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# **THE INFLUENCE OF LENS HAZE ON HEADLAMP BEAM PATTERNS**

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**April 1998**

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16. Abstract This study investigated changes in headlamp beam patterns as a function of the level of haze in sheets of plastic materials that were inserted in front of either a U.S. or a European low-beam headlamp. The level of haze was measured according to the method required by the U.S. National Highway Traffic Safety Administration. This method (ASTM Standard D 1003-92) measures the percentage of transmitted light that deviates from the incident beam through forward scatter by more than 2.5°. The actual effects on the beam pattern were then compared with predictions based on modeling the effects by assuming Gaussian distributions of the scattered light. The main finding is that the predictions for the four different plastic materials tested were neither uniformly accurate nor uniformly inaccurate. This lack of consistency is in agreement with the fact that the ASTM definition of haze does not uniquely specify the distribution of the scattered light. This problem with using the ASTM definition was confirmed by measuring the distributions of light scattering by two materials that had essentially the same ASTM index of haze. The implication of this research is that establishing a justifiable maximum haze level for headlamp lens materials would require using a definition of haze that uniquely defines the resultant distribution of the light scatter. Consequently, it is recommended that future research should evaluate the distribution of scattered light using actual materials for headlamp lenses after different lengths of weathering exposure.					
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## Introduction

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 current U.S. vehicle lighting regulations state 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, 1997, p. 224) using the method of ASTM (1992). In turn, 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).<sup>1</sup> On the other hand, SAE recommends that "plastic materials used for forward road illumination devices, excluding cornering lamps, shall show no deterioration" (SAE, 1991, p. 1).

The usual discussion concerning haze deals with the appropriate haze limits for different vehicle-lighting applications. However, there is a more fundamental issue: Is the ASTM method applicable to vehicle lighting? If not, the issue of what should be the limit of haze as defined by the ASTM method is not relevant.

As pointed out by Weidner and Hsia (1979) and Sivak, Flannagan, Hashimoto, and Kojima (1997), there are two major problems with the ASTM definition of haze. First, 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 level of haze, as defined by ASTM, does not uniquely describe what will happen to the emitted light.

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<sup>1</sup> There is a newer version of the ASTM standard (ASTM, 1995). However, it is essentially the same as ASTM (1992). Furthermore, the current U.S. regulations explicitly reference ASTM (1992).

In our previous study on this topic (Sivak et al., 1997), we simulated the effects of haze by applying Gaussian (normal) spread functions to each point of a beam pattern. That simulation used actual photometry from a U.S. low-beam headlamp and a European low-beam 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% (as defined by ASTM). The results indicated that even the smallest amount of haze tested may produce major changes in both the visibility and glare illumination provided by low-beam headlamps.

The results in Sivak et al. (1997) are based on the assumption that the effects of haze are well described by Gaussian distributions. However, we are not aware of any information on the distribution of the light scatter in actual materials used for headlamp lenses. To obtain such information, a flat piece of the lens material (to comply with the specifications provided by hazemeter manufacturers) would have to be exposed to outdoor weathering for three years; accelerated weathering is not permitted (FMVSS, 1997, p. 224).

The present study investigated changes in headlamp beam patterns as a function of the level of haze in sheets of plastic materials that were inserted in front of the lamp. These actual effects were then compared with the predictions based on modeling the effects by assuming Gaussian distributions of haze. Consequently, this research can be viewed as a test of the validity of the simulation in Sivak et al. (1997).

## Method

### Approach

The beam pattern of each of two low-beam headlamps was measured with and without sheets of plastic material with known ASTM indexes of haze inserted in front of the lamp. The resultant changes in light output due to the presence of the plastic materials in front of the lamp were then compared with predictions based on modeling the effects by assuming Gaussian distributions of haze.

### Simulation

Gaussian spread functions, corresponding to particular levels of haze, were applied to each individual point in the original (without haze) beam pattern (Sivak et al., 1997). 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 10%, there will be a unique corresponding Gaussian function with 10% of its area beyond  $\pm 2.5^\circ$ . (This is the case because haze is defined as the percentage of the transmitted light that is scattered more than  $2.5^\circ$  from the intended direction.) In this manner, a unique function was derived for each of the four levels of haze, corresponding to the haze levels of our four plastic materials (see below). In addition to being Gaussian, these functions were further constrained as follows:

- (1) The width of the spread was set at  $\pm 5^\circ$ . Thus, the effects of haze were truncated at  $\pm 5^\circ$ . This constraint is unlikely to affect the results noticeably, because the area outside of  $\pm 5^\circ$  is 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  $-5^\circ$  to  $+5^\circ$ ) was set equal to 1. (The step size was  $0.5^\circ$ .)

These Gaussian haze functions were then used as multiplicative functions at each point of the beam pattern. Thus, each original (without haze) value of luminous intensity was distributed within  $\pm 5^\circ$ , according to the particular haze function under consideration. (The same Gaussian function was applied to each original intensity, and thus each intensity was distributed within  $\pm 5^\circ$  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. Finally, adjustments due to transmittance losses (see Table 1) were made.



## Photometry

The photometry for each lamp was performed in 0.5° steps from 10° down to 10° up, and from 25° left to 25° right. However, the results will be presented only from 5° down to 5° up, and from 20° left to 20° right. This is because 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.

The photometry was performed five times for each lamp: without any plastic material in front of the lamp, and with each of the four materials in front of the lamp. The measurements were made in a photometry laboratory. The voltage was set at 12.8 V.

## Plastic materials

Four sheets of plastic materials were used. The ASTM haze index and transmittance of each material are listed in Table 1. These measurements were made using a BYK Gardner XL-211 Hazegard Hazemeter.

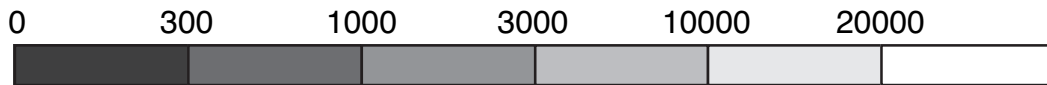
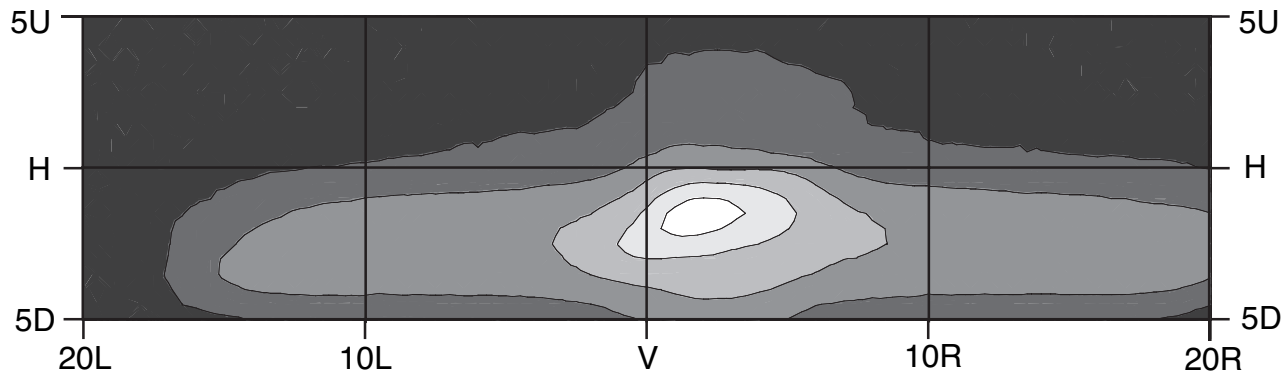
Table 1.  
The ASTM haze indexes and transmittances of the plastic materials used in the study.

No.	Type	Haze (%)	Transmittance (%)
1	Acrylic	0.2	87.6
2	Polyester	3.3	87.0
3	Polyester	5.0	90.6
4	Acrylic	10.5	92.4

## Beam patterns

Two low-beam headlamps were used, one manufactured for sale in the U.S., and one for sale in Europe. Figure 1 presents the original photometry, obtained without any plastic material in front of the lamps.

### U.S. low beam



Luminous intensity (cd)

### European low beam

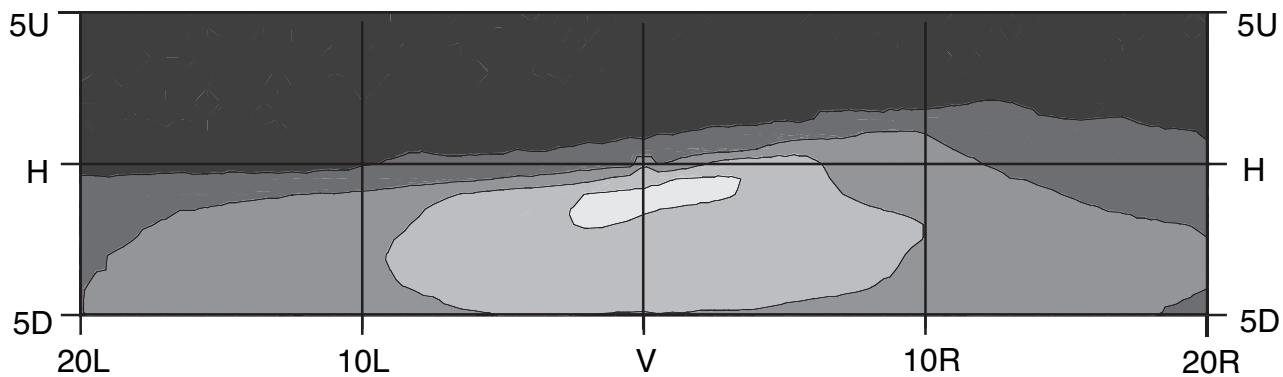
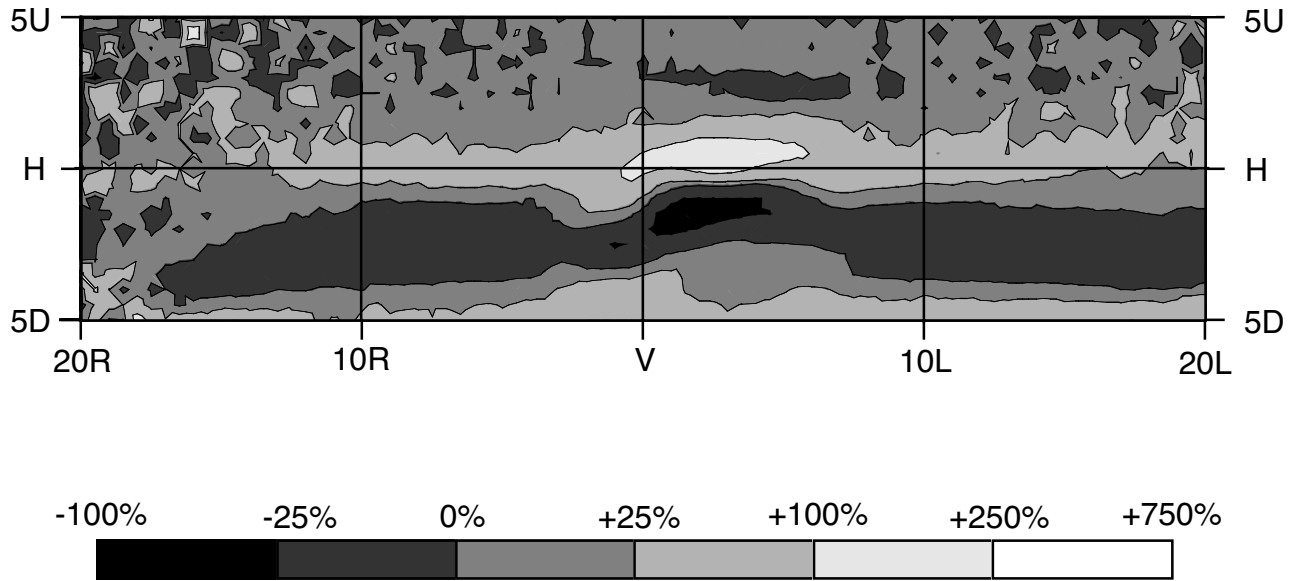


Figure 1. Photometry of the U.S. and European low beams tested.

## Results

Figure 2 shows the predicted changes (top panel) and the actual changes (bottom panel) in luminous intensities for the U.S. lamp in the 0.2% haze condition. Figure 3 presents the corresponding predictions and actual changes for the European lamp. The results for the haze conditions of 3.3, 5.0, and 10.5% are shown in Figures 4 through 9. Figures 10 through 17 present correlations of the actual changes with the predictions.

**Simulation**  
**U.S. low beam, 0.2% haze**



**Actual measurements**  
**U.S. low beam, 0.2% haze**

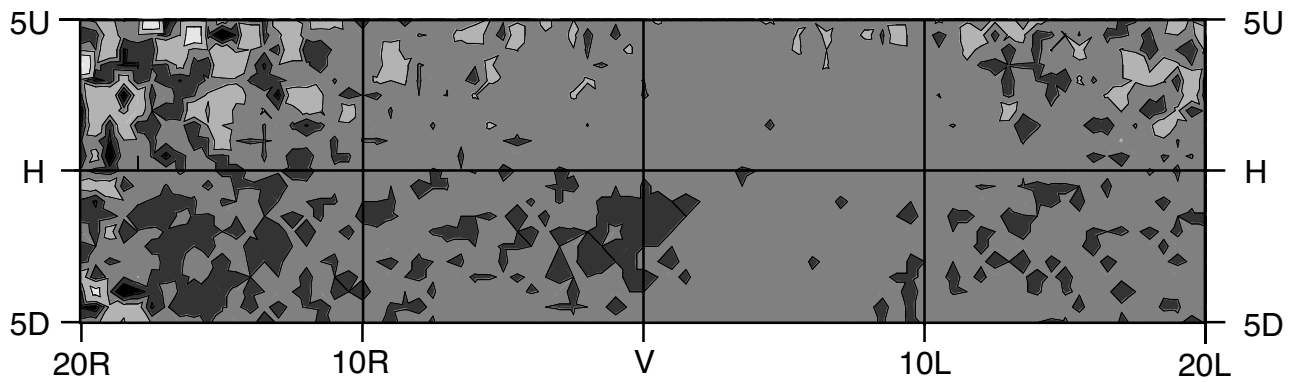
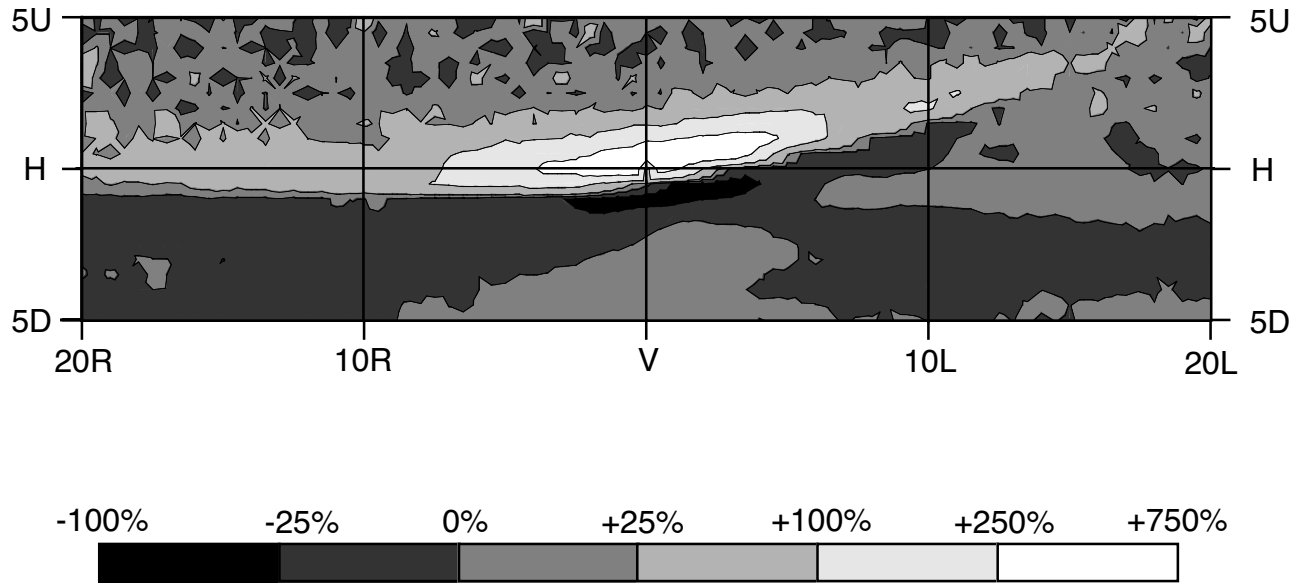


Figure 2. The predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 0.2% haze material.

**Simulation**  
**European low beam, 0.2% haze**



**Actual measurements**  
**European low beam, 0.2% haze**

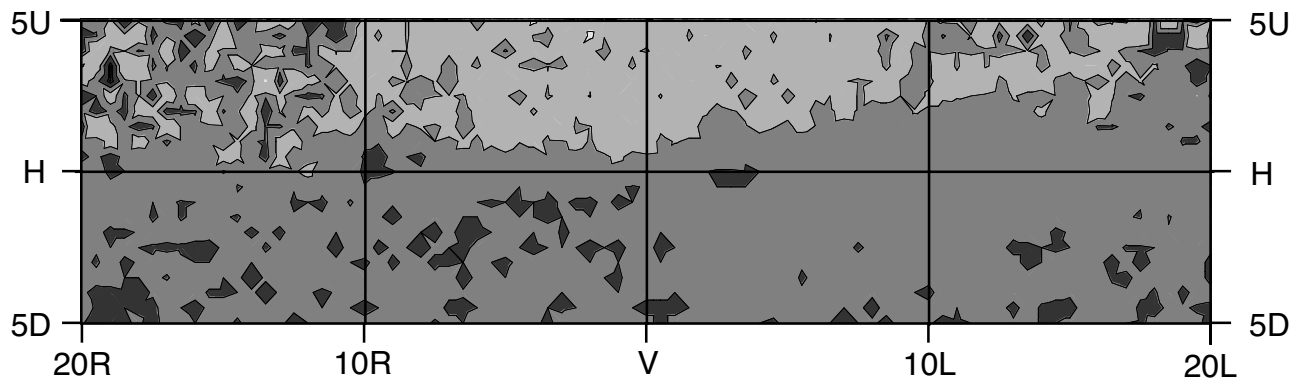
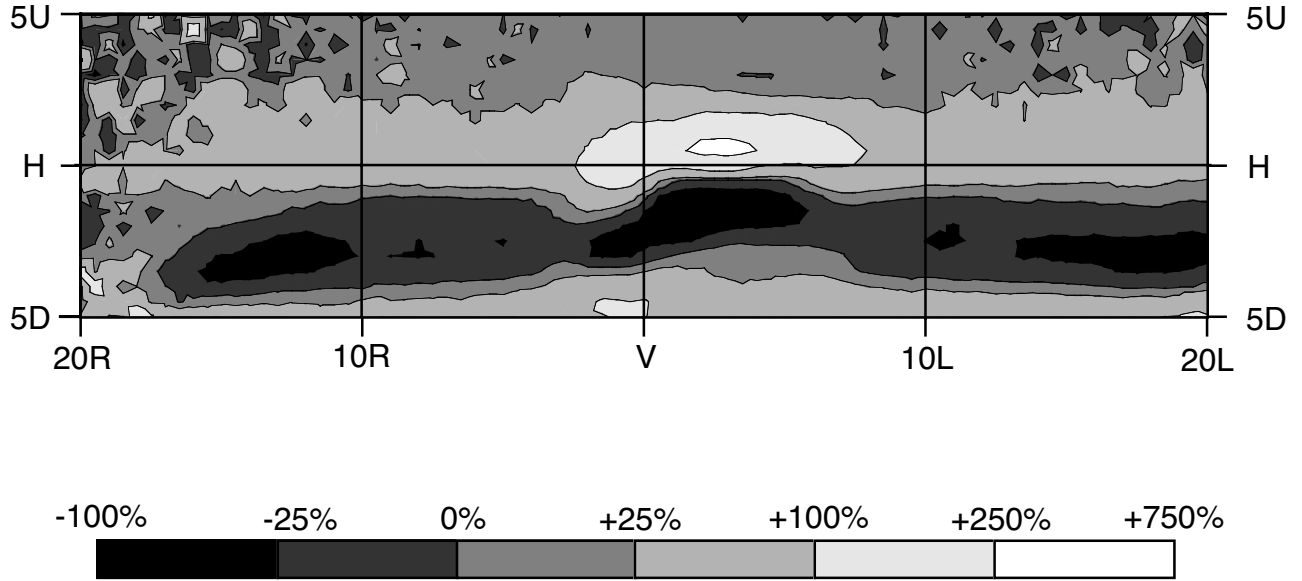


Figure 3. The predicted and actual percentage changes in luminous intensities for the European low beam and the 0.2% haze material.

**Simulation**  
**U.S. low beam, 3.3% haze**



**Actual measurements**  
**U.S. low beam, 3.3% haze**

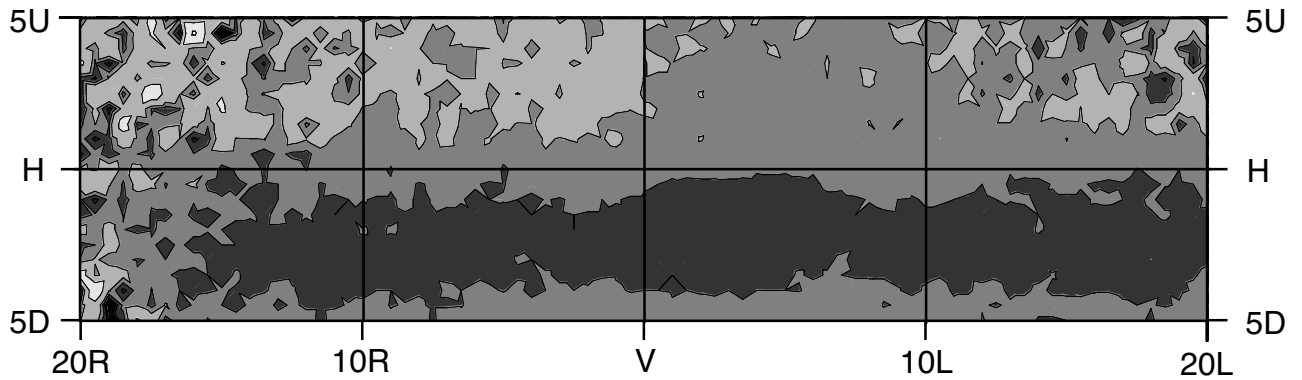
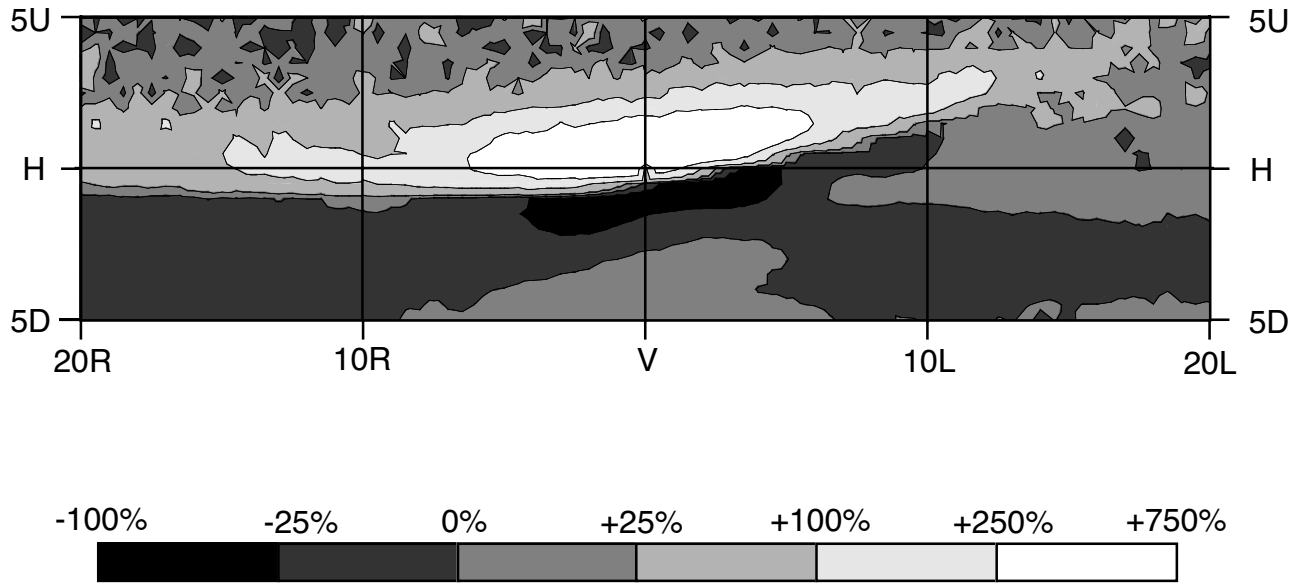


Figure 4. The predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 3.3% haze material.

**Simulation**  
**European low beam, 3.3% haze**



**Actual measurements**  
**European low beam, 3.3% haze**

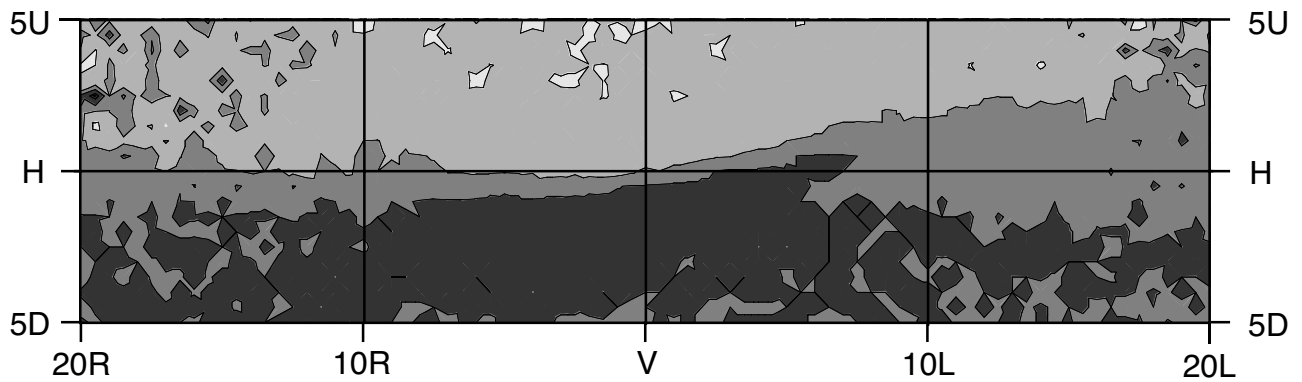
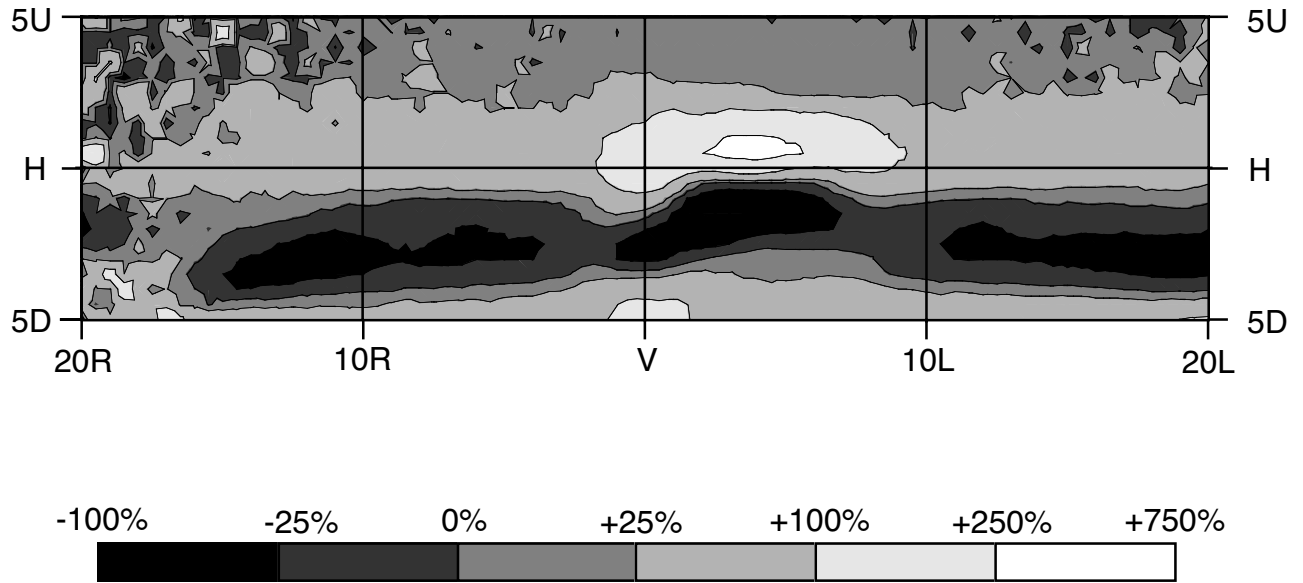


Figure 5. The predicted and actual percentage changes in luminous intensities for the European low beam and the 3.3% haze material.

**Simulation**  
**U.S. low beam, 5.0% haze**



**Actual measurements**  
**U.S. low beam, 5.0% haze**

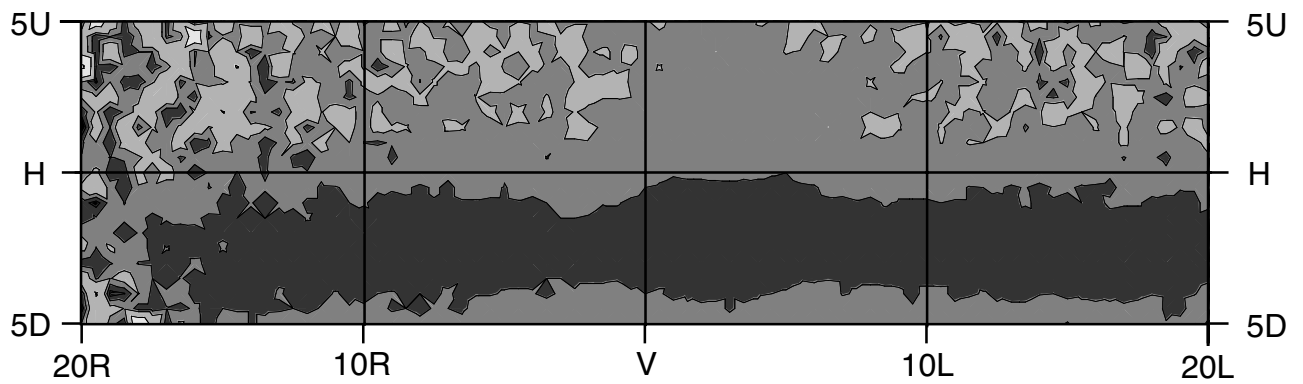
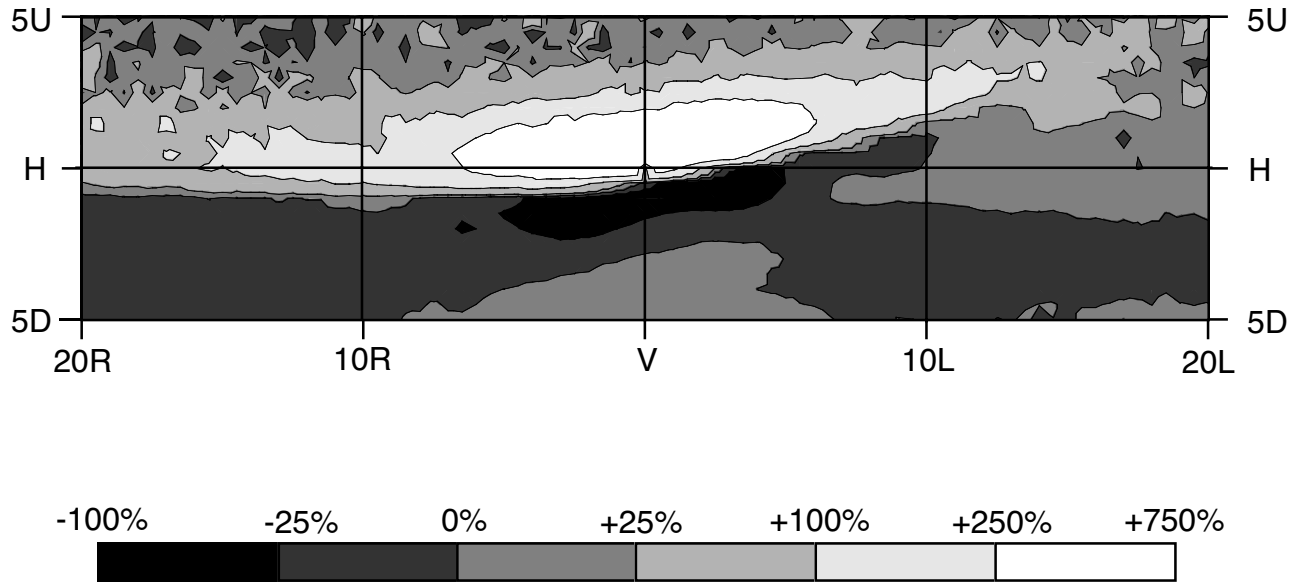


Figure 6. The predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 5.0% haze material.



**Simulation**  
**European low beam, 5.0% haze**



**Actual measurements**  
**European low beam, 5.0% haze**

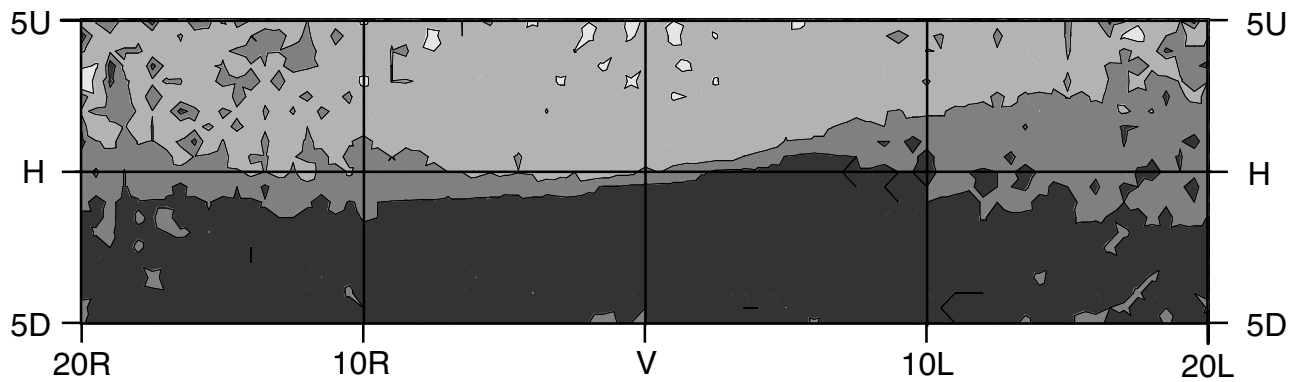
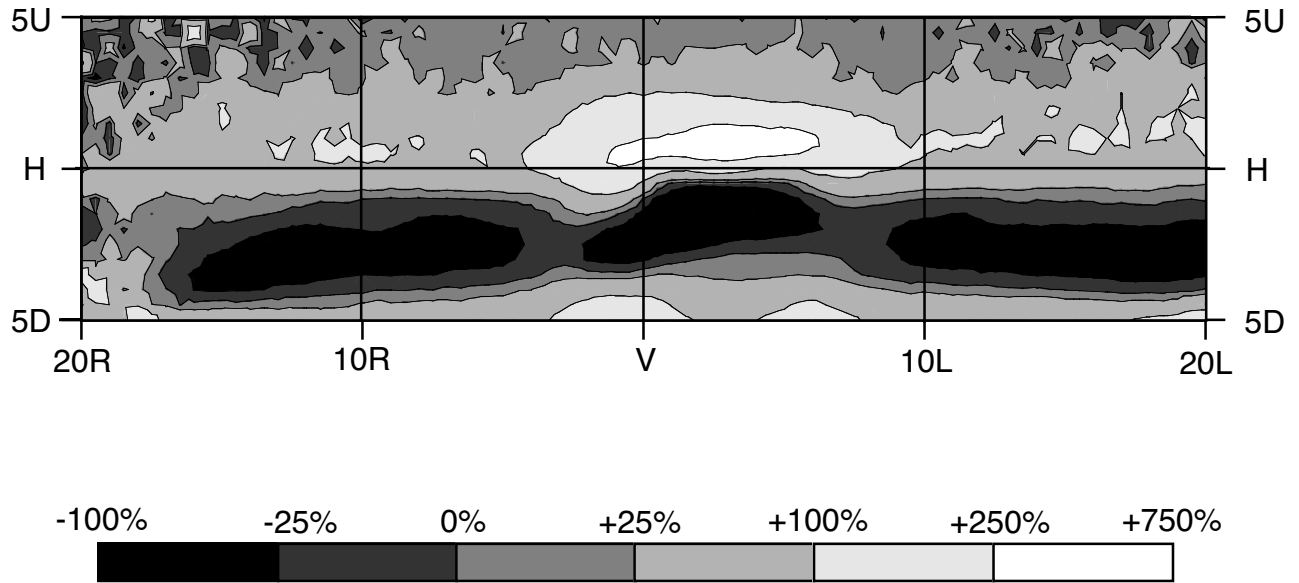


Figure 7. The predicted and actual percentage changes in luminous intensities for the European low beam and the 5.0% haze material.

**Simulation**  
**U.S. low beam, 10.5% haze**



**Actual measurements**  
**U.S. low beam, 10.5% haze**

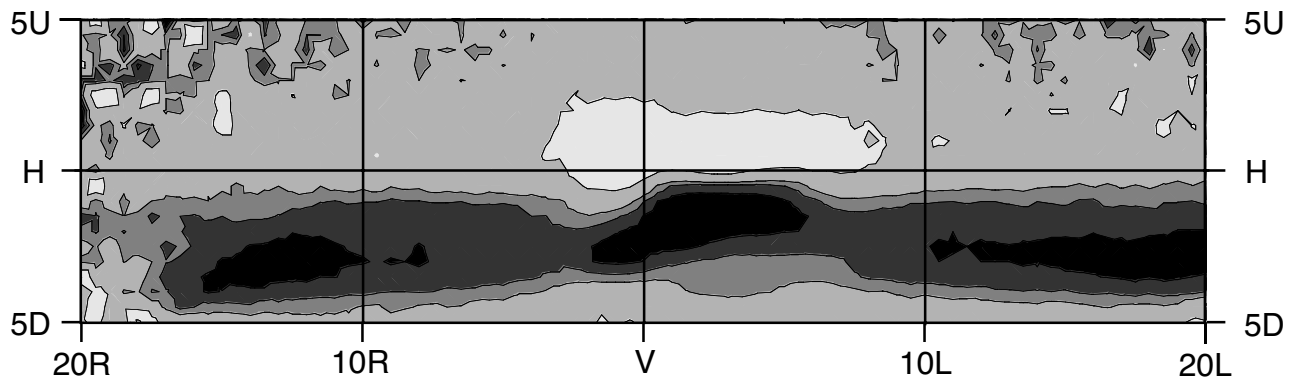


Figure 8. The predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 10.5% haze material.

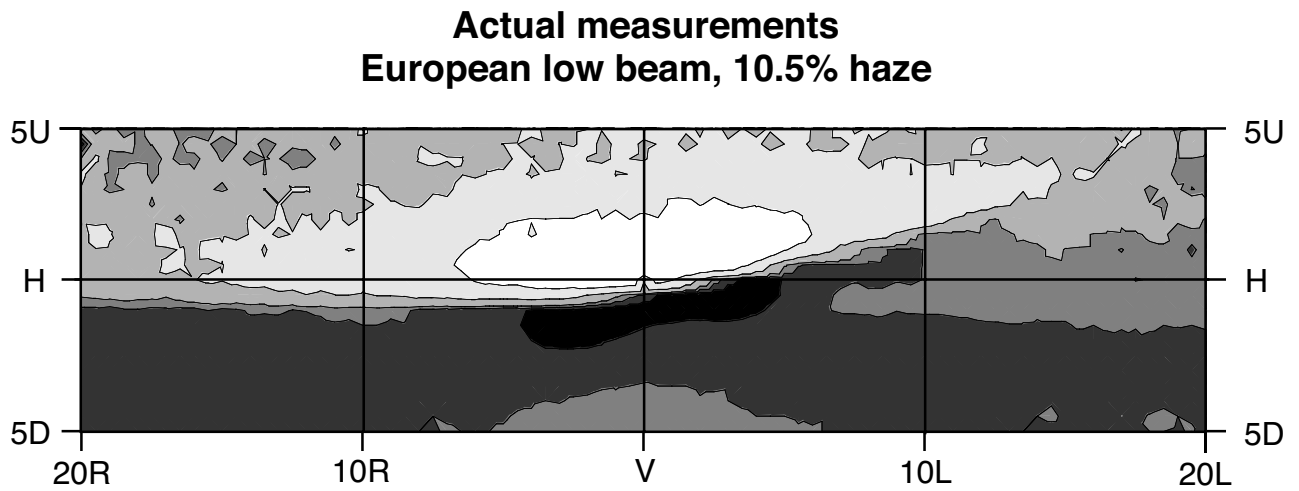
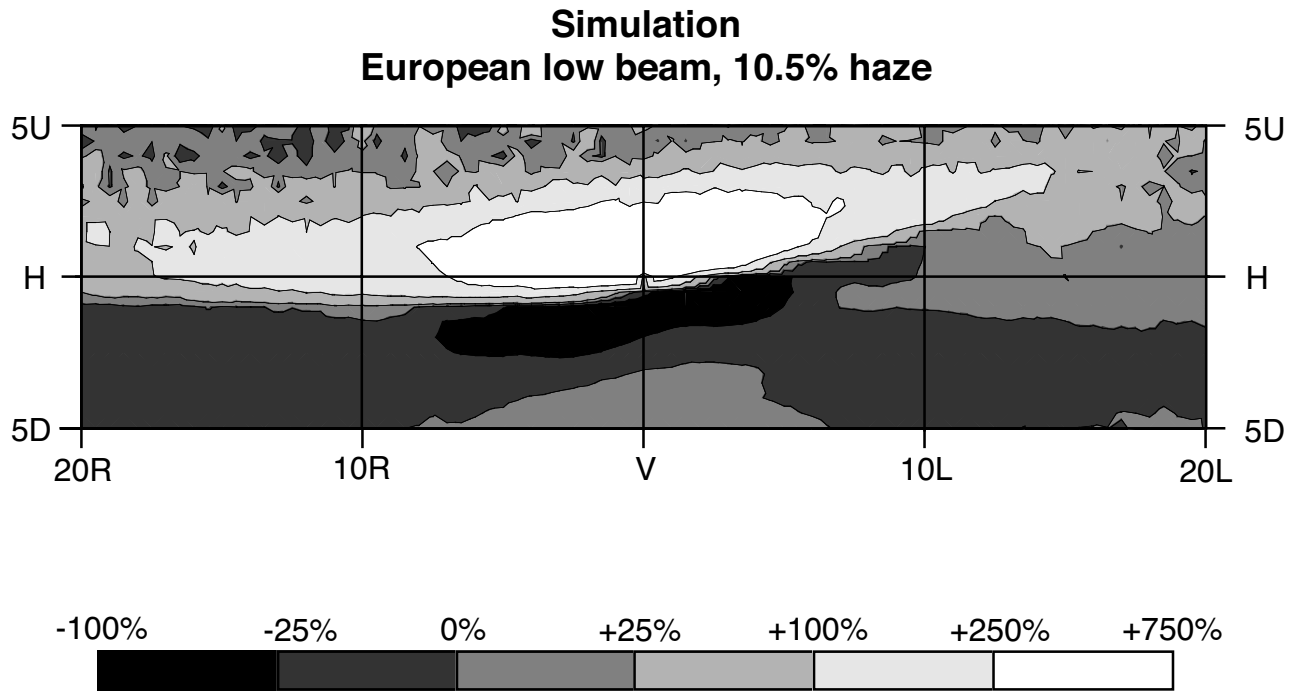


Figure 9. The predicted and actual percentage changes in luminous intensities for the European low beam and the 10.5% haze material.

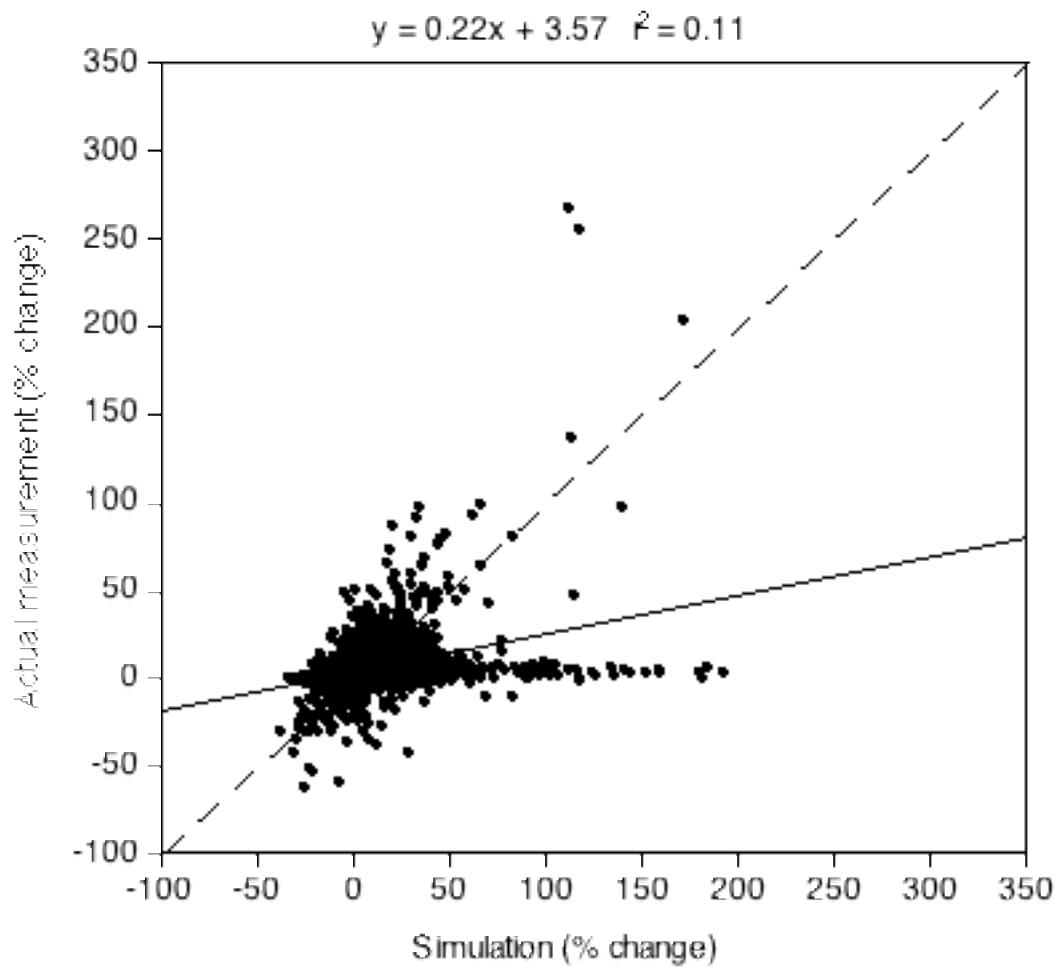


Figure 10. The relationship between the predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 0.2% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.

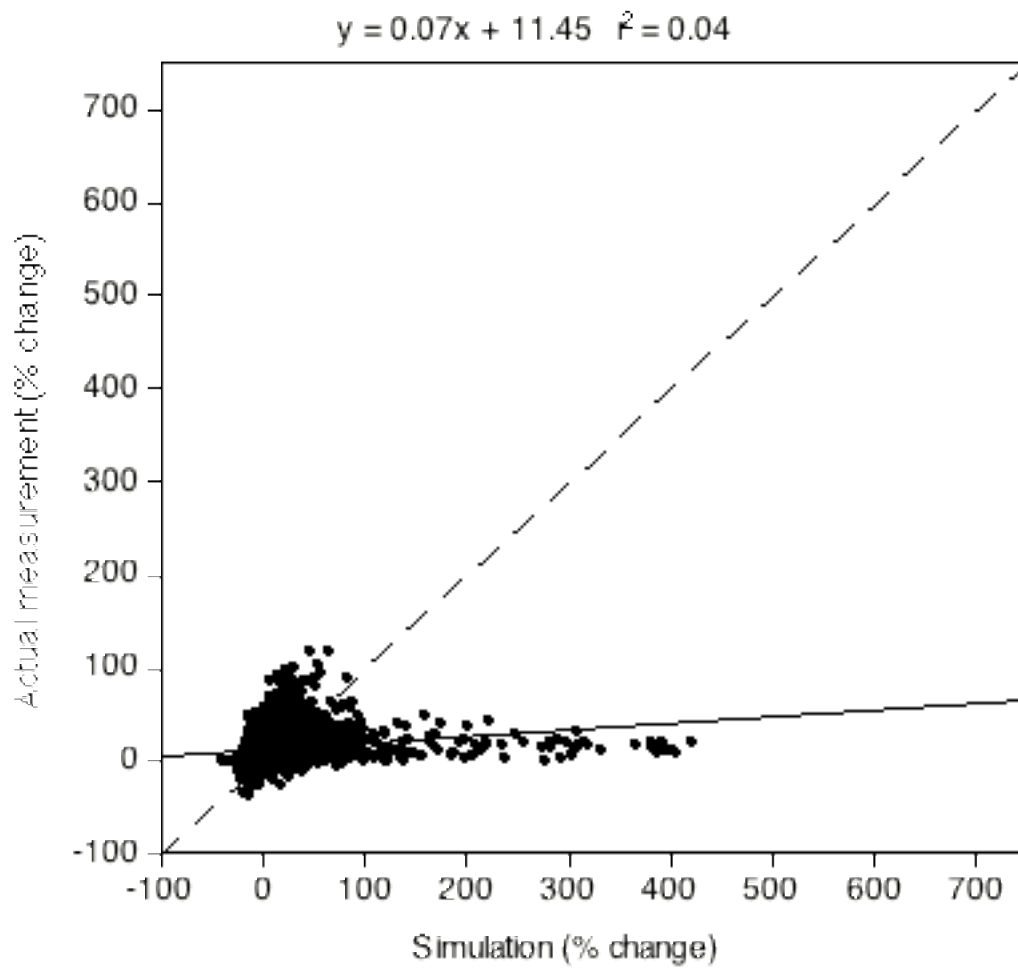


Figure 11. The relationship between the predicted and actual percentage changes in luminous intensities for the European low beam and the 0.2% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.

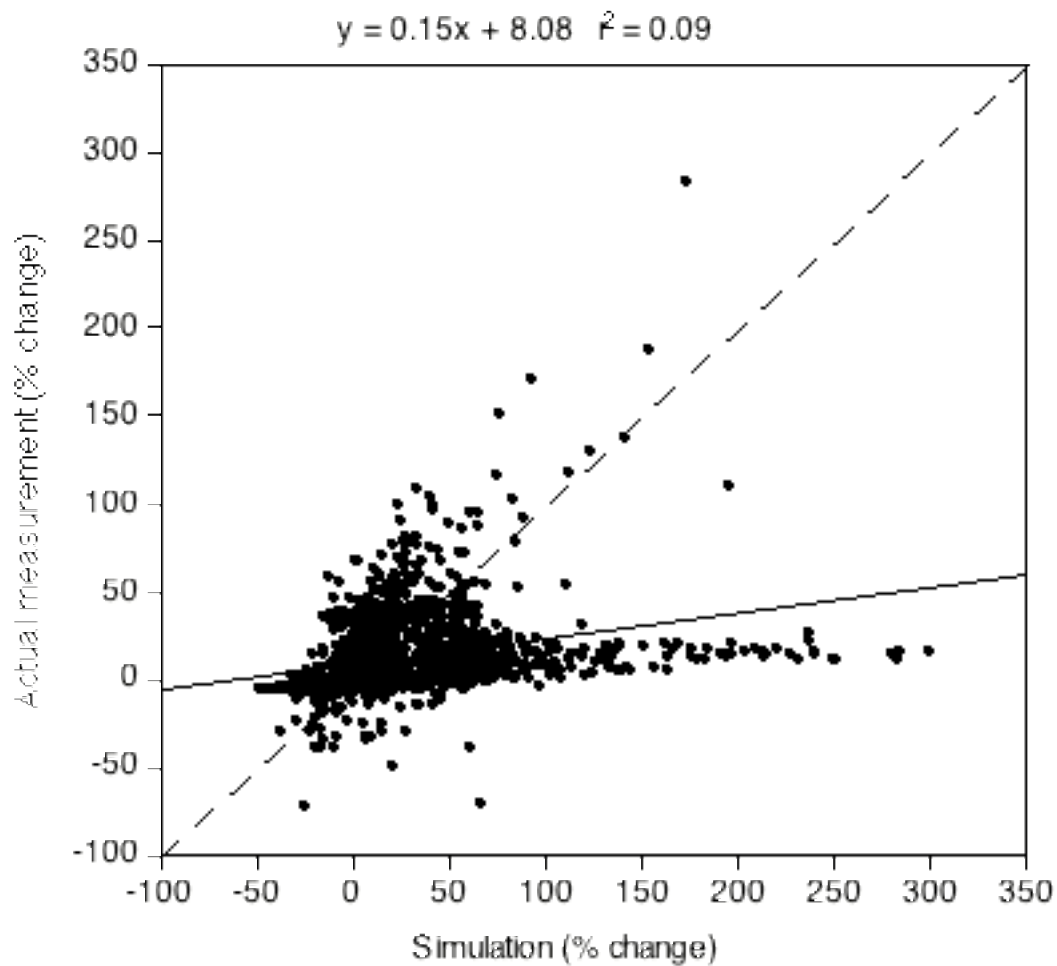


Figure 12. The relationship between the predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 3.3% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.

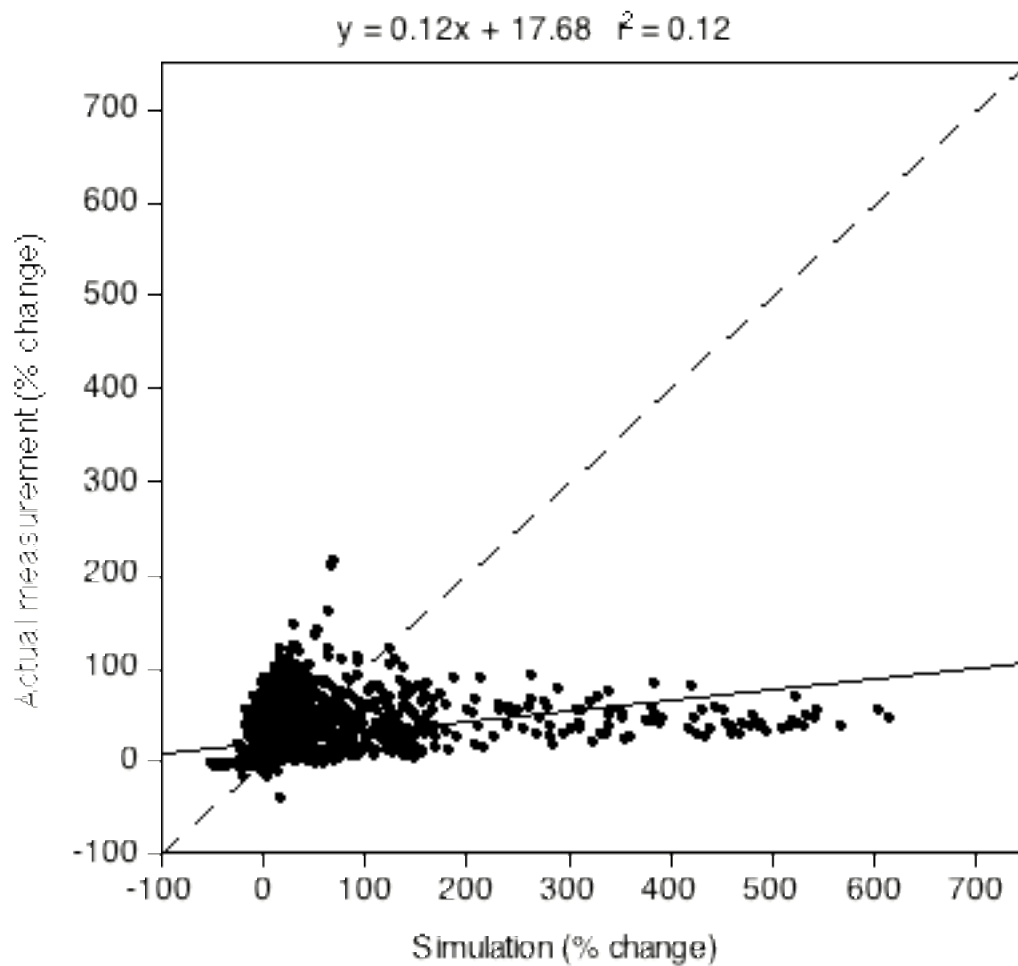


Figure 13. The relationship between the predicted and actual percentage changes in luminous intensities for the European low beam and the 3.3% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.

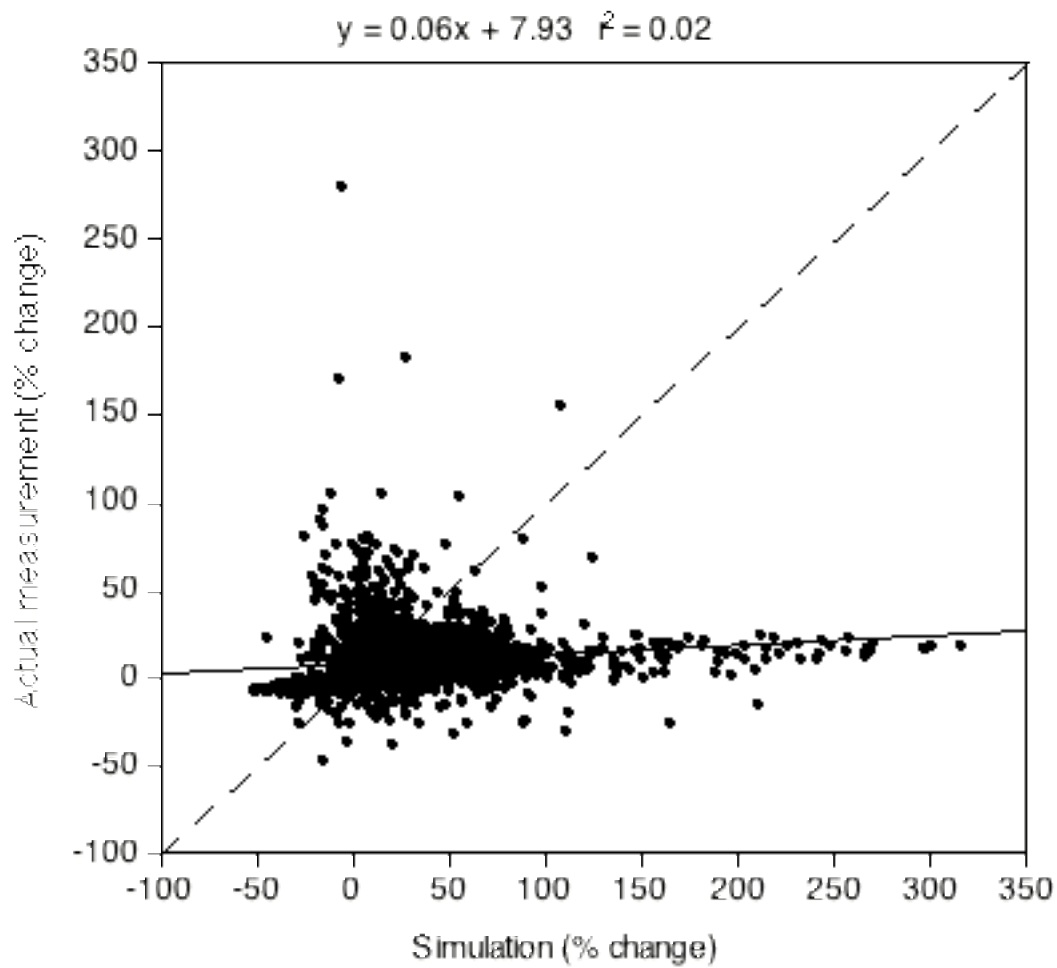


Figure 14. The relationship between the predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 5.0% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.



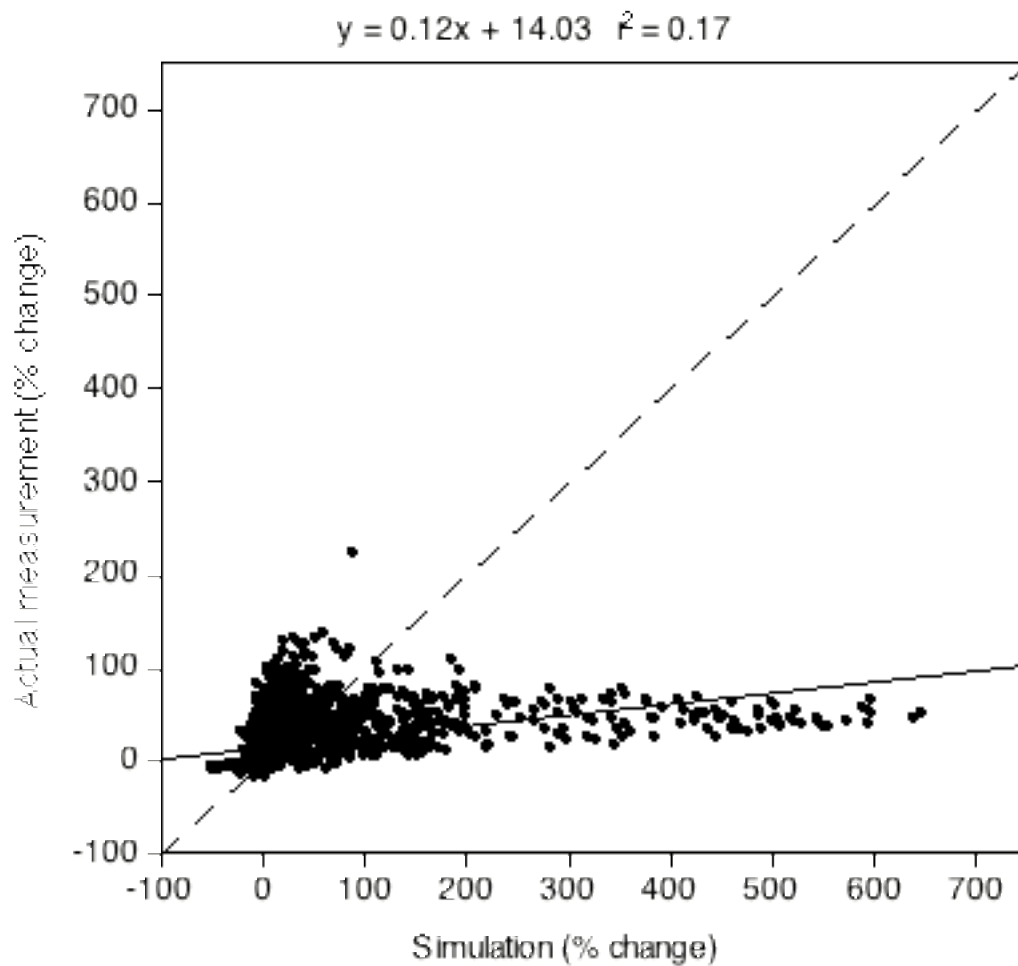


Figure 15. The relationship between the predicted and actual percentage changes in luminous intensities for the European low beam and the 5.0% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same

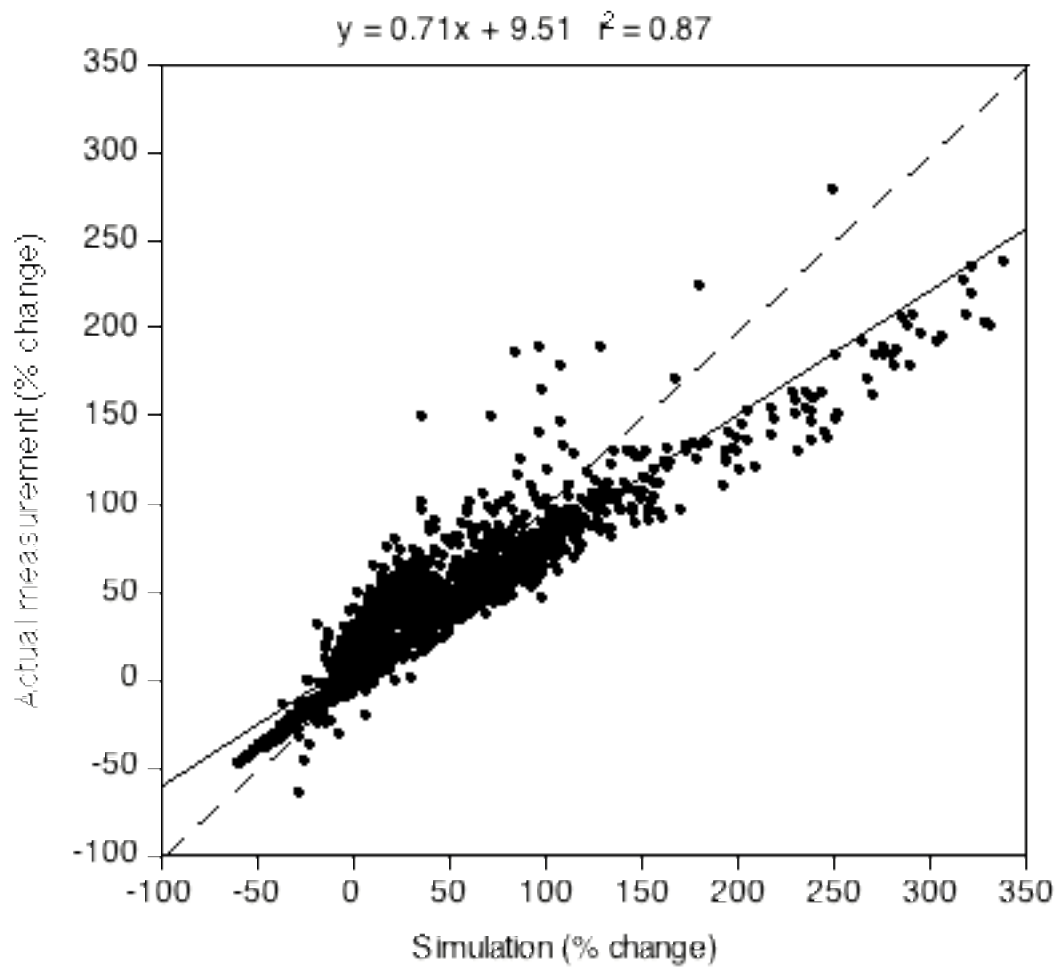


Figure 16. The relationship between the predicted and actual percentage changes in luminous intensities for the U.S. low beam and the 10.5% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.

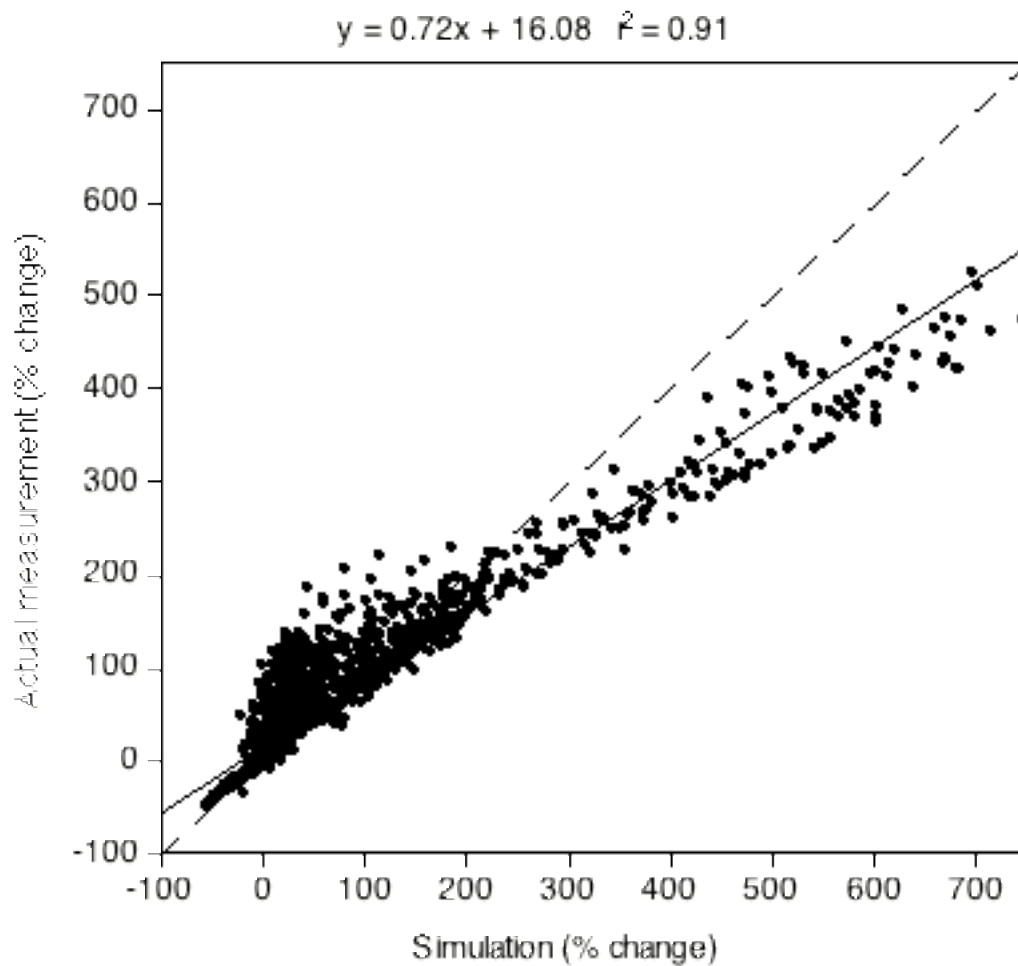


Figure 17. The relationship between the predicted and actual percentage changes in luminous intensities for the European low beam and 10.5% haze material. The solid line is the best-fitting linear model. For comparison, the dashed line shows where points would fall if the predicted and actual changes were the same.

## Discussion

The data in Figures 2 through 17 indicate that the simulation yielded reasonably accurate predictions for the 10.5% haze material, but inaccurate predictions for the other three materials. This pattern of results was obtained for both the U.S. and European low beams.

In general, the predictions were more extreme than the actual effects. In other words, the simulation predicted greater reductions and greater increases than proved to be the case. In Figures 2 through 7, this is most evident when one examines the parts of the beam pattern just above the horizontal and near the vertical: Here the predictions call for greater increases than were obtained with the actual materials.

Substantial numbers of points in both beam patterns, which were predicted to be affected by the materials with 0.2, 3.3, or 5.0% haze, were relatively unaffected. In Figures 10 through 15, these points lie in the horizontal groups of points near 0% actual change.

Consistent with the results of the simulation, the actual effects of haze were greater for the European than the U.S. beam pattern. This is a consequence of a sharper vertical gradient for the European beam pattern.

The most intriguing finding is the fact that the predictions for the four materials were neither uniformly accurate nor uniformly inaccurate. This finding brings us back to an observation we made in the Introduction: The ASTM definition of haze does not uniquely specify the distribution of the scattered light. We believe that differences in the distributions are responsible for the differences in the fit of the predictions.

To illustrate that the ASTM definition does not uniquely define the distribution of the scatter, we measured the scattering properties of two materials with nominally the same haze index. One material was the 10.5% haze material used in the main study. The other material was a calibrated haze standard purchased from BYK Gardner. According to the manufacturer, the haze index of this particular standard was 10.1%—virtually identical to the haze index of our 10.5% sample.

In order to make a rough assessment of the overall distribution of scatter from the two materials, a laser was aimed through each sample at a CCD array, and the resulting scatter was measured. Figure 18 shows the relative amount of scatter as a function of angle from the axis of the laser for the two materials in question.

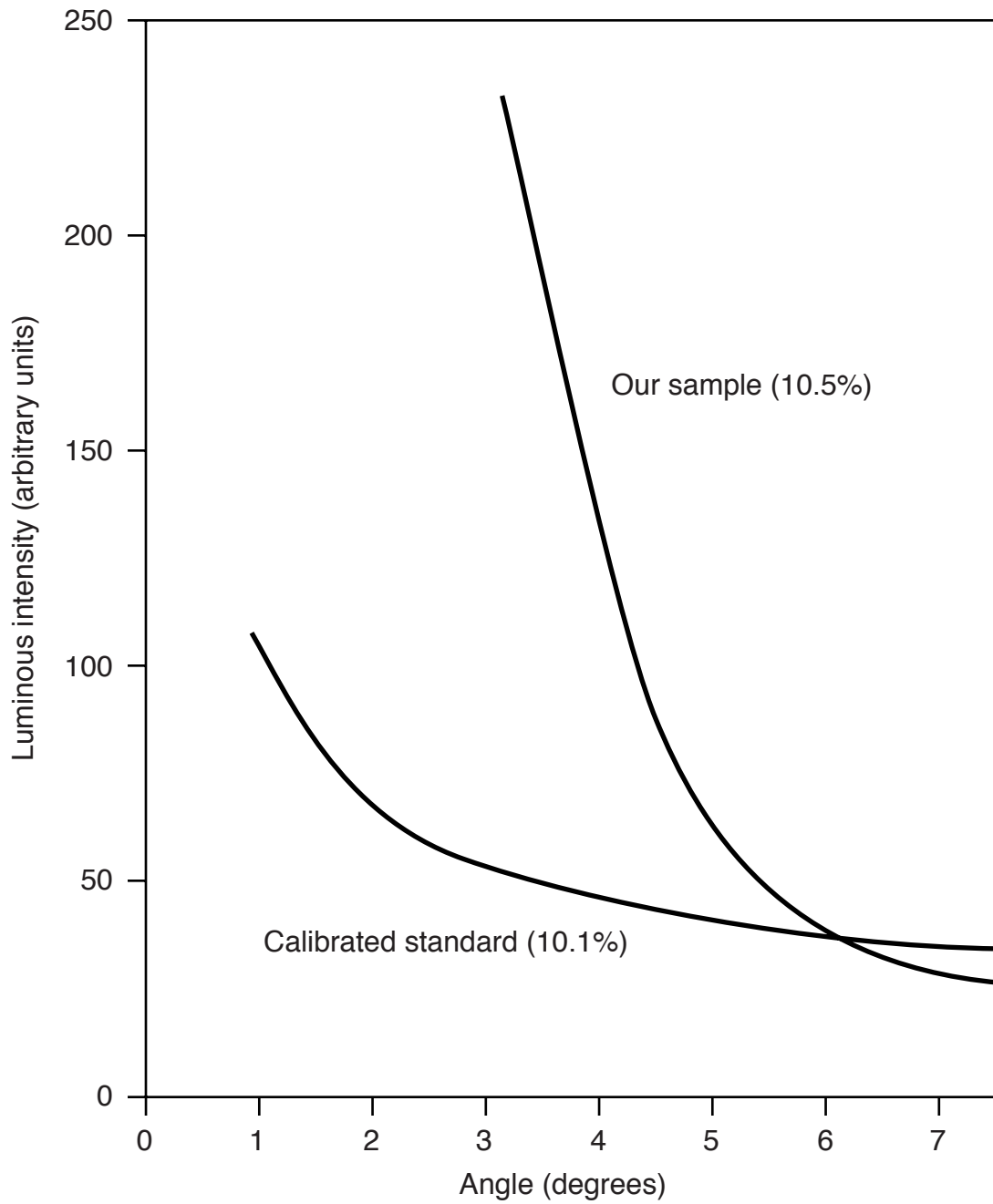


Figure 18. Scattering functions for a test material with an ASTM haze index of 10.5%, and for a calibrated haze standard with an ASTM haze index of 10.1%.

Because of the extreme differences in luminous intensity between the center and periphery of the scatter patterns, these measurements do not provide the complete scattering functions. However, even the partial functions in Figure 18 are sufficient to show that under these conditions, the patterns of scattering by the two materials are not the same. Note that the functions cross over, so that no adjustment in the vertical axis units (to compensate, for example, for possible differences in transmittance) will bring them into alignment.

Although these measurements cannot be used to establish whether either of the scattering functions is Gaussian, together with the haze index results (which indicate that for both functions about 10% is scattered beyond 2.5%), they indicate that they cannot *both* be Gaussian. Because of the success of the Gaussian model in the case of our 10.5% material, it is tempting to speculate that the scattering function for that material is Gaussian. There are several straightforward ways in which these measurements would need to be extended (e.g., using white light rather than a laser, and using a wider range of receptor sensitivity) in order to characterize the scattering functions well enough to make useful predictions about visual performance. The purpose here is simply to raise the issue of the need for such measurements.

## Conclusions

This study investigated changes in headlamp beam patterns as a function of the level of haze in sheets of plastic materials that were inserted in front of either a U.S. or a European low-beam headlamp. The level of haze was measured according to the method required by the U.S. National Highway Traffic Safety Administration. This method (ASTM Standard D 1003-92) measures the percentage of transmitted light that deviates from the incident beam through forward scatter by more than  $2.5^\circ$ . The actual effects on the beam pattern were then compared with predictions based on modeling the effects by assuming Gaussian distributions of the scattered light. The main finding is that the predictions for the four different plastic materials tested were neither uniformly accurate nor uniformly inaccurate. This lack of consistency is in agreement with the fact that the ASTM definition of haze does not uniquely specify the distribution of the scattered light. This problem with using the ASTM definition was confirmed by measuring the distributions of light scattering by two materials that had essentially the same ASTM index of haze.

The implication of this research is that establishing a justifiable maximum haze level for headlamp lens materials would require using a definition of haze that uniquely defines the resultant distribution of the light scatter. Consequently, it is recommended that future research should evaluate the distribution of scattered light using actual materials for headlamp lenses after different lengths of weathering exposure.

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