THE OCEANIC PRECIPITATION MEASUREMENT SURFACE VALIDATION DATA SET

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ABSTRACT

State-of-the-art satellite derived and reanalysis based precipitation climatologies show remarkably large differences in frequency, amount, intensity, variability and temporal behavior of precipitation over the oceans. Additionally so far appropriate in-situ validation instruments were not available for shipboard use. The uncertainties are largest for light precipitation and cold season high-latitude precipitation including mix-phase and snowfall. Hence, a long-term issue on which IPWG and GPM-GV is urging more attention is the provision of high quality surface validation data in oceanic areas using innovative ship-based instruments for statistical properties of rain and snow rates using particle size distributions and case study intercomparisons. A systematic shipboard data collection effort and analysis can additionally be used to constrain precipitation retrievals.

To achieve this goal, the KlimaCampus / Initiative Pro Klima and the Max Planck Institute for Meteorology in Hamburg, Germany funded the project “Oceanic Precipitation Measurement – Surface Validation” that uses automated shipboard optical disdrometers ODM470, capable of measuring liquid and solid precipitation using particle size distributions in minute intervals on moving ships with high accuracy even under high wind speeds and rough sea states. Since the project start in 2009 the statistical basis for a conclusive validation has significantly improved with comprehensive data collection of more than 3 million minutes of precipitation measurements.

Currently, six ODM470 instrument systems are in long-term operation onboard ships. The core regions for the precipitation measurements comprise the Arctic and Antarctic Oceans, the mid-latitude storms tracks, the subtropical trade wind regions, the ITCZ, and the Southern Oceans.

This paper outlines in short the technical principles of the ODM470, the algorithms used to derive the rain and snow rate and provides the procedure of the data processing chain.

1. INTRODUCTION

A thorough knowledge of the global water cycle components is an indispensable prerequisite for the understanding and successful modeling of the global climate system. While the majority of the global precipitation falls over the oceans its detection and quantification still remains a challenging task. Global ocean observations of precipitation fields with high spatio-temporal sampling can only be derived from passive microwave satellite data and are used for assimilation into re-analysis data sets. Although recent evaluations of different state-of-the-art satellite derived and re-analysis based precipitation climatologies show that the commonly known patterns are well represented, remarkably large differences still exist in terms of detection, amount, variability and temporal behavior among the products (Andersson et al., 2010b, Romanova et al., 2010). The uncertainties are largest in climate system hotspot areas like the ITCZ or the cold season high-latitudes. Evaluation studies indicate that the HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data (www.hoaps.org) precipitation retrieval exhibits fairly high accuracy in these regions (Andersson et al., 2010a). However, the statistical basis for a sophisticated over ocean validation has to be significantly improved. To further increase the observing capability of global precipitation from space the Global Precipitation Measurement (GPM) Mission aims at 3-hourly 0.25° resolution fields using a multitude of sensors that need to be inter- and cross-calibrated into global climatologies. Retrieving high quality estimates of rain and especially snow calls for the need of comprehensive surface validation of precipitation. Over land several instruments capable of measuring precipitation are used in supersites and field campaigns to receive GV data. However, these distribution droplet meters (disdrometers) and gauges are not designed for high wind speeds on moving ships; hence virtually no surface validation data exists over the ocean, especially for snow, but is urgently required.

This motivated the development of the optical disdrometer ODM470 by our KlimaCampus co-operation partners at Geomar, Kiel and the company Eigenbrodt. Today the ODM470 is the only instrument capable of measuring rain and snow with high accuracy under high wind speeds on moving ships. The prototype instrument for snow was tested during two field campaigns in 2005 and 2008 in the cold season Norwegian Sea. This data exhibits a dichotomous detection accuracy of 0.98 when point to area validated against HOAPS precipitation data (Klepp et al., 2010). Quantitative collocation between the disdrometer and HOAPS shows a correlation up to 0.6. However, this collocated campaign data comprises snowfall intensities below 1 mm/h only. Comparing case study data for intense snowfall up to 7 mm/h in both HOAPS and ODM470 data yields plausible results but also large spatio-temporal collocation mismatches (Brümmer et al., 2010). Hence, systematic collection of surface validation data over remote ocean areas on several ships in all climatic regions started in 2009 within the KlimaCampus project aiming at a data set capable of comprising all precipitation events from light to severe including liquid, mix-phase and solid precipitation for validation against satellite retrievals including particle size distributions in minute resolution.

2. THE ODM470 OPTICAL DISDROMETER

The optical disdrometer originally developed by Großklaus et al. (1998) for rainfall only measurements is today called ODM470 (Fig. 1) and is commercially available from Eigenbrodt Environmental Measurement Systems near Hamburg, Germany. It was successfully validated to measure liquid and solid precipitation even under high wind speed conditions (Großklaus, 1996; Bumke et al., 2004). Lempio et al. (2007) further developed the snowfall algorithm and successfully intercompared the disdrometer measurements during a field campaign in Uppsala, Sweden in winter 1999/2000. Comparison with gauge data and manual measurements showed reliable instrument performance.
The measurement principle of the ODM470 disdrometer is based on light extinction of an infrared light emitting diode caused by hydrometeors passing through a cylindrical sensitive volume which is kept perpendicular to the local wind with the aid of a wind vane. The cylindrical form of the volume causes the measurement to be independent of the incident angle of the hydrometeors (Lempio et al., 2007). Both features are unique to existing disdrometers. The relative wind speed is measured using an anemometer. The electronic signal caused by the hydrometeor is proportional to its cross-sectional area. The disdrometer measures the size of the cross-sectional area and the residence time of hydrometeors in the sensitive volume within a size range of 0.4–22 mm. Measurements are partitioned in 128 size bins with highest resolution on small particles and a logarithmic increase in size. The averaging time interval is set to 60 s. Coincidence effects of multiple hydrometeors within the sensitive volume at the same time and edge effects of partly scanned hydrometeors are considered for liquid phase precipitation.
The precipitation rate in mm h^{-1} is calculated using the size bins, terminal velocity, mass of the hydrometeors and the particle size distribution density which is calculated after Clemens (2002) by particle counting given the local wind speed along with the measuring time interval and the size of the optical volume. The determination of the rainfall rate through its liquid water content or mass and the fall velocity is parameterized as rain drops have a nearly spherical shape and a constant density.

In contrast to rainfall, solid precipitation is characterized by a variety of complex shapes with different fall velocities and different equivalent liquid water content even if identical in maximum dimension. The measured cross-sectional area depends on size, shape and orientation of the solid particles hindering the development of a unique solid precipitation retrieval scheme. The steps to derive the snowfall rate are described by Hogan (1994), Brandes et al. (2007), Macke et al. (1998). Lempio et al. (2007) found from theoretical experiments that the product of the terminal velocity and the equivalent liquid water content as a function of the crosssectional area of different types of snow crystals are of the same order of magnitude and allow using one common parametrization for lump graupel. As lump graupel is nearly spherical in shape, it needs no transformation function from cross-sectional area to maximum dimension. The parametrization for lump graupel is applicable for particles with a size range of 0.4–9 mm. Furthermore, lump graupel was the most frequently observed precipitation type over the Nordic Seas during the LOFZY campaign (Klepp et al., 2010).

3. DATA SET PRODUCTION

3.1 Shipboard operation

The roots of this project date back to February/March 2005 when first successful experience with the prototype ODM470 MkI for rain and snow measurements was gathered onboard the Irish R/V "Celtic Explorer" over the cold season Nordic Seas (Klepp et al., 2010; Brümmer et al, 2010). During this experiment, detailed precipitation observations were logged manually regarding the type, duration and intensity to ensure good discrimination of the precipitation phase (Klepp et al., 2010). The next opportunity to obtain more Nordic Sea cold season disdrometer measurements was in March 2008. In close cooperation with the Bjerknes Centre for Climate Research (BCCR) and the Norwegian Coast Guard (Kystvakten) the ODM470 MkI participated in the THORPEX field campaign within the International Polar Year and operated successfully onboard K/V "Senja".

The results of these campaigns motivated the KlimaCampus, Hamburg project by the beginning of 2009 to establish a long-term comprehensive statistical basis of oceanic precipitation data for surface validation of satellite, re-analysis and model data. Using the automatic version of the ODM470 MkII that includes a precipitation detector the long-term routine measurements began in June 2010 onboard the German icebreaker R/V "Polarstern" of Alfred Wegener Institute (AWI) and in September 2010 onboard Russian R/V "Akademic Ioffe" of P.P.Shirshov Institute of Oceanology, RAS, Moscow. Both ships routinely transect the entire Atlantic Ocean from the Arctic via the ITCZ to the Southern- and Antarctic Ocean allowing for precipitation measurements in all climatic regimes. In September and October 2010 a third instrument took part in the LPVEX (Light Precipitation Validation Experiment) campaign embedded in GPM-GV in the Baltic Sea area off the coast off Helsinki onboard the R/V "Aranda" of the Finnish Meteorological Institute (FMI). The aim of this campaign was to measure light precipitation from a variety of measurement devices, both on land and over the sea. Since December 2011 also the German RV "Maria S. Merian" operated by Briese Research is equipped with the ODM470 measuring with focus on subtropical, tropical and mid-latitude regions of the Atlantic Ocean. After 28 months of continuous measurements with half yearly maintenance intervals on R/V "Polarstern", 25 months of continuous measurements with no maintenance possibilities onboard R/V "Akademic Ioffe" and 9 months of continuous measurements onboard R/V "Maria S. Merian", all the ships were re-equipped in September and October 2012 with the newest version of the ODM470 MkIII and all three MkII instruments were converted into MkIII standard. This new standard includes a Linux-based data logger instead of a Windows PC, the reduction of three outdoor cables into a single one and a new instrument design to further reduce flow distortion effects. Another of these new generation instruments was additionally installed onboard the German R/V "Sonne" owned by Partenreederei MS Sonne during a cruise from Busan, South Korea to the Fidji Islands in the Pacific Ocean in September and October 2012. A comprehensive overview on the shipboard measurement activities in chronological order is given in Table 1. Currently two more ODM470 MkIII are available for long-term measurements. One is planned to be installed on the new Australian R/V "Investigator" for data collection in the Pacific and

Southern Oceans. The other instrument is planned to be installed on the SeaOrbiter project in the context of the HYMEX campaign in the Mediterranean Sea.
All three long-term installations and four campaign based measurements onboard currently seven ships have in common that data is collected all important climatic regions. Moreover, all ships do not circumvent high impact weather so that the resulting data set is not biased in terms of undersampling storm and extreme data. Therefore the instruments are installed high on the ships superstructure, preferably in the highest parts of the mast to reduce the effects of flow distortion and sea-spray to a maximum extent possible.

Table 1: Operational data collection overview of all 7 ODM470 disdrometers.

ODM 470 #	Ship Name or Place of Usage	Start Date	End Date	Area of Operation	Remarks
1	R/V Celtic Explorer	02/2005	03/2005	Nordic Seas	Prototype
	K/V Senja	02/2008	03/2008	Nordic Seas	Prototype
	Hamburg, Germany	01/2009	11/2011	Lab Calibrator	Discarded 11/2011
2	R/V Polarstern	06/2010	10/2012	Atlantic Ocean	
	Hamburg, Germany	10/2012	10/2012		Conversion Update
	R/V Polarstern	10/2012	ongoing	Atlantic Ocean	
3	R/V Akademic Ioffe	09/2010	10/2012	Atlantic Ocean	
	Hamburg, Germany	10/2012	10/2012		Conversion Update
	R/V Akademic Ioffe	10/2012	ongoing	Atlantic Ocean	
4	R/V Aranda	09/2010	10/2010	Baltic Sea	LPVEX campaign
	R/V Maria S. Merian	12/2011	09/2012	Atlantic Ocean	
	Hamburg, Germany	09/2012	09/2012		Conversion Update
	R/V Maria S. Merian	09/2012	ongoing	Atlantic Ocean	
5	R/V Sonne	09/2012	10/2012	Pacific Ocean	
	Boulder, USA	03/2013	04/3013	MountainSnowfall	SPICE Project
	SeaOrbiter	late 2013		Mediterranean	HYMeX Project
6	R/V Investigator	2014		Southern Ocean	
7	to be determined	NN		NN	

3.2 Data Collection

The data stream needed to estimate geolocated precipitation rate and phase through the PSD requires joining different data sources. The ODM470 stores in minute resolution the date, time, bin size, the number of particles in each bin, the residence time in the sensitive volume for both liquid and solid particles plus the relative wind speed and the reference voltage. The precipitation phase is not known to the instrument and needs to be determined using ancillary data. It is important to note that the ODM470 time series is discontinuous in terms that only minutes containing precipitation are logged into daily files. Hence, data files of days without precipitation contain only the file header. From this the PSD a hypothetical all-rain and all-snow time series is calculated following the procedure

described in Section 2. Ancillary data provided by routine shipboard operations comprise date, time, longitude and latitude (GPS) data in at least minute resolution along with data from automatic meteorological data loggers (METEO) that store data in minute to ten-minute intervals with a varying number of meteorological and oceanographic parameters. These include at least the date, time, air temperature, relative and absolute wind speed and direction and the surface pressure and humidity. Additionally most ships provide three to six hourly logs of weather observations stored in the WMO standard present weather (ww) and past weather W1 and W2 codes referred to as SYNOP (http://www.wmo.int/pages/prog/www/WMOCodes/Manual/Volume-I-selection/Sel2.pdf).
The times of all data sets are synchronized and stored in universal time (UT) and the common data format is ASCII. The data is collected offline during port time maintenance or cruise lag crew exchange. The postprocessing of the data stream, the collocation and the method to identify the precipitation phase is described in the following section.

3.3 Data Processing

As a first step of the postprocessing chain the continuous GPS and METEO data is collocated into one dataset based on the highest possible common temporal resolution, preferably minute or ten-minute data. In the next step the discontinuous ODM470 data is calculated to provide minute resolution PSD and hypothetical all-rain and all-snow time series, given that the precipitation phase is at this step still an unknown parameter. If SYNOP codes are available, these are manually inspected for periods of observed rain, mix-phase and snowfall and stored to a log file (LOG). The METEO data is visualized into a continuous time series and manually inspected for air temperature values to be consistent with the SYNOP log file information about liquid, mix-phase and solid precipitation periods. Based on this information the LOG file is first order discriminated into the precipitation phases and contains date, time, temperature, ww, W1, W2 and a preliminary precipitation flag that is set to 0 for rain, 1 for snow and 2 for mix-phase precipitation. Consequently the hypothetical all-rainfall time series of the ODM470 is visually inspected. Beside a realistic range of rainfall values the time series also contains differently long phases ranging from minutes to weeks of unrealistically high values that clearly stand out from the rain values with spikes beyond 200 mm/h. Comparisons with the LOG file indicate that these unrealistic spikes are phases of mix-phase and snow as the comparably large particles of diameters beyond 6 mm are treated by the rainfall algorithm as huge drops generating extreme rainfall. As these spikes in the all-rain algorithm of the ODM470 time series are in accordance with the LOG file data these spikes can be used to estimate the onset and offset of the solid precipitation precisely down to the minute data resolution. Consequently all real rainfall minutes of the all-rain time series are flagged finally with the value 0. In reverse the residual minutes of the all-rain time series are replaced by the corresponding all-snow time series values by receiving the preliminary flag 1 indicating snow.
The precipitation rates of the ODM470 time series are finalized with this step as to date no mix-phase algorithm exists to differentiate the liquid from the solid fraction in the PSD. Nonetheless it is important to distinguish between snow and mix-phase events. However, it

is important to note that the mix-phase precipitation rate is by definition underestimated compared to the unknown true rate as the liquid to solid precipitation ratio is not well known and the liquid fraction is treated by the algorithm also as solid particles. The underestimation is the larger the more liquid droplets contribute to the PSD of the minute spectra. The mix-phase precipitation is flagged with the value 2 according to the LOG file of the SYNOP information. If no SYNOP data is available the air temperature information along with the spike peak height serves as a good indicator for mix-phase precipitation. In such cases the temperature is mostly between +/- 1.5°C and the all-rain data shows unrealistic spikes that, however, are not reaching the height of pure snow spectra. Overall, the difficulties associated with mix-phase precipitation rate estimates are tolerable as less than 1.8% of the precipitation events measured during two years of data are classified as mix-phase.

Finally the rain, snow and mix-phase flagged ODM470 time series is collocated and merged with the GPS/METEO time series resulting in a discontinuous time series of minutes with precipitation only in ASCII format. For R/V “Polarstern” this time series contains 22 values of which 16 are meteorological parameters (Table 2).

Table 2: Description of 22 parameters of the R/V “Polarstern” precipitation time series.

parameter	unit or value range	source	format
line count	[ ]	calculated	I7.7
date	DDMMYYYY	common to all	I8.8
time	HHMM [UT]	common to all	I4.4
minutes of the day	1-1400	calculated	I4.4
latitude	-90° to 90°	GPS	F8.4
longitude	-180° to 180°	GPS	F9.4
air temperature	°C	METEO	F4.1
dew point temp.	°C	METEO	F4.1
relative humidity	%	METEO	I2.2
sea level pressure	hPa	METEO	F6.1
relative wind speed	m/s	METEO	F4.1
relative wind direction	deg	METEO	I3.3
absolute wind speed	m/s	METEO	F4.1
absolute wind dir.	deg	METEO	I3.3
global radiation	W/m^2	METEO	F5.1
horizontal visibility	m	METEO	I4.4
low cloud base height	m	METEO	I4.4
max. wind speed	m/s	METEO	F4.1
ship rain gauge	mm/h	METEO	F6.4
precipitation rate	mm/h	ODM470	F6.2
relative wind speed	m/s	ODM470	F5.2
flag for rain/mix/snow	0=rain, 1=snow, 2=mix	calculated	I1.1

To date the R/V “Polarstern” data set comprises more than 100.000 discontinuous minutes of precipitation equivalent to two years of data of which 43.000 minutes are rainfall, 31.500 minutes snowfall and 17.000 minutes with mix-phase precipitation. Overall, precipitation occurred in 9.6% of the time with 4.5% rain, 3.3% snow and 1.8% mix-phase. The total column of precipitation was 927 mm 88.2% rain, 8.4% snow and 3.4% mix-phase precipitation.

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