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Vortex Detection by improved Gamma Method

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1. Introduction

The Vortex Detection Code (VDC) aims to detect and identify the vortex flow motions in the 2D numerical observational solar data. Inspire by the Γ method (Graftieaux et al. 2001) and the convolution Γ_1 (Fernando Zigynov. 2019), we improve the gamma function and combine with new design vortex boundary algorithm to tracking more accurate detection result in observational data.

2. Advanced Γ Method

2.1 Original Γ method:

Γ_1 is a dimensionless scalar function about point *P* , Where *S* is a two-dimensional area surrounding *P* . *M* lies in *S*, *PM* denote the displacement vector from point *P* to a point *M* in *S*. *UM* denotes the velocity vectors at *M*; *Z* is a unit vector normal to the plane. *A* is the area of *S*; Up is the local convection velocity around the vortex center

$$\Gamma_1(P) = \frac{1}{A}\int_{M\in S}\frac{(PM\times U_M)\cdot z}{\parallel PM\parallel\cdot\parallel U_M\parallel}dS = \frac{1}{A}\int_S \sin(\theta_M)dS$$

$$\Gamma_2(P) = \frac{1}{A}\int_{M\in S}\frac{(PM\times (U_M-\overline{U_P}))\cdot z}{\parallel PM\parallel\cdot\parallel U_M-\overline{U_P}\parallel}dS$$

2.2 Convolution Γ method:

Consider only longitudinal and latitude velocity (2-D velocity field). The Γ method can be expressed in 2-D with convolution as follow. Computation in with convolution will speed up the computation by 3 order at least than just using the original discrete form of the function.

$$\Gamma_1(P) = \frac{1}{N_1}\left[\frac{PM_x}{\parallel PM\parallel}\circledast\frac{U_{My}}{\parallel U_M\parallel}-\frac{PM_y}{\parallel PM\parallel}\circledast\frac{U_{Mx}}{\parallel U_M\parallel}\right]$$

$$\Gamma_2(P) = \frac{1}{N_1}\left[\frac{PM_x}{\parallel PM\parallel}\circledast\frac{PM_x}{\parallel PM\parallel}\frac{U_{My}-U_{py}}{\parallel U_M-U_p\parallel}-\frac{PM_y}{\parallel PM\parallel}\circledast\frac{U_{Mx}-U_{px}}{\parallel U_M-U_p\parallel}\right]$$

- U_{My} longitudinal velocity field component
- U_{Mx} latitude velocity field component
- PM_x x component of radius vectors from center P to all potential M point, current point P is the origin
- PM_y y component of radius vectors from center P to all potential M point, current point P is the origin
- $||\cdot||$ magnitude
- N the number of points in the current velocity fields that around the vortex center P.

'$\circledast$' denotes the convolution operator

2.3 Advanced Γ method:

We notice that convolution Γ method using two convolution kernel $\frac{PM_x}{||PM||}$ and $\frac{PM_y}{||PM||}$. According to the convolution theorem, we also notice that kernel are separable if the rank of it is 1. But we notice that only the numerator part could be separable. In order to using the computation advantage of the separable convolution. We improve the algorithm by estimate a reasonable single scalar Z to approximate the denominator in the kernel. As a result we got the advanced form of it.

*w*1 and *w*2 as two 1-D vector

$$PM_x = w_1\times w_2$$

$$PM_y = (w_1\times w_2)'$$

$$\Gamma_1(P) = \frac{1}{ZN_1}\left[((w_1\circledast\frac{U_{My}}{\parallel U_M\parallel})\circledast w_2)-((w_2\circledast\frac{U_{Mx}}{\parallel U_M\parallel})\circledast w_1')\right]$$

$$\Gamma_2(P) = \frac{1}{ZN_i}\left[((w_1\circledast\frac{U_{My}}{\parallel U_M\parallel})\circledast w_2)-((w_2\circledast\frac{U_{Mx}}{\parallel U_M\parallel})\circledast w_1')\right]$$

Z the estimates scalar rate that approximate displacement magnitude matrix $\parallel PM\parallel$, which enable $Gamma_1$ and $Gamma_2$ bound by 1.

By using the separable convolution kernel, it will faster as least m/2 times than the convolution form, where m is the size of the 1-d vector.

3. Unfixed Circular Area

Traditionally, the Γ method utilizes the same/similar fixed-size S as in the velocity field that sampling from the PIV procedure. Adopting the same fixed-size S does not influence on finding the vortex center in the Γ1 method. However, in Γ2, it involves the local convection velocity around the center point. Traditional Γ2 will take all points in area *S* into account for calculating the local convection velocity *UP* , even the point local in the bottom right corner of area *S*. Thus, the spatial geometric relationship between suspect point *M* and other points in area *S* will influence the result of *UP* since it traditionally defined as the local convection velocity field around vortex center *P* .

Thus we introduce the unfixed circular area in N2 when calculate gamma 2. VDC will self design the area that in gamma 2 and thus provide a better boundary detection result. Fig 1 show one of the example when detecting the boundary, where the blue point indicate the circular are, this area will variate according to the radius from the current suspect boundary point to the vortex center

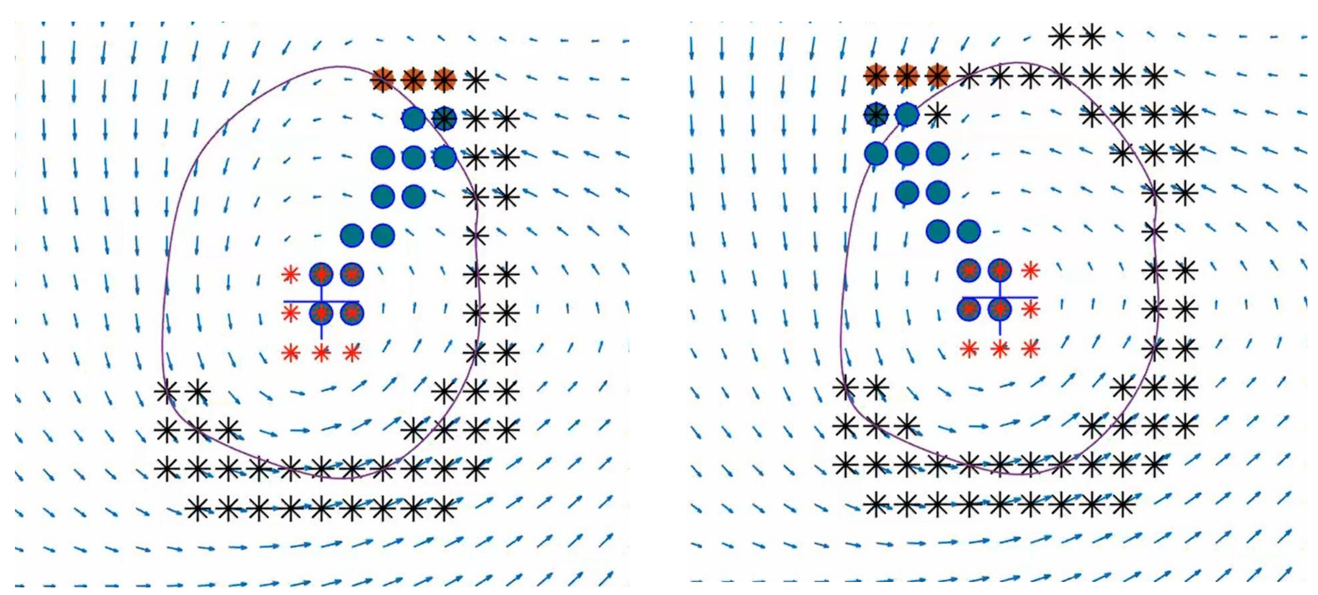

Figure 1. Unfixed Circular Area.
Blue point indicate the unfixed circular section that used to compute the local convection velocity of current boundary point.
Black point indicate the searching process.

4. Detection result

The observation data comes from CRISP. The image scale of the CRISP observations is 0 059 per pixel and the mean cadence is about 8.25s.

VDC will tracking most of the vortex that it detect and record each of their lifetime, change of area, gamma 1 value, boundary, radius velocity and tangential velocity during its lifetime.

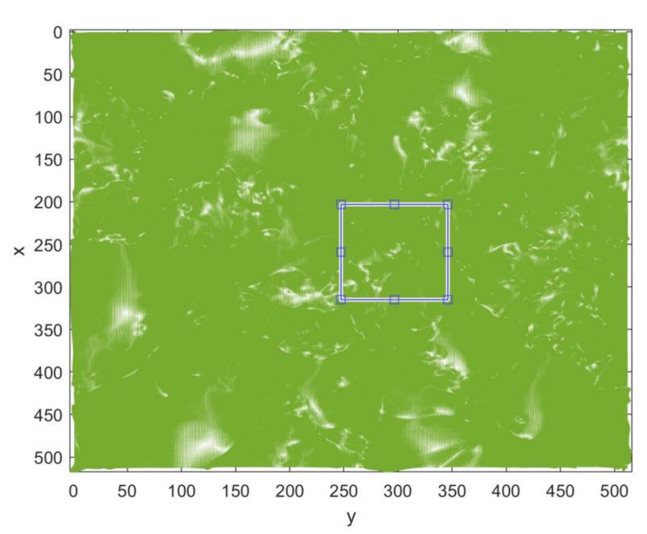

Figure 2: The region of interest (ROI) is marked by rectangle.

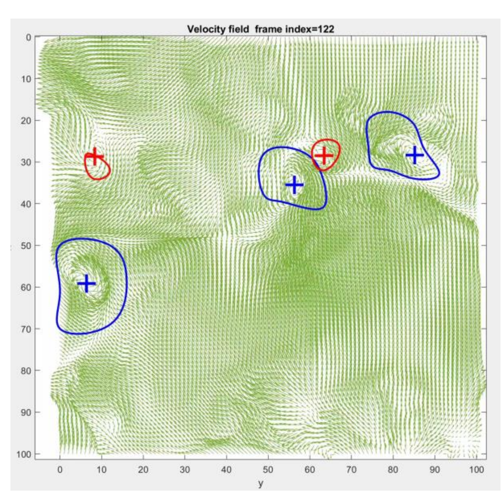

Figure 3: The snapshot of the of the detected vortices boundaries and centers. Red colour corresponds to the clockwise rotated vortex and blue to the counter-clockwise rotation.

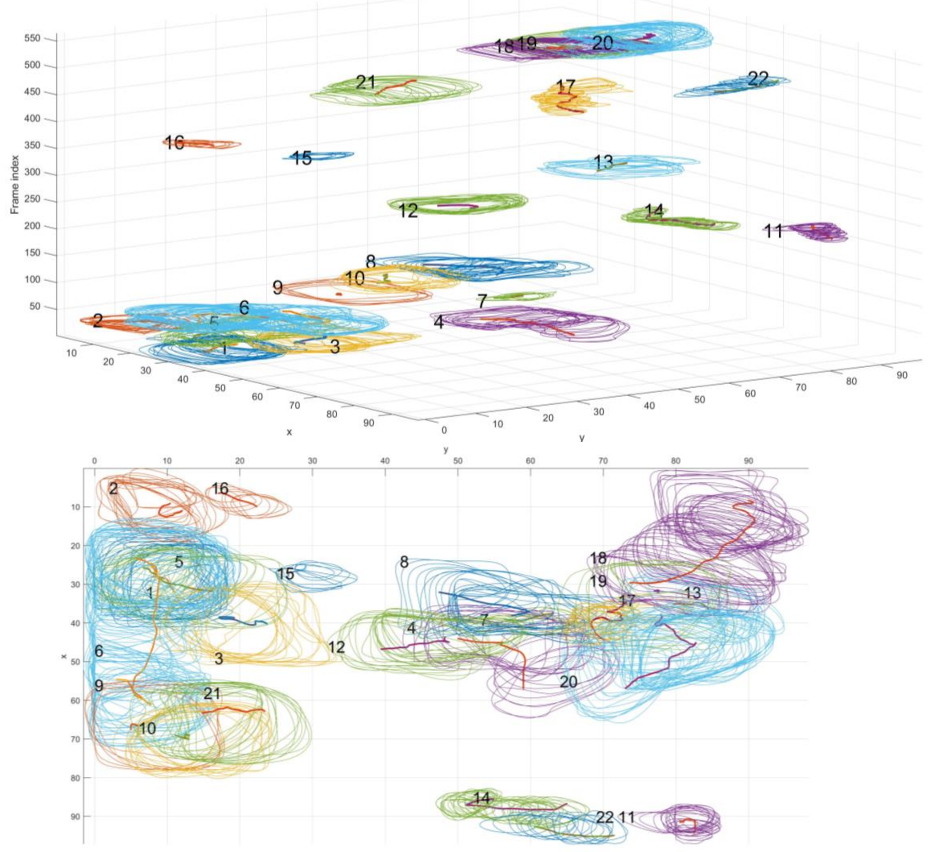

Figure 4: The region of interest (ROI). The top panel (a) and bottom panel (b)show all the detected vortices in ROI. The red lines correspond to the trajectory of the vortices centers. The vertical axis of the left panel indicate the number of frame in observational data, where the mean cadence is about 8.25s

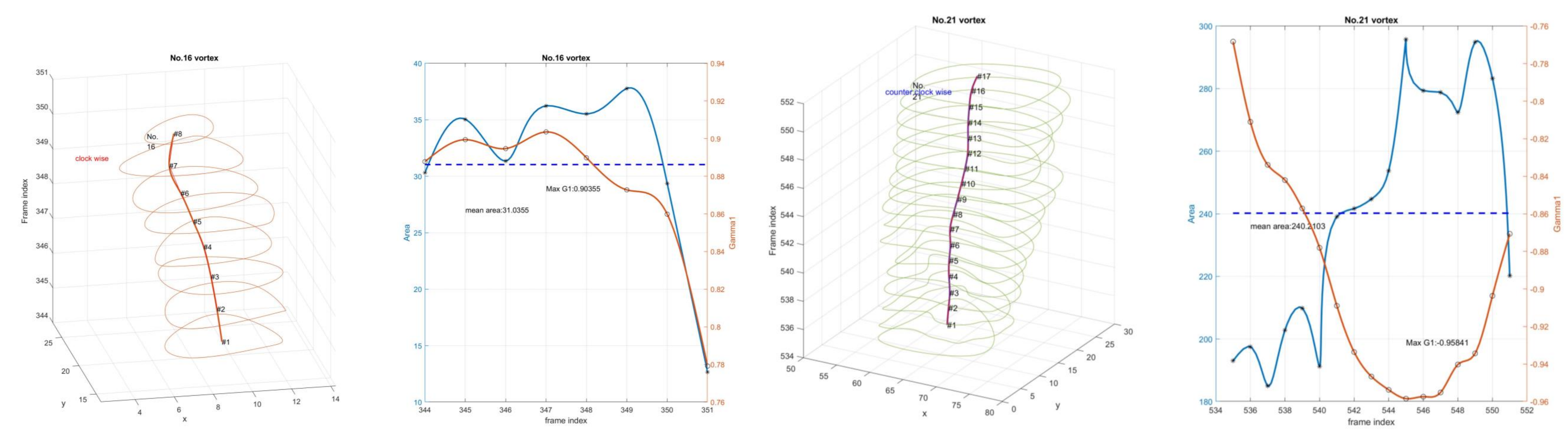

Figure 5: Vortex boundary change as a function of time. The two isolated verticesNo.16 and No.21 are shown on the left and right panels respectively.

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*** Reference**

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