Flow Analysis of Cloud Images from Geostationary Satellites

Aimamorn Suvichakorn and Adrian R. Tatnall

Astronautics Research Group, School of Engineering Sciences
University of Southampton

Introduction

In this paper, motion analysis of cloud images from a geostationary satellite has been examined by the method of optical flow. The original model of the optical flow is adjusted to cater for the compressible property of clouds. Also, the spiral movement equation is added to derive the movement of occluded depressions which circulate around a vortex. The analysis aims to support rainfall analysis and prediction.

Geostationary satellites are a valuable source of rainfall information due to the availability of a global view of clouds at an acceptable spatial and temporal resolution. However to retrieve the information from the satellite images is a significant challenge. For example, precipitation peaks while the cloud area is rapidly growing and reduces at the time of maximum cloud area [4], Visible (VIS) and Infrared (IR) channels of the satellites can see only the top-of-the-clouds, not rain at the surface of the earth. Moreover, how a cloud changes with time reflects atmospheric instabilities that occur and most instabilities lead to precipitation. As a consequence, we need some descriptions of cloud motion and pattern changes as an explicit link to rain rate.

To derive the velocity of an object in three dimensional space from a sequence of two dimensional images or **optical flow**, Horn and Schunck [2] introduced the fluid dynamics constraint reducing the ambiguity of the velocity field, thus making the recovery of an object's motion possible. The idea is also relevant to cloud motion, which is a special case of fluid motion and consists of very complex motion dynamics [5]. Furthermore, its probability distribution allows representation of the uncertainties in the optical flow computation [3].

Algorithm and Implementation

Original model

Let the intensity at position $\vec{x}$ and time t be $I(\vec{x},t)$ and the intensity after a small change in time and position be $I(\vec{x}+\delta\vec{x}, t+\delta t)$. Using the assumption that the brightness is constant over time,

$$I(\vec{x},t) \cong I(\vec{x}+\delta\vec{x},t+\delta t) = I(\vec{x},t)+\nabla I\cdot\delta\vec{x}+I_t\delta t+... \quad (1)$$

Assume that the high order terms in Taylor series expansion are negligible, we get the brightness constraint:

$$\nabla I\cdot\frac{\partial\vec{x}}{\partial t}+I_t=0, \quad (2)$$

$$\nabla I\cdot\vec{\omega}+I_t=0. \quad (3)$$

The intensity of image can be viewed as the density of the optical flow. The brightness constancy corresponds to constant density, which is the property of an incompressible and homogeneous fluid.

Compressible optical flow

Dominique Béréziat and Jean-Paul Berroir [1] proposed the total brightness constraint for each cloud object:

$$\nabla I\cdot\omega+I_t+Idiv(\omega)=0. \quad (4)$$

With the divergence term, the problem now is of a compressible fluid which its density ϱ depends on the coordinates $\vec{x}$ in space and may depend on time as well. Considering that the radiance is a measure of temperature, which relates to elevation, the total brightness of a cloud equals the volume of the column of air between the cloud top and the altitude of reference. In other words, the total brightness constraint is equivalent to the conservation of cloud volume. [1]

Spiral movement of vortex

By observation, the movement of clouds is non-linear–and often circular or spiral, due to the effect of air and ocean circulation. This suggests that adding spiral movement into the optical flow model would obtain a more accurate velocity field. It is assumed that cloud moves as an equiangular spiral, which is defined as a spiral that forms a constant angle between a line from the origin to any point on the curve and the tangent lines angle at that point and its tangent is equal to the original angle as shown in Figure 1. Given α a constant angle, r a radius, a an arbitrary constant and θ an angle from the considered point to the x-axis, the spiral equation is

$$r=ae^{\theta cot(\alpha)}. \quad (5)$$

As $x=rcos(\theta)$ and $y=rsin(\theta)$, one can solve the velocity field from

$$\vec{\omega}=[\frac{\partial x}{\partial t} \quad \frac{\partial y}{\partial t}]^T. \quad (6)$$

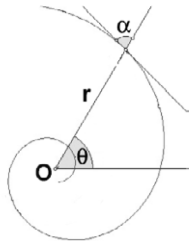

Figure 1: An equiangular spiral

Result and Analysis

Figure 2 represents a problem called aperture problem. When the object is larger than the processing window and there are no texture changes, the velocity becomes zero. Thus, the total brightness constraint method solves this by considering the whole object, instead of a window. More velocity within the vortex can be recovered but there are still some erroneous directions. When the spiral movement is added to guide the optical flow, the result seems to be satisfactory. However, smooth texture of cloud does not give clear edges, there results in error that still occur in some parts.

When the description of cloud movement is given, together with the texture description, the information will be used to find the relationship to the rainfall rate.

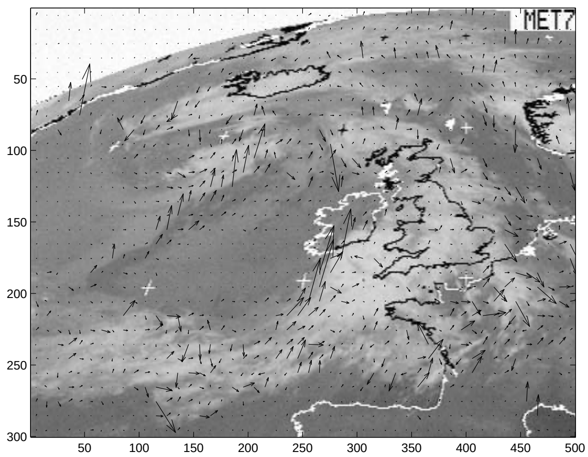

Figure 2: Motion from the original optical flow method

Conclusion

Incorporating the spiral movement equation and the toltal brightness constraint in the optical flow analysis makes a significant improvement to motion cloud analysis.

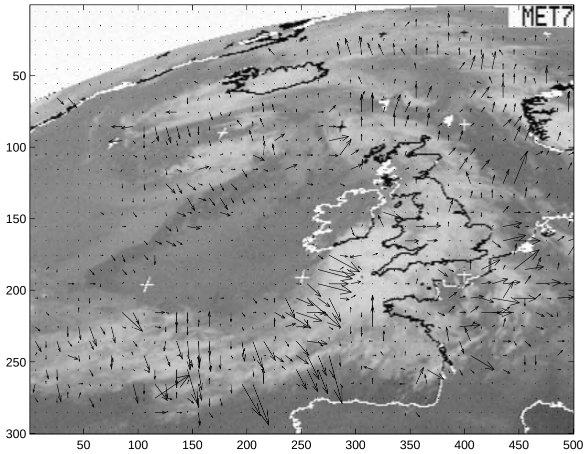

Figure 3: Motion from the total brightness constraint method

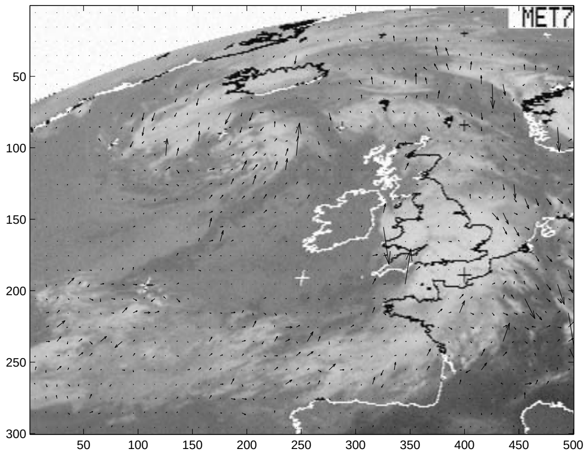

Figure 4: Total brightness and spiral movement constraint method

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