Discussion Measurement Models and Algorithms of the Wind Vector Field Based on Satellite Images

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ABSTRACT

This article aims to discuss the strike two-dimensional wind vector on geostationary satellite imageries. The magnitude and direction of the wind vector are decided by the moving speed of the clouds. First, based on the features of the cloud map, we extract the characteristics of clouds and establish matching model for the clouds image. Maximum correlation coefficient between the target modules and tracking module is obtained by using infrared brightness temperature cross-correlation coefficient method. Then, the beginning and end of the wind vector can be ascertained. Using the spherical triangles of the law of cosines, we determine the magnitude and direction of the wind vector.

Keywords: Meteorological Satellite; Cloud Motion Winds; Related Coefficient; Styling; Image Matching

1. Introduction

A variety of detection tools provide various means to obtain information for basic theoretical research. Wind vector generated due to atmospheric motion can also be obtained through a variety of detection tools. To detect wind vector in addition to the use of traditional wind vane, anemometer (such as the windmill anemometer, thermal anemometer, acoustic anemometer and laser anemometer), obtained directly, but also through other means, such as weather balloons, radars and satellites’ sounding data.

The meteorological satellite remote sensing since the 1960s is a major breakthrough for meteorological observation. The satellite imageries information it provides cannot be compared to any previous detection means on time and space continuity. The meteorological satellite imageries have played an extremely important role in the research about mastering the atmospheric circulation, medium and long-term weather forecasts and severe weather science. A method for observing atmospheric circulation is to mark wind vector on the satellite image. The magnitude and direction of the wind vector is decided by moving speed of the cloud. The wind vectors where there are no clouds or clouds unstable are defined as zero wind vectors. Defined by the movement of the clouds, the wind vector is called cloud track wind. The meteorological department already has some methods to computing cloud track wind based on the changes of the satellite cloud. Such method is also called cloud motion wind. Izawa and Fujita [1], Hubert and Whitney [2] took advantage of movie animation technology to intuitive judgment the movement of clouds by the visible screen, resulting in the cloud motion wind vector. This manual identification method is obvious anthropogenic factors greatly, not very accurate, time-consuming and labor-intensive. End lich [3] and Wolf [4], using pattern recognition techniques respectively, calculate cloud track wind according to find some characteristic quantities of the clouds. Leese [5] and Smith [6] use infrared brightness temperature cross-correlation coefficient method to cloud track wind.

The main purpose of this paper is as follows: At first, obtain Infra-red satellite wind image by using the geostationary meteorological satellite. Then, according to the adjacent times image data and its characteristics obtained by the infra-red satellite wind image, establish measurement models and algorithms to describe the actual wind vector field as accurately as possible.

Determine a two-dimensional wind vector need four indicators: The latitude and longitude of the starting point and direction of the wind vector (unit: mass angle from clockwise direction of true north) and size (unit: m/s). This article gets the two-dimensional gray-scale matrix data obtained by the geostationary meteorological satel-
In this article, we extract cloud mass in accordance with $16 \times 16$ pixels for a region. When the mean of the gray values of the selected area is greater than the threshold, we think there are clouds and we can calculate the wind vectors continue. However, when the mean of the gray values of the selected area is less than the selected threshold, we can treat this area as cloudless regions. Consider this place as zero wind vectors area.

When all the clouds are extracted, the next step is to match clouds.

3. The Cloud Image’ Module Matching

3.1. Correlation Coefficient

In the tracer cloud object module’s tracing algorithm of the ventilation system, which module identification factor is of ten used is the correlation coefficient between the target module and the tracking module, and satisfactory results has been achieved. According to the research of Wang Zhenhui et al. [12], this paper utilizes the correlation coefficient $OC$ of the original dot pitch to achieve the module matching, which is defined as follows:

$$
OC(I, J, M, N) = \frac{\sum_{i,j} S_0(i,j)S_1(i,j)}{\sqrt{\sum_{i,j} S_0(i,j)^2 \sum_{i,j} S_1(i,j)^2}}
$$

(2)

In the expression, $S_0$ and $S_1$ respectively mean pixel intensity matrix which come from two different modules to be compared. And $OC(I, J, M, N)$ is the correlation coefficient of the original dot pitch between $S_0$ whose reference position is $(I, J)$ and $S_1$ whose reference position is $(M, N)$. Use $OC(I, J, M, N)$ as recognition factor in the producing process of the wind vectors. In addition, we can use it as a control condition in the quality control of the wind vector to make the wind vector in a higher reliability on the continuity and uniqueness when we conduct the multiple-factor general editing for the generated cloud motion wind.

3.2. Matching Algorithm

In this case, we set the Matching window of the Pixel block size to $16 \times 16$ pixels and the search range is limited to $64 \times 64$ pixels. The steps are as follows:

1) Take two consecutive geostationary satellite cloud images, interval between 0.5 h to 1 h.

2) We determine a sampling point $A$ in wind vector field of the first cloud map. The point $A$ is the starting position for the wind vector. Then we can get a sample module $T$ it is a $16 \times 16$ pixels module with $A$ as the center (Figure 1).

3) Find the probed area $S$ it is a $64 \times 64$ pixels module with $A$ as the center in the second cloud image.

4) In the second cloud image, scan the target template $T$ over the probed area $S$, pixel by pixel. Calculate the
correlation coefficient $OC$ once $T$ moves one pixel. So we need to calculate a total of $64 \times 64$ correlation coefficients. It indicates that the similarity of those two areas is the largest when the value of $OC$ is the maximum of all. Therefore, we choose the position as the ending of the vector where $OC$ is the maximum in the second image. By now, the position of a wind vector is determined (Figure 2).

5) Match as described above for the next sampling point until the end of the matching.

We can use the MATLAB software for the specific operation.

4. Wind Vectors’ Calculation

Determining a two-dimensional vector requires four indicators: The latitude, longitude of the starting point, direction (unit: measured angle from true north clockwise) of the wind vector and size. After the above module match, we have come to the beginning and end of the wind vector. Next, we have to calculate the size and direction of the wind vector. Set the initial position of the tracer cloud as $A$ and the end position as $B$. Point $A$ and $B$ is marked on the sphere (Figure 3). Because points $A$, $B$, and vertex $C$ compose a spherical triangle, so we can seek the magnitude and direction of the wind vector in accordance with the law of cosines of the spherical triangles.

Spherical triangles of the law of cosines [13]: Any side of the spherical triangle cosine equal to the other on both sides of the cosine of the product of plus this on both sides of the sine and cosine of the angle even multiplied.

Calculated as follows:

First of all, the row and column coordinates of $A$, $B$ can be converted into Latitude and longitude coordinates through the conversion of visual field coordinates and the ground coordinates. It was made a detailed description in reference [9] (see Figure 4).

As shown above: Infrared detector is located at $S$. And $P$ is an arbitrary sampling point on the Earth. $Q(I, J)$ is sub-satellite point coordinates. $OQ = a$ and $ON = b$ are the semi-major and semi-minor axes of the ellipsoid. We can obtain the conversion Formula (3).

\[
\begin{align*}
\varphi &= \arctan \left( \frac{c - a^2 d + a \sqrt{a^2 d - dc^2 + 1}}{a^2 d + 1} \right) \\
\lambda &= \lambda_0 + \arctan \left( \frac{m \left( c - a \sqrt{a^2 d - dc^2 + 1} \right)}{a^2 c d + \sqrt{a^2 d - dc^2 + 1}} \right)
\end{align*}
\]
where
\[ m = \tan \left( (I - i)\alpha \right), \quad n = \tan \left( (J - j)\beta \right) \], \quad d = \frac{m^2}{a^2} + \frac{n^2}{b^2}.

So we can get that the longitude and latitude of the point \( A \) are \( \lambda_1 \) and \( \phi_1 \), and the longitude and latitude of the point \( B \) are \( \lambda_2 \) and \( \phi_2 \).

We can see the earth as a uniform sphere. Earth’s radius is \( R \). So in the Spherical triangle \( ACB \), according to the law of cosines we have:

\[
\begin{align*}
\cos \angle AOB &= \sin \angle COA \sin \angle COB \cos \angle EOJ \\
&\quad + \cos \angle COA \cos \angle COB \\
\cos \angle COB &= \sin \angle COA \sin \angle AOB \cos \angle MAN \\
&\quad + \cos \angle COA \cos \angle AOB
\end{align*}
\]

Equator

And considering
\[ \theta = \angle AOB, \quad \angle COA = 90^\circ - \phi_1, \quad \angle COB = 90^\circ - \phi_2, \]
\[ \angle EOJ = \lambda_2 - \lambda_1, \quad \angle MAN = \angle A \]

Then we can get
\[
\begin{align*}
\cos \theta &= \sin(90^\circ - \phi_1) \sin(90^\circ - \phi_2) \cos(\lambda_2 - \lambda_1) \\
&\quad + \cos(90^\circ - \phi_1) \cos(90^\circ - \phi_2) + \\
&\quad \cos(90^\circ - \phi_2) = \sin \theta \sin(90^\circ - \phi_1) \cos A \\
&\quad + \cos \theta \cos(90^\circ - \phi_1)
\end{align*}
\]

This is equivalent to
\[
\begin{align*}
\theta &= \cos^{-1} \left[ \sin \phi_1 \sin \phi_2 + \cos \phi_1 \cos \phi_2 \cos(\lambda_2 - \lambda_1) \right] \\
A &= \cos^{-1} \left[ \frac{\sin \phi_2 - \cos \theta \sin \phi_1}{\sin \theta \cos \phi_1} \right]
\end{align*}
\]

In addition, \( AB = R\theta \), wind speed for the wind vector can be obtained as
\[ FS = \frac{R\theta}{\Delta t} \]

Among them, \( \Delta t \) is the time difference through the point \( A \) to the point \( B \).

And wind direction is
\[ \begin{cases} 
A, & \lambda_2 > \lambda_1 \\
360^\circ - A, & \lambda_2 < \lambda_1 
\end{cases} \]
As can be seen from the above clear that it basically draw the wind vector at the nonzero wind vector area and the directions of the arrows roughly agree with the clouds moving trend. About the size of the wind speed, for instance, the wind speeds of typhoon located at the lower right corner are around 20 (m/s). It is generally consistent with the weather of the time.

6. Conclusion

Cloud motion wind map reflects the strength and direction of wind very well. It can be generalized as the important reference for the long-term weather forecasts in meteorology. It is also playing an important role on mastery atmospheric circulation and indicating disastrous weather. This article has completely described the whole process of calculating cloud motion wind by the use of the theory of analytic geometry and MATLAB computing software. The method is simple, fast, and easy to operate and promote. Using relevant meteorological data, we present intuitive and basically consistent with the actual cloud motion wind map. However, the window size of the clouds this algorithm selected is limited to 16 × 16 pixels. And the search scope is limited to 64 × 64 pixels. But in practical application, fixed window size and search scope do not completely extract the feature information of images. Missing information reduce the quality of the pixel block matching. Therefore, it has limitations. In order to improve the quality of the pixel block matching, we can consider abolishing the limited window size and search scope. Design the effective method which can adaptively determine the window size and the search range. Because errors exist in both the cloud map matching process and the cloud motion wind calculating process, how to reduce these errors and make the accuracy of the results to a further improvement and enhancement is our work that we need to continue research.

REFERENCES