A SNOWFALL VALIDATION DATA SET FOR OCEANIC SATELLITE PRECIPITATION RETRIEVALS

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ABSTRACT

Embedded in the special research project on cyclones and the North Atlantic climate system at the University of Hamburg, a field campaign was carried out in February and March 2005 to study the influence of cyclones on the air-sea interaction. The shipborne part of the experiment in the Lofotes area offshore Norway (LOFZY) was used to gain measurements and detailed observations of high latitude over ocean solid precipitation. Quantitative in-situ measurements, particularly of solid precipitation at high latitudes, are extremely seldom although there is a strong need for such measurements for validation of satellite precipitation retrievals. During the LOFZY campaign, data of 31 case studies were collected utilizing a snow calibrated optical disdrometer for quantitative values, a precipitation detector, Hellman gauges and detailed 24 hour precipitation and synoptic observations. Over 90% of the observed precipitation cases contained snowfall. This shipborne data set is collocated and compared to precipitation retrieval estimates of the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data set (HOAPS-3), the Global Precipitation Climatology Centre (GPCP) and AVHRR satellite images along with the AVHRR Processing scheme Over cLouds, LAnd and Ocean (APOLLO) data. Results show, that the HOAPS-3 precipitation patterns and intensities are in overall good agreement with the in-situ ship data. In contrast, GPCP detects none of the high-latitude solid precipitation, but all cases where rainfall occurred.
1. INTRODUCTION

In-situ precipitation measurements over the global oceans are of extreme importance for validation of instantaneous precipitation patterns as well as climatological parameters, such as annual precipitation amounts derived from satellite observations. For the latter, the constraint is that the assessment of the yearly mean amount of precipitation is in the order of 1000 mm/a, compensating a latent heat flux of about 79 W/m². Furthermore, the net global ocean freshwater flux determines how much water is transported over the continents. This amount needs to be balanced by discharge from the continents and ice-covered regions at the poles. Especially during the cold season, high latitude precipitation is predominated by snow and graupel. As quantitative solid precipitation estimates including accurate precipitation patterns still remain a challenging topic for most of the microwave based precipitation retrievals, a workshop on global microwave modelling and retrieval of snowfall was addressed by the International Precipitation Working Group (IPWG, http://cimss.ssec.wisc.edu/ipwg/meetings/snowfall2005/).

Satellite based retrievals that estimate instantaneous precipitation on a pixel basis need to be validated to ensure for quality control and the ability to detect all processes that lead to precipitation. Especially, in-situ based validation data over the oceans for quantitative precipitation amounts on a case study basis merely exists. Here, qualitatively observed precipitation by Voluntary Observing Ships (VOS; http://www.vos.noaa.gov/vos_scheme.shtml) is of high importance. Beside a simple but important precipitation / no precipitation information, the type of precipitation is a valuable source of information. VOS data can be easily classified into stratiform or convective precipitation types. The endurance of an event or the cloud types can give even further insight. Klepp et al. (2003) showed that the use of VOS data is in principle suitable for the evaluation and validation of satellite derived precipitation products. Especially over the North Atlantic, frequent intense winter time convective mesoscale precipitation, called post frontal lows (PFL), were found in the satellite based HOAPS-3 climatology but not within the also satellite based retrievals of the GPCP climatology (Adler et al., 2003). These precipitation events mostly occur offshore New Foundland within the cold air sector of mature cyclones over the North Atlantic and were successfully validated in the HOAPS-3 data base using VOS data. The occurrence of more than 1000 events during the time series of HOAPS-3 from 1987 to 2005 points out the need for in-situ based validation data. Klepp et al. (2005) also showed that these events are seldom reproduced by models, i.e. ERA-40. Neglecting the PFL precipitation to the west of mid latitude cyclones results in a substantial underestimation of the total water transport within individual cyclones (Klepp et al., 2003). Also PFLs are proven to produce high impact weather and can sometimes even reach the coastlines of Europe causing gale force winds and heavy precipitation up to 16 mm/h (Williams, 2000). This leads to the conclusion that high latitude precipitation is not adequately represented in most of the satellite retrievals and NWP models (Klepp et al., 2003; Klepp et al., 2005; Huffman et al., 2005). In most cases, the PFL precipitation is a mix of snow, graupel, hail and rain. Given that already the mix of solid and liquid precipitation is causing significant differences in the precipitation retrievals of HOAPS-3 and GPCP there is further essential need for comparisons of high latitude snow only precipitation validated against in-situ data. Quantitative in-situ data for solid over ocean precipitation so far...
The strong need for quantitative precipitation measurements in these regions is also recommended by the IPWG (Ebert, 2005) of the Coordination Group for Meteorological Satellites (CGMS). To gain knowledge about the performance of the precipitation retrievals under cold season high latitude conditions, a snowfall measurement experiment was carried out during the Lofotes Cyclone field campaign (LOFZY) in 2005 that serves as a HOAPS-3 validation site. The field campaign along with the data collected is described in Section 2 including the satellite data used. In Section 3 a validation case study and further findings are presented followed by a discussion of the results and conclusions in Section 4.

2. DATA AND INSTRUMENTS

From 22 February to 24 March 2005 a wintertime field campaign was carried out within the special research project “Cyclones and the North Atlantic climate system” (SFB512) by the University of Hamburg including the Irish research vessel “Celtic Explorer”. The campaign focus was to study the ocean atmosphere interaction during the passage of cyclones in the Lofotes region offshore Norway. For this purpose, two circular lags centered around 70°N and 10°E were carried out including a stopover in Tromsoe, Norway on 7 March 2005 (Figure 1).

![Figure 1](image.png)

**Figure 1:** The experiment array of the R/V “Celtic Explorer” LOFZY field campaign in February and March 2005. The dots indicate different oceanographic stations during the intensive operation period along which the snowfall data is measured. The green line indicates the transfer route to and from Galway, Ireland, where the ship is based.
Ideally suited for in-situ wintertime over ocean precipitation measurements an optical disdrometer from the University of Kiel, a rain detector and two Hellmann gauges were installed aboard the RV “Celtic Explorer”. The main focus of this study is to validate HOAPS-3 and GPCP satellite precipitation data during LOFZY case studies against the shipborne in-situ snowfall measurements.

2.1 THE SHIP INSTRUMENTS

An ODM470 optical disdrometer from the University of Kiel, Germany was used to obtain a quantitative measure of the snowfall during the experiment (Großklaus, 1996). For this purpose the instrument was calibrated in advance for snowfall-only measurements. The disdrometer works as a photoelectric barrier where the snowflakes cause a size dependent light extinction within a cylindrical sensitive volume. The measurement volume has a length of 120 mm with a radius of 11 mm allowing a measurement of snow particles between 0.4 and 22 mm in size. The infrared light emitting diode works at 860 nm. The volume is pivot-mounted including a vane that continuously orientates the device perpendicular to the wind direction (Figure 2). The wind speed is measured separately using an anemometer. Residence time and shadow area are measured each time a particle crosses the volume. Then the shadow area is calculated into an equivalent diameter of a circular area and stored in one of 128 corresponding size dependent bins. In contrast to rain measurements, a snow calibrated disdrometer accounts for a logarithmic bin size with a finer resolution at small particle sizes. The instrument was operated regularly during the entire field campaign. Maintenance was carried out during precipitation-free conditions only.

![Figure 2: The setting of the fully operational precipitation measurement instruments aboard the R/V “Celtic Explorer” during the LOFZY 2005 campaign.](image)

The duration of the measurement intervals were set to one minute. Given that at least one particle has passed the volume the values are automatically stored. These are date, time, bin number, the number of particles within the bins, the drop size density of
the particles, the precipitation rate using a parameterization after Hogan (1994) and the wind speed. Further technical properties of the instrument and the successful ground validation of the disdrometer compared to different gauges over land are documented by Lempio (2006). The disdrometer was placed at the front left part of the ship’s mast at approximately 20 m height. That minimizes the risk of measuring sea spray and allows the optimal incident flow without being disturbed too much by the platform of the ship (Figure 2).

Alongside with the optical disdrometer the precipitation detector IRS88 was operated automatically. This instrument gives an electronic signal every time a particle crosses its volume. As even the very small droplets of sea spray can be detected, this instrument was used to distinguish between real precipitation and sea spray-only cases, when operated simultaneously with the disdrometer.

Additionally two Hellman gauges including snow crosses were used to measure accumulated precipitation. One gauge was installed on the ships bow and one on the stern. Both gauge places were stronger affected by airflow of the ship’s superstructure than the instruments in the mast (Figure 2).

Detailed 24 hour precipitation observations were carried out in shift operation during the entire cruise. This comprises the occurrence, duration and type of precipitation observed together with a crystal type and size description, intensity changes, cloud fraction, type and photography. All standard meteorological measurements were additionally stored in one minute intervals.

### 2.2. THE SATELLITE DATA

These in-situ data and observations are compared to collocated satellite precipitation retrieval data of HOAPS-3 and GPCP. The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data Set – Version 3 contains 18 complete years of global fields of precipitation, evaporation and the resulting freshwater flux over the global ice free oceans and all atmospheric state variables to derive these fluxes. Except for the NOAA Pathfinder SST Version 5.0 data set, all variables are derived from SSM/I passive microwave satellite data (Andersson et al., 2007). A thorough evaluation and improvements over the earlier version (Klepp et al., 2005) led to a new neural net based precipitation algorithm, that is validated for snowfall in this paper. As the comparisons are carried out on a case study basis, the time-spatially collocated precipitation scan data of HOAPS-S is used resembling the original SSM/I resolution of 50 km per pixel. Due to the inhomogeneous emissivity in coastal zones, HOAPS-3 data is available 50 km off the coast only. Therefore ship data within the coastal zones is neglected. All individual overpasses of the SSM/I radiometers on DMSP F13, F14 and F15 are used for the comparison that led to daily intensive operation periods (IOP) aboard of the ship between 6 to 11 UT and 14 to 19 UT each day.

Additionally APOLLO (AVHRR Processing scheme Over cLouds, Land and Ocean) data is used which derives cloud physical parameters from AVHRR measurements. The cloud cover product is used to obtain information about cloud optical depth, cloud liquid water, ice path (vertical column content), cloud top temperature, and cloud thermal emittance. A special feature of the APOLLO product is the daytime only precipitation likelihood that is especially used for comparison with the in-situ LOFZY data as the
The spatial resolution of the GAC data is 1.1 km at nadir up to about 5 km to the edges of the swath (http://wdc.dlr.de/apollo/).

The findings are additionally compared to the one degree daily (1DD) data of the Global Precipitation Climatology Project (GPCP, Adler et al., 2003). GPCP is a combined data set that utilizes a combination of low orbit microwave and infrared satellite data along with rain gauge data from the Global Precipitation Climatology Center (GPCC, Rudolf and Schneider, 2005). Over the oceans GPCP mainly relies on SSM/I while TOVS (Tiros Operation Vertical Sounder) data is widely used to derive precipitation north and south of 40°. Due to the one degree resolution and the daily resolution, only the precipitation patterns of GPCP 1DD are compared with in-situ and HOAPS-3 data for plausibility control. The scientific cruise of the RV “Celtic Explorer” with more detailed information on the meteorological data collected is documented on the webpage www.lofzy.zmaw.de. The LOFZY precipitation case studies are split into two daily IOPs, resembling the overpass times of the SSM/I radiometers onboard the DMSP F13, F14 and F15 satellites between 6 to 11 UT and 14 to 19 UT. In total, 31 IOPs were carried out while the ship was at least 50 km off the coast of Norway. The results along with a polar low case study are described in Section 3.

3. CASE STUDY RESULTS

During 7 IOPs no precipitation was observed and measured, neither by the ship mounted instruments nor by any of the satellite retrievals. In 24 IOPs precipitation was observed and measured on board with 3 IOPs of drizzle rainfall and 21 with solid precipitation. In most of these cases graupel predominated, followed by snowflakes and hail. The solid precipitation described above was frequently observed in clouds that resemble the structure of Cumulonimbus with perfectly shaped anvils occurring in cellular patterns. Radiosonde ascents showed, that these cold air clouds have a cloud top height of approximately 3 km with no further clouds above. This shallow but convective cloud type, called PCb (Polar Cumulonimbus) in the following, led to intensive precipitation with a mix of graupel and snow (Figure 3).

Figure 3: Typical shallow Polar-Cumulonimbus (PCb) clouds photographed during the LOFZY cruise. These cells crossed the R/V” Celtic Explorer” on 05 March 2005 causing intensive convective solid precipitation. Note the downdraft area with heavy precipitation to the left of the cloud center.
In the following, a polar low case study during the LOFZY experiment is exemplarily shown utilizing the data described in Section 2.

3.1 A polar low passage on 15 March 2005

On 15 March 2005 two polar lows developed offshore the Norwegian coast in the area off the Lofotes Islands and off the Bergen area, both existing for about 20 hours. Between 04 and 06 UT the northerly polar low reached its mature phase within the experiment area and passed over the R/V “Celtic Explorer”, resulting in blizzard like precipitation with a mix of graupel and snowfall out of PCb’s in short successions including mammatus-shaped clouds as observed onboard the ship (Figure 5). The APOLLO precipitation likelihood is high within the polar low, resembling the structure of the brightest and therefore coldest clouds in the AVHRR infrared image (Figure 4).

![Two Polar Lows on 15 March 2005 offshore Norway. The mark within the red box indicates the ship position at 11:36 UT coinciding with the AVHRR satellite channel four infrared data (left) and the APOLLO precipitation likelihood (right). The dark blue colors indicate areas of high precipitation likelihood.](image)

Figure 6 shows the precipitation measured by the optical disdrometer and the precipitation detector between 03:55 and 06:10 UT with intensities varying from 0.1 to 1.7 mm/h. In the evening a single precipitation event occurred at 18:15 UT followed by intense snowfall between 19:30 and 20:20 UT.
At 06:10 UT the snowfall stopped while the first SSM/I satellite F14 passed over the ships position. The HOAPS-3 precipitation rate shows a maximum of 2.3 mm/h, 50 km west of the ship, including a spiral precipitation pattern that resembles the polar low cloud structure of the AVHRR infrared image and the APOLLO precipitation likelihood (Figure 7).

The cloudhead of the polar low passed over the ship in the morning resulting in persistent intense solid precipitation. The HOAPS-3 precipitation field also shows two lines of scattered showers up to 0.8 mm/h southwest of the polar low that show a cyclonic curvature. This is also supported by the AVHRR and APOLLO data as this
precipitation belongs to the complex low pressure system with at least three low pressure cores. In the evening the northerly polar low was shifted to the West. This resulted in intermittent precipitation at the ships position out of scattered PCb clusters that are also well represented by the HOAPS-3 precipitation field with values up to 1 mm/h. A 2.9 mm water equivalent was accumulated during the intense snowfall between 04 und 06 UT within the Hellman gauges. The southerly polar low that developed off the coast of Bergen, Norway exhibits intense precipitation in HOAPS-3 with up to 3 mm/h. The area of HOAPS-3 precipitation is rather small and resembles the area of strongest precipitation likelihood in the APOLLO data. GPCP shows no precipitation neither in the polar lows nor the entire complex low pressure system but recognizes the frontal precipitation pattern of a large scale low pressure system south of Iceland in good agreement with HOAPS-3 (Figure 7).

**Figure 7:** The HOAPS-3 precipitation for the F15 morning overpass on 15 March 2005. The ship position is indicated by the black dot in the red boxed experiment area. Note the spiral precipitation structure of the polar low in the morning (left panel). The right panel shows the precipitation field of GPCP 1DD.

In total in-situ data of 31 case studies of solid high-latutude precipitation were collected during the intensive operation period onboard R/V “Celtic Explorer” between 22 February and 24 March 2005 while the ship was at least 50 km off the coast of Norway. 7 case studies showed no precipitation, which is in accordance to all in-situ measurements and remote sensing data. In 21 out of 24 case studies solid precipitation was observed. During the remaining 3 case studies drizzle was observed. The identification of precipitation between the disdrometer, the detector and the observations are in overall good agreement, while the Hellmann gauges are not capable for precipitation detection and measurements except during intensive snowfall events over a longer time period.
4. DISCUSSION AND CONCLUSIONS

In general, HOAPS-3 is capable to detect solid precipitation in 15 out of 21 cases and identifies all 3 drizzle cases. In 3 cases graupel from scattered cold air convection PcB cells occurred, that were not seen by HOAPS-3. In these cases the area fraction of these cells within the SSM/I footprint is too small to be detected as precipitation. Similar results stem from further 3 cases in which the solid precipitation measured by the disdrometer was below 0.1 mm/h. During these events scattered snow flakes were observed in very light intensity which falls below the detection threshold in HOAPS-3. In one case HOAPS-3 detected a precipitation rate of 0.3 mm/h that was not observed or measured in-situ.

The 1DD data set of GPCP shows precipitation in 3 out of 24 cases which coincide with the 3 drizzle cases mentioned above. This indicates that GPCP 1DD detects all rainfall, but none of the solid precipitation cases. The area covered by precipitation in these 3 cases is much larger in GPCP compared to HOAPS-3. This may result from a latitude dependent blending of TOVS infrared data into the GPCP product. Comparisons with APOLLO infrared data shows, that the large precipitation areas of GPCP 1DD correspond to high, and therefore cold, thin cirrus clouds, that originate from occlusions. The in-situ measured and observed precipitation was in these 3 cases intermittent light drizzle.

As an overall result HOAPS-3 is able to detect solid precipitation and rainfall at high-latitudes. Further analysis is needed to investigate the precipitation amounts measured by the disdrometer and its comparison with HOAPS-3. This concerns both the uncertainties of the disdrometer measurement and the comparison of a satellite footprint with a resolution of 50km against a point measurement. This is even more complicated as in most of the case studies cold air PcB’s cells with scattered showers occurred with diameters less than 10 km in size. The successful detection of snowfall in polar lows and scattered graupel showers in the HOAPS-3 data shows promising results compared to the disdrometer data and Hellmann gauges while there is no solid precipitation occurring in the GPCP 1DD data.

5. REFERENCES


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