FIELD MEASUREMENTS OF RAINDROP ORIENTATION ANGLES

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INTRODUCTION

Natural raindrops have a significant impact on polarisation properties of tropospheric wave propagation. In telecommunication applications this may cause unwanted polarization rotation, whereas radar meteorology takes advantage of this effect. Whereas analyses of differential weather radar returns have widely been investigated, interpretation of crosspolar reflectivities from rain still could be improved, if statistically reliable knowledge on raindrops' canting and orientation angles would exist. To the authors' knowledge up to now relevant observations had not been carried out under field conditions on a continuous basis. With a 2D-Video-Distrometer, an imaging precipitation gauge, measurements were performed, which allow the determination of raindrops' canting and orientation angles. Furthermore information on the presence of drops' oscillation may be obtained as well.

THE 2DVD DROP ORIENTATION MEASUREMENT METHOD

A 2D-Video-Distrometer (2DVD) [1] was used for measuring raindrops' orientation angles. This imaging device is based on line scan cameras and thus does not give instant matrix pictures of particles. Instead the successive line scans are shifted against each other in case a particle is horizontally moving. Fig. 1 gives an example, the side view of a horizontally moving 8 mm sphere is shown and its distortion is clearly visible. The yellow line connecting the contour's top and bottom indicates the distortion, it may easily be corrected by simple redirection to the upright position. The result is shown in Fig. 2. In case of canted raindrops however, this method does not give precise results any longer but constitutes an approximate correction only. Nevertheless a precise correction is possible whenever a particle's view contains an axis of symmetry, regardless of a possible canting angle. First step for the full recovery of such a particle's view is therefore to identify the presence of such axis. In the distorted view angles and distances are generally destroyed. But straightness, parallelism and proportionality factors are being kept. The axis of symmetry is defined by its feature, that orthogonal lines cut the contour of the view at both sides at the same distance. Orthogonality is lost by distortion. But even in the distorted view the axis of symmetry is the location of all centres dividing a set of parallel lines into two halves of equal distance to the contour. The axis of symmetry in the distorted view may therefore be found as follows, a visualization is given in Figures 3 - 5: A set of parallel

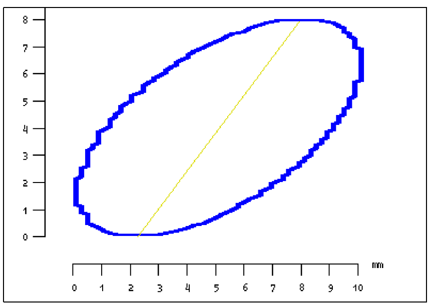

Fig. 1. Side view of 8 mm sphere in horizontal motion. Distortion caused by line scanning principle.

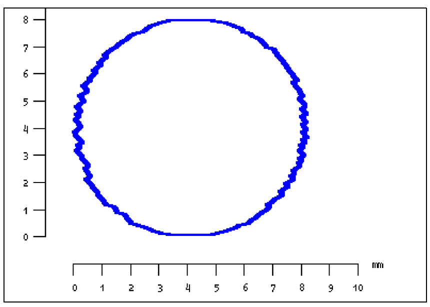

Fig. 2. View shown in Fig. 1 after approximate correction of distortion. Precise result yielded in case of sphere.

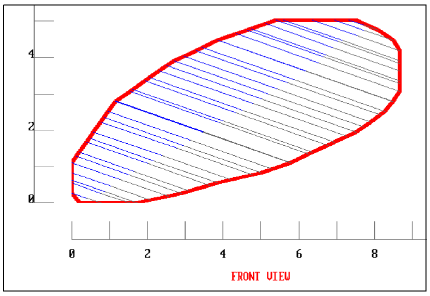

Fig. 3. Testing for -20 deg

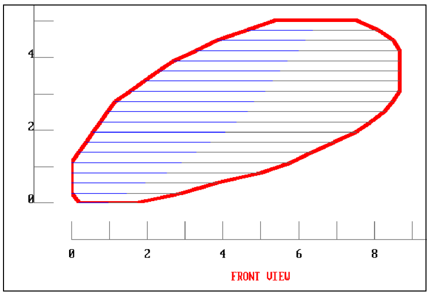

Fig. 4. Testing for 0 deg

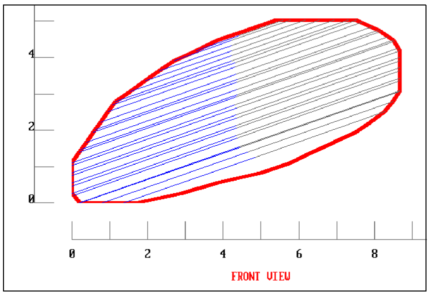

Fig. 5. Testing for +20 deg

lines is placed over the view at an arbitrary angle with respect to the bottomline. The contour of the view cuts each line twice, the centres between the two cutting points have to be found. If all these centres are located on a straight line, this is the axis of symmetry. If not, another angle has to be tested. In practice the implementation of this method starts at the lowest angle of interest (e.g. -30 deg) and tests all angles up to the highest angle of interest (e.g. +30 deg) at a certain step width (e.g. 0.5 deg). For each of these angles the mean square distance of the centres from their regression line is calculated. The regression line with minimum mean square distance is considered to be the axis of symmetry. Figures 3 - 5 present three pictures from such a search process, visualizing the test for the angles -20, 0 and +20 deg. The possible axis of symmetry is given by the centres of the parallel lines, marked by transition from blue to grey color. Whereas these centres in Fig. 3 and Fig. 4 clearly do not form a straight line, the centres in Fig. 5 could be represented rather well by a straight line. The minimum mean square distance was found for an angle of 16.0 deg, the corresponding axis of symmetry at an angle of 78 deg, obviously missing orthogonality. The distortion by horizontal motion has to be corrected now. That is done by restoring orthogonality of the axis of symmetry and the set of parallel lines. This may easily be done by use of vector analysis algorithms, a more detailed description is given in [2]. The resulting shape is given in Fig. 8, presenting the typical equilibrium dropshape, with an axis of symmetry and flattened at the bottom. The resulting parameters are a canting angle of 18.8 deg and a horizontal velocity (in the front view only) of 18.97 km/hr or 5.27 m/s, significantly differing from the value obtained by the approximation method (35.52 km/hr or 9.87 m/s). Application of the precise method to front and side view allows to compose the orientation angles and the horizontal velocity components of the drop. In windy conditions some drops are observed with rather irregular shapes. They hardly allow to recognize an axis of symmetry. The use of this method is therefore recommended at moderate wind only, also because of the restricted validity of drop shape studies at windy conditions (windshear near to the ground, turbulences around the instrument). Figures 6, 7 and 8 give a summarizing visual impression. Figure 6 presents the drop's front view as recorded by the camera including distortions due to horizontal motion. Figure 7 presents the result of the approximate correction and Fig. 8 that of the precise method.

Preliminary Results

The method described above was applied to data sets recorded by 2D-Video-Distrometers. In a first step a data set obtained in a test environment was investigated. A simple water pipe was opened directly above the distrometer in a height of 35 meters. This fall distance is more than sufficient for the drops to reach their terminal fall velocity. This setup also excludes wind effects, since even light wind blows away the drops and prevents them hitting the sensing area. As a preliminary analysis the mean zenith angle for water drops in 0.25 mm diameter classes was determined. Fig. 9 gives the result. The term zenith angle here denotes the deviation of a drop's axis of rotation from the vertical, regardless in which (azimuth) direction it is pointing. It is evident that this method works only with 'bigger' drops, they are more oblate and thus in most cases allow to determine the axis of rotation after the described method. The smaller drops are more spherical and, because of imaging

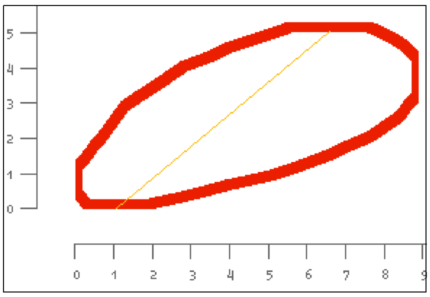

Fig. 6. Front view to be corrected for distortion due to horizontal motion

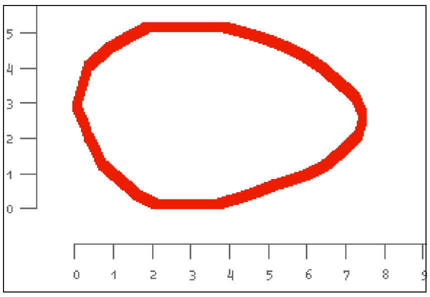

Fig. 7. Same as Fig. 6, corrected by approximation method

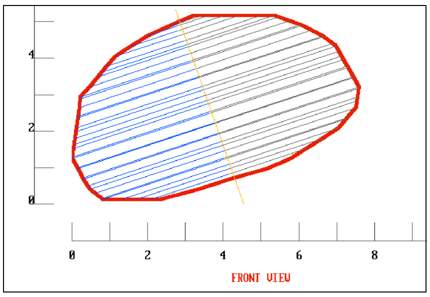

Fig. 8. Same as Fig 6, corrected by precise method, canting angle = 18.8 deg

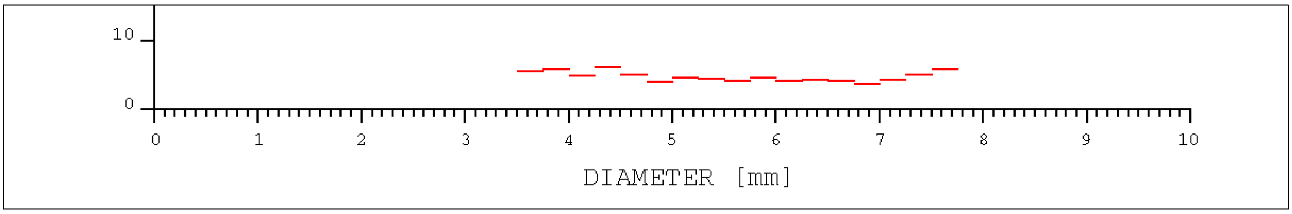

Fig. 9: Zenith angles of drops' axes of rotation (deg) vs. equivolumetric sphere diameter (mm). Data recorded in test environment

quantisation effects, in many cases it is impossible to determine the axes of symmetries reliably. Therefore for the present analysis a diameter lower limit of 3.5 mm was introduced below which no zenith angle evaluations were performed. Fig. 9 shows that for this data set the zenith angle is practically independent of the drop size. Within the full observation range (from 3.5 up to 7.75 mm) the zenith angles remain between 3.78 and 6.21 deg, with a mean of 4.79 deg. As a next step the method was applied to data acquired in field conditions. A tropical rain event recorded in Lae, Papua New Guinea was chosen, because of the really calm conditions on that day, i.e. August 29, 1995. For the period 19:45 - 20:30 the windsensor reported a mean windspeed of 0.43 m/s with a maximum of 1.24 m/s, mean rainrate was 9.85 mm/hr. Fig. 10 presents the result, again in the zenith angles vs. diameter diagram. The observation range (from 3.5 mm up to 4.25 mm) is clearly smaller than in Fig. 9, tropical rain typically is made out of many small drops. The observed zenith values however are practically nearly identical. The mean is 5.25 deg, the minimum 4.98 and the maximum 6.54 deg. The azimuth angles were determined as well for both, the test environment and the tropical rainfall event. As expected no significant main direction but an equal spread was found. The preliminary findings of these measurements and analysis method is, that under conditions without significant horizontal wind forces raindrops do reveal a zenith angle of approx. 5 deg, regardless of their size. Further work is needed to gain statistical significance. In analogy to the question of drop shape the results found in stagnant air conditions (the equilibrium drop shape models) may very well be used for applications considering rain volumes aloft (polarimetric weather radar, radio communications, etc.).

Further Verification and Use of the 2DVD Drop Orientation Measurement Method

The preliminary results presented above are outcomes of a first basic stage only. Further investigations should answer questions after the zenith (and azimuth) angle in light wind conditions and should also give a wider basis to all results. Comparisons of 2DVD derived and wind sensor - measured horizontal velocities will help for verification. To avoid the effect of turbulences around the instrument itself, it is recommended to use it as a pit gauge. For acquiring the wind profile near to the ground the use of at least two wind sensors is recommended, one mounted in a height of 10 meters and another one directly located at the 2D-Video-Distrometer.

OSCILLATIONS OF RAINDROPS

Raindrops' oblatenesses oscillate around their mean value, i.e. the oblateness of equilibrium state. As may be shown theoretically such oscillations have a noticeable impact on interpretation of polarimetric weather radar reflectivities. The degree of natural drop oscillations needs therefore to be determined experimentally. 2D-Video-Distrometers provide the relevant data. Figures 11, 12 and 13 present three drops recorded in Lae, Papua New Guinea on April 19, 1995, very close in time (21:37:03, 21:36:17 and 21:37:01). The three drops have nearly the same size (4.73, 4.75 and 5.02 mm) and practically the same fall velocity (8.78, 8.9 and 9.03 m/s). Their height to width ratios (H/W) however differ significantly (0.61, 0.67 and 0.83). The reason for are drop oscillations. Future analyses should provide reliable descriptions of these phenomena, questions like dependence on drop size may be solved. The impact of wind onto measurements has carefully to be observed.

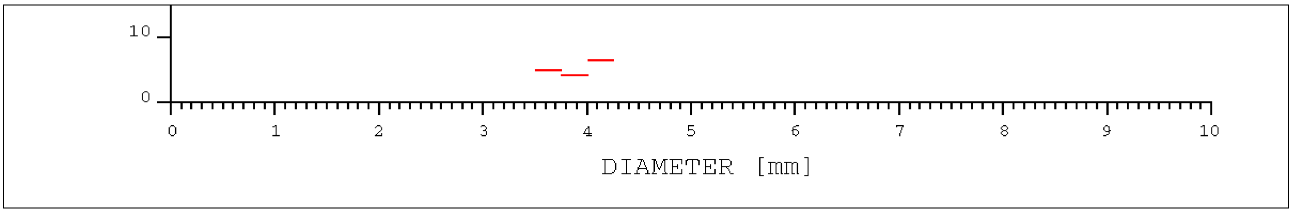

Fig. 10: Zenith angles of raindrops' axes of rotation (deg) vs. euqivolumetric sphere diameter (mm). Data recorded on August 29, 1995, 19:45 - 20:30 in Lae, Papua New Guinea

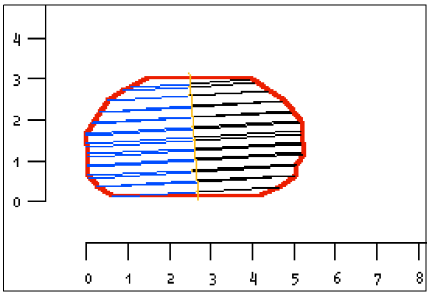

Fig. 11: Drop with 4.73 mm diameter.
Fall velocity = 8.9 m/s,
height/width ratio of front view = 0.60

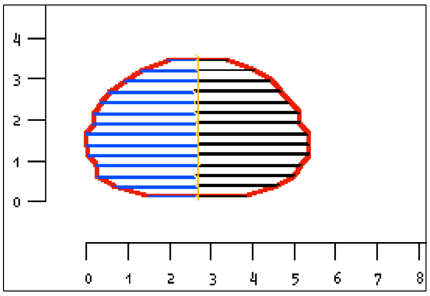

Fig. 12. Drop with 4.75 mm diameter.
Fall velocity = 8.78 m/s,
height/width ratio of front view = 0.67

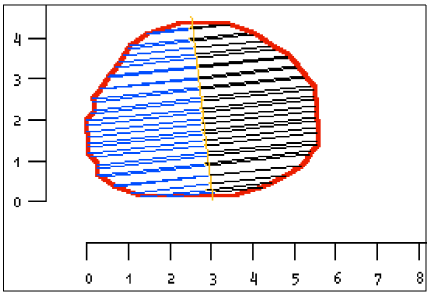

Fig. 13. Drop with 5.02 mm diameter.
Fall velocity = 9.03 m/s,
height/width ratio of front view = 0.81

CONCLUSIONS AND OUTLOOK

The 2DVD drop orientation measurement method was presented. To the authors' knowledge, it is the first method to provide raindrops' orientation angles under field conditions on a continuous basis. Preliminary results state that in stagnant air conditions the drops' mean zenith angle is approx. 5 degree, to a great extent independent from their size. Future work should give statistical significance and also include investigations in light wind conditions. The method and its results have a great impact onto wave propagation questions, especially onto interpretation of polarimetric weather radar returns. As shown recently [3] natural rain frequently does contain drops up to 8 mm in size. Their contribution to crosspolar reflectivities may be estimated on basis of the above analyses and radar-based particle identifications further be enhanced. Improvements are possible for radio communication purposes as well: detailed knowledge on drops' orientation angles allows a better prediction of polarization rotation and distortion.

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