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On Tracking of Cloud and Cyclone using Satellite Images

A dissertation submitted in partial fulfilment of the requirements for the Master of Technology (Computer Science) degree of the Indian Statistical Institute

by

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Certificate Of Approval

This is to certify that the dissertation work entitled "On Tracking of Cloud and Cyclone using Satellite Images" submitted by Sandip Debnath , in partial fulfilment of the requirements for M.Tech in *Computer Science* degree of the *Indian Statistical Institute* is an acceptable work for the award of the degree.

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Dipti Prasad Mukherjee.

Abstract

Study of cloud tracking is an important part of routine numerical weather analysis study. In this paper we present an algorithm to track clouds in INSAT image sequence. Given a pair of sequence images taken at half hourly time interval the objective of cloud tracking is to derive the path of movement of a cloud contour in the first image to the corresponding contour of the second image. This has direct relevance to cloud motion vector (CMV) analysis by which wind speed and direction are estimated. We have utilized an improved CMV algorithm to generate a set of initial estimates of possible cloud motion vectors. These initial estimates are filtered through a shape based approach. The contour of cloud mass is modelled as a perfectly flexible string. Following the proposed string based model, the cloud contour of first image is deformed for every possible CMV direction. The CMV direction for which the deformed contour best matches the second contour gives the optimum path of cloud movement from first to second image.

Tropical cyclone intensity analysis using satellite images has got a good step-by-step method after the work by Vernon F DVorak of Satellite Applications Laboratory of USA. The shape of cyclone has typical characteristics and their corresponding gradation numbers that it needs detailed study of those numbers to track its future course. Today it is widely used in the NOAA (National Ocean and Atmospheric Administration) and NESDIS (National Environmental Satellite Data and Information System) of USA and abroad also. In this thesis we have tried to implement a user-friendly software package using the proposed method. The aim of the software package is to assist experienced users iterate easily through the cyclone monitoring steps. The image processing utilities incorporated in the package will help an experienced user to analyze the different stages of cyclone development.

Chapter 1

Introduction

This thesis investigates the problem of tracking of cloud and cyclone in a sequence of geostationary satellite images. It presents image processing to enhance the quality and quantity of cloud motion vectors using geostationary imageries. This is both for regular operational purpose and also for cyclonic disturbances. The specific objectives are:

- To identify and track cloud tracers for improved wind estimation.
- To develop a software package to monitor stages of development and path of cyclonic disturbances.

Study of spatio temporal life cycle of meteorological structures is an important part of routine synoptic scale weather analysis and study. By spatio-temporal life cycle of cloud, we mean the generation, dissipation and assimilation of clouds seen in a sequence of geostationary satellite pictures. Cloud Motion Vector (CMV)s are detected in geostationary satellite (e.g., INSAT, GMS) images and they provide wind speed and direction at given lat-long coordinates. Detection of wind speed is the major objective of tracking of cloud. Tracer clouds whose shapes are utilized in sequence images in order to determine CMV. From the *computer vision* point of view, this tracking of cloud images may be considered as the study of *deformable shape*. In day-to-day numerical weather predictions, *tracer* clouds are taken as candidate for cloud tracking and subsequent wind speed estimation analysis. The major characteristic of tracer cloud is that it has comparatively higher "form" or shape stability over at least the period of observation. This period, as mentioned earlier, is typically 30 minutes.

The second part is to track the cyclone. The tracking of cyclone needs detailed study of each of its shape and brightness characteristics and the study of the corresponding gradation numbers. So the second problem is to study the cyclone charactristics through the gradation numbers over a sequence of satellite imageries of development of a particular cyclone. Tropical cyclone intensity analysis using satellite images has got a good step-by-step method after the work by Vernon F DVorak of Satellite Applications Laboratory of USA [3,4,5]. He had undertaken a detailed analysis of cyclone characteristics. His approach relies at different stages of its development. It has got superb potential to be implemented as a software package. Here we have used his method to implement a user friendly software to help the meteorologists in forecasting the maturity and path of cyclones. about the cyclone.

1.1 Related works

The process of CMV detection dates back to early seventies [19,29,12] followed by implementations in the India Meteorological Department [14,15] in late eighties. Even recently, there are extensions and quality control initiatives of CMV studies not only with cloud images but also with images from satellites equipped with water vapour channels [22,20]. The crux of such approaches has following major steps:

- The cloud mass whose displacement is detected in subsequent image frames is selected by the meteorologists. This is mainly an expert dependent process. As mentioned earlier, such a cloud mass is called as tracer cloud.
- The source image s and destination image d are registered to same scale (as they are taken from a single geo-stationary satellite over a time interval). For every given $m \times m$ (typically, 15×15 pixels) subimage c_s of the tracer cloud in image s, an $n \times n$ search window w_d is selected in d. Note that the centre coordinates of c_s and w_d are

identical as s and d are registered to the same scale. Typically, the dimension of n is 37 for low clouds whereas 61 in case of medium or high clouds.

- Given c_s and w_d, the problem of detection of CMV is to find out the best correlation measure between c_s and any one of $m \times m$ subimage within w_d. The vector originating from the centre coordinate of c_s to the centre of best matched $m \times m$ subimage of w_d gives the CMV. The process is explained in figure 1.1.
- The correlation measures are some sort of similarity measure between time varying subimages. From that stand point, the method is also known as (*intensity*) *gradient based* approach and the similarity measures are classified as:
  - Maximum cross-correlation measure (MCC) [30]
  - Sum of Absolute value difference measure (SAVD) [14,32]
  - Sum of squared difference measure (SSD) [33]

Kelkar and Khanna [14] claimed that the sum of absolute difference between corresponding pixels of c_s and 15×15 subimage of w_d ($\sum_0^{224} |x - y|$, x is a pixel of c_s and y is the corresponding pixel of 15×15 subimage of w_d) is a good and computationally attractive yardstick compared to cross-correlation measure $((\overline{xy}/\sigma_x\sigma_y) - (\sum xy/N\sigma_x\sigma_y)$, $N = 225)$ originally proposed in [19]. We are not going into the details of different correlation based approaches. Interested readers can refer to any of the references mentioned above for details and justification (from meteorological point of view) of selection of several parameters mentioned above.

The correlation based approaches are by and large adopted by different operational agencies [23,24] for routine numerical weather prediction. The major reason is computational simplicity. Also, such CMV detection is always subjected to quality control by expert meteorologists where the inconsistent CMVs are removed manually. However, as expected this process has severe limitation. The prime bottleneck is that in a dynamic situation of meteorological nature the correlation surface between the source subimage c_s and the candidate subimage within w_d is typically multimodal and unimodal only in very special cases. Such a matching technique also has an implicit assumption of rigidity in form of the cloud mass. However, in actuality of the cases, the cloud not only get translated, rotated, sheared but also deformed in temporal scale. Such problems could be eliminated

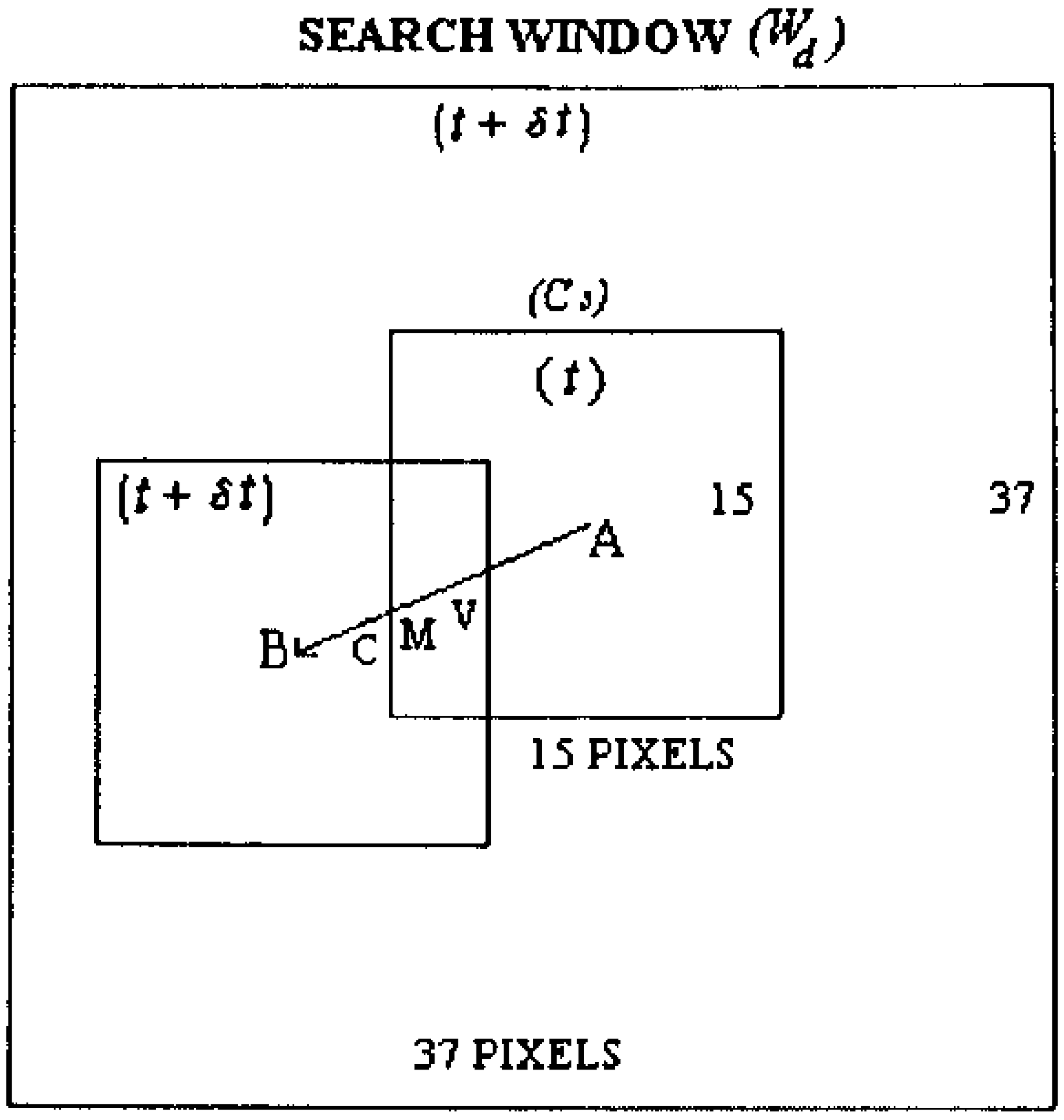


Figure 1.1: The schematic for CMV detection process.

to a large extent if images could be acquired at very high temporal rate. Unfortunately, for practical operational constraints, frame grabbing at such an increased speed is not possible (except during severe cyclonic disturbances).

To improve this aspect, various quality control initiatives [27] of CMV detection are being undertaken. There are energy based approaches, specifically gabor energy filters [25,26] to extract motion information. The major limitations in such cases being the requirement of large number of sequence images at shorter intervals. Also there are several feature based approaches [28] which primarily focuses on invariant features in time varying images; but most cases an implicit assumption of shape rigidity is ensured. In a different context, an excellent review of shape from motion is provided by Aggarwal and Nandhakumar [7]; however, even though it surveys a number of gradient based approaches, the issue of shape deformability is not addressed is detail.

We discuss a hybrid approach proposed by Wu [1] as it has relevance to our work. This hybrid approach improves the correlation estimates after incorporating a relaxation labelling algorithm [21]. For a $p \times p$ subimage of s, his model is given by:

$$f(x, y) = a.g(x, y; u, v) + m + n, \qquad 1 \leq x, y \leq p \tag{1.1}$$

where $f(x,y)$ is basically the c_s mentioned earlier and $g(x,y;u,v)$ is the (u,v) shifted version of $f(x,y)$ within the search space w_d. The factor a is a scale factor considering the change in image contrast in δt time, m is a mean bias in modelling intensity and n is a typical zero-mean gaussian noise. He has derived that the similarity measure between c_s and the candidate in w_d depend on a factor $i(u,v)$:

$$i(u,v) = \sum\sum((f(x,y) - \bar{f}) - (g(x,y;u,v) - \bar{g}(u,v)))^2 \tag{1.2}$$

Interested reader can refer to [1] for detail derivation. For every point of interest in image s and corresponding w_d, he detects a set of CMVs. Each of such CMVs is associated with a probability value which is the similarity or normalized correlation measure between $f(x,y)$ and $g(x,y;u,v)$. CMVs with correlation measure less than a threshold is rejected outright. However, the major contribution of his approach is in updating this probability values in a iterative process where consistency between two neighbouring vector directions is utilized. The iterative process follows the relaxation labelling algorithm described by Rosenfeld and Kak [21]. Since, neighbouring CMV direction consistency has been taken care in this algorithm, he has got attractive result even in case of cyclonic storms where shape stability is very poor.

The deficiency of extending this algorithm in cloud tracking is that it does not incorporate any shape based features. The fragmented cloud regions of interest in case of his experiment [1] is of few pixel wide. Note that typically, for geostationary satellites like INSAT, each pixel resolution represents 2-8 Km in earth (depending on Visible or IR band). The assumption of CMV directional consistency over such a small region of fragmented cloud cover is well tenable. However, such a directional consistency over a relatively large cloud tracer, which is used in routine day-to-day cloud tracking operations, may not be a safe assumption. Moreover, for a large cloud tracer, because of shape deformation, even though the deformation is marginal, can result in *false correspondence* between images s and d.

Given this, in our proposed cloud tracking algorithm [2], we have implemented a variation of the correlation measure of Wu [1] to generate an initial estimate of motion of contour of tracer cloud. Subsequent to this, we present a shape based matching criterion between the parts of contour of source and that of destination tracer cloud. In this context let us review the existing cloud tracking approach which has direct relevance to our algorithm. But before that, we explore how the problem of deformable shape is tackled in similar cases. Obviously, our objective is not to address the whole lot of literatures which deal with deformable shape in a set of sequence image, but to discuss only relevant ones pertaining to our work. Interested readers can refer to chapter 2 for details.

The first methods developed for the purpose of tracking cyclones were used operationally in the early 1960's when only one satellite picture a day of a tropical cyclone was available for the analysis [6,40]. At that time the intensity estimation was made from the appearance of a storms eye, its banding , and the size of tropical storms in most cases, but they had serious shortcomings when the cloud pattern of a storm was either unclear or when it was undergoing extreme short-period change. The next important work in this field was by Arnold [41]. He has estimated convective cloudiness between stages of tropical cyclone development. The different stages of tropical cyclone development was enumerated by Dvorak in 1985 [5]. The major contribution of Dvorak's work is to analyze the patterns generated in stages of cyclone development. He also came up with a T-number to rate the intensity of cyclone. The process of generation of T-number based on pattern analysis in geostationary satellite images were given in algorithmic fashion and is now regularly used by the meteorological departments for routine tropical cyclone study. This has made the problem suitable for computer implementation specially to use it as a tool for assistance to expert meterologists. The details of this software development process is reported in chpater 3.

1.2 The present work

As discussed earlier, the existing CMV algorithms are, in most cases, a correlation based approach. The correlation is calculated comparing the grey values of a subimage at time t and that at time $t + \delta t$. The measure of correlation is essentially a grey value similarity measure. Unfortunately, the similarity surface between the source and the target image is rarely unimodal and multimodal in most cases. Therefore, it gives rise tio ambiguity while establisghing the correspondence between the grey value structures in a sequence of satellite images. Researchers like Wu [1] and Rosenfeld [21] has modified the correlation based approach using relaxation labelling techniques. However, there is hardly any work where shape, specifically, contour based approaches are utilized to refine the correlation based approach. In our present work, we have modelled the contour of the tracer cloud of image at time t as a string. Further, the deformation of the string is taken care of at high curvature points on the contour. Our assumption is that the high curvature points are relatively stable in the process of deformation from cloud contours at t to $t + \delta t$. A family of deformation is applied on the contour of the tracer depending on initial sets of CMV derived by correlation measure. The principles of deformation is explained in chapter 2. Finally, the CMV for which the deformed contour best matches with the target contour in the $t + \delta t$ image is selected as the optimum CMV. The algorithmic steps and implementational details are given in chapter 2.

As mentioned earlier, Dvorak's algorithm to monitor and rate tropical cyclone is a fit case for computer implementation. This is to assist experienced meteorologists to go through differen stages of cyclone prediction more easily and with much more choices at a given point of time. Given this, we have implemented his algorithm in JAVA compatible to Windows95 platform. The language JAVA is selected as it is near independent of platform. Also it has the advantage of better network support comapred to any existing languages. The software is developed following object oriented design methodologies. The detail of implementation is given in chapter 3.

1.2.1 Publication

We have written a paper on cloud tracking and it is already communicated to the Indian Conference on Computer Vision, Graphics and Image Processing to be held on 21-23 December, 1998 in New Delhi, India.

Our proposed method of tracer cloud tracking is a two stage process. In the first stage, a set of initial cloud motion vectors are detected using intensity gradient based approach [1,19,14]. In the second stage these initial directional estimates are filtered using shape (contour) based approach.

Chapter 2

Cloud Motion Vector Analysis

2.1 Introduction: A Close Look at the Problem of Cloud Tracking

The specific issues associated with the problem of cloud tracking could be enumerated as follows:

- Tracer clouds are detected in a source satellite image s taken at, say, time t. As discussed earlier the tracer clouds have comparatively higher "form" or shape stability over the period of observation. Given minor deformations over a time period δt (which is typically 30 minutes), the problem is to identify the same in destination image d taken at time $t + \delta t$. The example INSAT images that are shown in this thesis is also taken at half-hourly interval.

- Establishing a point to point correspondence from the source cloud contour to the destination cloud contour. The result of tracking is then the minimum energy or cost path through which points of interest of the start contour deform to corresponding points of the destination contour.

The existing CMV algorithm is already discussed in the introduction.

- There is a whole bunch of *snake* based approach [2,13,9,17] where, in general, either an initial contour is detected or a seed contour is made to take the shape of the contour to be tracked after minimizing energy corresponding to the profile of the shape boundary.

- In a different approach [10], a set of shape invariant points or "point landmarks" are located in the boundary. These points are generally the high curvature points on the contour. It is assumed that the amount of deformation is marginal at or close to the high curvature points. This is certainly true for images of deformable biological organs [10]. In absence of any active meteorological phenomenon, high curvature points in satellite images at half-hourly rate, have higher form stability compared to the rest of the contour. We utilize this assumption while dealing with our tracking problem.

Tracking of meteorological structures namely cloud through curve matching is proposed by Cohen and Herlin [11]. They have assumed that the flow of source contour to the destination contour takes place along a minimum cost path. The source and destination areas are represented using level sets [16]. Their definition of shortest path between two points on a surface is given by the minimal geodesic. The tracking path from the source contour to the destination contour is characterized by the minimal cost path. The optimum cost path p^{opt} is defined by:

$$C(p_{X_s}^{opt}) = \min_{p_{X_s}} C(p_{X_s}) \quad \text{where} \quad C(p_{X_s}) = \int_{X_s}^{X_d} c(x,y)ds \tag{2.1}$$

p_{X_s} is the path from the source contour point X_s to matching point X_d on the destination contour. Evaluation of p^{opt} is then the minimization of a cost function $c(x,y)$. Cohen and Herlin [11] have defined this cost function as a combination of distance maps of the source and the destination contours. In this context they have mentioned that: "A more elaborate model should take into account the geometrical properties of the curve. For example, curvature information in a small neighbourhood of the source and destination areas."

2.2 The proposed algorithm

In our proposed model, we stress on the point mentioned in the last paragraph of the above section. As mentioned earlier, we utilise a variation of cross-correlation measure proposed by Wu [1] to detect a set of possible directional vectors on source contour points along which possible movement of source contour points have occurred. Then a shape based cost function is used to find the best direction out of them along which contour displacement has taken place from source to destination. It uses a combination of gradient based approach followed by filtering using shape based approach. It avoids the directional consistency assumption proposed by Wu [1] and adds on geometrical properties of the contour which is lacking in Cohen and Herlin's approach [11]. It also avoids the complex geodesic calculation as in [11].

Our proposed algorithm is outlined as follows. We start with source and destination contours, c_r and c_d respectively, of the tracer cloud. The contours of individual cloud clusters are obtained applying an active contour model, called *g-snake* as proposed by Lai and Chin [17,18]. Since border detection is not the prime objective, we avoid the detail implementation which is readily available in [17].

- A snake following algorithm coupled with split and merge of linear and curvilinear segments is applied on c_r to detect the set of control points on the contour [31]. Note that all the significant points on the contour including high curvature points will be selected as vertices of the guiding polygon. Coordinates of all the guiding polygon vertices are stored in a vertex table.

- For every entry v_i in the vertex table, a $p \times p$ mask $f(x,y)$ is considered centered around the vertex v_i. A search window w_d of radius V_m is assumed in destination image d. The centre of w_d corresponds to the coordinate of v_i of c_r. Similar to CMV detection process, a similarity measure is established for every $p \times p$ mask inside w_d with the $p \times p$ mask centered around v_i of c_r. We have used the following similarity measure given by:

$$i(u,v) = \sum\sum((f(x,y) - g(x,y;u,v))^2 \qquad (2.2)$$

This is a computationally simpler version compared to the measure in equation 1.2.

Since, the resultant direction vector is filtered through shape based matching in the next step, our emphasis is on generating as many direction vectors as possible in the shortest possible time.

Note that the similarity measure is thresholded at ρ such that all directional vectors with similarity measure less than ρ is outright rejected. The result of this step is a set of direction vectors at every vertex of the guiding polygon of c_r. This is demonstrated in Figure 2.1(a).

- For every vertex v_i of the vertex table, vertices v_{i-1} and v_{i+1} are indexed. Surface normals N_{i-1} and N_{i+1} are drawn from v_{i-1} and v_{i+1}, respectively. Normals N_{i-1} and N_{i+1} intersect the destination contour c_d at I_{i-1} and I_{i+1} respectively. Contours between v_{i-1} and v_{i+1} of c_r and I_{i-1} and I_{i+1} of c_d are considered for shape based matching. The process is shown in the schematic of figure 2.1(c). We are not assuming that the entire contour between v_{i-1} and v_{i+1} of c_r transformed to I_{i-1} and I_{i+1} of c_d; but given marginal deformation in sequence images, it is expected that there would be an overlap present between the two. We term these contour pairs as "related contours".

- At this stage, for every vertex v_i, there are n number of direction vectors D_{ij}. Following each D_{ij}, a corresponding point m_i could be detected on c_d. Let us define $p(v_i, m_j)$ is the path to be tracked between v_i (on source c_r) and m_j (on destination c_d). Even if there could be n number of such paths (as there are n number of D_{ij}), only one out of them is the correct path which needs to be established.

- Our shape based measure considers each of these paths $p(v_i, m_j)$ individually. Following each of these paths, we construct a deformed source contour between v_{i-1} to v_{i+1}. This construction is based on the qualitative assessment of curvatures between the source and the destination contour. Note that there will be n such deformed contours (as there are n number of paths $p(v_i, m_j)$). These deformed contours are compared with the destination contour between I_{i-1} and I_{i+1} for best matching. The optimum path $p(v_i, m_j)$ is the one which provides best match between the deformed source contour D_s and the destination contour c_d.

$$p^{opt}(v_i, m_j) = min_n \int (D_s|_{v_{i-1}}^{v_{i+1}} - c_d|_{I_{i-1}}^{I_{i+1}})\ dl \qquad (2.3)$$

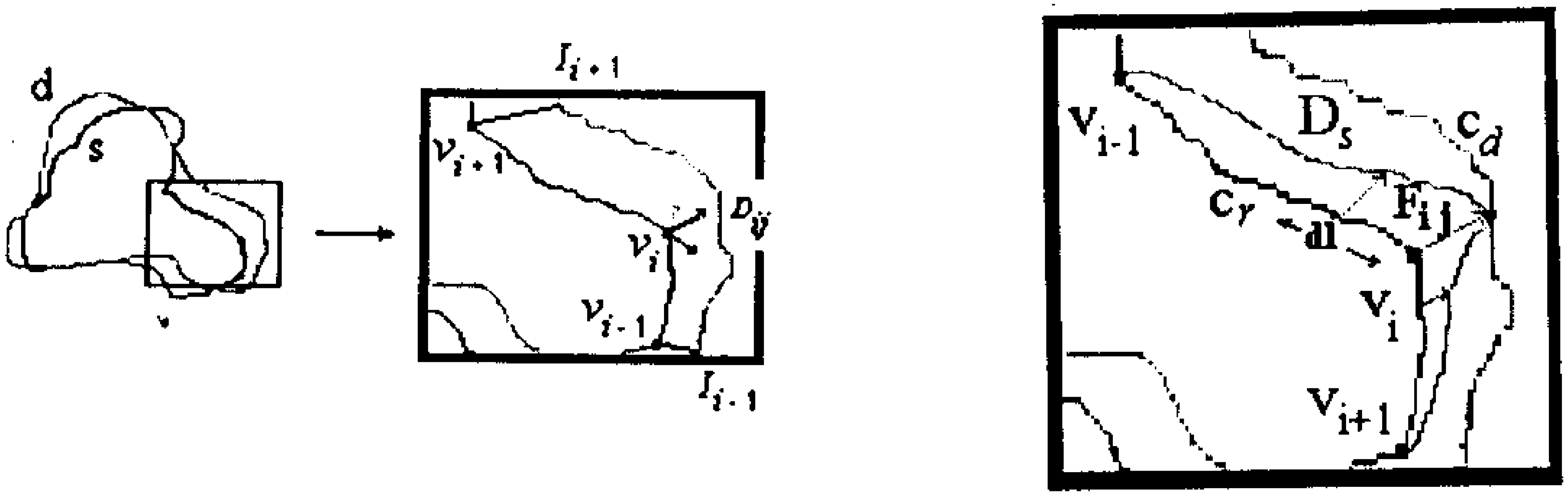
- Construction of deformed source contour: Let us consider the source contour to be a perfectly flexible string fixed at both the ends (v_{i-1} and v_{i+1} in this case). Over the period of observation δt, the displacement at v_i is known considering the corresponding point m_j at the destination contour. Therefore, the tension at the string position v_i is known for any particular direction vector D_{ij}. Let this tension be F_{ij}. At the close neighbourhood of v_i, the tension in the string is calculated based on the value of F_{ij}. In absence of any other force system, the effect of F_{ij} should decrease as we move away from v_i. However, we either decrease or increase the tension at the neighbourhood comparing curvatures between corresponding parts of related contours. Refer to figure 2.1(b). For a neighbourhood dl (along arclength) around v_i, the derived tension of the string at $(v_i + \delta l)$, $F_{v_i+\delta l}$, is given by:

$$\begin{aligned} \text{for } (\kappa_s - \kappa_d)\,|_{dl} = 0, \quad F_{v_i+\delta l} &= F_{ij} \\ (\kappa_s - \kappa_d)\,|_{dl} < 0, \quad F_{v_i+\delta l} &= F_{ij}(1 + \Delta\kappa) \\ (\kappa_s - \kappa_d)\,|_{dl} > 0, \quad F_{v_i+\delta l} &= F_{ij}(1 - \Delta\kappa) \end{aligned} \tag{2.4}$$

κ_s and κ_d stand for curvatures of the source and destination contours along arclength dl. The weight $\Delta\kappa$ is to boost or reduce the tension in the string:

$$\Delta\kappa = \frac{1}{\nu} \left| \frac{\kappa_s - \kappa_d}{\kappa_s + \kappa_d} \right| \tag{2.5}$$

Since, the string is fixed at both ends, for every tension at v_i, there would opposing forces at v_{i-1} and v_{i+1}. Factor ν, the damping coefficient, should take care of this. From the derived force at $(v_i + \delta l)$, the displacement at $(v_i + \delta l)$ is calculated parallel to the tension F_{ij} at v_i. The process is repeated for all "snakexels" to cover the entire arclength between v_{i-1} and v_{i+1} to construct the deformed source contour.



(a) (b)

Figure 2.1: (a)The source and destination contours s and d are shown along with vertices. The possible directional vectors D_{ij} are shown on the vertex v_i. (b) Construction of deformed source contour D_s is shown in between the source and the destination contour.

2.3 Experimental Results

The proposed method is tested on a number of image sequences of INSAT and GMS. Three sets of result are presented in this section. Tracer cloud images are taken from INSAT 1D at 05:00 and 05:30 GMT. Figure 2.2 and 2.3. and figure 2.4 and 2.5 are the corresponding source and destination (IR) image pairs respectively. These images are registered to same scale and cropped out from full disk images of earth. Snakes fitted to regions of interest on tracer clouds of source images are shown along with significant points in figure 2.6 and 2.7. Result after initial estimates of cloud motion vectors following equation 2.2 is shown in figure 2.8 and 2.9. Note that the size of candidate subimage in source is taken as 15×15 pixels while the window size in destination image is taken as 37×37 pixels (V_m of w_d). For clarity of display, all direction vectors with correlation value less than 0.8 are discarded The multiple direction vectors at the vertices justify the multimodal nature of correlation surface between the source subimage and destination search window. Clearly some of these directions are not conforming to the possible movement of the cloud mass.

The optimum path $p(v_i, m_j)$ corresponding to best match between the destination contour and deformed source contour sets are shown in figure 2.10 and 2.11. To calculate deformed contour, comparison of curvatures between related contours is performed on every 5-pixels long arclength (dl). The tension is calculated at every third pixel (δl) of dl

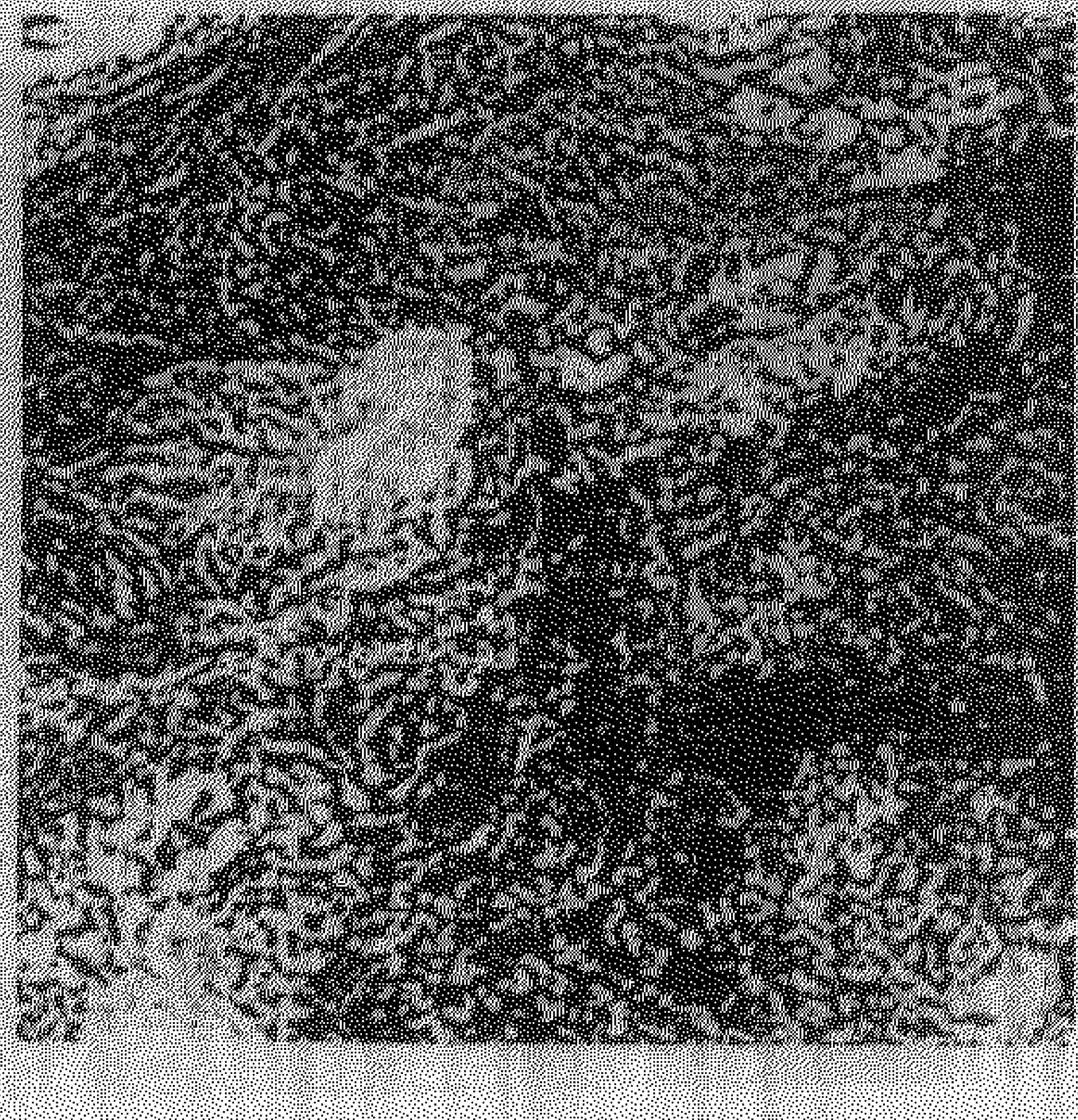


Figure 2.2: The first source (IR) image of INSAT 1D (200×200 pixels) cropped out from the full disk image of earth (1024×1024 pixels).

within the span of v_{i-1} and v_{i+1}. For this set of result, the damping coefficient ν is taken as 0.5. The matching between deformed source contour and the destination contour is based on the sum of squared Eucledean distance between sampled (every third) points on related contours. These points are taken starting from v_i and m_j of source and destinaton contours respectively and moving along both directions of the curve.

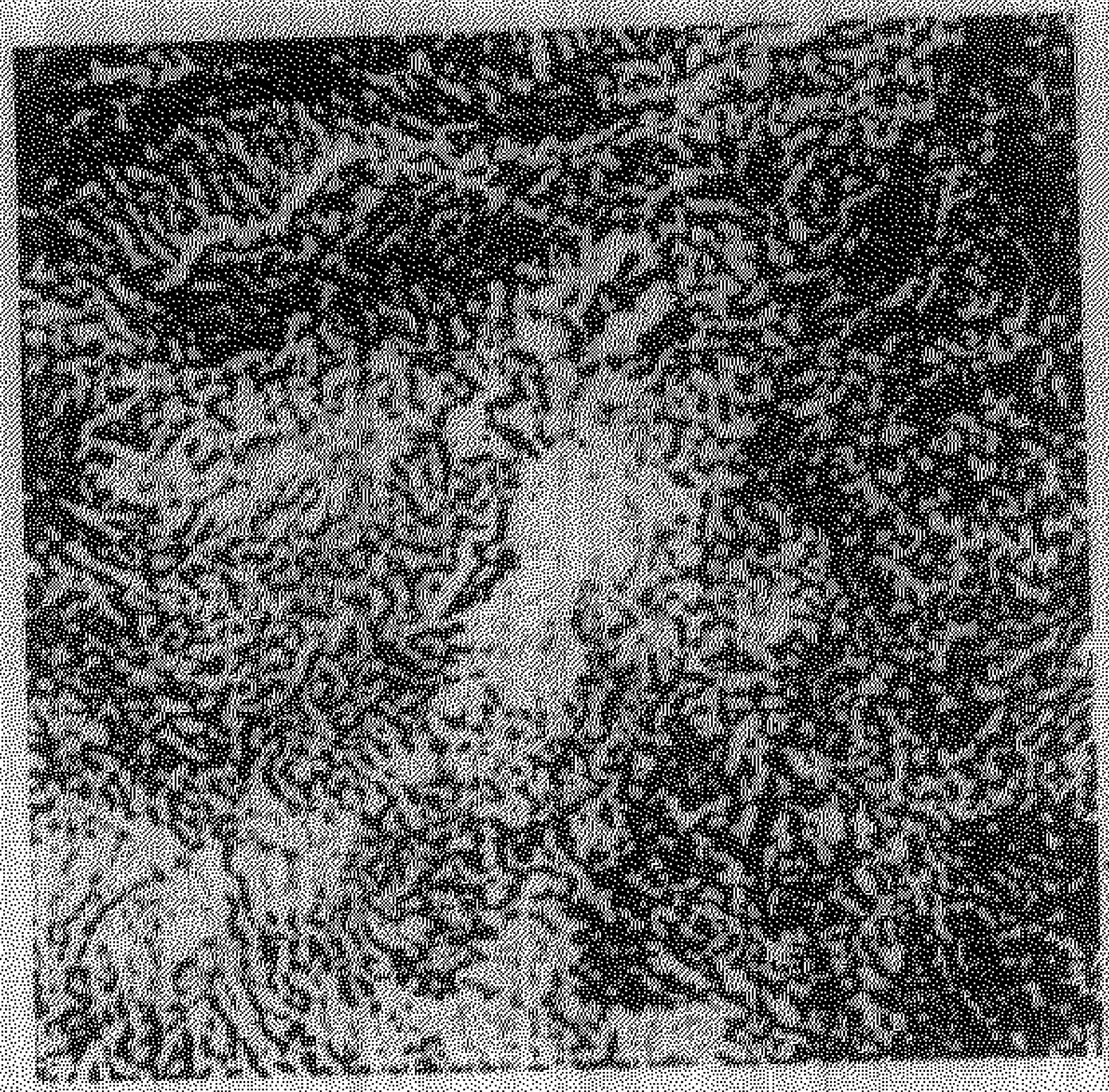


Figure 2.3: The second source (IR) image of INSAT 1D (200 × 200 pixels) cropped out from the full disk image of earth (1024 × 1024 pixels).

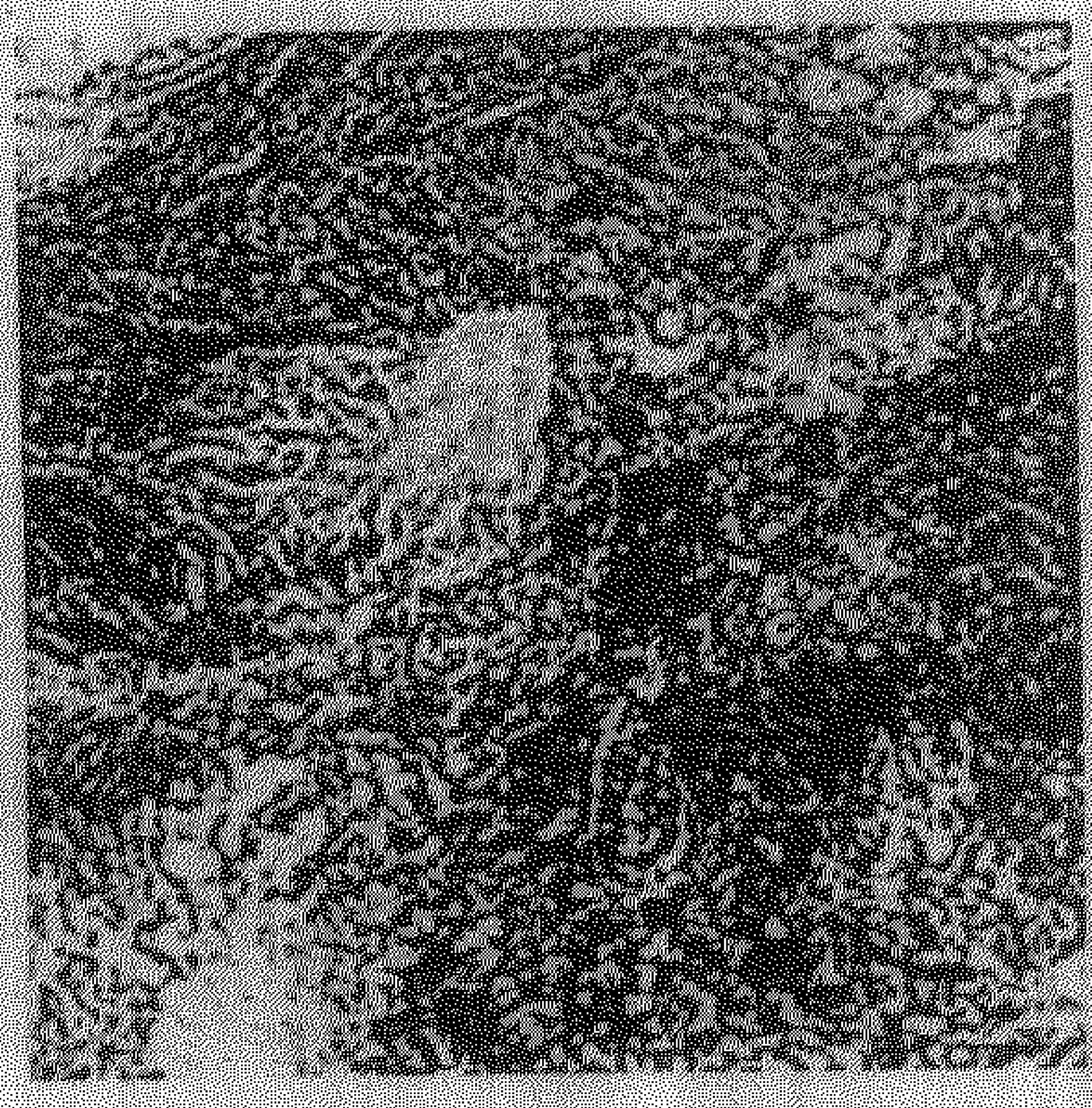


Figure 2.4: The first destination (IR) image corresponding to source image of figure 2.2 is shown.

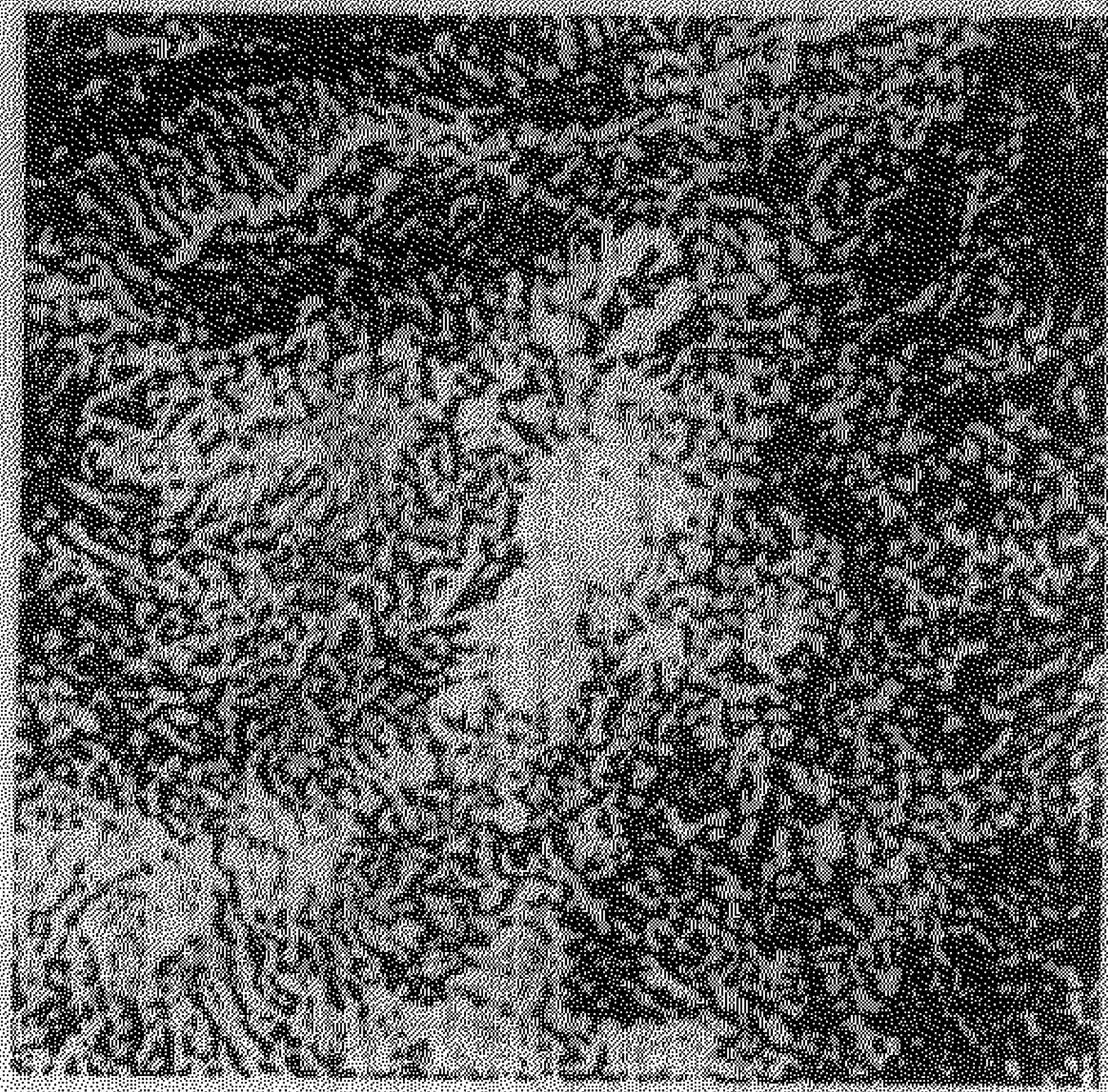


Figure 2.5: The second destination (IR) image corresponding to source image of figure 2.3 is shown.

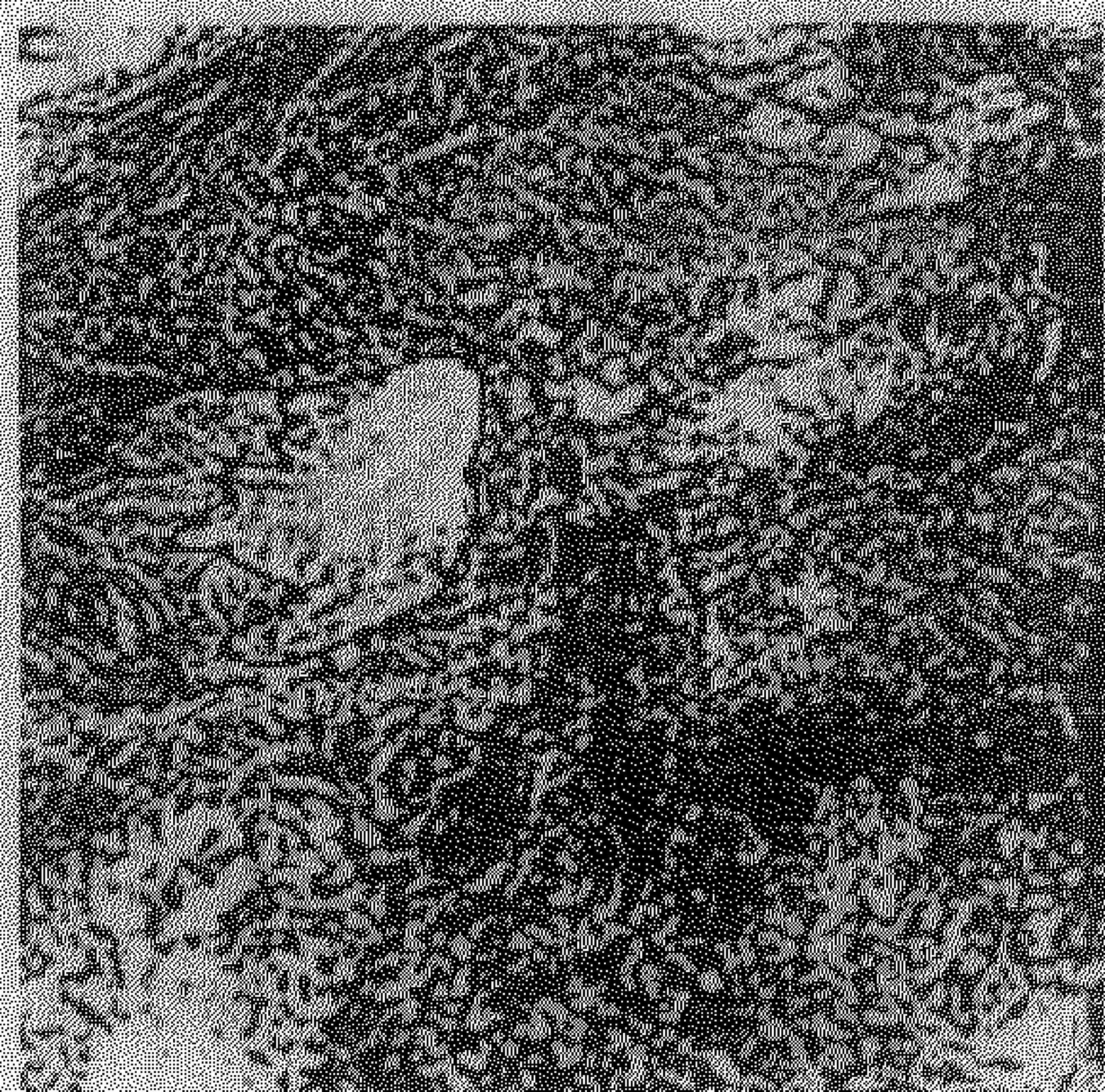


Figure 2.6: Snake fitted to regions of interest in tracer cloud of figure 2.2 is shown. The black square boxes represent significant points on the snake.

Figure 2.7: Snake fitted to regions of interest in tracer cloud of figure 2.3 is shown. The black square boxes represent significant points on the snake.

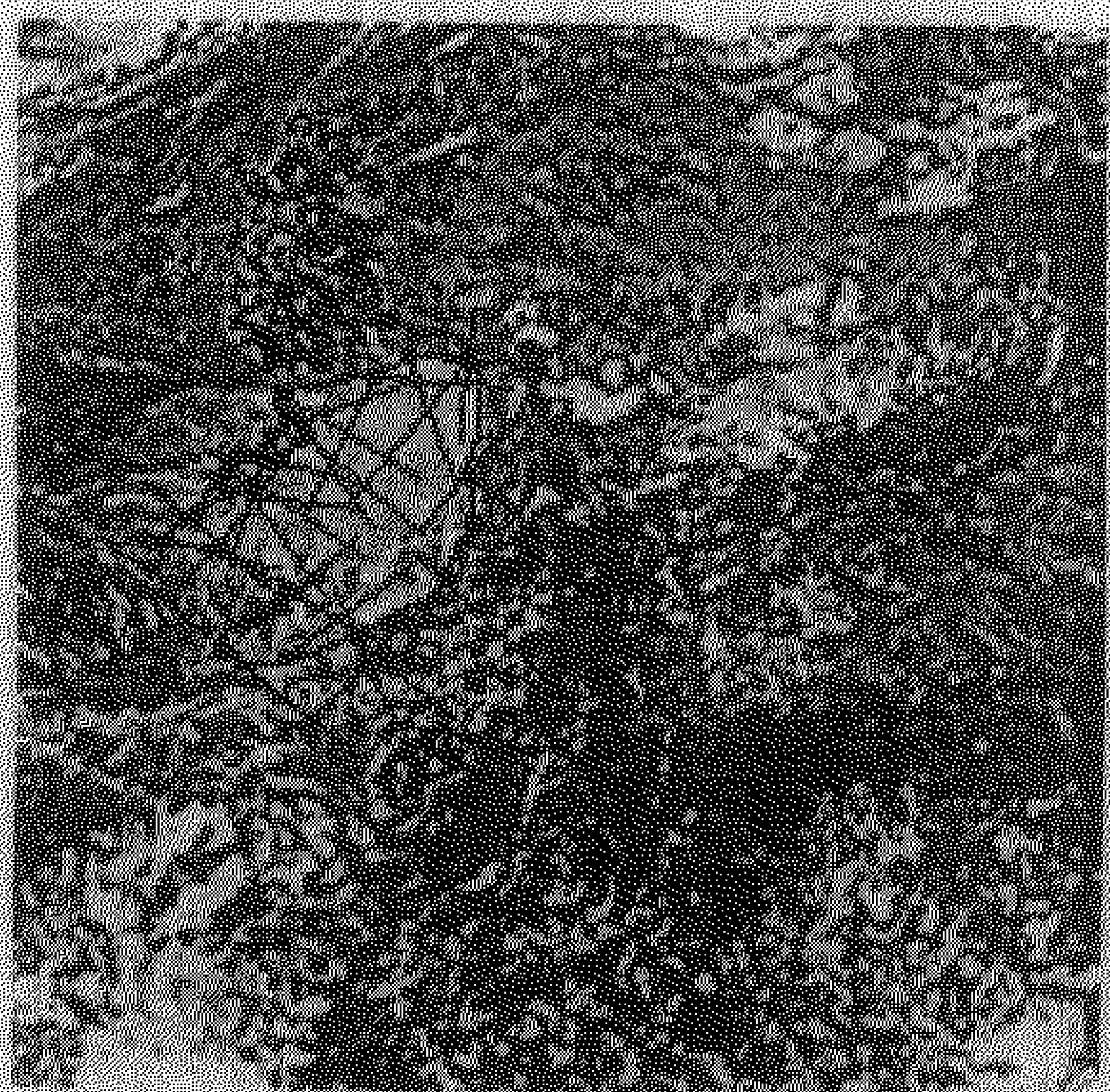


Figure 2.8: Initial estimates of cloud motion vectors are calculated on source image 2.2 following equation 2.2. For clarity of display, all direction vectors with correlation value less than 0.8 are discarded.

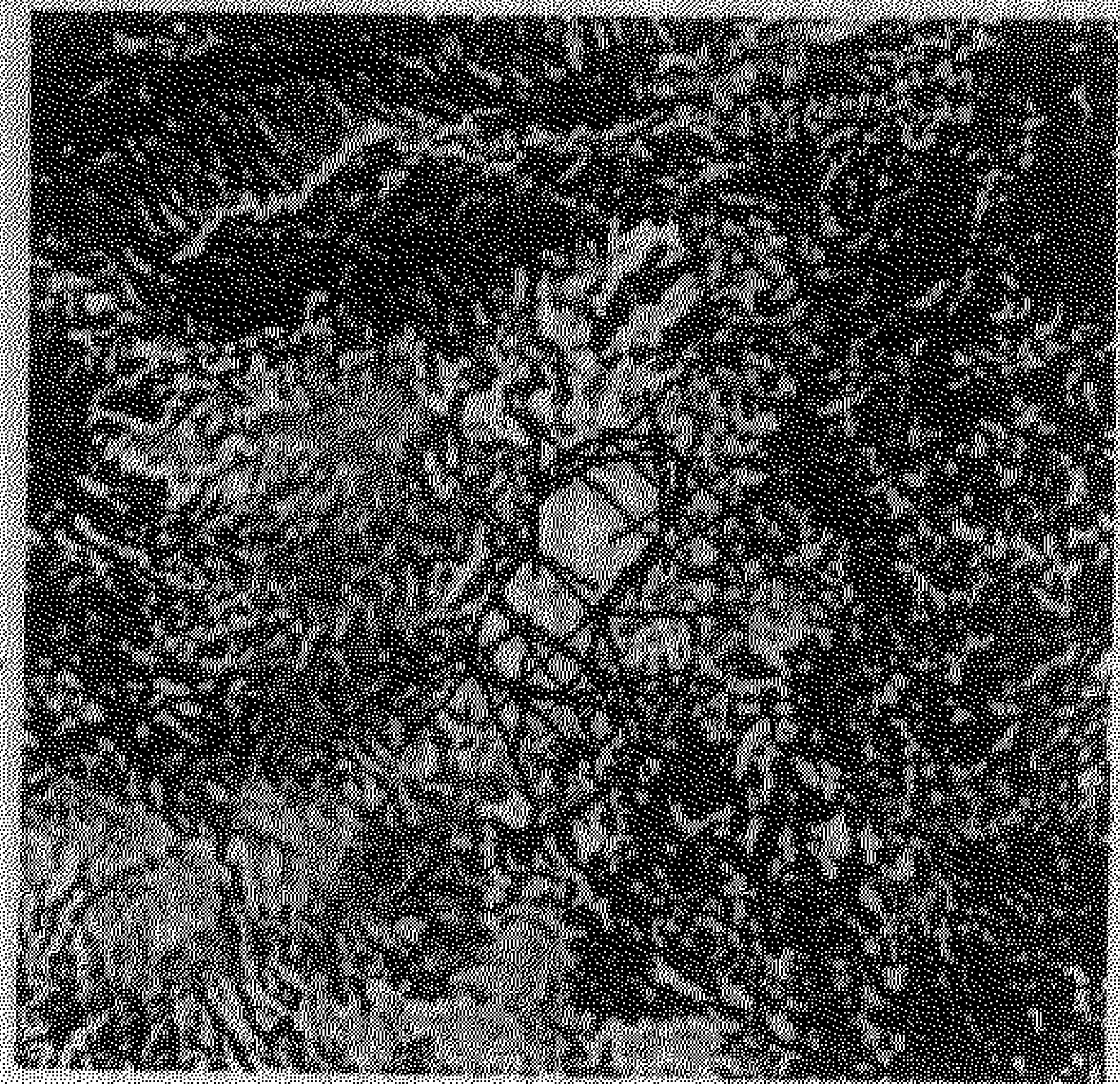


Figure 2.9: Initial estimates of cloud motion vectors are calculated on source image 2.3. For clarity of display, all direction vectors with correlation value less than 0.8 are discarded.

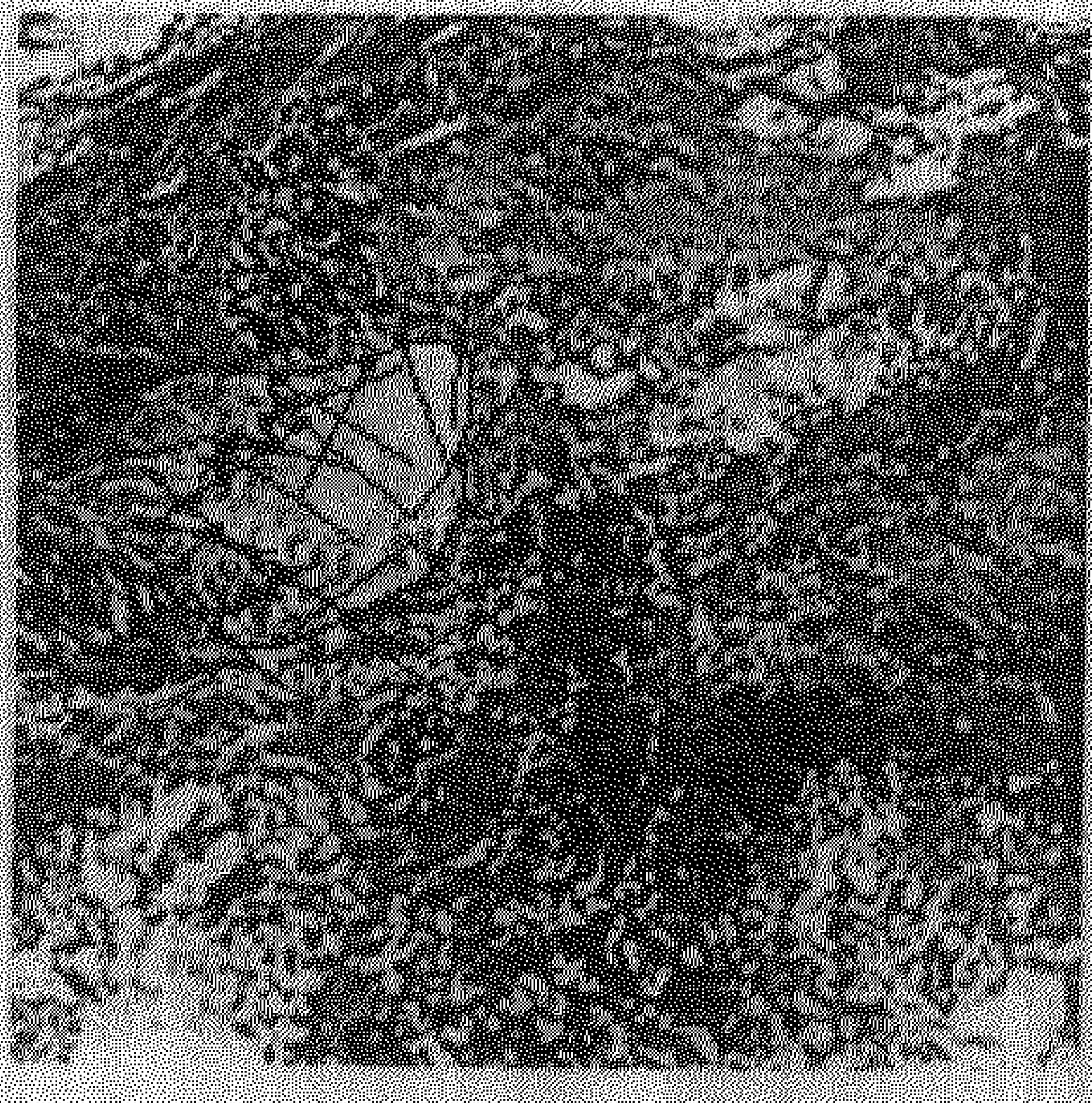


Figure 2.10: Optimum paths along which the significant points of source contour have moved are shown.

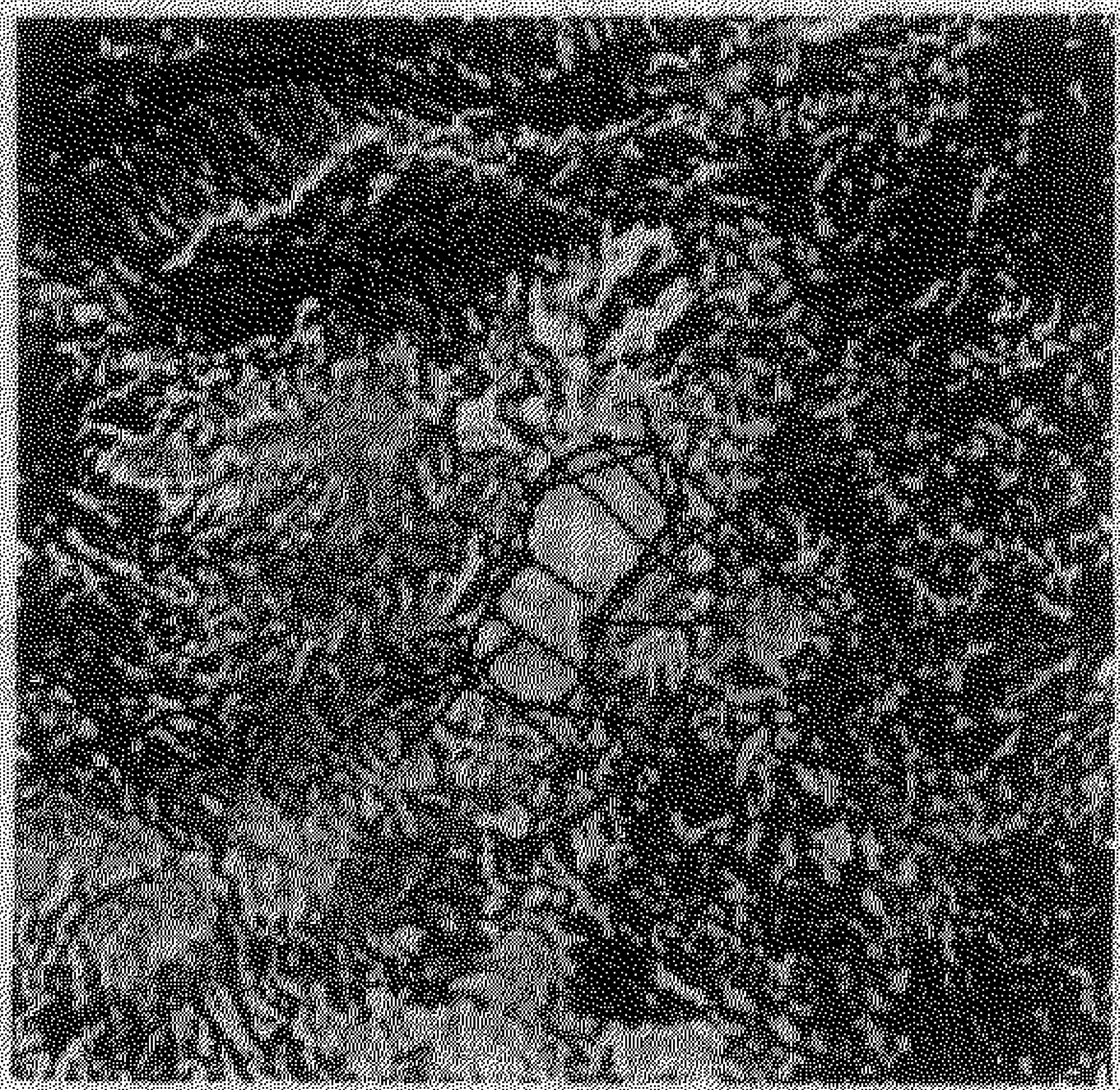


Figure 2.11: Optimum paths along which the significant points of source contour have moved are shown.

2.4 Summary

This chapter presents a combined approach of intensity and shape based methods in tracking meteorological structures. This certainly has an edge over either the gradient or the shape based approach applied individually. The algorithms developed in this chapter have given attractive result. Possibilities of extending the scope of present algorithm is discussed in chapter 4. In the next chapter, software to track and monitor the stages of cyclone development is discussed.

Chapter 3

The Software for Cyclone Monitoring

3.1 The Empirical Method of Vernon F Dvorak, 1975

The empirical method of Vernon F Dvorak [3,4,5] is a step by step method to characterize a cyclone by matching its pattern with some standard pattern generally seen in the cyclogeneration process. After matching with the existing patterns the method suggests to impose some characteristic number. After comparing the characteristic numbers for a sequence of cyclone images for a specific cyclone we can come to a conclusion of the future course or stages of the cyclone.

The analysis procedures [5] are summarized in the following figures. The procedue consists of ten steps in which the analyst determines the intensity of a tropical cyclone.

- Locate the cloud system center.
- Analyze using standard patterns.
- Central Cold (Dense) Cover pattern.
- Determine the past 24 hour trend.
- Determine the Model Expected T Number.
- Determine pattern T Number.

- T Number determination.
- Final T Number constraints.
- Current Intensity Number determination.
- 24 hour forecast.

3.2 Software Requirment Specification (SRS)

3.2.1 Introduction

Purpose: To facilitate the cyclone intensity analysis method (which is a manual method) by giving user a GUI based environment. To help experienced users to analyze and forecast about cyclone efficently and without much error.

Scope: The software can be used in weather forecast system. And even in the time of absence of any cyclogeneration it can be used to find the motion of the cloud to find the approximate location of raining if the cloud is rain-bearing .By processing the mode or nature of the cyclone given by the user it can predict through a well-established method some characteristic numbers of the cyclone by which a experienced user can identify the amount of intensity the cyclone has and some other characteristics of the cyclone.

Definitions, Acronyms, Abbreviations: CMV: Cloud Motion Vector. Optical flow: The [dx/dt dy/dt] vector set.

Overview: The package is written in JAVA. It is written in JAVA because we wanted the package to be run machine independently. It can also be run through network. For that we have to change the application to applet form. The package provides user interface of GUI nature. Among the usual menus there are File , Edit , Help etc. Except that there are Analysis, Forecast etc menus are meant for specific processing. Other than these some pre-processing steps as sharpening, contrast stretching etc are also provided. File menu includes options as image file open, save, save as, print etc.

3.2.2 General Description

Product Functions: To aid the analysis, to aid the forecasting of cyclones by giving the experienced user the quick processing and by giving the unexperienced user help tours and guided ways to work with it.

User Characteristics: A good thing is if the user is an experienced one with the acquintance with the manual method for forecasting and analysing the cyclonme nature

. He will get good and quick reference and guide with this software. But a novice and under-experinced user can also use this software and he will get assistance which is needed for the processing.

3.2.3 Functional Requirements

Input: Here input is a sequence of satellite images of cyclones taken in regular interval from a definite place in a day or during a couple of days.Input images are not processed through any kind of pre-processing and it is just a raw data image.

Output: The output of the package is of two nature. In the analysis portion and forecasting portion the software package will come out with just a string with some characteristic number of the cyclone concerned. The string consists of T number for Tropical cyclone, Today's T number/Current Intensity number, Indication of ongoing change as PLUS/MINUS/LEAVE , past change as D/S/W , amount of past change/hours since previous observations (e.g 15/6/MINUS/W1.5/24hrs) [5].

3.2.4 External Interface Requirements

User Interface : The package is written in JAVA1.1.4 and so it is platform independent.

Hardware Interface: Any of the following.

- Intel x86 or higher.
- MIPS R4600
- SPARC Solaris (2.3 or higher)
- PowerMac or, at least, a 68030/25MHz processor with System 7

Software Interface:

- Windows95

- WindowsNT
- IRIX
- SPARC Solaris (2.3 or higher)
- Mac OS

3.2.5 Performance Requirements

Standard Windows95 system requirements are sufficient for the image loading and image displaying with the standard size of cache memory and for image processing as JAVA is a bit slow in the client side so it takes some time to process the image . Otherwise this is OK .

3.2.6 Design Constraints

The design constraints are just the same as the constraints of JAVA in the Windows95 environment . Other than that we are doing the object oriented design and so the oodesign needs the extensive experiment and removing redundancy regarding the object and it needs software redesigning ,functional refinement and object refinement . We have very short time period to cover the refinement and redesigning and so the first phase designing is here the final designing.

3.3 Design

3.3.1 Organization

The organization here is somewhat different than other packages. Here we have done the package for a sequence of satellite images and the sequence consists of different satellite images of same cyclones but taken at different time from the same satellite from the same place. Now for this job we have organize the file as follows. For a specific cyclone we will create a separate directory . The image files of different time are stored in the directory and different image files of deffrent cyclones are stored in different directory. The information about the cyclone characteristic numbers will be stored in some file.txt where the file name will be same as the image filename of the cyclone and this file will be unique for unique sequence ,i.e for a single cyclone image. Now constant updating will be needed for the .txt file and this will done through the cyclone class as the cyclone class consists of cyclone characteristic numbers as the public data. The methods needed for the cyclone class will be shown in the diagrams.

3.3.2 Class concepts

Here the important class is the cyclone class and it has all the required characteristic numbers as the public data part. The loading of images the cut, paste, crop, preprocessing etc are all the methods. Other than the cyclone class there will be numerous other classes and those will be needed for the GUI based file processing as the file opening error message, edit error message, pre-processing error message etc. Those classes are needed for further redesigning, improvement, debugging etc which can be done upon the software.

used to find out DT number.The formula are given below.

CF = E Number + Eye Adjustment
DT = CF + BF

3.4.3 Step 3: Central Cold Cover (CCC) Pattern

The CCC pattern is defined when a more or less round , cold overcast mass of clouds covers the storm center or comma head obscuring the expected signs of pattern evolution. The outer curved bands and lines usually weaken with the onset of CCC.

3.4.4 Step 4: Determine the trend of the past 24 hour intensity change

The trend of the past 24 hour intensity change is determined qualitatively by comparing the cloud features of the current picture with those in the 24 hour old picture of the storm. In general , a disturbance has developed when its center appears better defined with no change in the relation to the dense clouds of the disturbance or is more involved with dense overcats clouds. There are three grades by which the past trend can be marked : D for developing , W for weakening , S for steady state .

3.4.5 Step 5: Model Expected T Number (MET)

The Met is determined by using the 24 hour old T number , the D,S or W decision in step 4 , and the past amount of intensity change of the storm.When the growth rate has not been established in the case of new developments or reversals in trend , assume a past rate of change of one T number per day. Equations for determining the MET are given below .
MET = 24 hour old T number + (0.5 to 1.5) when D was determined
MET = 24 hour old T number - (0.5 to 1.5) when W was determined
MET = 24 hour old T number when S was determined

3.4.9 Step 9: Current intensity (CI) number

The CI number relates directly to the intensity of the storm. After each intensity analyses, the previous analyses of the storm should be reviewed in the light of the current data. The CI number is the same as the T number while a cyclone is weakening. This is done because a lag is observed between the time a storm pattern indicates weakening has begun and the time when the storm's intensity shown weakening for 12 hours or more. The CI number is then held one higher than the T number as the storm weakens.

3.4.10 Step 10: The 24 hour intensity forecast (FI)

The forecast intensity (FI) is an extrapolation forward of the past 24 hour change in T number (not to exceed 1 1/2 T number per day) unless the cyclone's cloud pattern or its environment indicates a change in one of the following. Remenber that the FI number is similar to a forecast CI number higher than the forecast T number.
Step 10A: Strong unfavorable signs for future development within the cloud pattern.
Step 10B: Strong unfavorable signs for future development within the environment.
Step 10C: Strong favorable signs for future development within the cloud pattern.
Step 10D: Favorable signs for future development within the environment.
Step 10E: Signs of Peaking.

3.4.11 Step 11:(Optional)

Encode the intensity estimate using the code in figure 10 below. The code is self-explanatory except for the PLUS and MINUS (indications of ongoing change).

T(Todays T number)/(CI)/PLUS/MINUS/LEAVE / D/S/W (amount of past change) /(hours since previous observation)hrs

Chapter 4

Conclusion

This thesis presents a combined approach of intensity and shape based methods in tracking meteorological structures.

- This certainly has an edge over either the gradient or the shape based approach applied individually.
- At the same time it opens up several new research issues associated with the study of deformable shape.
- The operational procedures of CMV is restricted to a pair of sequence images. Incorporation of a few more of sequence images should help implementing a "predictor-corrector" scheme in estimating cloud motion.
- In our shape based approach, cloud contour is modelled as a perfectly flexible string and the local computation approach is restricted within a segment bounded by three consecutive vertices. This scheme could be upgraded considering the directional vectors at the neighbouring vertices which is not considered at present.
- We can use Bernstein Polynomial to get the optimum CMV.
- Determination of centre of curvature for the case finding the stable or high curvature points may be a good method.

- The scheme can also be used to predict about the flow of pollution particles like dust particles, smoke particles etc which are carried by a cloud.
- This scheme can also be used to predict about the time and place of raining if the cloud is rain bearing.
- The cyclone monitoring software can be further modified by including all types of image processing methods related with satellite imageries.
- The software can also be improved for any new pattern of cyclones at the time of development which is not there in the standard set of patterns.
- There is possibility of using learning mechanism using neural network in case of band pattern matching in steps 2 and 3.

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