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Use of cameras for monitoring visibility impairment

William Malm[a,*], Scott Cismoski[b], Anthony Prenni[c], Melanie Peters[c]

[a] Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO 80523, United States
[b] Air Resource Specialists, Inc., Fort Collins, CO 80525, United States
[c] National Park Service, Air Resources Division, Lakewood, CO 80235, United States

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ABSTRACT

Webcams and automated, color photography cameras have been routinely operated in many U.S. national parks and other federal lands as far back as 1988, with a general goal of meeting interpretive needs within the public lands system and communicating effects of haze on scenic vistas to the general public, policy makers, and scientists. Additionally, it would be desirable to extract quantifiable information from these images to document how visibility conditions change over time and space and to further reflect the effects of haze on a scene, in the form of atmospheric extinction, independent of changing lighting conditions due to time of day, year, or cloud cover. Many studies have demonstrated a link between image indexes and visual range or extinction in urban settings where visibility is significantly degraded and where scenes tend to be gray and devoid of color. In relatively clean, clear atmospheric conditions, clouds and lighting conditions can sometimes affect the image radiance field as much or more than the effects of haze. In addition, over the course of many years, cameras have been replaced many times as technology improved or older systems wore out, and therefore camera image pixel density has changed dramatically. It is shown that gradient operators are very sensitive to image resolution while contrast indexes are not. Furthermore, temporal averaging and time of day restrictions allow for developing quantitative relationships between atmospheric extinction and contrast-type indexes even when image resolution has varied over time. Temporal averaging effectively removes the variability of visibility indexes associated with changing cloud cover and weather conditions, and changes in lighting conditions resulting from sun angle effects are best compensated for by restricting averaging to only certain times of the day.

1. Introduction

Visibility has varied and diverse meanings. Usually, its definition includes a statement about the degree of atmospheric clarity, specifically the greatest distance through the atmosphere at which a prominent object can be identified with the naked eye, typically referred to as the atmospheric or meteorological visual range. However, atmospheric clarity affects more than the distance from which large objects can be seen against a background sky; scenic landscape features have their inherent scenic beauty compromised in an atmosphere filled with haze. Coming upon a mountain an observer does not ask, “How far do I have to back away before the vista disappears?” Rather, the observer will comment on the color of the mountain, on whether geological features can be seen and appreciated, or on the amount of snow cover resulting from a recent storm system (Malm, 2016). There is a need for the management of a visual resource in the context of its inherent scenic qualities or beauty, as opposed to the distance at which the resource disappears or can just be barely detected or seen. Urban area managers have also identified good visibility in the urban setting as an important value worthy of being protected (Gesler, 2005; Velarde et al., 2007).

Important factors involved in seeing an object include illumination of the overall scene, including illumination resulting from sunlight scattered by clouds and the atmosphere, as well as reflections by ground and vegetation; landscape characteristics such as color, texture, form, and brightness; optical characteristics of the intervening atmosphere that cause image-forming information (radiation) originating from landscape features to be scattered and absorbed (attenuated) as it passes through the atmosphere toward the observer; sunlight, ground-reflected light, and light reflected by other objects scattered by the intervening atmosphere into the sight path (air light); and the psychophysical response of the eye–brain system to incoming radiation (Malm, 2016).

A real-world example of the role air light plays in the seeing of scenic landscape features is highlighted in Fig. 1, photos of Eagle Mesa in Monument Valley in northern Arizona. Photo “a” is a picture of the mesa viewed at a distance of about 1 km, while photo “b” shows the

* Corresponding author.
E-mail address: wc.malm@colostate.edu (W. Malm).

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Fig. 1. Photos of a butte in Monument Valley in northern Arizona. Photo “a” was taken at a distance of about 1 km, while photo “b” was taken at a distance of about 15 km.

same mesa but viewed at a distance of about 15 km. The pictures were taken within a few minutes of each other. The contrast between the sky and mesa is somewhat reduced, but the most significant effect of increased haze between the observer and landscape feature is the dramatic color shift toward the blue end of the spectrum. Color change or a shift from red to purple is caused primarily by added air light to the sight path that is the color of the sky, or bluish in nature.

Because visibility is not defined by a single parameter, it follows that a single monitoring methodology does not exist. However, visibility monitoring methods can be divided into three classes: view, optical, and particle monitoring. Visibility, in the most general sense, reduces to understanding the effects that various types of atmospheric particles and lighting and meteorological conditions have on the appearance of landscape features. Many visibility indexes quantify the appearance of a scene; however, a picture relating the effects particles have on the appearance of landscape features is the most simple and direct form of communicating visibility impairment. Therefore, a systematic photographic or digital imaging program (view monitoring) that records the appearance of the scene under a variety of lighting conditions and aerosol concentrations is a key part of any visibility monitoring program. But it is difficult to routinely extract quantitative optical data from photographs or digital images that can be related to atmospheric aerosols; therefore some direct measure of fundamental optical properties of the atmosphere is also desirable. Finally, particle concentration measurements should be made in conjunction with optical and imaging measurements to link visibility impairment to emission sources that contribute to haze (Malm, 1992; U.S. Environmental Protection Agency, 1999).

Webcam images have been employed in national parks and other federal lands as far back as 1998 with a general goal of meeting interpretive needs, as opposed to being used as a quantitative monitoring tool. These images are collected every 15 min, 24 h a day, 365 days a year. National Park Service visibility webcam images are available at http://www.nature.nps.gov/air/webcams/, U.S. Forest Service at http://www.fsvisimages.com/descriptions.aspx, and U.S. Fish and Wildlife at http://www.fws.gov/refuges/airquality/monitoring.html. Other visibility webcam sites can be found at http://www.hazecam.net/, which covers much of the northeastern United States, and http://airnow.gov/index.cfm?action=airnow.webcams, which includes some monitoring sites not available at the above web addresses.

The primary goal of the following analysis is to explore the possibility of extracting a quantifiable index from webcam images that reflects the effects of haze on a scene, allowing these images to be used to determine the distribution of visibility conditions associated with a given scene and how fundamental atmospheric variables, such as the atmospheric extinction coefficient, change over time and space. A secondary goal is to identify indexes that reflect people's perception of good and bad visibility. To understand the physical significance of the many proposed indexes, it is helpful to review a few basic radiation transfer equations.

2. Relevant radiation equations and associated metrics

A complete discussion of relevant radiation transfer equations related to visibility metrics is covered in Malm (2016) and is summarized here. Image-forming information is lost by the scattering of radiant energy out of the sight path and absorption within the sight path, while ambient light scattered into the sight path adds radiant energy to the observed radiation field. This process is described by

$$\frac{dN_r}{dr} = \underset{(loss)}{-b_{ext}N_r} + \underset{(gain)}{N_*} \tag{1}$$

where N_r is the apparent radiance at some vector distance r from a landscape feature, N_* (referred to as the path function) is the radiant energy gain within an incremental path segment, and $b_{ext}N_r$ is radiant energy lost within that same path segment. The atmospheric extinction coefficient b_{ext} is proportional to the amount of radiation absorbed in or scattered out of the path represented by r. Although not explicitly stated, it is assumed that each variable in, and each variable derived from, equation (1) is wavelength dependent.

Equation (1) with a number of limiting assumptions can be solved to yield

$$_lN_r = T_{rl}N_o + N_s(1-T_r) = T_{rl}N_o + N_r^* \tag{2}$$