近似カルマンフィルタによるオーロラ動画データからの情報抽出

Extraction of geophysical information from auroral movies using an approximate Kalman filter

中野 慎也 (統計数理研究所), 小川 泰信 (国立極地研究所)

S. Nakano (The Institute of Statistical Mathematics) and Y. Ogawa (National Institute of Polar Research)

Introduction

The features and variations of aurorae are highly complicated. In addition, some aurorae blink with various periods. Thus, it is difficult to quantify the properties of the aurorae. In order to quantify some of the auroral properties, we have developed a method for decomposing the variations of aurorae into a persistent component and fluctuating component by using an algorithm which approximates the Kalman filter.

Method

The variation of the persistent component ℓ, which does not rapidly change in brightness, should satisfy the following optical flow equation:

$$\frac{\partial \ell}{\partial t} + u\frac{\partial \ell}{\partial x} + v\frac{\partial \ell}{\partial y} \approx 0. \tag{1}$$

where (u, v) indicates the optical flow vector, which corresponds to auroral motion on an image. Based on this equation, we derive a predictive model from the image at the previous time t_{k-1} as follows:

$$\ell_{i,k} = \ell_{i,k-1} - u_{i,k-1}\frac{\partial \ell_{i,k-1}}{\partial x} - v_{i,k-1}\frac{\partial \ell_{i,k-1}}{\partial y} + \varepsilon^{\ell}_{i,k}, \tag{2a}$$

$$u_{i,k} = u_{i,k-1} + \varepsilon^{u}_{i,k}, \tag{2b}$$

$$v_{i,k} = v_{i,k-1} + \varepsilon^{v}_{i,k}, \tag{2c}$$

where the subscript i indicates i-th pixel on an image and ε^{ℓ}, ε^{u}, and ε^{v} are system noise terms. The observed brightness $y_{i,k}$ is the sum of the persistent component $\ell_{i,k}$ and the fluctuating component $w_{i,k}$:

$$y_{i,k} = \ell_{i,k} + w_{i,k}. \tag{3}$$

Eqs. (2) and (3) are regarded as a nonlinear state space model in which $\ell_{i,k}$, $u_{i,k}$, and $v_{i,k}$ are the state variables. Thus, these state variables could be estimated using the extended Kalman filter. However, the standard extended Kalman filter is computationally costly because one auroral image consists of tens of thousands of pixels. In order to reduce the computational cost, we approximate the filtered covariance matrix by a diagonal matrix. On the basis of this approximation, we have derived an efficient algorithm for estimating the state variables, $\ell_{i,k}$, $u_{i,k}$, and $v_{i,k}$. Using this efficient algorithm, we estimate the persistent component. The fluctuating component is then obtained by subtracting the persistent component from the original image