, 3.5° left in Europe), and the points of the maximum luminous intensity for the two lamps tested (2° down, 1.5° right for the U.S. lamp, and 1° down, 1.5° right for the European lamp). (The European visibility and glare test points were rounded to the nearest 0.5°.)

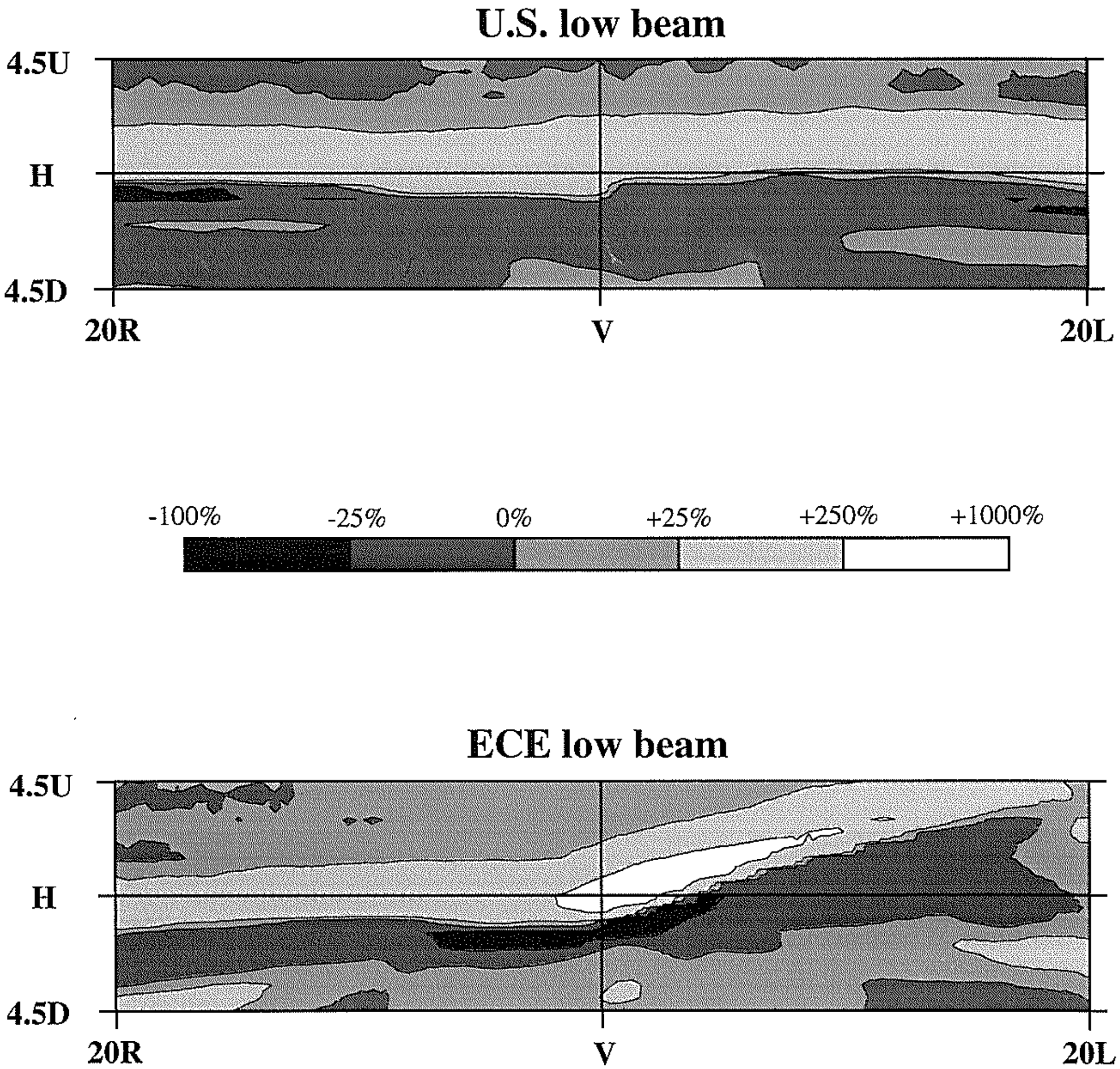

Figure 2. Changes in the luminous intensities with simulated haze of 1% compared to no haze. The largest changes were +216% at 0.5° up, 19.5° left, and -30% at 1° down, 20° left for the U.S. lamp and +701% at 0.5° up 2.5° right, and -62% at 1° down, 1.5° right for the European lamp.

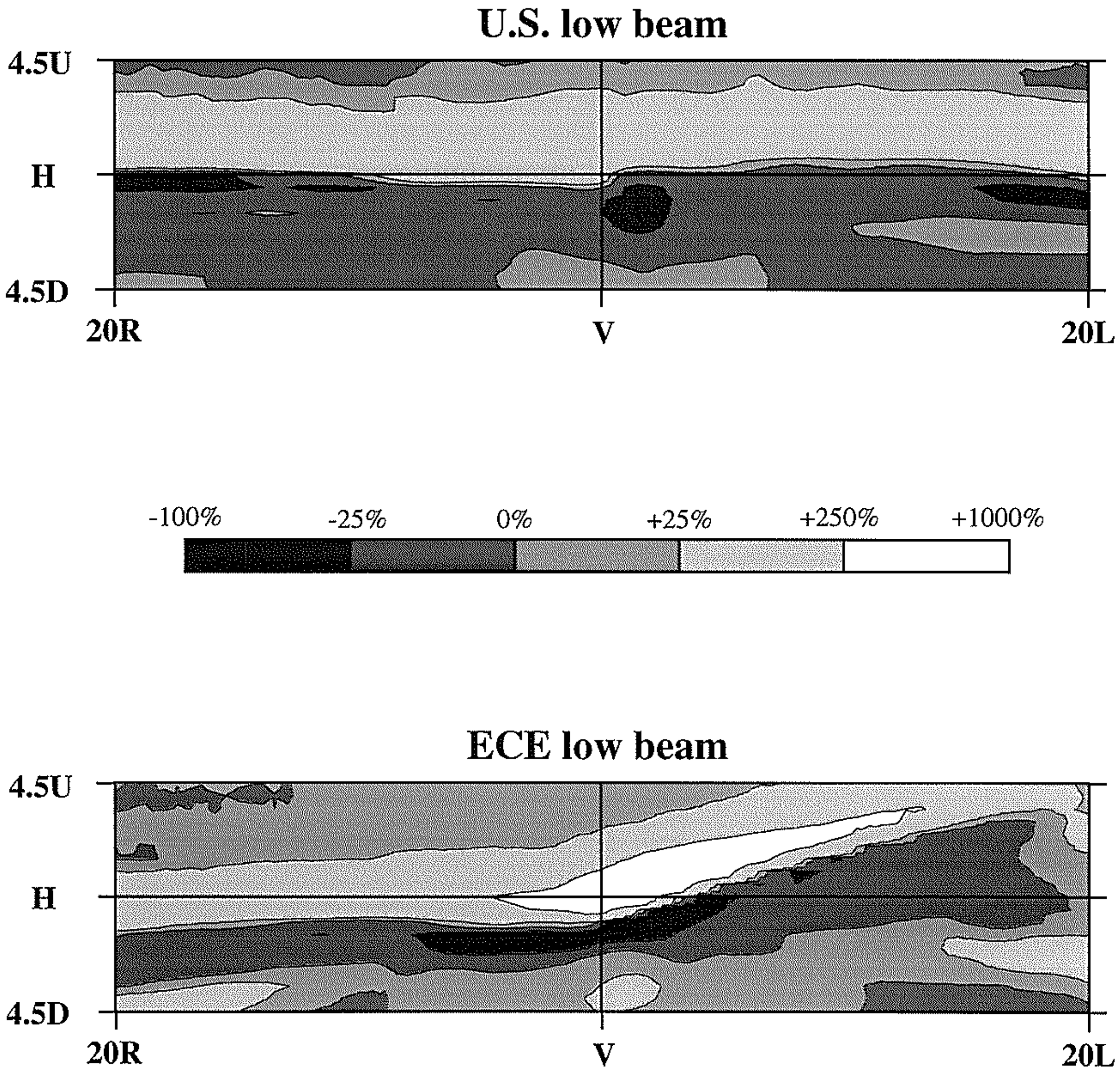

Figure 3. Changes in the luminous intensities with simulated haze of 3% compared to no haze. The largest changes were +252% at 0.5° up, 13.5° left, and -33% at 1° down, 20° left for the U.S. lamp and +784% at 0.5° up 2° right, and -67% at 1° down, 1.5° right for the European lamp.

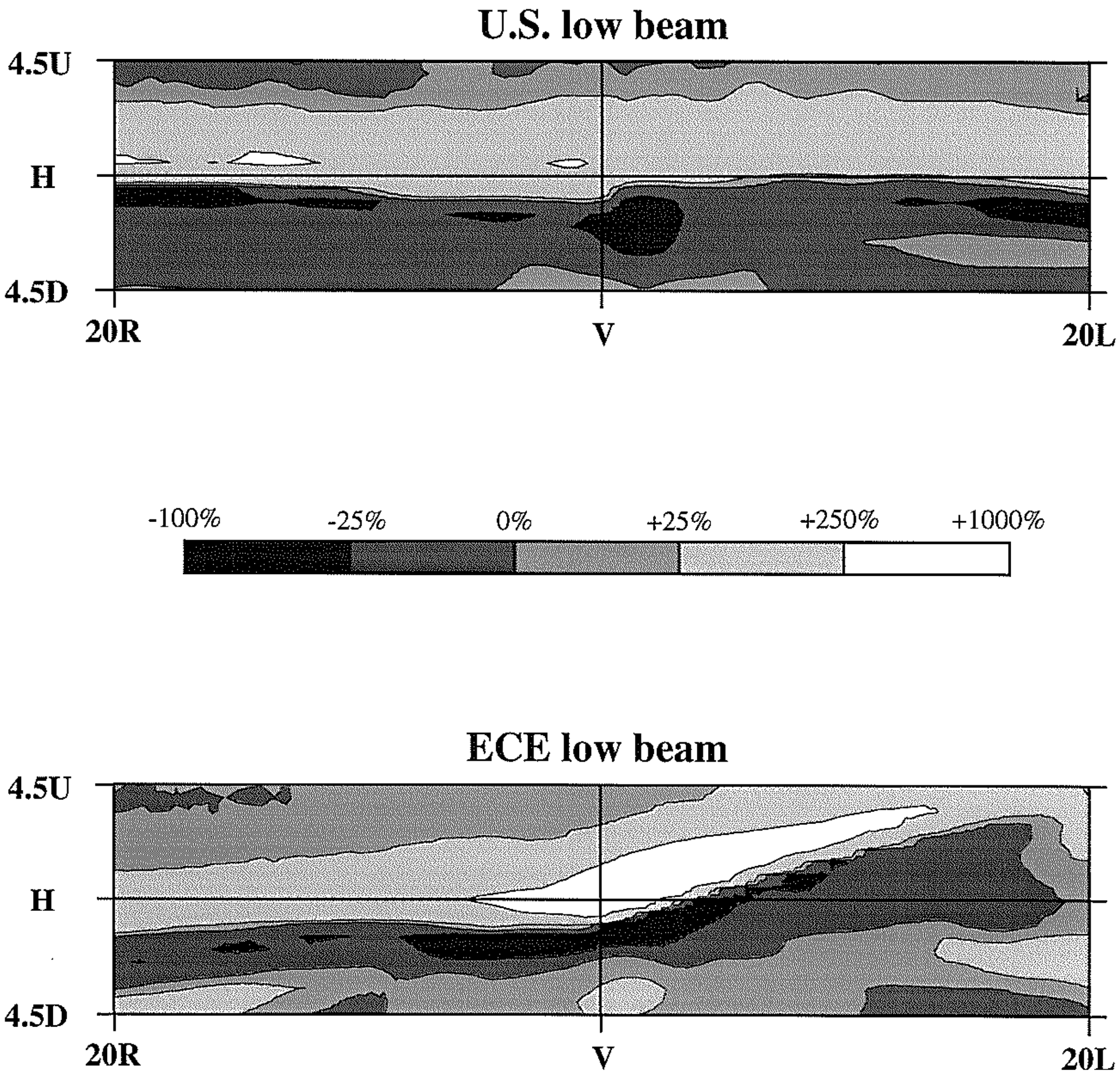

Figure 4. Changes in the luminous intensities with simulated haze of 5% compared to no haze. The largest changes were +277% at 0.5° up, 13.5° left, and -35% at 1° down, 20° left for the U.S. lamp and +820% at 0.5° up 2° right, and -69% at 1° down, 1.5° right for the European lamp.

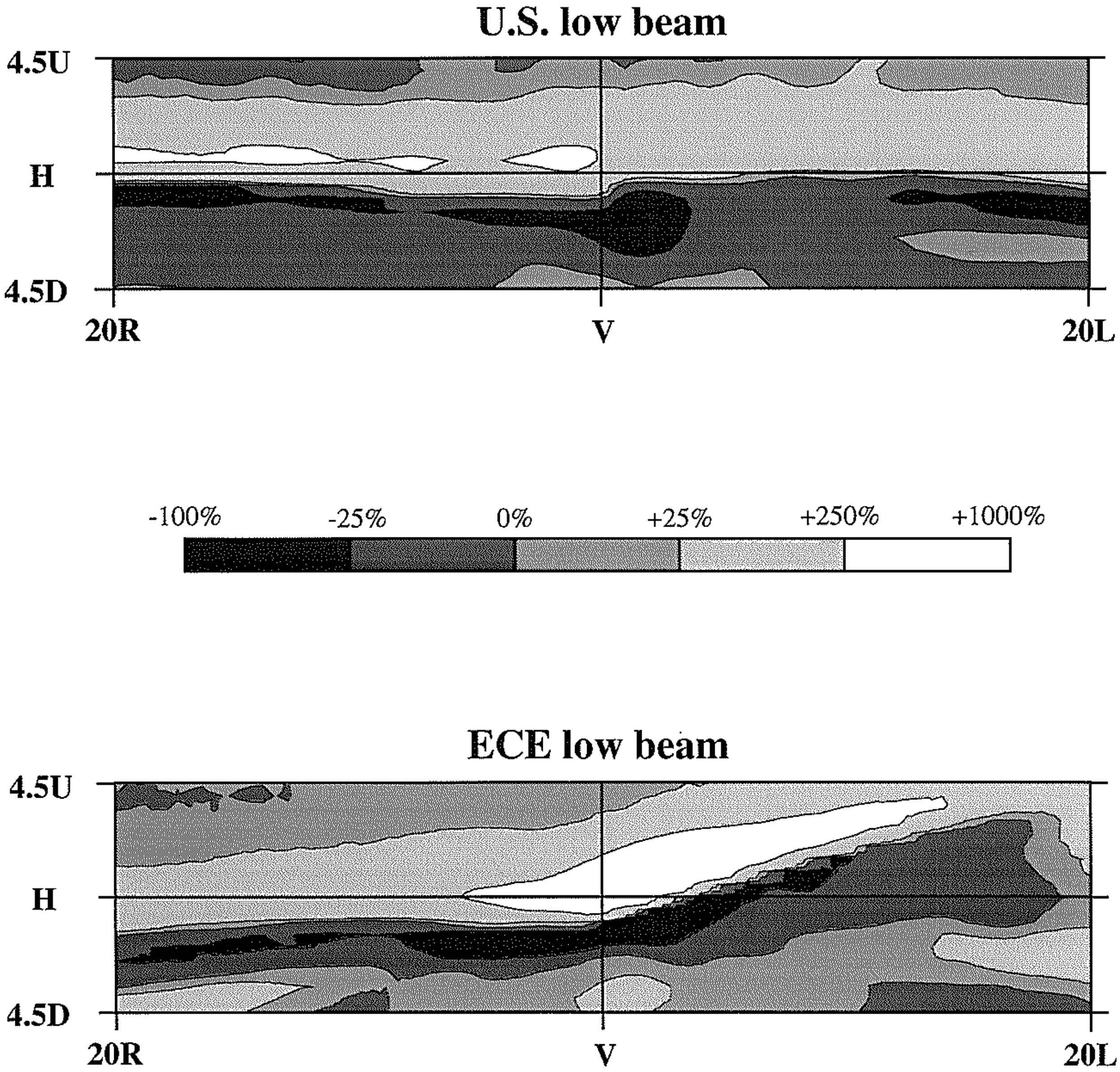

Figure 5. Changes in the luminous intensities with simulated haze of 7% compared to no haze. The largest changes were +295% at 0.5° up, 13.5° left, and -37% at 1° down, 20° left for the U.S. lamp and +838% at 0.5° up 2° right, and -71% at 1° down, 1.5° right for the European lamp.

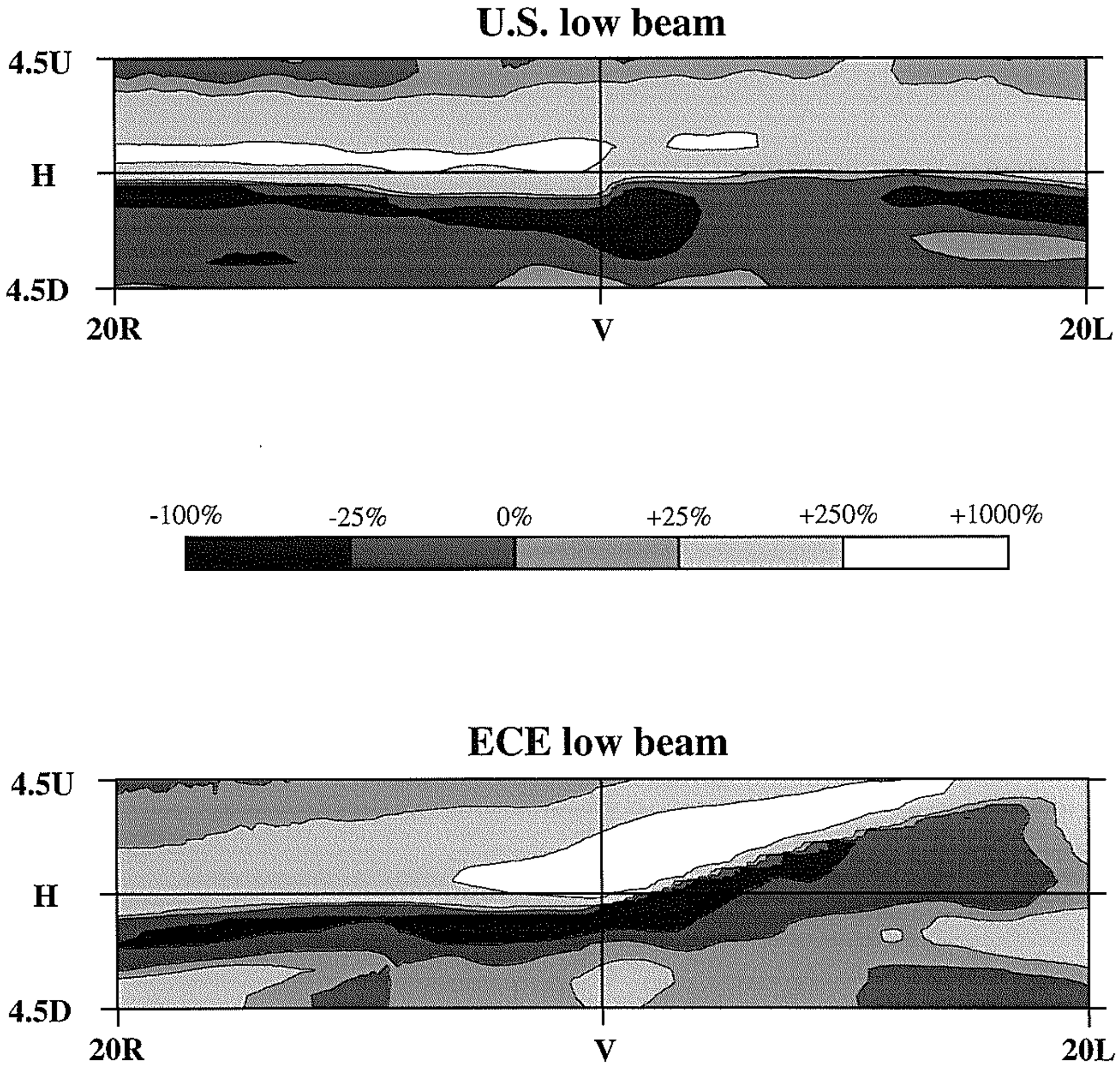

Figure 6. Changes in the luminous intensities with simulated haze of 10% compared to no haze. The largest changes were +331% at 0.5° up, 1.5° left, and -41% at 2° down, 1.5° right for the U.S. lamp and +853% at 1° up 2.5° right, and -73% at 1° down, 1.5° right for the European lamp.

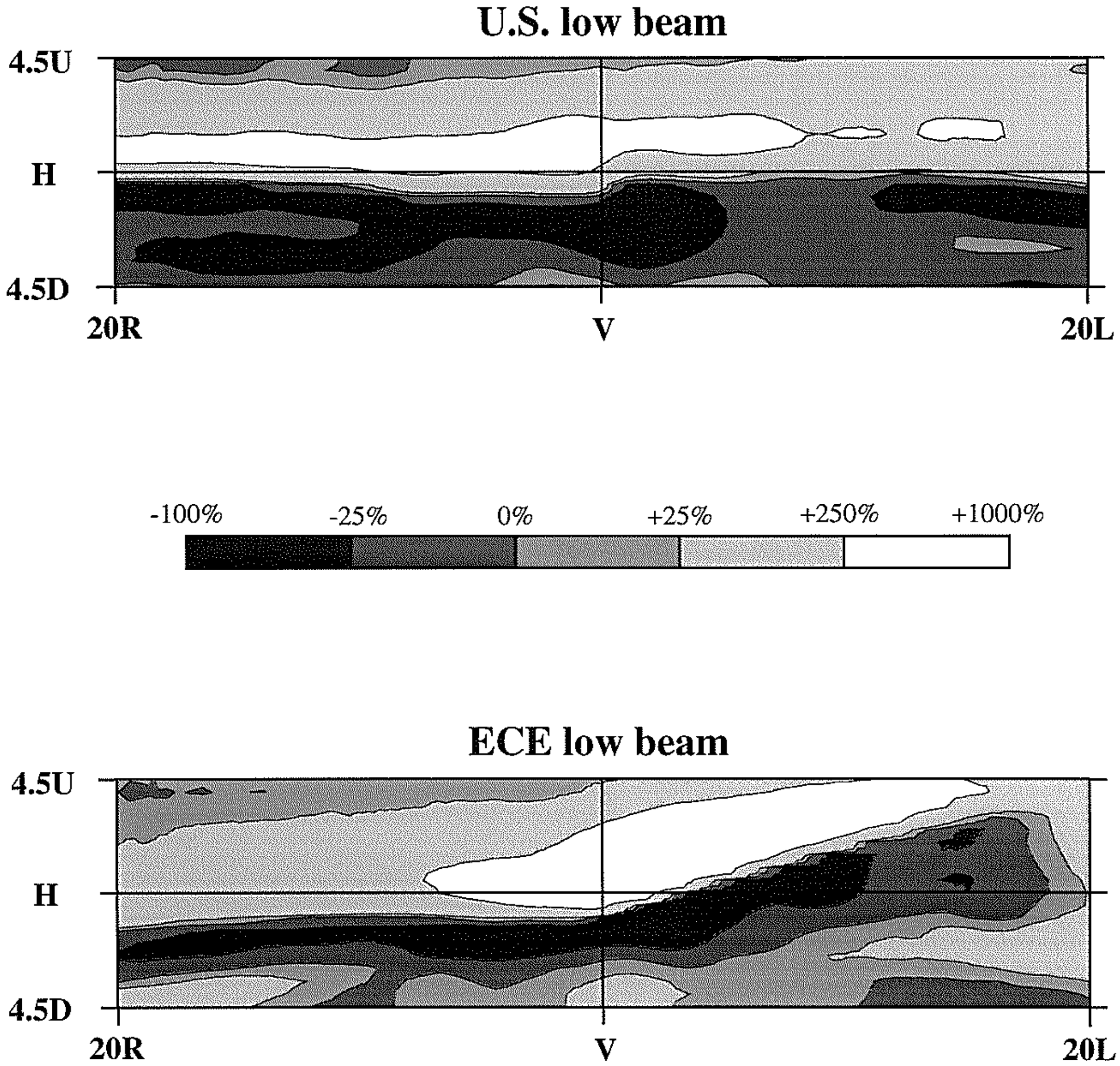

Figure 7. Changes in the luminous intensities with simulated haze of 20% compared to no haze. The largest changes were +442% at 1° up, 1.5° left, and -51% at 2° down, 1.5° right for the U.S. lamp and +933% at 1° up 2.5° right, and -78% at 1° down, 1.5° right for the European lamp.

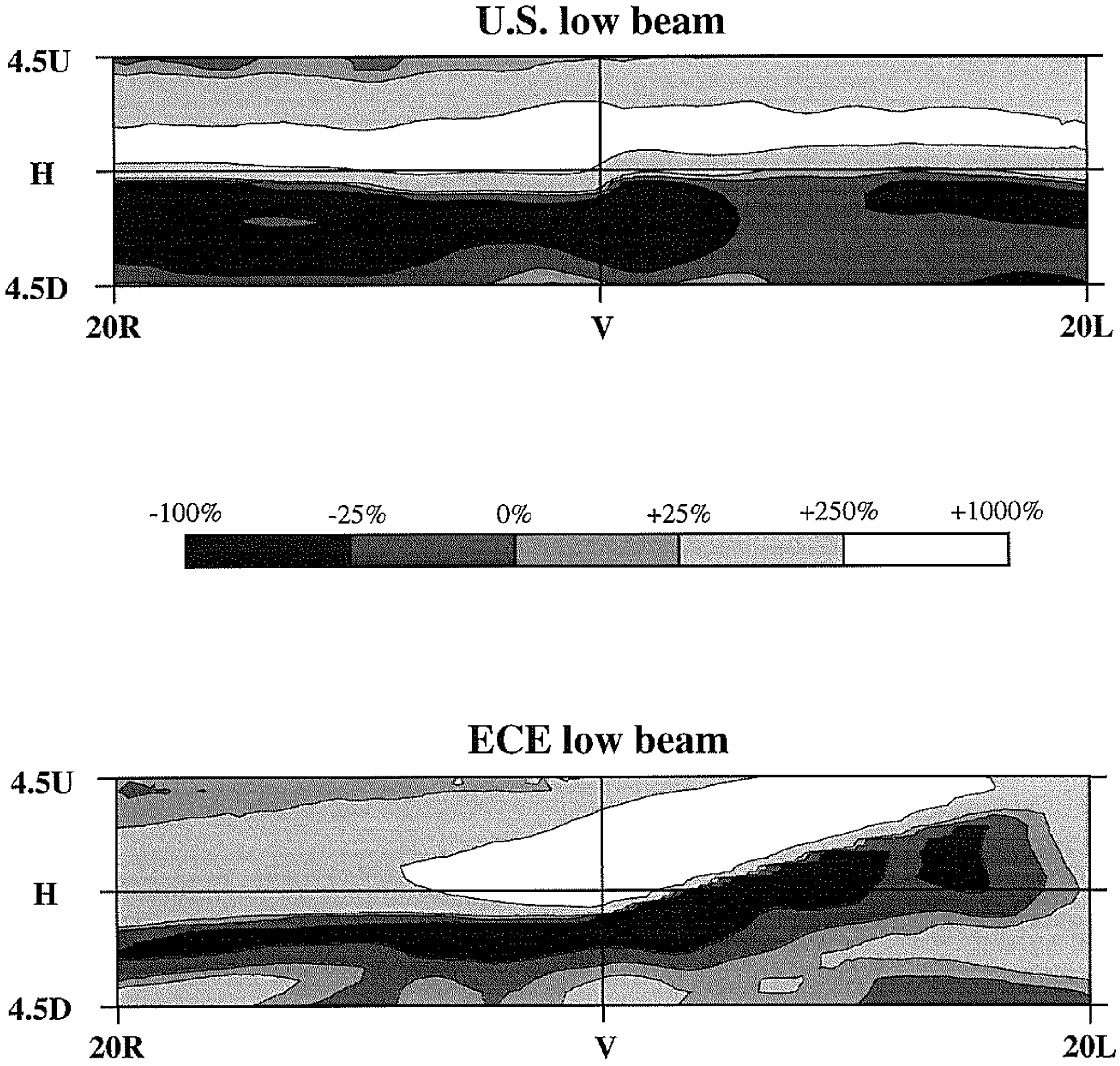

Figure 8. Changes in the luminous intensities with simulated haze of 30% compared to no haze. The largest changes were +531% at 1° up, 2° left, and -57% at 2° down, 1.5° right for the U.S. lamp and +951% at 1° up 2.5° right, and -80% at 1° down, 1.5° right for the European lamp.

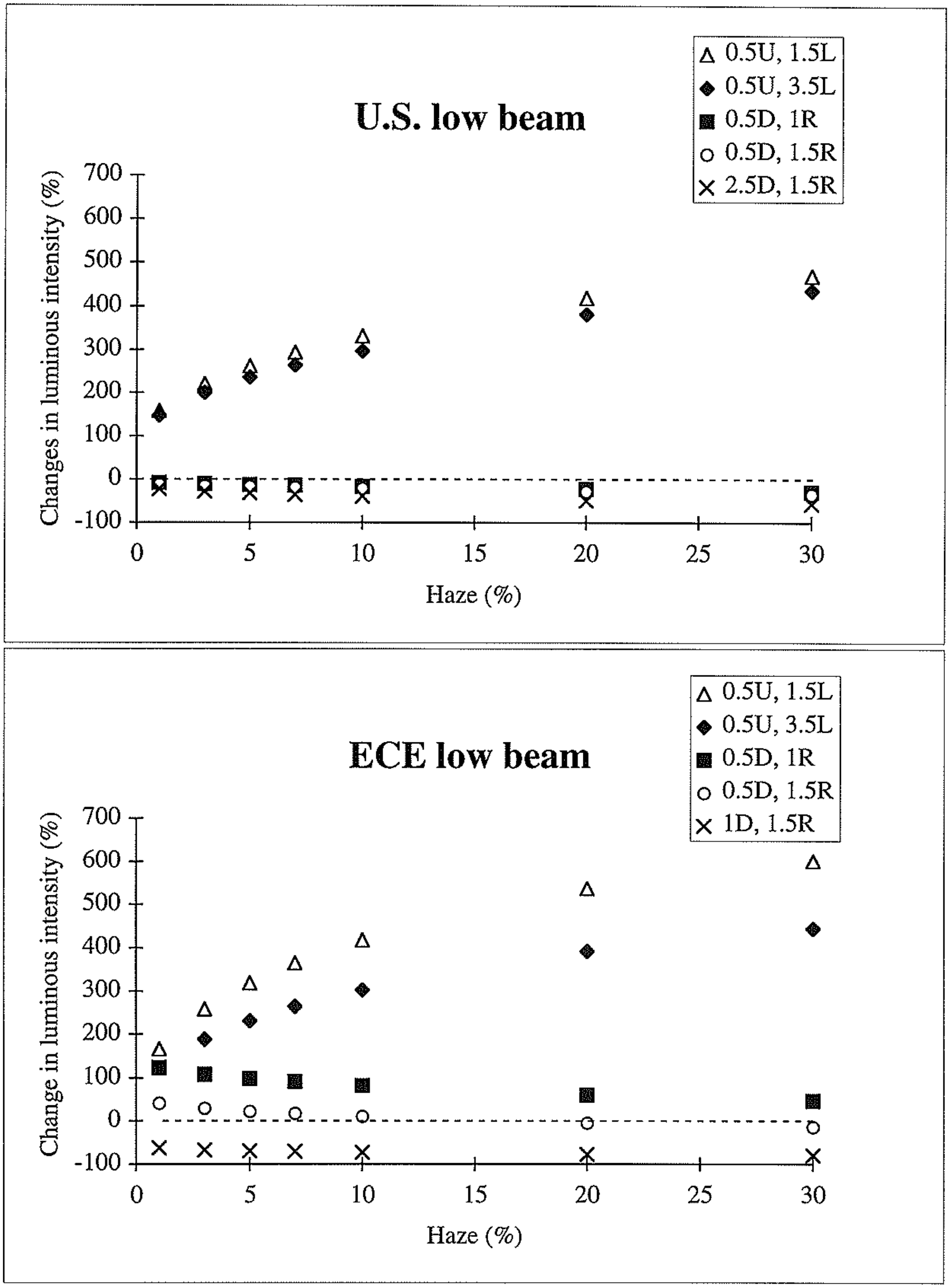

Figure 9. Changes in the luminous intensities due to haze at selected points for the U.S. and European low beams tested.

Discussion

Major findings

The major findings of this research are as follows:

(1) Haze in the lenses of headlamps may have a major effect on headlamp performance. Even amounts of haze considerably below 30% appear to have large effects. Specifically, even the smallest amount of haze simulated (1% haze) resulted in large areas of changes exceeding 25%.

(2) The effects were generally larger for the European lamp than for the U.S. lamp—a consequence of a sharper vertical intensity gradient for the European lamp.

(3) For the U.S. lamp, all levels of haze resulted in decreases in luminous intensity for most of the area below about 1° down. Conversely, there were increases in luminous intensity for most of the area above about 1° down.

(4) For the European lamp, the general pattern consisted of increases above the cutoff and decreases in the area extending from the cutoff to about 2 to 4° below the cutoff. (The cutoff refers to the imaginary line of the sharpest vertical gradient. For the European lamp tested this line was just below the horizontal in the left part of the beam pattern, and extended upward at an angle of about 15° on the right side of the beam pattern.)

Caveats

There are two major concerns related to the validity of the present results.

(1) The present simulation was based on the assumption that the effects of haze follow a Gaussian distribution. In the absence of any information about the distribution of the effects of haze, a Gaussian distribution is a reasonable candidate, but this assumption needs to be validated.

(2) The simulation disregarded the effects of the geometric details of the optical elements in the lens. (However, the effects of haze in plastic covers that are not optically functional, such as those typical of projector headlamps, would not involve this consideration.) The possible interactions introduced by the optics in the lens need to be studied to determine their importance for the overall effects.

Additionally, the current simulation (in agreement with the ASTM definition of haze) disregarded the light that is backscattered or absorbed. A comprehensive analysis of haze would have to take into account what happens to all of the emitted light.

Summary and Conclusions

This study was designed to provide a preliminary evaluation of the possible effects of haze in plastic lenses of headlamps on the performance of low-beam headlamps. The approach was to simulate the effects of haze by applying Gaussian spread functions to each point of a beam pattern. The simulation used actual photometry from a U.S. headlamp and a European headlamp. The measure of interest was the percentage change, at each point in the beam pattern, of the luminous intensity with haze compared to the luminous intensity without haze. Seven levels of haze were simulated: 1, 3, 5, 7, 10, 20, and 30%.

The results of the simulation suggest that even the smallest amount of haze tested may produce major changes in both the visibility and glare illumination provided by low-beam headlamps. However, these are tentative findings that need to be interpreted with caution. There are two reasons for the caution: First, the assumption that the effects of haze follow Gaussian distribution needs to be validated. Second, the potential contribution of the optics in the lenses was disregarded in the present simulation. The influence of the optics would need to be assessed before accepting the present results as generally applicable. Because of these concerns, no quantitative recommendation can be made from the present research for a maximum level of haze.

The standard definition of haze (ASTM, 1992) does not specify the distribution of the forward-scattered light, and it disregards the light that is backscattered or absorbed. Consequently, a given haze index using this method (i.e., a given percentage of haze) does not uniquely define what happens to the emitted light. Further refinement of the haze definition is needed for a haze index to be truly meaningful.

The main conclusion of this study is that haze of considerably less than 30% (as defined by ASTM, 1992) has the potential to be a major factor in the performance of headlamps with plastic lenses. Further research is needed to clarify the haze effects of actual headlamps.

References

ASTM (American Society for Testing and Materials). (1992). *Standard test method for haze and luminous transmittance of transparent plastic* (Standard D 1003-92). Philadelphia, PA: Author.

FMVSS (Federal Motor Vehicle Safety Standard). (1995). Standard No. 108: Lamps, reflective devices, and associated equipment. In, *Code of Federal Regulations, [Title] 49*. Washington, D.C.: Office of the Federal Register.

Huey, R., Dekker, D., and Lyons, R. (1994). *Driver perception of just-noticeable differences of automotive signal lamp intensities* (Report No. DOT HS 808 209). Washington, D.C.: National Highway Traffic Safety Administration.

SAE (Society of Automotive Engineers). (1991). *Plastic materials for use in optical parts as lenses and reflex reflectors of motor vehicle lighting devices* (SAE Standard J576). Warrendale, PA: Author.

Weidner, V.C. and Hsia, J.J. (1979). NBS reference hazemeter: Its development and testing. *Applied Optics*, *18*, 1619-1626.