Rain Drop Shapes and Fall Velocities in “Turbulent Times”

M. Thurai[1], M. Schönhuber[2], V. N. Bringi[1] and G. Lammer[2]

[1]Colorado State University, Fort Collins, CO, United States

[2]Joanneum Research, Graz, Austria

EMS Annual Meeting: European Conference for Applied Meteorology and Climatology 2018 | 3–7 September 2018 | Budapest, Hungary

Introduction

- Raindrop size, shape and fall speed distributions form the basis for radar-based QPE (eg hydrology); for numerical modeling of microphysical processes that shape the DSD (collisional processes such as coalescence and break-up; sedimentation; evaporation); in soil erosion studies where kinetic energy due to rain drops is important.

- Under strong winds/turbulence, the microphysical properties of raindrops such as asymmetric drop oscillations (i.e. increased variance in shapes) and hence broadening of the fall speed distributions occur that influences collisional coalescence and break-up processes that in turn can affect the DSD evolution, and hence modify the storm environment and subsequent storm evolution

- There is no theory or model that can link turbulent intensity (or, eddy dissipation rate) to above factors due to non-linear interactions (except for cloud droplets which have no inertia)

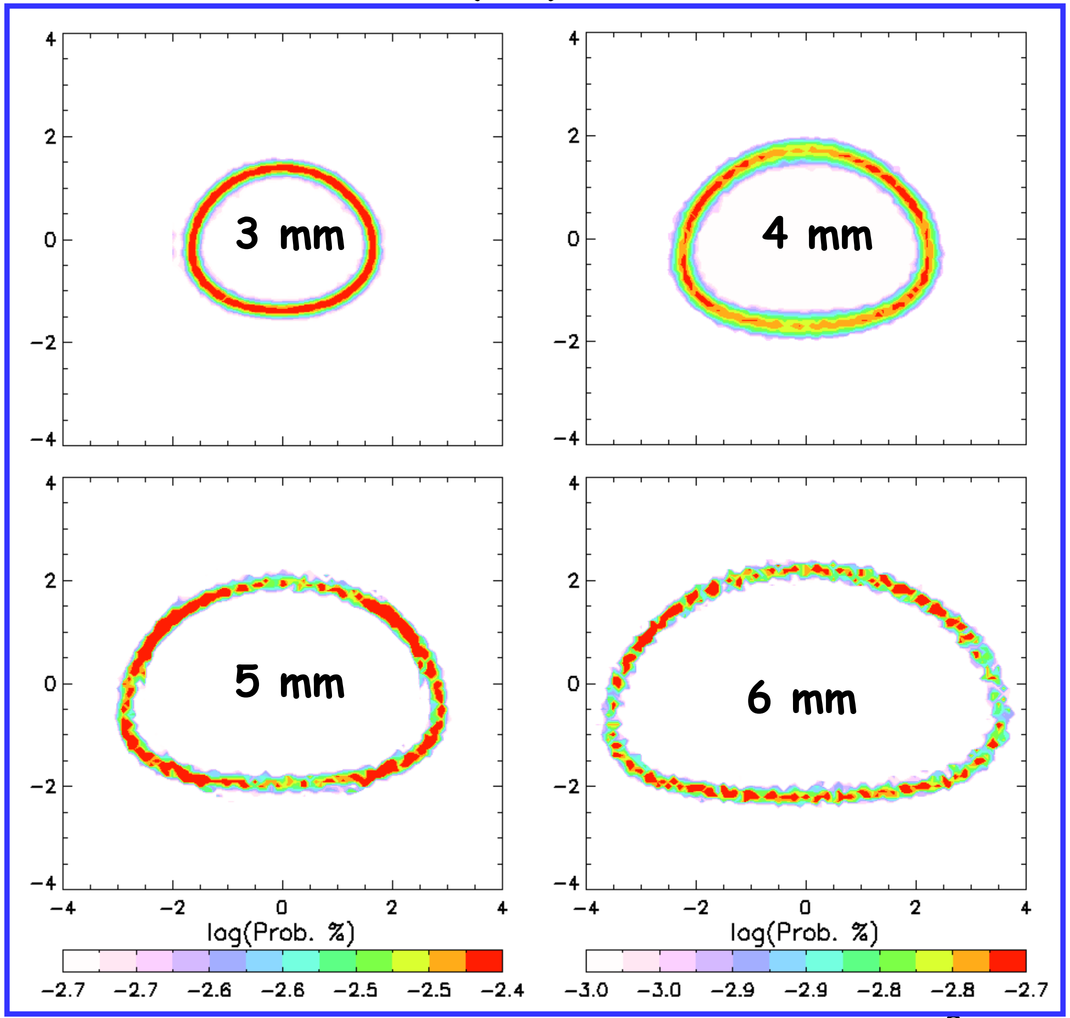
- Resort to correlating wind gusts to careful measurement of drop shapes and fall speeds as well as DSD changes. **Here we present case examples based on 2DVD measurements.**

Shapes and Fall Velocities from 2D video disdrometer

First: An artificial rain experiment:

80 m fall, captured more than 115,000 drops, with diameters in the range: 1.5 mm to 9.5 mm. Images from both cameras processed to derive drop shapes and categorized in terms of their drop diameters.

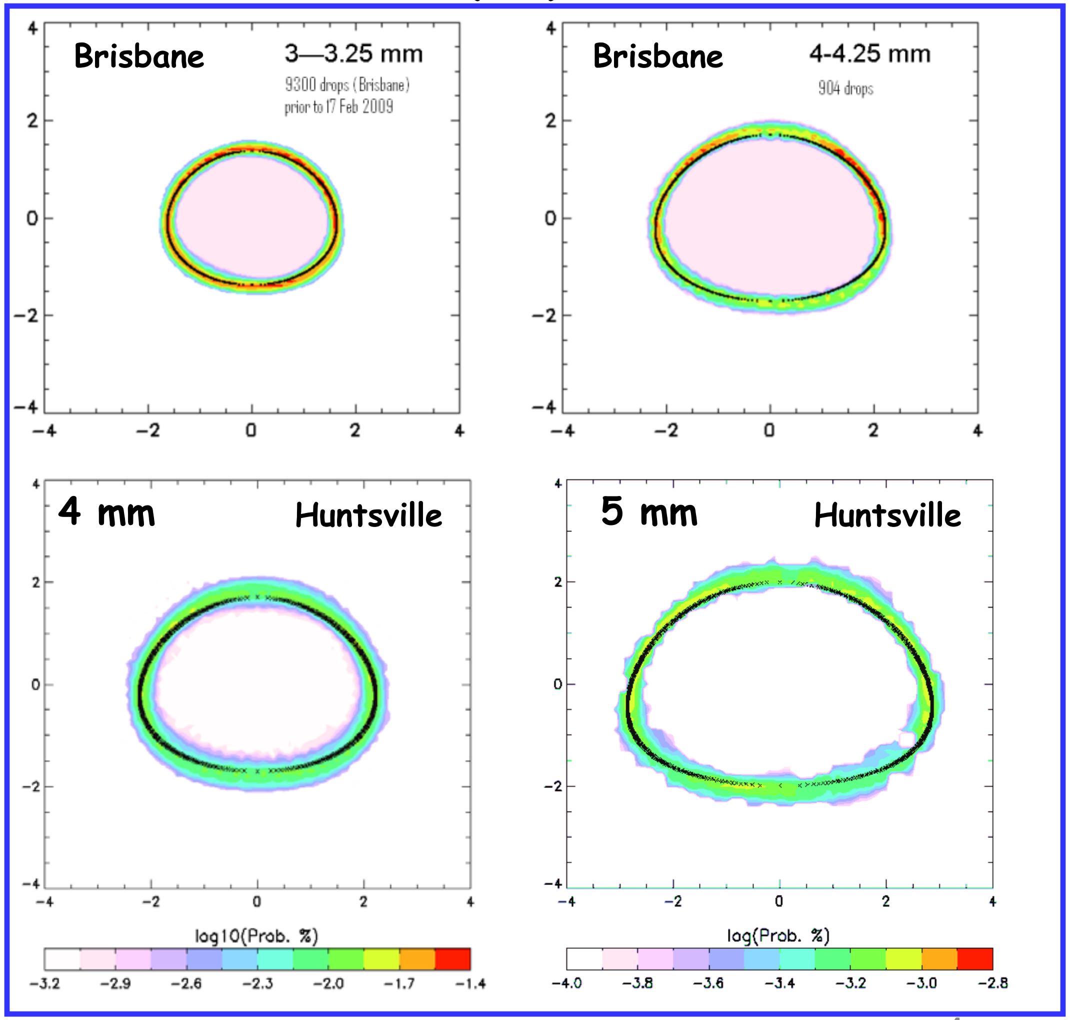
X-Y (mm) dimensions



Shapes and Fall Velocities from 2D video disdrometer

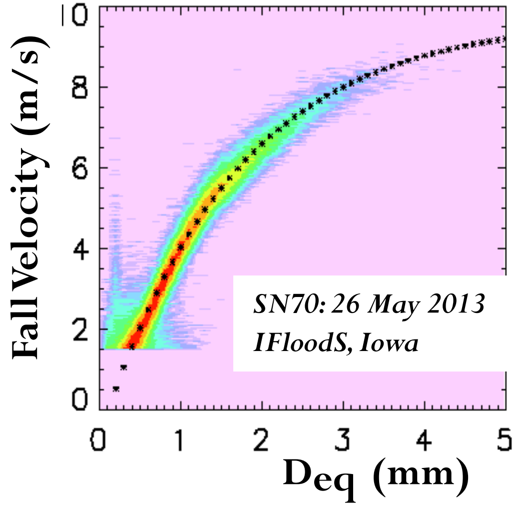
In natural rain, for vast majority of cases, the shapes appear to conform to those arising from the axisymmetric (2,0) mode

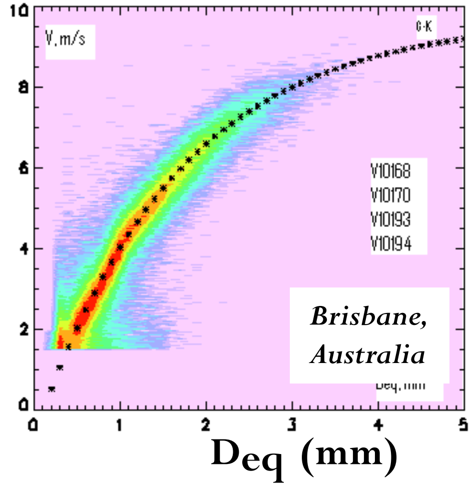
X-Y (mm) dimensions



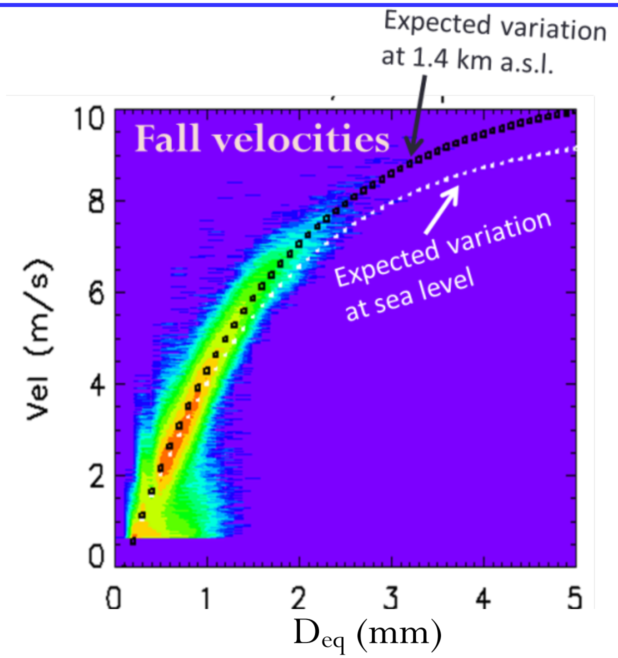
Shapes and Fall Velocities from 2D video disdrometer

Fall velocity variation with D_{eq} as color intensity plot, compared with the Gunn-Kinzer variation: Examples from 2 different locations



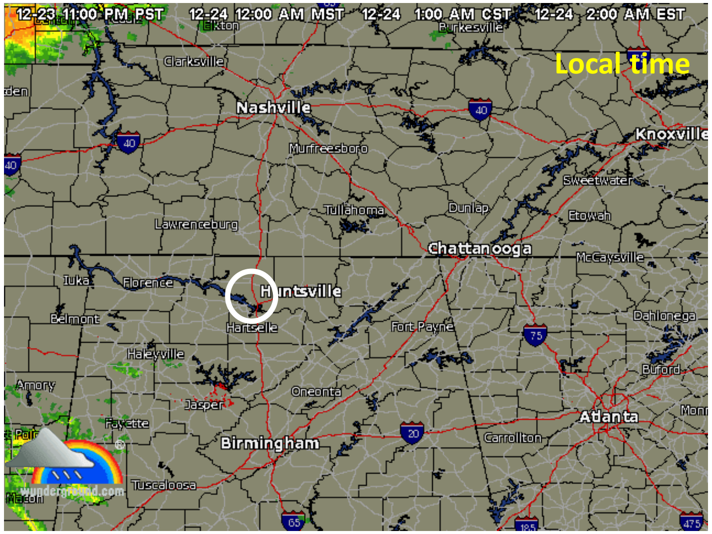


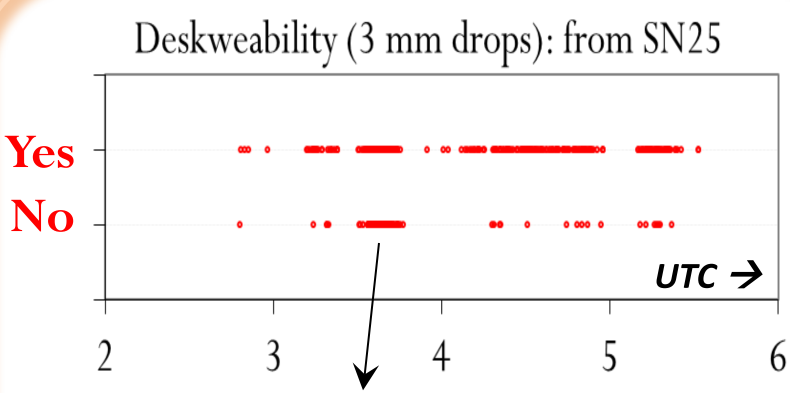
For Greeley Colorado, an altitude adjustment needs to be made



25 Dec 2009, Huntsville, AL – An unusual event

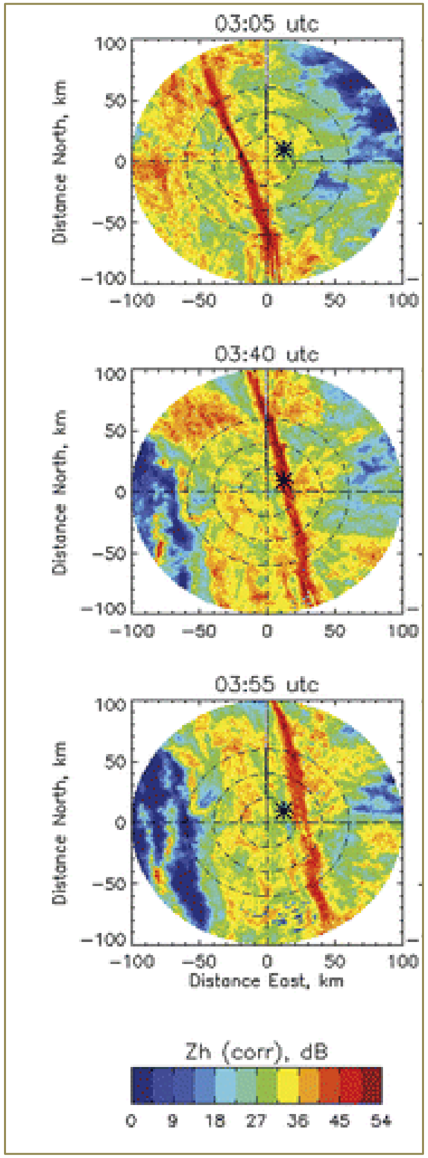
2DVD-SN16 and SN25 collocated (white circle)





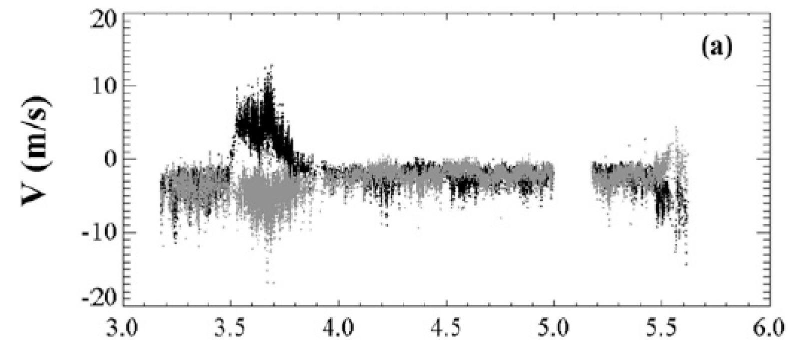
Much higher % of asymmetric drops during 0330 – 0345 UTC

ARMOR C-band radar data (Attenuation corrected)
* Represents SN16, SN25 location

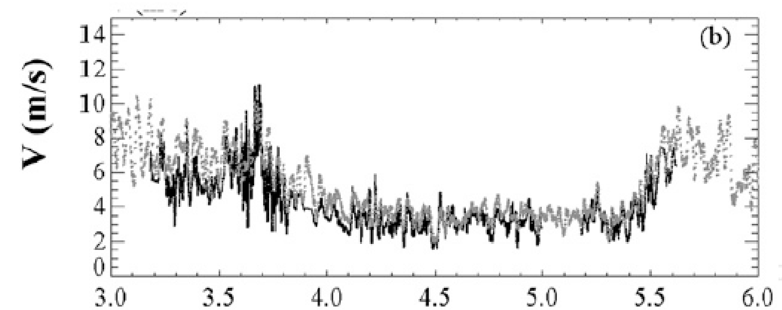


25 Dec 2009, Huntsville, AL – An unusual event

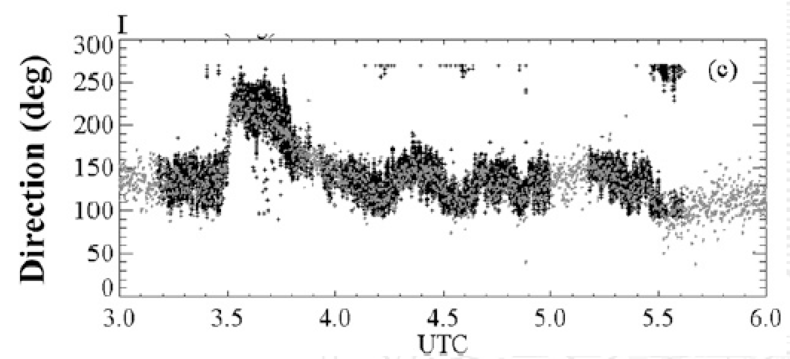
Drop horizontal velocities
From Cam A and B



Magnitude of drop horizontal velocities
from Cam A and B (black)
and 10 m wind sensor data (grey)



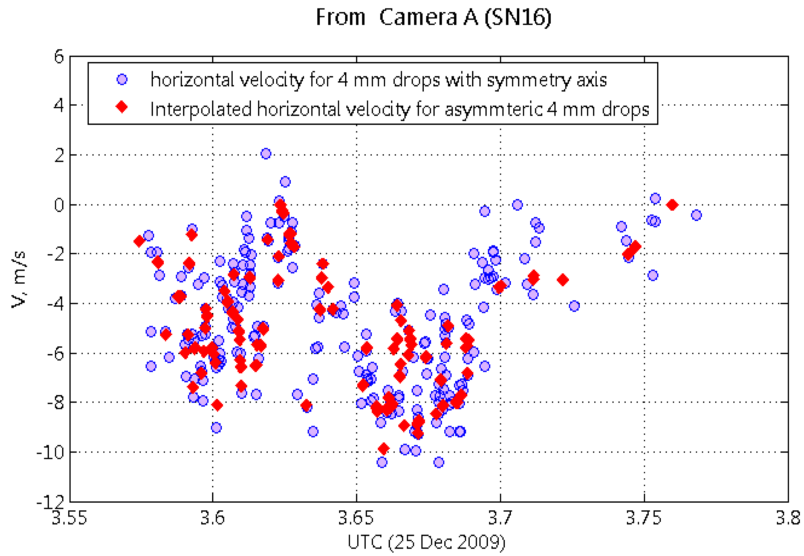
Direction of drop horizontal velocities
from Cam A and B (black)
and 10 m wind sensor data (grey)

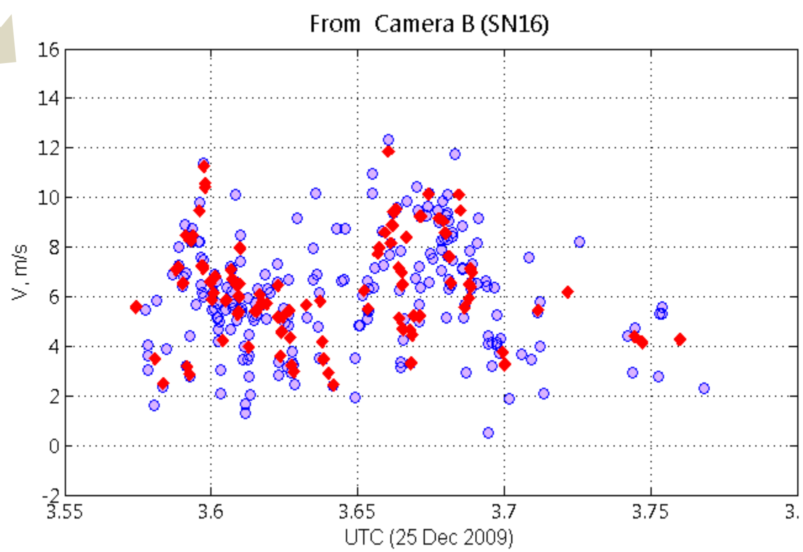


Very good agreement

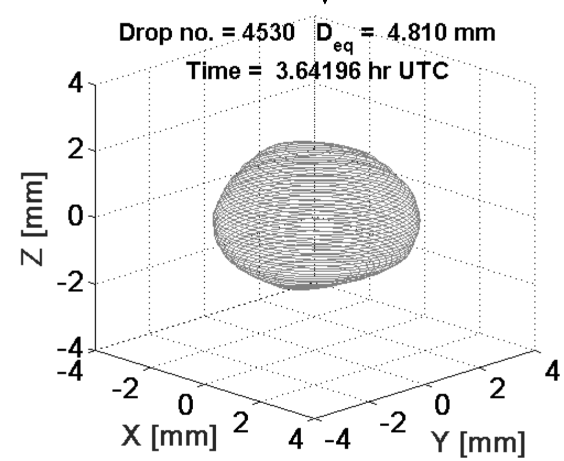
25 Dec 2009, Huntsville, AL – An unusual event

Interpolation of horizontal velocities for asymmetric drops

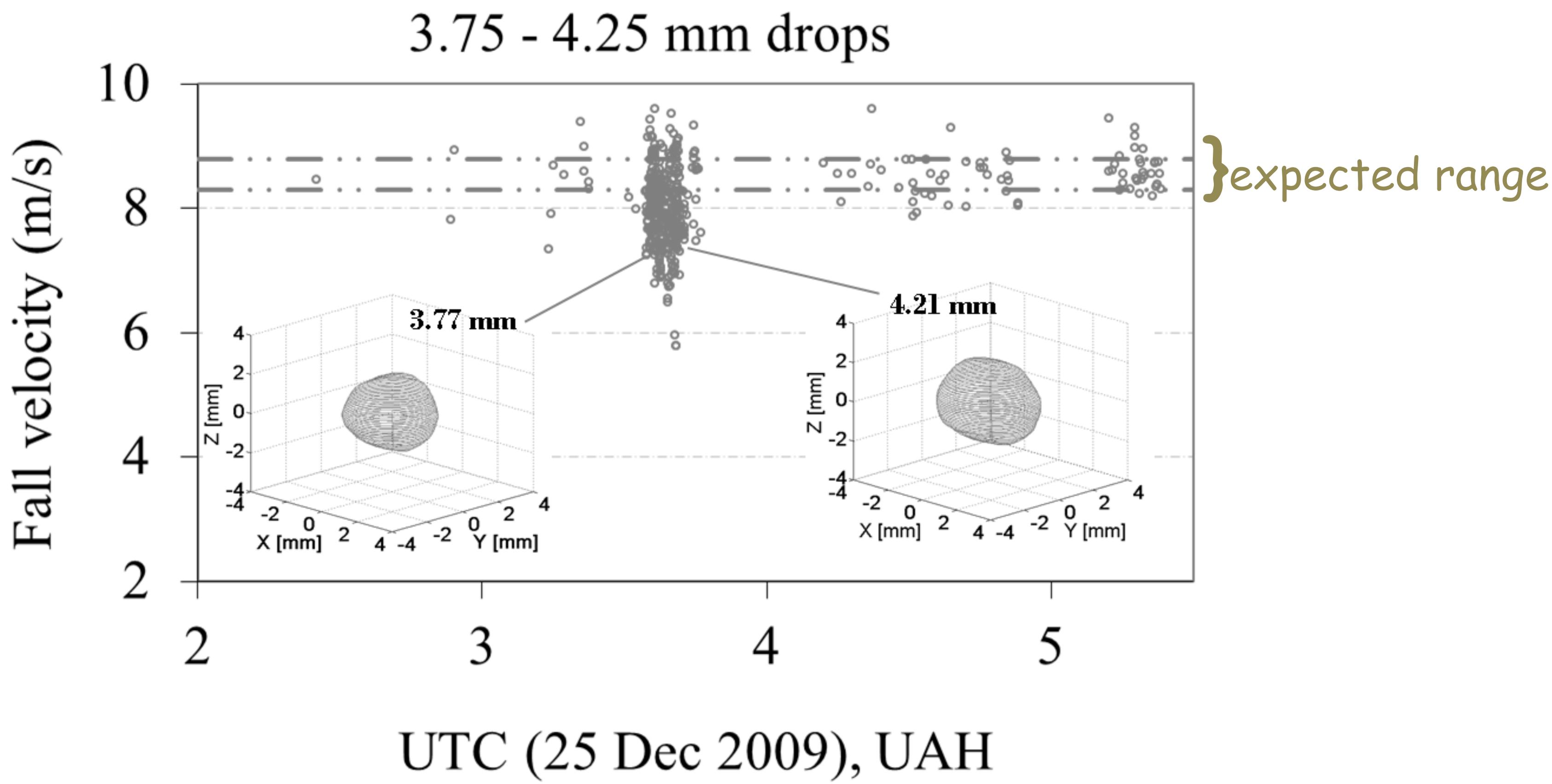




Apply the red points to correction of contours of asymmetric drops

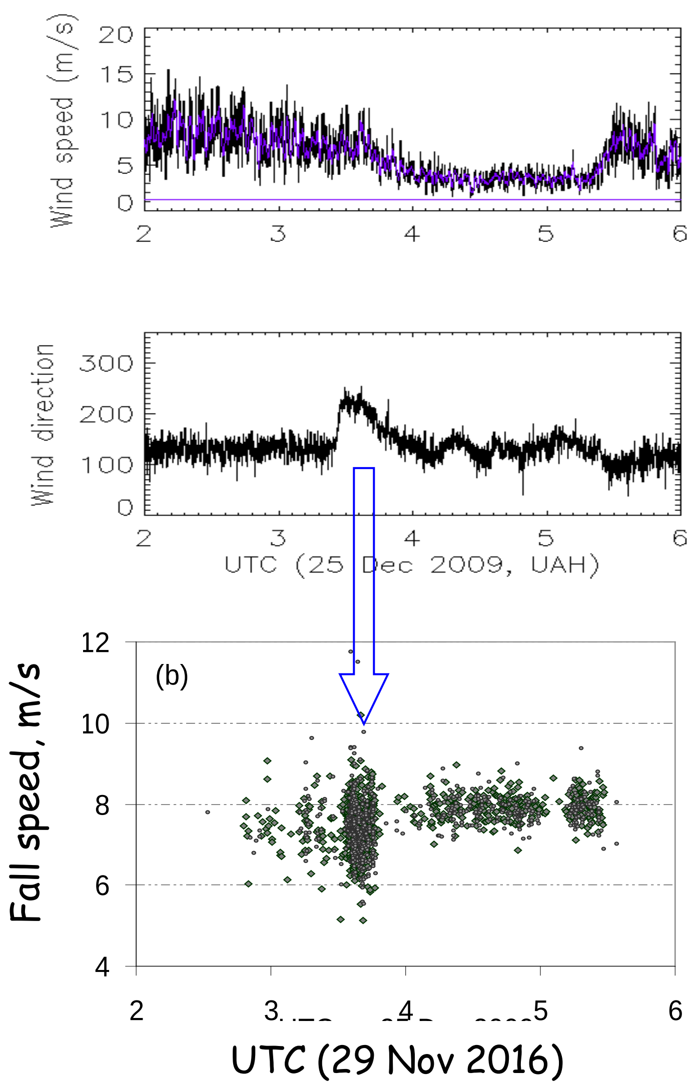


25 Dec 2009, Huntsville, AL – An unusual event

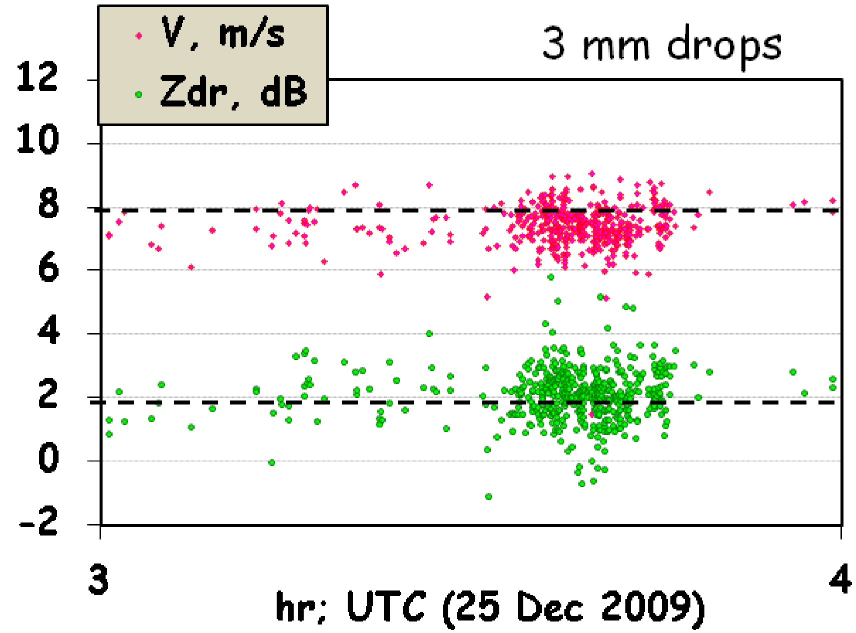


Note also: Reduced fall velocities for significant % of drops

25 Dec 2009, Huntsville, AL – An unusual event



Correlation with change in wind direction .. i.e. sheer-induced turbulence

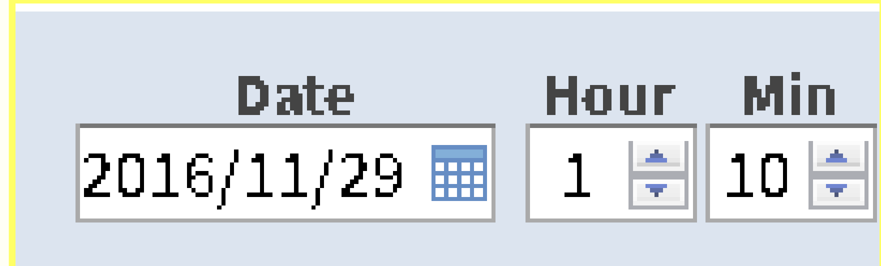


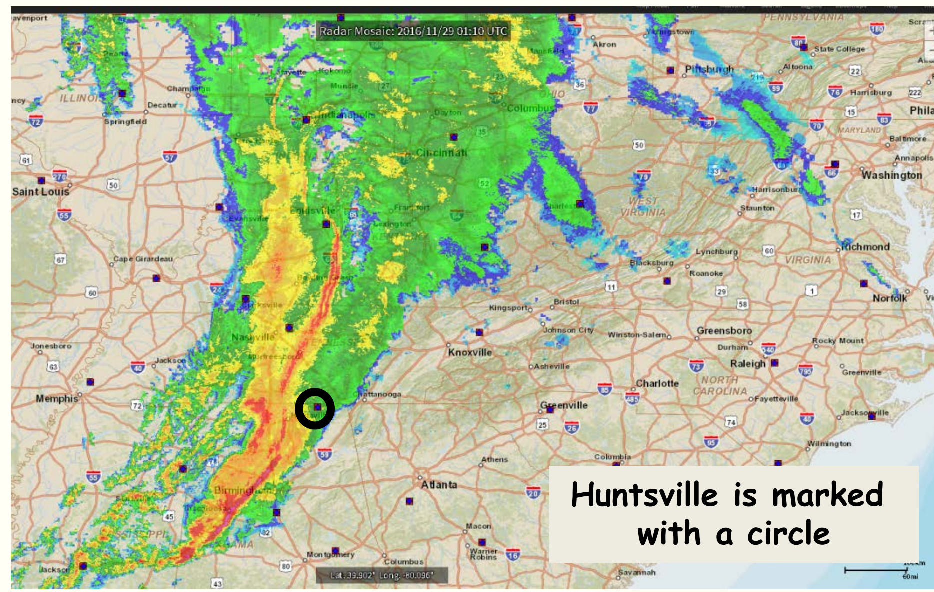
Expected values shown as dashed lines

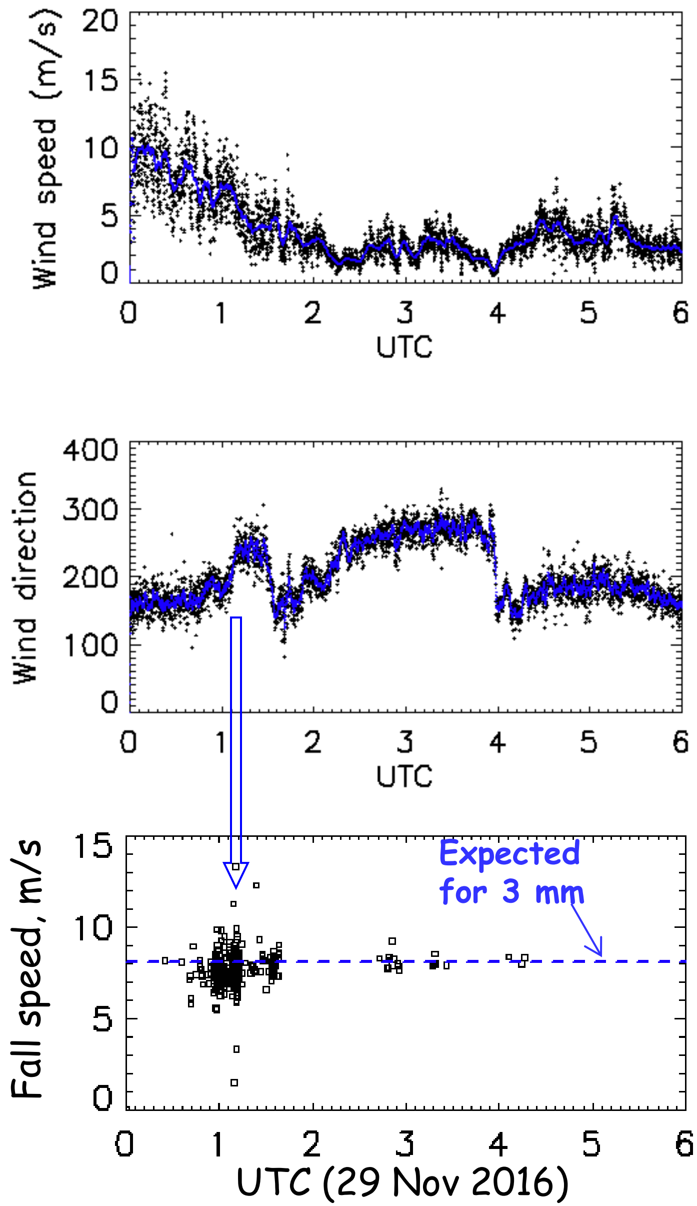
Shapes fluctuate (mixed mode, large amplitude oscillations), with change in wind direction.
(Manić et al., JAOT 2018)

And velocities are lowered.

2nd Example: 29 Nov 2016, UAH

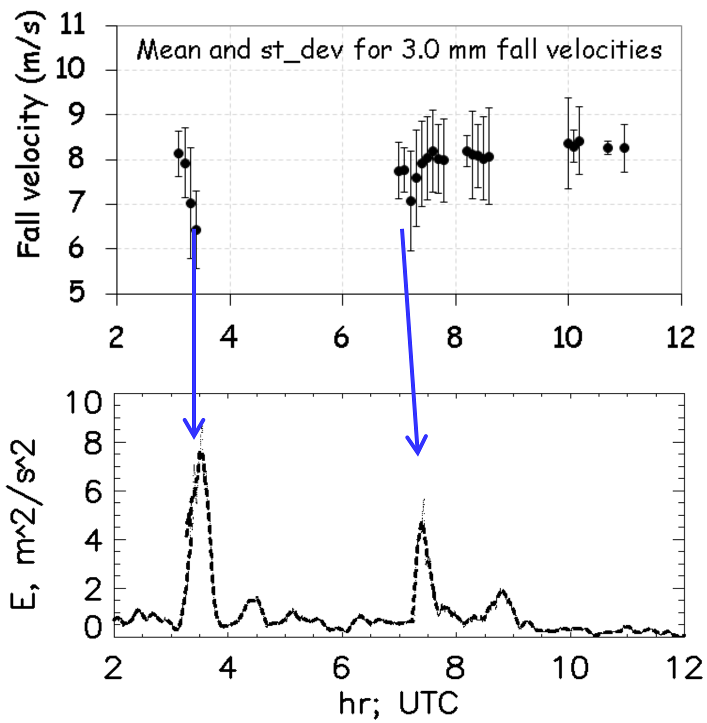




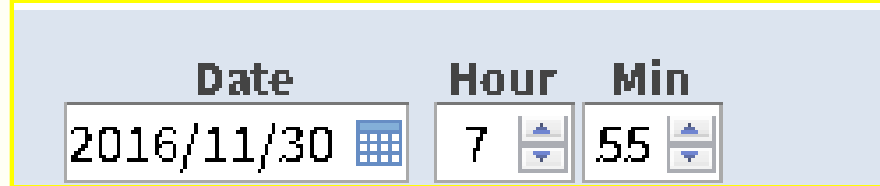


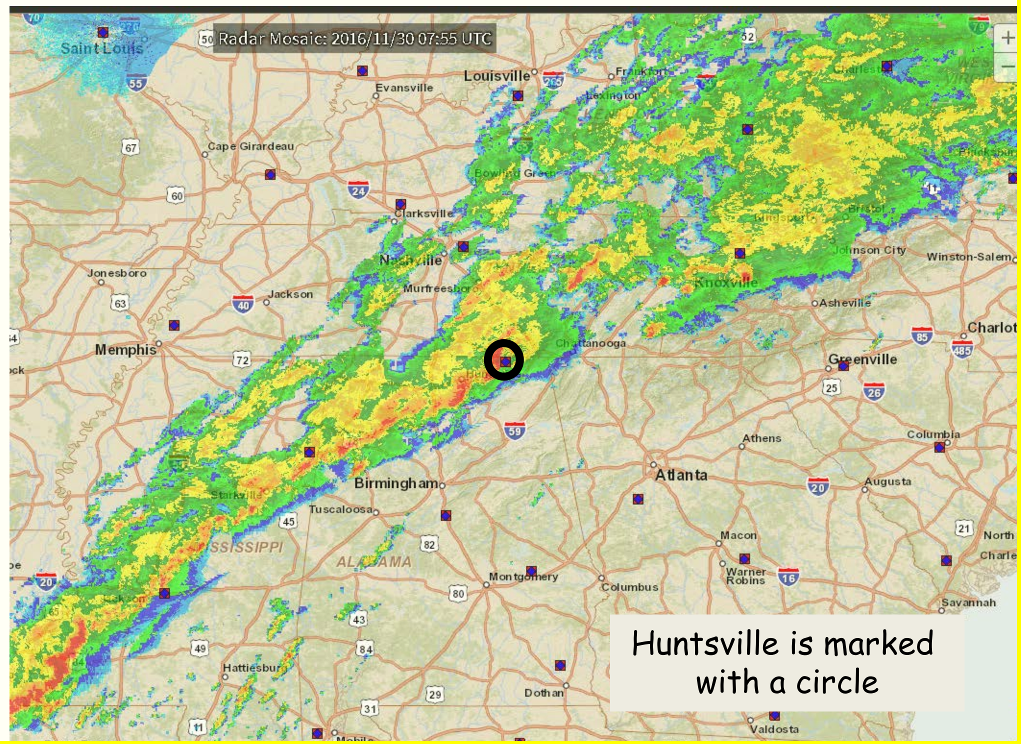
Again, lowered fall speeds
during change in wind direction

3rd Example: 30 Nov 2016, UAH



Proxy for turbulence index
E = [gusts – average wind]² / 2



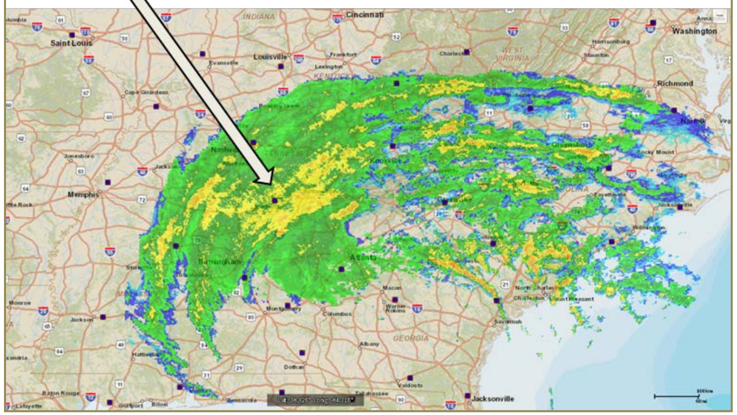


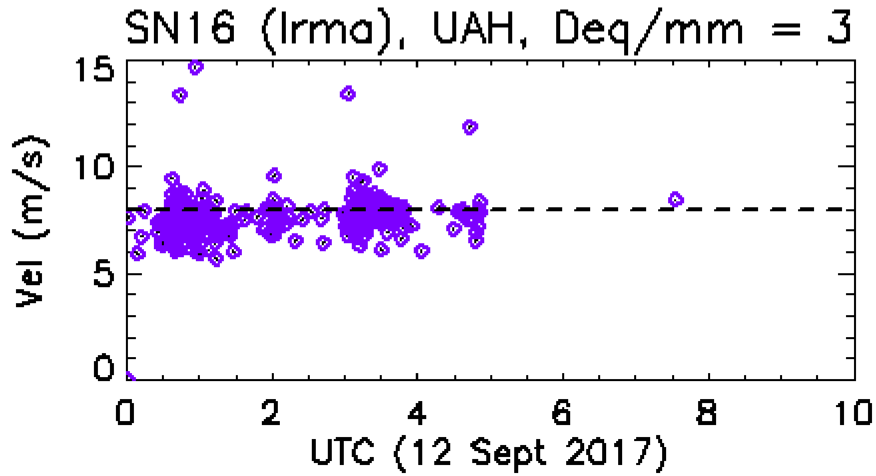
Research article

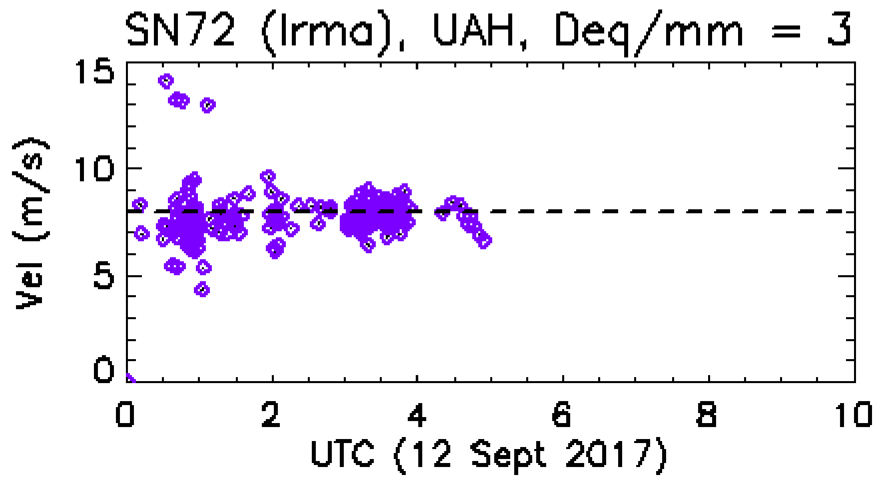
Raindrop Fall Velocities from an Optical Array Probe and 2D-video Disdrometer Bringi et al., 2017, Atmos. Meas. Tech.

4th Example: 12 Sept 2017, UAH (Irma outer bands)

IRMA at 0055 UTC, 12 Sept. 2017, HSV



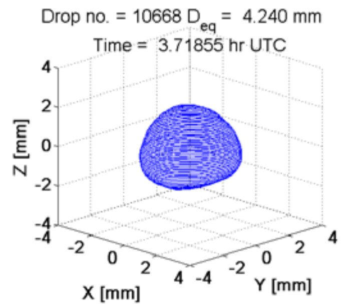


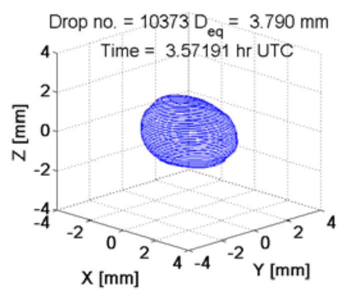


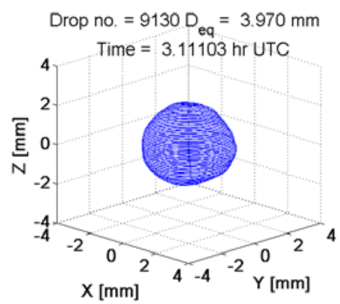
- 2DVD-SN16 inside DFIR (double wind-fence)
- 2DVD-SN72 outside DFIR
- Both collocated

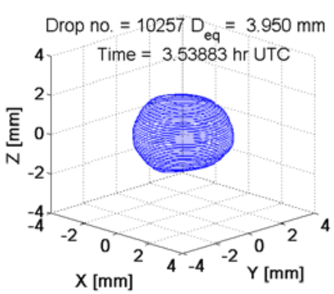
4th Example: 12 Sept 2017, UAH (Irma outer bands)

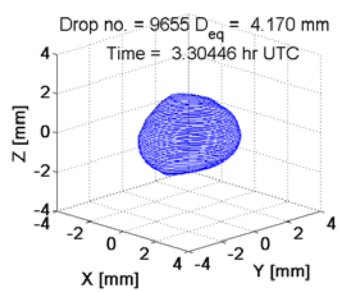
Reconstructed large drops from Irma outer bands

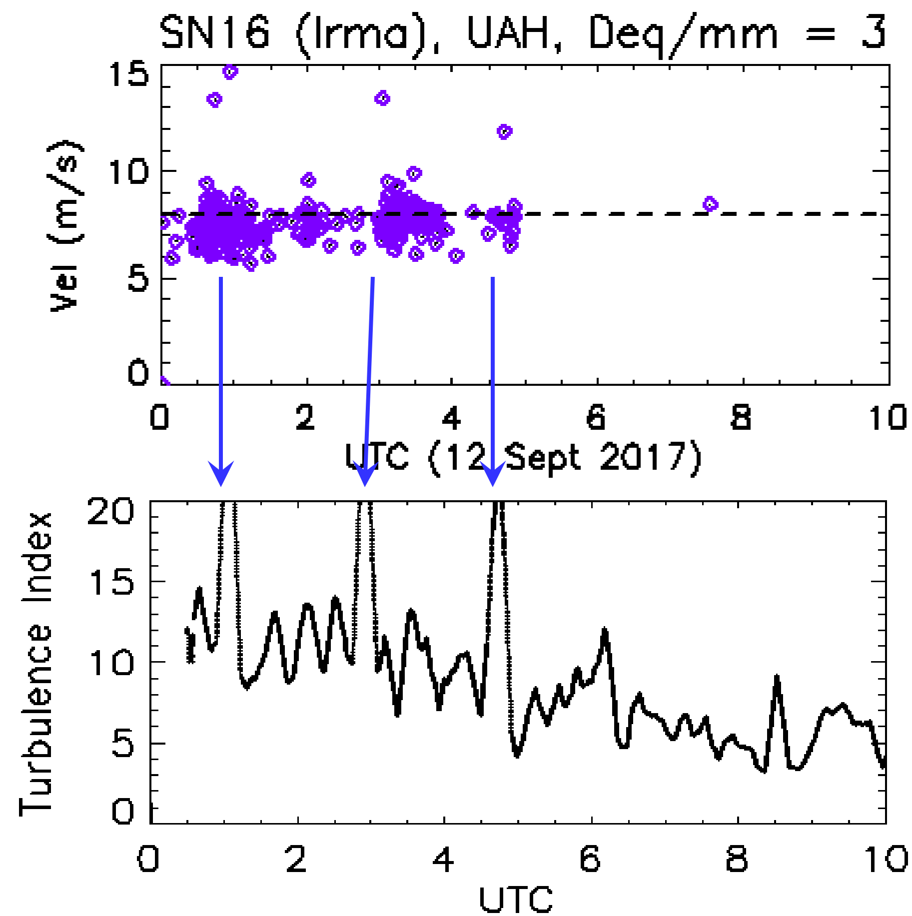












Lowered fall speeds again associated with turbulence index, E

Summary

- In vast majority of the cases, 2DVD drop shape measurements show that they largely conform to low amplitude axisymmetric oscillations, and the velocity measurements show good agreement with the G-K model, with altitude adjustments in the appropriate cases.
- Drop horizontal velocities (magnitude and direction) derived from the 2DVD measurements show remarkable agreement with the 10 m wind sensor measurements.
- Notable exceptions … 4 examples shown here. In all cases, 10 m height wind-sensor data were used to derive proxy-indicators for turbulent intensities. In all four cases, our results for D_{eq} > 2 mm clearly show very strong gusts, directional wind shifts (i.e. shear) and/or inferred high turbulence intensity are correlated with reduced fall speeds, reaching values ~25–30% less than the expected values, i.e. sub-terminal fall speeds.
- Significant percentage of asymmetric drops (> 2 mm) deviating from the most probable axisymmetric shapes were also detected for some events.