Comparison of wind retrieval techniques from Single and Multi-Doppler Radar

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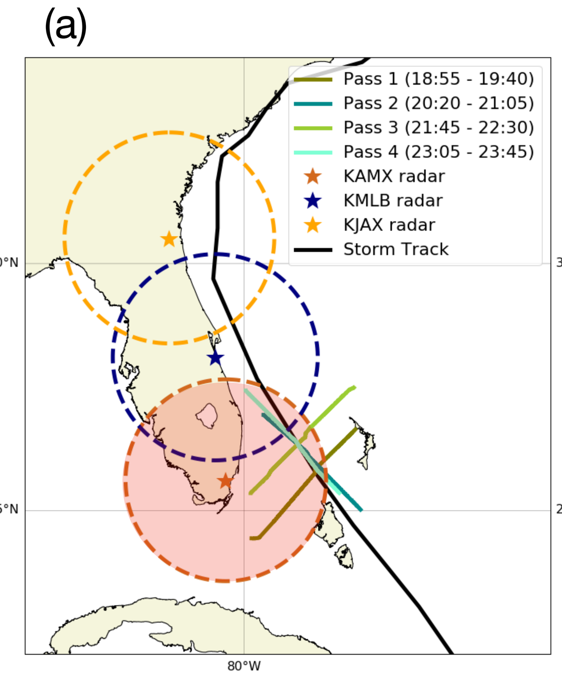
Using either one or multiple Doppler radars to retrieve the wind and derive the kinematic structure of hurricanes have been two widely utilized techniques for decades. Although each platform has its own advantages and disadvantages, none of previous studies conducts the comparison comprehensively between the two platforms due to the lack of simultaneous observations. Hurricane Matthew (2016) was observed by the NEXRAD KAMX polarimetric radars and NOAA P-3 airborne radar when it approached the southeastern United States for five hours, providing an unique opportunity to evaluate the wind retrievals.

Overview of Single and Multiple Doppler radar observations

(a)



(b)

KAMX radar	NOAA P3 tail radar
• S-band single Doppler radar (10.5 cm) • Complete each volume scan every 6 minutes	• X-band dual Doppler radar (3.22 cm) • 20° fore and aft beams • Steady-State Assumption for one flight leg

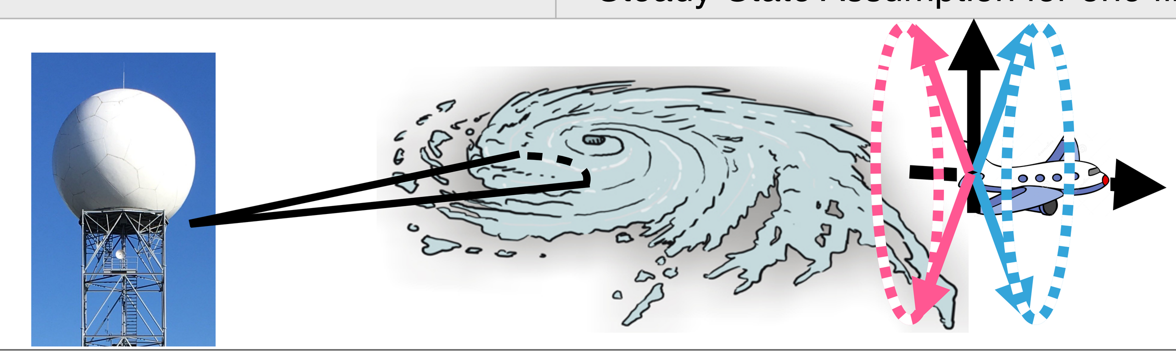
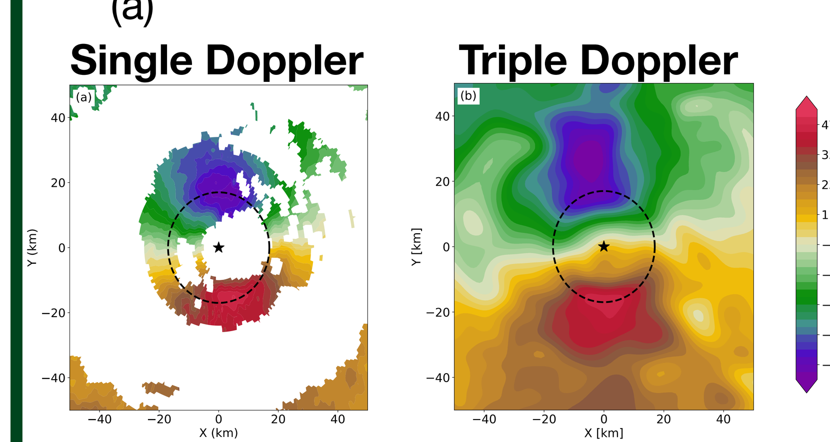


FIG. 1. (a) Simultaneous observations by the P3 ail radar and KAMX radar when Hurricane Matthew traveled along the east coast of Florida from 19 UTC to 24 UTC October 6. (b) Comparison of single and multiple Doppler radar observations.

What are the pros and cons of the wind retrievals with multi-Doppler and single Doppler analyses respectively?

Comparison of wind retrievals between single Doppler and triple Doppler analyses

(a)

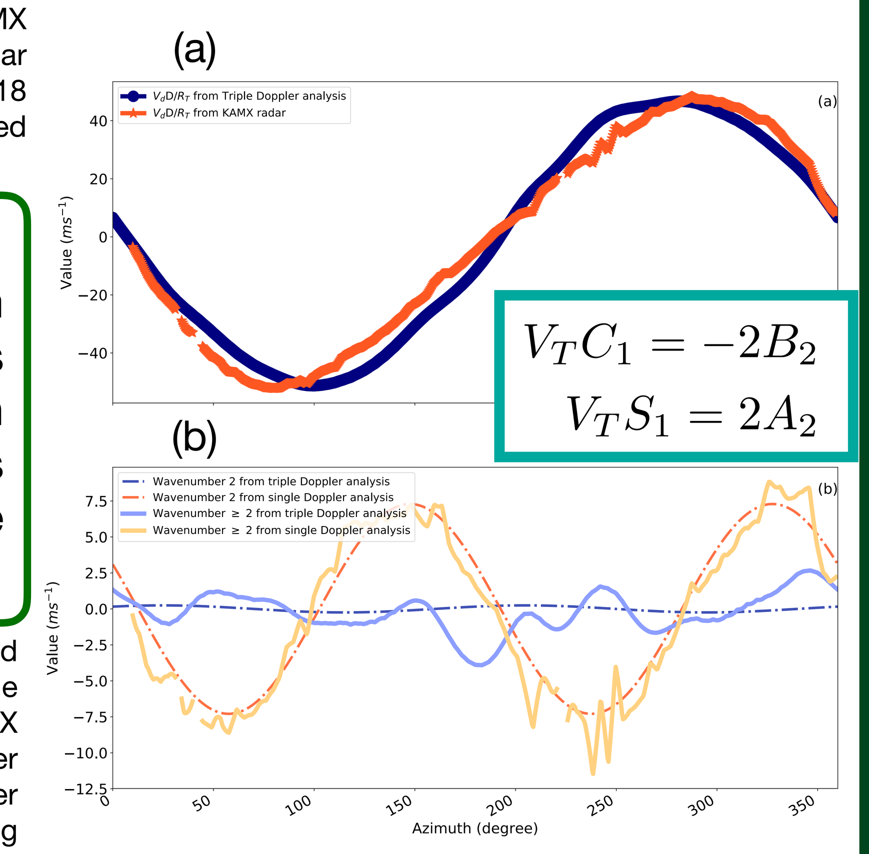


(b)

Coefficients	Single Doppler	Triple Doppler
A_0	-0.66 (m/s)	-1.28 (m/s)
$\sqrt{{A_1}^2+{B_1}^2}$	44.94 (m/s)	43.2 (m/s)
$\sqrt{{A_2}^2+{B_2}^2}$	**7.29 (m/s)**	**0.245 (m/s)**

FIG. 4. (a) The Doppler velocity observed by KAMX obtained from KAMX radar and triple Doppler analysis. The black star denotes the radar location, and the dashed circle denotes the radius of maximum wind (18 km) estimated from the GVTD analysis. (b) Comparison of retrieved coefficients from the single and triple Doppler radar analysis.

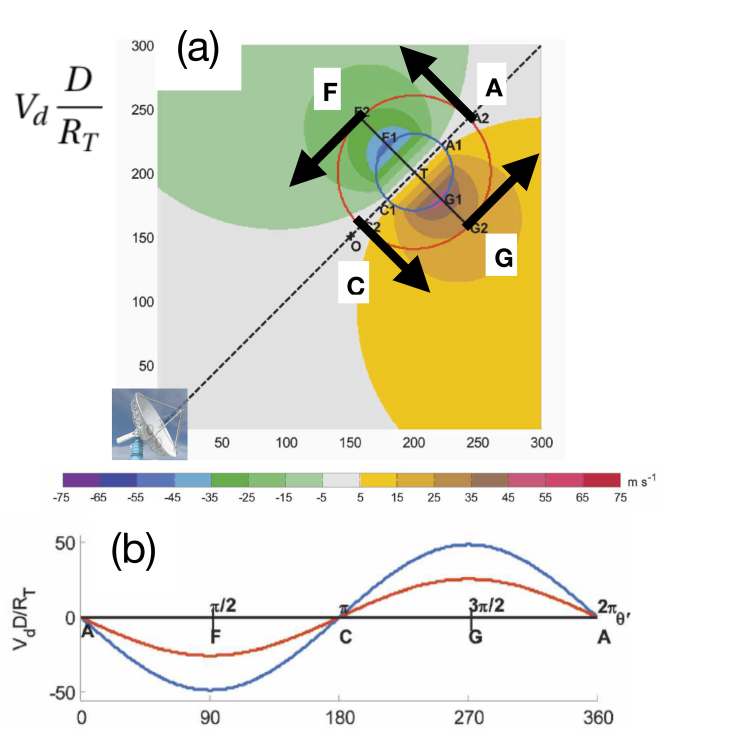
- Both A0, A1, B1 magnitude are similar. However, the magnitude of A2 and B2 from the triple Doppler analysis are much less than the single Doppler radar. The mismatch of retrieved wavenumber 1 tangential wind is due to the assumption of steady state in the triple Doppler analysis.



$$V_T C_1 = -2B_2$$
$$V_T S_1 = 2A_2$$

FIG. 5. (a) Comparison of retrieved VdD/RT between triple Doppler and single Doppler analyses. Blue line denotes retrieved VdD/RT from triple Doppler analysis, and orange line denotes retrieved VdD/RT from KAMX radar. (b) Comparison of retrieved wavenumber 2 and even higher wavenumber of VdD/RT between triple Doppler and single Doppler analyses. The solid line denotes the residuals of subtracting wavenumber 0 and 1 from VdD/RT. The dash-dotted line represents the wavenumber 2 component of VdD/RT.

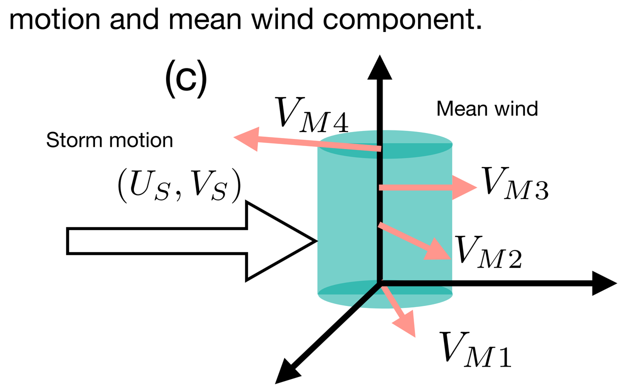
Overview of the GVTD technique and improvement



$$V_d \frac{D}{R_T}(R,\theta') = A_0 + \Sigma A_n cos n\theta' + \Sigma B_n sin n\theta'$$

FIG. 2. (a) VdD/RT display for a pure rotating vortex. (b) VdD/RT profiles at R = 30 and 60 km. (c) Schematic of storm motion and mean wind component.

(c)



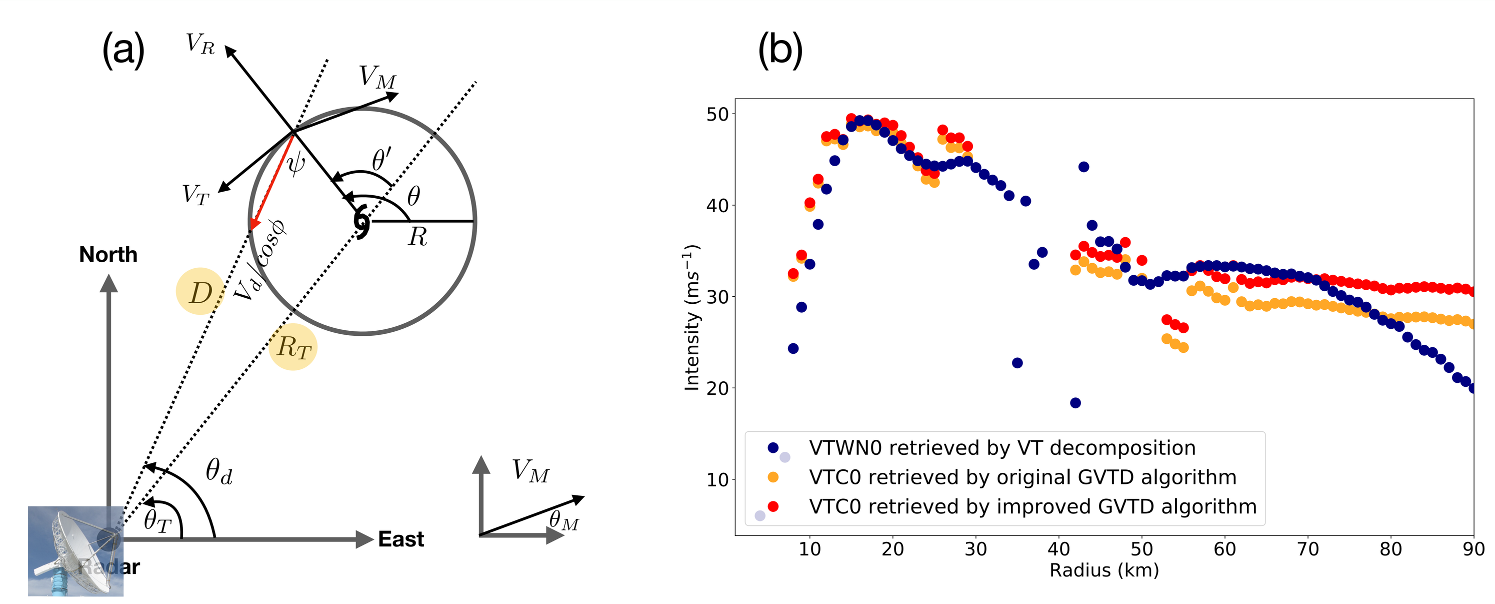


FIG. 3. (a) The geometry and symbols used in the formulation of GVTD (modified from Jou et al. (2008)). Red arrow denotes the Doppler velocity. (b) Wavenumber 0 tangential wind is retrieved respectively by Fourier decomposition of tangential wind from the triple Doppler analysis (blue dots), original GVTD algorithm from the single Doppler analysis (orange dots), and improved GVTD algorithm from the single Doppler analysis (red dots).

$$V_d/cos\phi = \boxed{V_M cos(\theta_d - \theta_M) + U_S cos\theta_d + V_S sin\theta_d} - V_T sin\psi + V_R cos\psi$$

$$V_T C_0 = \boxed{-B_1 - B_3}$$ Fourier Coefficients of VdD/RT

$$\boxed{+\frac{R}{R_T}[-U_S sin\theta_T + V_S cos\theta_T]}$$ We added the Storm motion

$$\boxed{+\frac{R}{R_T}[-V_M sin(\theta_T - \theta_M) + V_R S_1 + V_R S_3] + V_R S_2}$$ Neglecting asymmetric components of radial wind

- The GVTD technique takes advantage of the Doppler velocity signatures of a vortex with a dipole pattern. The velocity appears as a sine curve on a GVTD ring. Based on the characteristics of the Doppler velocity, we are able to resolve the wind with the Fourier decomposition method.
- The storm motion is a deep layer flow over the vortex, and the mean wind is a function of height. **We improve the algorithm by separating the storm motion from the mean wind component.**

Examination of the steady state assumption in the triple Doppler analysis

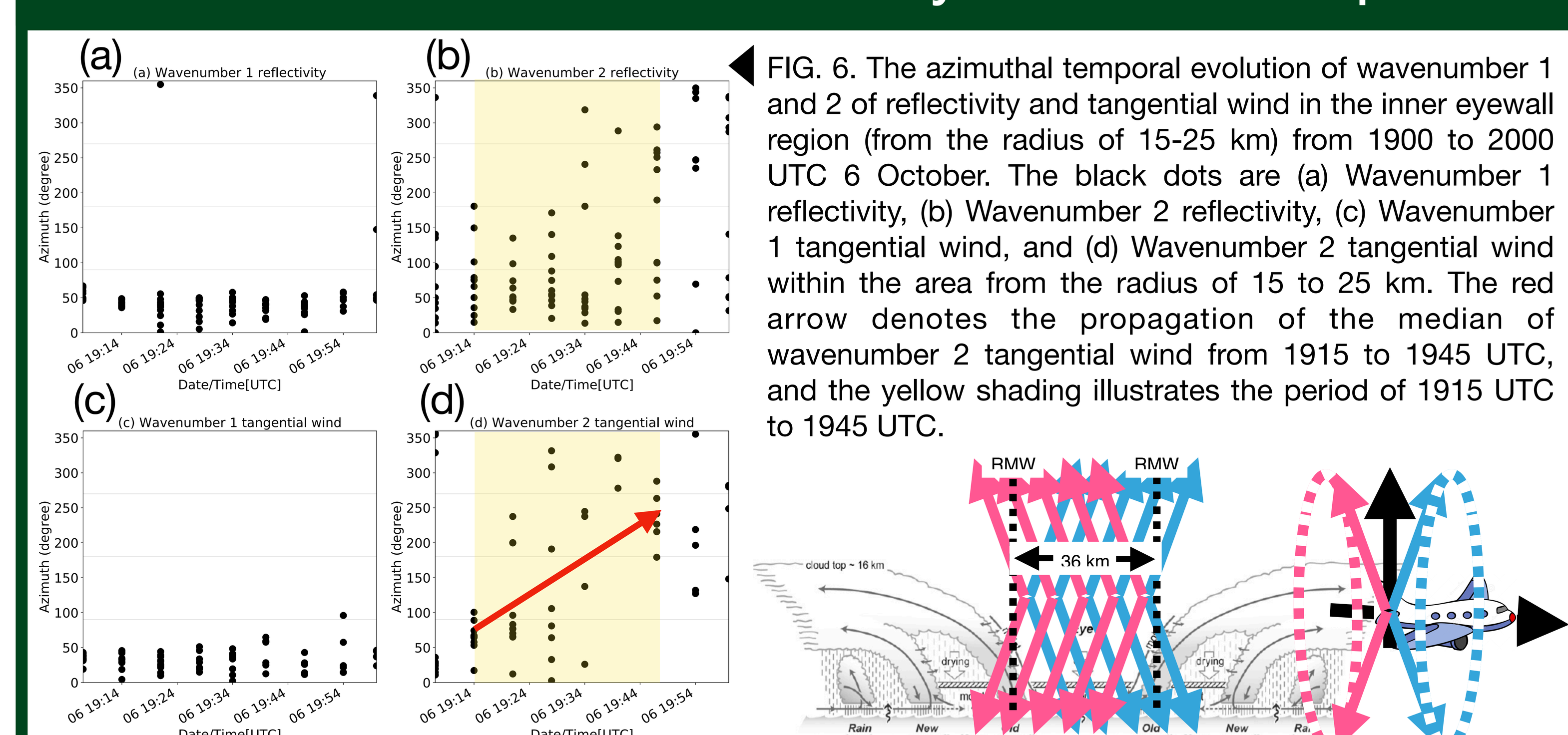


FIG. 6. The azimuthal temporal evolution of wavenumber 1 and 2 of reflectivity and tangential wind in the inner eyewall region (from the radius of 15-25 km) from 1900 to 2000 UTC 6 October. The black dots are (a) Wavenumber 1 reflectivity, (b) Wavenumber 2 reflectivity, (c) Wavenumber 1 tangential wind, and (d) Wavenumber 2 tangential wind within the area from the radius of 15 to 25 km. The red arrow denotes the propagation of the median of wavenumber 2 tangential wind from 1915 to 1945 UTC, and the yellow shading illustrates the period of 1915 UTC to 1945 UTC.

- The P3 flight speed as 120 m/s, and the diameter of the eye is 36 km. It took 5 minutes for P3 to fly across the inner eyewalls. A wavenumber 2 tangential wind with the propagation speed of 23 m/s had already propagated for 22 degrees by the time the P3 flew across the eyewalls.
- The propagation of a wavenumber 2 tangential wind likely caused the discrepancy in wavenumber 1 tangential wind between single Doppler and triple Doppler observations.

Conclusion

- This study improves the algorithm of the GVTD technique by separating the storm motion from the mean wind component which yields a more accurate estimation of mean wind, wavenumber 0 tangential and radial winds.
- The comparison between single and multi-Doppler analyses points out that each platform has its own advantages and disadvantages.

	Single Doppler	Multiple Doppler
Resolution	Higher temporal resolution, Lower spatial resolution.	Lower temporal resolution, Higher spatial resolution.
Axisymmetric tangential wind retrieval	The retrievals from these two platforms are in a good agreement.	
Asymmetric tangential wind retrieval	Aliased by the asymmetric components of radial wind.	Aliased by the rotating system and short temporal scale activities.

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