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Determination of apparent bulk velocity of auroral images

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Abstract In this paper we use a correlation analysis technique of random pattern to calculation of shift velocity of auroral image. The velocity thus obtained is a kind of apparent "average" velocity of whole image, instead of the velocity of some certain points or parts in the auroral pattern. The technique is used to an example of aurora australis recorded at Zhongshang Station of Antarctica in 1997. The typical velocity of the auroral pattern for the studied cases is about 3 km/s.

Key words auroral image, all-sky camera, random pattern, correlation analysis.

1 Introduction

The aurora is the most readily observed consequence of the dynamic behavior of the magnetosphere. For thousands of years men must have seen the northern and southern lights in the night sky, the aurora borealis and aurora australis, which therefore must surely qualify for a place among the oldest known geophysical phenomena.

It is one of the important aspects to determine auroral movement in the sky. Auroral illumination is caused by energetic particles coming from the magnetotail. Since it takes only a few seconds for the energetic particles to travel from the magnetotail to the ionosphere (Pudovkin and Egeland 1998), the movement of aurora in the ionosphere would directly reflect the shift signature in the source region of these particles, which would be a consequence of dynamic processes, such as magnetic reconnection in the plasma sheet.

In most cases we focus to the movements of particular parts of aurora, such as its leading edge, polar-ward or equator-ward boundaries, instead of the bulk velocity of auroral image.

In this paper we use the correlation analysis technique of moving random patterns (CAMRAP) to study auroral all-sky images. The pattern of auroral image is assumed to have a certain mean velocity, and also to change randomly in form as it moves. If we have two observations of the pattern (or "snapshots" of the whole pattern) separated by a known time interval, we can get the average bulk velocity of the pattern in this time interval, as well as the parameters describing the spatial properties and the random changes. This method can be used to separate the moving component and randomly deforming component in a pattern, such as ionospheric drift by using large aerial arrays, movement of light emission patterns in the night sky, moving meteorological weather pattern, oil layer floating on the ocean.

2 Correlation analysis of moving random patterns (CAMRAP)

Moving random patterns occur quite commonly in geophysics. Usually the pattern has a certain bulk velocity, which is the most important quantity to be determined. Meanwhile the pattern changes randomly in form as it moves, some parameters are also often required to describe the spatial properties of the pattern and its random changes. The correlation analysis of moving random patterns (CAMRAP) can be used to get these two kinds of information (Briggs 1968a,b; Xu *et al.* 1999).

There are two schemes of CAMRAP. The first scheme depends on the observations at a few fixed recorders, each of which records one 'cross-section' of the pattern as it moves past. The second one depends on the whole pattern snapshots. As for all-sky auroral images, the second scheme is applicable.

We consider a two-dimensional pattern $F(x,y,t)$ in the plane (x,y) at time t, which moves with a velocity $\boldsymbol{V}$, and changes in form as it moves. If a coordination system $O'X'Y'$ moves together with the pattern, an observer in this moving system will not see any movement of the pattern except its random deformation. Since the random deformations have some time-life and spatial extension, there exists a certain correlation between two patterns observed at times $t=t$ and $t=t+\tau$, and their correlation coefficient can be written as follows:

$$\rho(\xi',\eta',\tau) = \frac{\sum(\Delta F_1 \Delta F_2)}{\sqrt{\sum(\Delta F_1)^2 \sum(\Delta F_2)^2}} \tag{1}$$

where $\Delta F_1 = F(x',y',t) - \overline{F_1}$ (2)

$$\Delta F_2 = F(x'+\xi', y'+\eta', t+\tau) - \overline{F_2} \tag{3}$$

$\overline{F_1}$ and $\overline{F_2}$ are respectively the average values of the patterns at time t and $t+\tau$, and are not equal usually.

The correlation coefficient $\rho(\xi',\eta',\tau)$ has its maximum value at $\xi' = \eta' = 0$. Around the maximum point the function $\rho(\xi',\eta',\tau)$ can be expressed approximately as following:

$$\rho(\xi',\eta',\tau) = f(A\xi'^2 + B\eta'^2 + K\tau^2 + 2H\xi'\eta') \tag{4}$$

Transforming to the fixed coordinate system $O-\xi\eta\tau$, we get:

$$\rho(\xi,\eta,\tau) = f\{A(\xi - V_x\tau)^2 + B(\eta - V_y\tau)^2 + K\tau^2 + 2H(\xi - V_x\tau)(\eta - V_y\tau)\} \tag{5}$$

The necessary condition for the maximum value of $\rho(\xi,\eta,\tau)$ is:

$$\frac{\partial\rho}{\partial\xi} = \frac{\partial\rho}{\partial\eta} = 0 \tag{6}$$

that means

$$\begin{cases} \xi_0 = V_x\tau \\ \eta_0 = V_y\tau \end{cases} \tag{7}$$

It can be seen in equation (5) that the contours of $\rho(\xi,\eta,\tau)$ for a given time interval τ are a family of ellipses with a center at $\xi_0 = V_x\tau$, $\eta_0 = V_y\tau$. The components V_x, V_y of the pattern velocity can be obtained from ξ_0, η_0 and τ.

3 Calculation of bulk velocities of auroral images

The treatment of an aurora form as a moving random pattern is underlain with two pre-assumptions, namely, (a) that the target aurora shouldn't change dramatically so that the change of aurora pattern can be regarded "random", and (b) that an auroral image should be a "snapshot" of the whole pattern of the target aurora. An auroral arc usually extends beyond an all-sky image and it changes drastically. Therefore, we have to choose the auroras which satisfy above-mentioned assumptions. In this paper the method of CAMRAP is used to an example of auroral image taken by all-sky camera at Zhongshan Station in Antarctica.

The case we studied is a quiet aurora occurring on June 23, 1997. The successive images for a period of 100 s from 12 h 54 min 05 s to 55 min 45 s are shown in Fig. 1, in which the time interval between successive two images is 10 s.

As well known, the spatial distribution of optical aurora obtained by all-sky camera is not linear scale for longitudinal and latitudinal direction. A correction of luminous intensity and geometry is necessary before the CAMRAP is used. By means of the correction method proposed by Yang *et al.* (1997), the auroral images in Fig. 1 are transformed into linear format in both geometry and intensity, as shown in Fig. 2. Selecting the luminous area in the middle part of the images as the calculation area, the contour maps of correlation coefficient for two images with a 20 s interval are drawn in Fig. 3, from which the bulk velocity averaged during the 20 s can be obtained, and depicted in Fig. 4. The maximum velocity is about 2. 8 km/s.

4 Discussion and summary

CAMRAP technique is an useful tool to determine the drift velocity of a moving random pattern. In principle, this method can be used to analyze auroral images. However, all-sky auroral images are usually complicated in both pattern and intensity, and their time variations are also dramatic. In order to obtain reliable results, a careful choice of studied target aurora is required. In our study only stable auroral arcs with minor deformation are chosen and analyzed.

An even more serious problem is that an auroral arc usually extends beyond an all-sky image, that make the CAMRAP technique fail. In our study we choose the target auroral arcs which are wholly in all-sky image during the studied time span.

Besides, we select insulated auroral arcs in this paper to avoid mutual interference of different arcs.

This preliminary study is summarized as follows:

(1) Correlation analysis of moving random patterns (CAMRAP) can be used to separate the moving component and randomly deforming component in a pattern. When this method is used to determine the velocity of an auroral image we must choose the auroras that shouldn't change dramatically and should be a "snapshot" of the whole

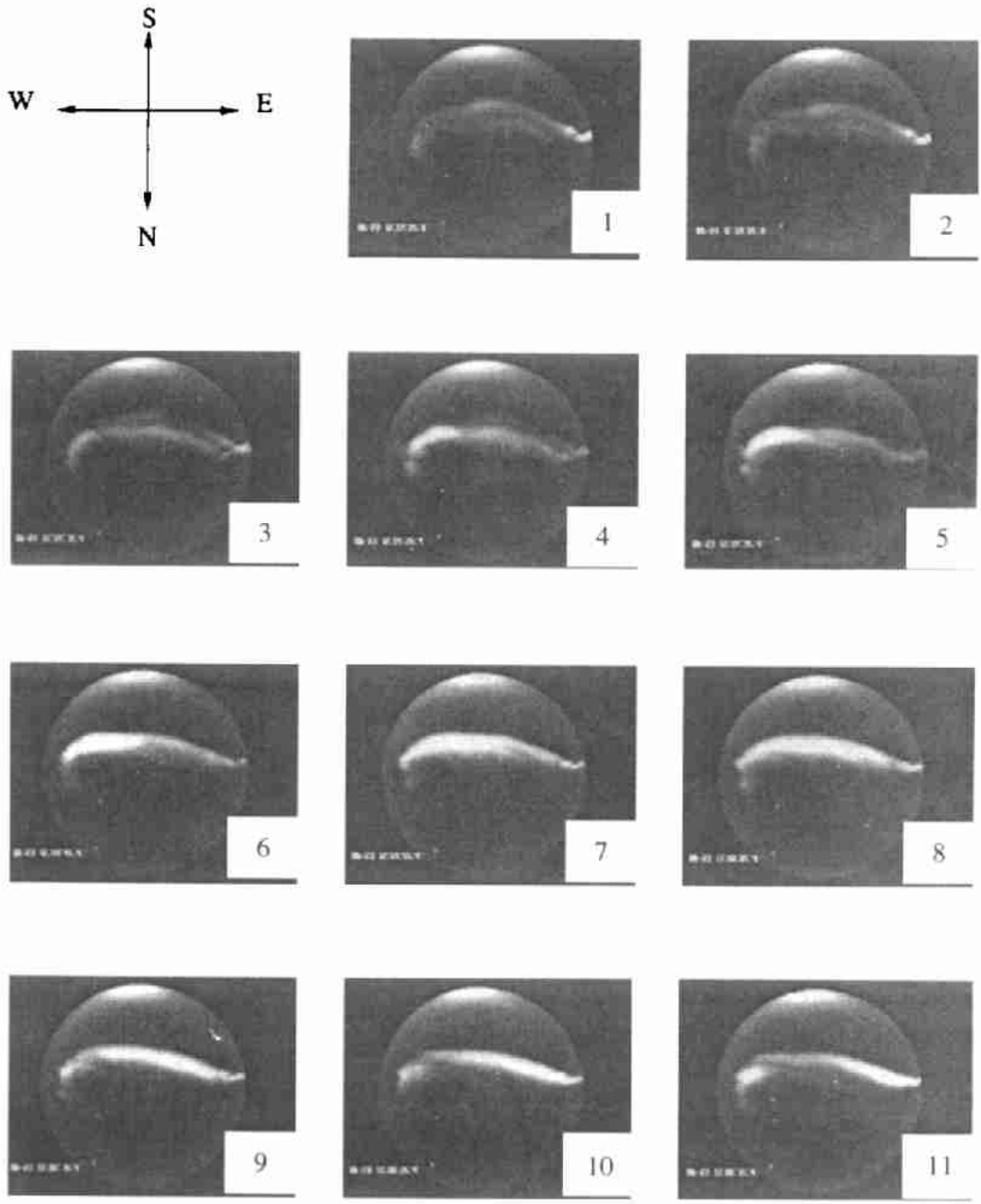

Fig. 1. Sequence of all-sky auroral images taken at Zhongshan Station of Antarctica on June 23, 1997. The time interval between successive images is 10 s.

pattern of the target aurora.

(2) The velocity thus obtained is a kind of apparent "average" velocity of whole

image, instead of the velocity of some certain points or parts in the auroral pattern.

(3) The typical velocity of the auroral pattern for an example of aurora australis in this paper is about 3 km/s.

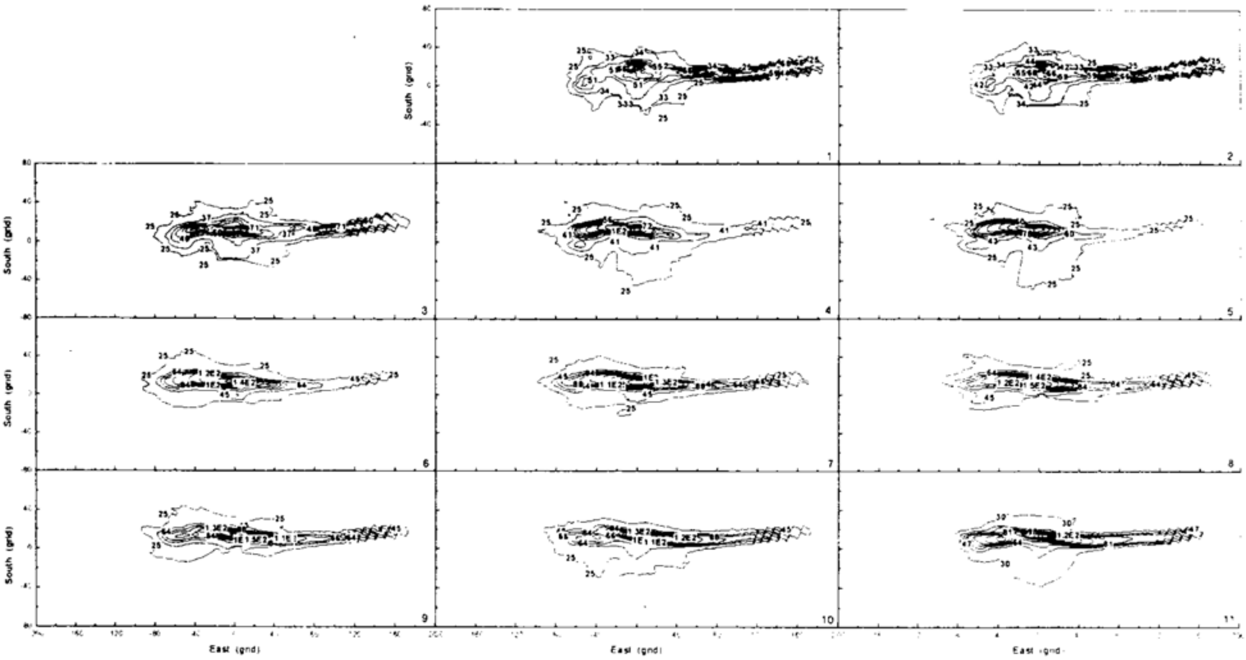

Fig. 2. Contours of luminous intensity after geometric and intensity corrections.

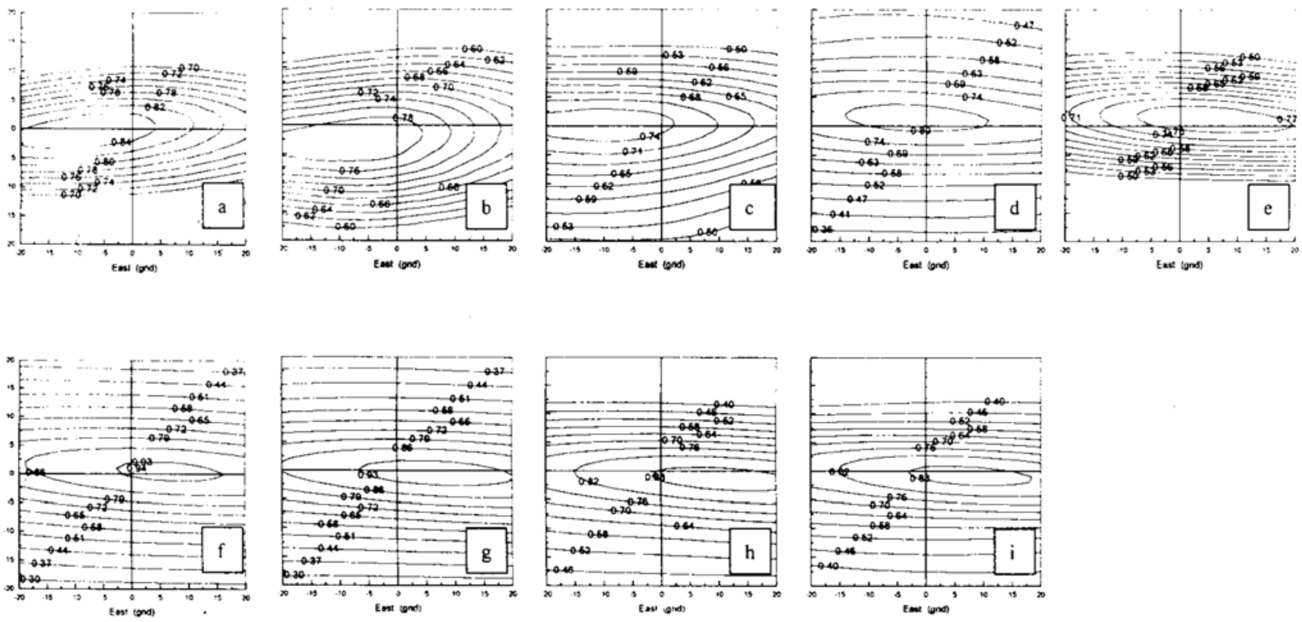

Fig. 3. Contours of correlation coefficient of two images with a 20 s interval.

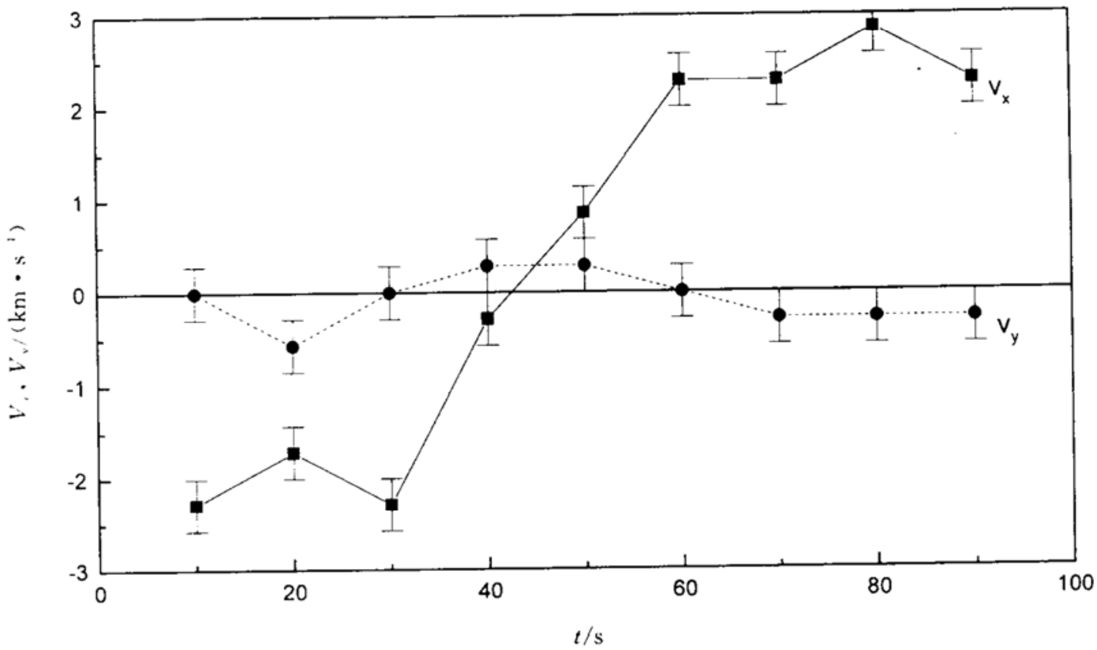

Fig. 4. Bulk velocity of the auroral images on June 23, 1997.

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References

Briggs BH(1968a): On the analysis of moving pattern in geophysics, 1. Correlation analysis. J. Atmos. Terr. Phys., 30: 1777 - 1788.

Briggs BH(1968b): On the analysis of moving pattern in geophysics, 2. Dispersion analysis. J. Atmos. Terr. Phys., 30: 1789 - 1794.

Pudovkin MI, Egeland A (1998): Large-scale electric field in the dayside magnetosphere. In: Moen J, Egeland A and Lockwood M, ed. Polar Cap Boundary Phenomena, Kluwer Academic Publishers, Dordrech/Bosten/London, 141 - 156.

Xu WY, Wei ZG, Zhang BC, Hu HQ, Liu RY(1999): A method of determination of aurora shift. Chinese Journal of Polar Research, 11(3): 192 - 202.

Yang HG, Liu RY, Sato N(1997): Intensity correction in transformation of all-sky auroral image. Chinese Science Bulletin, 42, 217 - 219.