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EROSION

D1.4 Data on rain drop size distribution at selected sites observed 1 year and stored in database

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Forsidefoto: Parsivel^2 next to the wind turbines at DTU Risø campus by Anna-Maria Tilg
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Preface

This report describes the **Data on rain drop size distribution at selected sites observed 1 year and stored in database** for the EROSION project.

The project is funded by Innovation Fund Denmark and project partners. The project period is from April 1st, 2017 to March 31st, 2020 (3 years).

The aim of the project **EROSION – Wind turbine blade erosion: Reducing the largest uncertainties** is to create knowledge and methods to avoid blade erosion caused by rain and hail. The hypothesis is that by reducing the tip speed of the blades, where rain and hail cause severe blade erosion, a significant extension of blade lifetime can be obtained with reduced maintenance cost and negligible loss of production.

The key objective of EROSION is to enable longer lifetime of wind turbine blades at multi-MW machines. To achieve the objective the project work will include testing of specimen in the rain erosion tester and investigation and analysis of damage on leading edges of blades. Furthermore, the rain in real atmosphere will be investigated from ground-based instruments (disdrometers) and modelling of rain based on rain radar data. Finally a new prototype instrument will be developed in order to measure rain at wind turbines for making decision on control, to set 'erosion safe mode' with regulation of turbines. Much longer lifetime of wind turbine blades and reduced operation and maintenance costs are expected.

Project web-site is http://www.rain-erosion.dk/

Contents

Executive summary

The rain drop size distribution data collected in the EROSION project are important for further insight to the environmental conditions causing the leading edge erosion at turbine blades. The data set is unique. Firstly, data are collected a sites highly relevant for offshore turbines. Secondly, contrasting rain and wind climate conditions exist at the various stations and enable in-depth analysis of similarities and differences. Thirdly, one-year long observations enable seasonal characterization of the rain-wind climate.

The disdrometer stations cover sites in eastern Denmark (Risø, Roskilde), central Denmark (Voulund, Jutland) and coastal stations at the west coast (Hvide Sande and Thyborøn, Jutland) and offshore in the Baltic Sea (Rødsand) and the North Sea (Horns Rev 3).

In addition, data at two heights 5m and 123m are collected at Risø, to characterize possible differences in rain-wind climate with height. Wind turbines operate around 100 m so the rain-wind climate at this height is of special importance.

Two other perspectives will be covered from the EROSION disdrometer network.

One perspective is to make it possible to do analysis between the DMI dual-pol radar data. This analysis will be important for improving and verifying the accuracy in the now casting of rain events.

The other perspective is to identify the rain drop sizes most relevant for rain erosion testing in laboratories, to mimic particular environmental conditions relevant for leading edge erosion.

The Parsivel^2 disdrometer is the state of the art instrument. Comparison to a novel radar-based instrument (WS100) was performed. Unfortunately, the data quality from WS100 is not of sufficient quality for the application of leading edge erosion.

The data are stored in MySQL database with documentation of the parameters.

1 Introduction

In the EROSION project the research hypothesis is that large rain drops cause significant erosion at the leading edges of wind turbine blades. The research hypothesis is sketched in Figure 1.

1. Research hypothesis: Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime can be obtained with negligible loss of production.

2. Methodology: Define rain and hail erosion classes to quantify leading edge blade in-field and in lab testing. Correlations between rain intensity, droplet size, impact speed, materials properties, etc. will be established.

3. Measurement Device: Low-cost prototype for precipitation measurement on site and real time warning device enabling modern control of wind turbines.

4. Erosion safe mode: A safe mode control based on the erosion classes to control the wind turbine, reducing the tip speed under severe conditions – preventing aerodynamic degradation and reducing maintenance costs.

Figure 1: Sketch of the research hypothesis in the EROSION project.

Disdrometer measurements, which include the number, size and velocity of precipitation particles, provide information that is essential for different work packages. Hasager and Vejen (2017) gave already an overview about the selection process of sensor and location as well as expectations for the planned field campaign.

To capture precipitation in different seasons and its different characteristics during the year, the time series needed to be at least one year. Furthermore, the influence of the environment on the measurements was considered by placing the disdrometers at different places in and around Denmark (inland, at the shore, at wind parks).

This report gives an overview about the used instruments and the locations where there are (or were) installed. Furthermore, we present an analysis of one year disdrometer data of a selected station and give an overview about the data in the database.

2. Overview instruments

2.1 Installed instruments

Parsivel^2 disdrometer

The Ott Parsivel^2 disdrometer is a laser disdrometer which can measure the size and velocity of particles by analyzing the attenuation of the laser beam. An internal algorithm uses these data to calculate the precipitation type, rain intensity or kinetic energy and other parameters. The website of the manufacturer provides further detailed information about this sensor (https://www.ott.com/en-us/products/meteorological-sensors-26/ott-parsivel2-laser-weather-sensor-2392/). Well-known problems of the disdrometer are the splashing of particles at the sensor structure (reduced by using a special material), particles falling at the edge of the laser beam and the influence due to wind.

WS100 Radar Precipitation Sensor (“Smart Disdrometer”)

The manufacturer of the Parsivel^2 offered us the new developed WS100 Radar Precipitation Sensor for having a smaller device than the Parsivel^2 (being handier for installing at remote locations). The measurement principle is different to the one of the Parsivel^2. The WS100 uses a 24GHz Doppler radar for detecting falling precipitation particles and calculates internally after a post-processing for example rain intensity and precipitation type. More details can be found at the manufacturers’ website (https://www.lufft.com/products/precipitation-sensors-287/ws100-radar-precipitation-sensor-smart-disdrometer-2361/).

2.2 Locations with Parsivel^2 and/or WS100 installations

In total, Parsivel^2 and WS100 are (or were) installed at eight different locations. The map in Figure 2 gives an overview of them.

At all locations, temperature and wind speed/directions measurements are also available. The tables and figures below give a detailed overview about the location and start date of the measurements. In one case, the measurements were stopped because of relocation of the sensors. This is also noted in the table.

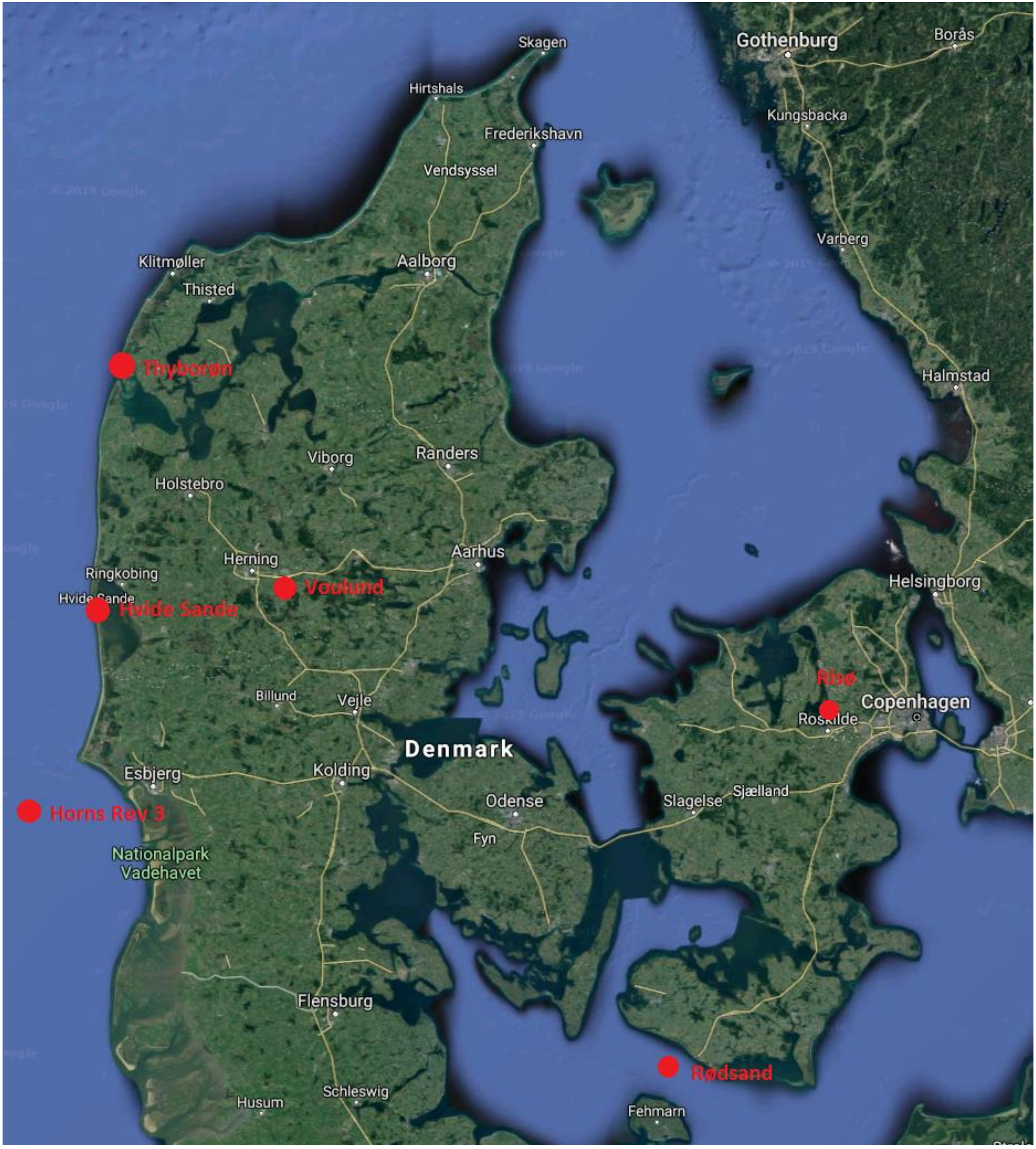

Figure 2: Map showing locations with Parsivel^2 and/or WS100 installations

Table 1 gives overview about disdrometer installations at the DTU Risø campus.
Figure 3 to Figure 5 show photos of the installations of the disdrometer at the DTU Risø campus.

The data from the location called "Risø true wind site (RTW)" was used for the Deliverable 3.1. (Sjöholm and Mikkelsen, 2018). The Parsivel^2 and WS100 output was compared with drop estimations from a lidar.

Table 1: Overview of Ott Parsivel^2 disdrometer installations at DTU Risø campus

Name (Abbreviation)	Risø met mast (RMM)	Risø true wind site (RTW)	Risø top met mast (RTM)
Description	Risø – at the ground next to the tall meteorological mast	Risø – next to the turbines, true wind field site	Risø – at the top of the tall meteorological mast
Altitude			~ 123 m (at top of mast)
Start measuring	01.05.2018 17:45	1.5.2018 17:45	19.12.2018 17:49
End measuring		11.12.2018 09:52	
Operator	DTU	DTU	DTU
Comment		RTW was moved to RTM	

Figure 3: Disdrometer installation at DTU Risø campus next to the tall meteorological mast (RMM)

Figure 4: Disdrometer installation at DTU Risø campus at the true wind site (RTW)

Figure 5: Disdrometer installation at DTU Risø campus (left) at the top of the meteorological mast (RTT) and (right) view from the top.

Table 2 gives overview about disdrometer installations of DMI.
Figure 6 to Figure 8 show photos of the installations of the disdrometers by DMI.

Table 2: Overview of Ott Parsivel^2 disdrometer installations of DMI

Name (Abbreviation)	Hvide Sande (DHS)	Thyborøn (DTH)	Voulund (DVO)
Description	Installed at DMI site	Installed at DMI site	Installed at HOBE field site
Start measuring	9.3.2018 15:08	4.5.2018 11:33	30.1.2018 14:59
End measuring			
Operator	DMI	DMI	DMI
Comment			The disdrometer was installed in January 2018, but the raw data (size,speed) was not measured permanently until 23.4.2018 10:33

Figure 6: Disdrometer installation in Hvide Sande – DHS - next to the Weather Sensor (Vaisala FD12P)

Figure 7: Disdrometer installation in Thyborøn - DTH

Figure 8: Disdrometer installation in Voulund - DVO

Table 3 gives overview about disdrometer installation at wind parks.

Table 3: Overview of Ott Parsivel^2 disdrometer installations at wind parks

Name (Abbreviation)	Horns Rev 3 (VHR3)	Rødsand 2 (ERO2)
Description	Installed at wind park Horns Rev 3 (in construction; owned by Vattenfall)	Installed at wind park Rødsand 2 (owned by E.ON)
Start measuring	13.02.2019 18:17	11.12.2018 10:20
End measuring		
Operator	Vattenfall	E.ON
Comment	No photos available at the moment	No photos available at the moment

Table 4 gives an overview about WS100 installations.
Figure 9 to Figure 10 show photos of the installations of the WS100 at Risø. The WS100 installed at Risø top met mast (WS-RTM) can be found in the photo of Figure 5 (white sensor between Parsivel^2 disdrometer and signal lamp).

For the installation at Horns Rev 3 no photo is available at the moment.

Table 4: Overview of Lufft WS100 Radar installations

Name (Abbreviation)	Risø met mast (WS-RMM)	Risø true wind site (WS-RTW)	Risø top met mast (WS-RTM)	Horns Rev 3 (WS-VHR3)
Description	Risø – at the ground next to the tall meteorological mast	Risø – next to the turbines, true wind field site	Risø – at the top of the tall meteorological mast	Installed at transformer station at wind park Horns Rev 3 (in construction; owned by Vattenfall)
Start measuring	13.07.2018 21:30	09.07.2018 10:20	19.12.2018 08:50	14.2.2019 16:20
End measuring		23.10.2018 15:10 (?) / 14:30 (WS4)		
Operator	DTU	DTU	DTU	Vattenfall
Comment		3 WS100 within short distance – see photo	One of the WS100 installed previously at RTW (WS1)	One of the WS100 installed previously at RTW (WS4)

Figure 9: WS100 radar (WS-RMM) and disdrometer (RMM) next to the tall meteorological mast

Figure 10: Three WS100 radars (WS-RTW) – indicated by red circles - and disdrometer (RTW) – indicated by a blue circle - at the true wind site within short distance

3. One year observations at a selected station

Figure 11 to Figure 15 show the temporal evolution of following parameters between 1 May 2018 and 31 May 2019 measured at the location Risø met mast (RMM) with a time resolution of 1 minute:

- Rain intensity [mm/h]
- Rainfall kinetic energy [$Jm^{-2}h^{-2}$]
- Number of detected and validated drops
- Precipitation type, SYNOP code according to table 4677
- Size-velocity histogram / drop-size distribution (DSD)

The internal algorithm of the Parsivel^2 directly calculated the values for these figures. However, no quality controlled has been applied yet to remove signals due to spider webs or dust in the measurement area. A quality control can by done by applying already published routines (e.g. Friedrich et al. 2013a) and if available by comparing with other precipitation measurements (e.g. rain gauge).

All parameters are relevant for estimating or modelling leading edge erosion. Therefore, a one-year observation is important to clarify if there are for example seasonal variations but also to get a variety of different events (stratiform, convective).

A general comment to the summer period 2018: The long period without precipitation is not only because of missing values but also due to an unusual dry summer in many European countries, also in Denmark.

Figure 11 shows higher rain intensities from late spring to late summer in 2018. Additionally, there was an extraordinary severe thunderstorm at May 10, 2019 with lightnings, hail and wind causing the maximum values of rain intensity and kinetic energy in the observed time period.

The kinetic energy due to rain showed a similar seasonal behavior as rain intensity. However, there is no 1:1 relation between these two parameters. For example, the event at May 10, 2019 had a rain intensity of 150 mm/h and a rainfall kinetic energy slightly above 4000 J/m^2h, whereas an event in May 2018 has “only” a rain intensity of 50 mm/h but a kinetic energy around 2000 J/m^2h.

The number of detected and validated drops shown in Figure 13 was low in the first months (May to July 2018) but higher afterwards. The high value of 30 000 drops in one minute in March 2019 is quite unrealistic and might be an error. As the parameters rain intensity and kinetic energy do not indicate a severe event at that time, this value might be excluded as part of the quality control.

The SYNOP code according to WMO code table 4677 provides information about the precipitation type. As Figure 14 indicates most of the precipitation is rain or drizzle and between end of November 2018 and end of March 2019 snow was registered. The highest numbers describe showers of snow pellets or small hail with or without rain. Hence, also solid precipitation different to snow was observed repeatedly.

The last figure giving an overview of the measurements between May 1, 2018 and May 31, 2019 at RMM is showing the size-velocity histogram (Figure 15). The number of particles within a certain bin is plotted together with the terminal velocities of different precipitation types (e.g. Friedrich et al. 2013b). The highest number of registered particles is along the terminal velocity of rain with diameters between 0.312 mm and

3.25 mm (mean bin size) and fall velocities up to 7.6 m/s (mean bin velocity). It is important to note that the high number of slow falling particles (below terminal velocity of snow) is caused partly by raindrops hanging in spider webs and need to be removed as part of the quality control. A regular inspection of the Parsivel^2 instruments has been necessary to remove spider webs to avoid such values.

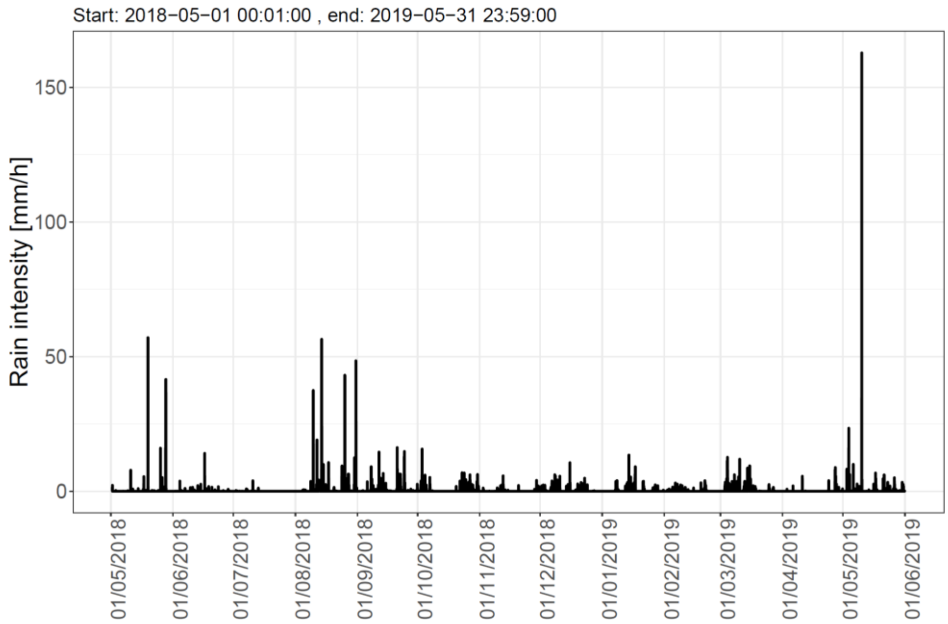

Figure 11: Rain intensity from May 1, 2018 to May 31, 2019 measured at RMM at DTU Risø campus

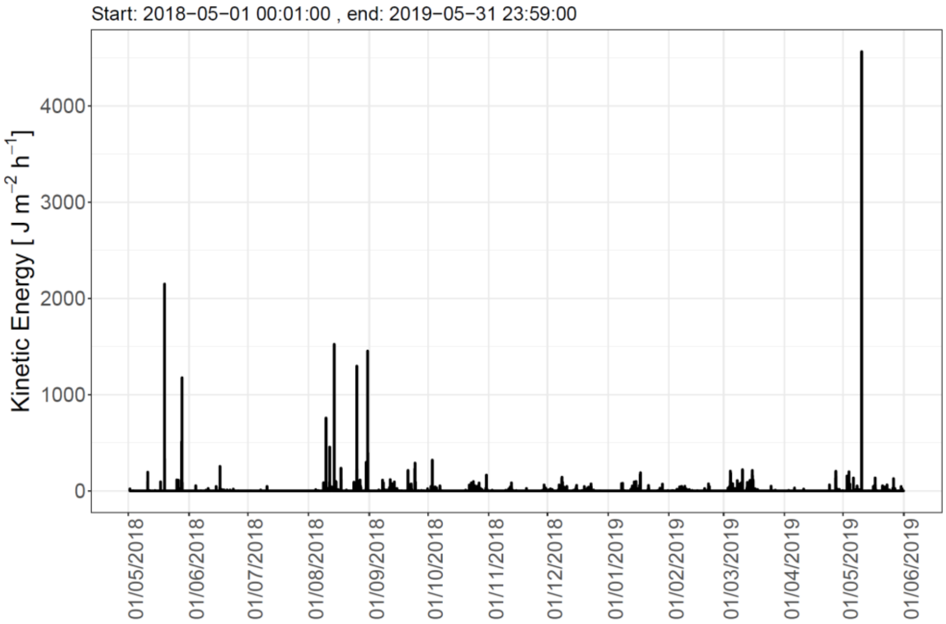

Figure 12: Kinetic energy from May 1, 2018 to May 31, 2019 calculated automatically by the used Parsivel^2 at RMM at DTU Risø campus

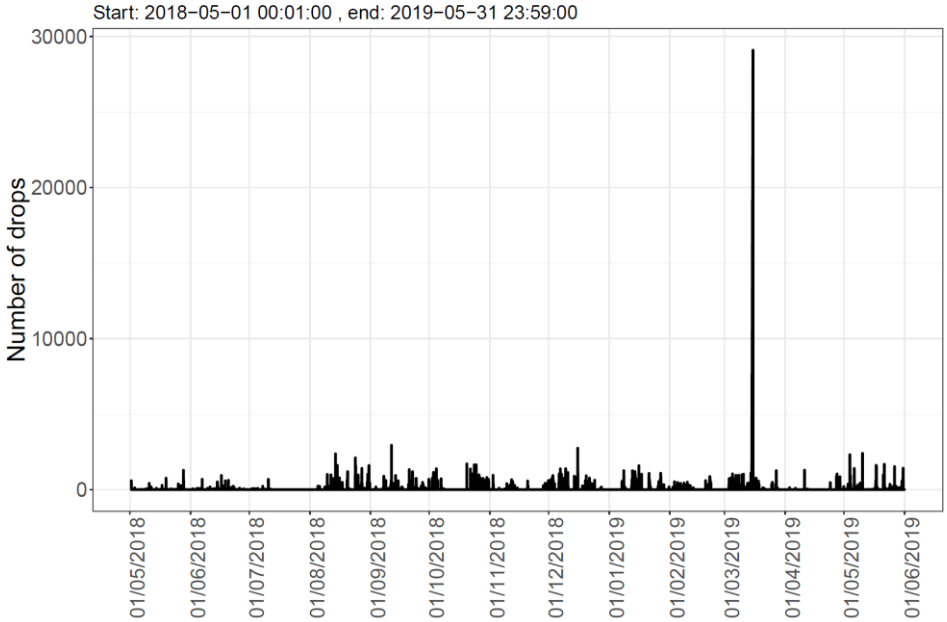

Figure 13: Number of detected and validated drops from May 1, 2018 to May 31, 2019 measured at RMM at DTU Risø campus

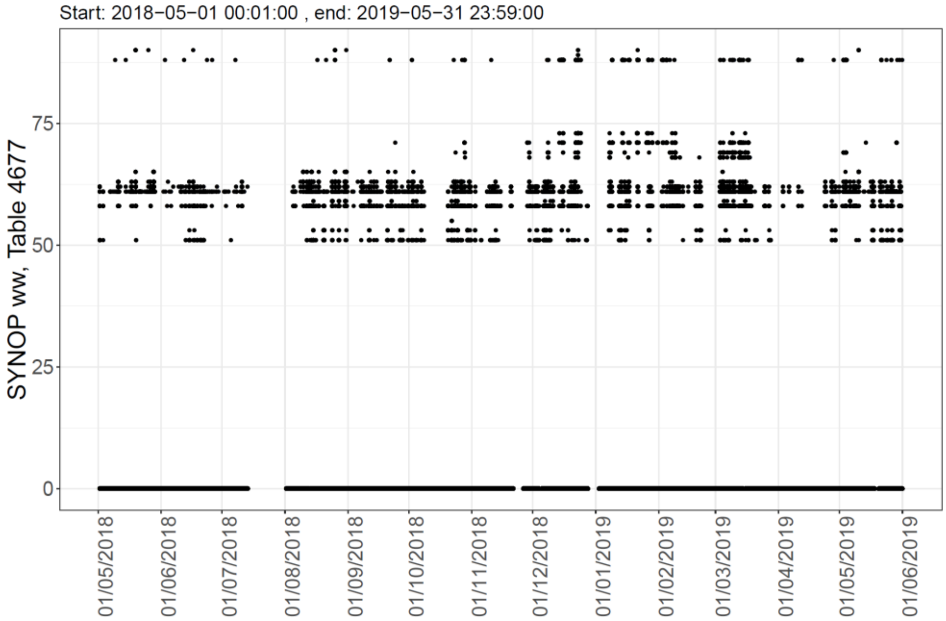

Figure 14: SYNOP code (precipitation type) from May 1, 2018 to May 31, 2019 measured at RMM at DTU Risø campus

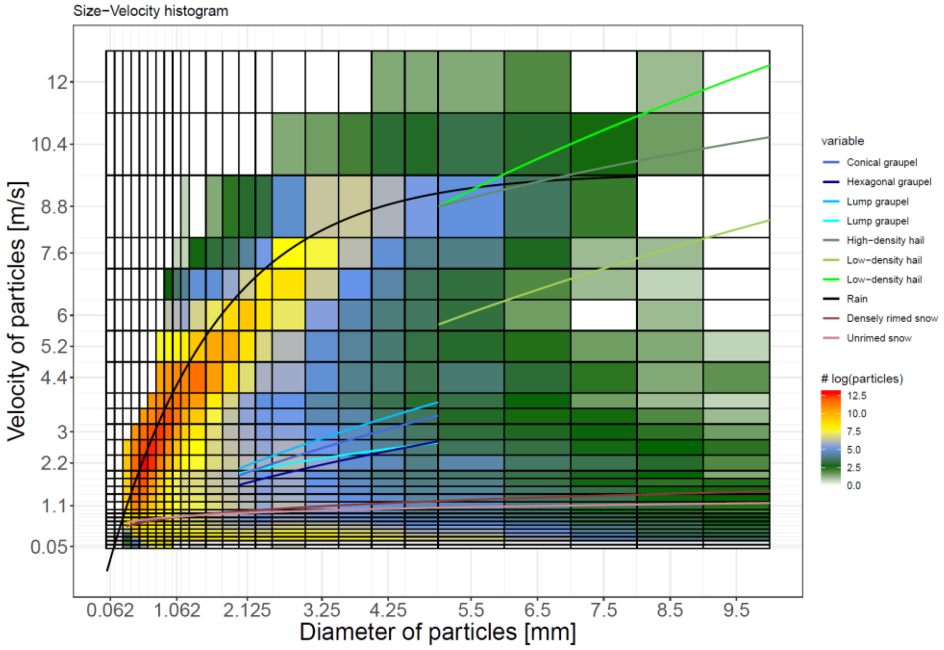

Figure 15: Size-velocity histogram including terminal velocities of different precipitation types based on the raw data from May 1, 2018 to May 31, 2019 measured at RMM at DTU Risø campus

4. Data in database

The data of the Parsivel2 measurements has been stored into a database. As the output of the measurement software is line wise, pre-processing of the data was needed to get the data into a table structure.

The data are stored in a MySQL database. Each row in the database consists of 1110 data fields where 1087 of these fields are primary rain measurements. The rest of the fields contains various other information such as time, visibility, temperature, laser power, etc. Each row represents 1 minute of measurements. All the values, except the time information, are stored as 4-byte single precision floating point numbers. (IEEE 754-1985, IEEE 754-2008). Table 5 gives an overview of the stored parameters.

Table 5: Overview of parameters in database

Shortcut	**Unit**	**Description according to manual**
datevec		Date vector in format YYYYmmddHHMMSS
day		Day
Ekin	$J/(m^2h)$	Kinetic energy
heat_status	A	Heating current
hour		Hour
i_rain	mm/h	Rain intensity
i_snow	mm/h	Snow depth intensity (volume equivalent)
laser_amplitude		Signal amplitude of the laser strip
minute		Minute
month		Month
nr_detect		Number of all particles detected
nr_detect_valid		Number of particles detected and validated
p_acc	mm	Rain amount accumulated
power_voltage	V	Power supply voltage
sample_interval	s	Sample interval
station_id		Station name
status		Sensor status
synop_wa		Weather code acc. To SYNP WaWa; Table 4680
synop_ww		Weather code acc. To SYNOP ww; Table 4677
temp_sensor	C	Temperature in the sensor housing
visibility	m	MOR visibility in precpitation
year		Year
Z_refl	dBz	Radar reflectivity (32 bit)
d_0.062_s_0.05		Raw data (volume equivalent diameter)
d_0.187_s_0.05		=> 1024 lines (32 diameters, 32 speeds)
d_0.312_s_0.05		
d_DIAMETER_s_SPEED		
Nd_0.062		average volume equivalent diameter of the 1. class
Nd_0.187		average volume equivalent diameter of the 2. class
Nd_0.312		average volume equivalent diameter of the 3. class
Nd_DIAMETER		=> 32 different diameters
vd_0.05		average particel speed of the 1. class
vd_0.15		average particel speed of the 2. class
vd_0.25		average particel speed of the 3. class
vd_SPEED		=> 32 different speeds

5. Summary and conclusions

The one-year long rain drop size distribution data set collected in the EROSION project is unique.

The disdrometer stations cover sites in eastern Denmark (Risø, Roskilde), central Denmark (Voulund, Jutland) and coastal stations at the west coast (Hvide Sande and Thyborøn, Jutland) and offshore in the Baltic Sea (Rødsand) and the North Sea (Horns Rev 3).

In addition, data at two heights 5m and 123m are collected at Risø, to characterize possible differences in rain-wind climate with height. Wind turbines operate around 100 m so the rain-wind climate at this height is of special importance.

For the first time rain drop size data are collected at sites in Denmark highly relevant for offshore turbines. The one-year long observations enable seasonal characterization of the rain-wind climate that differ between the sites.

The Parsivel^2 disdrometer is the state of the art instrument. Comparison to a novel radar-based instrument (WS100) was performed. Unfortunately, the data quality from WS100 is not of sufficient quality for the application of leading edge erosion.

The data are stored in MySQL database with documentation of the parameters.

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