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MEASUREMENT OF PRECIPITATION AT SEA

L. Hasse, M. Großklaus and K. Uhlig

Institut für Meereskunde, Kiel

Introduction

Measurements of precipitation at sea are an important part of the WCRP and GAW. Unfortunately, because of high wind speeds, conventional instruments fail at moving ships. Undisturbed precipitation measurements at sea, except from a few stations at small islands and atolls, are practically not existent. We hope that in future numerical weather forecast models and satellite remote sensing methods will provide improved precipitation estimates for the world oceans. However, at present, precipitation estimates from weather forecast models and satellite remote sensing algorithms urgently need ground truth at sea, as do ground based remote sensing methods, e.g. seaward looking radars.

The present note deals with a specialised mechanical ship rain gauge that was developed at Institut für Meereskunde Kiel in order to overcome the present difficulties for rain measurements at sea.

Basic principle

The ship rain gauge is designed to enable rain fall measurements from moving ship. The high relative flow velocities at a cruising ship in a wind field at sea may carry the rain almost horizontally over the ship. By measuring the amount of water collected by a vertical surface, a correction for the wind effect is possible. It is evident that the local relative wind speed at the site of the instrument should be measured simultaneously.

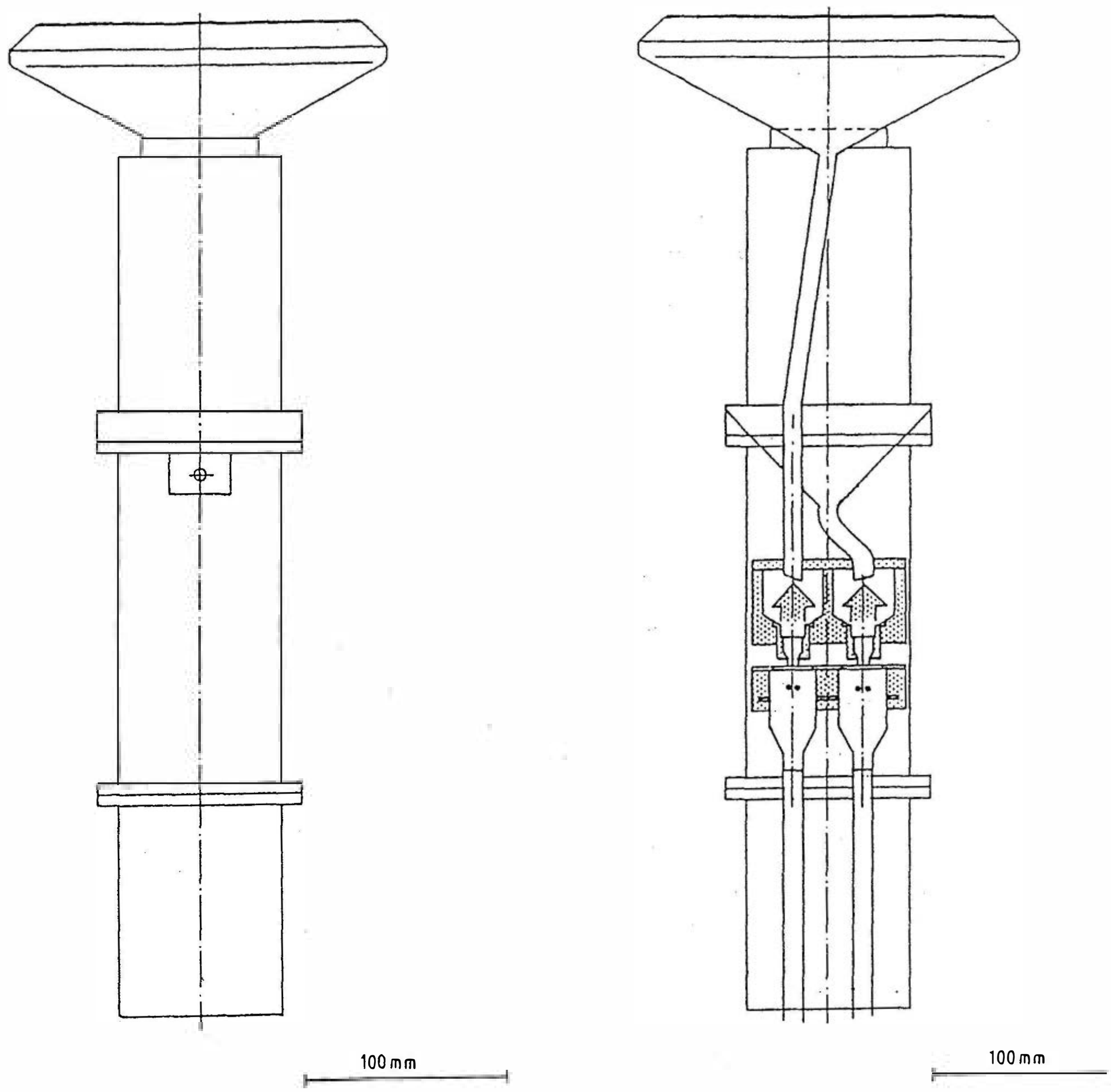
The horizontal orifice measures rainfall like any landbased conventional raingauge. The vertical collecting surface measures liquid water content in the volume of air defined from the cross-section of the gauge and the local relative windspeed. From the liquid water content of the air, the rainfall rate can be estimated by assuming a raindrop size distribuion. From the informations of the two collecting suraces, considering local flow velocity, an empirical calibration of the instrument is feasible.

Technical realisation

In our design, the horizontal orifice of a conventional raingauge has been supplemented by a cylindrical vertical collecting surface (figure 1) . The water amount from both surfaces is collected separately, and measured by forming and counting drops of calibrated size. The aerodynamic shape of the instrument was designed to reduce the undercatch resulting from flow distortion by the gauge itself.

The measurement of the liquid water content is independent of local up- or downdrafts. The catch by the horizontal orifice can be influenced by local up-/or downdrafts, depending on the drop-size distribution. This requires to place the instrument high up above the superstructure of the ship in order to minimize influence of local ship induced velocities. In order to deal with ship roll motions in a seastate, the instrument is suspended to swing freely around an axis parallel to the ship's long axis.

The instrument output provides counts of calibrated drops from the top and from the side. Typically, these are recorded together with the counts of a cup anemometer (and



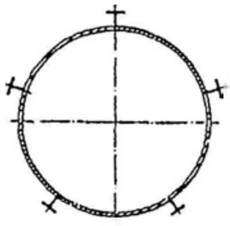


Figure 1 Side view and vertical cross-section of the ship gauge, and horizontal cut through the vertical collector.
Rain is collected at the horizontal orifice (arrows) and at the vertical collector (shaded). There are 5 vertical T-bars at the circumference of the vertical collector that hinder rain water to wander around the cylinder and be blown off in lee (shown in the horizontal cut only). Horizontal sampling area is 200 cm^2, and vertical sampling cross-section 106.6 cm^2. Total length is 48.5 cm and weight 4.0 kg

auxiliary data like date, time, position of ship) on a PC. Basic recording time unit is two minutes. For this time, rainfall rates are calculated for the top and the side separately and a corrected rain fall rate is obtained as a wind speed dependent weighted average.

Calibration

The calibration of the ship rain gauge depends on the flow around the instruments. Even with the improved aerodynamic shape, some wind influence on the catch with the horizontal collector is expected (Sevruk, 1989), and an empirical calibration is necessary. The catch of the liquid water content at the sides also depends on the areodynamics of flow around the cylinder. The effective cross-sectional area needs not equal the geometric cross-section. Hence, we need to calibrate the ship rain gauge in the field. For this purpose we use optical disdrometers.

Calibration of ship rain gauge is obtained in the field by simultaneous measurements with an optical disdrometer in natural rain. An example of such measurements is given in figure 2 from a cruise of IfM research vessel ALKOR. The correlation appears to be rather good. There is some unevitable scatter due to different sampling characteristics: With beginning rain, the surface of collectors of a rain gauge needs to be wetted before water can be collected. Even with wet surfaces, the ship rain gauge collects water before the formed drop is released and counted. The optical disdrometer gives a signal immediatly. The averaging time intervall for the disdrometer therefore is well defined, while for the ship rain gauge the forming of drops introduces some time delay, especially for low intensity rain. On the other hand, the active cross-section of the disdrometer is only 26.4 cm^2. The probability for larger drops, that contribute considerably to the rain rate, to pass through the active cross-section is much lower than for small drops. Hence, there is some natural variability from the disdrometer measurements. With a correlation coefficient of 0.978, the unexplained standard deviation is 15%. We assume that the accuracy will considerably be improved with further calibration.

The in field calibration also allowed to check the performance of the upper and sideward collection separately. Not surprisingly it was found that at low wind speeds, the measurements by the upper horizontal orifice are more accurate, while at higher relative wind speeds the sidewards collection performs better. Hence, we use one or the other collecting surface according to wind speed with a linear transition between 9 m/s and 11 m/s. It may be mentioned that the drop forming devices are rather linear and agree with each other up to about a rain intensity of 60 mm/h, while above calibration is possible, but behaviour of individual droplet formers differs.

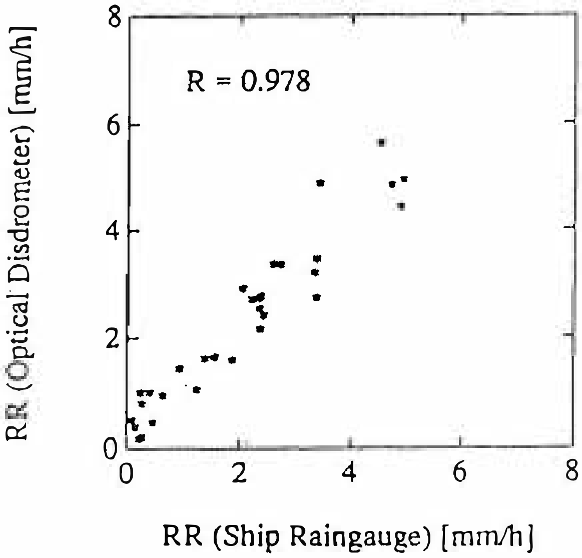


Figure 2: Calibration of ship rain gauge against optical disdrometer from a cruise with R.V. ALKOR. Time interval is two minutes. The scatter is mainly due to different sampling characteristics of the two intrument types and reduces with longer averaging times.

Optical disdrometer

Two types of optical disdrometer have been used: a disdrometer built by Illingworth at UMIST (Illingworth and Stevens, 1987) and another type built by Institut für Meereskunde, Kiel. The disdrometer by Illingworth was designed for windy conditions, but its sampling characteristics deteriorate increasingly under high wind speeds. This has led us

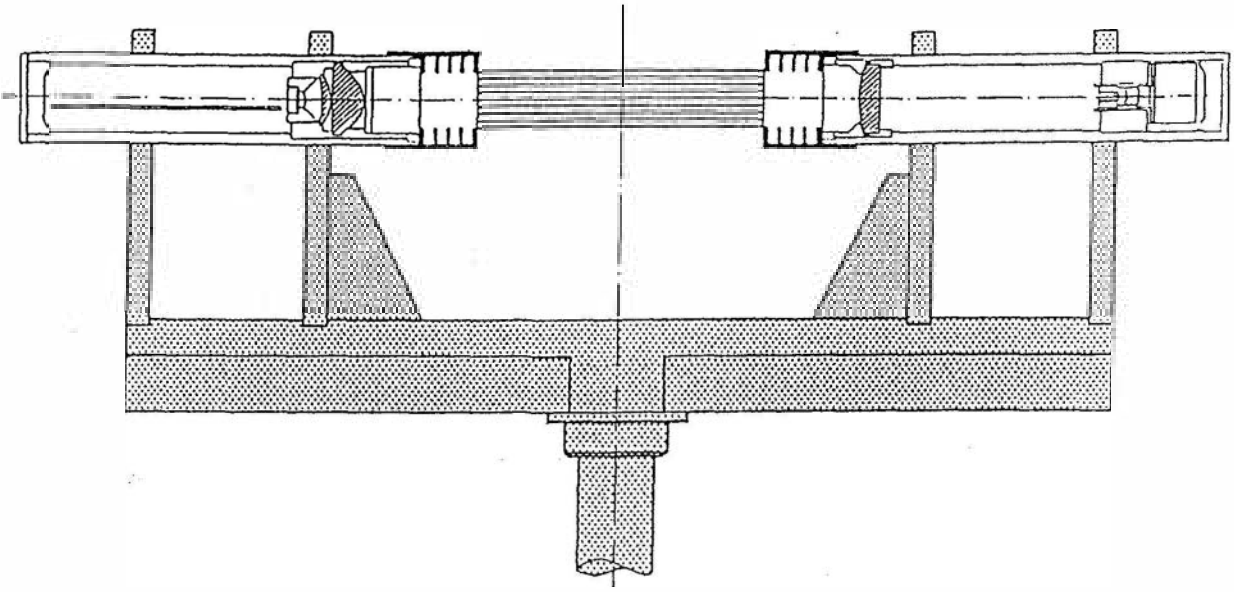


Figure 3 Cross-section of IfM optical disdrometer mark II. From left to right: electronics compartment, light emitting laser diode, lens system, window, baffles, optical blend, achromatic collector lens, field stop, lens, photodiode, electronics.

to construct our own optical disdrometer as described below.

The present version (mark II) is somewhat improved compared to our earlier version reported in Hasse et al., (1992). A schematic of the mark II optical disdrometer of IfM is given in figure 2. Improvements include: as light source a laser diode of 100 mW is used. The homogeneity of light along the optical active volume has been improved by aid of a lens system.

Our optical disdrometer essentially uses a cylindric active volume, that is hold perpendicular to the local flow direction by aid of a wind vane. The cylindrical form makes the measurement independent from the incidence angle of the rain drops. Hence, local up- and downdrafts do not influence the measurements.

The principle of operation is light extinction. Each drop passing through the active volume results in a reduction of light received at the end of the path. The depth of the pulse is proportional to the drop cross-sectional area. Additionally, the time of flight of the drops through the volume is measured. Minimal detectable size of droplets is 0.32 mm. Each drop is measured separately and recorded with a resolution of 0.05 mm diameter to form a droplet size spectrum. From the available information the available information, for a given size the number of drops per volume can be calculated. The rain rate is determined from the droplet spectra by assuming terminal fall velocity of the drops according to their size. The sensitivity of the optical volume can be calibrated quite accurately, hence the disdrometer can be used to calibrate the ship rain gauge under natural conditions.

Experience with several optical disdrometers show that homogeneity and isotropy of the light in the active volume is essential for the interpretation of data. The combination of relative wind speed and fall velocity of drops makes the angle of incidence rather variable. Hence, disdrometer designs, that are optimised for airplane use or ground based operation in low wind speed conditions, may exhibit anisotropy, that makes them unsuitable for shipborne use. Unfortunately, most light sources show some anisotropy as well as inhomogeneity. Also, inhomogeneity along the length of the optical volume (due e.g. to diverence of light) needs to be minimized. Figure 4 shows an example of the calibration of the optical volume of our mark II disdrometer. The remaining inhomogeneity results in a r.m.s. scatter of 4%, that can be corrected for during the data reduction cycle. There are additional difficulties that result from coincidences (presence of two or

Windspeed 1 m	ship rain gauge 1 m	Hellmann rain gauge 1 m	total precipitation pit
< 5 m/s	96.0%	91.6 %	486 mm
> 5 m/s	99.9 %	84.9 %	81 mm

Table 1: Comparison of ship rain gauge at Harzgerode, March through Dezember 1992. Since the wind speeds measured at 1 m height did not significantly exceeded 10m/s, only the measurements from the upper, horizontal orifice are considered.

more droplets in the volume at the same time) and grazing incidence where a droplet hits the volume only partially. The effect of multiple occupancy and grazing incidence, fortunately, can be corrected for, at least in the mean (see Großklaus et al., 1993, this volume).

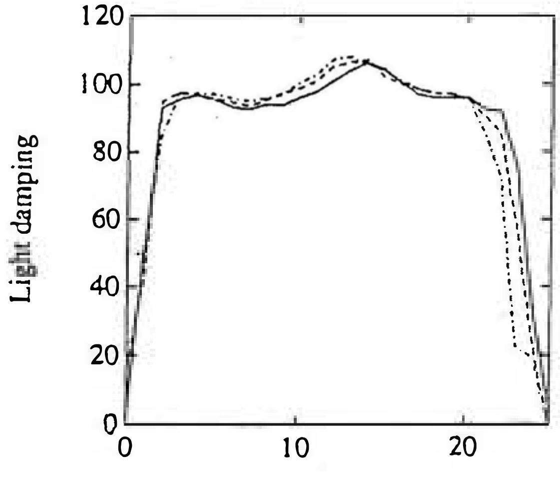


Figure 4: Homogeneity of active volume of IfM Kiel mark II optical disdrometer. The recorded intensity of light extinction of a calibrating sphere at three transverse sections at different positions along the optical path is shown: Near light source solid line; center, dashed line; near receiver dash- dotted.

Results

Comparisons of the ship rain gauge have been conducted both at sea against ship borne optical disdrometers and at land against standard meteorological rain gauges. The intercomparison at land has been made at the test site of the Deutscher Wetterdienst at Harzgerode. The ship rain gauge was mounted such that the horizontal orifice was at 1 m height above the ground. The same height was used with the standard Hellmann type recording rain gauge of the weather service. Additionally, a Hellmann rain gauge in a pit, with its orifice level with the surrounding ground, was used. It is anticipated that under windy conditions the standing Hellmann will experience some undercatch as a result of flow distortion, and that the measurements in the pit can be used as a reference. The results of the intercomparison are given in table 1.

Unfortunately, situations with higher wind speeds and rain are rare. Winds exceeded 10m/s only marginally even at the exposed site of Harzgerode (in the Harz mountains, station height about 440 m). In table 1, we give the results for wind speeds greater 5 m/s separately. It shows that the ship rain gauge compares well with the pit measured rain amount, better than the standard "Hellmann" does. Because of the moderate wind speeds, the comparison pertains to the upper, horizontal collector only. We may mention that these measurements were obtained with our mark I ship rain gauge (as detailed by Hasse et al., 1992). The good agreement is in line with the investigation of Folland (1988), who suggested a champagne bowl shape for rain gauges. The present form of our ship rain gauge (c.f. fig. 1) should show even less flow distortion.

Conclusion

We have shown the feasibility to measure rain at moving ship with a specialised ship rain gauge. Calibration is obtained by use of optical disdrometer in natural rain. An intercomparison at land showed improved performance of the ship rain gauge compared to standard rain gauge, due to improved aerodynamic design. Hence, the design could be used to improve rain measuring networks at land, too.

Our ship rain gauge has now successfully operated at R.V. METEOR for two years. We feel assured that we can recommend this ship rain gauge to WMO for introduction to operational use at ships.

Acknowledgement

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