Validation of Simulated Hurricane Raindrop Size Distributions using Dual-Polarized Radar

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Introduction

Recent upgrades to the U.S. radar network now allow for polarimetric measurements of landfalling hurricanes, providing a new dataset to validate cloud microphysical parameterizations used in tropical cyclone simulations. Polarimetric radar variables simulated by the Weather Research and Forecasting model were compared with real radar observations from 2014 in Hurricanes Arthur and Ana. Six different microphysics parameterizations were tested that were able to capture the major features of both hurricanes, including accurate tracks, asymmetric distributions of precipitation, and the approximate intensity of the storms. However, most of the schemes produced a higher frequency of larger raindrops than observed. The Thompson aerosol-aware bulk and a spectral bin microphysical (SBM) scheme showed the best fidelity to the observed joint probability distribution of horizontal and differential reflectivity. The SBM also produced the most accurate intensity and lowest rainfall accumulation, but required much higher computational resources than the bulk schemes.

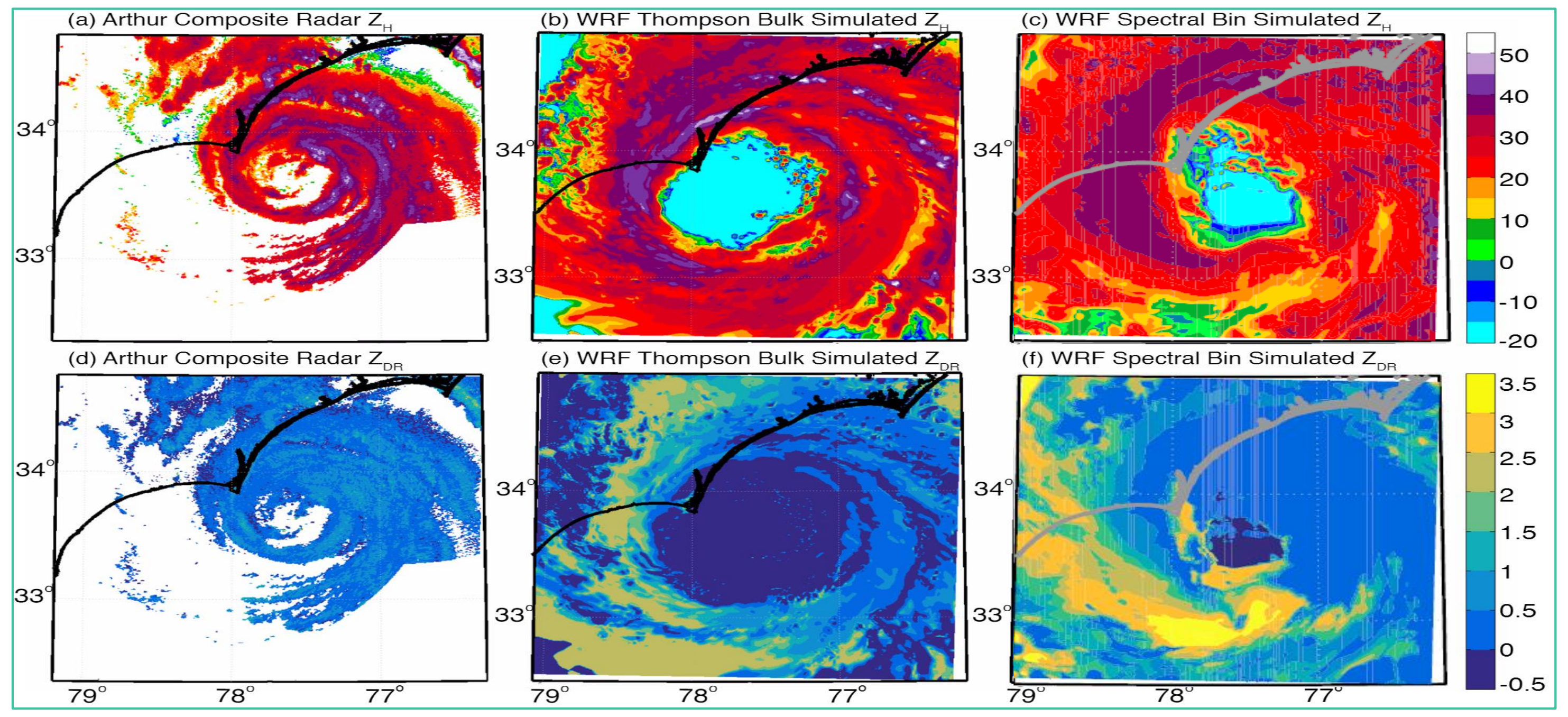


Fig. 1: An example of observed and modeled ZH (top row) and ZDR (bottom row) for Arthur at 2230 UTC 3 July 2014, at an elevation of 2 km.

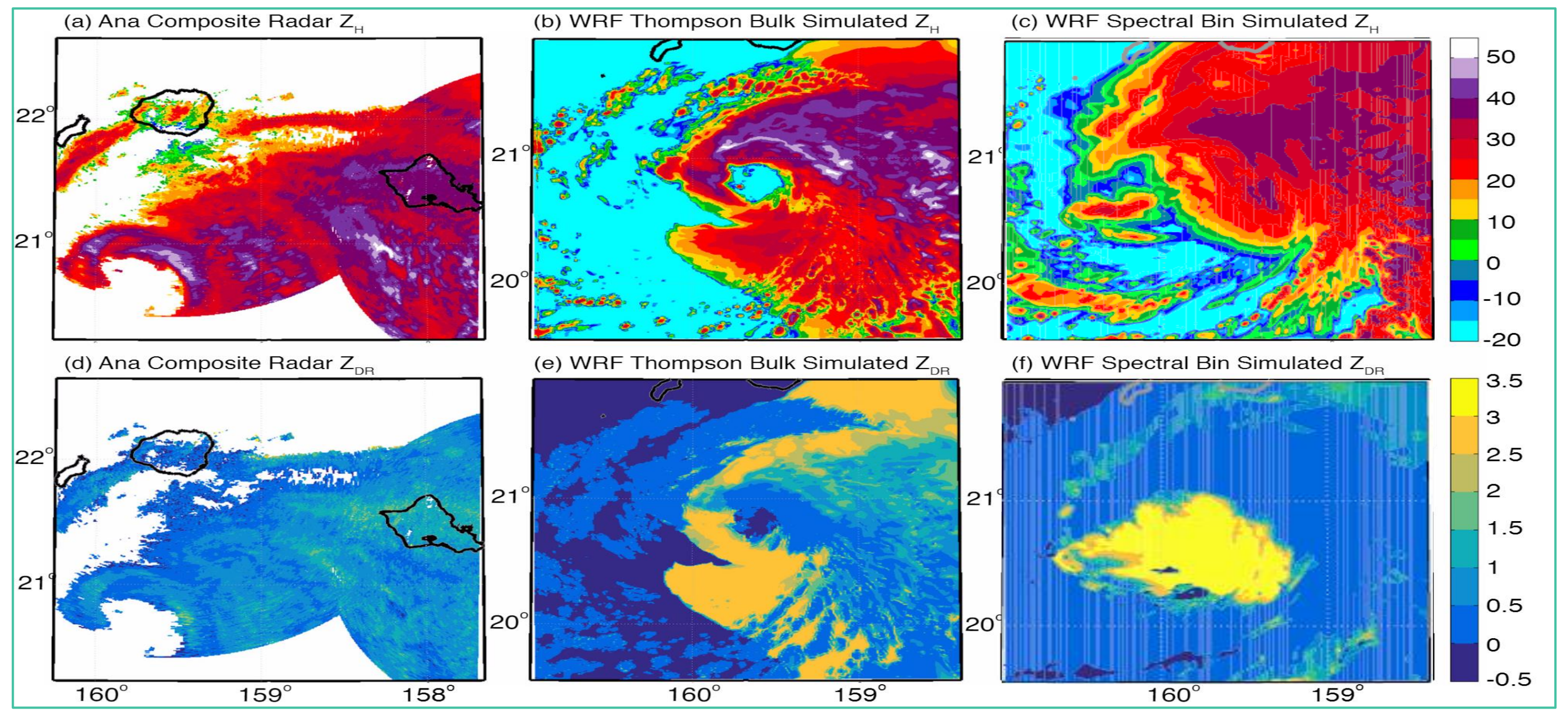


Fig. 2: As above, for Ana at 2215 UTC on 19 Oct 2014.

Radar Simulator, Data, and Model

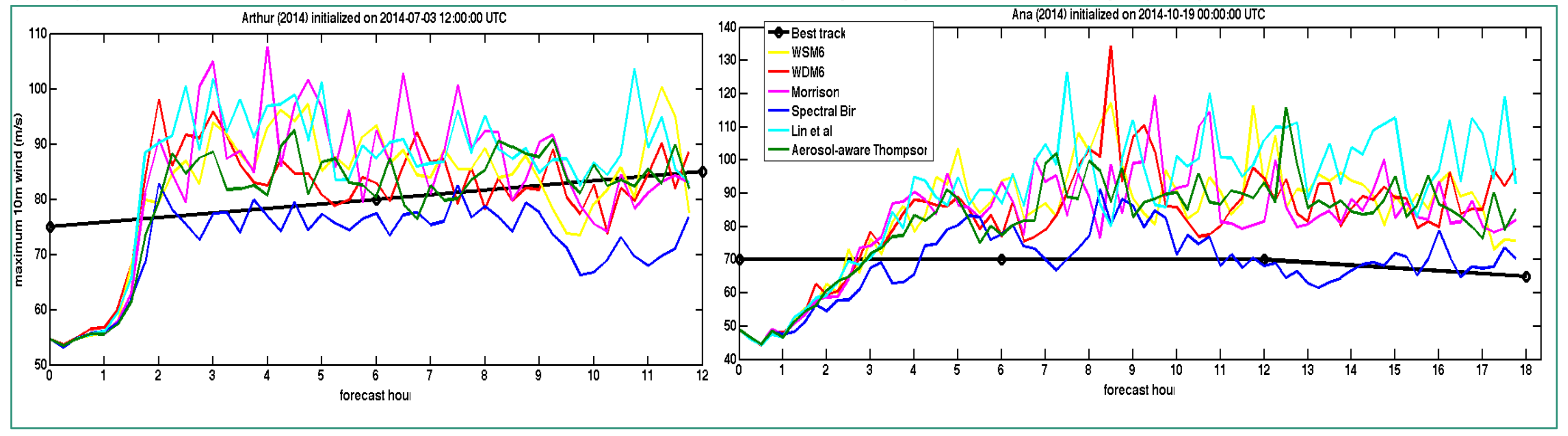
Level II data was obtained from the dual-polarized WSR-88D radars at KLTX and KMHX (Arthur) and PHMO and PHKI (Ana), and was gridded and composited. Only points with $1.0 \geq \rho_{hv} \geq 0.95$ are included. WRF-ARW v3.6.1 was initialized with 0.5° GFS FNL analyses on domains with 18, 6, 2 and 2/3 km resolution (results shown are for 2/3 km domain). Microphysics tested were: Single-moment (Lin, WSM6), double-moment (WDM6, Thompson, and Morrison) and explicit bin ("fast" spectral bin - SBM). The polarimetric observation simulator uses the shape, slope, and intercept parameters from the microphysics scheme and calculates the 10-cm radar backscatter using the T-matrix method of Mishchenko (2000) as in Jung et al (2010) and Ryzhkov et al (2011). The raindrop shapes are calculated from Beard & Chuang (1987) and their orientations are assumed to be distributed along a 2-dimensional Gaussian with a mean canting angle of 0° and a distribution width of 10°.

	CCN	Cloud	Rain	Ice	Snow	Graupel
WDM6	✓	✓	✓			
Morrison			✓	✓	✓	✓
Thompson	IN ✓ CCN✓		✓	✓		
SBM	✓	✓	✓	✓	✓	✓

Table 1: Prognostic number concentrations used by WRF double-moment and bin schemes.

Model Forecasts

Fig. 3: The maximum 10m wind for Arthur (left) and Ana (right).

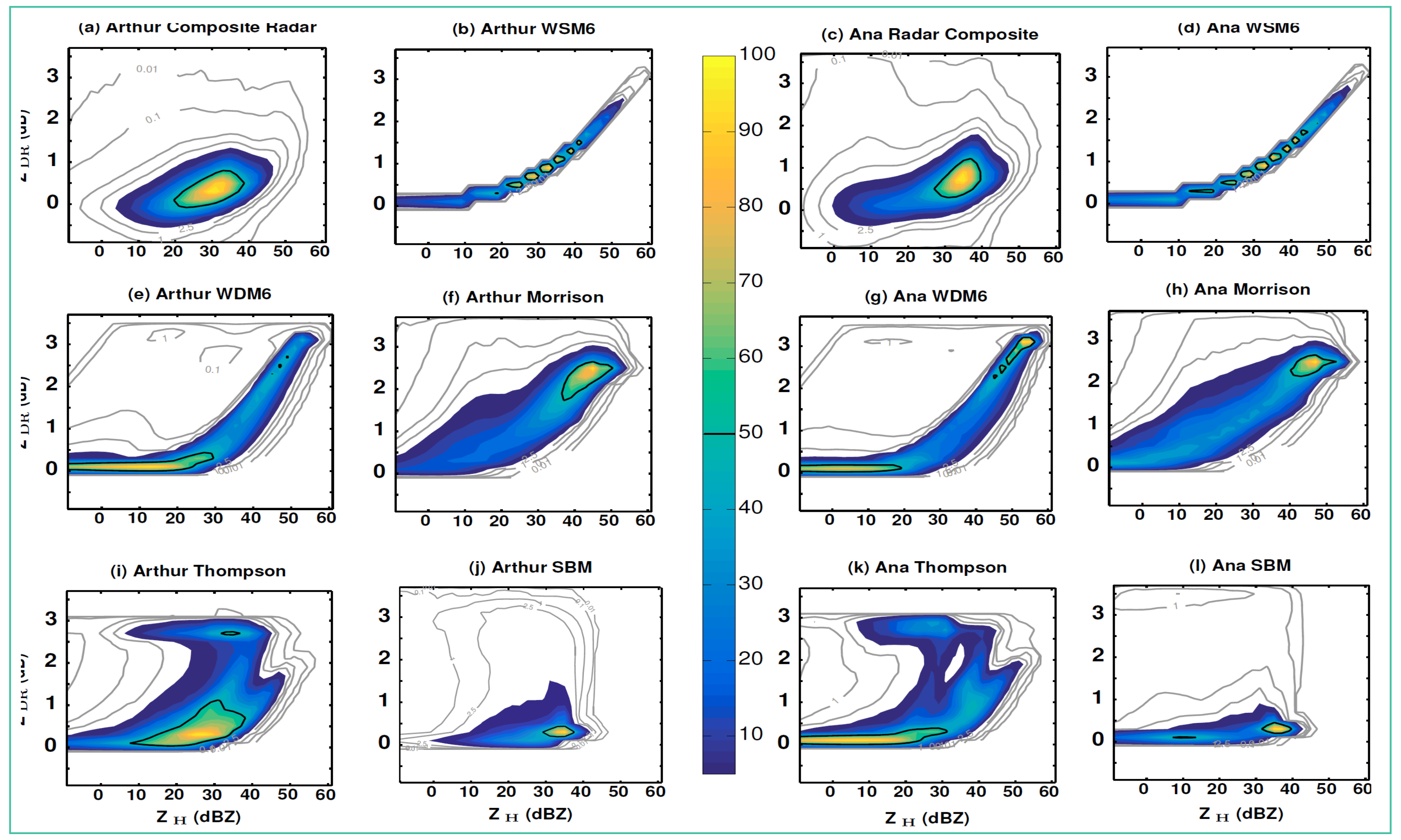


	Lin	WSM6	WDM6	Morrison	Thompson	SBM
Arthur bias (m/s)	4.5	2.8	9.4	3.5	1.4	-3.5
Ana bias (m/s)	14.2	10.3	1.1	9.2	8.7	1.3
RMS error (m/s)	12.6	9.4	8.6	9.0	7.7	4.0
Arthur Rainfall (mm)	401	327	289	270	254	191
Ana Rainfall (mm)	698	606	651	574	485	368

Table 2: Intensity bias (using maximum wind speed) and the combined intensity RMS error, all given in m/s; rainfall refers to the maximum accumulated rainfall in mm on the outermost (18km) domain at any point over the forecast time (12 hours for Arthur, 18 hours for Ana).

Joint Probability Distributions of Z_H and Z_{DR}

Fig. 4: Joint probability distributions of horizontally polarized radar reflectivity (abscissa) and differential reflectivity (ordinate) normalized by the maximum frequency in each dataset. Statistics are limited to below 3.3 km to ensure only liquid particles are considered. Results for Lin are virtually identical to WSM6, thus are not shown.



Joint PDFs from hurricanes at different intensities in different ocean basins at different forecast times yield remarkably similar results for the radar observations and each microphysical scheme. PDFs for single-moment schemes exhibit much narrower distributions for a given Z_H than observed. The higher frequency of high-Z_{DR}/low-Z_H regions evident in the Thompson PDFs could be due to the double-moment representation of size-sorting (Kumjian & Ryzhkov 2012), but is also seen at a lower frequency in the SBM which resolves the full DSD.

Summary

All of the microphysics schemes tested simulated the two hurricanes reasonably well, but the spectral bin microphysics had the most accurate intensity forecasts and best representation of the DSDs at the highest computional cost. Further investigation of the physical processes in the model using other polarimetric variables including ice and aerosol fields is ongoing.

References: Mishchenko, M. I. (2000): "Calculation of the Amplitude Matrix for a Nonspherical Particle in a Fixed Orientation" *Applied Optics*, **39**, 1026-1031. Jung, Y., M. Xue, G. Zhang (2010): "Simulations of Polarimetric Radar Signatures of a Supercell Thunderstorm Using a Two-Moment Bulk Microphysics Scheme" *J. Appl. Meteor. And Climo.*, **49**,146-163. Ryzhkov, A., M. Pinksky, A. Pokrovsky, A. Khain (2011): "Polarimetric Radar Observation Operator for a Cloud Model with Spectral Microphysics" *J. Appl. Meteor. And Climo.*, **50**, 873-894. Beard, K., C. Chuang (1987): A New Model for the Equilibrium Shape of Raindrops" *J. Atmos. Sci.* **44**, 1509-1524. Kumjian, M., A. Ryzhkov (2012): "The Impact of Size Sorting on the Polarimetric Radar Variables" *J. Atmos. Sci.,* **69**, 2042-2060