Tests of the Cross-Correlation Algorithm Using Synthetic Backscatter Lidar Images and Wind Fields

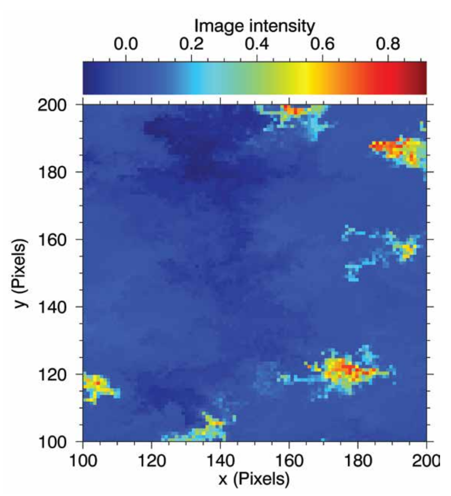
Paper Number: A13G-0311

Masaki Hamada, Pierre Dérian and Shane D. Mayor, Department of Geological and Environmental Sciences, California State University, Chico, U.S.A.
e-mail: mhamada1@mail.csuchico.edu, pderian@csuchico.edu, smayor@csuchico.edu

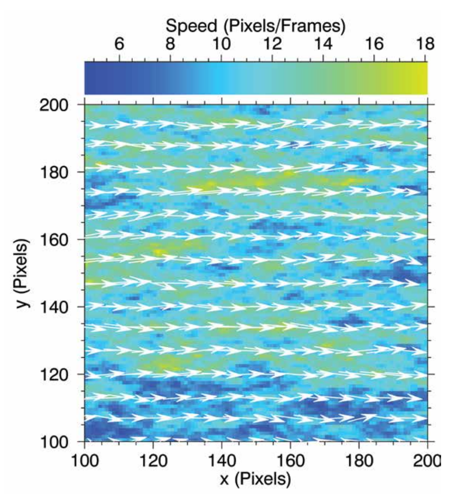
Abstract

The **cross-correlation algorithm** [1] is a numerical method used to estimate the motion of features between two frames in image sequences. Prior to this research, it was applied to real aerosol lidar for **wind measurements** [2, 3]. However, an evaluation of the cross-correlation algorithm involving precise control of aerosol features and flow fields has not been performed. Therefore, we have evaluated performance of the cross-correlation algorithm using synthetic backscatter images and flow fields. The results show that the cross-correlation algorithm provides reliable displacement vectors if the flow is uniform, but the performance of the cross-correlation algorithm decreases as non-uniformity of the flow fields increases

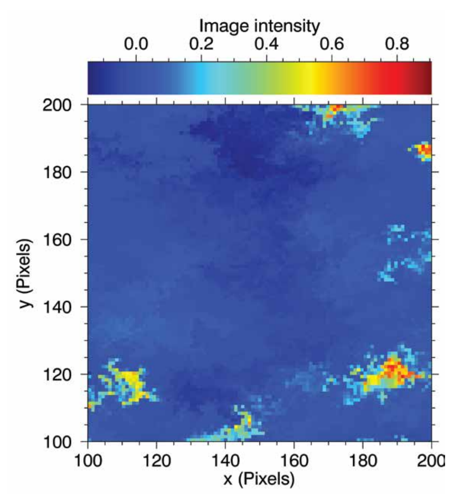
Methodology



(Block 1)



(Velocity Field)



(Block 2)

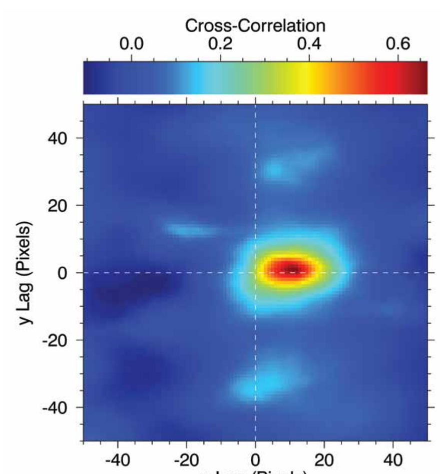
Fast Fourier Transform $g(\vec r+\tau)$

Complex Conjugate of Fast Fourier Transform $f^*(\tau)$

Calculate Cross Spectra $(f\star g)(\vec r)$

$$(f\star g)(\vec r) = \int_{-\infty}^{\infty} f^*(\tau)\, g(\vec r+\tau)\, d\tau$$

Take Inverse Fourier Transform to calculate the Cross-Correlation Function (CCF)



(Cross-Correlation Function)

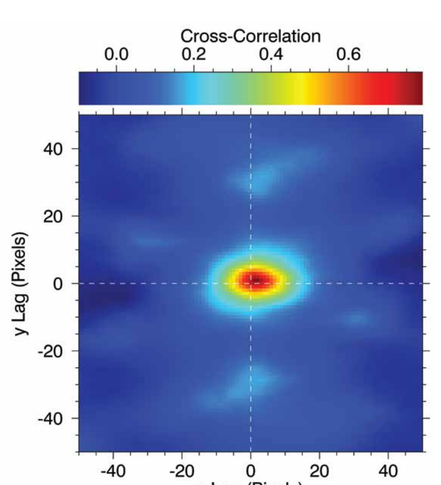
Peak of the Cross-Correlation Function (CCF) represents the displacement vector

We create a **synthetic backscatter image** in computer using Interactive Data Language (IDL). This is done by two-dimensional array filled with random numbers and smoothing the array with a two-dimensional moving average. Then, we randomly place Gaussian features in the array and diffuse the features using turbulent fluctuation fields [4, 5]. We call this array "Block 1".

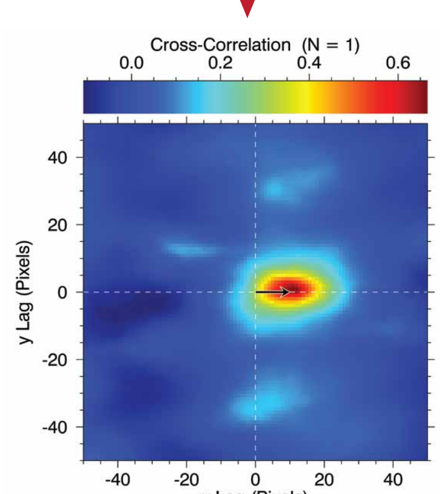
Next we create a two-dimensional, two-component, **velocity field** (u, v) by sum of an analytical function of flow field and a turbulent fluctuation field (u', v') based on the model of Jacob Mann [4, 5].

Then, we move each pixel in "Block 1" to a new location according to the velocity at that pixel location. An image of the displaced pixel distribution is formed by applying a **bicubic interpolation**. The **new image** with dispaced features is reffered to as "Block2".

The **cross-correlation algorithm** is applied to the images to estimate the **displacement vector**.



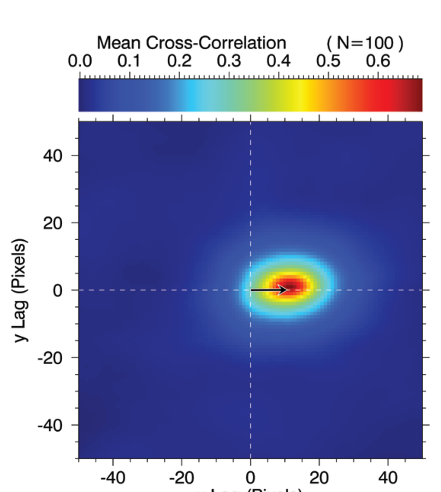
To make a better approximation of the displacement vector, we move the "Block 2" according to the initial estimation of the displacement vector, and apply the cross-correlation algorithm again (**multi-pass approach**). In this case, we use a polynomial fit to estimate the **subpixel fluctuation** of the displacement vector.



Finally we add the initial estimate of the displacement vector and the subpixel fluctuation of the displacement vector to get the **resultant displacement vector**.

Why Use Synthetic Backscatter Images?

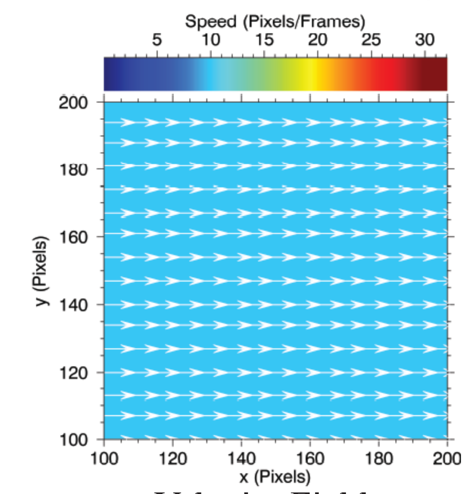
We cannot control the atmosphere to test.



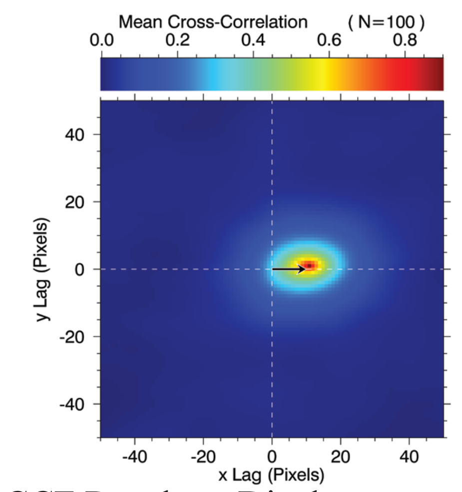
Test is repeated by using different synthetic backscatter images (**N=100**). Then, the **mean displacement vector** and the **standard deviation** due to different synthetic backscatter images are calculated. Finally, we compare the displacement vector with the prescribed velocity field.

Results

1. Uniform Flow

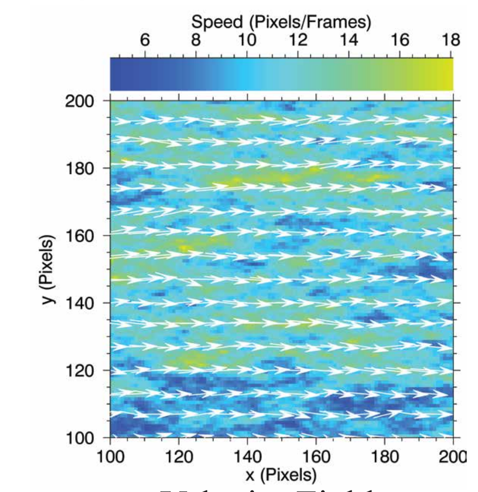


Velocity Field
Mean (10.000, 0.000) Pixels/Frames
SD (0.000, 0.000) Pixels/Frames

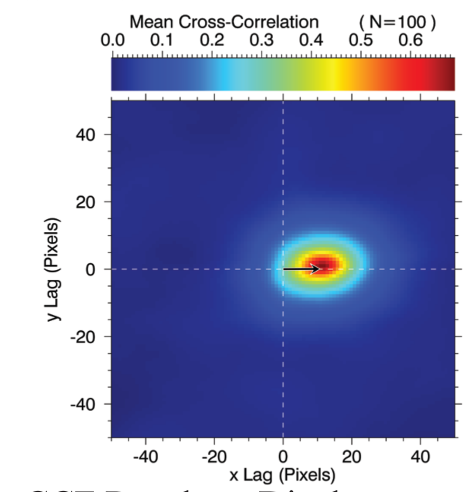


CCF Resultant Displacement (N=100)
Mean (9.98426, 0.00005) Pixels
SD (0.00355, 0.00044) Pixels

2. Uniform Flow with Turbulent Fluctuations

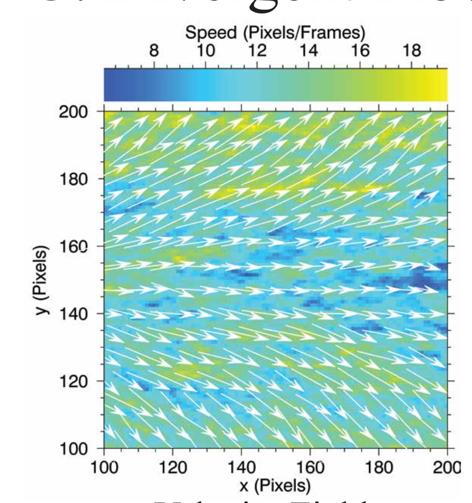


Velocity Field
Mean (11.083, 0.104) Pixels/Frames
SD (1.971, 1.232) Pixels/Frames

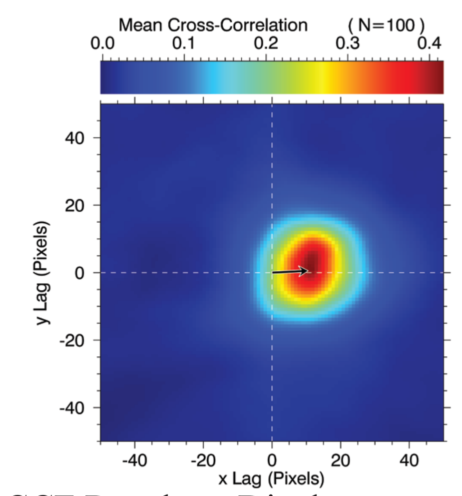


CCF Resultant Displacement (N=100)
Mean (10.7476, 0.07016) Pixels
SD (0.77810, 0.28854) Pixels

3. Divergent Flow with Turbulent Fluctuations

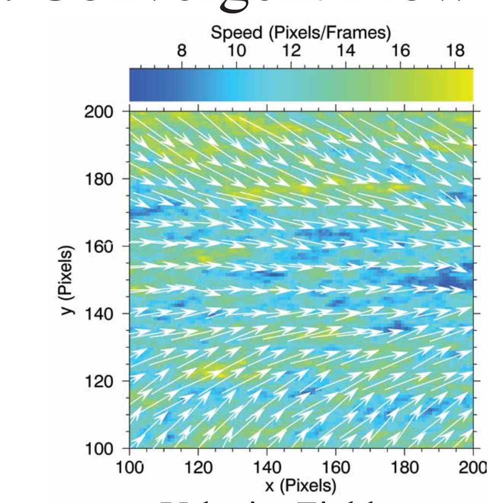


Velocity Field
Mean (11.083, 0.103) Pixels/Frames
SD (1.971, 6.183) Pixels/Frames

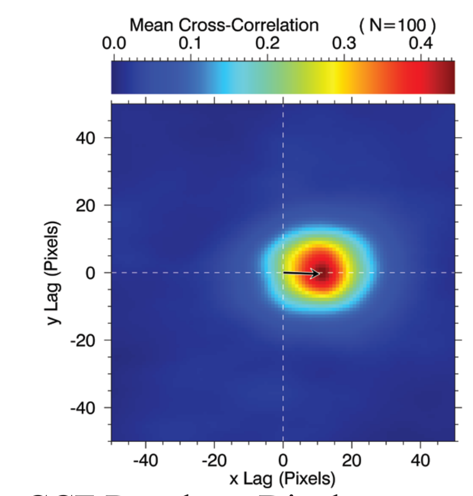


CCF Resultant Displacement (N=100)
Mean (10.5628, 0.55299) Pixels
SD (1.72201, 5.34860) Pixels

4. Convergent Flow with Turbulent Fluctuations

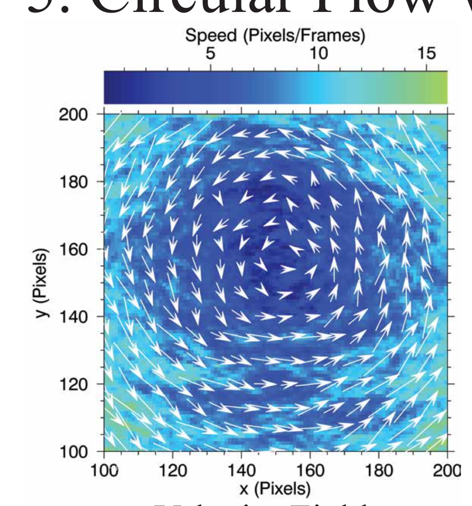


Velocity Field
Mean (11.083, 0.103) Pixels/Frames
SD (1.971, 5.728) Pixels/Frames

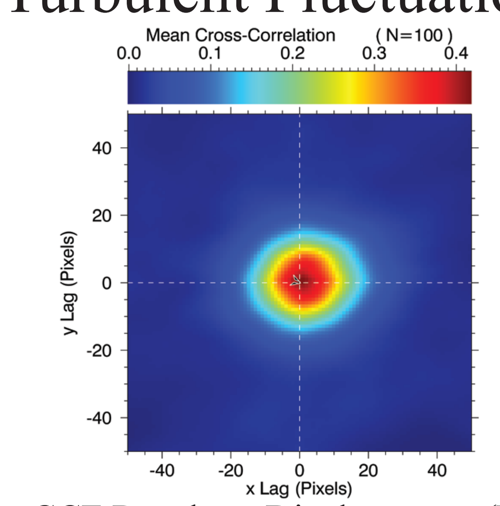


CCF Resultant Displacement (N=100)
Mean (10.7123, -0.39521) Pixels
SD (1.54535, 3.53784) Pixels

5. Circular Flow with Turbulent Fluctuations

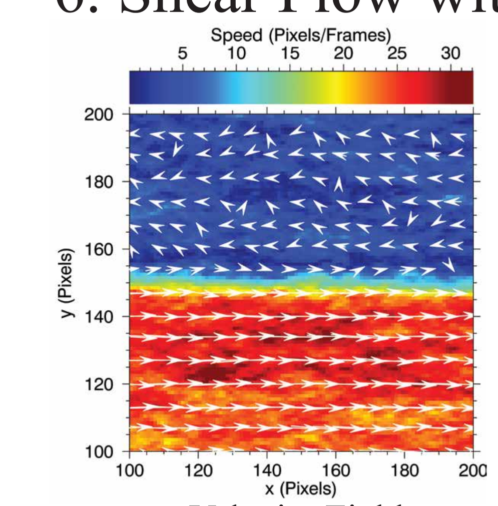


Velocity Field
Mean (1.083, 0.104) Pixels/Frames
SD (5.462, 5.922) Pixels/Frames

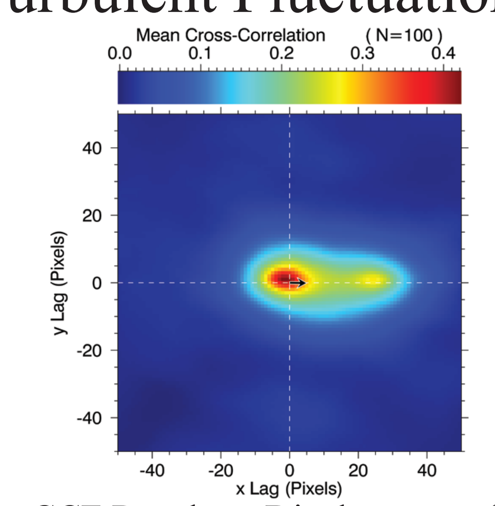


CCF Resultant Displacement (N=100)
Mean (0.34509, -0.11779) Pixels
SD (3.37916, 4.33848) Pixels

6. Shear Flow with Turbulent Fluctuations



Velocity Field
Mean (11.232, 0.104) Pixels/Frames
SD (13.870, 1.232) Pixels/Frames



CCF Resultant Displacement (N=100)
Mean (4.94471, -0.11452) Pixels
SD (14.1630, 0.97839) Pixels

Conclusion

The results show that the cross-correlation algorithm provides reliable displacement vectors if the flow is uniform. However, because the cross-correlation algorithm only results in one displacement vector for the entire block, information that could describe non-uniformity is not retrived. As a result, ambiguity increases, and the performance of the cross-correlation algorithm decreases as non-uniformity of the flow fields increases.

References

[1] Schols, J. L. and E. W. Eloranta, 1992: The calculation of area-averaged vertical profiles of the horizontal wind velocity from volume-imaging lidar data. J. Geophys. Res., 97, 18 395–18 407.
[2] Eloranta. E. W., J.M.King and J. A. Weinman, 1975: The determination of wind speeds in the boundarylayer monostatic lidar. J. Appl. Meteor, 14, 1485-1489.
[3] Mayor, S. D., J. P. Lowe, and C. F. Mauzey, 2012: Two-component horizontal aerosol motion vectors in the atmospheric surface layer from a cross-correlation algorithm applied to elastic backscatter lidar data, J. Atmos. Ocean. Technol., 29, 1585-1602.
[4] Mann, J. 1994: The spatial structure of neutral atmospheric surface-layer turbulence, J. Fluid Mech., 273, 141-168.
[5] Mann, J. 1998: Wind field simulation, Prob.Engng. Mech. 13, 269-282

"This work was supported by NSF AGS 1228464."