

1 **Response to Anonymous Referee #1**

2

3 **We thank the reviewer for his/her very valuable comments. We responded to the**
4 **comments (in bold) and made modifications in the paper accordingly.**

5

6 **RC: reviewer comments**

7 **AR: author response**

8

9 GENERAL COMMENT:

10 RC1: This paper is well organized, in a clear and simple manner, starting by the
11 description of the HOPE experiment and associated instrumental set up, and ending
12 by an analysis of the three case studies from three polarimetric X-band radar
13 observations.

14 The interest of the paper lies in taking advantage of multi-parameter measurement
15 capability to improve or assess microphysical phenomena knowledge. The data
16 interpretation is quite consistent and well referenced, and recent and interesting
17 approaches are used (e.g. QVP by Ryzhkov et al., 2016). However, even if the paper
18 aims at presenting some preliminary step to some more ambitious study (as stated
19 in the conclusion), the analysis shown would be worth being completed by additional
20 measurements from the radars themselves. For instance, X-band Radar Doppler
21 measurements in vertical pointing mode may alleviate some uncertainties about
22 distinguishing between aggregation and riming above the melting layer (as
23 mentioned in Case 3). At least, this could be mentioned or discussed in the paper.

24

25 **AR1:**

26 **We agree with the referee that, the Doppler velocity may offer a special insight into**
27 **the distinction between different microphysical processes. We didn't use the**
28 **Doppler velocity from vertical scans in this paper since the spatial and temporal**
29 **shifts between the QVPs and vertical scans can dim the robustness of the results.**

30 The QVPs shown in this paper were calculated at an elevation of 18° . It is thus not
31 convincing to apply directly the Doppler measurements of radar vertical scans to
32 distinguish aggregation and riming in this paper, considering the temporal and
33 spatial offsets between QVPs and vertical scans.

34 We thus rephrased Section 5 and discussed the possibility of using Doppler velocity
35 at vertical scans to complement the analysis in the paper.

36 *P26, line 11-20: "...While there were clear signs of other processes like riming and*
37 *aggregation, a distinction between these two processes is still difficult with the*
38 *available observations. Doppler velocities at the vertical pointing mode were*
39 *analyzed but the observed values (between 1 - 2 m/s) still makes the distinction*
40 *ambiguous. Furthermore, the exact time from the QVP and vertical pointing scans*
41 *cannot be matched, and one has to be careful when comparing the QVP with*
42 *vertical scans. Additional analysis in conjunction with other independent*
43 *observations e.g. from microwave radiometers, lidars and cloud radars which were*
44 *deployed at the JOYCE site is also required for a better distinction between riming*
45 *and aggregation, which is the focus of an ongoing study. ..."*

46

47

48 RC2: Polarimetric measurements from the three radars are used in the microphysical
49 analysis, as suggested by the title of the paper. Additionally, ground based
50 instruments are used, not only to confirm, but also or to complete this analysis. The
51 title should suggest the use of such complement.

52

53 **AR2:**

54 Thanks for the suggestion, the title of the paper was revised to "Precipitation and
55 Microphysical Processes Observed by Three Polarimetric X-Band Radars and
56 Ground-Based Instrumentation during HOPE" in order to complete the use of
57 disdrometers/rain gauges/MRRs for the microphysical analysis.

58

59 SPECIFIC COMMENTS:

60 RC3: Except for rain rate estimation, rain (or hail or melting snow) attenuation
61 impacting X-band measurements is not mentioned at all in the paper. Indeed, the
62 analyses use Z and ZDR, potentially biased by such attenuation. Are Z and ZDR
63 corrected for attenuation?

64

65 **AR3:**

66 **We didn't perform attenuation correction in this paper. Firstly, the precipitation**
67 **during HOPE is not intense and the HOPE site is close to the KiXPol and JuXPol,**
68 **within 10 km. Thus, for the low rain rate, the attenuation effects due to**
69 **precipitation can be negligible. Secondly, for rain rate > 8 mm/h (the duration of**
70 **rain rate > 8 mm/h during HOPE is only around 1 hour), R-Kdp relation which is**
71 **unaffected by attenuation effects is employed instead of R-Z relation.**

72 **To make it clearer, the following statement is added: (p11, lines 24-26) "...Z and Z_{DR}**
73 **attenuation along each radial is neglected since the rain intensities were generally**
74 **low over the HOPE area....". (see also response to Reviewer#2, AR1)**

75

76 RC4: p7 lines7-9: Why are BoXPol disdrometer measurements not used, while MRR
77 observations at the same site are?

78

79 **AR4:**

80 **Sorry for the confusion. The disdrometer measurements close BoXPol are not used**
81 **for the precipitation analysis presented in Section 3, since BoXPol disdrometers are**
82 **~50 km away. Thus considering the spatial and temporal variability of precipitation,**
83 **the statistical analysis of precipitation over the central HOPE area shown in Section**
84 **3 is only performed with the disdrometers/rain gauges in the vicinity of Juelich. In**
85 **Section 4, the microphysical processes are analyzed with a combination of**
86 **polarimetric radars and ground-based instruments. The MRR data in Section 4 is**
87 **only used for analyzing microphysical process (size sorting in Fig.11) close to**
88 **BoXPol.**

89 **To make this clearer, the sentence was modified. "...Disdrometer observations at**

90 ***BoXPol which is ~48.5 km away from JuXPol are not taken into account in Section 3***
91 ***when statistically analyzing the precipitation over HOPE, considering the spatial***
92 ***and temporal variability of rainfall....” (p8 lines3-5).***

93

94 RC5: p9 lines 15-16: I do not understand how the distribution shown in Fig.4 results
95 from individual measurements of disdrometers instead of averaging over
96 disdrometer sites at a single time step. Does that mean, for instance, that 80 hours of
97 [0,1] mm/h rain have been obtained by summing rainfall observation time over the N
98 disdrometers (thus representing 80/N hours each)?

99

100 **AR5:**

101 **Sorry for the confusion, we revised the sentence in p9 lines 15-16.**

102 ***(now P9 lines 22-23) “...The distribution of rain intensities was calculated based on***
103 ***individual measurements of disdrometers over the HOPE area...”***

104 **Figure 4 was calculated following the steps below:**

105 **(1) for each disdrometer, the distribution of rain intensities was calculated**
106 **individually.**

107 **(2) averaging the rain hours over the number of disdrometers at each rain rate**
108 **intervals. For instance, at [0,1] mm/h rain rate, when one disdrometer has a**
109 **duration of 100 hours and another one has 60 hours, an average over the two**
110 **disdrometers is 80 hours of [0,1] mm/h, as shown in Figure 4.**

111

112 RC6: p12 lines 16-17 and p13 line 13: the lack of consistency between rain rates also
113 probably suffers from the representativeness error impacting BoXPol measurements
114 (higher altitude of sampling volume).

115

116 **AR6:**

117 **Thanks to the referee’s suggestion. We revised the sentence to better explain the**
118 **low rain rate from BoXPol measurements and added “the high altitude of sampling**
119 **volume” as one of the error sources which result in a low rain rate of BoXPol.**

120 *“...JuXPol and KiXPol are in a better agreement with the surface measurements*
121 *than BoXPol for the very low rain rates, which probably suffers from the effects of*
122 *non-uniform beam filling effects due to the much larger distance from the HOPE*
123 *area (Giangrande and Ryzhkov, 2008) and higher altitude of sampling volume of*
124 *BoXPol....” (p12, lines 14-18)*

125 *“...again probably caused by beam broadening (Giangrande and Ryzhkov, 2008)*
126 *and high altitude of sampling volume of BoXPol over the HOPE area....” (p13, line*
127 *13-14)*

128

129 RC7: p14 Fig.7: When comparing KixPol and JuxPol rain accumulation, the south-west
130 quarter of the panels shows significant differences. How could this be explained? Is
131 this a problem of projection on ground?

132

133 **AR7:**

134 **The discrepancies in the south-west quarter is not caused by the projection on the**
135 **ground. It could be because:**

136 **(1) due to the beam blockage of KiXPol, the radar signals in the south-west**
137 **direction are missing. KiXPol was deployed at an altitude ~116 m, while close to**
138 **KiXPol, where the significant discrepancies occur, the altitude is above 200 m.**
139 **(2) JuXPol and KiXPol didn't measure at the same time and the same location. The**
140 **time and space shifts exist between JuXPol and KiXPol and result in the different**
141 **precipitation patterns especially when it is close to the radar. JuXPol is roughly 10**
142 **km away. At an elevation of 4,5° it reaches a height of roughly 800 m above KiXPol.**
143 **The time differences between the two radar measurements are in an interval of 5**
144 **min, which should be also taken into account. We thus proposed the**
145 **reconstruction of the three radar observations needs to be done for better**
146 **comparisons.**

147 **To make this clear, we added the explanation in the text. “...A 30-min rain**
148 **accumulation over the inner HOPE area on 29 May 2013 shows that, the three**
149 **radar estimates result in an overall agreement of the rough precipitation pattern**
150 **(Figure 7). However, when we zoomed into details and noticed also the minor**
151 **differences between these patterns, e.g., lower precipitation observed by BoXPol**
152 **and missing pixels near KiXPol and JuXPol. Bins close to KiXPol and JuXPol were**
153 **contaminated by ground clutters while the beam broadening and height at the**
154 **larger ranges deteriorates the similarity between the BoXPol and KiXPol/JuXPol**
155 **estimates (Fig. 7). The different radar observation scenarios, i.e., at an elevation of**
156 **4.5° JuXPol reaches 750 m above KiXPol and the time differences between the two**

157 *radar measurements are up to 5 min, also needs to be considered. A combination*
158 *of the three radar observations will definitely be an advantage to reconstruct the*
159 *precipitation patterns over the HOPE area in a future study..."*

160

161 RC8: p25 line 3: About measurements indicative associate updraft, what about radar
162 Doppler measurements at vertical incidence? (see general comment)

163

164 **AR8:**

165 **we agree with the referee that, the Doppler velocity may offer a special insight into**
166 **the distinction between different microphysical processes, as mentioned above.**

167 **We thus revised Section 5 and discussed the possibility of using Doppler velocity at**
168 **vertical scans to complement the analysis in the paper. (See response to**
169 **Reviewer#1, AR1)**

170

171 TECHNICAL CORRECTIONS:

172

173 **AR:**

174 **Thanks to the careful reading of the referee, we corrected all the technical errors**
175 **listed below according to the suggestions.**

176

177 RC9: p1 line 21: replace "another three disdrometers" by "three other disdrometers".

178 **AR9: Corrected. (now p1 line 22)**

179

180 RC10: p14 line 9: remove "s" in radars (replace "three radars estimates" by "three
181 radar estimates").

182 **AR10: Corrected. (now p14 line 11)**

183

184 RC11: p17 line 12: replace "30 dBz" by "30 dBZ".

185 **AR11: Corrected. (now p18 line 8)**

186

187 RC12: p23 line 11: add "of" after "a region"

1 **Precipitation and Microphysical Processes Observed by**
2 **Three Polarimetric X-Band Radars and Ground-Based**
3 **Instrumentation during HOPE**

4 **Xinxin Xie¹, Raquel Evaristo¹, Clemens Simmer¹, Jan Handwerker² and Silke**
5 **Trömel¹**

6 ¹Meteorological Institute, University of Bonn, Bonn, Germany

7 ²Institute of Meteorology and Climate Research , Karlsruhe Institute of Technology,
8 Karlsruhe, Germany

9 *Correspondence to:* Xinxin Xie (xxie@uni-bonn.de)

10

11 **Abstract.** This study presents a first analysis of precipitation and related
12 microphysical processes observed by three polarimetric X-band Doppler radars
13 (BoXPol, JuXPol and KiXPol) in conjunction with a ground-based network of
14 disdrometers, rain gauges and vertically pointing micro rain radars (MRR) during the
15 High Definition Clouds and Precipitation for advancing Climate Prediction (HD(CP)²)
16 Observational Prototype Experiment (HOPE) during April and May 2013 in Germany.
17 While JuXPol and KiXPol were continuously observing the central HOPE area near
18 Forschungszentrum Juelich at a close distance, BoXPol observed the area from a
19 distance of about 48.5 km. MRRs were deployed in the central HOPE area and one
20 MRR close to BoXPol in Bonn, Germany. Seven disdrometers and three rain gauges
21 providing point precipitation observations were deployed at five locations within a
22 5×5 km² region, while **three other** disdrometers were collocated with the MRR in
23 Bonn. The daily rainfall accumulation at each rain gauge/disdrometer location
24 estimated from the three X-band polarimetric radar observations showed a very good
25 agreement. Accompanying microphysical processes during the evolution of
26 precipitation systems were well captured by the polarimetric X-band radars and

1 corroborated by independent observations from the other ground-based instruments.

2 **1. Introduction**

3 In the frame of the project “High Definition Clouds and Precipitation for advancing
4 Climate Prediction” (HD(CP)²), which aims at **evaluating and** improving the accuracy
5 of climate models in relation to cloud and precipitation processes, the HD(CP)²
6 Observational Prototype Experiment (HOPE) was conducted during April and May
7 2013 within the study area of the Transregional Collaborative Research Center 32
8 (Simmer et al., 2015) in the vicinity of the Juelich ObservatorY for Cloud Evolution
9 (JOYCE) in Germany (Löhnert et al., 2015). The HOPE was conducted in order to
10 provide observations for high-resolution climate models and to improve our
11 understandings of cloud and precipitation processes.

12 An array of ground-based instruments deployed during HOPE provided
13 comprehensive cloud and precipitation process observations. In this study we
14 concentrate on the precipitation monitoring instruments. Three polarimetric X-band
15 Doppler radars installed in Bonn (BoXPol) and in the vicinity of the JOYCE site
16 (JuXPol and KiXPol), respectively, were operated together to continuously monitor
17 3D precipitation patterns in order to obtain a holistic view of precipitating systems
18 from micro- and macro-physical perspectives. BoXPol and JuXPol were installed at a
19 distance of 48.5 km from each other and were operated by the Meteorological
20 Institute of the University of Bonn and the TERENO program of the Helmholtz
21 Association (<http://teodoor.icg.kfa-juelich.de>, Zacharias et al., 2011), respectively (see
22 Diederich et al., 2015a for details on both radars), while KiXPol, which was ~9.6 km
23 (~50.6 km) away from JuXPol (BoXPol), was deployed by the Karlsruhe Institute of
24 Technology (KIT). A network composed of rain gauges and disdrometers measured
25 local precipitation, and collocated Micro Rain Radars (MRR) simultaneously
26 measured vertical profiles of precipitation and raindrop size distributions (DSD).

27 Dual-polarization radars provide multiparameter measurements, which improve
28 quantitative precipitation estimation (QPE) compared to single polarization radars

1 (Zrníc and Ryzhkov, 1999; Zhang et al., 2001; Brandes et al., 2002; Ryzhkov et al.,
2 2014). A thorough comparison of retrieval algorithms for rainfall estimation using
3 polarimetric observables for the HOPE area can be found e.g. in Ryzhkov et al. (2014)
4 and Diederich et al. (2015b). Many studies **have** already shown the potential of
5 polarimetric radars to identify fingerprints of macro- and micro- physical processes
6 related to the evolution of precipitation systems (Kumjian and Ryzhkov, 2010, 2012;
7 Kumjian et al., 2012; Andric et al., 2013; Kumjian and Prat, 2014), based on the
8 sensitivities of polarimetric observables to particle size, shape, concentration and
9 composition (Bechini et al., 2013; Ryzhkov and Zrníc, 1998; Giangrande et al., 2008).
10 E.g., very few large rain drops near the ground or at the leading edge of a rain cell
11 result in a larger mean particle size and induce strong differential reflectivity (Z_{DR})
12 accompanied by small reflectivity (Z), which indicates the occurrence of size sorting
13 (Kumjian and Ryzhkov, 2012). Increasing mean particle sizes due to evaporation and
14 coalescence may enhance Z_{DR} , while Z is reduced during evaporation by the depletion
15 of small rain drops (Kumjian and Ryzhkov, 2010; Li and Srivastava, 2001). Z , Z_{DR}
16 and specific differential phase (K_{DP}) all decrease when large raindrops break up
17 (Kumjian and Prat, 2014). Such information thus can be used to validate cloud and
18 precipitation parameterization schemes.

19 The paper is structured as follows. Section 2 introduces the instrumentation deployed
20 during HOPE, while Section 3 presents the surface rainfall estimated from the radars,
21 in conjunction with disdrometers and rain gauges. Section 4 presents and discusses
22 the development of different precipitation systems and related microphysical
23 processes. Size sorting due to vertical wind shear and coalescence will be illustrated
24 via the combination of two X-band polarimetric radars. Another case of size sorting
25 captured by BoXPol and a nearby MRR and disdrometers will also be examined in
26 detail. Finally, observed riming/aggregation signatures will be discussed. Conclusions
27 will be given in Section 5.

28

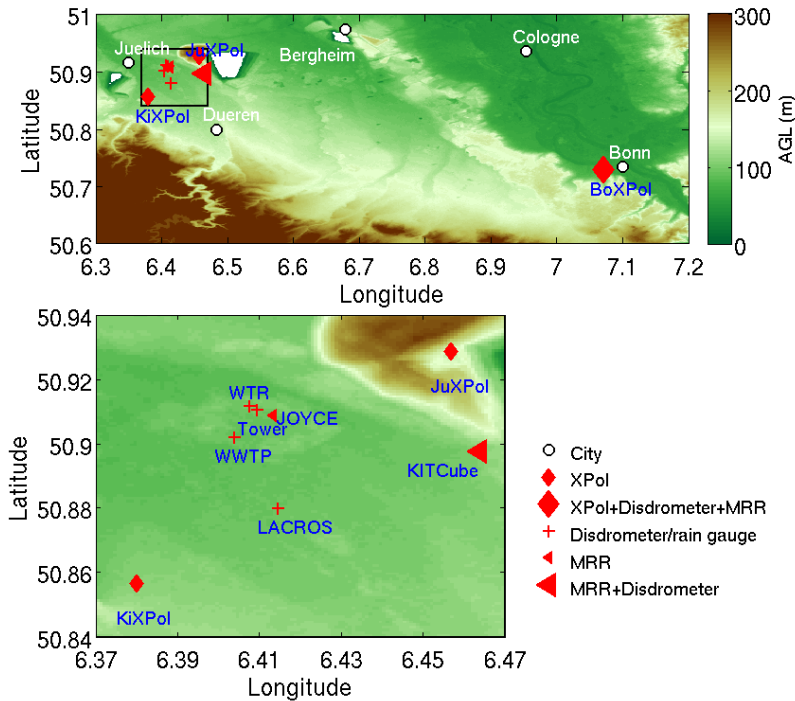
29 **2. Instrumentation**

1 **2.1 Three X-band polarimetric radars**

2 The three polarimetric X-band Doppler radars BoXPol, JuXPol, and KiXPol were
3 operating at a frequency of 9.375 GHz. Topography and the locations of the radars,
4 disdrometers, rain gauges and MRRs are shown in Fig. 1. While JuXPol and KiXPol
5 were both performing observations in the vicinity of Juelich, Germany, BoXPol
6 observed the HOPE area from a distance of about 48.5 km on the roof of a building
7 next to the Meteorological Institute of the University of Bonn in Bonn, Germany,
8 collocated with one OTT Parsivel and two Thies optical laser disdrometers. The three
9 polarimetric radars provide the standard polarimetric variables observed in a
10 simultaneous transmit and receive (STAR) mode, namely Z , Z_{DR} , K_{DP} , and ρ_{HV}
11 (copolar correlation coefficient) in addition to the radial Doppler winds and its
12 variance. **Detailed technical specifications of JuXPol and BoXPol can be found in**
13 **[Diederich et al. \(2015a\)](#) and for KiXPol under www.imk-tro.kit.edu/english/5438.php.**
14 **The calibration bias of the three radars were corrected following Diederich et al.**
15 **(2015a).**

16 Figure 2 shows the operation duration of the three polarimetric radars during HOPE.
17 BoXPol had technical problems on 15 May 2013 and was back to work at around
18 0800UTC on 16 May 2013. JuXPol performed observation from 5 to 8 April 2013.
19 Afterwards, no measurements were available until 22 April 2013 due to technical
20 problems. From 26 to 29 April 2013, JuXPol was only taking range height indicators
21 (RHI) at 233.7° azimuth oriented towards JOYCE every minute. KiXPol started its
22 observations on 3 Apr 2013 but had two breakdowns during April. In May, when
23 KiXPol was performing only RHI scans on request, no PPIs were available.

24



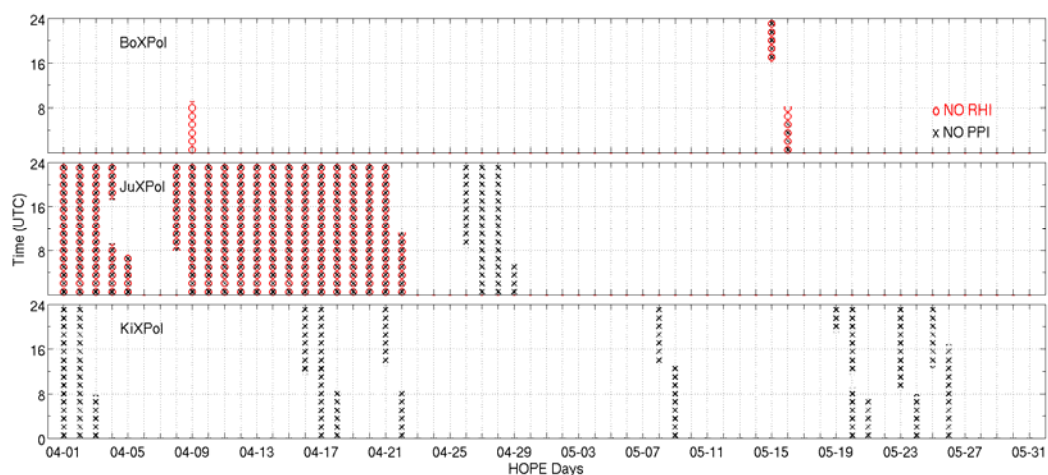
1

2 Figure 1. Location of the three polarimetric X-band radars (XPoL) and associated
 3 micro rain radars (MRR), rain gauges and disdrometers during HOPE. **The bottom**
 4 **panel is the zoomed-in region of the black box area on the top.** The red diamond
 5 markers indicate the locations of the X-band polarimetric radars, the red crosses
 6 indicate the locations of disdrometers and/or rain gauges at the sites of LACROS (the
 7 Leipzig Aerosol and Cloud Remote Observations System), KITCube (Kalthoff et al.,
 8 2013), WWTP (wastewater treatment plant), Tower, WTR (wind-temperature-radar),
 9 and the red triangles are the MRR locations at JOYCE and KITCube. White areas
 10 (elevations below sea level) are open-pit mines.

11

12 The three polarimetric X-band radars were performing volume scans consisting of
 13 stacked plan position indicators (PPI) with different scan strategies (Table 1). In
 14 addition to the volume scans, BoXPoL and JuXPoL also performed RHIs and vertical
 15 scans. A full volume scan of BoXPoL and JuXPoL takes about 5 min; in between RHI
 16 scans and one vertical scan (bird bath scan) were performed. The two RHIs of
 17 BoXPoL were oriented towards JOYCE (290°) and LACROS (293.4°) after 9 April
 18 2013, while JuXPoL made RHIs only towards JOYCE. JuXPoL made RHIs every

1 minute between 26 and 29 April 2013 followed by volume scans with PPIs at 10
 2 elevations and one RHI and vertical scan in 5 minute intervals. KiXPol performed
 3 only volume scans at 14 elevations every 5 minutes from April 2013 on (see Table 1).
 4 In May 2013, volume scans were interrupted on demand and instead RHI scans
 5 directed towards the prevailing wind direction were performed with a temporal
 6 resolution of 1 minute (Fig. 2).



7

8 Figure 2. Operation time of the polarimetric X-band radars BoXPol, JuxPol, and
 9 KiXPol during HOPE from 1 April to 31 May 2013, with the red circles indicating
 10 “no range height indicator (RHI) available” and the black crosses indicating “no plan
 11 position indicator (PPI) available”. KiXPol performed only RHIs on demand in May
 12 where “no PPI” was marked. The general scan strategies of the three polarimetric
 13 X-band radars are described in Table 1.

14

15

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17

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19

1 Table 1 The three polarimetric radars during HOPE

	BoXPol	JuXPol	KiXPol
location in latitude/longitude	50.73°/7.07 °	50.93 °/6.46 °	50.86 °/6.38 °
elevation in m a.s.l.	100.0	310.0	106.6
PPIs at elevation in °	1/1.5/2.4/4.5/7/8.2/ 11/14/18/28	1/2/3.1/4.5/6/8.2/ 11/14/18/28	0.6/1.4/2.4/3.5/4.8 /6.3/8/9.9/12.2/14.8/ 17.9/21.3/25.4/30
RHIs at azimuth in °	309.5/298.6 (1-8 April); 290.0/293.4 (9 April-31 May)	118.6 (1-25 April); 233.7 (26 April-31 May)	on request in May
bird-bath scan	yes	yes	No
radial resolution in m	100 - 150	100 - 150	250
scan period	every 5 min	every 5 min	every 5 min
3-dB beam width	1.05°	1.1°	1.35°
Frequency in GHz	9.3	9.3	9.37
Pulse repetition frequency (PRF) in Hz	250 - 1600	25 - 1600	1000
Antenna rotation rate(°/s)	12 - 28	12 - 28	12 - 28

2 **2.2 Rain gauges, disdrometers, MRRs and radiosondes**

3 In the vicinity of JOYCE, disdrometers and rain gauges were installed within an area
4 of approximately 25 km². Seven disdrometers observed surface rain rates and DSDs

1 while three rain gauges measured rain accumulations (Table 2). The disdrometers and
 2 rain gauges close to Juelich are used to evaluate radar derived QPE. **Disdrometer**
 3 **observations at BoXPol which is ~48.5 km away from JuXPol are not taken into**
 4 **account in Section 3 when statistically analyzing the precipitation over HOPE,**
 5 **considering the spatial and temporal variability of rainfall.**

6

7 Table 2 Information on rain gauges and disdrometers deployed during HOPE

Site name	Location (Latitude, Longitude)	Instrument (quantity)	Temporal resolution (s)	operation period
KITCube	(50.90°,6.46°)	Joss-Waldvogel disdrometer (1)	60	1 Apr - 31 May 2013
		OTT Parsivel2 (1)	60	1 Apr - 31 May 2013
LACROS	(50.88°,6.41°)	OTT Parsivel2 (1)	30	2 May - 31 May 2013
WTR	(50.91°,6.41°)	OTT Parsivel2 (1)	30	17 Apr - 31 May 2013
		OTT Pluvio (1)	10	17 Apr - 31 May 2013
WWTP	(50.90°,6.40°)	OTT Parsivel2 (1)	30	17 Apr - 31 May 2013
		Tipping bucket rain gauge (1)	--	17 Apr - 31 May 2013
Tower	(50.91°,6.41°)	OTT Parsivel1 (1)	30	17 Apr - 31 May 2013
		OTT Parsivel2 (1)	30	17 Apr - 31 May 2013
		OTT Pluvio (1)	10	17 Apr - 31 May 2013
BoXPol	(50.73°,7.07°)	OTT Parsivel2 (1)	30	1 Apr – 31 May 2013
		Thies Disdrometer (2)	60	1 Apr – 31 May 2013
		OTT Pluvio (1)	60	1 Apr – 31 May 2013

1 Three MRRs were deployed close to JOYCE, KITCube and BoXPol. At JOYCE and
2 KITCube, the MRRs measured vertical DSD profiles with a vertical resolution of 100
3 m, at BoXPol 150 m. Due to the near field scattering effects, MRR observations at the
4 first three gates are not used.

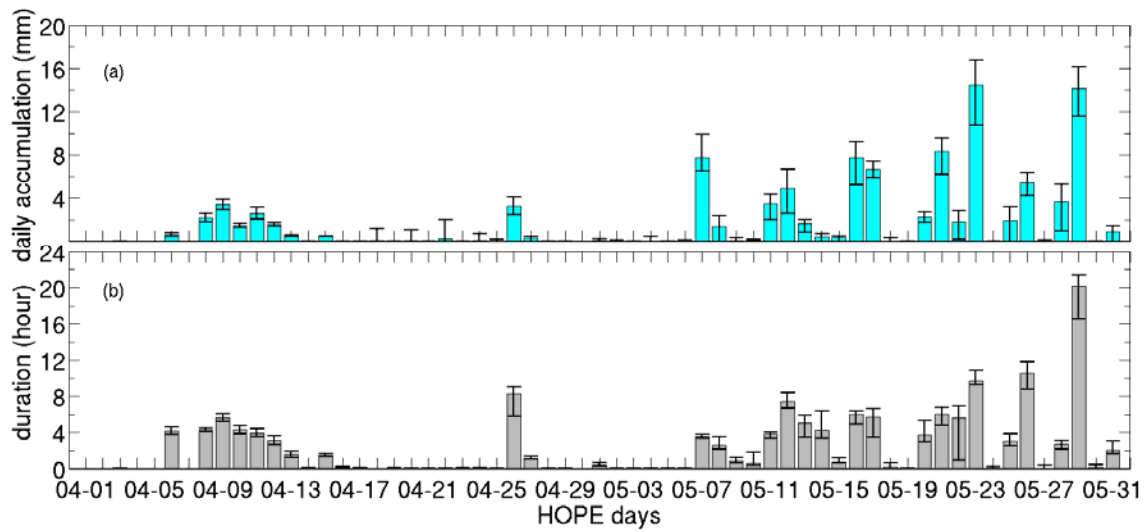
5 Radiosondes were launched regularly twice per day at KITCube, one at 1100 UTC
6 and another at 2300 UTC. Additional radiosondes were launched during intensive
7 observation periods (IOPs).

8 **3. Precipitation during HOPE**

9 We first compare QPE derived from the polarimetric radar observations with the
10 observations of the surface network of rain gauges and disdrometers, in order to
11 corroborate the consistency and accuracy of both estimates.

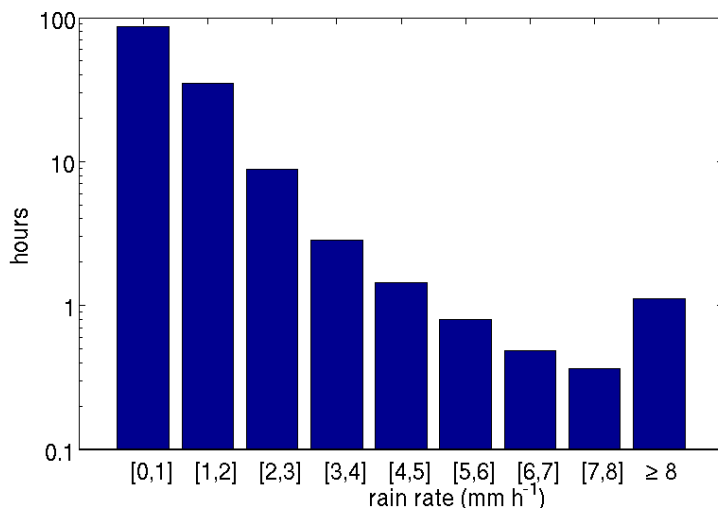
12 Figure 3 shows the daily rain accumulation and precipitation duration averaged over
13 the rain gauge/disdrometer observation sites in the HOPE region (Fig. 1). For rainfall
14 duration, only disdrometer observations are used since the weighing-type rain gauges
15 often indicate small noisy rain-like signals, which prevent accurate information on
16 rainfall duration. According to these observations, the maximum daily rain
17 accumulation was ~ 14.5 mm, the total rain accumulation during HOPE was ~ 104.8
18 mm, and the total rainfall time was ~ 144 hours, i.e., 10% of the total HOPE period.
19 The rainfall observations at the five locations are in good agreement with each other,
20 as indicated by the bars in Fig. 3, which show the full range of the observations.

21 According to the disdrometer observations, precipitation during HOPE was not very
22 intense (Fig. 4). **The distribution of rain intensities was calculated based on individual**
23 **measurements of disdrometers over the HOPE area.** Rain rates determined at a
24 temporal resolution of 1 minute were below less than 2 mm h^{-1} for more than 88% of
25 the total precipitation duration, while rain rates above 5 mm h^{-1} were observed for less
26 than 3 hours. Only one hour of rain rates above 8 mm h^{-1} did occur.



2 Figure 3. (a): Daily rainfall accumulation during HOPE. The height of the columns
 3 indicates the mean value while the bars indicate the range of the maximum and
 4 minimum rain accumulations observed by the 3 rain gauges and 7 disdrometers at the
 5 five station locations (Fig. 1). (b): Daily precipitation duration derived only from the 7
 6 disdrometers (see discussion in the text). Again the bars denote the range of the
 7 observations.

8



9

10 Figure 4. Distribution of rain intensities observed over one minute by the
 11 disdrometers in the inner HOPE area.

12

1

2 In accordance with the relatively light rainfall events during HOPE, the polarimetric
3 radar observables Z_{DR} and K_{DP} were low and quite noisy. Under these conditions,
4 most of the time, we simply used Marshall-Palmer relation for quantitative rainfall
5 estimations (Marshall and Palmer, 1948),

$$6 \quad Z_H = 200R^{1.5} \quad (\text{or } R = 0.029Z^{0.67}) \quad (1)$$

7 where Z_H (in $\text{mm}^6 \text{m}^{-3}$) is the radar reflectivity for horizontal polarization in linear
8 scale and R is the rain rate in mm h^{-1} .

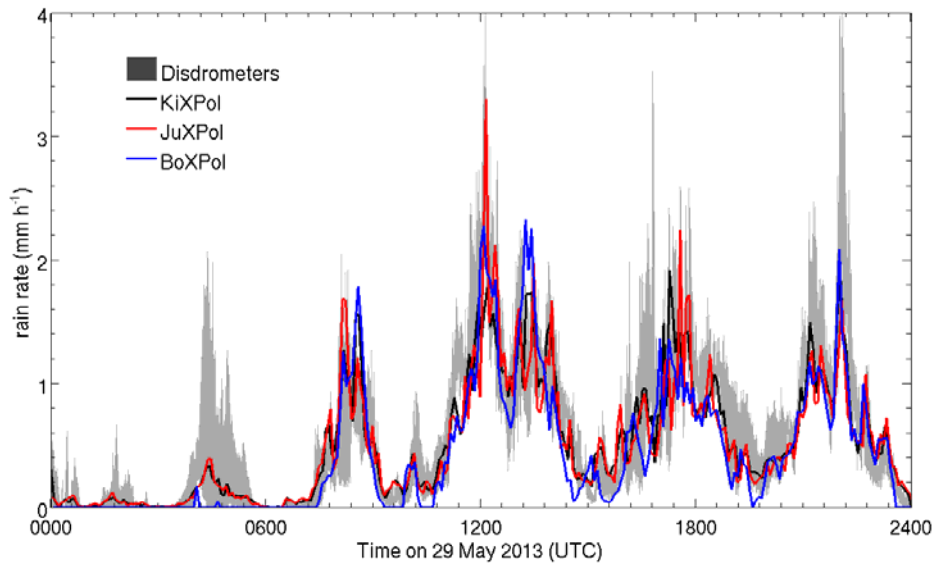
9 Since Equation (1) tends to overestimate stronger rain intensities (Zrnić et al., 2000;
10 Trömel et al., 2014b), the R- K_{DP} relation is employed for rain rate estimation when Z_H
11 is above 37 dBZ, i.e., the instantaneous rain rate is above 8 mm h^{-1} (Diederich et al.,
12 2015b; Ryzhkov et al., 2014). K_{DP} is independent of calibration and unaffected by
13 attenuation (Ryzhkov et al., 2014). Thus, following Diederich et al. (2015b) and
14 Ryzhkov et al. (2014), in this case the rain rate is determined by

$$15 \quad R = 16.9K_{DP}^{0.801} \quad \text{if } K_{DP} > 0 \quad (2)$$

16 where K_{DP} is the specific differential phase ($^{\circ} \text{ km}^{-1}$) and filtered from polarimetric
17 radar measurements following Hubbert and Bringi (1995).

18 Radar bins with copolar correlation coefficient $\rho_{HV} < 0.75$ have been neglected in
19 order to eliminate the ground clutter contamination. For JuXPol and KiXPol,
20 observations at elevations 4.5° and 3.5° , respectively, are used to calculate the rain
21 rates and avoid the possible impacts from a 120-m height meteorological tower at
22 Forschungszentrum Juelich, while an elevation of 1° is chosen for BoXPol rainfall
23 estimation since the radar beam at longer distance is less affected by the ground
24 clutter and certainly overshoots the meteorological tower. **Z and Z_{DR} attenuation along**
25 **each radial is neglected since the rain intensities were generally low over the HOPE**
26 **area.** The mean beam diameter of BoXPol over the HOPE area is around 850 m,
27 which is almost 10 times larger than that of JuXPol and KiXPol, and its beam height

1 (~860 m) is about 2 times larger comparing to JuXPol and KiXPol.

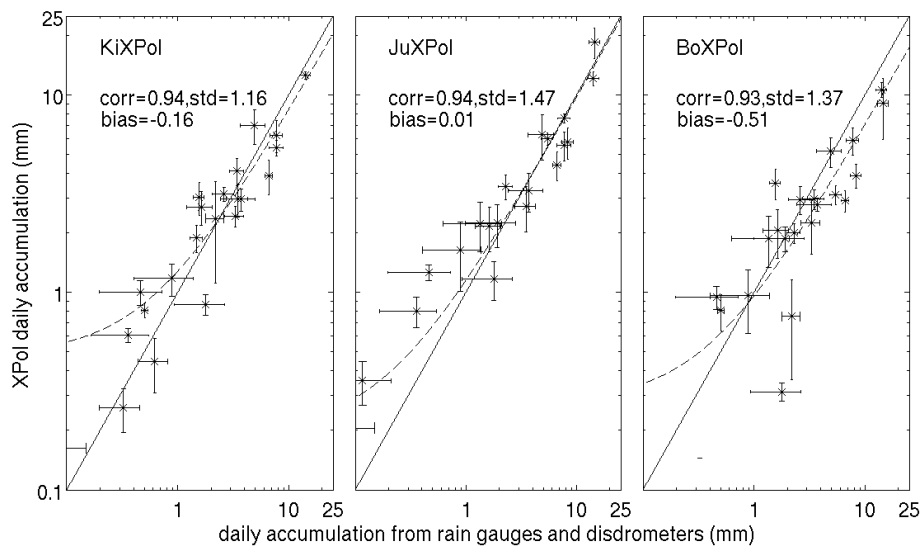


2

3 Figure 5. Time series of rain rates derived from observations of the seven
4 disdrometers and the three polarimetric radars on 29 May 2013. The shaded gray area
5 indicates the range of rain rates observed by the disdrometers with 1-min temporal
6 resolution in the HOPE area while the rain rate from the three polarimetric radar
7 observations is calculated at the radar gates that are coincident with disdrometer
8 locations and also averaged over the five disdrometer locations.

9

10 Figure 5 compares as an example the mean rain rates derived from the three X-band
11 polarimetric radar over the five disdrometer locations with the disdrometer
12 observations for 29 May 2013. Precipitation fell intermittently with five more intense
13 periods separated by short periods of no or very low rain rates and maximum rain
14 rates between 1 and 3 mm h⁻¹. In general, the variability of the radar-derived surface
15 precipitation matches very well the disdrometer measurements. **JuXPol and KiXPol**
16 **are in a better agreement with the surface measurements than BoXPol for the very low**
17 **rain rates, which probably suffers from the effects of non-uniform beam filling effects**
18 **due to the much larger distance from the HOPE area (Giangrande and Ryzhkov, 2008)**
19 **and higher altitude of sampling volume of BoXPol.**

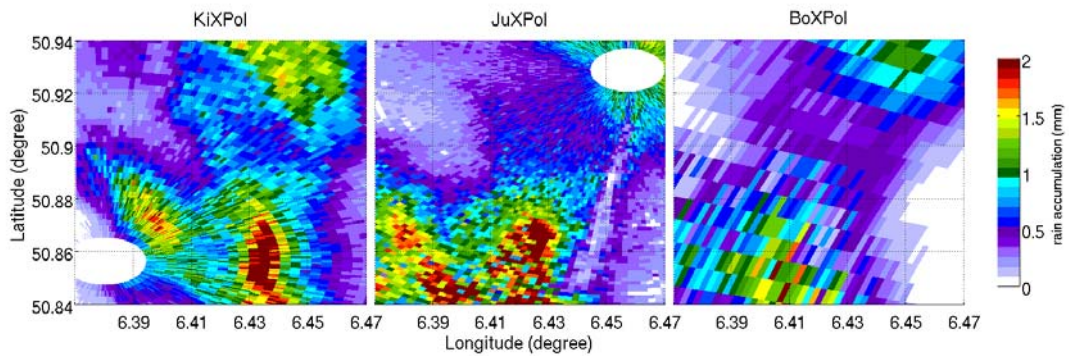


1

2 Figure 6. Mean daily radar-derived rain accumulation over the disdrometer/rain
 3 gauge locations, compared to the surface precipitation observed by the rain gauges
 4 and disdrometers in the HOPE area. The bars indicate the standard deviation of the
 5 estimates from the particular radar (vertical bars) and from the surface observations
 6 (horizontal bars) . The dashed black line is the best linear fit of the daily rain
 7 accumulation on the logarithmic scale while the solid black line is the 1:1 line.

8

9 Daily-accumulated rainfall estimated by the three polarimetric radars are compared
 10 with the observations of rain gauges and disdrometers in Fig. 6. Both estimates are
 11 very consistent as indicated by correlations above 0.93. As for 29 May 2013, BoXPol
 12 estimates result in lower daily accumulations than for the other two radars, **again**
 13 **probably caused by beam broadening (Giangrande and Ryzhkov, 2008) and high**
 14 **altitude of sampling volume of BoXPol over the HOPE area.**



1

2 Figure 7. Rain accumulation over the HOPE area between 0830 and 0900 UTC (6
 3 PPIs) on 29 May 2013 observed by the three polarimetric radars.

4

5 With a range resolution of 150/250 m and a beam diameter of approximately 87/850
 6 m over the HOPE area, the three polarimetric radars allow to characterize the
 7 precipitation patterns in the HOPE domain in high resolution, which will be important
 8 for model evaluation. A 30-min rain accumulation over the inner HOPE area on 29
 9 May 2013 shows that, the three radar estimates result in an overall agreement of the
 10 rough precipitation pattern (Figure 7). However, when we zoomed into details and
 11 noticed also the minor differences between these patterns, e.g., lower precipitation
 12 observed by BoXPol and missing pixels near KiXPol and JuXPol. Bins close to
 13 KiXPol and JuXPol were contaminated by ground clutters while the beam broadening
 14 and height at the larger ranges deteriorates the similarity between the BoXPol and
 15 KiXPol/JuXPol estimates (Fig. 7). The different radar observation scenarios, i.e., at an
 16 elevation of 4.5° JuXPol reaches 750 m above KiXPol and the time differences
 17 between the two radar measurements are up to 5 min, also needs to be considered. A
 18 combination of the three radar observations will definitely be an advantage to
 19 reconstruct the precipitation patterns over the HOPE area in a future study. Since no
 20 adjustments of the $R-Z_H$ and $R-K_{DP}$ relations were made, these results are very
 21 promising. The three radar estimates together with the direct comparisons with the
 22 rain gauges and disdrometers allow to attribute robust error estimates to these
 23 precipitation fields, which will be valuable when compared with model simulations.

1 **4. Observed microphysical processes**

2 Falling hydrometeors are subject to growth and/or depletion by a range of
3 microphysical processes which leave their fingerprints in the spatial and temporal
4 evolution of several polarimetric moments. Since microphysical processes are
5 simulated in atmospheric models with increasing details, polarimetric radar
6 observations can be used for model validations and thus spur further improvements.
7 In this section we present three cases, where such microphysical processes could be
8 observed by the radars and substantiated by MRR and disdrometer observations.

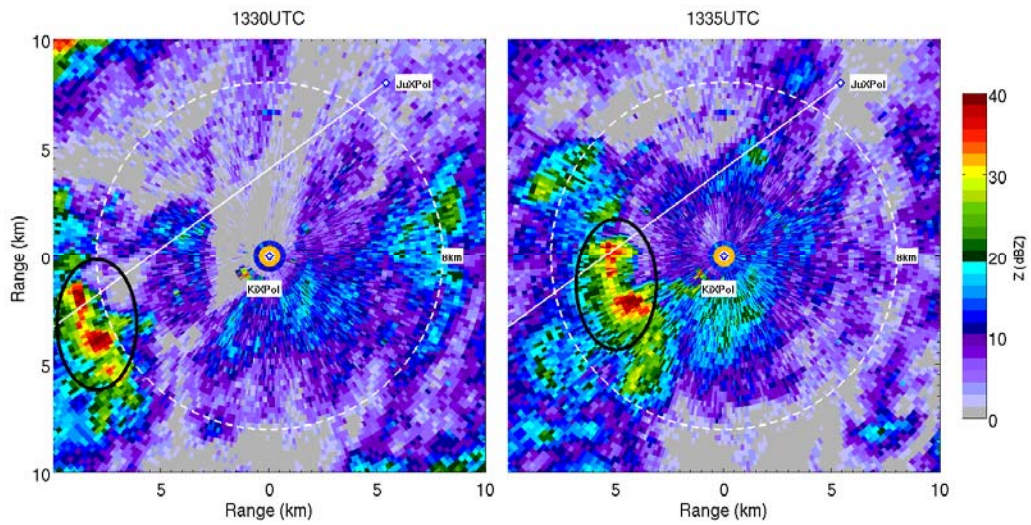
9 **4.1 Case 1: Size sorting and coalescence**

10 On 26 Apr 2013, a cold front passed over Germany, which came with a large band of
11 stratiform rain that persisted from the morning hours until the end of the day. The
12 daily rain accumulation recorded by the surface observations was about 3.5 mm while
13 the precipitation lasted up to 8 hours (Fig. 3). Six radiosondes launched at KITCube at
14 0700 UTC, 0900 UTC, 1100 UTC, 1300UTC, 1600 UTC and 2300 UTC, respectively,
15 recorded a freezing level above 2100 m during daytime, which descended down to
16 830 m at about 2300 UTC.

17

18

19

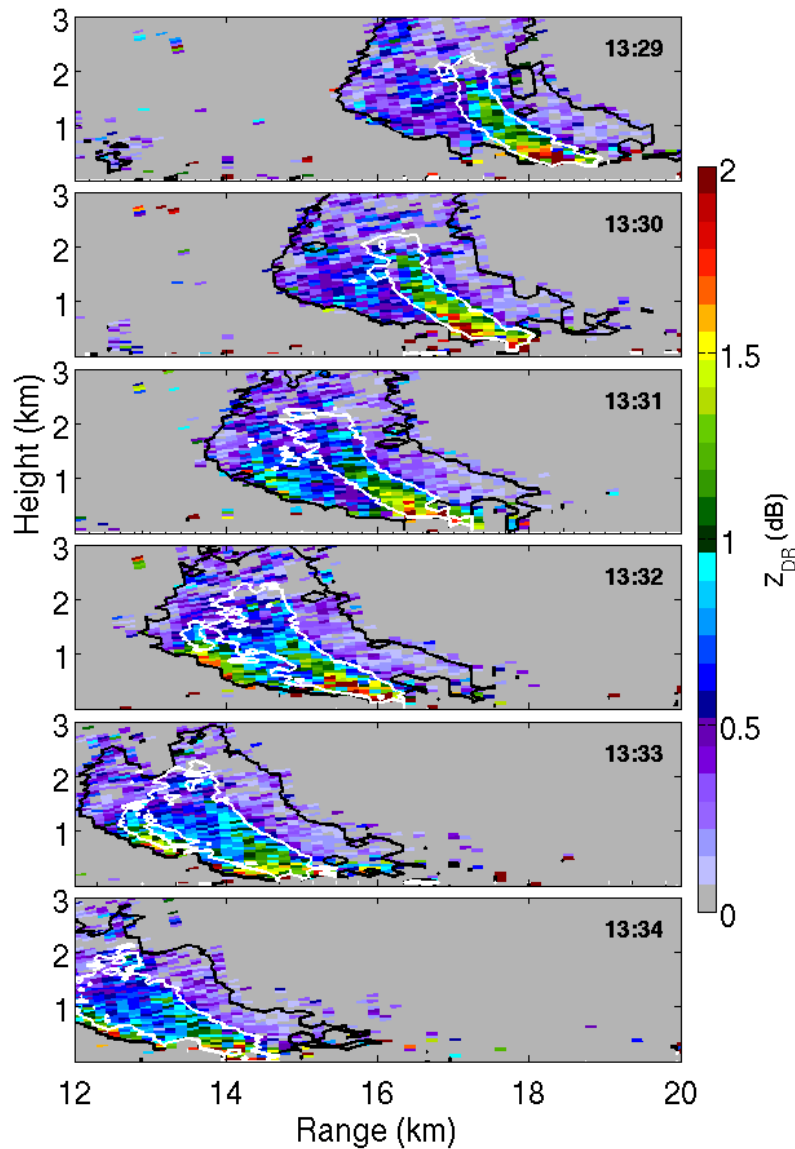


1

2 Figure 8. Reflectivity (Z_H) of KiXPol observed at an elevation angle of 3.5° at 1330
 3 UTC and 1335 UTC on 26 April 2013. The precipitating cell examined in the text is
 4 highlighted by the black ellipse. The white solid line indicates the azimuth direction
 5 of the JuXPol RHIs, while the white dashed circle delineates the 8-km distance from
 6 KiXPol.

7

8 KiXPol performed volume scans every 5 min on that day, with scan elevations
 9 ranging from 0.6° to 30° (Table 1), while JuXPol made RHI scans in the direction of
 10 JOYCE every minute.



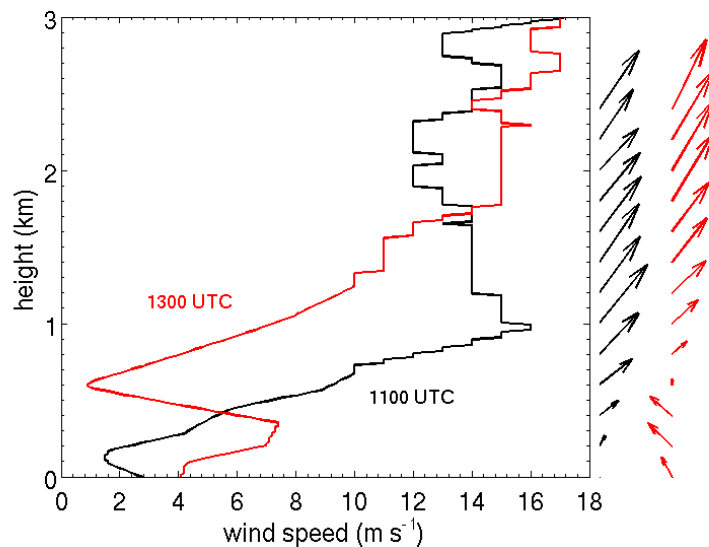
1

2 Figure 9. Sequence of RHIs of differential reflectivity (Z_{DR}) measured by JuXPol at
 3 an azimuth angle of 233.7° between 1329 UTC and 1334 UTC on 26 April 2013
 4 (from top to bottom). The contour lines indicate reflectivity values (Z_H) of 15 dBZ
 5 (black) and 30 dBZ (white), respectively.

6

7 At 1330 UTC KiXPol observed a precipitating cell approaching the radar from the
 8 southwest at about 10 km distance, which was moving towards JuXPol (Fig. 8). At
 9 1335 UTC the cell was within 8 km from KiXPol, where it started to dissolve (not
 10 shown). RHIs performed with JuXPol at the azimuth direction 233.7° nicely tracked

1 the approaching cell (Fig. 9).
 2 The high temporal resolution of the JuXPoI RHIs allows for a detailed insight into the
 3 evolution of the precipitating cell. The cell was first observed by JuXPoI at 1300 UTC
 4 at about 45 km distance and kept moving towards JuXPoI with low reflectivities at
 5 about 20 dB (not shown). At 1329 UTC, JuXPoI detected the precipitating cell
 6 entering its RHI at 20 km range (Fig. 9). In the center of the precipitating cell tilted
 7 towards the northeast by the wind shear (See Fig. 10), near surface Z_{DR} values were
 8 up to 2 dB while Z_H was above 30 dBZ. Z_{DR} increases towards the ground concurrent
 9 with an increasing Z_H . This behavior is a clear sign of coalescence, which shifts small
 10 raindrops to larger sizes and increases the mean raindrop size (Kumjian and Prat,
 11 2014).



12
 13 Figure 10 Wind profiles derived from radiosondes launched at KITCube at 1100 UTC
 14 and 1300 UTC. The arrows on the right indicate the wind vector (0° indicates the
 15 north) while their lengths are proportional to wind speed.

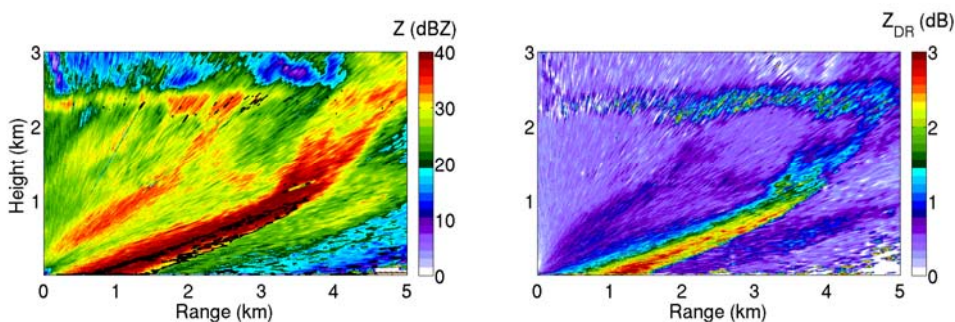
16
 17 While moving towards JuXPoI, the tilt of the cell led to a concentration of large rain
 18 drops at the leading edge of the precipitating cell, where their larger fall speed
 19 separates them from the smaller droplets which largely remain in the flow volume

1 (e.g., Kumjian and Ryzhkov (2012)). From 1329 UTC to 1330 UTC, Z_{DR} at the
2 leading edge of the cell is below 0.5 dB (Fig. 9). At 1331 UTC, Z_{DR} begins increasing
3 and later on reaches up to 2 dB while Z_H remains in the order of 15 dBZ in that region.
4 When the cell begins to dissipate as it moves forward, Z_{DR} decreases down to ~ 1 dB
5 both in the center and upstream of the precipitating cell.

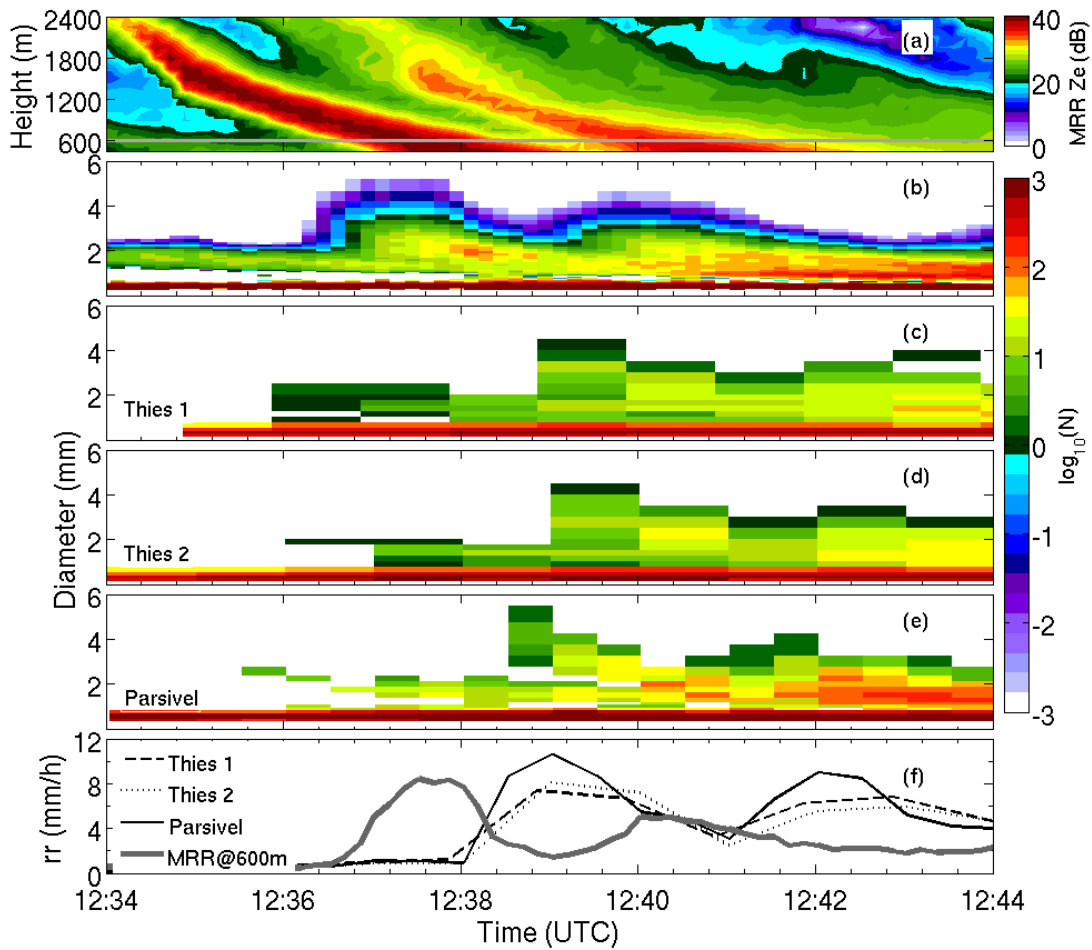
6 **4.2 Case 2: Size sorting due to vertical wind shear**

7 A second case on size sorting caused by the vertical wind shear was well captured by
8 BoXPol on 17 May 2013. A deep low pressure system reaching from the surface up to
9 200 hPa was found over the Northeast Atlantic and the British Isles on the previous
10 day, while a surface low was moving from the western Mediterranean to the north,
11 towards central Europe. As a result a complex pattern of fronts was affecting France
12 and Germany due to the interaction of both systems. On 17 May 2013, a stationary
13 front along with a through of warm air aloft passed over West Germany, moving
14 eastwards. Low atmosphere levels were characterized by high humidity and a sharp
15 West-East temperature gradient. A band of mostly stratiform rain affected
16 south-western and western Germany earlier in the day, while later on convective rain
17 with lightning activity developed over south east and central Germany. About 8 mm
18 of rain accumulated over 6 hour time spans as recorded by the disdrometers (Fig. 3).

19



21 Figure 11. Reflectivity (Z_H , left) and differential reflectivity (Z_{DR} , right) observed by
22 BoXPol at an azimuth angle of 290° at 1240 UTC on 17 May 2013. The black isoline
23 in the left panel indicates the 2-dB Z_{DR} contour line.



1

2 Figure 12. Different instrument observations located within distances of 5 meters
 3 close (200 m) to the BoXPoI location in Bonn, Germany, between 1234 UTC and
 4 1244 UTC on 17 May 2013. (a): Reflectivity observed by vertically pointing micro
 5 rain radar (MRR). The grey horizontal solid line indicates the 600 m height level. (b):
 6 MRR-observed DSDs at 600 m altitude. (c) DSDs observed by a Thies disdrometer
 7 with its transmitter and receiver line pointing along the east-west direction (Thies 1);
 8 (d) same as (c) but for a Thies disdrometer pointing along the south-north direction
 9 (Thies 2); (e) Same as (c) except for an OTT Parsivel disdrometer; (f) Rain rate
 10 observed by an MRR at 600 m height and the three disdrometers collocated with the
 11 MRR at the BoXPoI station.

12

1 The precipitating cell moving westwards was captured by the BoXPol RHI scan. The
2 melting layer can be easily identified by the enhanced Z_H and Z_{DR} at an altitude of
3 ~ 2.2 km in the RHI performed at an azimuth angle of 290° (Fig. 11). Similar to the
4 first case presented above, the strong Z_{DR} at the leading edge indicates the increase of
5 mean raindrop size due to the accumulation of large raindrops by size sorting.

6 At 200 m distance from BoXPol, vertical profiles of DSDs were observed by an MRR.
7 Figure 12 shows the time series of MRR-derived reflectivity (Panel a) with the
8 corresponding DSDs at an altitude of 600 m (Panel b). The first cell of a precipitation
9 system passed BoXPol and the MRR before 1240 UTC with reflectivities up to 40
10 dBZ in the center, followed by a second peak with reflectivities up to 35 dBZ (Fig.
11 12a). The derived DSDs indicate that, fast falling large raindrops tend to concentrate
12 at the upstream side of the cell, while raindrops less than 3 mm in diameter have a
13 larger number concentration downstream (Fig. 12b). **However, the coarse temporal**
14 **resolution of BoXPol RHI scans (every 5 min) makes it difficult to compare directly**
15 **the MRR observations with BoXPol over the MRR site.**

16 The OTT Parsivel and Thies optical laser disdrometers collocated with the MRR also
17 captured the precipitation event on that day (Fig. 12c-12f). One Thies disdrometer
18 was deployed with its transmitter-receiver line in the west-east direction (Thies 1) and
19 the other in the south-north direction (Thies 2). For the surface DSDs shown in Fig.
20 12b-12e, the largest raindrops collected by the two Thies disdrometers are below 4
21 mm after 1239 UTC. Similar to MRR observations, however, the Parsivel observed
22 larger raindrops up to 5 mm at an earlier time step since it was operated at a temporal
23 resolution of 30 s. It implies that a temporal resolution of better than 1 min is required
24 to better interpret the DSD evolution caused by size sorting due to vertical wind shear
25 and to improve the surface rainfall estimations.

26 The surface rain rates observed by the three disdrometers differ from the MRR
27 observations at 600 m considering the spatial and temporal shifts (approximately 2
28 min) (Fig. 12f). The maximum rain rate estimated from the MRR at 600 m is ~ 8 mm
29 h^{-1} at 1238 UTC, with a second peak of ~ 6 mm h^{-1} at 1240 UTC. **Considering the**

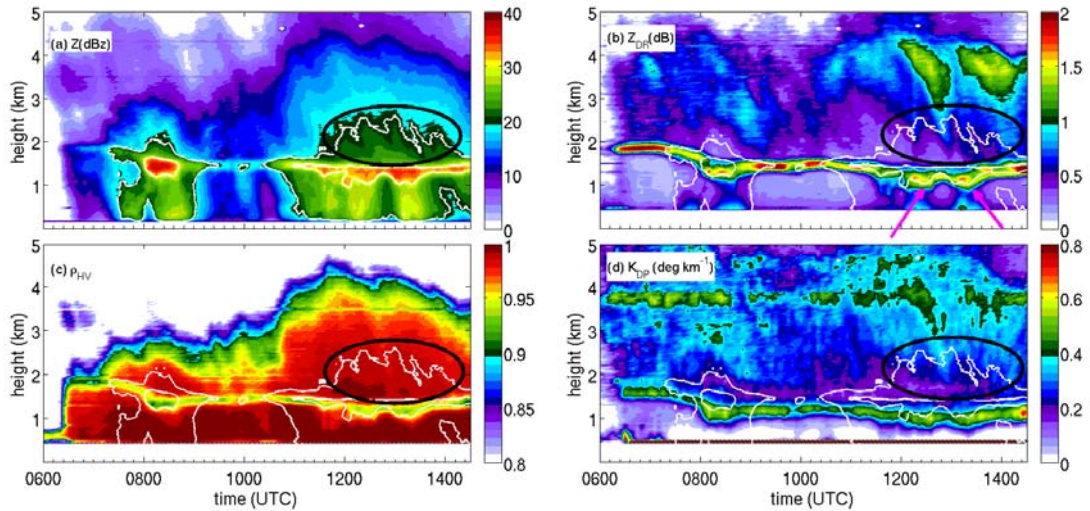
1 effects from size sorting and other possible microphysical processes, the rain rate at
2 high altitudes is usually higher than on the surface. The two Thies disdrometers close
3 to the Parsivel, which provide measurements at 1 min time interval, also show a
4 smaller maximum rain rate near the ground. We thus conclude that the Parsivel is
5 overestimating the rain rate (Fig. 12f). Nevertheless, these observations are consistent
6 with the occurrence of the size sorting process shown from the radar observations..

7 **4.3 Case 3: Riming/aggregation processes observed by JuXPol**

8 On 29 May 2013 a cut-off process was underway over western and middle Europe,
9 resulting in a broad and well defined upper level vortex. At lower levels the pressure
10 distribution was more complex with several small surface lows and generally weak
11 pressure gradients. One of these surface lows, initially situated over southern England
12 at 0000 UTC, moved to eastern France during the day. The corresponding cold front
13 became quasi-stationary, as indicated by a sharp θ_e (equivalent potential temperature)
14 gradient over Be-Ne-Lux and western Germany (not shown). At 0000 UTC and 0600
15 UTC frontogenetic forcing was strongest due to deformational processes in the
16 vicinity of the front as it interacted with a second low over the northern half over
17 Germany. This resulted in a subsequent reinforcement of frontal precipitation over the
18 HOPE area until 1200 UTC. During and after that intensification period the frontal
19 temperature gradient gradually dissolved due to evaporative cooling and the advection
20 of a colder maritime air mass also on the warm side of the front. As a consequence
21 frontal precipitation weakened by the end of the day.

22 The daily rain accumulation for 29 May 2013 recorded by the surface observations
23 was ~14 mm while precipitation lasted up to 20 hours (Fig. 3): this was the day with
24 the longest rainy period which also lead to the second largest daily rain accumulation
25 during HOPE. Three radiosondes were launched at the location of KITCube, one at
26 2300 UTC on 28 May and two at 1100 UTC and 2300 UTC on 29 May. According to
27 the soundings, the freezing level was located at ~2.2 km at 2300 UTC on 28 May
28 2013 and subsided down to ~1.7 km at 1100 UTC on 29 May 2013.

1 Figure 13 shows so-called Quasi-Vertical Profiles (QVPs) of Z_H , Z_{DR} , ρ_{HV} and K_{DP}
 2 based on JuXPoI measurements at 18° elevation angle between 0600 and 1430 UTC.
 3 QVPs were first used by Trömel et al. (2014a) to reliably estimate backscatter
 4 differential phase and Ryzhkov et al. (2016) further expanded the QVP
 5 methodology and demonstrated its multiple benefits. The QVPs of polarimetric
 6 variables are obtained by azimuthal averaging of the radar data collected during
 7 conical PPI scans at higher antenna elevation angles in order to reduce statistical
 8 errors of the variables and assign their average vertical profiles to a conical volume in
 9 a time-height display. QVPs are especially beneficial for monitoring the temporal
 10 evolution of microphysical processes active on a larger scale.



11
 12 Figure 13. (a) Time series of Quasi-Vertical Profiles (QVPs) of Z_H derived from
 13 PPIs measured with JuXPoI at 18° elevation on 29 May 2013 between 0600UTC and
 14 1430UTC. The white lines indicate the 20 and 30 dBZ contours of Z_H ; (b), (c) and (d):
 15 the same time series as (a) but for Z_{DR} , ρ_{HV} and K_{DP} , respectively. The black ellipses
 16 highlight the area for aggregation/riming while the magenta arrows in Panel (b)
 17 indicate the Z_{DR} saggings (see text for detail).

18
 19 The most striking feature in Fig. 13 is the descent of the melting layer from 1.8 km
 20 down to ~ 1.5 km height between 0700 and 0900 UTC. After 1200 UTC, a region of
 21 enhanced K_{DP} above 3.5 km accompanied with $Z_{DR} > 1.2$ dB aloft can be identified.

1 Bands of enhanced Z_{DR} and bands of enhanced K_{DP} are both considered as signatures
2 of dendritic growth (Kennedy and Rutledge, 2011). According to the radiosonde
3 ascending at 1100 UTC, the temperature zone of $-10^{\circ}\text{C} \sim -15^{\circ}\text{C}$ which favors the
4 growth of ice dendrites is located between 3.8 and 4.7 km. Thus, we may suspect
5 dendrites growing above 3.5 km especially after 1200 UTC (Fig. 13).

6 When following the height evolution of polarimetric variable structures above the
7 melting layer (ML) after 1200 UTC (Fig. 13), riming/aggregation processes are
8 indicated by enhancements of Z_H and ρ_{HV} above the ML while Z_{DR} and K_{DP} decrease
9 with height in unison above the ML after 1200 UTC (ellipses in Fig. 13). Z_{DR} and K_{DP}
10 depressions aloft associated with increases in Z_H and ρ_{HV} above the ML suggest
11 increases of ice particle mean sizes due to riming and/or aggregation. Recently,
12 Moisseev et al. (2015) argued that the processes responsible for enhanced K_{DP} - and
13 Z_{DR} -bands might be different: they advocated that the K_{DP} bands are caused by high
14 number concentrations of oblate relatively dense ice particles (early aggregates) and
15 are linked to the onset of aggregation processes, while Z_{DR} bands in the absence of
16 K_{DP} bands are observed when crystal growth is the dominating snow growth
17 mechanism and the number concentration is lower. Following their arguments, it can
18 also be speculated that aggregation processes are ongoing near the end of the
19 observation period shown in Fig. 13.

20 Discrimination between riming and aggregation is important for aviation security,
21 since riming implies the existence of supercooled liquid water above the freezing
22 level, which could result in dangerous icing on aircrafts. Riming is also associated
23 with embedded updrafts, convective development and thus precipitation enhancement.
24 In the presence of such updrafts, enhanced condensation of water vapor occurs and
25 leads to small liquid droplets which may be accreted by dry snowflakes. These rimed
26 snowflakes may grow fast and reach large sizes with higher terminal velocity before
27 they fall through the ML. Due to their enhanced terminal velocity, they melt at a
28 lower height and lead to the “sagging” signature of the bright band in terms of Z_{DR}
29 and ρ_{HV} (Ryzhkov et al., 2016).

1 In Fig. 13, reduced Z_{DR} combined with enhanced Z_H and Z_{HV} above the ML occurs at
2 times, and also “sagging” signatures are clearly visible at around 1200 UTC and 1300
3 UTC (the magenta arrows in Fig. 13b). Starting from the bottom of the Z_{DR} - and K_{DP} -
4 bands at about 3 km height at 1200 UTC, Z_{DR} decreases and Z increases downwards
5 most probably due to aggregation and/or riming. Here Z_{DR} reduces down to a few
6 tenths of a dB just above the level where melting starts. However, this reduction is
7 expected to be more intense for riming than for aggregation. Riming makes the ice
8 particles more spherical leading to a lower Z_{DR} by 0.1 – 0.3 dB (Ryzhkov et al., 2016).
9 Thus, we speculate that riming causes the “sagging” effects of Z_{DR} and Z_{HV}
10 combined with relatively low Z_{DR} above the ML around 1200 UTC and 1300 UTC. To
11 more reliably distinguish between riming and aggregation, we require additional
12 measurements indicative e.g. of associated updrafts and supercooled liquid water
13 above ML, which could be provided by additional microwave radiometers and cloud
14 radars.

15 The discussed examples have clearly shown how polarimetric radars can be used to
16 identify and distinguish between different microphysical processes, like warm rain
17 processes and ice particle formation and growth. Converting the output of NWP
18 models into polarimetric radar variables and using a polarimetric forward radar
19 operator would provide an opportunity to validate the representation of the discussed
20 microphysical processes in such models.

21

22 **5. Conclusions**

23 This study presents a summary of rainfall observations and some examples of related
24 microphysical processes occurring during HOPE between 1 April and 31 May 2013.
25 At that time three X-band polarimetric Doppler radars observing the central HOPE
26 area of about 5 km×5 km over which a surface network of rain gauges, disdrometers
27 and MRRs was deployed to assess the accuracy of the radar-based precipitation
28 observations and to demonstrate the capability of polarimetric radars to detect

1 microphysical processes. Rainfall accumulations at the daily and even hourly scale
2 were surprisingly consistent between the different observations demonstrating the
3 high quality of QPE based on R-Z and R- K_{DP} relations at least for the low intensity
4 rainfall events prevalent during HOPE.

5 The combined observations of polarimetric radars and collocated instruments
6 demonstrated the ability of radar polarimetry to detect several microphysical
7 processes by so-called polarimetric fingerprints during the development and evolution
8 of precipitation systems. These fingerprints clearly identify microphysical processes
9 like coalescence, size sorting and riming/aggregation. Size sorting by wind shear was
10 e.g. well captured by the JuXPol and BoXPol RHI scans and corroborated by the
11 collocated MRR and disdrometer observations. **While there were clear signs of other
12 processes like riming and aggregation, a distinction between these two processes is
13 still difficult with the available observations. Doppler velocities at the vertical
14 pointing mode were analyzed but the observed values (between 1 - 2 m/s) still makes
15 the distinction ambiguous. Furthermore, the exact time from the QVP and vertical
16 pointing scans cannot be matched, and one has to be careful when comparing the QVP
17 with vertical scans. Additional analysis in conjunction with other independent
18 observations e.g. from microwave radiometers, lidars and cloud radars which were
19 deployed at the JOYCE site is also required for a better distinction between riming
20 and aggregation, which is the focus of an ongoing study.**

21

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4 Karlsruhe Institute of Technology (KIT) for providing KiXPol observations and the
5 observation data at KITCube station during HOPE.

6

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