Objective determination of wavelength and orientation of atmospheric canopy waves

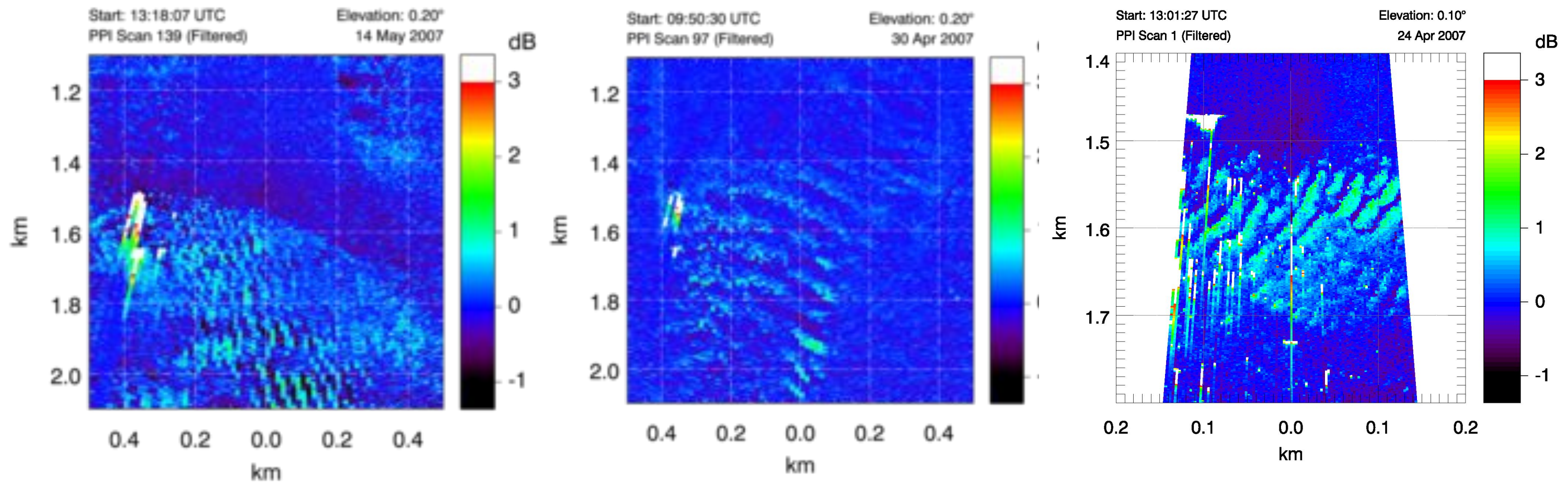
Katherine Mifsud

Faculty mentor: Dr. Shane D. Mayor, College of Natural Sciences

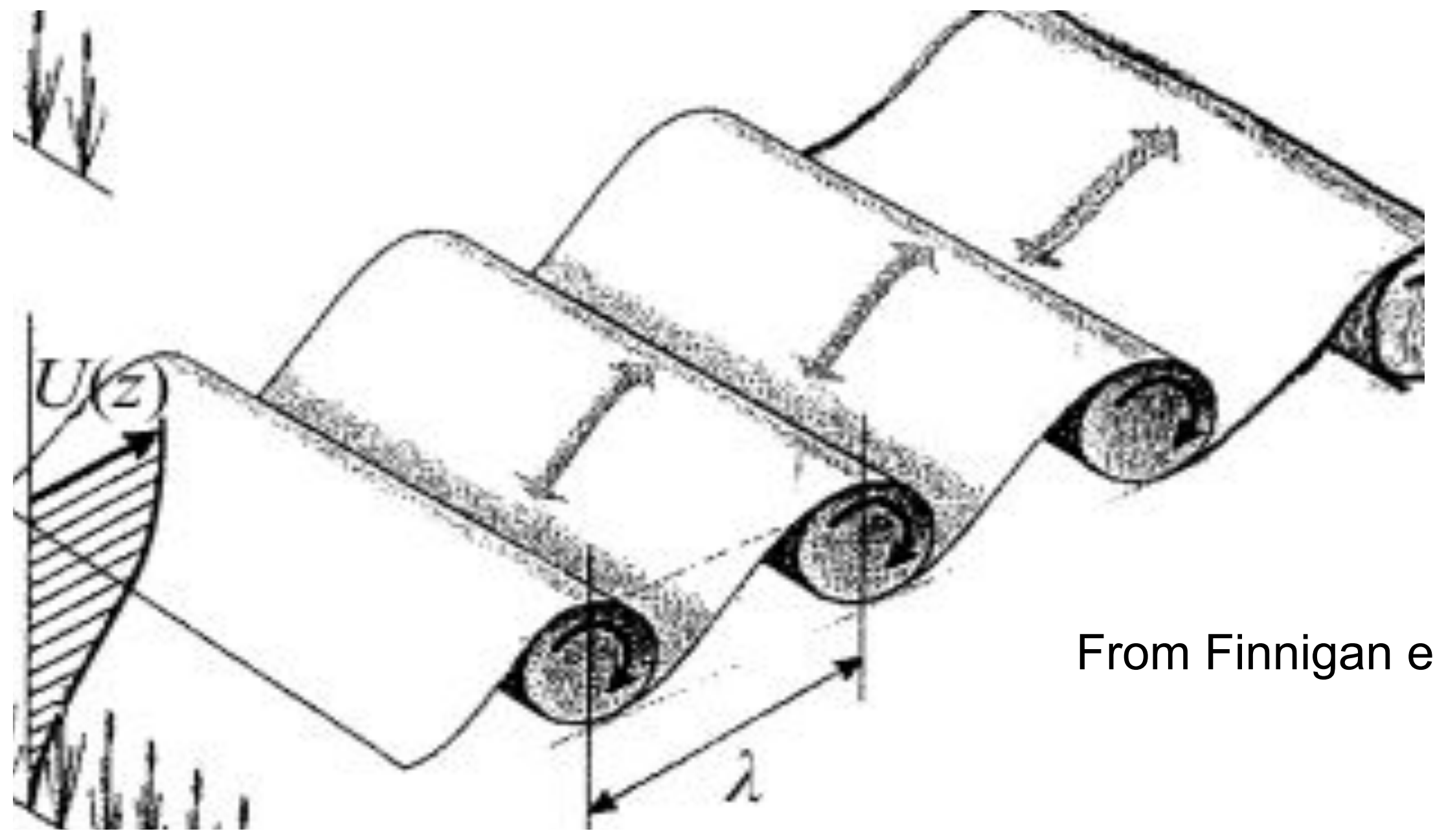
Introduction

53 canopy wave episodes were observed during the 2007 CHATS research project using a horizontally scanning aerosol LIDAR and tower-mounted in situ sensors. For more on the project see Patton et al. 2011.

- Canopy waves were considered to be an episode when they lasted longer than one minute and passed through the CHATS vertical tower located 1.6 km south of the LIDAR. The following images are examples of canopy waves observed by the LIDAR in the vicinity of the tower (see Jachens et al. 2012).



- Each episode appeared to vary in salient wavelength ranging from less than 20 m to over 100 m, thus making it a goal to automatically and objectively identify the salient wavelength for each case.
- Canopy waves are the result of inflection point instability in the mean wind speed profile and may result in Kelvin Helmholtz billows.

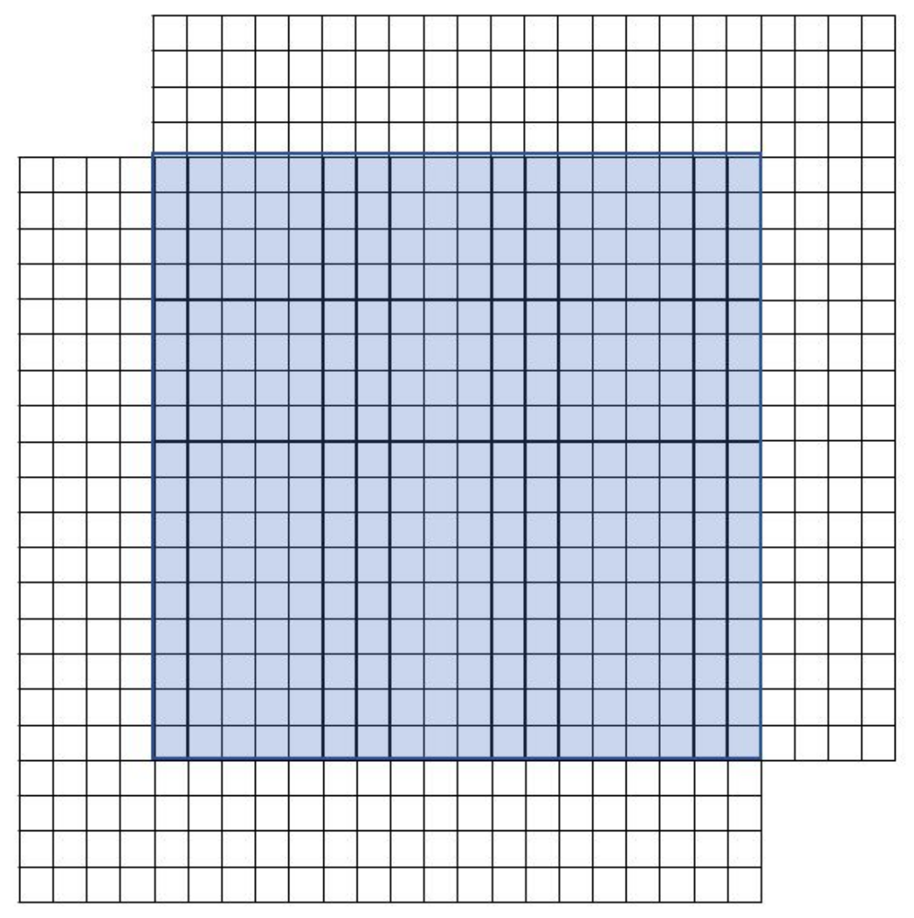


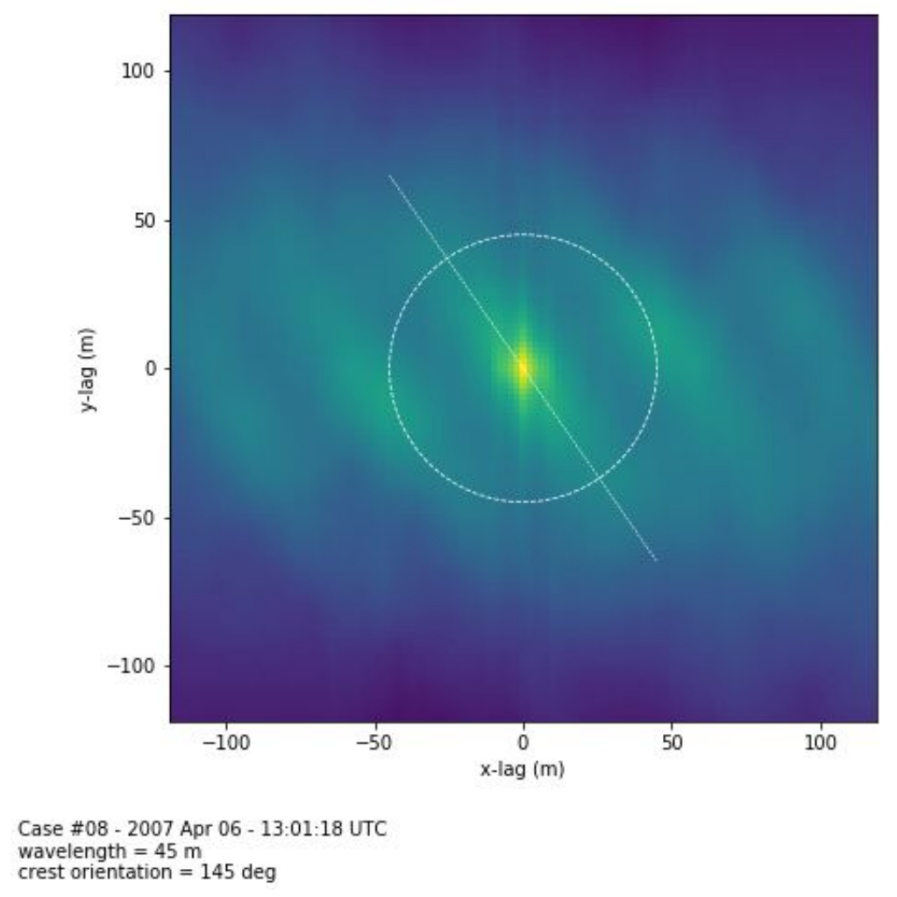
From Finnigan et al. 2009

- We hypothesize that an automated computer algorithm can find the wavelength and orientation automatically, quickly, and accurately as well as, or better than, a human can.

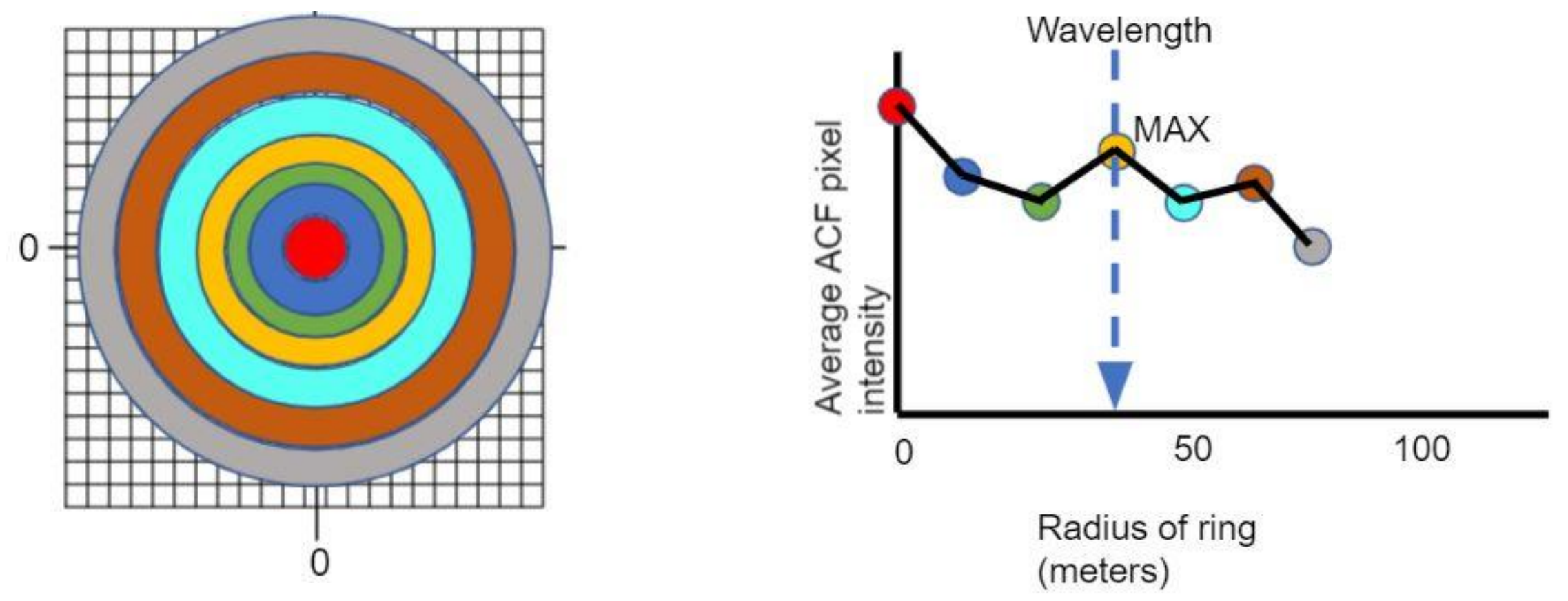
Methods

- Subjective measurements of wavelength and orientation were made by humans using rulers and protractors (see Mayor 2017).
- Objective measurements were collected using an algorithm developed and coded by Dr. Pierre Dérian. The algorithm was written in Python and shared through Jupyter Notebook.
- The first step of the algorithm is to compute an autocorrelation function (ACF) in a subset of pixels from a LIDAR scan.

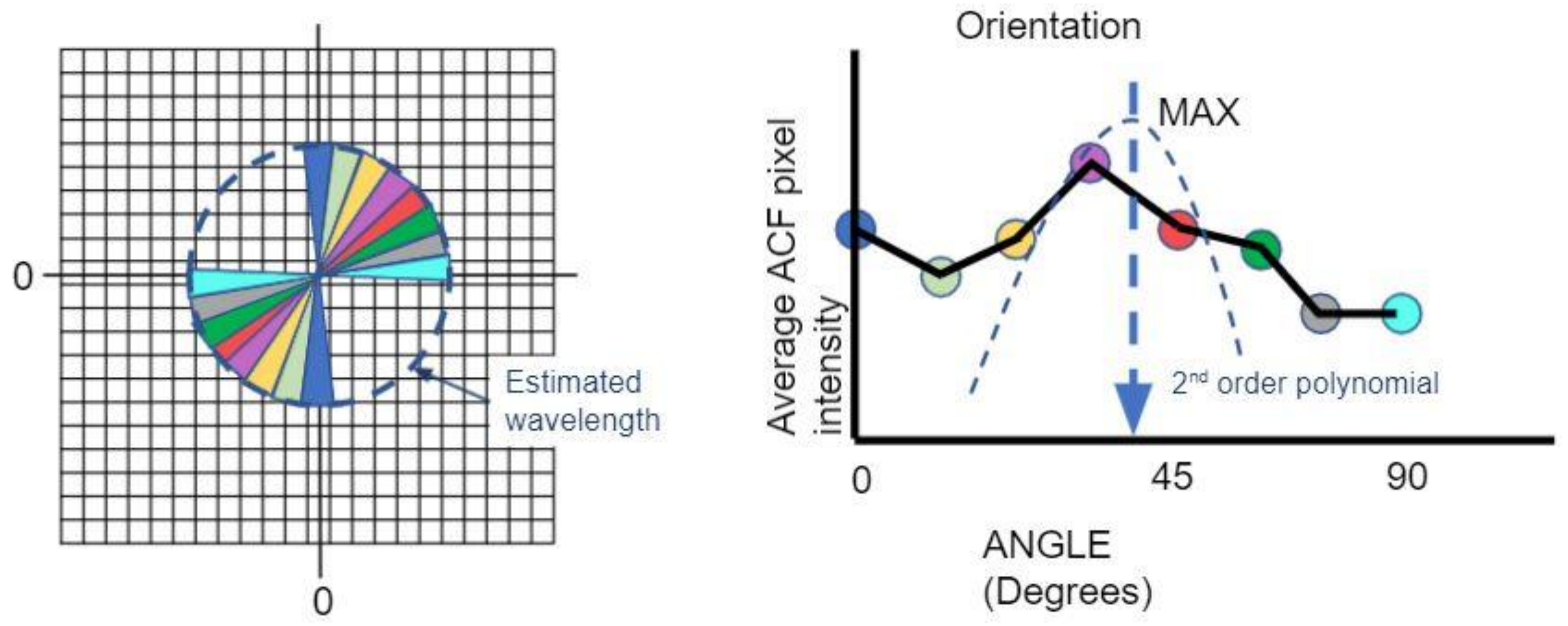




- An ACF (shown above to the right) is calculated by shifting the original image array with respect to itself by Δx and Δy, and computing the linear correlation coefficient of the overlapping area (blue shaded region above), and then placing that single value into the two-dimensional array of the ACF. In practice, this is done efficiently through the use of Fast Fourier transforms and the Weiner-Khinchin theorem.



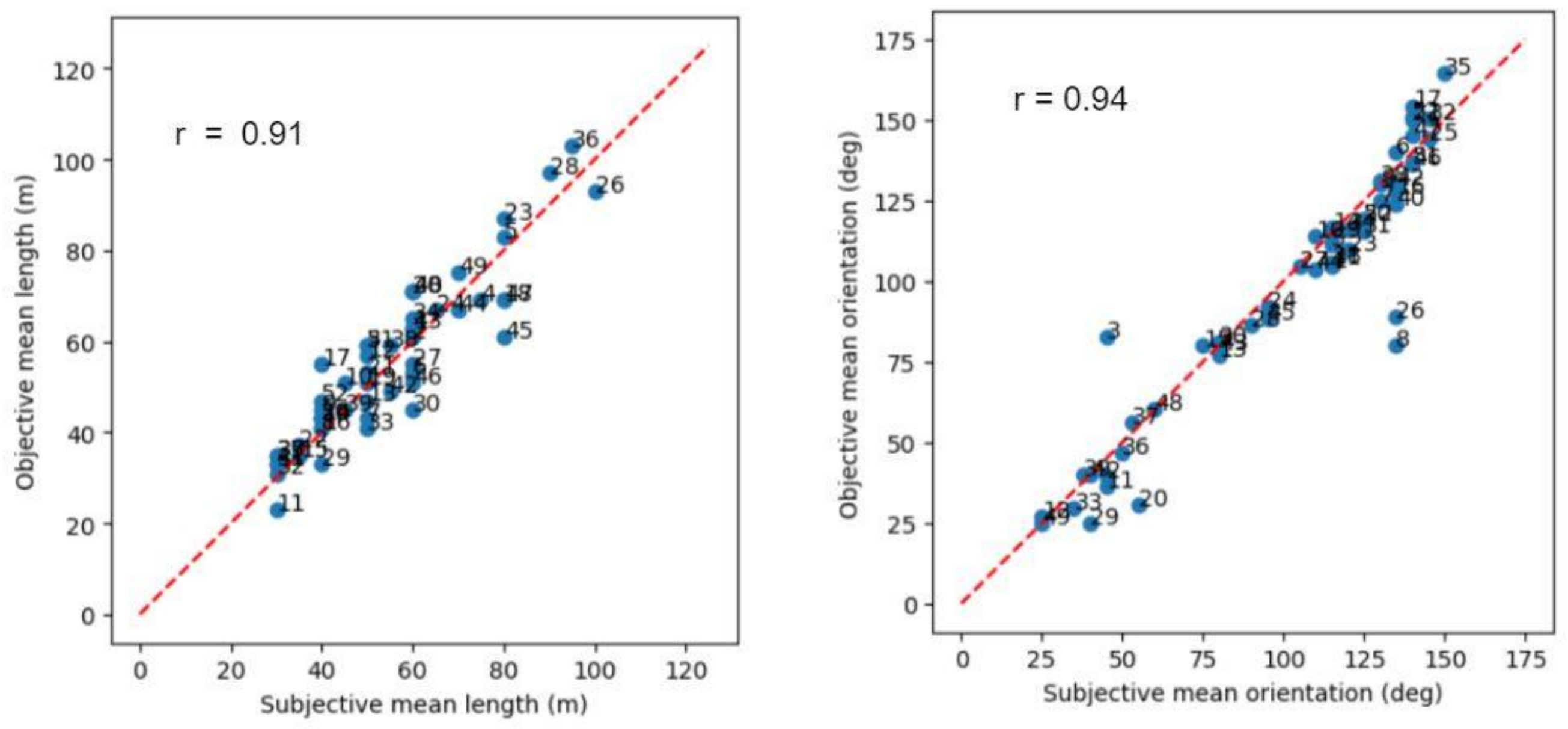
- Wavelength is determined by averaging all ACF values within a band of radii, and then finding the location of the second peak (see above).



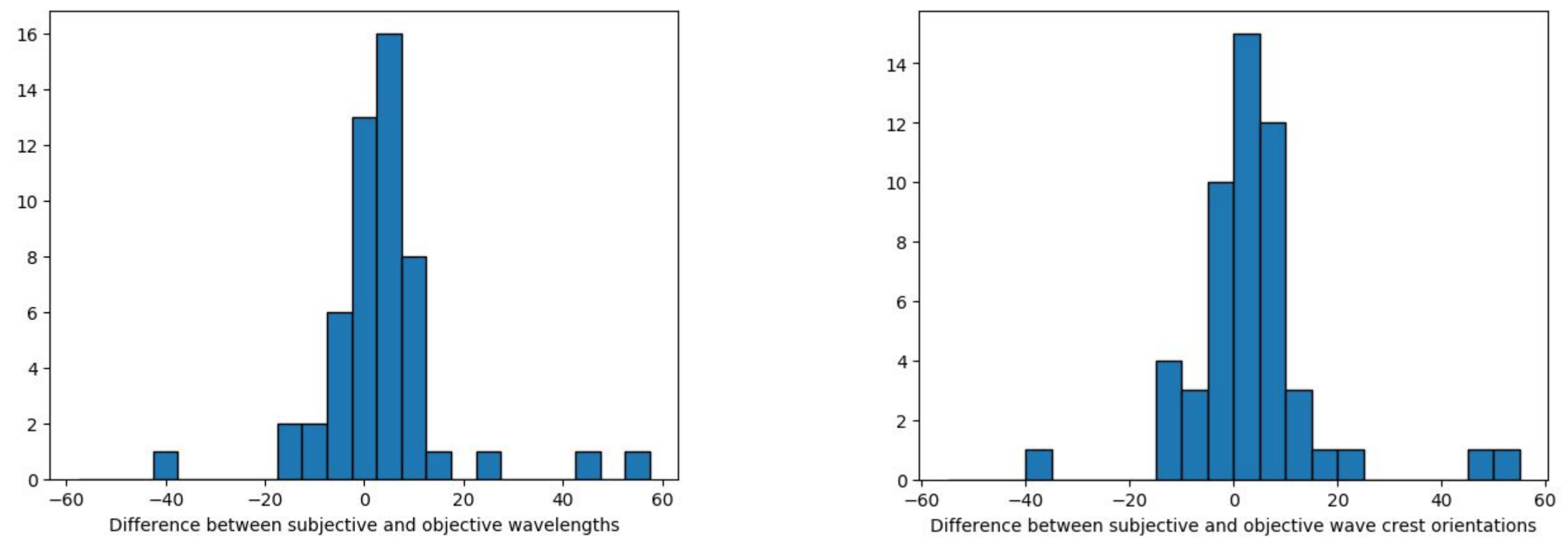
- Orientation is determined by averaging all ACF values within bands of angles up to a radius equal to the wavelength, finding the location of the maximum, and fitting a second order polynomial to the 9 points surrounding the maximum for improved angular resolution.

Results

- Below, we show comparison of the objective estimates with the subjective estimates in scatterplots.
- These plots show good agreement over the full range of observed wavelengths (left) and orientations (right).



- We calculated the differences between the objective and subjective estimates and plot those distributions in the histograms below.
- 85% of wavelengths lie within 10 m of zero (left).
- 76% of orientations lie within 10° of zero (right).



- We conclude that the algorithm is very skilled at retrieving wavelength and orientation automatically and efficiently.

References

Finnigan, J., Shaw, R., & Patton, E., 2009: Turbulence structure above a vegetation canopy. *Journal of Fluid Mechanics*, ***637***, 387-424.

Jachens, E. R. and S. D. Mayor, 2012: Lidar observations of fine-scale atmospheric gravity waves in the nocturnal boundary layer above an orchard canopy. Poster Presentation S8P-05 at the 26th International Laser Radar Conference, 25-29 June 2012 in Porto Heli, Greece.

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Patton, E. G. et al. 2011: The Canopy Horizontal Array Turbulence Study (CHATS), *Bull. Amer. Meteorol. Soc.* **92**, 593-611.

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