OCEANIC SHIPBOARD PRECIPITATION VALIDATION PROJECT

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Outline

- Motivation
- The Optical Disdrometer 470
- Measurement Activities
- Data Analysis
  - High-Latitude Atlantic Ocean (Rain, Mix, Snow)
  - Liquid and Frozen PSD
  - Tropical Atlantic Ocean (Light Precip vs Convection)
  - DSD
- Conclusion / Outlook
- Precipitation is a key driver for Earth’s climate
- Satellite and re-analysis data substantially differ
- Water cycle to large extent driven over oceans with transport over land
- Oceans mostly void of in-situ data
- Lack of suitable in-situ instruments for shipboard usage (strong wind / sea state / snow)
- IPWG recommendation “…urges more attention to the provision of high quality surface validation data in oceanic areas using innovative ship based instruments”
- No such data available for GPM-GV
- This project aims at providing a comprehensive data base using 6 shipborne ODM470 optical disdrometers with focus on oceanic climate hotspot regions
- for satellite data set / re-analysis validation (rate) and retrieval constraints (DSD / PSD)
Automatic Measurement System: Optical Disdrometer ODM 470

- cylindrical measurement volume
- pivoting by aid of wind vane
- adjusts perpendicular to relative wind
- photoelectric barrier
- sensitive volume 120 mm x 22 mm
- a size dependent light extinction
- cross-sectional area, shadow area
- residence time
- 128 size bins in log-scale, used range: 0.43 mm to 22 mm
- Reference voltage attenuates with occurrence of hydrometeors
- Measurement interval 1 minute

RAIN:
Terminal fall velocity and mass of hydrometeor
→ Atlas and Ulbrich, 1974

SNOW: (liquid water equivalent)
Terminal fall velocity and mass of hydrometeor
→ Hogan, 1994 with one common parameterization for lump graupel (Lempio, 2007)
Developed by Eigenbrodt, Geomar, MPI-M, KlimaCampus

\[ n(\text{bin}) = \text{particle size distribution density (Clemens, 2002)} \]
\[ \text{by particle counting } N(\text{bin}) \]
\[ n(\text{bin}) = \frac{N(\text{bin})}{L \cdot D \cdot T \cdot \sqrt{ff^2 + (v_\infty(\text{bin}))^2}} \]

after Großklaus (1996)

RAIN:
\[ V_{\text{fall}}(\text{bin}) = 9.65 - 10.3 \cdot \exp(-1.2 \cdot (dp(\text{bin}) \cdot 12./2.)) \]
\[ M_{\text{tr}}(\text{bin}) = \pi \cdot \frac{4}{3} \cdot 1000 \cdot (dp(\text{bin})/200.)^3 \]

SNOW:
\[ V_{\text{fall}}(\text{bin}) = 7.33 \cdot (dp(\text{bin}))^{0.78} \]
\[ M_{\text{tr}}(\text{bin}) = 0.0000107 \cdot (dp(\text{bin}))^{3.1} \]

\[ R = 3600 \cdot \sum_{\text{bin}=0}^{128} n(\text{bin}) \cdot V_\infty(\text{bin}) \cdot M_{\text{tr}}(\text{bin}). \]

Maintenance free system
Tested and calibrated during field campaigns Bumke, 2002; Lempio, 2007; Klepp, 2010

Calibration
Spherical particles from 0.5 to 22 mm
Disdrometer-constant for precip volume scaling
ANS410 gauge vs ODM470 disdrometer
Windspeed < 1 m/s to avoid gauge undercatch

Cyclone Rainfall, 31 May 2012, Hamburg
Calibration test, rainfall time series

+1.3% +0.26 mm at 20 mm
The project, ships and data …

Project duration: 2009 to 2016

4.5 a of data, > 3 Mio Minutes of Measurements with > 300.000 spectra … steadily growing

2 R/V Polarstern since Jun 2010, Atlantic Ocean
3 R/V Akademik Ioffe since Sep 2010, Atlantic Ocean
4 R/V Aranda, Sep/Oct 2010, R/V Maria S. Merian since Dec 2011, Atlantic Ocean
5 R/V Sonne from Sep 2012, Pacific Ocean
6 NCAR, Boulder, Snowfall // SeaOrbiter, Boulder / Med Sea
7 Argentinean Southern Ocean cruises and R/V Investigator, Southern Oceans
Oceanic Precipitation Validation
IPWG6, 15-19 October 2012, Brazil
Christian Klepp

The project, ships and data …

- QC checks (continuity, location, outliers, …)
- ODM470 time series calculated with both rain and snowfall algorithm
- Mix/solid precip shows up already as completely unrealistic rain data
- 3-hourly WW Obse data and Tair used to identify phase
- Merging rainfall, snowfall and mix-phase precip, quality checks with minute res-PSD
- Merging of data with GPS and meteo data from ships
- Data base contains 15 parameters plus PSD for every minute
- to date 300,000 minutes of precipitation in data base (growing with 4 ships)
4 years precipitation tracks of R/V Polarstern and R/V Akademik Ioffe

JUN-OCT
NH
OCT-MAY
SH

GV areas of interest for:
MT
GPM-GV Cloudsat
SSMIS

June 2010 to June 2012
43095 minutes of rainfall (black)
31460 minutes of snowfall (blue)
17128 minutes of mix-phase (green)
91683 minutes of precipitation in 2 years

Red: Air temperature
Grey: Relative wind speed
### How often occurs rainfall, snowfall and mix-phase precipitation during 2 years of Atlantic Ocean transects?

Precipitation occurred in 9.6% of the time with 4.5% rain, 3.3% snow, 1.8% mix-phase a total volume of 927.16 mm with 88.2% rain, 8.4% snow, 3.4% mix-phase

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Type</th>
<th>Rel%</th>
<th>Abs%</th>
<th>Volume (mm)</th>
<th>Vol%</th>
</tr>
</thead>
<tbody>
<tr>
<td>43095 minutes of rainfall</td>
<td>4.5</td>
<td>817.29</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28493 minutes of rainfall</td>
<td>3.0</td>
<td>61.41</td>
<td>7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13000 minutes of rainfall</td>
<td>1.4</td>
<td>329.61</td>
<td>40.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1602 minutes of rainfall</td>
<td>0.1</td>
<td>426.27</td>
<td>52.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31460 minutes of snowfall</td>
<td>3.3</td>
<td>77.77</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28976 minutes of snowfall</td>
<td>3.0</td>
<td>35.52</td>
<td>45.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2476 minutes of snowfall</td>
<td>0.3</td>
<td>41.41</td>
<td>53.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 minutes of snowfall</td>
<td>0.02</td>
<td>0.84</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17128 minutes of mix-phase</td>
<td>1.8</td>
<td>32.10</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16288 minutes of mix-phase</td>
<td>1.7</td>
<td>9.91</td>
<td>30.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>795 minutes of mix-phase</td>
<td>0.09</td>
<td>16.68</td>
<td>52.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 minutes of mix-phase</td>
<td>0.01</td>
<td>5.51</td>
<td>17.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

959.517 minutes no precip
91.683 minutes of precip
Extreme precipitation events in 2 years:

- 147 minutes > 30 mm/h (green)
- 64 minutes > 60 mm/h (blue)
- 35 minutes > 90 mm/h (red)

- Intense cyclones in stormtrack peaks up to 187 mm/h
- ITCZ up to 113 mm/h

Southern Ocean Cyclone
PFL, 30 JAN 2012
93 mm/h, 23 m/s

Postfrontal cluster
05 OCT 2010
91 mm/h, 20 m/s

ITCZ cluster
11 NOV 2010
113 mm/h, 16 m/s

Postfrontal cluster
30 OCT 2010
187 mm/h, 30 m/s
2 Years of ODM470 Polarstern Precipitation

98110 spectra: 10JUN2010 to 15MAY2012

- Number concentration 46421 spectra rain
- Number concentration 31529 spectra snow
- Number concentration 17130 spectra mix-phase

Logarithmic Number concentration

Particle Diameter (mm)

VIRGA

180 drops

100 flakes

50 mix-flakes

Cold/Warm Snow
Huch much drizzle, stratiform and convective precip falls in the ITCZ?

Here: 3 ITCZ transects! Now already 10!
## Tropical Precipitation Statistics (3 transects, now already 9)

<table>
<thead>
<tr>
<th>Precipitation type</th>
<th>Precipitation occurrence (cases)</th>
<th>Precipitation duration (hours)</th>
<th>Total occurrence (%)</th>
<th>Relative occurrence (%)</th>
<th>Accumulated occurrence (%)</th>
<th>Mean rainfall (mm/h)</th>
<th>Accumulated rainfall (mm)</th>
<th>Accumulated rainfall (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No precipitation</td>
<td>5406</td>
<td>90.1</td>
<td>96.16</td>
<td></td>
<td></td>
<td>7.12</td>
<td>25.64</td>
<td>100.00</td>
</tr>
<tr>
<td>Precipitation</td>
<td>216</td>
<td>3.6</td>
<td>3.84</td>
<td>100.00</td>
<td></td>
<td>0.13</td>
<td>0.27</td>
<td>1.07</td>
</tr>
<tr>
<td>Drizzle</td>
<td>131</td>
<td>2.2</td>
<td>2.33</td>
<td>60.65</td>
<td>60.65</td>
<td>1.67</td>
<td>1.23</td>
<td>4.79</td>
</tr>
<tr>
<td>Stratiform</td>
<td>44</td>
<td>0.7</td>
<td>0.78</td>
<td>20.37</td>
<td>81.02</td>
<td>35.32</td>
<td>24.10</td>
<td>94.14</td>
</tr>
<tr>
<td>Convective</td>
<td>41</td>
<td>0.7</td>
<td>0.73</td>
<td>18.98</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Transect R/V Polarstern, 10 - 14 November 2010, 5622 minutes (3.9 days)

| No precipitation   | 5434                             | 90.6                           | 90.18                |                        |                           | 2.34                  | 17.37                     | 100.00                   |
| Precipitation      | 592                              | 9.9                            | 9.82                 | 100.00                 |                           | 0.12                  | 0.72                      | 4.16                     |
| Drizzle            | 370                              | 6.2                            | 6.14                 | 62.50                  | 62.50                     | 1.59                  | 4.31                      | 24.79                    |
| Stratiform         | 162                              | 2.7                            | 2.69                 | 27.36                  | 89.86                     | 3.92                  | 10.37                     | 27.76                    |
| Convective         | 60                               | 1.0                            | 0.99                 | 10.14                  | 100.00                    |                       |                           |                          |

### Transect R/V Polarstern, 28 April - 2 May 2011, 6026 minutes (4.0 days)

| No precipitation   | 7924                             | 132.1                          | 91.12                |                        |                           | 2.90                  | 37.35                     | 100.00                   |
| Precipitation      | 772                              | 12.9                           | 8.88                 | 100.00                 |                           | 0.13                  | 0.76                      | 2.04                     |
| Drizzle            | 341                              | 5.7                            | 3.92                 | 44.17                  | 44.17                     | 1.75                  | 10.37                     | 27.76                    |
| Stratiform         | 355                              | 5.9                            | 4.08                 | 45.98                  | 90.15                     | 7.32                  | 26.22                     | 70.20                    |
| Convective         | 76                               | 1.3                            | 0.88                 | 9.85                   | 100.00                    |                       |                           |                          |

### Transect R/V Akademik Ioffe, 19 - 25 October 2010, 8696 minutes (6.0 days)

| No precipitation   | 18764                            | 312.7                          | 92.23                |                        |                           | 3.28                  | 86.04                     | 100.00                   |
| Precipitation      | 1580                             | 26.3                           | 7.77                 | 100.00                 |                           |                       |                           |                          |
| Drizzle            | 842                              | 14.0                           | 4.14                 | 53.29                  | 53.29                     | 0.13                  | 1.76                      | 2.04                     |
| Stratiform         | 561                              | 9.4                            | 2.76                 | 35.51                  | 88.88                     | 1.70                  | 15.90                     | 18.48                    |
| Convective         | 177                              | 3.0                            | 0.87                 | 11.20                  | 100.00                    | 23.18                 | 68.38                     | 79.48                    |

All three transects: 20344 minutes (14.1 days)

Dry or wet transects
### ITCZ extreme values

<table>
<thead>
<tr>
<th>Convective extremes</th>
<th>Total number of occurrence (minutes)</th>
<th>Number of events (cases)</th>
<th>Event duration (minutes)</th>
<th>Maximum precipitation rate (mm/h)</th>
<th>Accumulated min/max Precipitation (mm)</th>
<th>Min/max wind speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transect R/V Polarstern, 10 - 14 November 2010, 5622 minutes (3.9 days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30 mm/h</td>
<td>19</td>
<td>6</td>
<td>1,7,1,2,3,5</td>
<td>58.6</td>
<td>0.55 to 8.55</td>
<td>3.1 to 9.4</td>
</tr>
<tr>
<td>&gt; 60 mm/h</td>
<td>8</td>
<td>5</td>
<td>4,1,1,1,1</td>
<td>72.1</td>
<td>1.08 to 6.00</td>
<td>4.3 to 9.4</td>
</tr>
<tr>
<td>&gt; 90 mm/h</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>113.7</td>
<td>3.52</td>
<td>4.3</td>
</tr>
<tr>
<td>Transect R/V Polarstern, 28 April - 2 May 2011, 6026 minutes (4.0 days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30 mm/h</td>
<td>10</td>
<td>4</td>
<td>2,3,1,4</td>
<td>56.4</td>
<td>0.64 to 2.78</td>
<td>1.0 to 9.8</td>
</tr>
<tr>
<td>&gt; 60 mm/h</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>74.5</td>
<td>1.24</td>
<td>5.5</td>
</tr>
<tr>
<td>&gt; 90 mm/h</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transect R/V Akademik Ioffe, 19 - 25 October 2010, 8696 minutes (6.0 days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30 mm/h</td>
<td>14</td>
<td>5</td>
<td>3,3,1,4,3</td>
<td>52.0</td>
<td>0.66 to 3.64</td>
<td>5.7 to 12.2</td>
</tr>
<tr>
<td>&gt; 60 mm/h</td>
<td>3</td>
<td>2</td>
<td>1,2</td>
<td>76.7</td>
<td>1.05 to 2.31</td>
<td>5.7 to 6.5</td>
</tr>
<tr>
<td>&gt; 90 mm/h</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>All three transects, 20344 minutes (14.1 days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30 mm/h</td>
<td>45</td>
<td>15</td>
<td>1 to 7</td>
<td>58.6</td>
<td>0.55 to 8.55</td>
<td>1.0 to 12.2</td>
</tr>
<tr>
<td>&gt; 60 mm/h</td>
<td>12</td>
<td>8</td>
<td>1 to 4</td>
<td>76.7</td>
<td>1.05 to 6.00</td>
<td>4.3 to 9.4</td>
</tr>
<tr>
<td>&gt; 90 mm/h</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>113.7</td>
<td>3.52</td>
<td>4.3</td>
</tr>
</tbody>
</table>
PDF
Accumulated Precipitation (%) vs rain rate (mm/h) for combined ship data in 4 resolutions

20344 values (0.2 km)
194 values (25 km)
97 values (50 km)
50 values (100 km)

- Line of data in time
- “100 ships in parallel”
- Representativeness of 3 transects
- More data available

PDF
Accumulated Precipitation (%) vs rain rate (mm/h) for ship data and different satellite datasets

Climatologies 1998-2005
All zero values included
Bin width = 0.1 mm/h

- Instantaneously sampled area
- Point to Area Problem
- Spatial differences
- Different thresholds
- Retrieval peculiarities
Shipboard ODM470 ITCZ Rainfall

Drop Size Distribution of 1659 Rainfall Spectra from 3 ITCZ Transects

- Number concentration 841 spectra of drizzle
- Number concentration 561 spectra of stratiform precipitation
- Number concentration 177 spectra of convective precipitation

10 drops

9.5 mm
Micro Rain Radar 24 GHz
on R/V Polarstern since 11 October 2012

Cooperation Chris Kidd, NASA GSFC, GPM-GV

- Doppler spectra of hydrometeors between 50 and 6000 meters height.
- Vertical profiles
- Highly detailed resolution in both time (10 sec) and height (30 m)
- Bright band of the melting zone
- Present weather sensor
- Precipitation rates and LWC

- Rarely used onboard ships (R/V Alkor, R/V Aranda)
- Interference with other shipboard radars likely
- Pitch / Roll corrections difficult
Conclusions

- to date the only non-gauge-based systematic oceanic precipitation validation effort
- > 250.000 minutes of in-situ shipboard precipitation data available
- Frequency, intensity, rates, accumulated amounts, phase (rain, snow, mix)
- Atlantic Ocean from Arctic to Antarctica, ITCZ, Trade zones, Pacific Ocean
- Data collection ongoing until 2016 with currently 6 instruments
- Instrument updated from Windows to Linux, from PC to Processor Box, End-to-End
- Precipitation over the Atlantic Ocean present in 9.6 % of the time within 2 years
- 4.5% as rain, 3.3% as snow, 1.8% as mix-phase
- 0.1% convective rain accounts for 52% of the rain volume
- Extremes in ITCZ but also post-frontally in mid-latitude cyclones
- ITCZ data: 53% drizzle accounts for 2% volume, 11% convective for 80% volume
- PSD data shows the differences between rain, snow and mix-phase precip
- Satellite data of different pixel size shows similar behavior as averaging ship data

Outlook

Usage of data:

- Validation for satellite based // re-analysis data sets …
- Retrieval constraints…
- GV for GPM-GV, Mehtatropique, Cloudsat, SSMIS …
- From PSD number concentrations to reflectivity…
- Point to area statistics…
- Validation of Virga-Precipitation

Additional (long-term) ship opportunities very welcome (merchant / research ships)
Thank You!

R/V Polarstern mast in 45 m height on 2 October 2012 in the Arctic