A presentation on…

Prediction of Antarctic Sea Ice Edge Using Active Contour Model

By

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Outline

- Problem
- Approach
- Prediction Model
- Result & Error Analysis
- Concluding Remarks

Antarctica: An Introduction

- **The southern most icy continent of the world surrounding the south pole.**
- **Located between the latitudes of approximately 65^{0} S and 90^{0} S**
- **The pulsating continent**

Salient Features of Antarctica

- **Fifth largest continent about $14X10^6$ km^2**
- **Mean Surface elevation is over 2000m**
- **Lowest temperature recorded -89 ^{0}C**
- **Wind velocity up to 200 km/h**
- **The driest continent in the world**
- **The highest point in the continent is Vinson Massif with height of 5140 m**
- **The thickness of ice on the remaining 90% of the continent is 0.6-4.5 km**
- **Antarctica started forming at least $50X10^6$ years ago**

Problem

Prediction of pulsating nature of Sea Ice Edge over the Antarctica

Pulsating Continent : Antarctica

Seasonal Variation of Antarctica Sea Ice Edge: 1st July 2002 to 1st July 2005

Why Antarctica Sea Ice Edge?

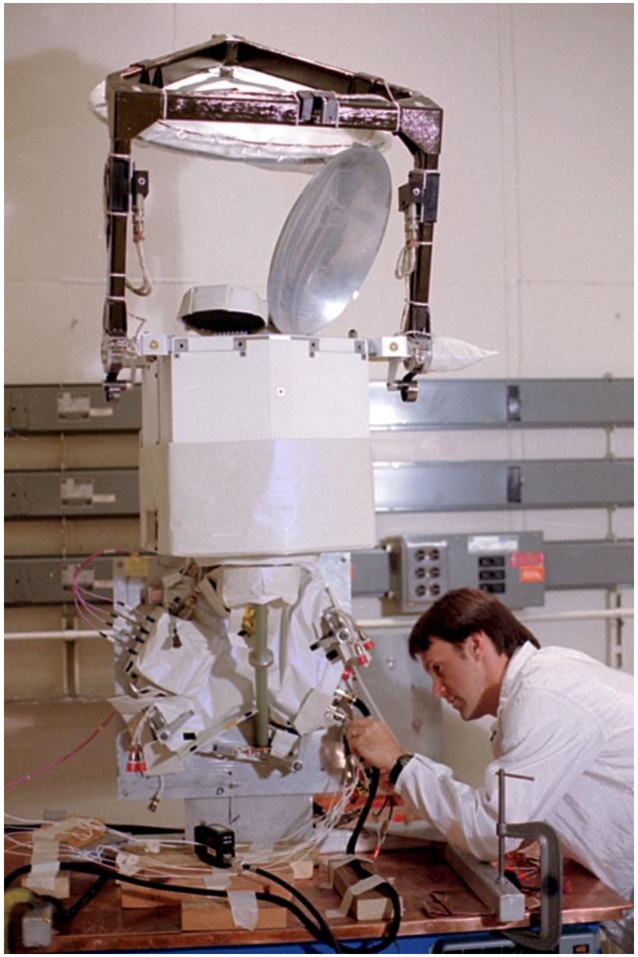
- **Earth Climate System**
  - **Earth Radiation Budget**
  - **Global Ocean Circulation**
- **Marine Biota**
- **Climate Modeling**
- **Military Operations**
- **Navigation**

Approach

- **Active contour Model**
- **Polynomial Statistical Method**

Sea Ice Concentration Data

Special Sensor Microwave/Imager

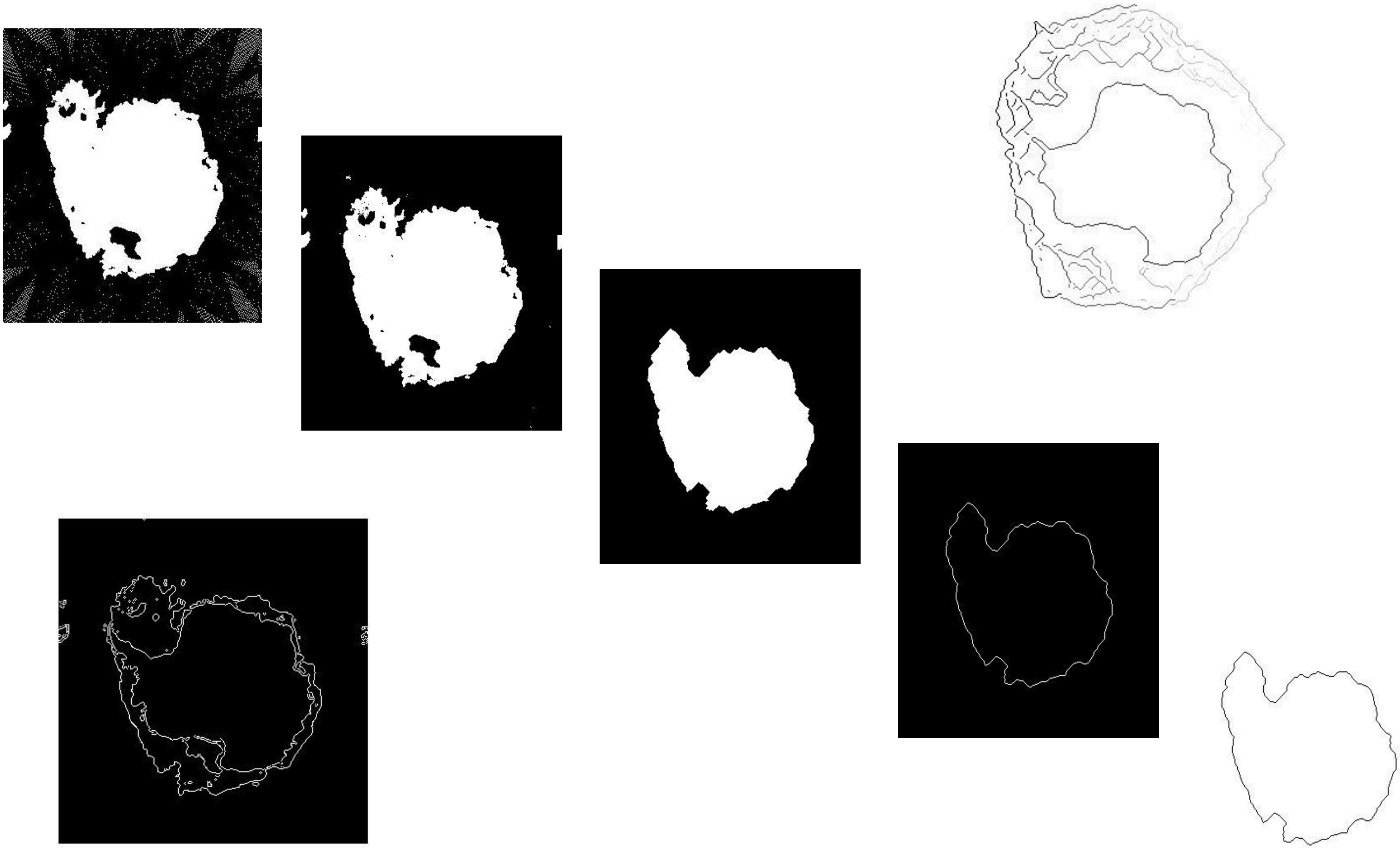


- Derived from the Special Sensor Microwave/Imager (SSM/I) using Bootstrap Algorithm with daily varying tie-points
- Gridded on polar stereographic projection with 25km x 25 km resolution
- Format :Binary two-byte integer.
- Spatial Coverage:
- Temporal Coverage: 1987 to till date, (Daily and monthly)

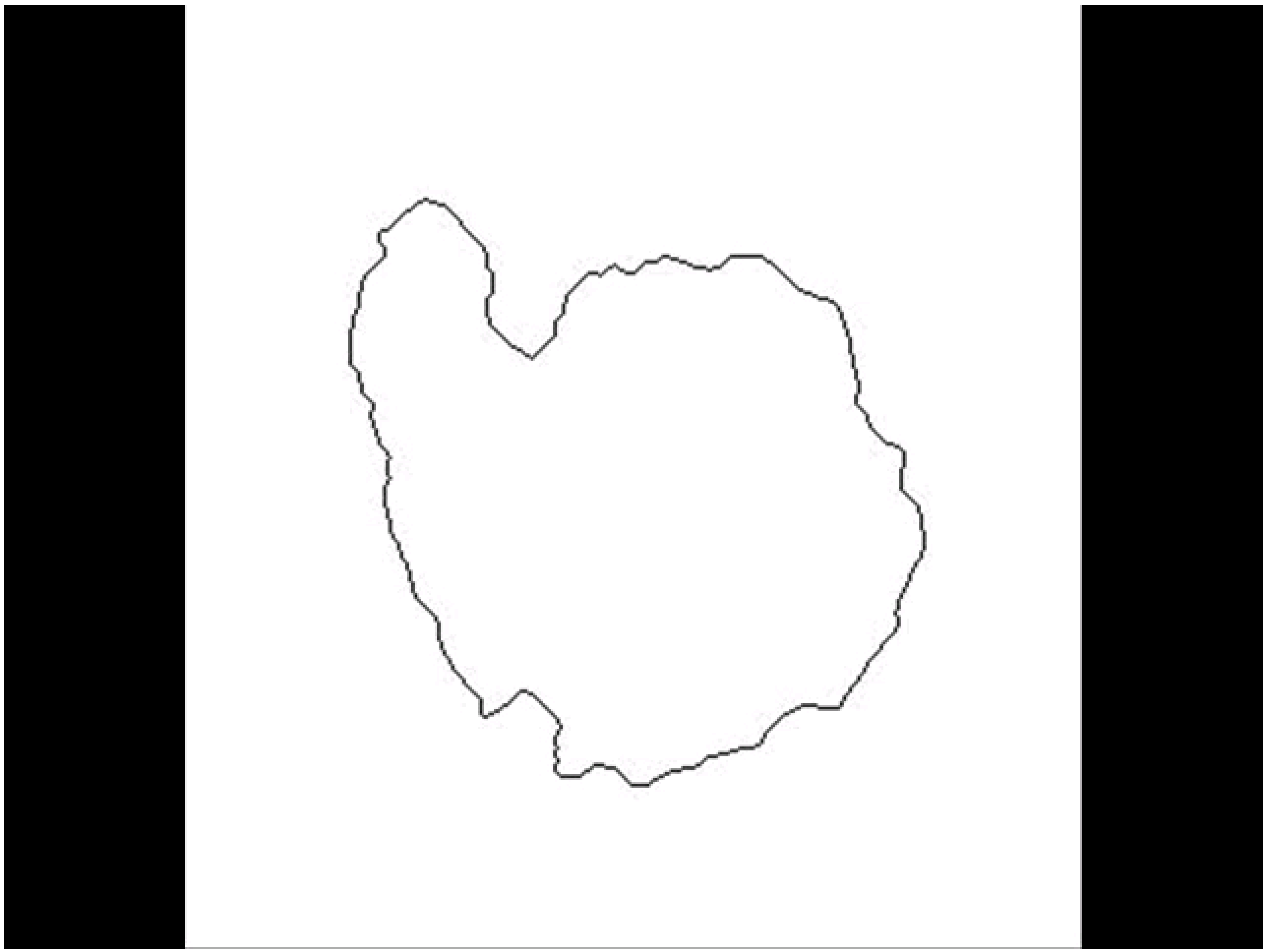
Bootstrap Algorithm: http://nsidc.org/data/docs/daac/bootstrap/index.html

Data Source :The National Snow and Ice Data Center (http://www.nsidc.org)

Different Steps To Getting Edge



Variation in Sea Ice edge in Antarctica in 2006



Gradient Vector Flow Snake

- **Snake (or Active Contour) are cures defined within an image domain that can move under the influence of the internal forces coming from within the cures itself and external forces computed form the image data**
- **An energy minimizing spline guided by external constraint forces and pulled by image forces toward features.**
- **Model is always minimizing its energy functional and therefore exhibits dynamic behavior : Active Contour Model.**
- **The way the contours slither in the model while minimizing their energy is know as Snake Model.**
- **The snake's energy depends on its shape and location**
- **Snakes can be closed or open**
- **GVF snake is active contour which use the gradient vector field as a external force.**

Applications of Snake

- **Edge Detection**
- **Motion Tracking**
- **Shape Modeling**
- **Image Segmentation**
- **Pattern Recognition**

Why Gradient Vector Flow Snake?

- **Insensitivity to initialization**
- **Large capture range**
- **An ability to progress into boundary concavities**
- **Detects shapes with boundary concavities**
- **Does not need prior knowledge about whether to shrink, or expand towards boundary**

GVF Snake Model

- **A snake is a curve $X(s)=[x(s),y(s)], s \in [0,1]$ that moves through the spatial domain of an image to minimize the energy functional**

$$E_{snake} = \int_0^1 [E_{internal}(X(s)) + E_{external}(X(s))]ds$$

where, $E_{internal}$ is the internal energy and $E_{external}$ is the external energy of the snake, respectively

Internal Energy

$$E_{Internal} = [\{(\underbrace{\alpha(s)|X'(s)|^2}_{\text{Elasticity}} + \underbrace{\beta(s)|X''(s)|^2}_{\text{Rigidity}})\}/2]$$

Note : **where X′ and X′′ are the 1st and 2nd derivatives of the snake with respect to s and α(s), β(s) specify the elasticity and rigidity of the snake, respectively.**

External Energy

- **The external energy computed from the image data is a weighted combination of energies which attract the snake to lines or edges Image data**
- **For a Gray-level Image I(x, y)**

$$E^1_{external} = -|\nabla I(x, y)|^2$$

$$E^2_{external} = -|\nabla[G_\sigma(x, y) * I(x, y)|^2$$

- **For a line drawing (black on white) Image I(x, y)**

$$E^3_{external} = I(x, y)$$

$$E^4_{external} = G_\sigma(x, y) * I(x, y)$$

where G_σ is the 2D Gaussian function with standard deviation σ and ∇ is the gradient operator

Implementation

The process of my implementation:

1 Import an image

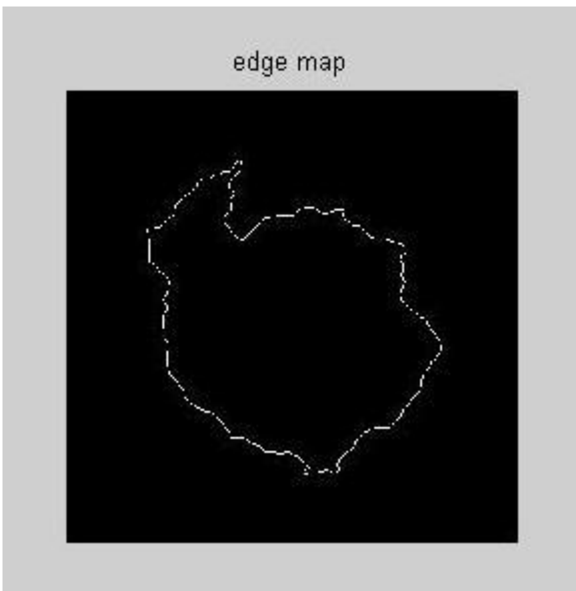
2. Initialize the snake for the image

3. Compute the edge map of the image

4. Input the edge map to the GVF solver

5. Deforms the snake

Edge Map



- **Edge map f(x , y) derived from the image I(x , y) having the property that it is larger near the image edges**

$$f(x , y) = -E^{(i)}_{external}(x , y)$$

i=1,2,3, or 4.

Gradient Vector of Edge Map

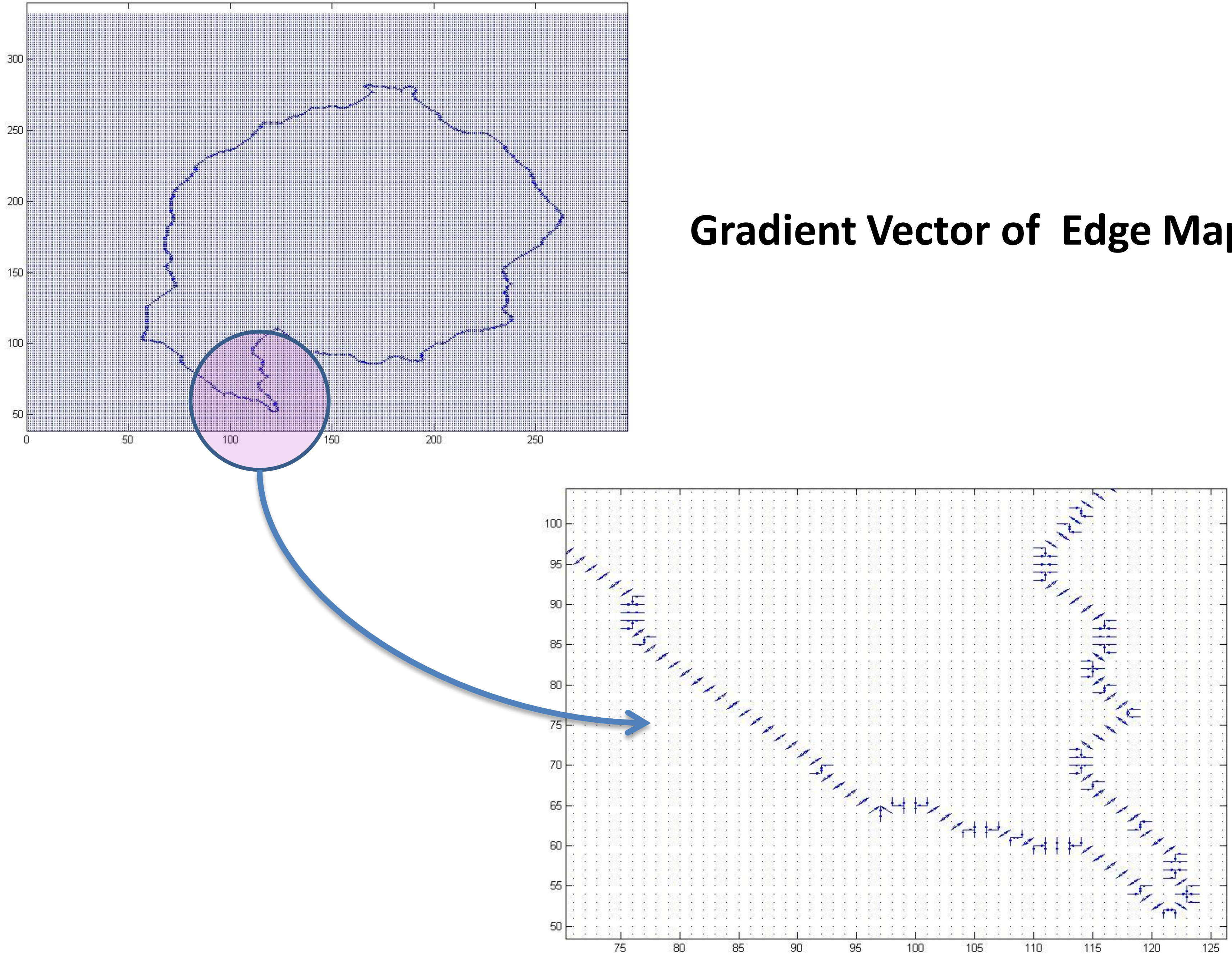
General Properties:

- Pointing toward the edges
- Large magnitudes only in the immediate vicinity of the edges
- In homogeneous regions,(I(x, y) ≈constant), $\Delta f \approx 0$.

Effects:

- A snake initialized close to the edge will converge to a stable configuration near the edge.
- The capture range will be very small
- In homogeneous regions, No external forces

Gradient Vector of Edge Map



Gradient Vector Flow

- **The GVF field is defined to be a vector field**

$$V(x , y) = [u(x , y), v(x , y)]$$

- **V(x , y) is defined such that it minimizes the energy functional**

$$\varepsilon=\iint \mu(u_x^2+u_y^2+v_x^2+v_y^2) +|\nabla f|^2|V - \nabla f|^2 dxdy$$

where f(x , y) is the edge map of the image and μ is noise parameter

- **Using the calculus of variations, GVF field can be obtained by solving following Euler equations**

$$\mu\nabla^2 u - (u - f_x)(f_x^2 + f_y^2)=0$$

$$\mu\nabla^2 v - (v - f_y)(f_x^2 + f_y^2)=0$$

where ∇^2 is the Laplacian operator and f_x and f_y are the partial derivative of the edge map

Numerical Implementation

- Equations can be solved by treating gradient vector flow u and v as functions of time and to set up the iterative solution, we can write

$$u_{i,j}^{n+1} = (1- b_{i,j}\Delta t)u_{i,j}^{n} + r(u_{i+1,j}^{n} + u_{i,j+1}^{n} + u_{i-1,j}^{n} + u_{i,j-1}^{n} - 4u_{i,j}^{n}) + c_{i,j}^{1}\Delta t$$

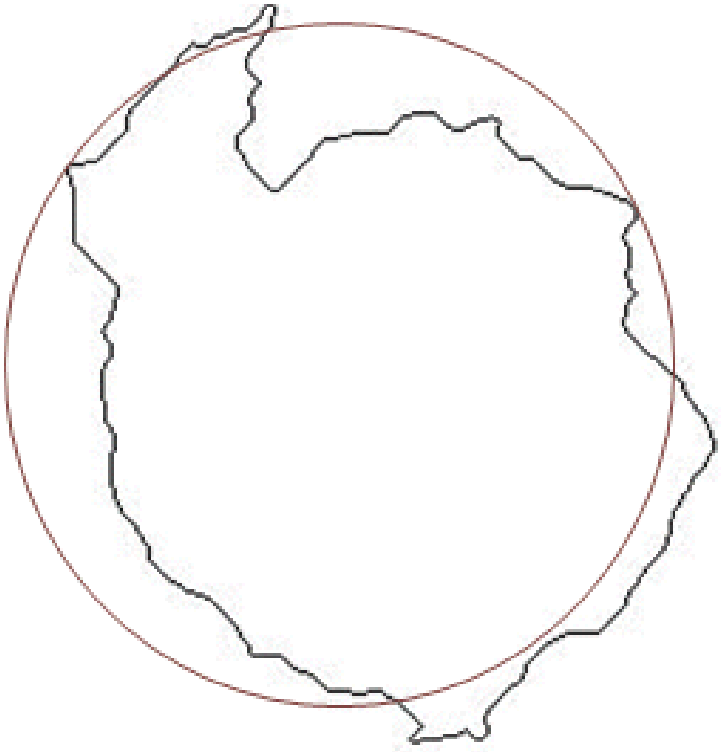
$$v_{i,j}^{n+1} = (1- b_{i,j}\Delta t)v_{i,j}^{n} + r(v_{i+1,j}^{n} + v_{i,j+1}^{n} + v_{i-1,j}^{n} + v_{i,j-1}^{n} – 4v_{i,j}^{n}) + c_{i,j}^{2}1\Delta t$$

where the indices i, j, and n correspond to x, y and t respectively,
$r = \{\mu\Delta t / \Delta x\Delta y\} \leq (1/4)$ and

$$b(x, y) = f_x(x, y)^2 + f_y(x, y)^2$$

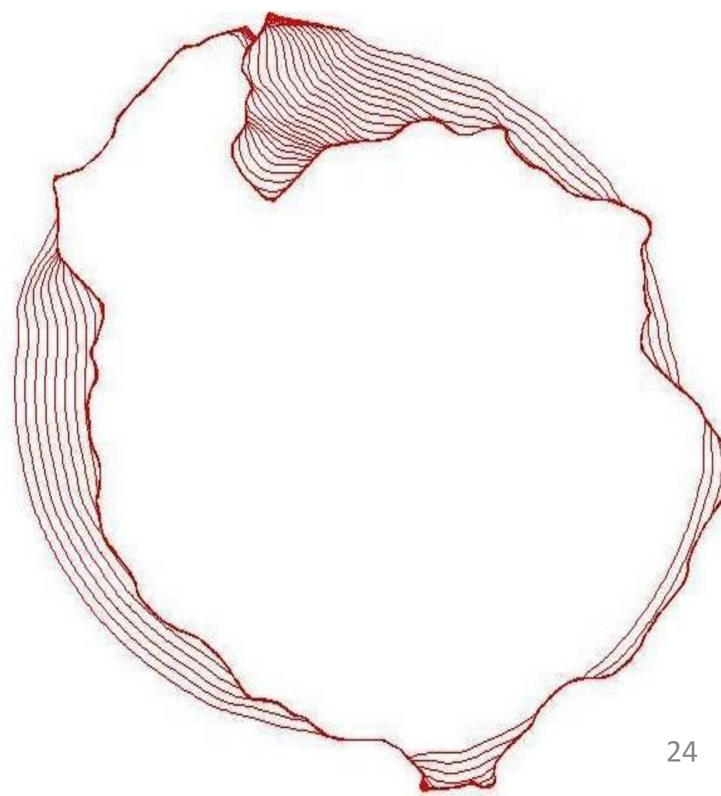
$$c^1=b(x, y)*f_x(x, y)$$

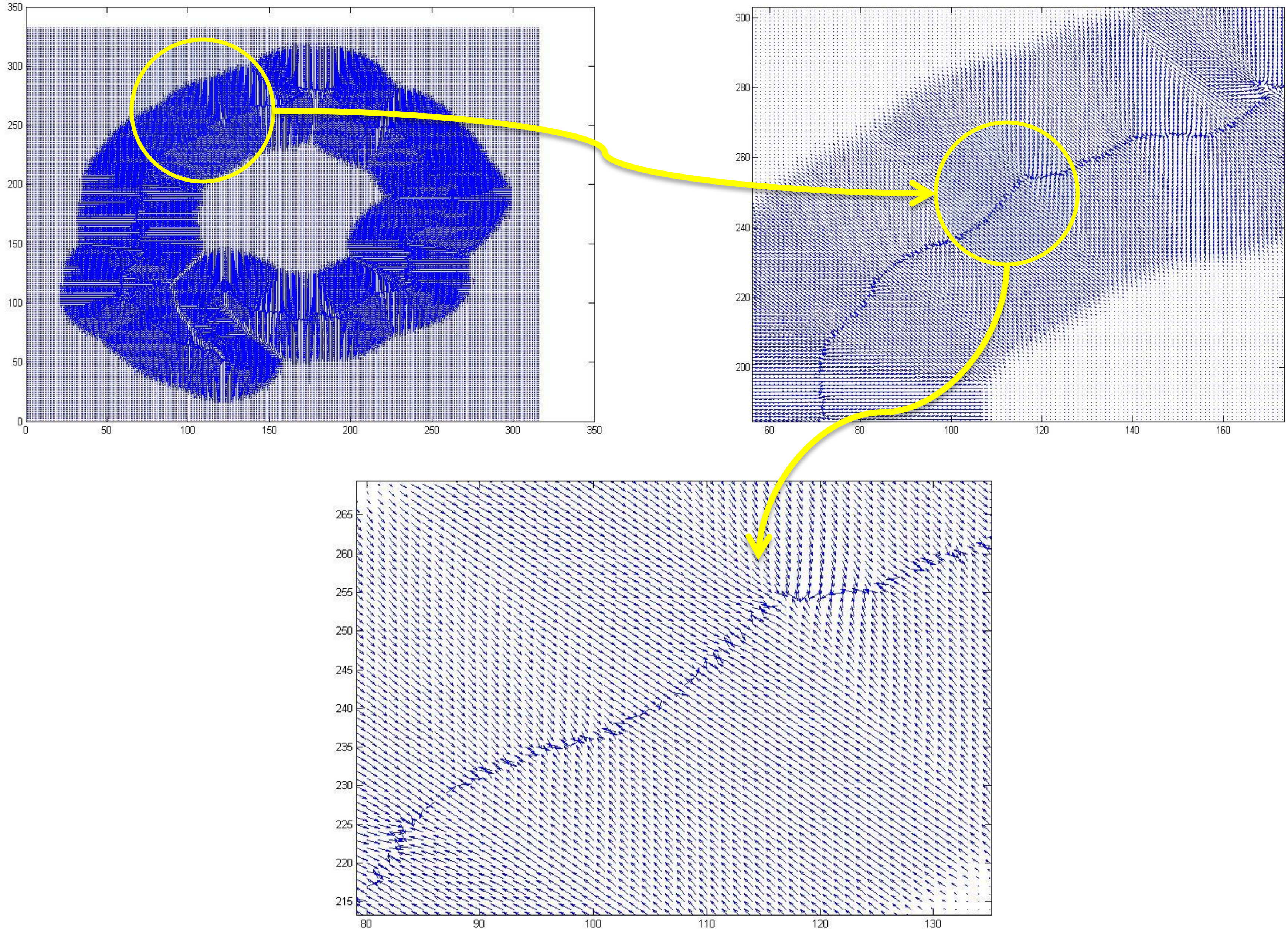
$$c^2=b(x, y)*f_y(x, y)$$



Initial GVF Snake

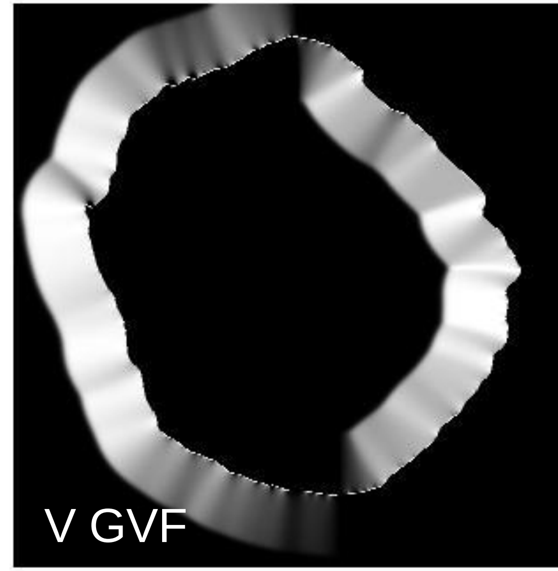
Convergence of a Snake using GVF external force towards edge





Normalized Gradient Vector Flow Field

September, 2006



Normalized GVF U- And V- Component

February, 2006

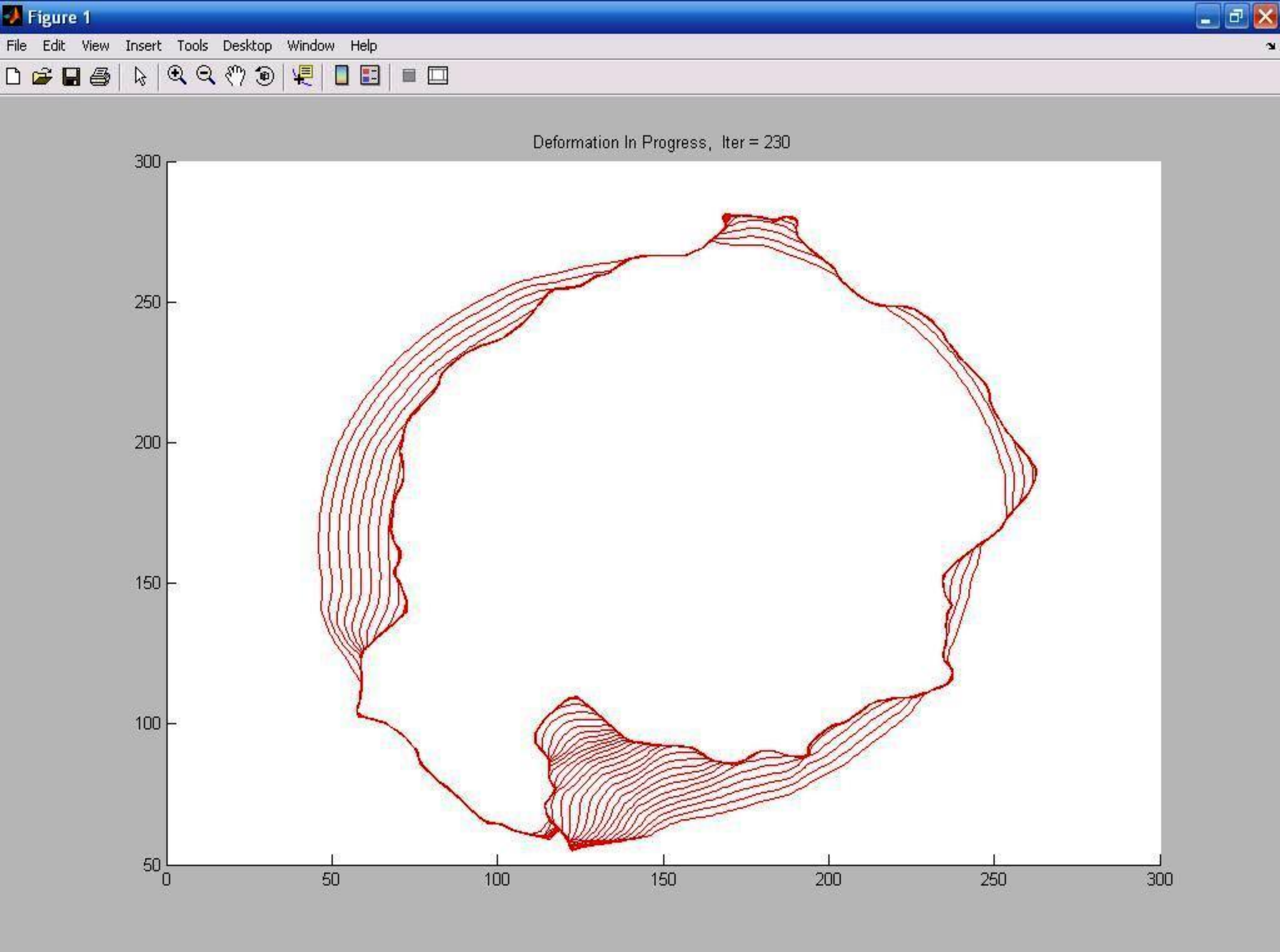
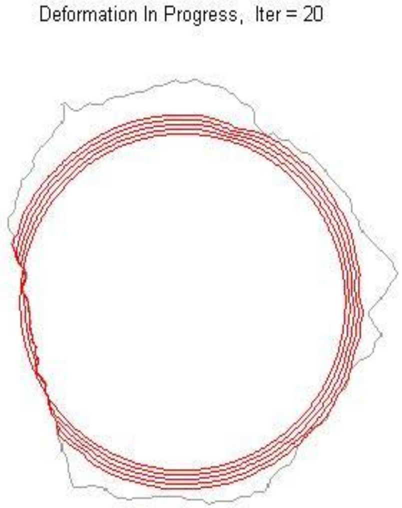
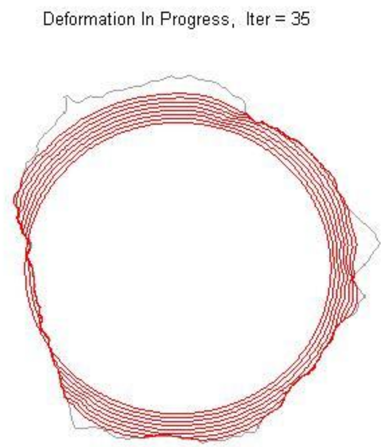
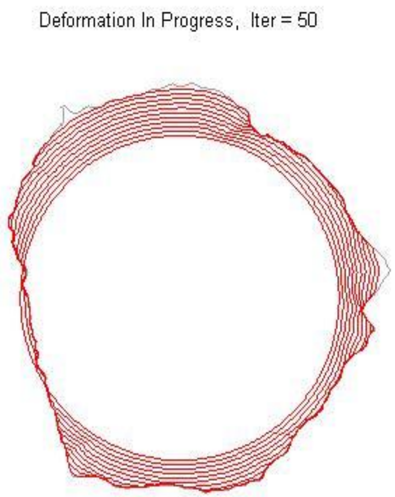


Figure 1
File Edit View Insert Tools Desktop Window Help
Deformation In Progress, Iter = 230
300
250
200
150
100
50
0
50
100
150
200
250
300

Deformation of GVF Snake

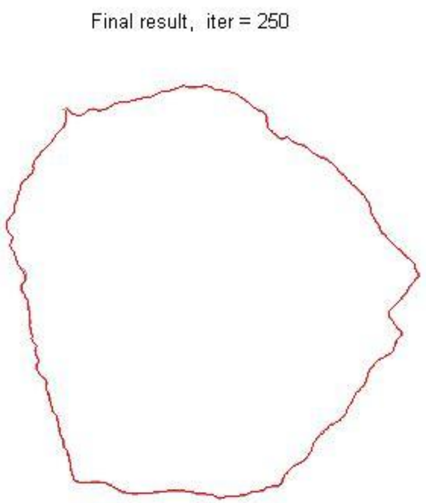




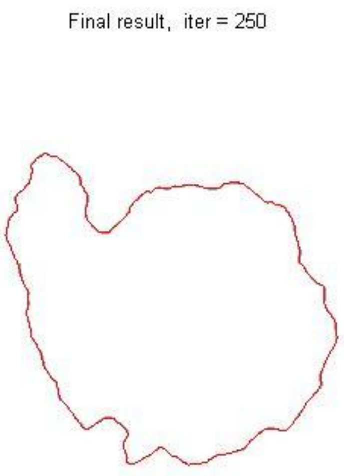


Simulation Result

September, 2006



February, 2006



GVF Snake Model Parameter

- **Elasticity(α) : 0.05**
- **Rigidity(β): 0**
- **Regularization (μ):0.02**
- **Damping coefficient (γ):1**

Prediction Method

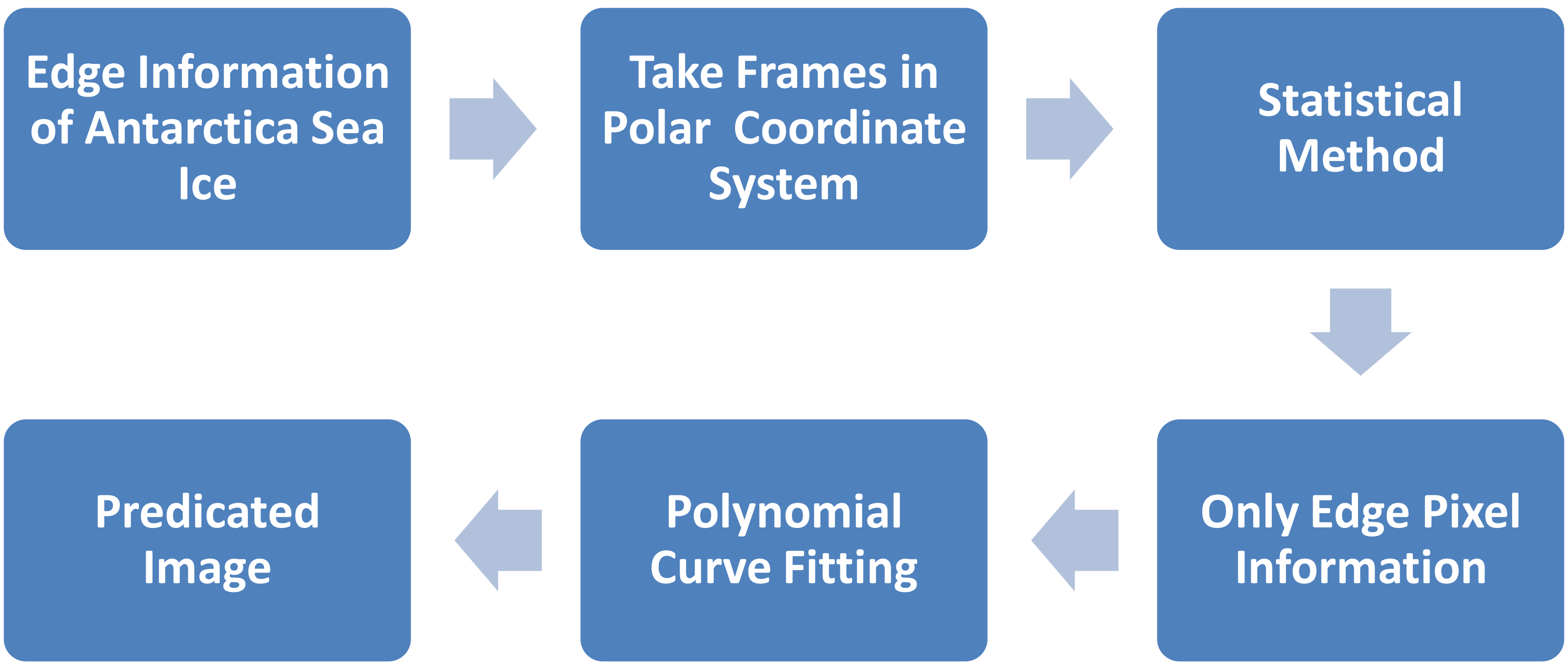
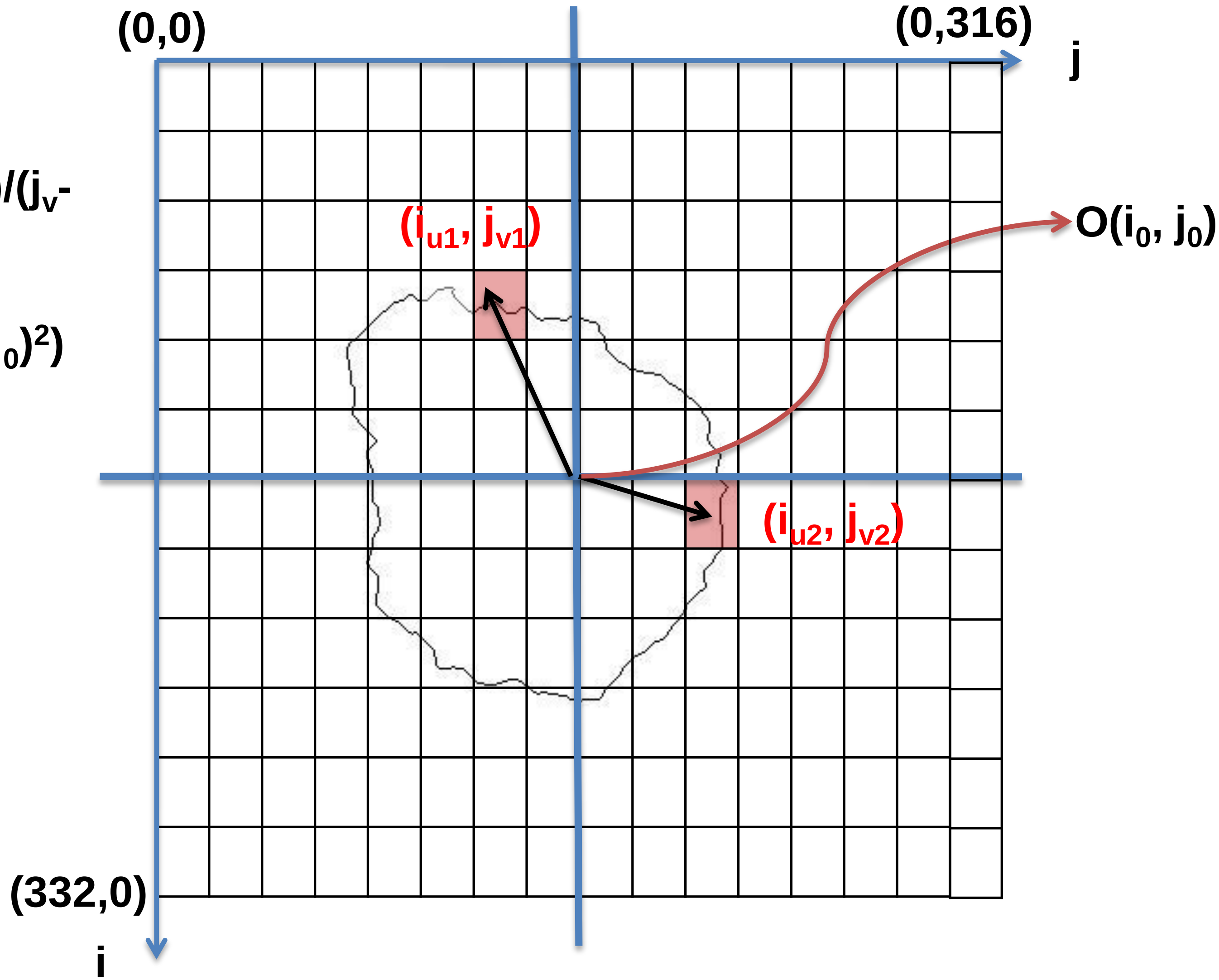


Image Polar Coordinate Parameter

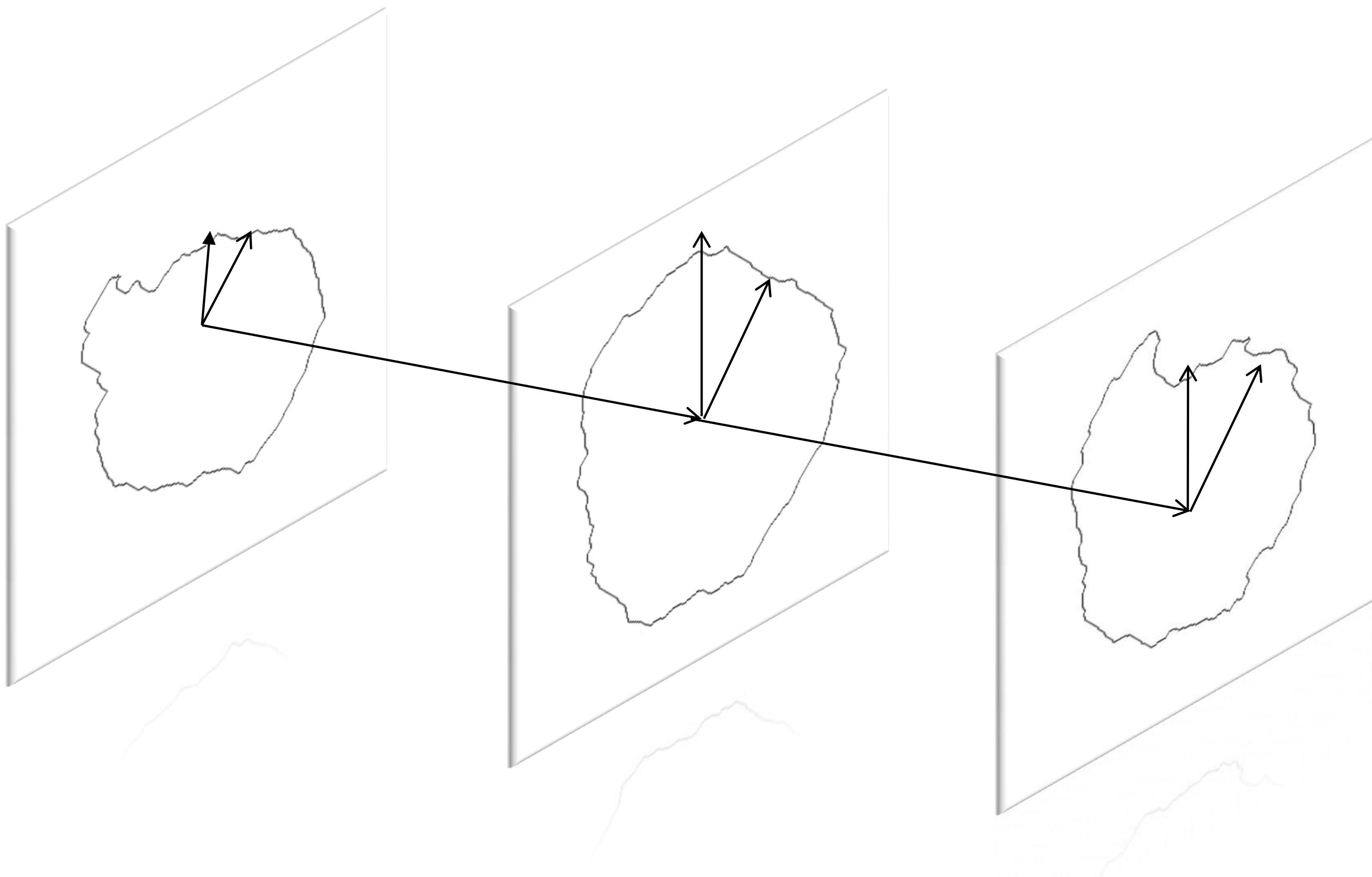
$\Phi = \tan^{-1} [(i_u - i_0)/(j_v - j_0)]$

$r = \sqrt{((i_u - i_0)^2 + (j_v - j_0)^2)}$

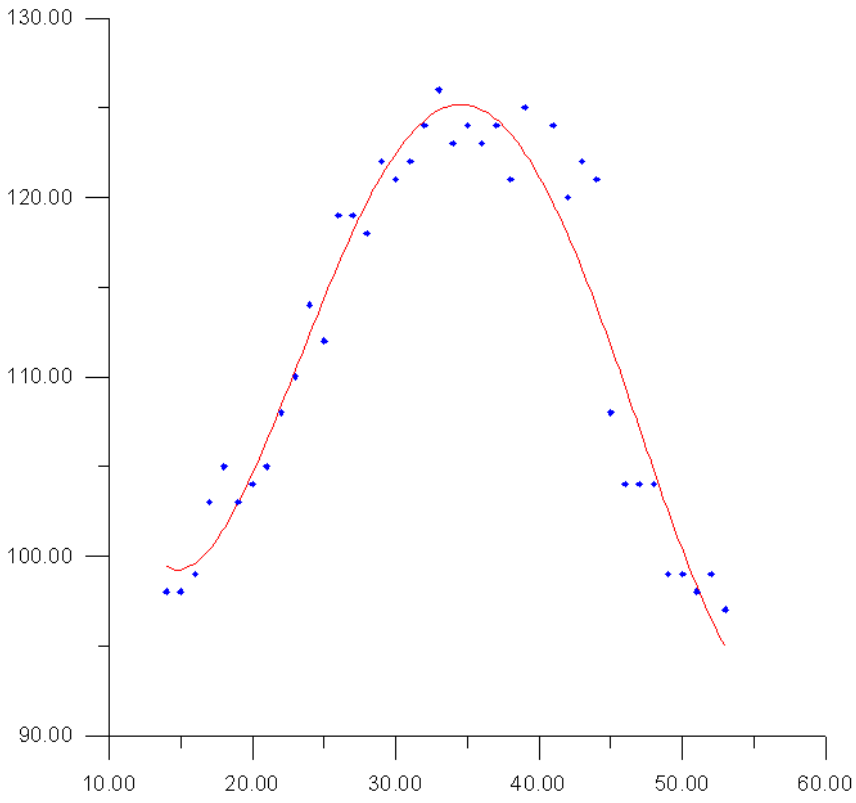
Where,
u=1,2,…332,
v=1,2,…316,



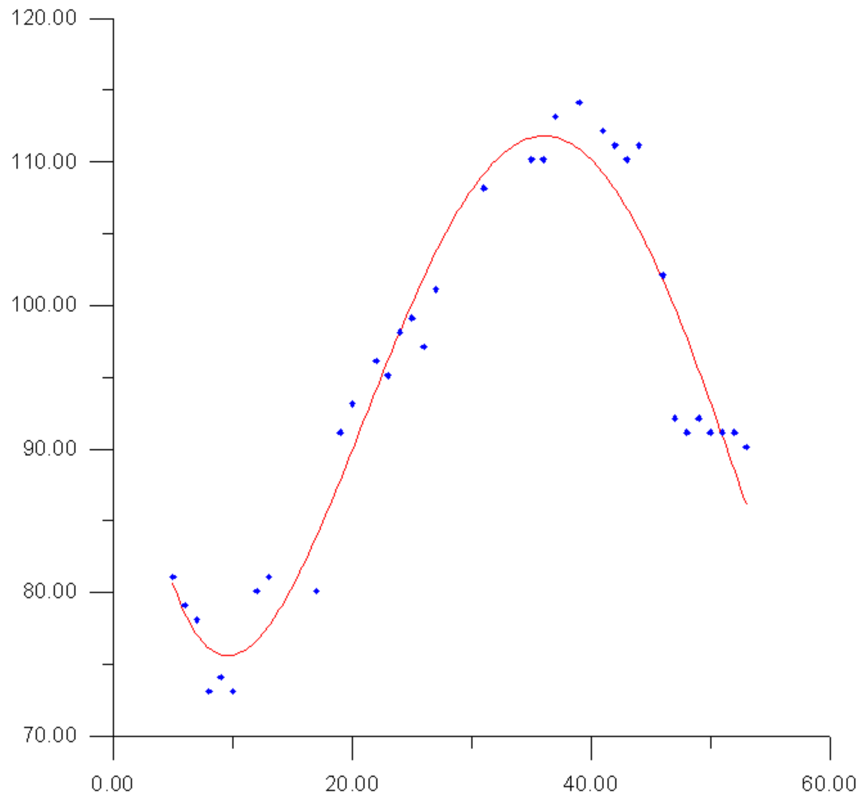
Angle Window Search



Polynomial Curve Fitting

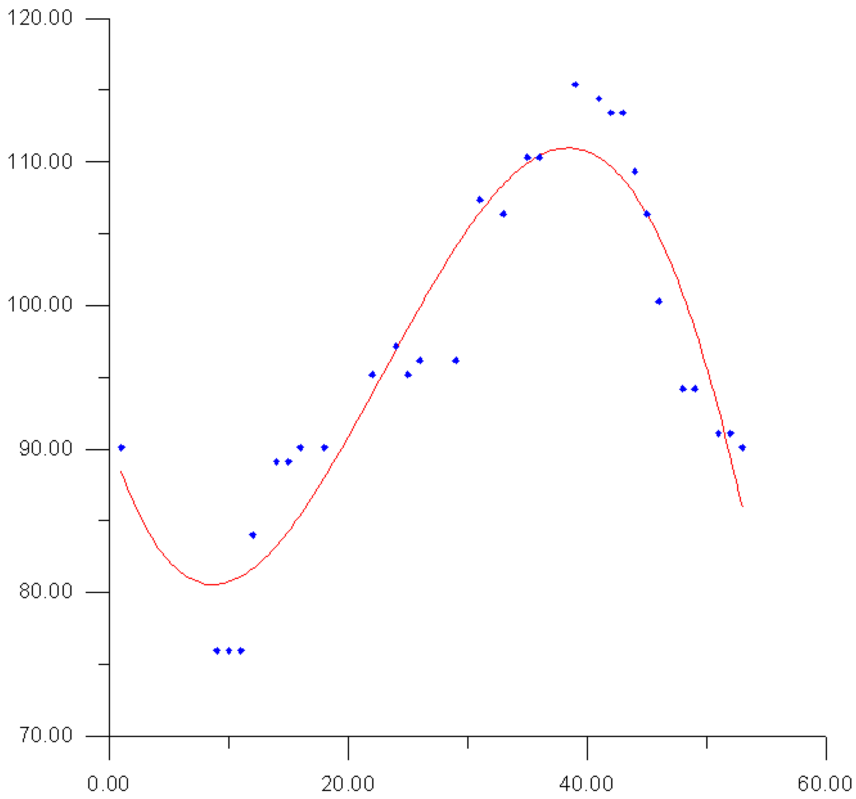


1^0

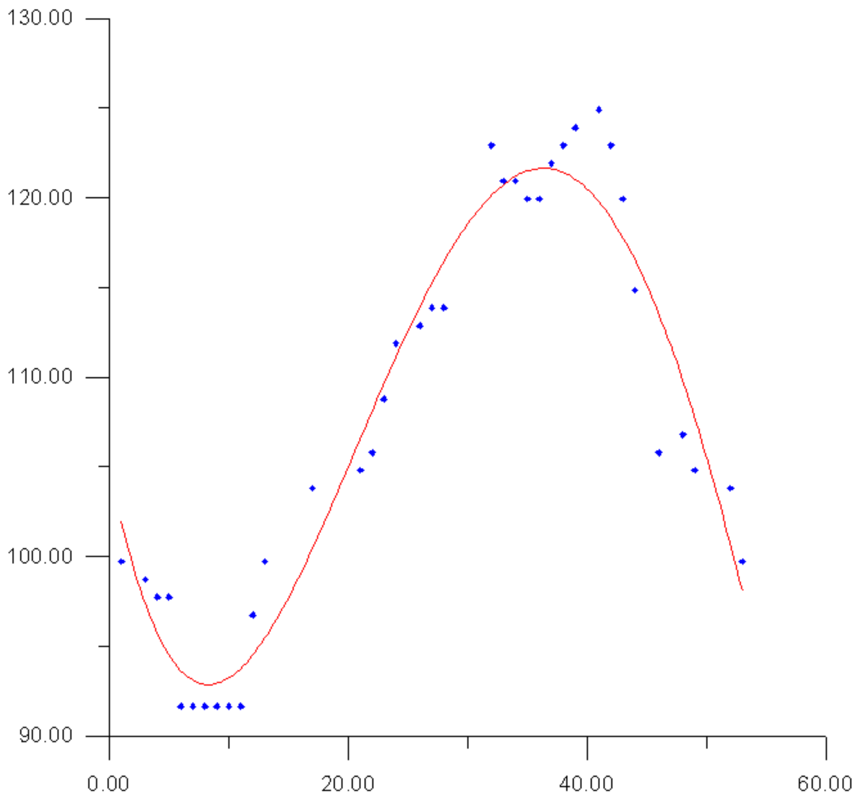


93^0

Polynomial Curve Fitting



185^0



153^0

Prediction Model Equation

$$\begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ \vdots \\ r_{360} \end{pmatrix} = \begin{pmatrix} A_1 & B_1 & C_1 & D_1 & E_1 \\ A_2 & B_2 & C_2 & D_2 & E_2 \\ A_3 & B_3 & C_3 & D_3 & E_3 \\ A_4 & B_4 & C_4 & D_4 & E_4 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_{360} & B_{360} & C_{360} & D_{360} & E_{360} \end{pmatrix} \begin{pmatrix} t^4 \\ t^3 \\ t^2 \\ t \\ 1 \end{pmatrix}$$

Or,

$$r = At^4 + Bt^3 + Ct^2 + Dt + E$$

where,

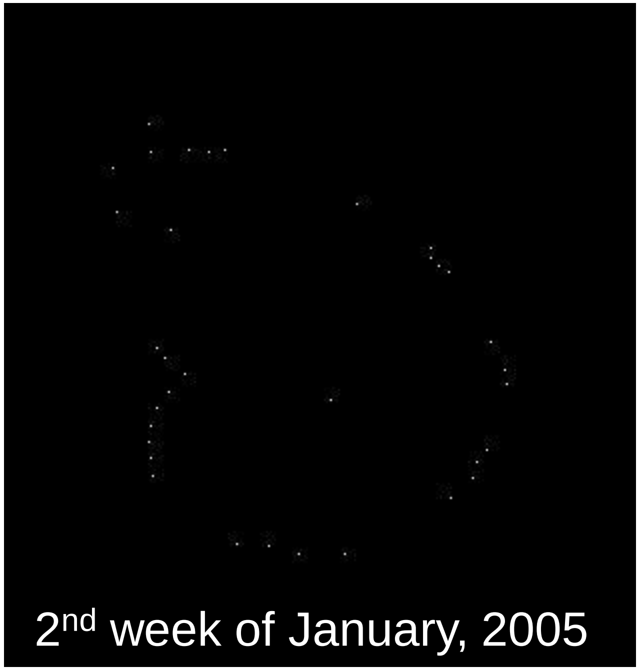
r_θ = The radius of the each pixel locations, θ=1,2,3,4…,360

t= Time, t=1, 2, 3, 4…

and

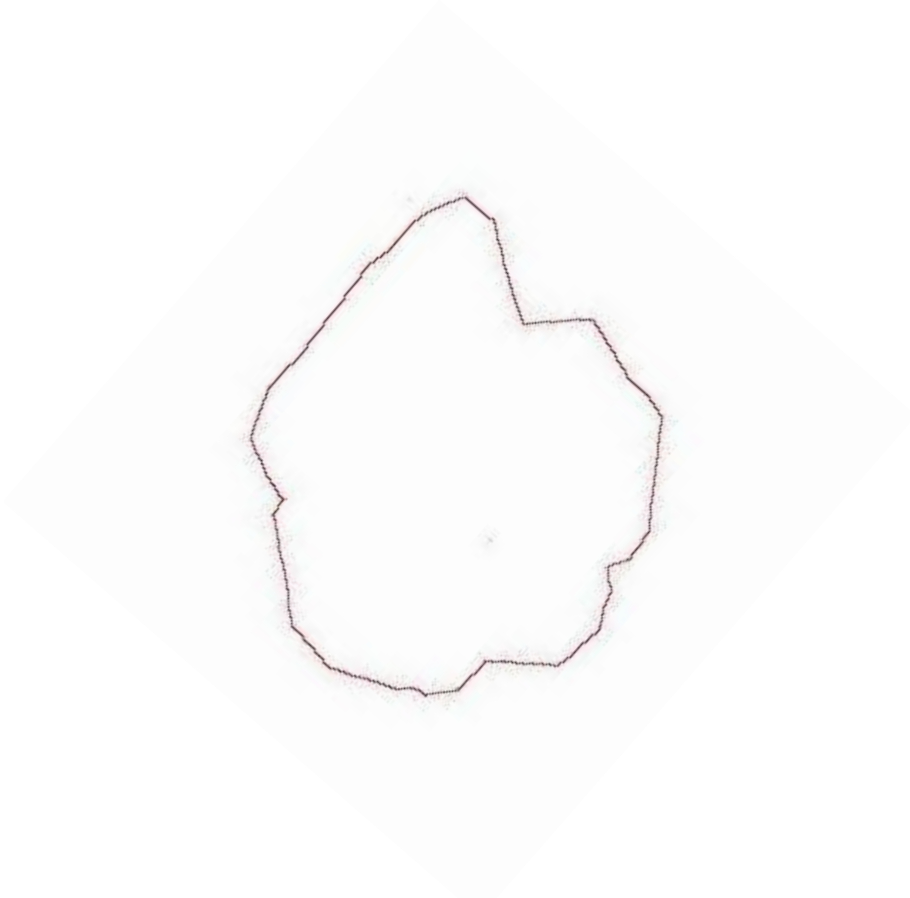
A, B, C, D,E = Polynomial Coefficients

Predicted Edge Pixel

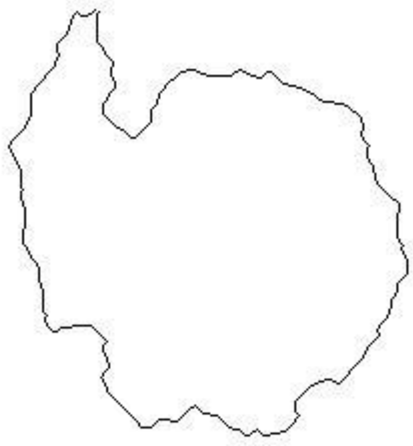


Result

Predicted Image : 1st week of January, 2005

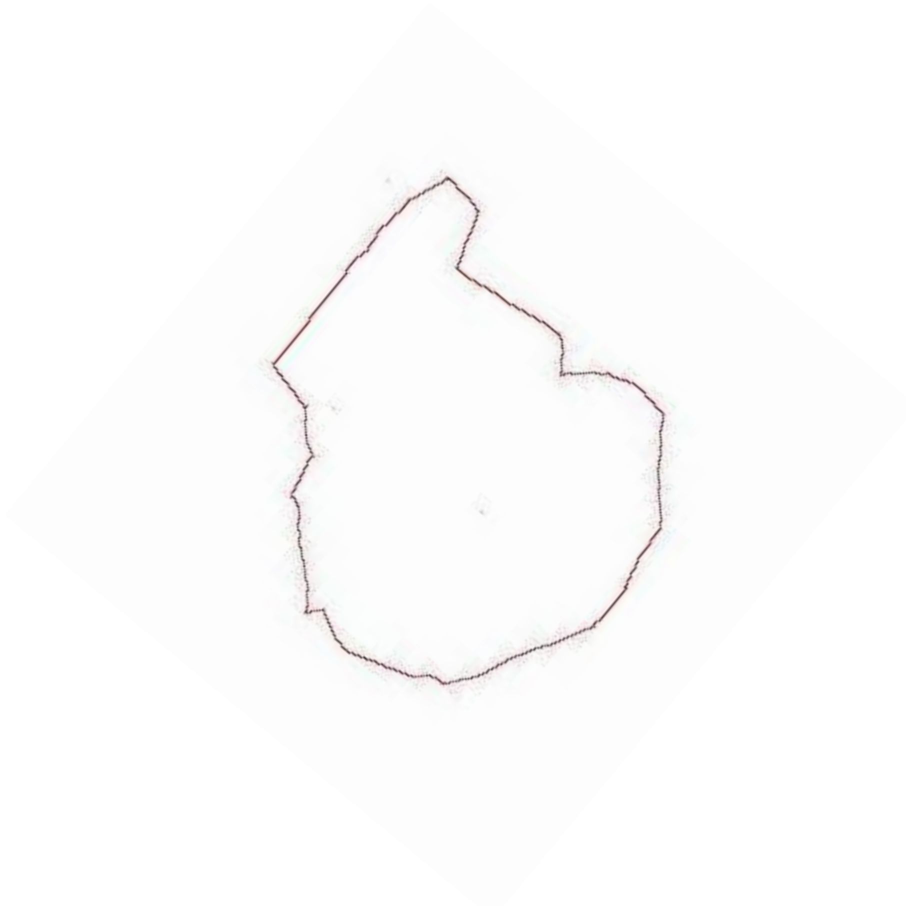


SSM/I Image: 1st week of January , 2005

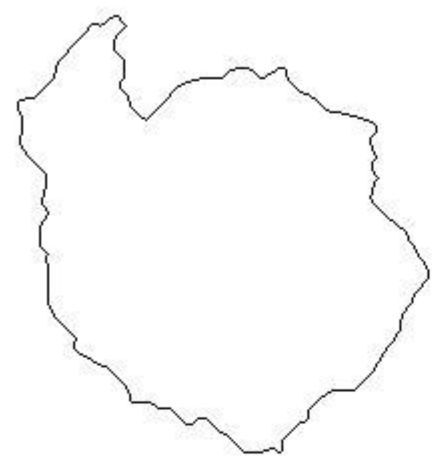


Result

Predicted Image : 2^{nd} week of January, 2005



SSM/I Image : 2^{nd} week of January, 2005



RMS Error Analysis

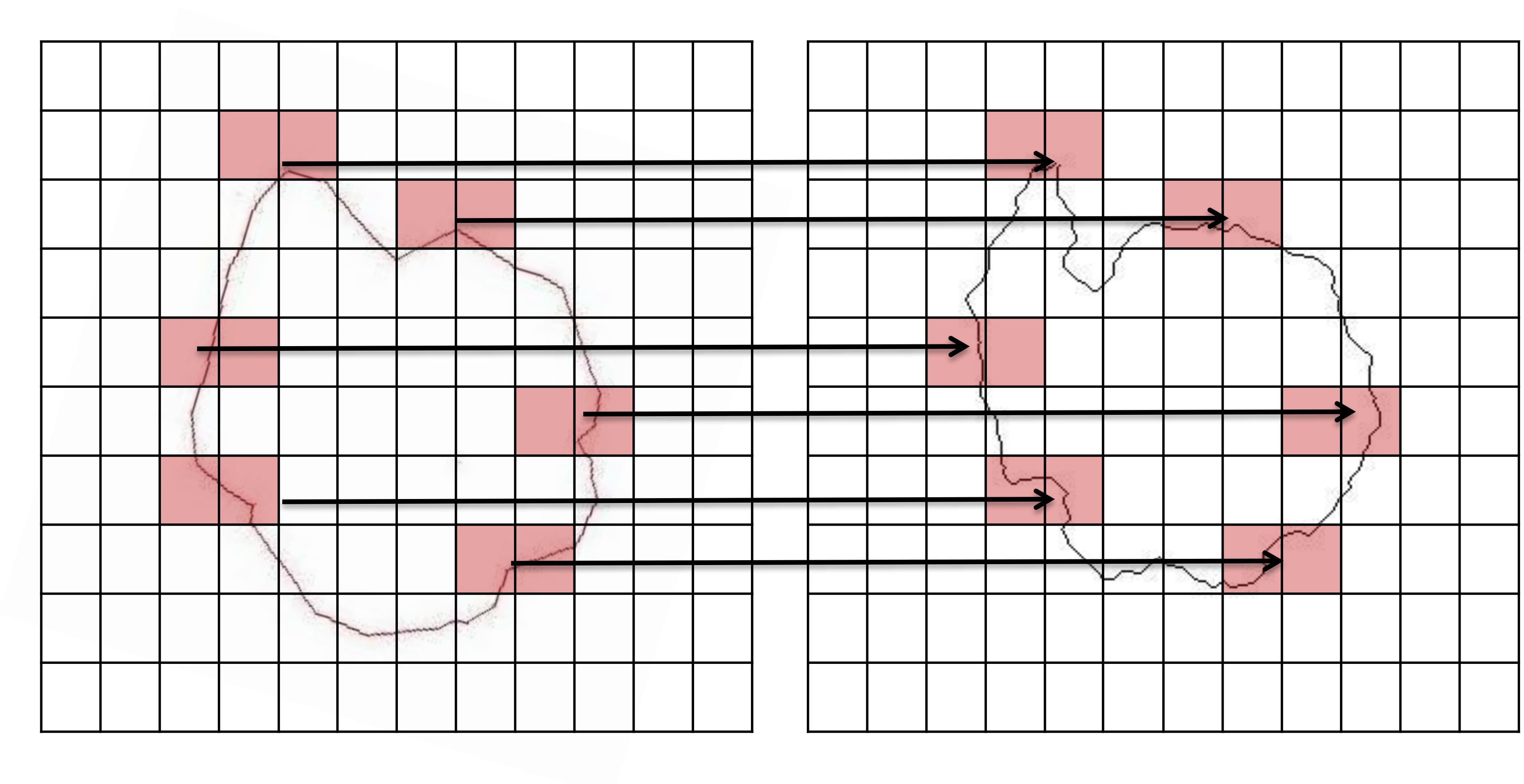
$$RMS = \sqrt{\frac{\sum_{n=1}^{n=360}\left(r_{reference} - r_{predicted}\right)^2}{n}}$$

Where, $r_{reference}$ = Reference Image Pixel Position
$r_{predicted}$ = Predicted Image Pixel Position

RMS Error Analysis

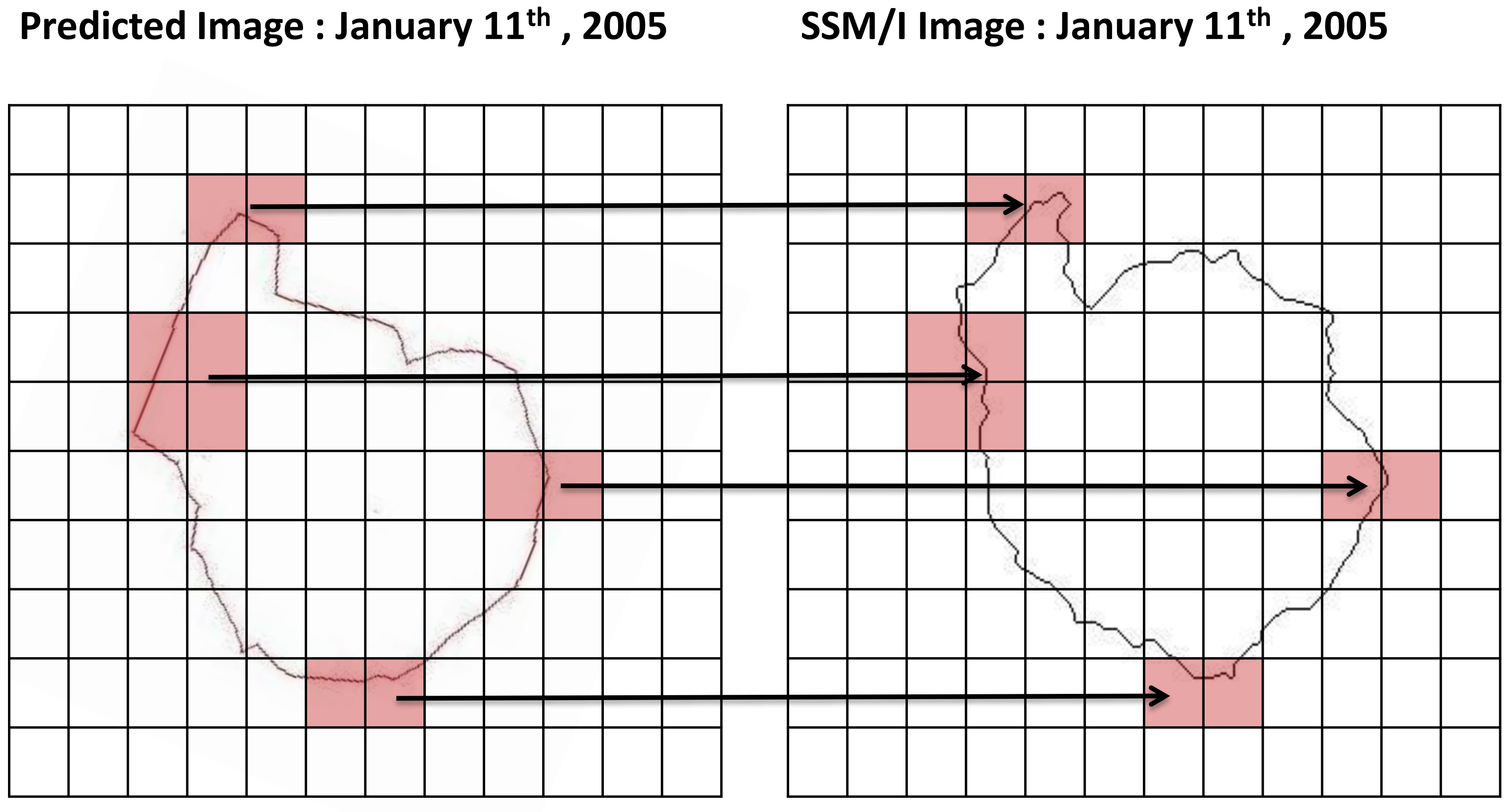
Average Error : 10 %

Predicted Image : January 4th , 2005 **SSM/I Image: January 4th , 2005**



RMS Error Analysis

Average Error : 11 %



Conclusion

- **The broad features of the predicted edge match well with that observed edge.**
- **Radial RMS Error = Order of 10%**
- **The visual interpretation shows the GVF snake model has simulated the ice edge with 90 % accuracy**
- **Large deviation at the region around Antarctic peninsula due to use of the Averaging Technique to decide the ice edge when multiple edges are present at a particular angle**

Future Work

- **Improve model reliability of Sea Ice Edge Prediction**
  - **By applying more robust techniques**
  - **By taking longer time series**
- **Used for the regional sea ice prediction**
- **Prediction of Random Deformation in Shape**
- **Estimation and Tracking of Ice Bergs Deformation**
- **Prediction of Biological Cell Growth and Decay**

Applications

- **Used for deriving the sea ice extent before the satellite era**
- **Used in the climate model to give a better forecast**
- **Used for better study of the climate change signal**
- **Help in coast effective navigation and military plan in Polar Region.**
- **Used for prediction of the ice edge in the Arctic**

References

- Chenyang Xu and J.L. Prince, 1998: Gradient Vector Flow: A New External Force for Snakes, Proc. IEEE Conf. on Comp. Vis. Patt. Recog. (CVPR), Los Alamitos: Comp. Soc. Press., 7, pp. 66-71

- Kass, M., A. Witkin, and D. Terzopoulos, 1987: Snakes: The Active contour models, International Journal of Computer Vision. *1, pp. 321-331*

Thank You