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Microarticle

Spatial variability of correlated color temperature of lightning channels

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ABSTRACT

In this paper, we present the spatial variability of the correlated color temperature of lightning channel shown in a digital still image. In order to analyze the correlated color temperature, we calculated chromaticity coordinates of the lightning channels in the digital still image. From results, the spatial variation of the correlated color temperature of the lightning channel was confirmed. Moreover, the results suggest that the correlated color temperature and peak current of the lightning channels are related to each other.

In order to analyze colors of lightning channels, we used a lightning flash image shown in Fig. 1 (Upper). The images were captured in Chikusei City, Ibaraki Prefecture, Japan, on October 27, 2008. At that time, optical filters such as ND filters were not used. The image was saved as RAW image data and then it was converted to an uncompressed tagged image file format (TIFF) image. Thus, it is considered that information deterioration on the digital image is minimized. Therefore the lightning flash image (Fig. 1 (Upper)) can be used to analyze the colors of lightning channels. The properties of the image is as follows: image size: 3000 × 2000, color space: sRGB, field of view: 34.1°, date: October 27, 2008, beginning time: 21:31:33, and exposure duration: 36 s. In the original image (Fig. 1 (Upper)), many parts such as buildings, artificial light sources, and cloud luminescence occurring with a lightning flash are not required for color analysis. Thus we extracted only the lightning channels from the image (Fig. 1 (Upper)) by applying the standard digital image processing techniques [1–3] and extraction processing techniques created by us. Fig. 1 (Lower) shows the extracted channels.

In order to analyze the extracted lightning channels based on the correlated color temperature (CCT), chromaticity coordinates on the CIE 1931 *xy*-chromaticity diagram shown in Fig. 2 (Left) were obtained. The chromaticity coordinates were calculated by applying the method explained below [4].

We first divided the nonlinear sRGB components, R_{sRGB}, G_{sRGB} and B_{sRGB}, by 255 and then we obtain the normalized values: $V'_{\mathrm{sRGB}} = V_{\mathrm{sRGB}}/255$, where $V = R,\ G$, and B and in the following we use this notation for the sake of shorthand. Then the normalized nonlinear sRGB components, V'_{sRGB} are transformed to linear sRGB components, V_{linear}, as follows :

If $V'_{\mathrm{sRGB}} \leqslant 0.04045$, then $V_{\mathrm{linear}} = V'_{\mathrm{sRGB}}/12.92$, otherwise if $V'_{\mathrm{sRGB}} > 0.04045$, $V_{\mathrm{linear}} = \left((V'_{\mathrm{sRGB}} + 0.055)/1.055\right)^{2.4}$. The linear sRGB components V_{linear}, (i.e. $R_{\mathrm{linear}},\ G_{\mathrm{linear}}$ and B_{linear}) are converted to the CIE XYZ system by the equation [5]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R_{\mathrm{linear}} \\ G_{\mathrm{linear}} \\ B_{\mathrm{linear}} \end{bmatrix}. \quad (1)$$

Using the tristimulus value $X,\ Y$, and Z the chromaticity coordinates $x,\ y$ on the *xy*-chromaticity diagram are given by

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}.$$

Applying the conversion method mentioned above to the extracted lightning channel yields the chromaticity coordinates on the CIE 1931 *xy*-chromaticity diagram. Fig. 2 (Right) denotes the projected points for the extracted lightning channel. Since the CCT is discussed in the range $\pm 0.02\Delta uv$, in this work we focus only on the points in the range $\pm 0.02\Delta uv$.

In order to study the spatial variability of the CCT of the lightning channels, we remapped the projected points on the CIE 1931 *xy*-chromaticity diagram shown in Fig. 2 (Right) to the former 2D image (see Fig. 3) inheriting the CCT. Furthermore in Fig. 3, to

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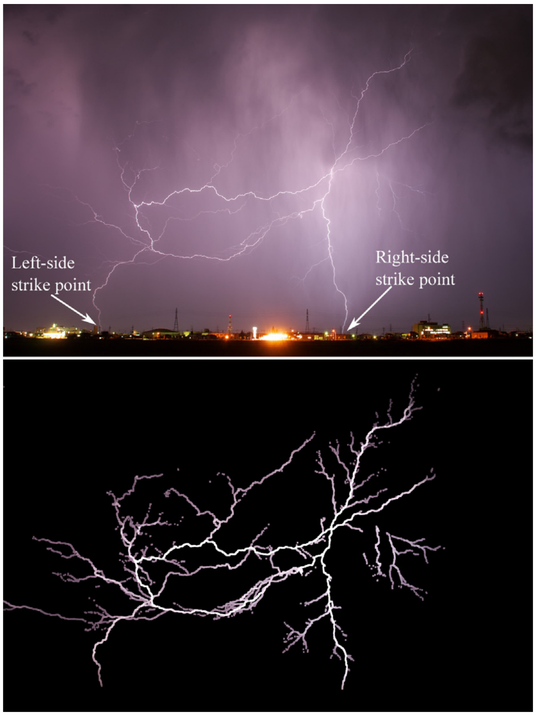

Fig. 1. (Upper) Original lightning image (Image courtesy of Mr. Yutaka Aoki) and (Lower) extracted lightning channel. The extracted lightning channel is thickened by applying thickening processing to improve visibility, since it is very thin.

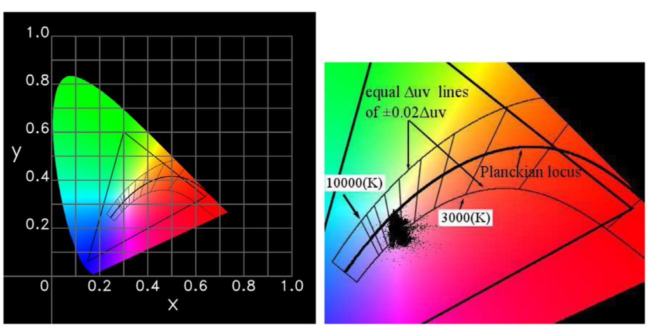

Fig. 2. (Left) CIE 1931 *xy*-chromaticity diagram and (Right) enlarged figure of the CIE 1931 *xy*-chromaticity diagram and all projected points of the extracted channels. In left side, the triangle indicates the sRGB color triangle and in both sides, the thick solid curve line denotes the Planckian locus and the thin solid lines crossing the Planckian locus denote the isotemperature lines. The thin solid curve lines along with the Planckian locus are the equal Δuv lines of ±0.02Δuv. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

emphasize small variation of the CCT, we narrowed the CCT range to 6000–7000 K. Note that the color on the color bar does not coincide with the actual color related to the color temperature of the Planckian radiator.

In Fig. 3, we can find that the CCT around the right-side strike channel is higher than the other channels. The CCT (T^{CCT}_{right}) around the right-side strike channel distribute in about 6500–7000 K. The CCT around the left-side strike channel (T^{CCT}_{left}) and other branch channels distribute in about 6000–6500. That is, $T^{CCT}_{left} < T^{CCT}_{right}$.

We have identified the properties of the left- and right-side strike points shown in Fig. 1 (Upper) using lightning data obtained by Japan Lightning Detection Network (JLDN). The details of the right-side strike channel in Fig. 1 (Upper) are as follows: time: 21:32:15:530283215 (JST), the location of the strike point: lat. 36.316°N and long. 140.0776°E, estimated peak current (I_{right}): 35 (kA), and type: −CG, where JST means Japan Standard Time and JST = UTC (Coordinated Universal Time) + 9 h, and the location is given in the World Geodetic System 1984 (WGS84). Similarly the details of the left-side strike channel in Fig. 1 (Upper) are as follows: time: 21:32:15:603968541 (JST), the location (WGS84) of the strike point: lat. 36.376°N and long. 140.0589°E, estimated peak current (I_{left}): 11 (kA), and type: −CG. As for estimated peak current, it is found that the right strike channel has higher current $I_{right} = 35$ kA than the left strike channel $I_{left} = 11$ kA, i.e. $I_{left} < I_{right}$.

The estimated peak current and the CCT of the right-side strike channel are higher than those of the left strike channel. It can be considered that the CCT may be related to the peak current of the lightning channel. If this relationship is established, it will be used as a new analysis method for lightning.

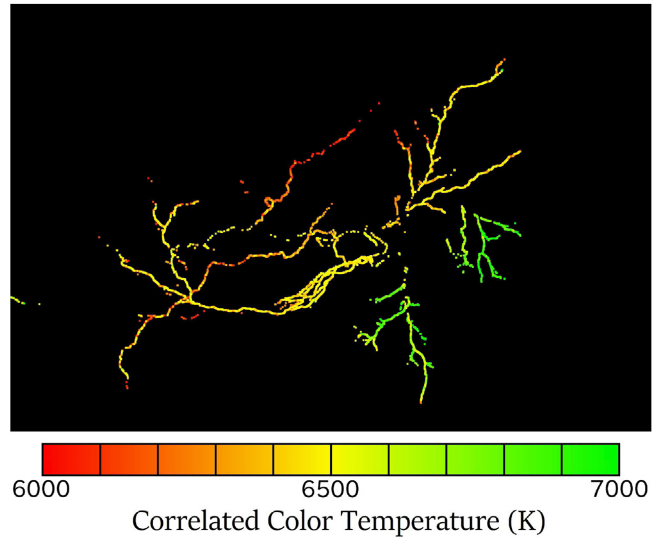

Fig. 3. Lightning channels represented by the CCT. The lightning channels are thickened by applying thickening processing, since it is very thin and evaluation of the variation of the CCT is difficult. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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