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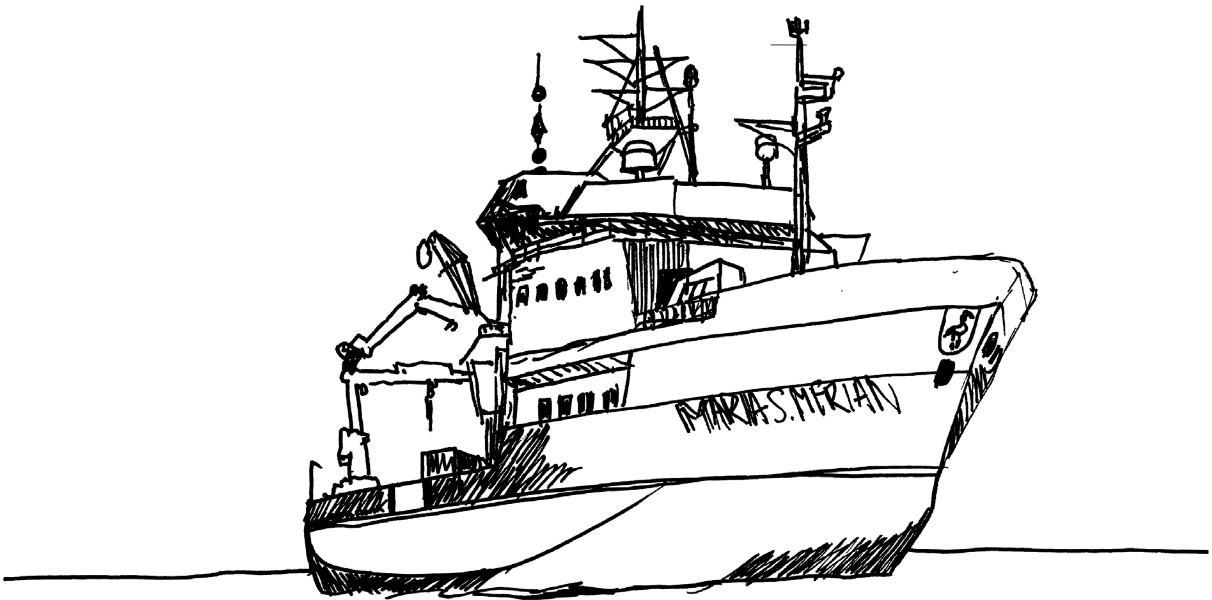
Expedition to the North Atlantic with RV MARIA S. MERIAN



Dr. Stephanie Fiedler

Hamburg 2018

Berichte zur Erdsystemforschung
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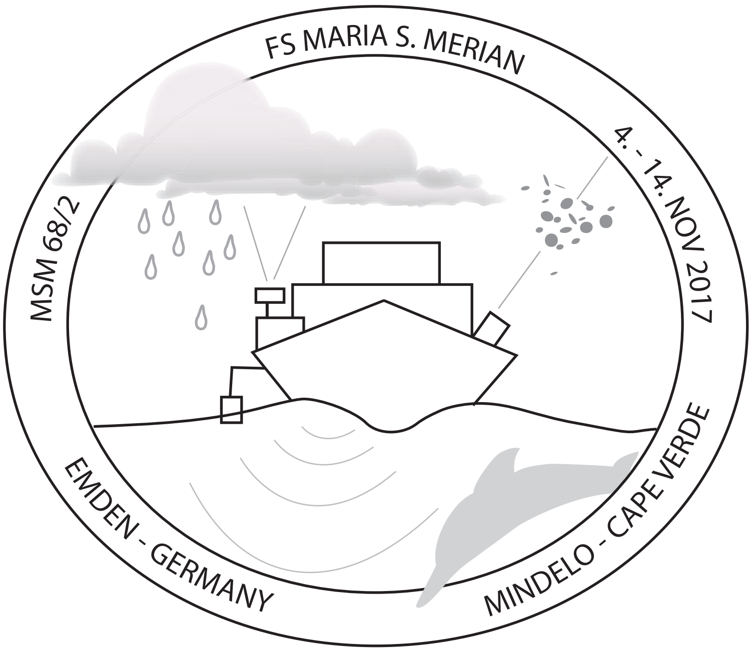
Expedition to the North Atlantic with RV MARIA S. MERIAN

Report on MSM 68/2



Max Planck Institute for Meteorology

November 2017 - October 2018

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Hamburg 2018

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"Dorthin – *will* ich; und ich traue
Mir fortan und meinem Griff.
Offen liegt das Meer, in's Blaue
Treibt mein Genüser Schiff."

Friedrich Nietzsche (1844 – 1900)
Nach neuen Meeren

ABSTRACT

The present report describes the North Atlantic expedition of the research vessel RV MARIA S. MERIAN. Starting in Emden, Germany, on 3 November 2017, the expedition MSM 68/2 went via the English Channel to the North Atlantic and ended in Mindelo, Cape Verde, on 14 November 2017. During the entire expedition, continuous measurements of the atmosphere and ocean were carried out for collecting reference data in ocean regions, where the ground-based observation network is sparse. Highlights of the expedition are (1) the successful deployment of the 'Pinocchio' cloud imager that continues to autonomously measure until 2019 as pilot phase for the initiative of the Marine Cloud Statistic (MCloudS), (2) the impressive outbreak of desert-dust aerosol from a synoptic-scale storm in North Africa, (3) the many underway sightings of marine mammals despite unfavourable conditions, and (4) the valuable measurements of instruments for seawater alkalinity and sunlight spectra that are part of research for obtaining PhD degrees. Additionally, we have contributed to coordinated marine observation networks, namely with measurements of the aerosol optical depth for the Maritime Aerosol Network (MAN) of NASA's AeroNet program, deploying a new free-drifting profiling float for the global and internationally acting Argo program, performing a CTD hydrocast at the long-term measurement site of the Cape Verde Ocean Observatory, and supporting measurements of other projects that include rainfall for OceanRAIN of UHH and bathymetry data of GEOMAR. After nearly one year since our expedition, we have used the new data for generating first analyses and thereby further developing our scientific research. The present expedition report serves to document our measurements during MSM 68/2 and show the first results. Based on our achievements, we outline how MSM 68/2 helps us to shape and pursue our own research endeavours or contributes to larger observational programs for supporting diverse research interests in the scientific community.

ACKNOWLEDGEMENTS

We would like to thank the captain and the crew of RV MARIA S. MERIAN for their generous help with the logistics and measurements aboard, as well as the „Leitstelle Deutscher Forschungsschiffe“ and Briese Research for the essential support in organising and coordinating preparations for this expedition. I am grateful for the opportunity to lead this expedition as chief scientist and the great contributions from everyone involved. Moreover, I would like to express my thanks to Alexander Smirnov and Brent Holben (NASA) for the usage of their sun photometer, as well as Bettina Diallo and Dörte de Graaf (MPI-M) for designing the webpage and uploading the daily entries for the blog during MSM 68/2.

We would like to acknowledge the financial support of the German Science foundation and the Max Planck Society that allowed us carrying out this research expedition. I was additionally funded by the EU project BACCHUS under grant number No. 603445. K. Seelmann has received funding from the EU Horizon 2020 research and innovation programme under grant agreement No. 633211 for the AtlantOS project. S. Neves acknowledges support of the MARCET project, a Macaronesian project (INTERREG – MAC 1.1b/149) from the MAC 2014-2020 program, approved in the first call of the Program of Territorial Cooperation INTERREG V-A-MAC (Madeira, Açores, Canarias) 2014-2020, financed by Fondo FEDER.

We acknowledge the use of images from the NASA Worldview application (https://worldview.earthdata.nasa.gov/) operated by the NASA/Goddard Space Flight Center Earth Science Data and Information System (ESDIS) project, as well as RGB composite images for the dust storm over North Africa in the collection of real-time images of the Meteosat 0 deg dust product (http://oiswww.eumetsat.org/IPPS/html/MSG/RGB/DUST/). Further, we would like to acknowledge the data usage of dust-forecast models, provided by the Northern Africa-Middle East-Europe (NA-Me-E) Regional Center of the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS, https://sds-was.aemet.es). We are grateful for the usage of the measurements of the on-board radiosondes of the German Weather Service and the technical support for the data from the University of Hamburg.

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ACRONYMS

AERONET - Aerosol Robotic Network

AOD - Aerosol Optical Depth

BSH - Bundesamt für Seeschifffahrt und Hydrographie

CTD - Conductivity Temperature Depth

CVAO - Cape Verde Atmosphere Observatory

CVOO - Cape Verde Ocean Observatory

DOAS - Differential Optical Absorption Spectroscopy

GEOMAR - Helmholtz Zentrum für Ozeanforschung

LIDAR - Light Detection and Ranging

LDF - Leistelle Deutscher Forschungsschiffe

MAX - Multi-Axis

MAN - Maritime Aerosol Network

MCloudS - Marine Cloud Statistics

MMOA - Marine Mammal Association

MPI-M - Max-Planck-Institut für Meteorologie

MPI-C - Max-Planck-Institut für Chemie

MSM - Maria S. Merian

NCAR - National Center for Atmospheric Research

NCEP - National Center for Environmental Prediction

OSCM - Ocean Science Centre Mindelo

PLOCAN - Plataforma Oceánica de Canarias

RV - Research Vessel

SDS-WAS - Dust Storm Warning Advisory and Assessment System

UHH - University of Hamburg

WMO - World Meteorological Organization

Part I

OVERVIEW

1 RESEARCH PROGRAM

1.1 OBJECTIVE

The expedition MSM 68/2 with RV MARIA S. MERIAN started in Emden, Germany, and followed a track via the North Sea and the English Channel to Mindelo, Cape Verde (Fig. 1). We used the transit cruise for measuring atmospheric properties with focus on clouds and aerosol, and made different types of ocean observations. The variety of data collected during the expedition makes a valuable contribution to filling gaps in the typically sparse ground-based observation network over oceans, and are promising to open new avenues for scientific research. Initial analyses addressing the new opportunities are discussed in this report and will be further explored in the course of the next years.

The overall aims of our expedition are

- testing new autonomous instruments for measuring clouds, the atmospheric composition, and the sea-water alkalinity, and
- enabling continuous observations of the atmosphere and ocean along our cruise track.

An overview of our observations and their scientific merit are given in the following section. The first results from our atmospheric and oceanic measurements are discussed in more detail in part ii and iii, respectively.

Figure 1: *Track of expedition MSM 68/2. Locations of stations and harbours are indicated (Credit for map: Google Earth).*

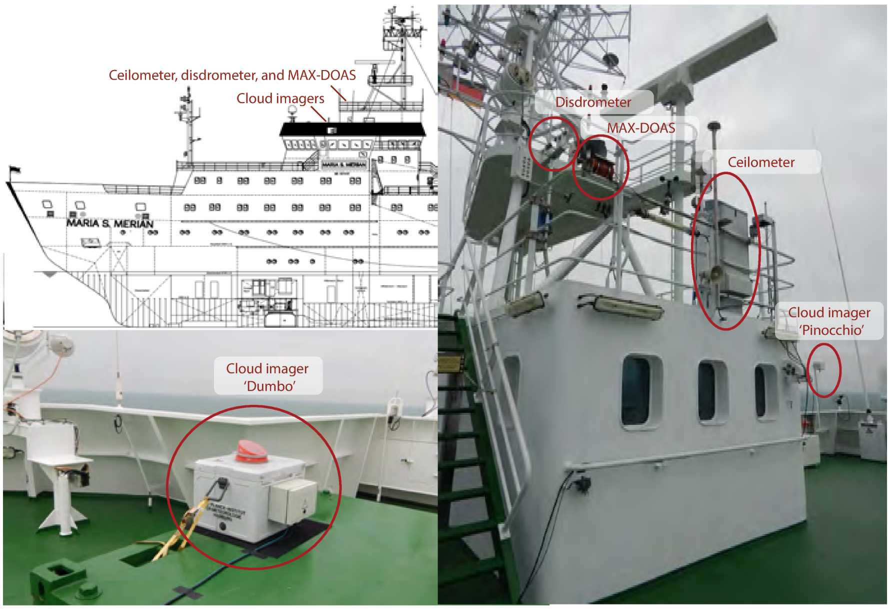

Figure 2: *Atmospheric lab during MSM 68/2. Shown are photos of the (right) bow view of the instruments on the raised pile deck and 'Pinocchio' at portside on the pile deck, as well as (left) 'Dumbo' at starboard on the pile deck. The schematic portside view of the vessel indicates the instrument positions (Credit for vessel's schematic: LDF).*

1.2 INSTRUMENTATION

1.2.1 *Remote Sensing of the Atmosphere*

We operated different instruments during expedition MSM 68/2. The atmospheric measurements were made with equipment of the research vessel, and mobile instruments that we installed on the pile deck at the top of the vessel (Fig. 2). Our atmospheric remote sensing instruments allow to derive:

1. the cloud fraction and base height from two imager systems and a ceilometer,
2. the precipitation rate and droplet size distribution from an Ocean-RAIN optical disdrometer,
3. the atmospheric gases and aerosol optical depth from a MAX-DOAS, and
4. the aerosol optical depth and the total water-vapor content from a hand-held MICROTOPS sun photometer.

A main task during MSM 68/2 is the instrument operation and ongoing software development for retrieving cloud fraction and height from the new cloud imager 'Pinocchio'. Along with the reference measurements from the older imager 'Dumbo' and the ceilometer, we

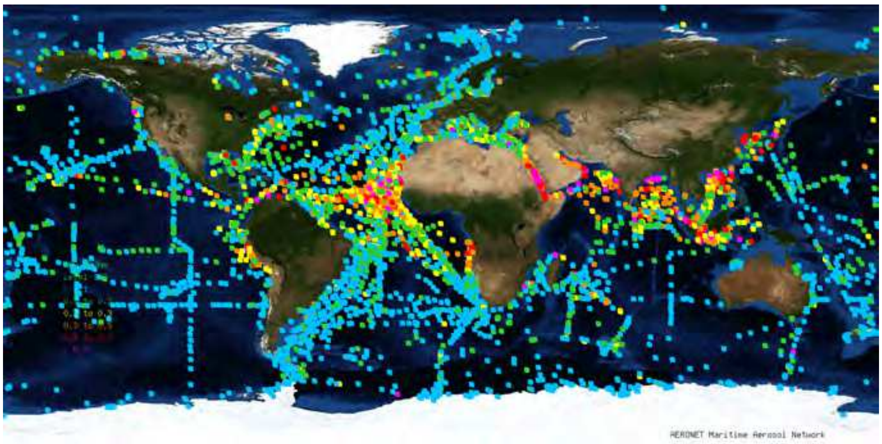

Figure 3: *Maritime Aerosol Network (MAN). Shown is a composite of all measurements of aerosol optical depth submitted to MAN (Credit: NASA).*

are able to validate 'Pinocchio's data and thereby develop the basis for autonomous cloud measurements aboard research vessels (Fig. 2). 'Pinocchio' autonomously records data on RV MARIA S. MERIAN until 2019. In addition to shorter measurements aboard other research vessels, e.g., RV POLARSTERN and RV SONNE (Fiedler, Kinne, and Jansen, 2017, Kinne et al., in prep.), the data record from RV MARIA S. MERIAN will allow us to compile a first ground-based cloud-type statistic over the Atlantic. Such a new cloud statistic can provide an avenue for new observation-based cloud analyses, validating both satellite retrieved cloud information as well as high-resolution modeling results from the German weather and climate model ICON (Crueger et al., 2018; Giorgetta et al., 2018). The development of ICON for performing high-resolution simulations, which explicitly resolves more moist convection on the model grid, is at the forefront of ongoing research at MPI-M and the German Weather Service.

Similarly sparse is the ground-based observation network for aerosol over oceans. We therefore measure the aerosol optical depth with a MICROTOPS sunphotomer as contribution to the Maritime Aerosol Network (MAN, Smirnov et al., 2009). It is important to continuously expand the data record of MAN (Fig. 3) for validating the representation of aerosol in satellite retrievals, weather and climate models, that often disagree in marine regions. Moreover, MAN data is used to construct the MPI-M aerosol climatology (MACv2 Kinne, submitted). MACv2 is the basis for the aerosol parameterization MACv2-SP (Fiedler, Stevens, and Mauritsen, 2017; Stevens et al., 2017) to be used in climate simulations for the next phase of the coupled model intercomparison project (CMIP6, Eyring et al., 2016; Pincus, Forster, and Stevens, 2016). These climate-model experiments will be analyzed for understanding aerosol effects on the energy balance of our planet and the climate response to aerosol that remain a major uncertainty in our understanding of climate changes (Bellouin et al., in prep.

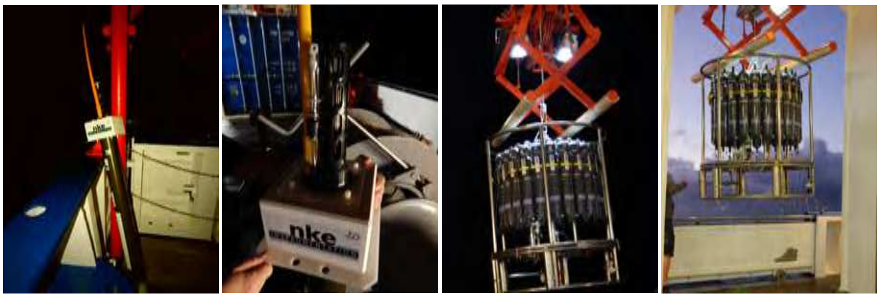

Figure 4: *ARGO float and CTD rosette. Shown are the (left) ARGO float and it's instruments prior to deployment, and (right) the CTD rosette at the start and end of the sounding, 9 November 2017.*

Myhre et al., 2013). Additionally to the observations for MAN, we operate a new MAX-DOAS instrument of MPI-C that measures temporally changing spectra of sunlight. The measurements can be used to retrieve vertical profiles of aerosol and atmospheric trace gases that are relevant to climate and human health. Moreover, we operate the OceanRAIN optical disdrometer of the University of Hamburg as part of a global network for vessel-based observations of rainfall (https://oceanrain.cen.uni-hamburg.de). The instrument autonomously detects rain events and measures the droplet sizes and rain rate.

1.2.2 *Ocean Observations*

We deployed a new ARGO float in the North Atlantic offshore of Portugal and enabled the validation by measuring a reference profile with the CTD rosette of the research vessel (Fig. 4). The attached instruments autonomously measure and transmit vertical profiles of the water temperature and salinity in the upper 2000 m of the ocean. The float is part of the international ARGO program, that strives to build a dense network of such measurements across the world. ARGO data are of great interest for continously monitoring the conditions of the oceans and better understanding the role of the ocean in our Earth system.

Another CTD sounding is carried out at the Cape Verde Ocean Observatory (CVOO, Fig. 5). Here we also used the Niskin bottles to take water samples for determining the content of nutrients and carbon. Collecting ocean data at the CVOO helps extending the existing record of vertical profiles at this site. CVOO is regularly revisited by research vessels to repeatedly measure vertical profiles. Similar to the ARGO program, these measurements help to better understand climate changes. CVOO data is additionally suitable for monitoring changes over the full ocean depth and detect bio-geochemical changes.

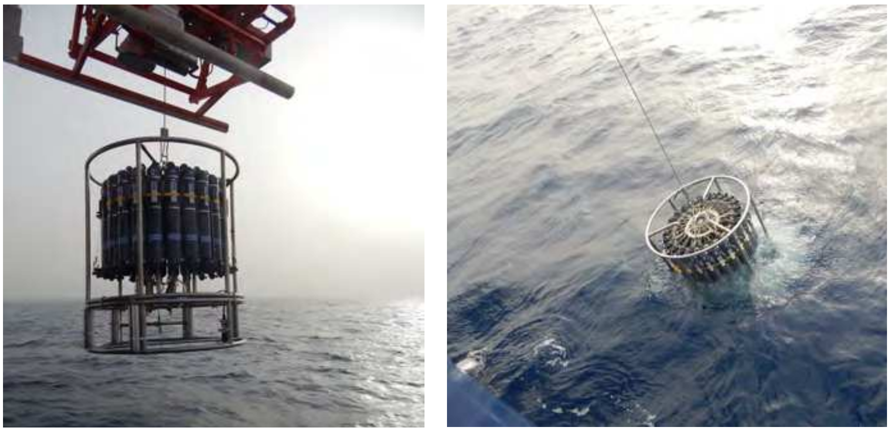

Figure 5: *CTD rosette at the Cape Verde Ocean Observatory at the start of the sounding, 13 November 2017.*

The continuous measurements of ocean properties are carried out with novel automated systems by GEOMAR. The systems determine the temperature, salinity, and total alkalinity of continuously pumped near-surface seawater. Measurements of seawater alkalinity are typically carried out by time-consuming analyses of seawater samples by hand. Having an automated system enables frequent measurements such that the pH value of seawater can be measured continuously over long periods of time. The systems operated also aboard a cargo ship in spring 2018 in preparation of autonomous operations. Testing the systems during MSM 68/2 was the last milestone before the usage aboard the first cargo ship.

The expedition also contributed to other scientific efforts. An echo sounding system of GEOMAR was active throughout the cruise for mapping the sea-floor topography. These measurements are a contribution to closing gaps in the map of the ocean floor that is, despite today's advanced technology, still not fully recorded. Moreover, a marine biologist of PLOCAN joined the expedition for recording underway sightings of cetaceans with photo IDs and GPS locations. The sightings are collected within the MARCET program that strives to gain and exchange information on marine mammals in Macronesia for scientific research and animal protection.

2 NARRATIVE OF THE CRUISE

S. Fiedler

2.1 OVERVIEW

The six science team members, listed in Table 1, embarked RV MARIA S. MERIAN on 2 November 2017 in Emden, Germany. The atmosphere lab (Fig. 2) was set up on the pile deck on the same day with additional technical support from MPI-M and MPI-C. Initial problems with some of the cloud instruments were quickly solved after identifying the causes for the errors and fixing the loose contacts of two wires in the evening.

We left the port a day earlier than originally planned, on the morning of 3 November 2017. The research vessel had just completed maintenance at the dockyards that required additional work offshore. These included testing the newly installed navigation system such that we stayed in the North Sea and circled around a similar position for half a day. Our cloud record during that time is a perfect test of our instruments for the later operation during the EUREC4A campaign, when research vessels will likewise stay at almost fixed positions. We are further able to compare our data against measurements from a 'Pinocchio' imager aboard of RV SONNE that passed us with low speed in the early morning of 4 November 2017. The data of the more precise cloud imager 'Dumbo' and the ceilometer aboard RV MARIA S. MERIAN (Fig. 2) are herein useful for validating the measurements of the new 'Pinocchio' imagers. Both 'Pinocchios' have undergone fresh calibration before installing them on the vessels. 'Pinocchio' and the ceilometer aboard RV MARIA S. MERIAN keeps recording clouds until 2019 for a marine cloud statistic.

After the technicians had left us, we set course for the English Channel (Fig. 1). Our daily science colloquium started on 5 November 2017 and was a great opportunity for learning about the scientific research of our inter-disciplinary team. On the same day, we were able to perform first sun photometer measurements with the handheld MICROTOPS instrument of NASA in the clear patches of the air behind the trailing cold front that we had passed in the course of the night. Like expected, the air was clean with low aerosol optical depth. Despite the increasing swell of up to 4 m, the instruments reliably recorded the clouds scenes during the front passage. We saw the first cetaceans, the common dolphin, already on the following day, which was unexpected at such a northern position. In the meantime,

Table 1: *List of participants in science aboard.*

Name	Role	Affiliation
Dr Stephanie Fiedler	Chief scientist	MPI-M
Samira Terzenbach	Sun photometer measurements	MPI-M
John Mrziglod	Cloud-data management	MPI-M
Sebastian Donner	MAX-DOAS measurements	MPI-C
Katharina Seelmann	Sea-water alkilinity measurements	GEOMAR
Dr Silvana Neves	Cetacean observation	PLOCAN
Michael Maggiulli	System operator	MSM
Friedhelm Jansen*	Technical support for cloud instruments	MPI-M
Steffen Dörner*	Technical support for MAX-DOAS	MPI-C
Dr Christian Klepp**	Rain measurements	UHH
Anja Schneehorst**	ARGO float logistics	BSH
Prof Colin Devey**	Bathymetry measurements	GEOMAR

* aboard in harbour of Emden, ** not aboard.

the novel systems for measuring the seawater alkalinity started to operate and successfully measured during the entire expedition. The swell further increased during the following days with waves of up to 6 m. Our daily work concerned the data management, initial analyses and regularly checking the instruments. From 7 November 2017 onwards, the crew also regularly launched radiosondes for the German Weather Service. The geographical positions of the radiosondes are marked in Figure 6.

In the early morning of 9 November 2017, we reached our first station offshore of Portugal. After testing and deploying the new ARGO float, we performed a 2000m-deep CTD sounding as reference for validating the first temperature and salinity profiles of the float. With the help of the experienced crew, we successfully completed this part of our mission and continued our cruise towards warmer waters after just two hours.

The weather development on the 10 November 2017 already indicated a dust outbreak towards the North Atlantic in the following days such that we got excited about measuring the aerosol optical depth and weather conditions. The models forecasted an eastward extending Azores High and strengthening north-easterly winds over Northwest Africa that mobilise and transport desert dust in our vessel's path. The geostationary satellite of Eumetsat captured widespread dust storms on 11 November 2017. Most of the desert dust reached us on 13 November 2017 with clear dust deposition on deck of the vessel. The associated aerosol optical depths were captured with MICROTOPS and were daily submitted for data quality checks and publication to the Maritime Aerosol Network (MAN, e.g., Smirnov et al., 2009) of NASA. The atmospheric measurements are discussed in detail in Part ii

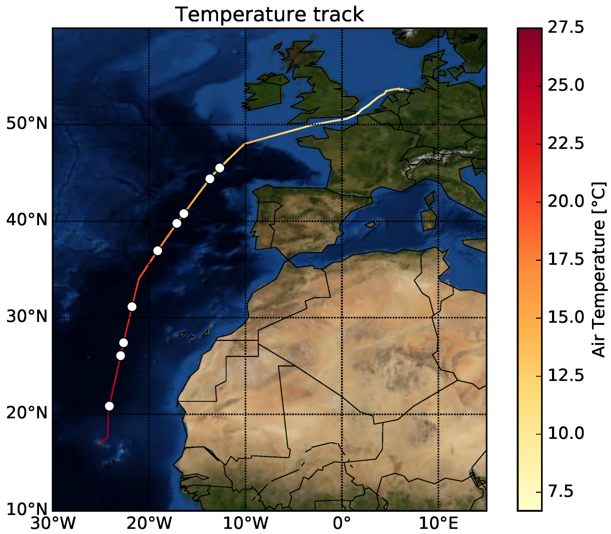

Figure 6: *Cruise trajectory. Shown are the (shading) air temperatures and (circles) the geographical positions of the radiosondes.*

On 13 November 2017, we completed our second and last station. At the Cape Verde Ocean Observatory, we did a full-depth CTD sounding with a hydrocast. Shortly after the device was back on deck, the water samples were prepared for the analysis in the lab on land. In the afternoon, we already reached the harbor of Mindelo after traveling through the dust plume. Despite the low visibility, we recorded sightings of spinner dolphins.

2.1.1 *Station list*

We had three stations during the expedition, listed in Table 2. Our first station is dedicated to the deployment of a new ARGO float from the "Bundesamt für Seeschifffahrt und Hydrographie". The ARGO float automatically measures the sea water temperature and salinity of the upper 2000 m. Since this is a new float, we carry out a matching CTD profile over the same depth. The profile is measured in some distance to the float for preventing any risk of collision of the float with the vessel.

The last station of the cruise is the Cape Verde Ocean Observatory (CVOO). Research vessels regularly revisit this site for establishing a long-term data record. We have measured the profile of ocean properties over the full depth of roughly 3500 m and took sea water samples at depths as specified by the CVOO protocol. The ocean measurements are discussed in Part iii.

Table 2: *List of stations.*

No.	Device	Date	Time [UTC]	Action	Position	Depth [m]
1	ARGO float	9.11.2017	05 : 46	deployed	37°30.738′ N, 18°42.546′ W	4,872.8
2	CTD	9.11.2017	06 : 14	start	37°28.961′ N, 18°43.833′ W	5,210.0
			06 : 55	return	37°28.993′ N, 18°43.797′ W	4,566.7
			07 : 31	end	37°28.991′ N, 18°43.800′ W	4,616.3
3	CTD	13.11.2017	09 : 13	start	17°34.971′ N, 24°18.010′ W	3,604.1
			10 : 18	return	17°34.971′ N, 24°18.010′ W	3,604.4
			11 : 29	end	17°34.970′ N, 24°18.010′ W	3,602.1

2.2 CHIEF SCIENTIST'S (B)LOGBOOK

MPI-M has published a daily blog about the life and research aboard the vessel. A short text contribution and a matching photo of Stephanie Fiedler have been uploaded to the institute's homepage. These were useful for sharing highlights during the expedition with other scientists and interested laymen. The (b)logbook and a selection of figures is reprinted in the following.

2.2.1 *Instrument mysteries*

2 November 2017, Emden
We have setup our atmosphere lab on the pile deck above the bridge in a small observation room. From here we are overlooking the ocean such that it is a great location for atmospheric measurements along our cruise from Emden to Mindelo. After some late hours, all our atmospheric observing systems are successfully recording aerosols, clouds, and rain. During the transport from Hamburg to Emden, wires and contacts of the ceilometer have loosened. It took Friedhelm and me some time to demystify and fix the problems. Also the disdrometer and the larger of our two cloud imager systems 'Dumbo' needed some extra care. We look forward to the expedition with 'FS Maria S. Merian' with many interesting science activities during the next twelve days. Let's hope the weather will permit exciting observations.

2.2.2 *Big vessel - little space*

3 November 2017, North Sea
Our departure is getting closer. While the crew is busy loading the remaining cargo for Cape Verde, Friedhelm leaves the vessel and the instrumentation for the continuous analysis of ocean water is setup in the chemistry lab on the blue deck. Also the first preparations for our station offshore of Portugal in a few days are being made. As we leave the port towards the North Sea, we have to squeeze into the small watergate with two smaller ships (Fig. 7). On our way out, we are watching the loading of new cars into giant windowless ships from Panama - a surreal scene since sheep enjoy their lunch nearby on the dike.

2.2.3 *Circles and 'Sonne'*

4 November 2017, North Sea
We are going in circles all night. Although it might seem like we have lost our way just when we have left the port, every little track change has a good reason. It is necessary for testing settings of the brand new navigation system of the vessel. Circling around the same position is also useful for having atmospheric measurements at an almost fixed location for twelve hours. We will be able to compare our data of our cloud imager 'Pinocchio' at this position against measurements from the same instrument type aboard of the sister vessel 'FS Sonne' passing us with low speed in the early morning. Our vision was not good enough for spotting Stefan on deck, but 'FS Sonne' lived up to it's name with the bright lights in the foggy air.

2.2.4 *With full speed through the channel*

5 November 2017, English Channel
We need to hurry a little bit for freeing enough time for the planned stations. With a speed of roughly 15.5 kn, we have reached the English Channel by the morning. We wake up and have a beautiful view on the British coastline (Fig. 7). By now the air has cleared as we have passed the trailing cold front of a mobile cyclone over the North Sea in the course of the night. We count the 'Schäfchen' clouds with the cloud imagers and use the clear patches for the first aerosol measurements with the MICROTOPS instrument. We are also making the first preparations for the vertical profiling of the ocean in the North Atlantic offshore of Portugal. At a spot around 37.5N the ocean observation network is less dense than in other places. We will fill that gap by deploying a brand new ARGO float and measure a reference profile with the ship's own CTD-rosette. Exciting!

Figure 7: *Impressions from board. Shown are photos of (left) the research vessel before entering the watergate in Emden, 3 November 2017, (middle) the British coastline with chalk cliffs, 5 November 2017, and (right) the rough waters and rain showers on the North Atlantic Ocean, 7 November 2017.*

2.2.5 *Increasing swell and visitors*

6 November 2017, 49°N, 7°W
Some of us got little sleep last night. The increasing swell with waves of around 4m height made the vessel swing in all directions. In the morning, I was relieved that all cloud instruments are working fine. Given the loose contacts during the installation of the ceilometer, I had some concerns for entering the rough sea towards the West. During our daily check of the imager lenses, we were greeted by a fairly large school of dolphins accompanied by a few sea birds. They are all looking for a breakfast. So did we and found a tasty English breakfast in the cosy dining room.

2.2.6 *The beauty of our growing cloud record*

7 November 2017, 45°N, 13°W
Showers evolve around the vessel and the sun highlights them with rainbows. The swell of 4-6m is following us, and we watch waves and weather playing with the vessel (Fig. 7). The waves give the sailing boat a hard time for competing in the race. They are nevertheless faster than us. In the meantime, our cloud record keeps growing every day. We are working on the management and post-processing of the cloud data. The analyses wing our hopes for getting cloud cover transects of this and other cruises. Having the cloud cover from our imager 'Pinocchio' would be less subjective than an observer's estimate. What a great progress this development is for getting ground-based cloud information over world regions where routine observations are rare.

2.2.7 *A special day*

8 November 2017, 40°N, 16°W
The swell is even more impressive when you look at the water from the working deck. We are here to ask for the crew's help to get the

ARGO float from the storage. We will test and deploy it early tomorrow, and want to prepare everything we can today. The CTD-rosette for the vertical sounding of the ocean near the deployment of the float is already at the right place and the bottles for taking sea water samples are prepared later today. According to the forecast, the swell will not decline soon, but the cloud cover already does. With 17.2 degree C, being in the sun and listening to the waves remind me of holidays during my morning tour on the pile deck. There could hardly be a better present than being right here. It was a lovely surprise getting birthday wishes, hand-made cards and cake from everyone on board. Every day at sea is special, but you made today memorable. Thank you!

2.2.8 *The awakening of the robot*

9 November 2017, 37°N, 18°W
5 am - early rise for an exciting start of the day. I just have a quick sip of coffee and go down to the working deck. It is time for breathing life into our robot friend #170356 with a shot of water in it's veins and animating the heart, a small hydraulic pump, with the build-in battery. We hear the ARGO float ticking, but it only lasts for 30 minutes. This is our time window for deploying the float in the North Atlantic. We leave it alone and will only get back in touch by monitoring the valuable measurements in the ARGO database, an international effort for collecting ocean observations. I have learned about this program in Australia, but I never would have thought that I will have the chance deploying a float myself. While the float disappears in the darkness behind the vessel, we prepare the vertical profiling of the ocean with the ship's own heavy gear. The CTD-rosette hits the water at our first station and we keep watching the growing record of the profile on the lab's monitor for 90 minutes. Positioning the rosette back on deck needs the full support of two men in the 4m swell. Everyone's effort will be great for validating the first measurements of the brand-new ARGO float. We are satisfied with this part of our mission and dream of the robot's adventures during a short nap.

2.2.9 *Strong breeze and low clouds at the Azores High*

10 November 2017, 31°N, 21°W
Oh, look at the weather development in North Africa. The models forecast an eastward extending Azores high and strengthening northeasterly winds over Northwest Africa that mobilise and transport desert dust in our vessel's path during the next days. The pattern looks like what we would refer to as Harmattan surge characterised by a postfrontal strengthening of near-surface winds. Such events are, from a climatological point of view, most important for emit-

ting desert dust in winter and spring. So it is rather early for a dust outbreak of that kind, but let's hope the forecast's promise becomes true. The winds at the margin of the high out here on the ocean are currently about 12 m/s. Such a value would be well above the necessary value for dust-aerosol emission. Here and now, this wind is perfect for stirring new waves and emitting sea-spray aerosol. Combined with the old swell, I enjoy the gentle ride with the roller coaster while cleaning the lenses of the cloud imagers. It is with 21 degree C pleasant to be outdoors, despite the wind. Back in the office, I have to tie my chair, to the desk for preventing me from rolling through the room while I am working.

2.2.10 *Radiosonde through the cloud*

11 November 2017, 27°N, 22°W
The crew aims to launch a radiosonde for the 12 and 18 UTC window every day. If you have a background in meteorology, you already know how valuable these measurements of the vertical profile of air temperature, humidity and winds are for weather predictions, even more so over remote ocean regions where the network of routine observations is sparse. The technical infrastructure of the radiosonde station aboard is great. The balloon is filled in a metal cylinder inside of a container. Before attaching the instruments to the balloon, they are brought into an instrument shelter for adjusting the sensors to outdoor conditions and establishing a connection with the data-receiving computer in the meantime. After a few minutes, the instruments are tied to the balloon, the container opens at the side, and the cylinder with the balloon tilts toward the railing for releasing the radiosonde. Strong winds can make the launch difficult. Indeed launches regularly have to be supported by the vessel by changing the course due to the strong winds during our expedition. Today we watch the balloon flying into one of the many cumulus clouds surrounding us. It would be great using the soundings in our cloud research back home at MPI-M.

2.2.11 *Waiting for the dust*

12 November, 22°N, 23°W
I get up an hour early and hurry up the stairs to the pile deck. I am just too curious about the colour of the rising sun over North Africa. A beautiful orange disk is my reward and gives me some idea of what's about to come. I spend the rest of the morning checking the latest dust forecasts and measurements. It is a tricky business as the model diversity is large and the station observation network in the Sahara is sparse. We can choose a forecast of anything between a weak dust transport offshore West Africa and a fairly strong outbreak toward

the North Atlantic. The geostationary satellite of Eumetsat already shows clear indications of dust storms behind an extending front of several 100 km length for yesterday afternoon. Admittedly, the crew is not too happy about this prediction as it will imply cleaning the deck. It is just a question of how much desert dust is transported downwind and when it will arrive at the vessel. We are ready to take measurements with our sun photometer. The data will be a fantastic opportunity for validating the model forecasts.

2.2.12 *Ship time flies*

13 November, Cape Verde Ocean Observatory
It feels as if we have left Emden just yesterday, but it is already time for packing up most of the instruments. Today is busy since we will already be in Mindelo in the afternoon. We still have another station at the Cape Verde Ocean Observatory in the morning. Here, we run a CTD for the entire ocean depth of roughly 3.5 km and take 19 water samples that need to be prepared for the analysis in the lab before leaving the ship. Luckily our sun photometer can be quickly put in the luggage and 'Dumbo' will be stored onboard until we hopefully come back for a second series of validation measurements next year. Our cloud imagers have done a great job. The rather rough sea during most of the expedition made me expect instrument problems, but apart from regularly wiping down sea spray, none of the instruments needed larger maintenance. That is great news since 'Pinocchio' and the ceilometer will continue operating on the vessel for the entire next year without us being present all the time. We have already captured many different cloud scenes, e.g., those during a front passage in the mid-latitudes and clouds in the northeasterly trades like in the image below. I look forward to more data from the instruments for compiling a marine cloud statistic.

2.2.13 *Farewell dust*

14 November 2017, Mindelo
We woke up in the harbour of Mindelo this morning, while the dust plume is transported further downwind. The sky is clearer than yesterday, but it is still uncertain whether flights can land on Sao Vincente. Moving through the haze was very impressive and almost scary when we got closer to land in the late afternoon. We clearly got dust deposition on deck and have hardly seen the volcanoes of the island. The dust plume is interesting in many ways. Being here for measuring the atmospheric conditions offshore gives us golden data for better understanding this type of dust event. Many thanks for giving us the great research opportunity aboard FS Maria S. Merian.

Part II

ATMOSPHERIC OBSERVATIONS

3 WEATHER

S. Fiedler and A. U. Cortes

3.1 DEVELOPMENT OVERVIEW

During the expedition from the mid-latitudes to the tropics, the vessel experienced weather conditions typical for the season. During the first days, the weather was characterised by passages of cold fronts associated with extra-tropical cyclones and the typical westerly winds of the mid-latitudes. The weather development is illustrated with synoptic analyses of the mean sea level pressure from ground observations in Figure 8. The cold fronts were recorded as decreases in air temperature and/or pressure, e.g. at 00 UTC on 7 November 2017 visible in the time series of the meteorological recordings of the vessel (Figure 9). The front passages were further associated with increases in relative humidity and wind speed.

Further South, the weather was determined by the Azores High. Between 8 and 9 November 2017, the vessel was located Southeast from the center of the High (Figure 8). During this period, we measured continuously increasing temperature and air pressure, and decreasing relative humidity (Figure 9). The winds clearly showed the characteristic shift from the mid-latitude westerlies to easterlies.

On 11 November 2017, the vessel reached a position south of the centre of the Azores High near 30°N. During travelling further southwards, the air temperature continued to increase and approached the values of the near-surface ocean water. As the same time the humidity increased, the winds slackened, and the air pressure showed only small variability compared to the mid-latitudes.

The weather was only weakly disturbed by waves after the 11 November 2017, visible in the near-surface pressure time series (Figure 8). An indicator for a larger disturbance is the formation of the near-surface cyclone over the coast of West Africa (Figure 8) on 11 November 2017 that moved westwards on the same day but had little impact on the weather recorded on the vessel. A relatively strong disturbance that influenced us occurred towards the end of the expedition. This event is visible as a sharp decrease in relative humidity due to the advection of drier air from the Sahara. Given the origin of the air mass, the air temperature even exceeded the one of the warm waters. These disturbances were associated with a dust outbreak, discussed in Section 3.3.

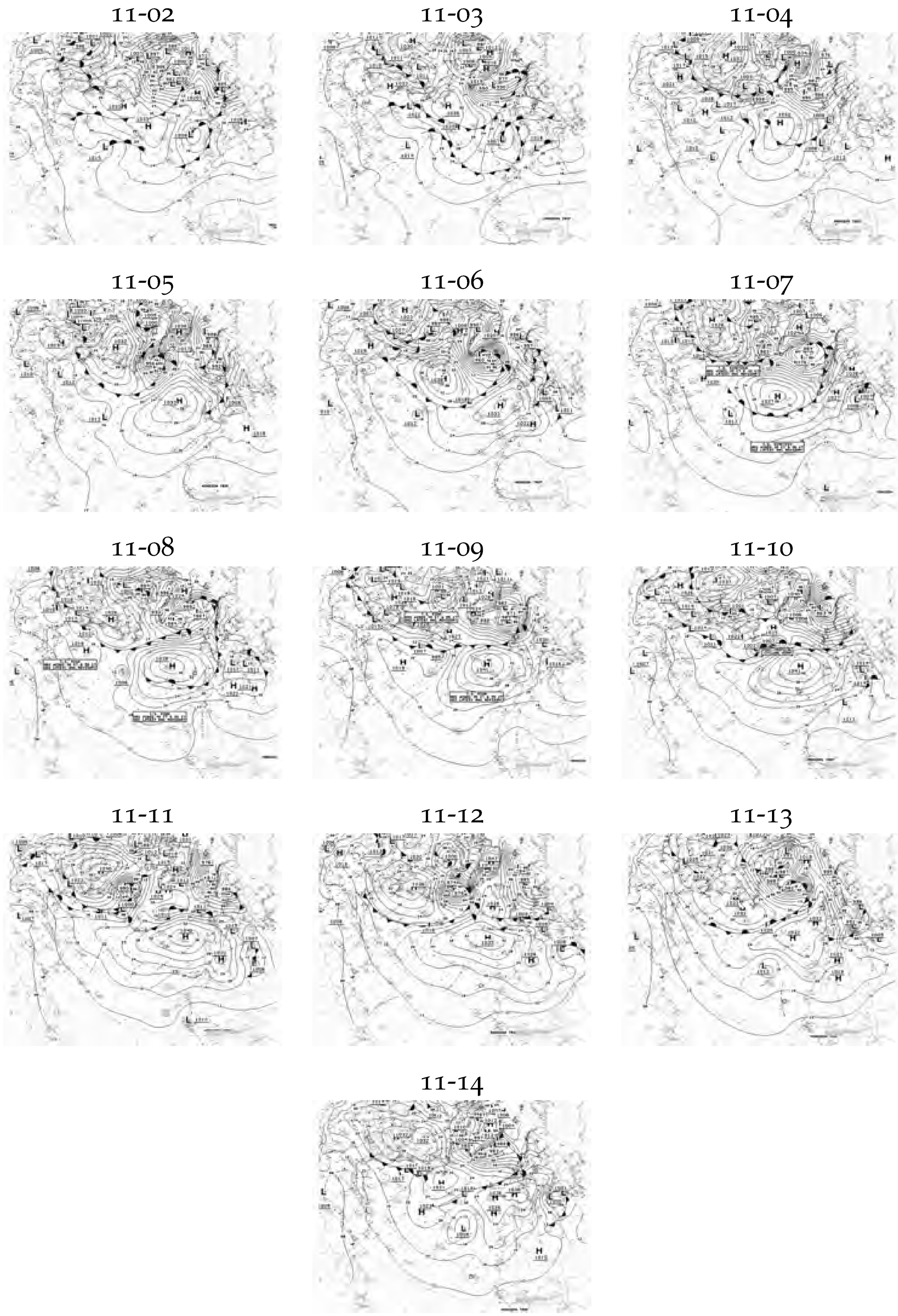

Figure 8: *Synoptic evolution during the expedition. Shown are the near-surface pressure analyses of NCEP/NCAR at 00 UTC with isobars in steps of 4 hPa and front lines. The circles indicate the vessel's location at the time. (source: www.wetterzentrale.de)*

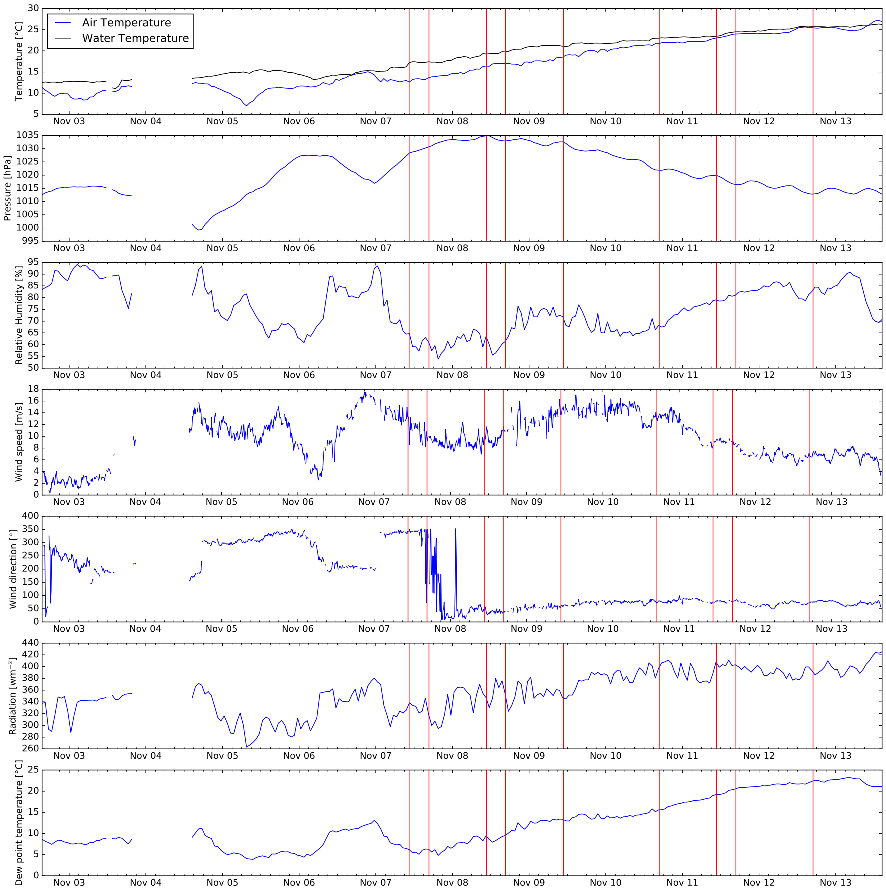

Figure 9: *Time series of the meteorological records. Shown are the ten-minute means of air temperature, near-surface pressure, relative humidity, wind speed and direction, downwelling broadband radiation, and dew-point temperature during the expedition. The red lines indicate the times for the launches of radiosondes from the vessel.*

3.2 VERTICAL SOUNDINGS

During the expedition, radiosondes were launched for the German Weather Service in support of operational weather predictions at different geographical positions marked in Figure 10. Figures 11 and 12 show the vertical temperature profiles from the radiosondes up to 25 km and 5 km above sea level. We diagnose the height of the lowest temperature inversion for better characterising the vertical profiles during the expedition. The inversion height is determined as the lowest level above which five consecutive measurements show a positive temperature gradient. Additionally, we calculate the temperature gradient between the inversion height and the uppermost measurement of the radiosonde for obtaining a quantitative measure of the free-tropospheric stability in preparation of a further development of the cloud-imager software for MCloudS (Chapter 4).

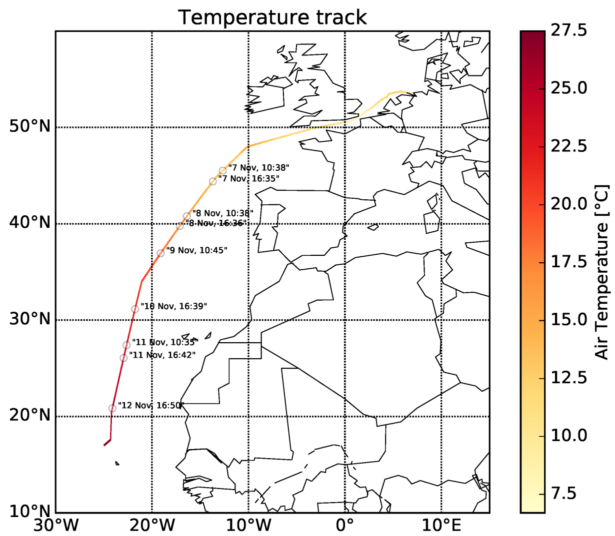

Figure 10: *Temperature along the cruise trajectory. Shown are the (shading) air temperatures and (circles) the geographical positions of the radiosondes with the time of launching.*

For supporting the imager-software development in the future, we further display the vertical profiles of the relative humidity in Figures 13 and 14. These will be useful for validating the height of the cloud base from the cloud-imager retrieval in the future (Section 4). We mark the lifted condensation level (LCL), internally calculated by the Vaisala software package of the radiosondes. In most cases, LCL is a good indicator for the lowest level with high relative humidity as evidence for cloud occurrence, given a sufficient supply of moisture. For instance, LCL and layers of high relative humidity coincide well on 8 November 2017. An exception is the 12 November 2017, when the humidity of the lowest air layers was generally too small for forming clouds.

3.3 DUST STORM

We observed the development of a synoptic-scale dust storm over North Africa during the expedition. The storm was associated with the post-frontal strengthening of the northerly winds behind an eastward moving mobile cyclone, the clouds of which are visible in the satellite image of SEVIRI (Figure 15). Such a weather pattern is typically referred to as Harmattan surge. These events are an important mechanism for dust emission in winter and spring (Fiedler, Kaplan, and Knippertz, 2015), and are characterised by complex dynamical processes acting on different temporal and spatial scales (Pokharel, Kaplan, and Fiedler, 2017a,b).

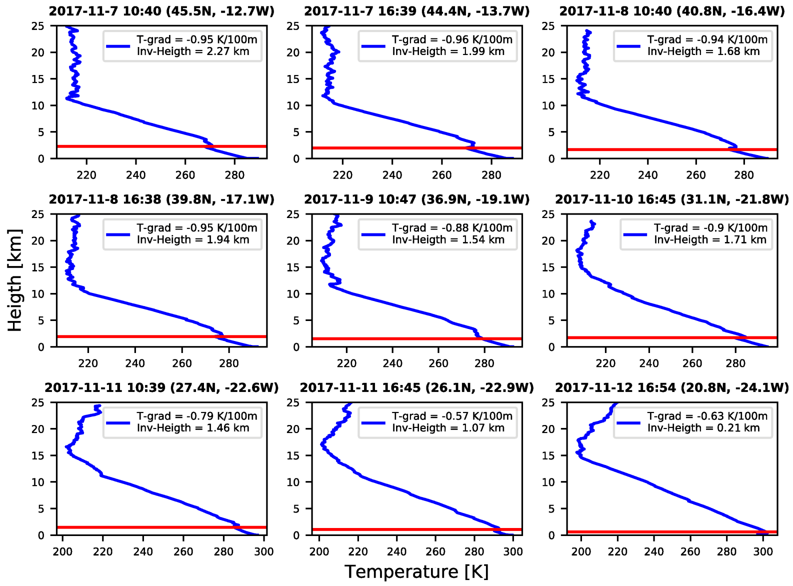

Figure 11: *Radiosonde profiles for the temperature. Shown are the vertical profiles from the surface to 25 km as recorded by the radiosondes launched during the expedition.*

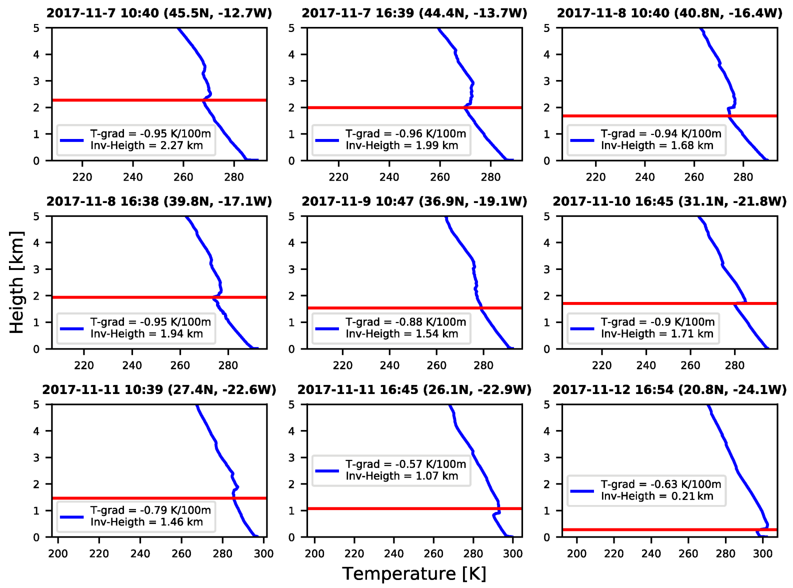

Figure 12: *Zoom to 5 km a.s.l. for Fig. 11*

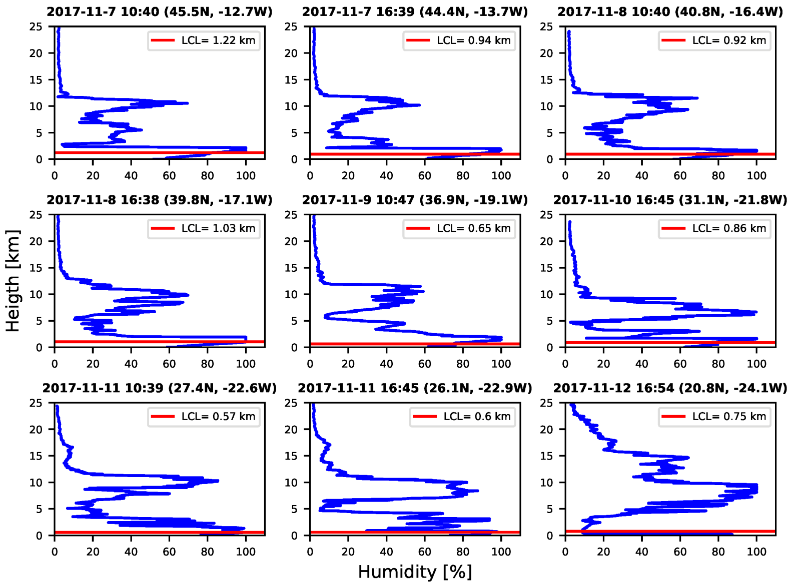

Figure 13: *Radiosonde profiles for the relative humidity. Shown are the vertical profiles from the surface to 25 km as recorded by the radiosondes launched during the expedition. Red lines indicate the lifted condensation level (LCL).*

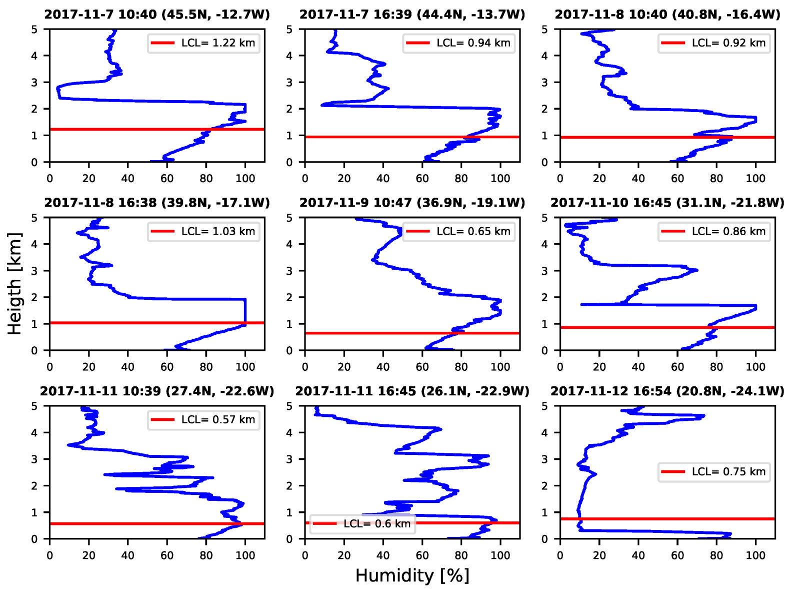

Figure 14: *Zoom to 5 km a.s.l. for Fig. 13*

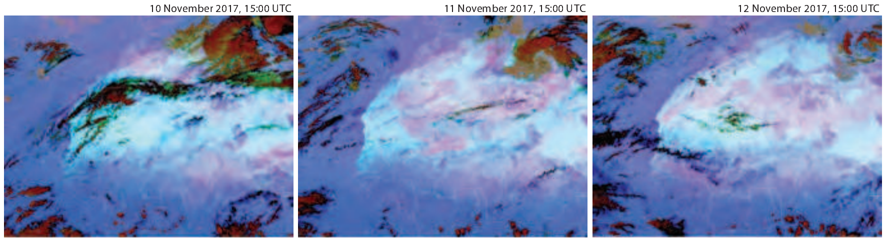

Figure 15: *Dust storm in EUMETSAT observation. Shown are false-color images of the Seviri instrument aboard the geostationary Meteosat satellite of EUMETSAT indicating dust aerosol in pink and clouds in red for 15:00 UTC of 10–12 November 2017 (Credit: Real-time Images of Meteosat odeg Dust, Copyright 2018 EUMETSAT).*

Dust emissions were driven by the strong winds associated with the synoptic conditions for several days. Initially, desert-dust particles were mobilised in the Northwest of the continent on 10 November 2017, indicated in pink in Figure 15. In the following days, dust aerosol was emitted in regions further East and South. In consequence, the atmospheric burden of dust aerosol over North Africa continuously increased.

The dust laden air was advected with the north-easerly winds towards the North Atlantic. The MODIS retrieval indicates the first dust aerosol offshore of Northwest Africa on 11 November 2017 (Figure 16). Most of the aerosol was, however, still to the east of the vessel's position during that day. The dust aerosol reached us on 12 November 2017 with a clear increase in the measured aerosol optical depth, τ, in both the MICROTOPS and MAX-DOAS measurements. MODIS shows large τ on that day. The day after, clouds hinder the measurements of aerosol substantially. In consequence, MODIS does not provide a retrieval at the position of the vessel for 13 November 2017. On board, we have used the intermittent cloud cover for measuring with MICROTOPS and MAX-DOAS (Section 5 and 6). These indicate even larger τ than on the previous day.

A spatially complete picture of the dust outbreak is given by the model median of 12-hour forecasts of the WMO Sand and Dust Storm Warning Advisory and Assessement System (SDS-WAS). The forecasts of the dust outbreak collected by the regional center capture the synoptic-scale storm and indicate the development of a long-trailing front marked by increased τ for desert dust (Figure 17).

The dust-forecast models, however, show large differences in the tempo-spatial development of the event. The model diversity is shown for mid-day for four selected models and the multi-model median of SDS-WAS (Figure 18). The spatial patterns and regional magnitudes are model dependent. As such the performance compared to the point measurement with MICROTOPS aboard is also very different. For instance, we have clearly measured increased τ on 12 November 2017 with both MICROTOPS and MAX-DOAS. Three of the four

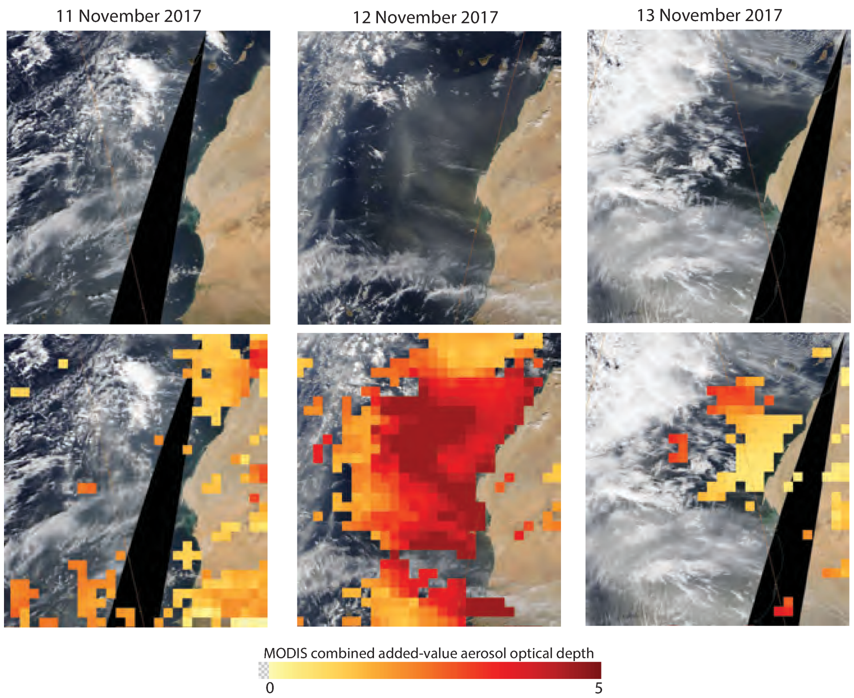

Figure 16: *Satellite view of dust storm. Shown are the combined (top) visible images of MODIS Aqua and Terra and (bottom) the product for the aerosol optical depth at 500 nm for 11–13 November 2017 (NASA Worldview).*

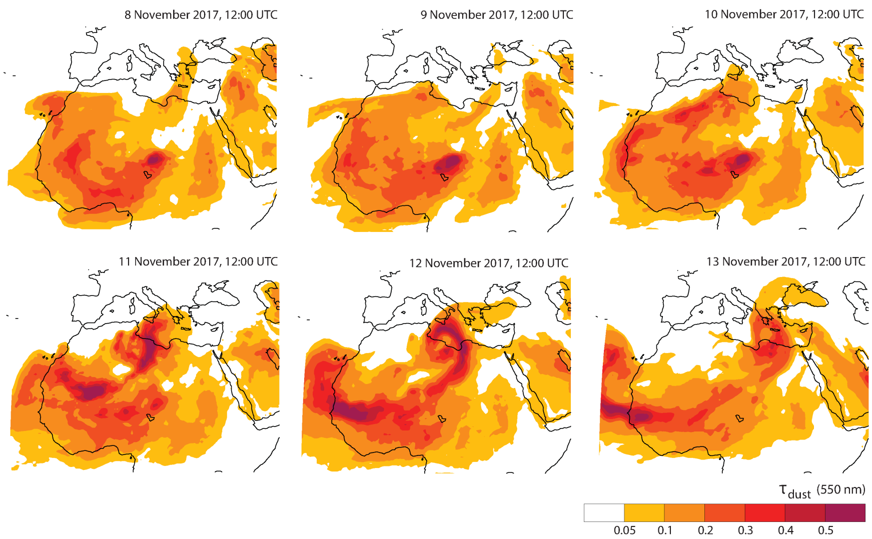

Figure 17: *Dust storm in WMO SDS-WAS forecasts. Shown are the median in dust aerosol optical depth at 550 nm of models participating in the Sand and Dust Storm Warning and Assessment System (SDS-WAS) of the World Meterological Organization (WMO) as 12-hour forecasts for mid-day of 8–13 November 2017.*

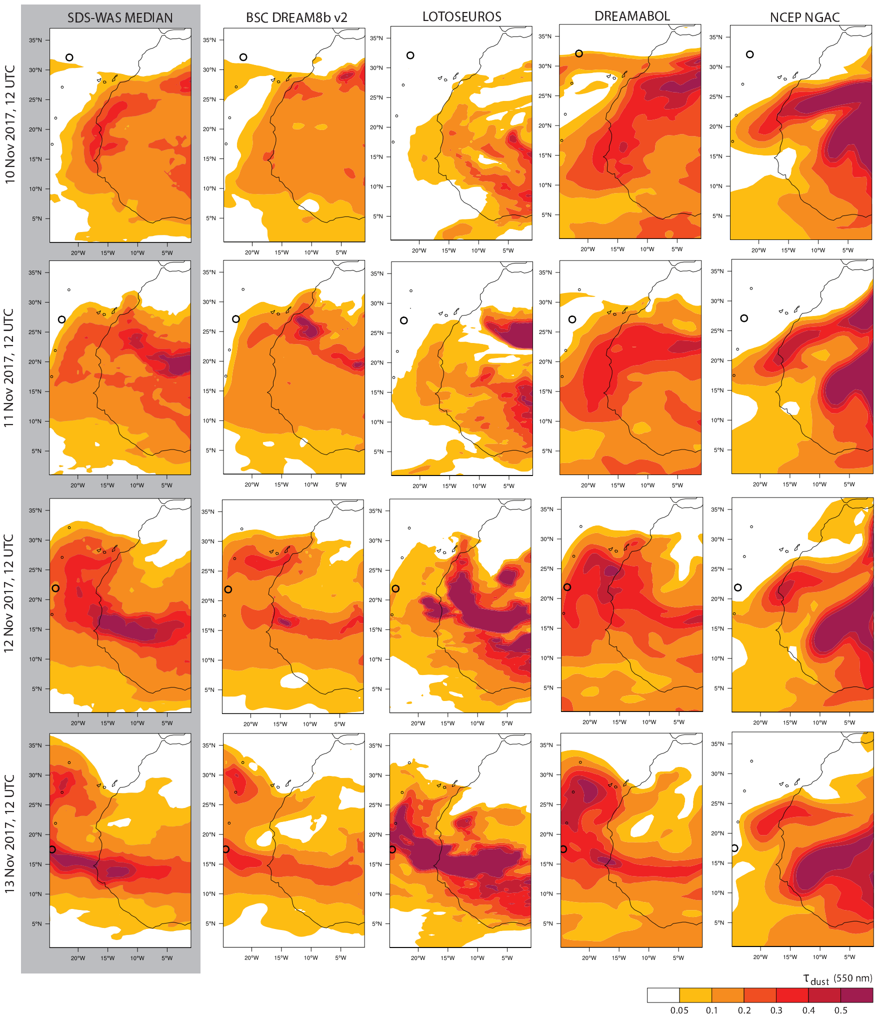

Figure 18: *Comparison of WMO SDS-WAS forecasts. Shown are the dust aerosol optical depth at 550 nm of the model median and a few individual models participating in the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) of the World Meterological Organization (WMO) as 12-hour forecasts for midday of 10–13 November 2017.*

selected models show dust aerosol τ on mid-day, but the magnitudes substantially differ.

3.4 OUTLOOK

To better understand the reasons for the model diversity for the synoptic-scale dust storm, we perform high-resolution model simulations for resolving more of the processes embedded in the dust storm. This is a joint work with Michael L. Kaplan and Saroj Dhital at the Desert Research Institute in Nevada, USA, who perform high-resolution simulations with WRF-Chem. The measurements during MSM 68/2 will be used for evaluating the model performance.

4 REMOTE SENSING OF CLOUD COVER AND BASE HEIGHT

S. Fiedler, F. Jansen, J. Mrziglod, and S. Kinne

4.1 OBJECTIVES

The main goal of the expedition was the field test and preparation for the automated operation of the new cloud imager 'Pinocchio' aboard the research vessel for 2017–2019. The instrument is shown in Figure 19. It was build at MPI-M for recording visible and infrared images of clouds. Such measurements are made for deriving cloud fraction and base height with the vision for a marine cloud statistic from ship-based observations. The development of the marine cloud statistics (MCloudS) is an initiative that is currently funded by the MPI-M as a basis for a larger funding proposal in the future.

Following a previous test deployment aboard the RV POLARSTERN in 2016 (Fiedler, Kinne, and Jansen, 2017), we have identified shortcomings of the settings of the fairly simple thermal camera of 'Pinocchio'. These included a too large file size of the images for long data recording and the automated adaptation of the colour bar for making quantitative assessments. As a consequence, the settings were changed for reducing the data volume and fixing the temperature range. For the latter, the instrument had undergone calibration in the laboratory of the UHH with a black body and a calibrated infrared thermometer. Moreover, the software for the handling and post-processing of the large amount of data has been strongly improved.

Figure 19: *'Pinocchio' imager during MSM 68/2. Shown are photos of the instrument from different directions.*

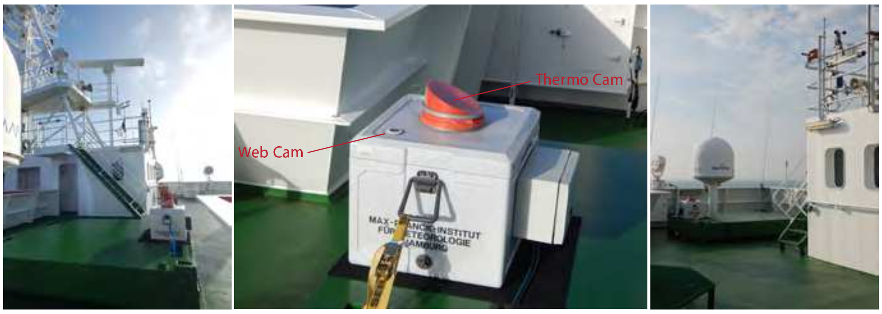

Figure 20: *'Dumbo' imager during MSM 68/2. Shown are photos of the instrument from different directions. The position of the infrared (Thermo Cam) and visible camera (Web Cam) of the system are indicated.*

The functionality of different independently developed codes for post-processing the imager's data and monitoring the measurements have been merged into one software package. The python software package can optionally use more than a single processor for speeding up the image processing and is object-orientated such that it is easily extendible by further functions in the future.

The operation of 'Pinocchio' during the expedition MSM 68/2 aboard RV MARIA S. MERIAN has the following objectives:

- Prepare and test the operation of 'Pinocchio' and the ceilometer for the automated measurements aboard.
- Test and develop the software for the data management and post-processing of the data of 'Pinocchio'.
- Collect reference data for validating 'Pinocchio' and preparing the development of a processing technique for the cloud-base height.

To achieve these objectives, 'Pinocchio' is operated along with the less-flexible, but more precise imager 'Dumbo' for cross-validating the data. Since we intend to derive the cloud-base height from the infrared images, we also operate a ceilometer that determines the cloud-base height with a good precision. In the following, we describe the instruments and the work during the expedition. We further show first analyses of the continuous measurements and outline the next steps for the MCloudS project as a whole.

4.2 WORK AT SEA AND FIRST ANALYSIS

4.2.1 *Cloud lab*

Our cloud lab consists of three instruments that enable observations of cloud cover and base height. Our work on board included the supervision, data management, and control of the instruments. Note,

Figure 21: *Inside view of cloud lab during MSM 68/2. Shown is a photo of the laptops recording the measurements of the (left) ceilometer and (right) 'Pinocchio'.*

however, that the lenses of 'Pinocchio' and the ceilometer were not checked daily during the cruise since reaching them was to risky in the rough sea-state during many days, but the subsequent inspection did not indicate any deposits from sea spray. The control of the data recording and copying was carried out daily inside of the observation room on the pile deck, shown in Fig. 21. The most time consuming daily maintenance was for the 'Dumbo' imager (Fig. 20). The routine for 'Dumbo' measurements included the replacement of the protecting foil as well as copying, post-processing, and restart of the measurements.

4.2.1.1 *Cloud imagers 'Dumbo' and 'Pinocchio'*

The two MPI-M cloud imager systems, 'Dumbo' (Fig. 20) and 'Pinocchio' (Fig. 19), are operated for deriving transects of cloud fraction and type along the ship track. Both systems consist of one camera for visible and one for infra-red light. Both camera types complement each other, because the thermal camera sampling needs to be intermittent around noon to avoid that direct sun-light deteriorates the thermal images and the functionality of the instrument detector of Dumbo. During that time the visible camera is the only measurement. The visible camera, however, is only useful during daytime such that the infra-red images are the sole data source at night. The simultaneous measurements during the morning and afternoon are useful for comparing and calibrating the results of 'Pinocchio' and 'Dumbo'. The larger and more complex system 'Dumbo' has a more advanced infra-red imager and needs more maintenance than the small, lightweight and flexible system 'Pinocchio'. The field of view of the imagers is about 35 degree, except the fisheye for the visible image of Pinocchio. This enables a record of spatial information of cloud scenes that is not possible with the narrow light beam of the ceilometer. An example for images of 'Pinocchio' are shown in Figure 22.

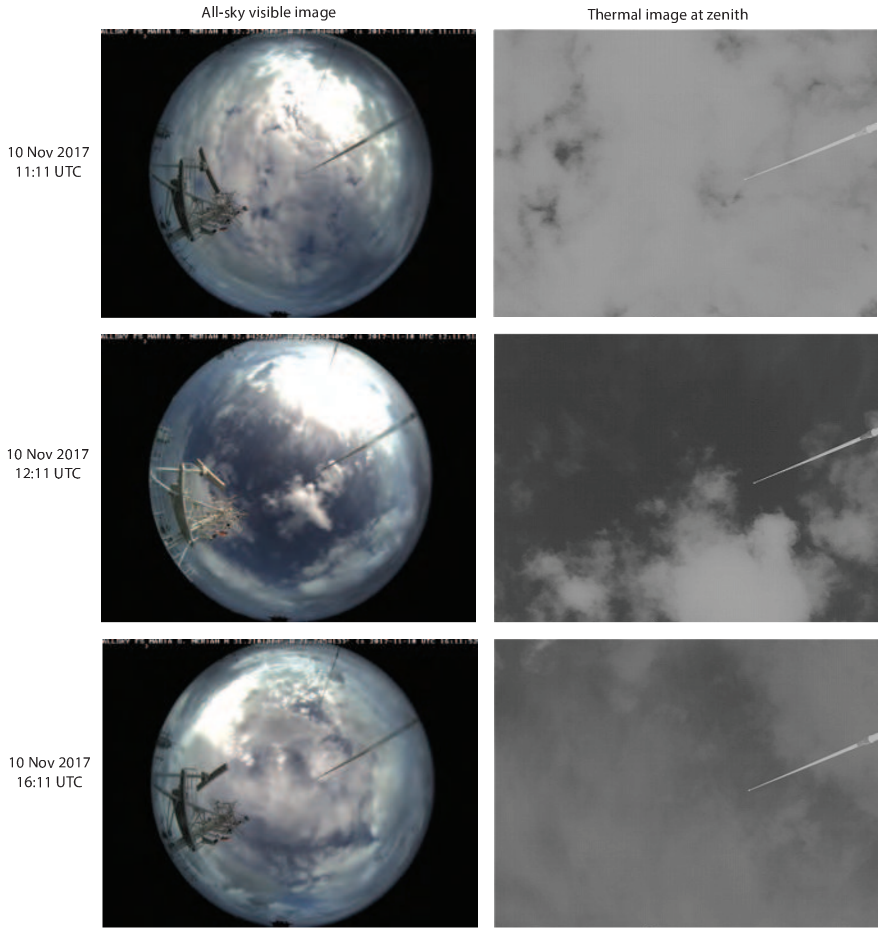

Figure 22: *Pinocchio's images on 10 November 2017. Shown are the all-sky images in the visible and the narrow view at the zenith from the thermal camera of Pinocchio.*

Figure 23: *Ceilometer during MSM 68/2. Shown are photos of the instrument from different angles.*

4.2.1.2 *Ceilometer*

The Jenoptik ceilometer of the MPI-M is operated for obtaining a reference dataset for the presence of clouds and their base height. It contains a system that vertically emits laser pulses at a non-visible near-infrared wavelength (1064 nm) and detects the range-resolved backscattered signal from the atmosphere with a telescope. The atmospheric transmission of this wavelength is not influenced by significant atmospheric trace-gas absorption such that the presence of other atmospheric components can be derived from the backscattered signal. Based on the time delay and strength of the backscattered signal the instrument measures an atmospheric profile of aerosol and clouds. Since the laser light is strongly attenuated in optically thicker clouds, usually no information is retrieved above the cloud base such that the data is primarily useful for information on the cloud-base height and frequency of cloud passage. In cloud-free conditions and below clouds, the aerosol backscatter profile is measured that might indicate the boundary layer depth, primarily in the presence of aerosol species of large size like mineral dust, e.g. on 13 November 2017 (Figure 24). The measurements below 500 m are not useful due to the instrument characteristics, but will be complemented by MAX-DOAS and MICROTOPS measurements (Chapter 5 and 6).

4.2.2 *MCloudS software*

The software package for MCloudS is well advanced. It is currently semi-automated with flexible handling of the image post-processing, retrieval and graphical display. It has a component for Pinocchio, Dumbo, the ceilometer, and the meteorological data collected by DSHIP. The entire package is written in python and is executebale with a namelist. The software package is documented in the appendix of the report.

Figure 25 shows the overview of the cloud lab data from MSM 68/2 as produced with the software package. The retrieval is working in

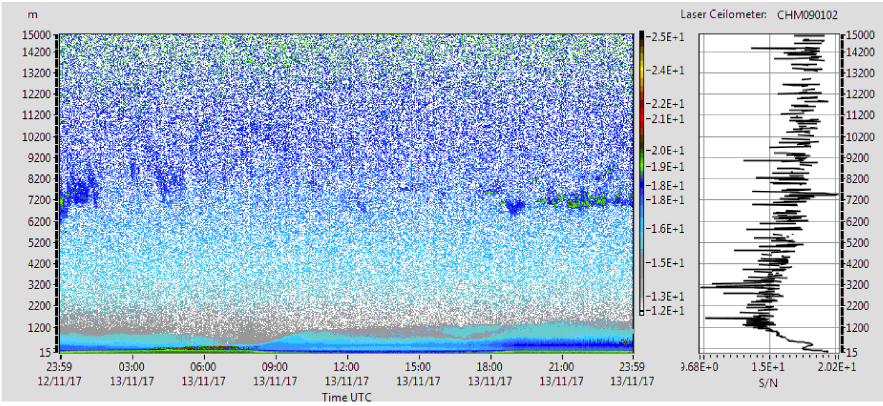

Figure 24: *Ceilometer measurement on 13 November 2013. Shown are (left) the profile of the backscatter signal as function of time and (right) the signal-to-noise ratio.*

Figure 25: *Overview from MCloudS software. Shown are the time series of the preliminary cloud fraction retrievals per height layer from the imagers 'Pinocchio' and 'Dumbo', the backscatter heights indicating the cloud base from the Ceilometer, and measurements from the onboard meteorological instruments of the vessel, i.e., sea and air temperatures, air pressure and relative humidity, for the entire expedition MSM 68/2. All values are hourly means excluding missing data.*

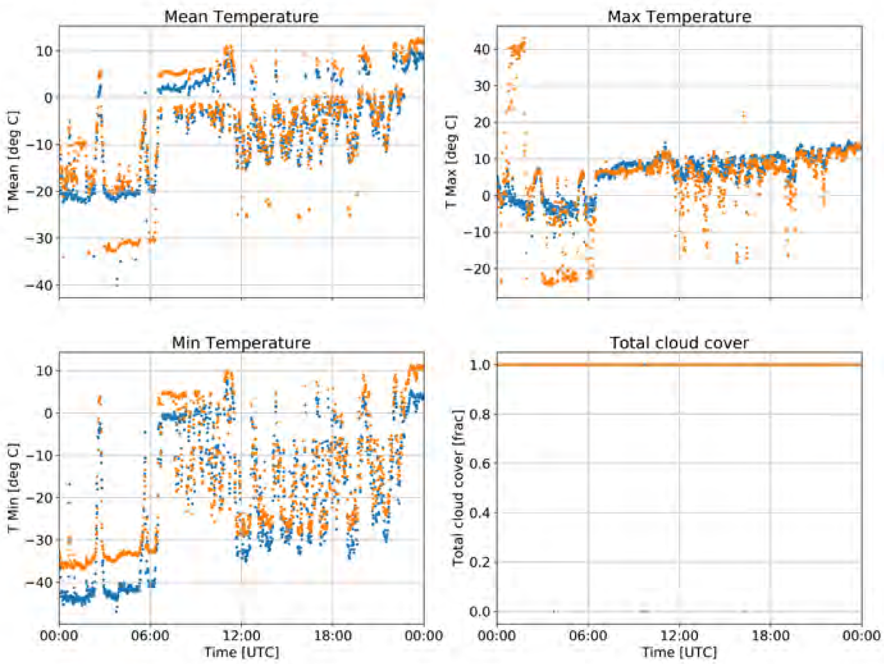

Figure 26: *Cloud imager comparison on 6 Nov 2017. Shown are the mean, maximum and minimum temperatures as well as the total cloud cover retrieval from the images of (blue) 'Pinocchio' and (orange) 'Dumbo' on the day.*

terms of deriving cloud fractions for different heights. Both imagers herein perform similarly well in hourly averages. We separate between low, middle, and high clouds for the cloud cover by specifying typical height ranges in the code. These are currently static with a fixed lapse rate for approximating the height above ship level with the on-board temperature measurement, displayed at the top.

4.2.3 *Cross-validation*

We compare shorter measurement sequences from both imagers against each other, using the MCloudS software (Figure 26-28). The temperatures are in good agreement, although 'Pinocchio' has a systematic offset of several Kelvin in the minimum and mean temperature of many images. The maximum temperatures from the imagers, however, are in better agreement for most cases. This is encouraging since the maximum temperatures are used for deriving the cloud-base height and the cloud cover.

The retrieval of the cloud cover and base height needs to be refined in the future. At the moment, the cloud cover is overestimated with a too frequent cloud cover of 100%. For improving the retrieval, the background temperature needs a better characterisation. For this purpose, the vertical soundings and meteorological records at near-surface level (Section 3) will be further explored and used in a future

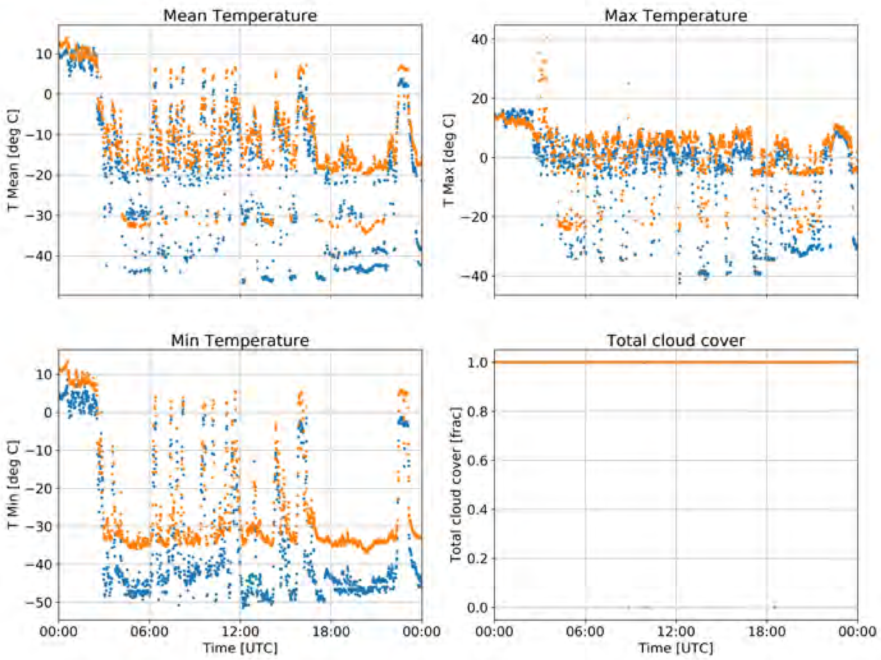

Figure 27: *Cloud imager comparison on 7 Nov 2017. As Figure 26.*

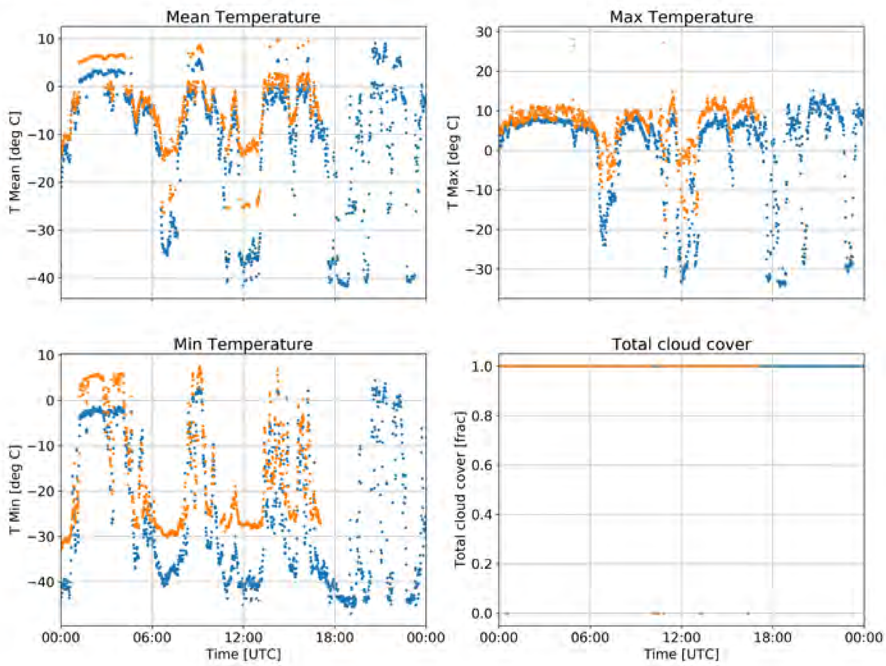

Figure 28: *Cloud imager comparison on 8 Nov 2017. As Figure 26.*

retrieval. A way for validating the retrievals, is the usage of the visible images during the morning and afternoon as reference. In these cases, the blue sky is distinct from the bright clouds around the zenith and easy for calibrating the retrieval of the cloud cover from the thermal images.

4.3 OUTLOOK

In the future, the intent is to deploy 'Pinocchios' on several research vessels for automated operations. As such the one-year deployment on board of RV MARIA S. MERIAN is a pilot phase of the longer-term plans for developing a marine cloud statistic (MCloudS). It is planned to further develop the software for MCloudS and obtain external project funding for the initiative for establishing a first network with a small number of instruments within the next five years. Subject to the success of these plans, we envision to further extend the MCloudS measurement network by involving more research vessels, e.g., in synergy with the OceanRAIN network led by Christian Klepp at UHH. Given the joint marine cloud and rain observations, MCloudS and OceanRAIN would complement each other.

5 SUN-PHOTOMETER MEASUREMENTS FOR THE MARITIME AEROSOL NETWORK

S. Fiedler, S. Terzenbach, S. Kinne, B. Holben[1], and A. Smirnov[1]

5.1 OBJECTIVES

The aim of MSM 68/2 is to measure reference data over oceans where the ground-based observation network is typically sparse. A key objective is the observation of the aerosol optical depth and water vapour with the hand-held sun-photometer MICROTOPS, provided by NASA. Our measurements are a contribution to their Maritime Aerosol Network (MAN, e.g., Smirnov et al., 2009) as part of the Aerosol Robotic Network (AERONET, e.g., Holben et al., 1998). Such data is important and in use for different scientific purposes ranging from compiling climatologies (e.g., Kinne, submitted) and the associated representation of aerosol optical properties in climate model simulations (e.g., Fiedler, Stevens, and Mauritsen, 2017; Giorgetta et al., 2018; Stevens et al., 2017) to validating aerosol in both complex aerosol-climate models and satellite retrievals (e.g., Johnson et al., 2011; Lacagnina et al., 2015; Smirnov et al., 2017).

5.2 WORK AT SEA AND FIRST ANALYSIS

5.2.1 *MICROTOPS sun-photometer*

The hand-held MICROTOPS sun-photometer measures the direct solar attenuation during cloud-free conditions that allow deriving information on the aerosol optical depth, aerosol size and water vapour content for the atmospheric path between the observer and the sun. The instrument works as follows. The top of the atmosphere incoming solar radiation is internally calculated from the location and time of the simultaneously operating GPS unit. The difference between the incoming solar radiation at the top of the atmosphere and the instrument on the ship determines the atmospheric attenuation of the solar radiation. The solar attenuation is measured at five wavelengths (380, 440, 675, 870 and 940 nm) that are differently affected by aerosol and trace gases. Those measurements in wavelengths that are weakly affected by trace gases (380, 440, 675 and 870 nm) are used to derive the aerosol optical depth (τ). The τ values at different wavelengths are used to diagnose the Angstrom parameter, the value of which

1 NASA/Goddard Space Flight Center Greenbelt, USA

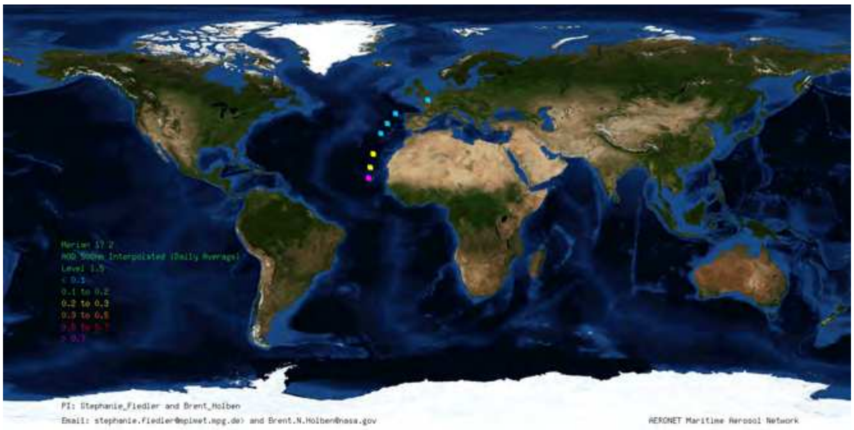

Figure 29: *Daily mean aerosol optical depth. Shown are the aerosol optical depth at 500 nm from the level 1.5 product with the measurements with the sun-photometer MICROTOPS for the AERONET's Maritime Aerosol Network (MAN) of NASA.*

is an indicator for the aerosol size and can be used to interpolate the measurements to different wavelengths, e.g., here 500 nm. In addition to τ, the atmospheric water vapour content is determined by using the measurement at 940 nm, characterized by strong water vapour absorption, and at 870 nm, which is not sensitive to the presence of water vapour.

Whenever the sun shines, we manually point the instrument directly to the sun. We take sequences of ten measurements with breaks of two minutes in between. The data are daily downloaded from the instrument and send to NASA from the vessel. After the submitted data has passed quality checks, it is made accessible via the online database of MAN. This process is typically completed within a few days.

5.2.2 *Cruise transect of aerosol optical depth*

The daily averaged τ at 500 nm continuously increased during the expedition ranging from less than 0.1 near Europe to more than 0.7 offshore West Africa, shown in Figure 29. We have measured primarily coarse mode aerosol. During the first days the coarse mode fraction of $40 - 80\%$ is indicative for the presence of sea spray aerosol that is characteristic for the natural marine background aerosol burden. In the North Sea the coarse mode fraction was herein lower than in the North Atlantic, possibly associated with the mixing of sea spray with anthropogenic aerosol although the low τ might not allow a robust

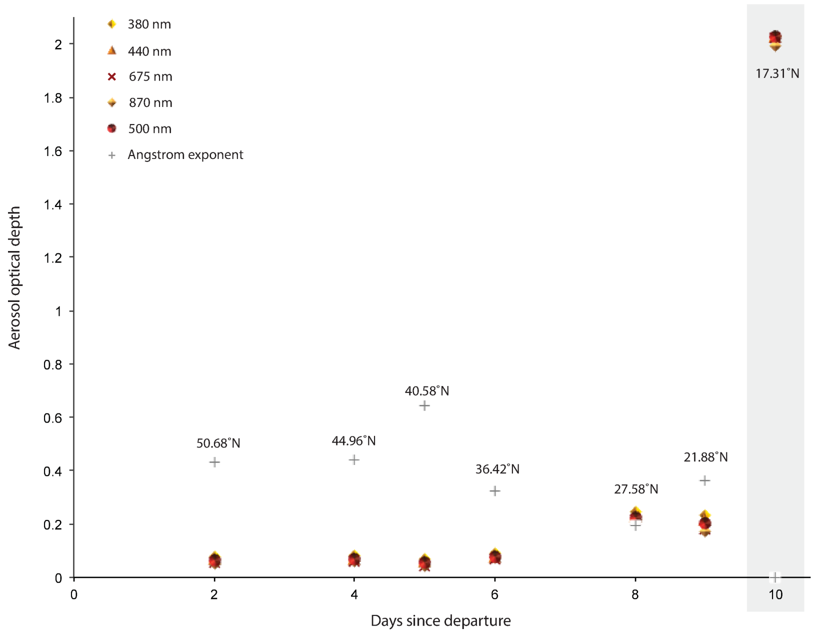

Figure 30: *Daily mean aerosol optical properties. Shown are the aerosol optical depth at different wavelengths and the Angstrom exponent from the measurements with the sun-photometer MICROTOPS for the Maritime Aerosol Network (MAN) of NASA. All data is from the level 2 product, but the grey-shaded level 1.5 data is shown for 13 November 2017.*

retrieval of the coarse-mode fraction during that time (compare Fig. 29).

Towards the end of the expedition, we sampled North African air with desert-dust aerosol associated with a continental-scale storm (Section 3.3). During that time, the aerosol mixture was clearly dominated by coarse particles with a coarse-mode fraction exceeding 60% (Figure 31). The vertical profile from the MAX-DOAS retrieval indicates that the dust-aerosol layer extends from the surface to a maximum depth of 4 km, but is constrained to the lowest 2 km during most of 12 November 2017 (Chapter 6). The low-level aerosol layer is in agreement with the ceilometer backscatter signal from the boundary layer (Section 4.2.1.2) and the observed dust deposition on deck.

On the last day of the cruise, we have measured the strongest burden of mineral dust aerosol from the North African storm. MICROTOPS yielded a daily mean around $\tau = 2$ in the level 1.5 product (Figure 30). The measurements on 13 November 2018 are likely overestimated. This is caused by the presence of high clouds, e.g., visible in the satellite image of the day (Figure 34) and the ceilometer backscatter during parts of the day (Figure 24). These clouds have been difficult to identify by eye while being on the vessel due to a low contrast between the aerosol layer and the high clouds. Figure

Figure 31: *Daily mean coarse-mode aerosol optical depth. Shown are the coarse-mode aerosol optical depth at* 500 *nm from the level 2 product of the measurements with the sun-photometer MICROTOPS for the AERONET's Maritime Aerosol Network (MAN) of NASA.*

Figure 32: *Visibility inside the dust layer. Shown are photos illustrating the dust-aerosol layer seen by eye on 13 November 2017.*

32 and 33 give an impression of the visibility in the dust storm with fairly good conditions for a cloud-free path for the measurements in the morning.

Due to the difficulty of identifying such thin clouds, the variability in τ measurements from the sequences on 13 November 2018 is much larger than on the other days of the expedition (Figure 35). Particularly, the measurement sequences with high τ are likely affected by clouds. We therefore assume that the optical depth measurements are biased high and choose the sequences with the lowest τ as a more likely representation of the aerosol layer. A value of $\tau = 1.5$ seems therefore more likely on 13 November 2017. Note that the data of that day has been completely removed in the level 2 product of MAN due to the likelihood of cloud contamination.

5.2.3 *Cruise transect of water vapour*

The cruise transect of water vapour in the atmospheric path of the MICROTOPS measurements reflects the typical behaviour one would expect from the weather situation. At the beginning of the expedition in Europe, we measured a water vapour content of 1 cm water, shown in Figure 36. As we travelled towards the south, the air tem-

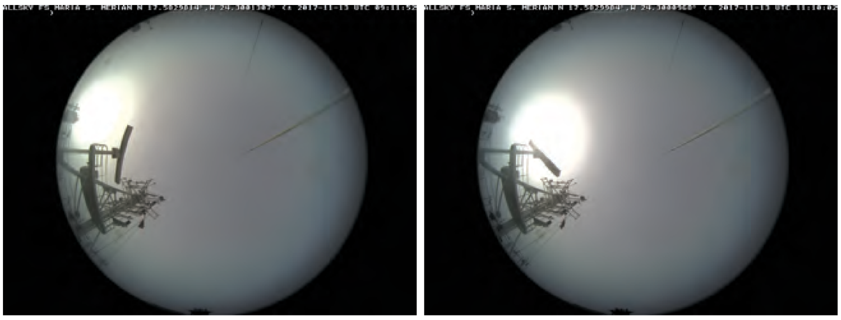

Figure 33: *'Pinocchio' images inside the dust layer. Shown are the all-sky visible images of 'Pinocchio' on 13 November 2017 for (left) 09:11 UTC and (right) 11:10 UTC.*

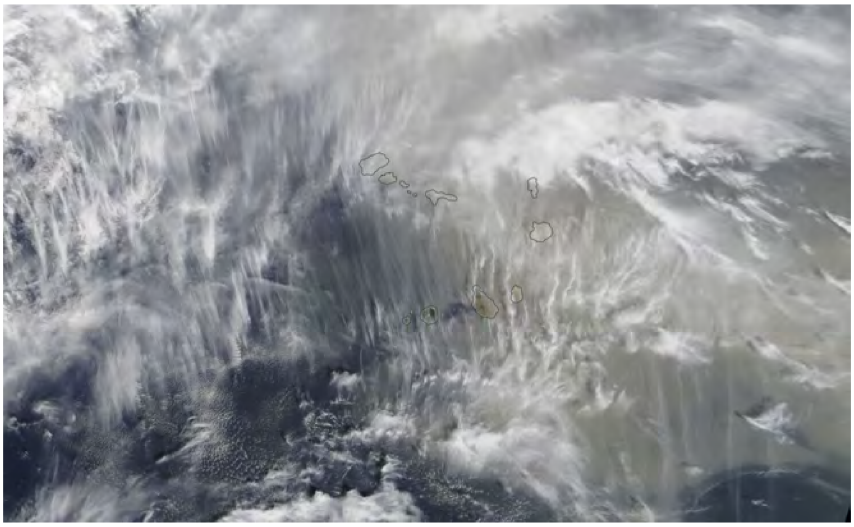

Figure 34: *Satellite view on 13 November 2017. Shown is the visible image from the MODIS combined visible product (NASA Worldview).*

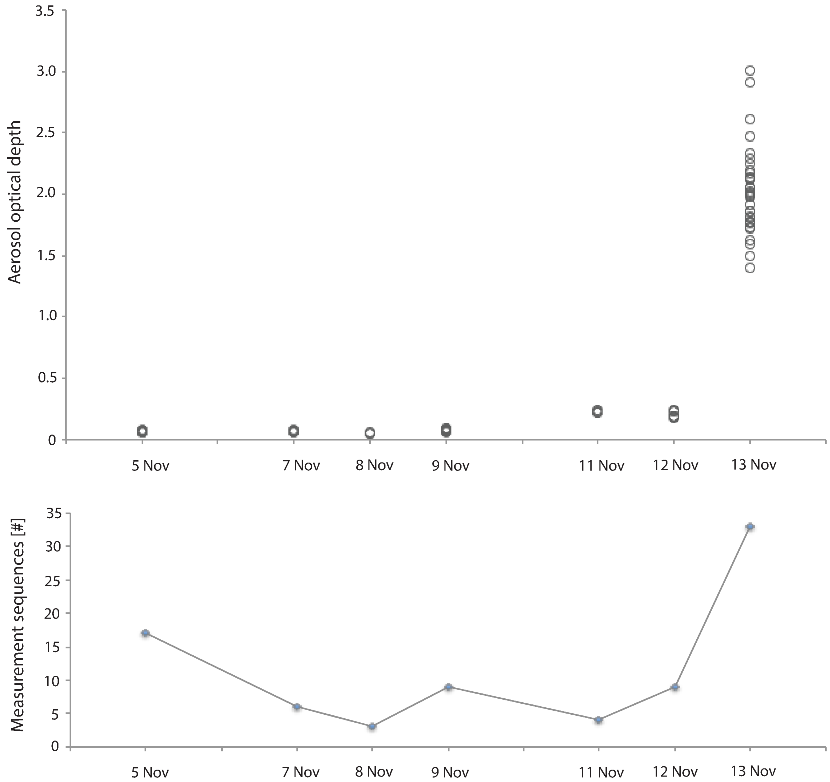

Figure 35: *Aerosol optical depth at 500 nm. Shown are (top) the aerosol optical depth at 500 nm averaged per measurement sequence and (bottom) the number of measurement sequences from the measurements with the sun-photometer MICROTOPS for the Maritime Aerosol Network (MAN) of NASA. All data is here from the level 1.5 product. The number of measurement sequences per day are shown*

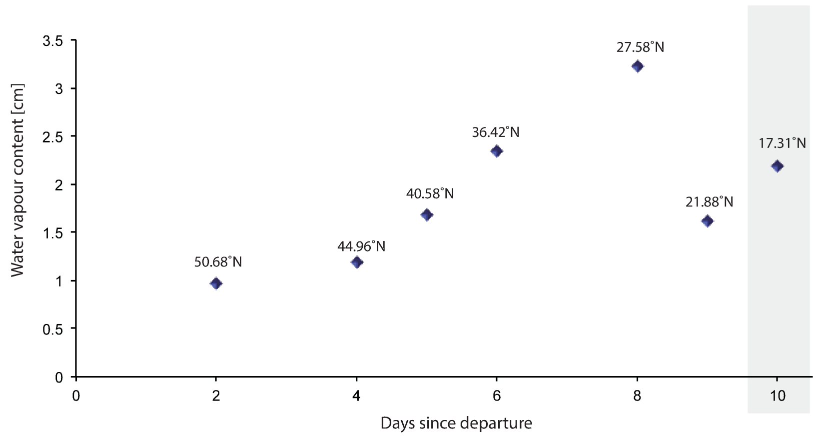

Figure 36: *Daily mean water vapour content. Shown is the water vapour path from the measurements with the sun-photometer MICROTOPS for the Maritime Aerosol Network (MAN) of NASA. All data is from the level 2 product, but the grey-shaded level 1.5 data is shown for 13 November 2017.*

perature increased and, based on the associated ability of the air to contain more water vapour, the vapour content increased to a maximum of 3.4 cm eight days later around 27°N. The subsequently occurring steep decrease of the water vapour content is associated with the comparably dry air mass from North Africa that also advected the desert-dust aerosol.

5.3 OUTLOOK

The MICROTOPS measurements from MSM 68/2 are quality controlled and available online (https://aeronet.gsfc.nasa.gov). These data will be useful for various applications. For instance, the expedition participants plan to use the MICROTOPS measurements for validating the MAX-DOAS retrieval (Chapter 6) and for studying the observed dust storm in more detail involving process modelling (Chapter 3).

6 MAX-DOAS MEASUREMENTS OF THE ATMOSPHERIC COMPOSITION

S. Donner[1], S. Dörner[1] and T. Wagner[1]

6.1 OBJECTIVES

Differential Optical Absorption Spectroscopy (DOAS) measurements make use of the narrow band absorption features of atmospheric trace gases in spectra of scattered sunlight (Platt and Stutz, 2008). These absorptions are unique for the individual trace gases and therefore allow to identify multiple species with only one instrument. Further, Multi-Axis (MAX)-DOAS instruments measure spectra of scattered sunlight at different (mainly very low) elevation angles (Hönninger, Friedeburg, and Platt, 2004). From these measurements also height profiles of atmospheric trace gases (e.g. NO_2, HCHO, CHOCHO, O_4, SO_2, BrO, IO) and aerosol extinction in the lowest 2 km to 4 km of the atmosphere can be derived (Wagner et al., 2011). MAX-DOAS measurements have the highest sensitivity close to the ground, where the atmospheric light paths can become very long (up to 20 km).

The main focus of the MAX-DOAS measurements during this cruise is the retrieval of aerosol extinction profiles which is based on the measurement of the oxygen dimer O_4. The derived aerosol extinction profiles have a rather coarse vertical resolution (with about 2 to 3 independent pieces of information), but are most accurate close to the surface, where LIDAR systems are typically almost blind. The retrieved profiles will be compared (and possibly combined) with the simultaneous LIDAR and sun photometer observations. Besides aerosol profiles, also trace gases (in particular NO_2, H_2O and BrO) will be analysed from the measured MAX-DOAS spectra. These species help to characterise the chemical composition of the atmosphere and provide important input for global modeling and comparisons to satellite data.

6.2 WORK AT SEA AND FIRST ANALYSIS

During the MARIA S. MERIAN cruise (MSM 68/2) from Emden, Germany to Mindelo, Cape Verde we operated a MAX-DOAS instrument, together with a GPS position tracker. For details on the measurement setup see section 6.2.1. While being aboard the ship, the main task was to maintain the instrument (cleaning of the optical system, check-

1 Max Planck Institute for Chemistry, Mainz, Germany

ing the angle stability etc.) and perform first analyses in order to see whether the instrument is running stably. Figure 37 gives an overview on the data availability. Here, the ship's track is displayed by a red line while the DOAS data points are represented by yellow and green dots. The green dots indicate measurements which fulfill some basic quality criteria, whereas yellow dots indicate measurements for which these criteria are not fulfilled, e.g. due to the presence of clouds or too high solar zenith angles. During night time no passive DOAS measurements are possible which explains the large data gaps.

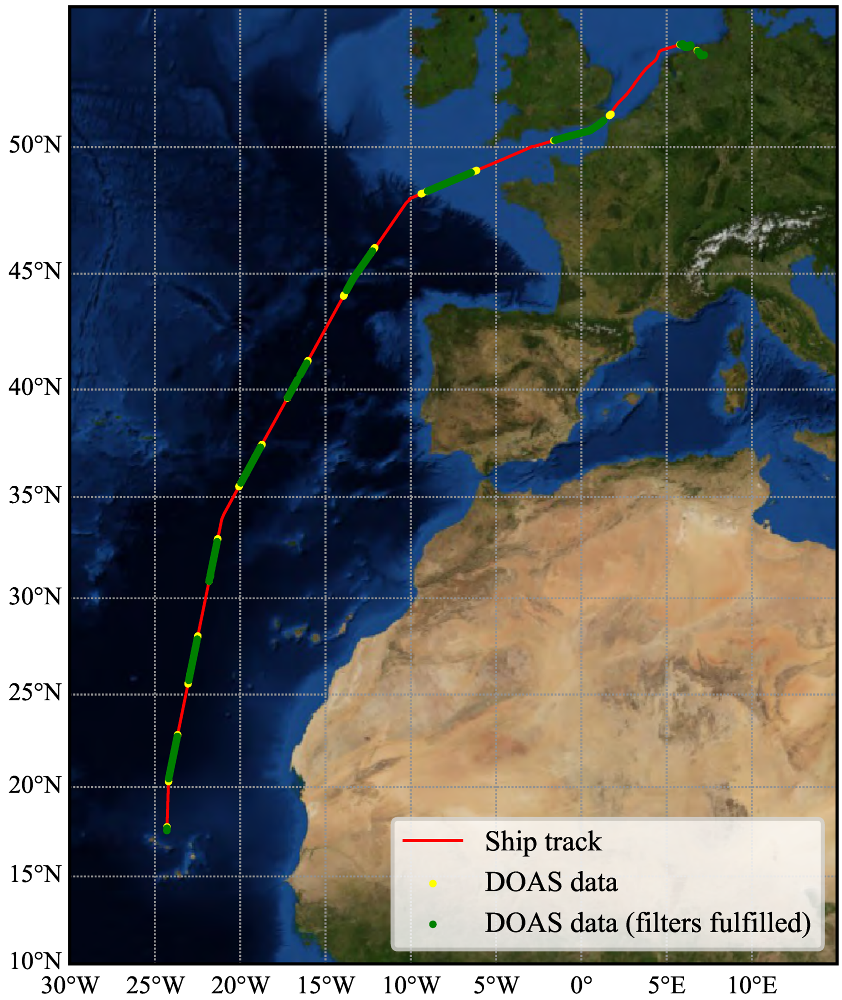

Figure 37: *Overview on the MAX-DOAS data availability. The green and yellow dots indicate valid and invalid data points, respectively.*

In the following sections first the instrumental setup is explained in more detail. Then the analysis procedure is shown followed by first preliminary results, where also first profiles for the aerosol extinction are shown.

6.2.1 *MAX-DOAS instrument*

The used MAX-DOAS system was the so-called TubeMAX-DOAS instrument which was developed and built together with the electronic workshop of the Max Planck Institute for Chemistry in Mainz. In the current setup it consists of two major parts. One contains the telescope unit and was mounted on the railing of the ship. The other part was located inside an observation room and consists of the spectrometer with a cooling unit.

The telescope unit (displayed in Figure 38) contains the telescope which is moved by a motor inside a plastic tube and collects the scattered sunlight at different elevation angles which is then transmitted via a glass fibre bundle to the spectrometer inside the observation room. Since the instrument was mounted on a moving system the telescope unit is equipped with a stabilisation sensor in order to stabilise the elevation angles by continuously adjusting the motor position according to the ship's movement.

Figure 38: *Telescope unit of the MAX-DOAS system mounted aboard MARIA S. MERIAN.*

As mentioned above the spectrometer was located inside and connected to the telescope via a glass fibre bundle. The spectrometer records the spectra of scattered sunlight. It is temperature stabilised by a Peltier element which is mounted on the spectrometer housing in order to keep the optical properties of the system constant and to reduce the effect of background noise.

In order to control the Peltier element and the motor a controlling system developed by the electronics workshop of the Max Planck Institute for Chemistry is used. This system basically sets and reads out the parameters of the different instrument parts and sends them to a laptop which controls the whole setup.

6.2.2 *Analysis procedure and settings*

The recorded spectra are first corrected for background intensities, namely offset and dark current. An example for a measured and background corrected spectrum can be found in Fig. 39.

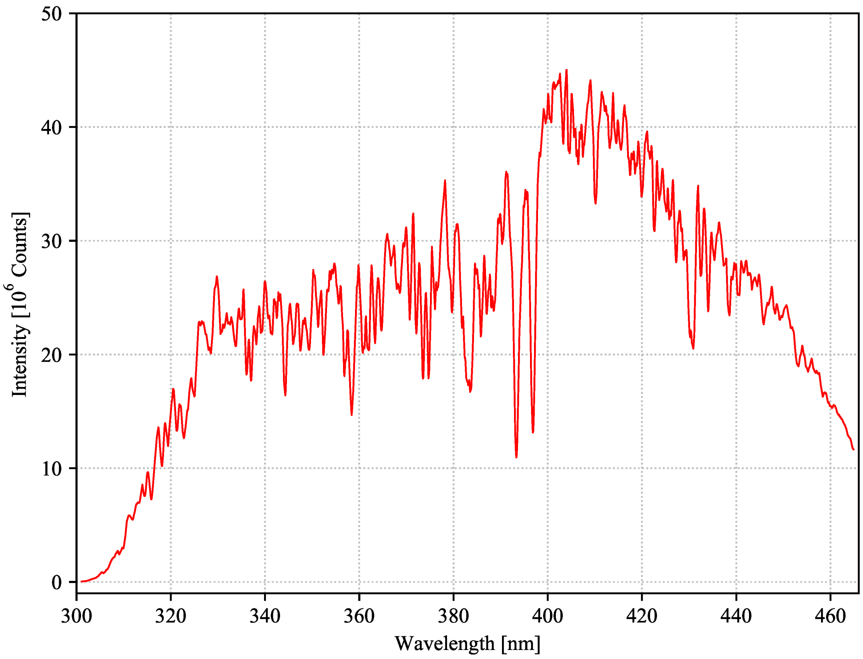

Figure 39: *Example for a measured spectrum. Shown is the spectrum at 5° elevation on 11th November 2017 at 13:16 UTC.*

Atmospheric differential Slant Column Densities (dSCDs) are retrieved using the DOAS principle (for details see Platt and Stutz, 2008). For that, reference absorption spectra are fitted in trace gas specific wavelength ranges to the measured spectra. Before, the spectra are divided by a so-called Fraunhofer reference spectrum (FRS) in order to remove the strong Fraunhofer absorption lines.

As mentioned above the main focus of the measurements during this campaign is the retrieval of aerosol extinction profiles which is based on the measurement of the oxygen dimer O_4. The retrieval settings and a fit example showing a strong O_4 absorption are displayed in Table 3 and Figure 40, respectively. Further, for the retrieval of the aerosol profiles a O_4 scaling factor of 0.8 was used (Wagner et al., 2018). Lastly, it should be mentioned that for the retrieval of these profiles clear sky conditions are needed which were rather rare during the cruise.

Fit interval	338 nm – 370 nm
Fitted cross-sections	NO_2 (298 K), NO_2 (220 K), O_3 (223 K), O_3 (243 K), O_4, HCHO, BrO, Ring and wavelength dependent Ring
Reference	sequential FRS interpolated to measurement time
Polynomial	5th order
Intensity offset	Constant and 1st order
Others	Spectra are allowed to be stretched and shifted

Table 3: *Fit settings for the O_4 fit which is needed to retrieve aerosol information from the MAX-DOAS measurements.*

Finally, profiles of the aerosol extinction and trace gas concentrations are retrieved using the obtained trace gas dSCDs and applying the MAinz Profile Algorithm (MAPA, for a detailed description see Beirle et al., 2018). The MAPA profiles are parametrised by three parameters, namely profile shape, layer height and vertical column density (VCD) which is defined as the integrated trace gas column in units of molecules/cm². In the aerosol case the VCD corresponds to the desired quantity, namely the aerosol optical depth (τ) which is the integral of the aerosol extinction.

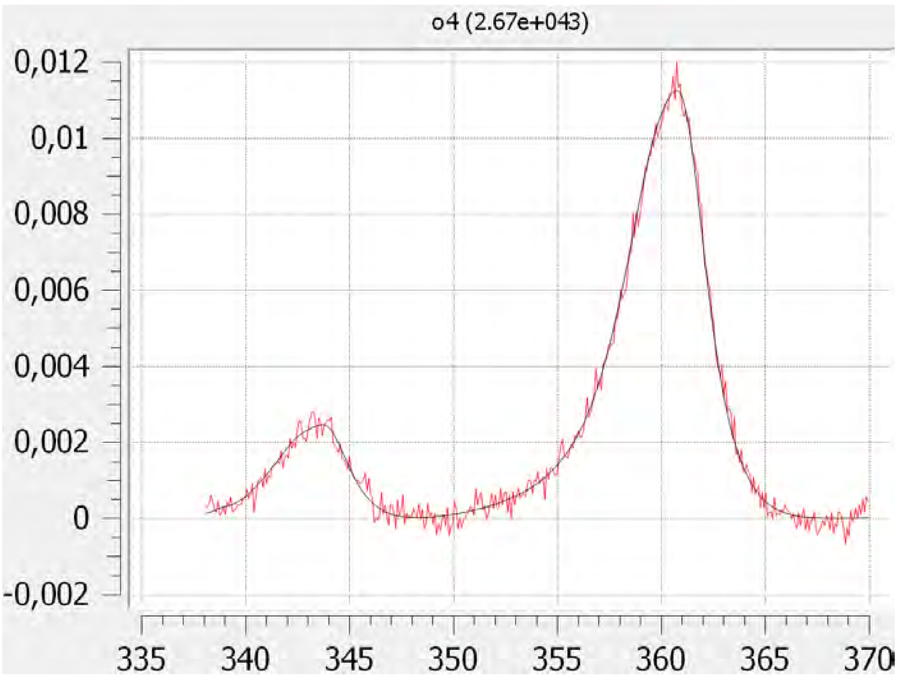

Figure 40: *O_4 fit example for a spectrum which was measured at 5° elevation on 11th November 2017 at 13:16 UTC.*

6.2.3 *Cruise transect of aerosol extinction*

The MAPA profile output is flagged based on quality criteria which identify invalid profiles. In the following only valid (unflagged) results are shown.

Figure 41 shows a time series of the obtained τ throughout the cruise. Despite the flagging of the profile retrieval output, there is still a lot of scatter and days with only few data points. This indicates that there are still some unflagged bad profiles which might be cloud contaminated and are not flagged by the MAPA algorithm. Nevertheless, on the 5th, 12th and 13th November 2017 the τ values are reasonable and less noisy. While the τ measured on the 5th have values from around 0.04 to 0.09 indicating a very low aerosol load, they are much higher on 12th and 13th with τ ranging from 0.1 to 0.6 indicating a high aerosol contamination.

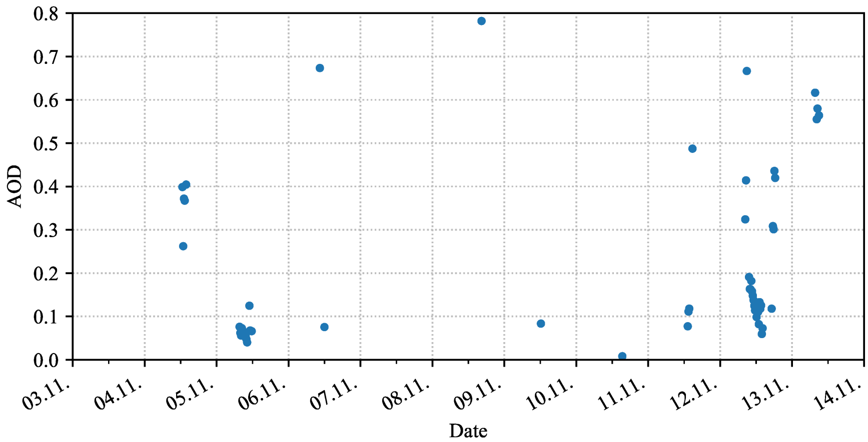

Figure 41: *Time series of all valid* τ *at* 360 nm *obtained during the cruise.*

Figure 42 depicts the same τ values on a map. Clearly visible are the very low τ on the 5th November, when the ship crossed the English Channel and the high τ on 12th and 13th November, when the ship was located west of the African shore. As explained elsewhere (Chapter 3) on these days the ship crossed an area which was dominated by a dust storm that reached from the African continent to the Atlantic Ocean which explains the rather high τ. Also the sun-photometer measurements showed enhanced τ on these two days (Chapter 5).

The profiles for the 5th (clean period in the English Channel) and the 12th November (entering the dust storm area) are depicted in Figures 43 and 44, respectively. Here, the upper panels show the individual profiles of the aerosol extinction (colour coded), while the lower panels show the corresponding τ values, both are plotted against the universal time (UTC). It should be noted that on the 5th at around 14:45 UTC an unrealistic profile is visible which is also most likely cloud contaminated. However, in the morning of that day the low

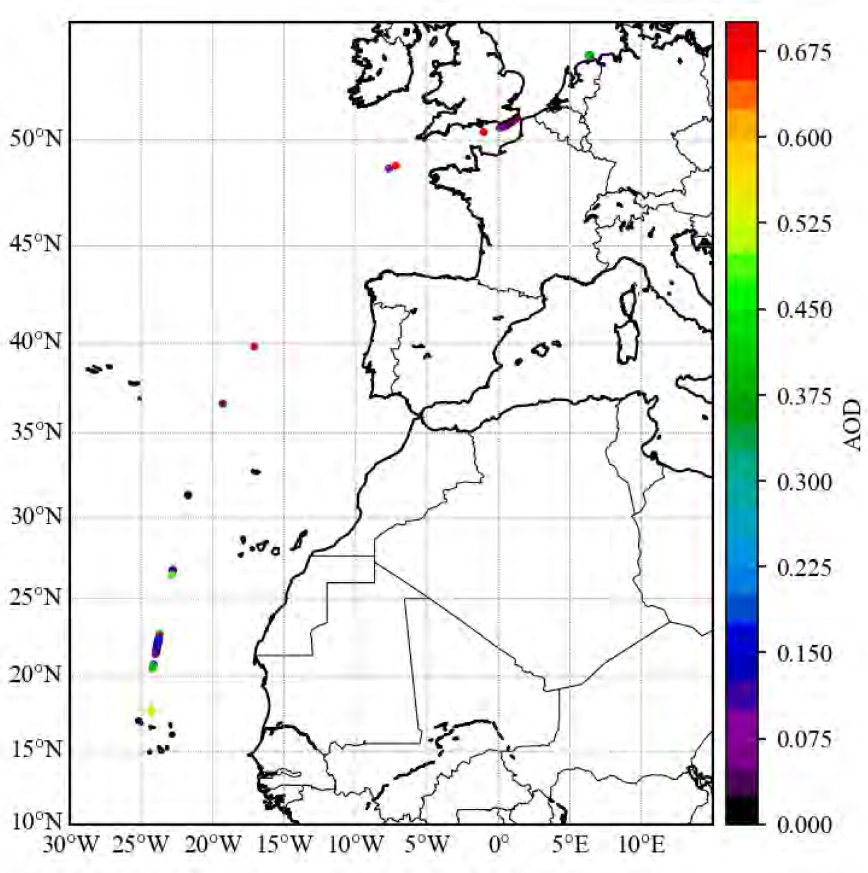

Figure 42: *All valid* τ *at* 360 nm *obtained during the cruise plotted on a map.*

τ and the corresponding low aerosol extinctions can be seen. Further, the aerosol is located within the marine boundary layer (below 1000 m).

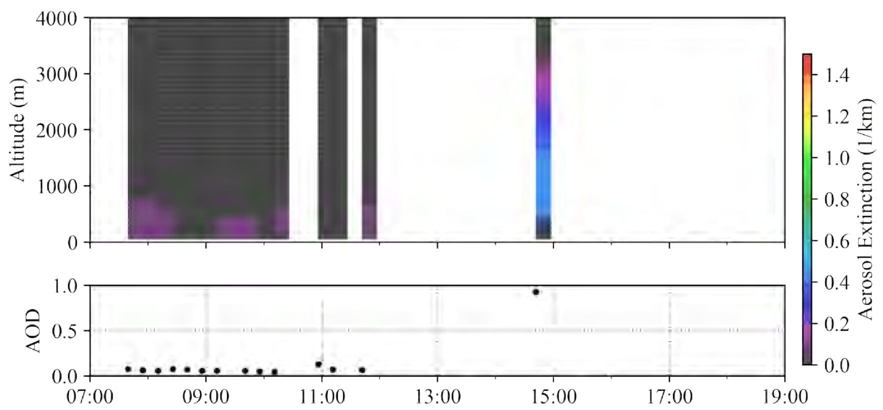

Figure 43: *Aerosol extinction profiles and corresponding* τ *at* 360 nm *obtained on* 5^{th} *November 2017.*

On the 12^{th} November valid profiles can be obtained in the morning and the afternoon. On that day the aerosol layer is thicker and exceeds an altitude of 1000 m. Further, the aerosol extinction in the individual layers is significantly higher than on 5th November. Already in the morning quite high τ were measured which also might indicate some air masses influenced by the dust storm. However, in the afternoon a continuous increase in the τ can be observed indicating that the ship is entering an area with even stronger aerosol contamination which was also crossed on the following day (see time series and map of τ values). As visible in Figure 41 even higher τ are found on 13th November. Unfortunately, no MAX-DOAS measurements are possible during night time and the increase in aerosol load could not be resolved continuously.

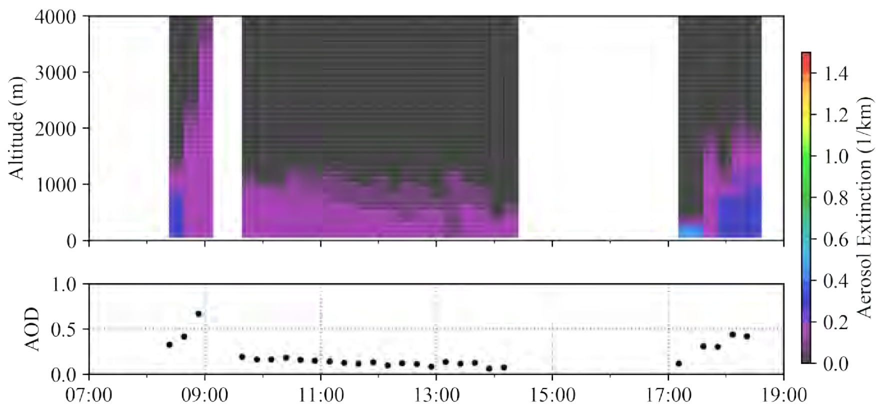

Figure 44: *Aerosol extinction profiles and corresponding* τ *at* 360 nm *obtained on 12th November 2017.*

6.2.4 *First trace gas results*

In this section some first trace gas results are presented for NO_2 and H_2O. It should be noted that for the trace gases only VCDs are presented since many profiles are flagged due to cloud contamination of the measurements. Further, also VCDs which are flagged as "warning" within MAPA are included in the following figures since the total column is a more robust measure than the actual profile.

Figure 45 shows a time series of the NO_2 VCDs which where obtained with MAPA. In the beginning of the cruise, where the ship passed a region with air masses still dominated by the continental outflow and with high ship traffic, the measured VCDs are rather high. In the further course of the cruise the NO_2 were strongly decreasing as the ship reached remote and pristine waters with only low ship traffic after passing the English Channel (see also map in Figure 46) and leaving the region of the influence of the European continent. Towards the end of the cruise the NO_2 VCDs are very close to the detection limit of the instrument. Nevertheless, some single enhanced

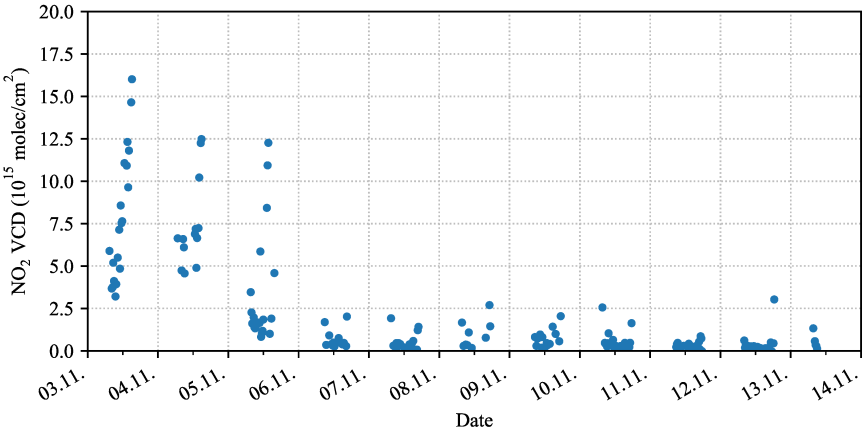

Figure 45: *Time series of NO_2 VCDs measured during the cruise.*

values can be found. These might be caused by nearby single ship plumes or even from the exhaust of the research vessel itself.

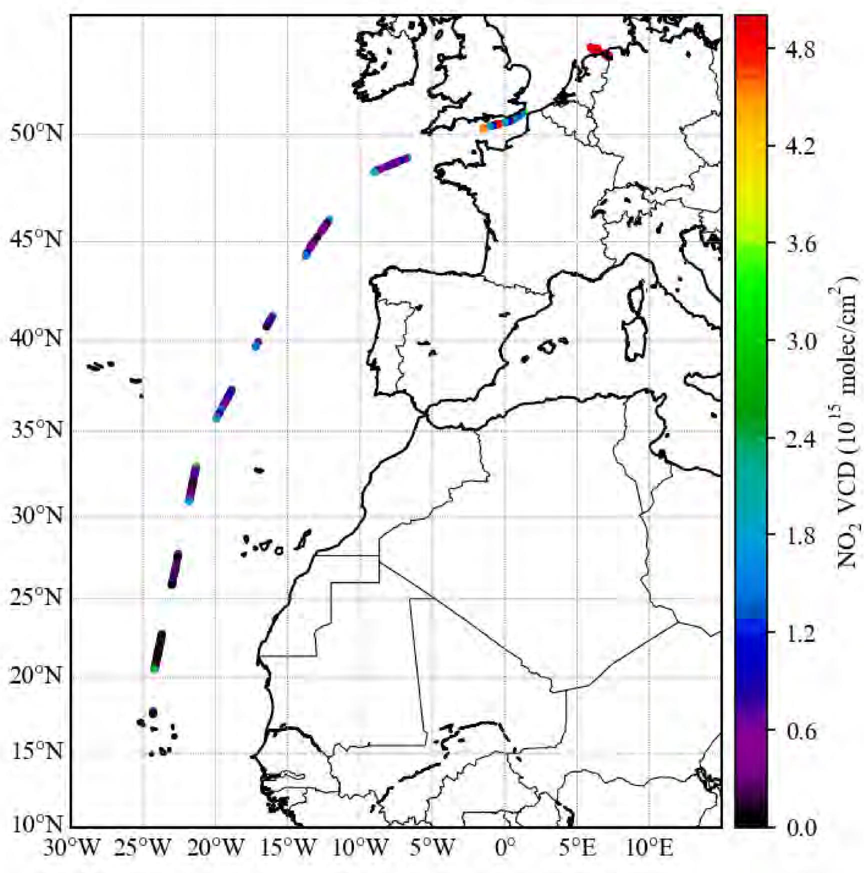

Figure 46: *Measured NO_2 VCDs plotted on a map.*

Lastly, the time series of water vapour is depicted in Figure 47, while Figure 48 shows the spatial distribution of H_2O on a map. When the ship passed through the open ocean with increasing temperatures of both air and water, the highest H_2O columns are measured (on 9th, 10th and 11th November). This represents the very high absolute humidity in subtropical and tropical regions. However, when the ship enters the dust storm area on 12th November the water vapour VCDs decrease since the air masses are then dominated by dry air originating from the African Continent and its deserts.

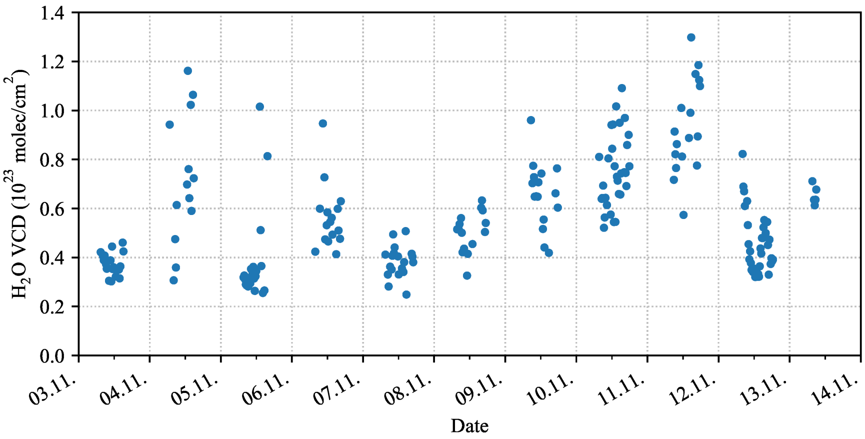

Figure 47: *Time series of H_2O VCDs measured during the cruise.*

6.3 OUTLOOK

Already the first analyses reveal promising results which could be obtained from the measurements during this MARIA S. MERIAN cruise MSM 68/2. Nevertheless, still some work has to be done.

First, a comparison to the other atmospheric measurements which where conducted aboard the ship has to be performed in order to better interpret the MAX-DOAS measurements. Here, the measurements of the cloud fraction might give valuable information for the interpretation of the aerosol profiles which need clear sky conditions. Also the τ values obtained by the MAX-DOAS measurements will be compared to the sun-photometer measurements for the clear sky periods. Lastly, the Ceilometer measurements can be used to yield information on the aerosol extinction profiles and therefore these results also will be compared to the MAX-DOAS aerosol extinction profiles.

Finally, the retrieval of weak absorbing and less abundant trace gases such as the halogen oxides BrO and IO will be performed.

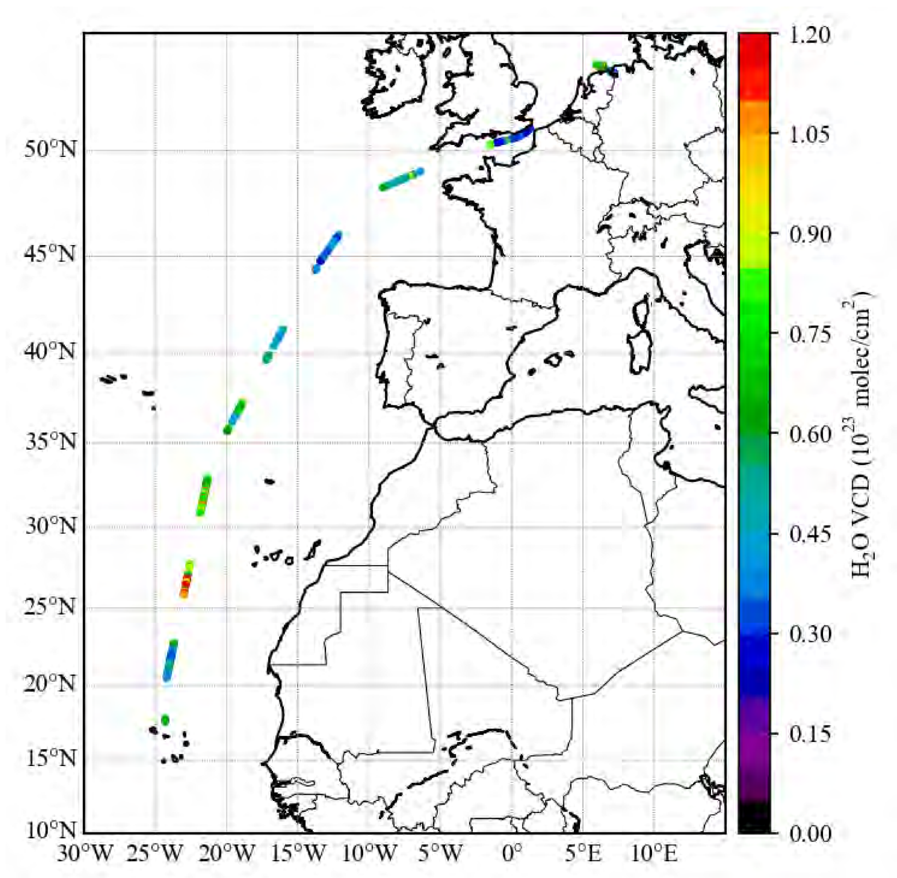

Figure 48: *Measured H_2O VCDs plotted on a map.*

Part III

OCEAN OBSERVATIONS

7 ARGO FLOAT DEPLOYMENT

A. Schneehorst[1], *S. Fiedler, and K. Seelmann*[2]

7.1 OBJECTIVES

The Argo program is part of the Global Ocean Observing System and has grown to be a major component of it. National contributions to the network of free-drifting profiling floats are shown in Fig. 49 for August 2018. The deployment of the new float #3901643 during MSM 68/2 was carried out on the behalf of the BSH that services and operates the German contribution to the global international Argo program. The main purpose of this float deployment was to maintain the completeness of the Argo array such that the position targeted a spatial gap in the network. This was offshore of Portugal at 37°30'N and 18°42'W.

Each float is equipped with pressure, temperature and conductivity sensors manufactured by Seabird Electronics. A full measurement cycle of a float is 10 days. It first drifts at a fixed pressure of 1000 dbar for nine days. From this parking depth it than descends to 2000 dbar before rising and measuring the vertical profile of pressure, temperature, and conductivity on the way to the surface. It herein measures with a varying vertical resolution. Once at the surface, the float transmits the collected data via satellite towards a land station. Having finished its transmission, the float sinks again to 1000 dbar and the cycle starts all over again. The float has a typical life time of up to five years or 300 cycles. The current ages of the deployed Argo floats are shown in Fig. 50. All Argo data are collected and immediately made freely available by the International Argo Program and the national programs that contribute to it. (http://www.argo.uscd.edu, http://argo.jcommops.org).

7.2 WORK AT SEA AND FIRST ANALYSIS

7.2.1 *Float preparation and deployment*

During cruise MSM 68/2 one new profiling float of type Arvor L was deployed. It is equipped with Argos satellite telemetry and was manufactured by NKE Instrumentation. The float has been checked in ad-

1 Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency), Hamburg, Germany
2 GEOMAR Helmholtz-Centre for Ocean Research Kiel, Kiel, Germany

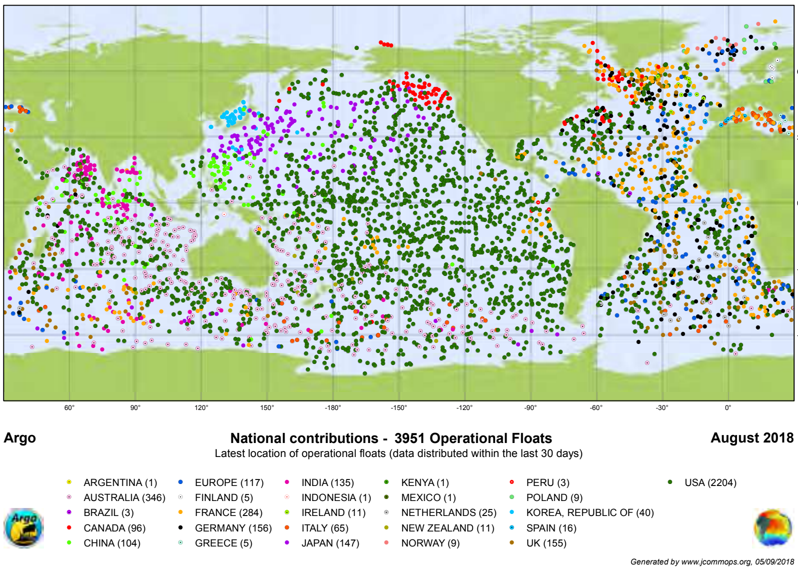

Figure 49: *Argo float network. Shown are the geographical positions of Argo floats as of August 2018 with colour-coded national contributions to the program (Figure credit: www.jcommops.org).*

vance, i.e., controlling the programmed configurations and absolving a functional test. On the vessel, the float was successfully prepared for the deployment following the instructions provided by the BSH. The preparations included the unpacking, activation and functionality tests of the float. After reducing the speed of the vessel, it was lowered into the water at the rear side of the vessel. Close to the deployment location, we did a CTD cast for collecting data for verifying the first float measurements.

7.2.2 *CTD reference profile*

In order to evaluate the measurements of the deployed ARGO float a reference CTD cast was carried out approximately one nautic mile away from the deployment position at 37°28′N and 18°43′W. The cast started at 06:19 UTC and ended at 07:32 UTC. The relevant equipment on the used CTD was:

- Two temperature sensors
  (last calibration: 15.07.2017)
- Two conductivity sensors
  (last calibration: 14.07.2017)
- Two oxygen sensors, SBE 43
  (last calibration: 16.08.2017)
- One fluorometer, WET Labs ECO-AFL/FL
  (last calibration: 18.04.2017)

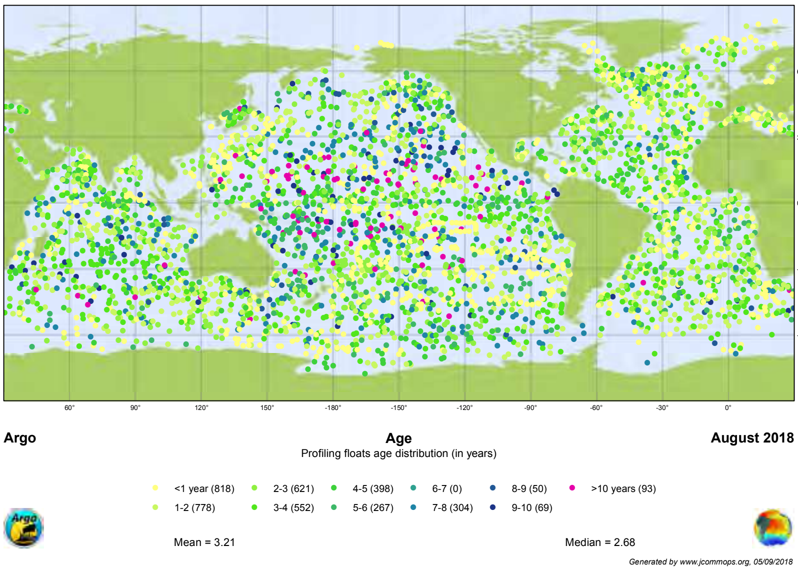

Figure 50: *Argo float age. Shown are the geographical positions of Argo floats as of August 2018 with colour-coded times since their deployment (Figure credit: www.jcommops.org).*

- One pressure sensor, Digiquartz with TC (last calibration: 08.09.2015)

For saving time, we measured the profile over the first 2000 m consistent with the maximum depth of the ARGO float. Figure 51 shows the reference CTD downcast profile with the parameters temperature [°C], salinity [PSU], oxygen concentration [µmol/kg] and fluorescence [mg/m^3] as function of the water depth [m]. These data are the basis for the validation of the first profiles measured by the Argo float #3901643. In addition, the upcast was used to test the bottles of the CTD sampling rosette prior to their use at the CVOO (Section 9). For doing so, all bottles were fired at random depths and checked for leakages or other problems on deck. All sampled water was discarded afterwards.

7.2.3 *First float measurements*

We show here, the measurements from the float #3901643 deployed during MSM 68/2 as graphically displayed online (Coriolis Data Center). The first measurement cycle of the float is shown in Figure 52. Both the temperature and salinity measurements of the float are in good agreement with the CTD reference profile (compare Figure 51).

Since the deployment, the float has measured 32 profiles and drifted with the ocean eddies. The trajectory since November 2017 is shown in Figure 53. The float has been westward displaced for most of the

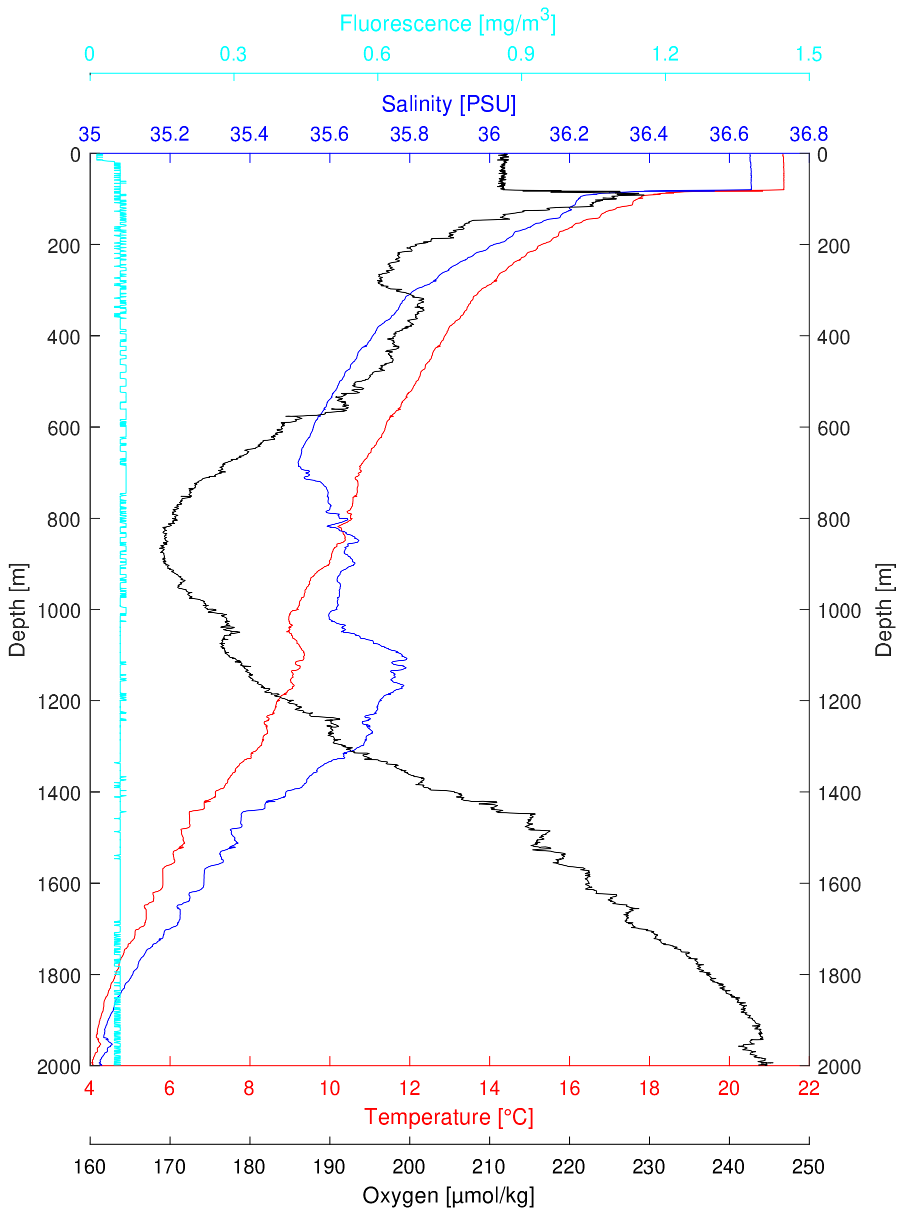

Figure 51: *Argo float reference CTD profile at 37°28′N and 18°43′W in the morning of 9 November 2017*

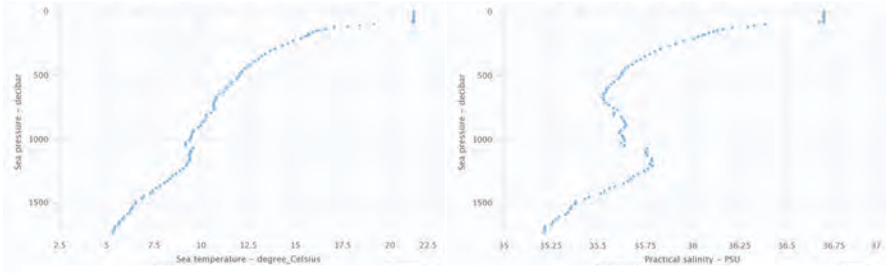

Figure 52: *Argo float first cycle. Shown are the in-situ temperature and salinity profiles from the first cycle of the newly deployed Argo float #3901643, transmitted on 10 November 2017 at 05:51 UTC (Coriolis Data Center)*

Figure 53: *Argo float trajectory. Shown are the positions of the newly deployed Argo float #3901643 between 9 November 2017 and 16 September 2018 (Coriolis Data Center)*

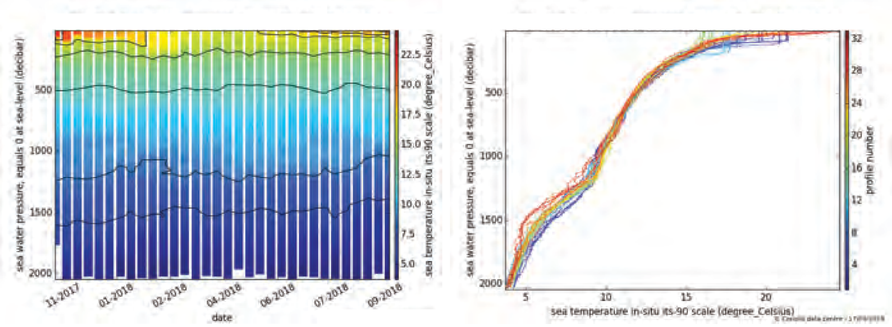

Figure 54: *Argo float temperature profiles. Shown are the in-situ temperature measurments of the newly deployed Argo float #3901643 between 9 November 2017 and 16 September 2018 (Coriolis Data Center)*

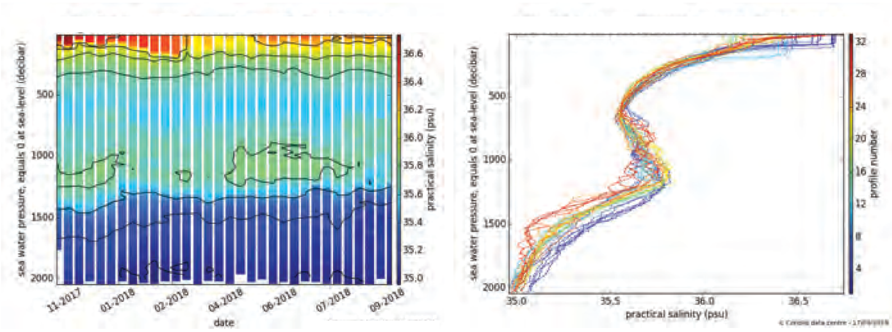

Figure 55: *Argo float salinity profiles. Shown are the in-situ salinity measurments of the newly deployed Argo float #3901643 between 9 November 2017 and 16 September 2018 (Coriolis Data Center)*

time with a varying north-south drift. As of September 2018, the float is approaching the Azores islands Santa Maria and São Miguel.

Since the deployment, the float from MSM 68/2 has reported valid data. Figure 54 and 55 give an overview of all recorded profiles as of 16 September 2018. Most parts of the profiles indicate little spatio-temporal variability during the almost one-year long drift of the float. Water temperatures decrease with depth below a well-mixed surface layer of roughly 100 m depth. The water temperature of the surface layer shows the largest spatio-temporal changes with differences by 15 °C. Likewise the salinity changes over time with differences of rougly 0.5 psu.

All measurements of the floats are usually freely available within hours after collection and can be downloaded from the CORIOLIS data center (http://www.coriolis.eu.org). Note that the data can be accessed in realtime (mode 'R'), but second order quality controls have than not been performed.

7.3 OUTLOOK

This year, fifty floats were deployed by different ships mainly in the North- and South Atlantic. To maintain an operational array of almost 4000 floats, the national partners need to deploy 800 floats per year. Germany tries to deploy fifty floats per year. After MSM68/2 two more cruises with RV MARIA S. MERIAN will be equipped with floats and one cruise with RV POLARSTERN. These floats will be deployed in the Atlantic, too.

The original global Argo array was designed for the open ocean and not for the marginal ice zones or marginal seas. Due to two-way communications and ice sensing algorithms the technical limitations get smaller. Including the seasonal sea-ice zones, the original target number of 3000 floats increases to 4000.

In the future, the interest is rising for the marginal ice zones. More and more floats will be equipped with biogeochemical sensors and an enhanced coverage of boundary currents and equatorial regions is planned. Deeper ocean areas are getting in the focus of interest, so the floats will be drifting in deeper current regions in the coming years.

The float's reliability has improved almost every year and the float lifetime has been extended. Argo has developed a large user community in universities, government labs and meteorological/climate analysis/forecasting centres. The need for global Argo observations will continue indefinitely into the future, though the technologies and design of the array will evolve, models will be improved, and more will be learned about the ocean.

8 SEA SURFACE TOTAL ALKALINITY

K. Seelmann and A. Körtzinger

8.1 OBJECTIVES

The main objective of our participation in the research cruise MSM 68/2 was to characterize the performance of the new autonomous measurement system *Contros HydroFIA® TA* (Kongsberg Maritime Contros GmbH, Kiel, Germany) for sea surface total alkalinity (TA) under long-term semi-continuous measurement conditions. Figure 56 shows a photo of the testing set-up in the chemistry lab of the research vessel.

8.2 WORK AT SEA AND FIRST ANALYSIS

8.2.1 *Contros HydroFIA® TA system - The measuring principle*

The *Contros HydroFIA® TA* system is a new autonomous wet chemical analyser for sea surface total alkalinity. The measuring principle is based on four operational steps:

1. Collecting the sample
2. Acidification of the sample with 0.1 M hydrochloric acid and adding an indicator solution
3. Mixing and degassing
4. Spectrophotometric measurement and calculation of the TA value

Figure 56: *The Contros HydroFIA® TA set-up in the chemistry lab of the RV Maria S. Merian (Photo: Katharina Seelmann)*

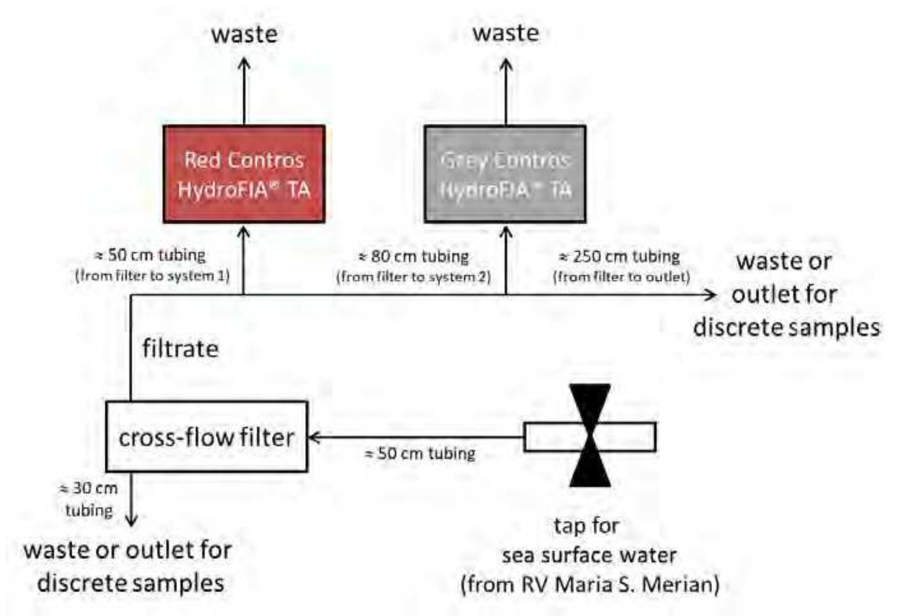

Figure 57: *Schematic set-up for sea surface total alkalinity measurements*

One measurement takes approximately 10 minutes and needs 50 mL of seawater.

8.2.2 *Set-up*

Two *Contros HydroFIA® TA* wet chemical analyser were used for the instrument tests. The serial numbers of the two systems are:

- TA-0615-001 (red system, see figure 56)
- TA-1116-001 (grey system, see figure 56)

Figure 57 shows the whole schematic set-up also with the length of the used seawater tubing. In order to filter the sea-surface water a cross-flow filter with 0.2 µm pore size was installed before the water enters the instruments (see Figure 57). It prevents tubing clogging and light absorbing particles in the systems.

8.2.3 *First steps*

Because the systems were flushed with MQ-water for storage and transport, a method for stabilization of the measurements was needed. For that, a bottled seawater substandard ($\approx$ 10 L) was measured with both systems every 10 minutes for 12 hours. After the measurements were stable (standard deviation $\leqslant$ 2 µmol/kg), the systems were calibrated with a Dickson Standard (Batch: CRM160).

8.2.4 *Daily working routine*

To get some information about the behaviour of the systems under semi-continuous measurement conditions the TA of steady pumped sea-surface water (underway; depth: ≈ 5 m) was measured. The measuring interval was 10 minutes. In order to monitor the precision and accuracy of the systems over the whole semi-continuous period, Dickson Standards (Batch: CRM160) were subsequently measured five times twice a day, i.e., once in the morning and once in the evening.

Discrete samples were taken during the entire cruise with a sampling of four to five times per day in order to determine the accuracy of the instruments within the working TA range. The samples were bottled, poisoned with mercury chloride and airtight sealed. The analysis will take place in the lab at the GEOMAR Helmholtz-Centre for Ocean Research Kiel with a reference measurement system (VINDTA 3S system, potentiometric titration) according to the *Guide to Best Practices for Ocean CO2 Measurements* (Dickson, Chris, and Christian, 2007). Table 4 gives an overview on all taken discrete samples.

8.2.5 *First results*

For the evaluation of the data it is important to distinguish between measurements around the TA of the calibration (CRM measurements) and measurements within the working TA range (underway measurements and discrete samples).

8.2.5.1 *CRM measurements*

Figure 58 shows the results of the daily CRM measurements. For a better understanding of the behaviour of the systems, the bias of the measured TA (mean of the five single measurements) to the certified value is shown. The bias in Figure 58 represents the accuracy of the instruments around the calibration TA value. Both the red *Contros HydroFIA® TA* system and the grey one show a trend over time, but the red system produced increasing values while the grey system measured a decrease.

Relating to the accuracy, both systems show a totally different behaviour under the semi-continuous measurement conditions. At the end of the cruise (November, 13th 2017) the offset between the red and the grey analyser is approximately 35 µmol/kg around the calibration TA.

The precision of the two systems is the standard deviation calculated out of the single CRM measurements. Each error bar in Figure 58 represents the precision of the measurement. Both systems show a precision from approximately 0.2 up to 3 µmol/kg with an averaged value of 1.2 µmol/kg (red system) and 1.1 µmol/kg (grey system). The standard deviations seem to be random, so there is no

Table 4: *Discrete TA samples taken during MSM68/2*

Sample Number	Date	Time (UTC)
1	04.11.2017	17:25:00
2	05.11.2017	07:15:00
3	05.11.2017	07:15:00
4	05.11.2017	15:46:00
5	06.11.2017	07:06:00
6	06.11.2017	09:52:00
7	06.11.2017	13:13:00
8	06.11.2017	18:28:00
9	06.11.2017	18:28:00
10	07.11.2017	07:58:00
11	07.11.2017	14:04:00
12	07.11.2017	16:34:00
13	07.11.2017	16:34:00
14	07.11.2017	20:42:00
15	08.11.2017	09:42:00
16	08.11.2017	12:13:00
17	08.11.2017	15:23:00
18	08.11.2017	15:23:00
19	08.11.2017	18:13:00
20	09.11.2017	08:56:00
21	09.11.2017	12:06:00
22	09.11.2017	16:26:00
23	09.11.2017	16:26:00
24	10.11.2017	09:20:00
25	10.11.2017	12:10:00
26	10.11.2017	15:10:00
27	10.11.2017	18:00:00
28	11.11.2017	10:32:00
29	11.11.2017	12:02:00
30	11.11.2017	14:52:00
31	11.11.2017	16:32:00
32	11.11.2017	18:22:00
33	12.11.2017	09:12:00
34	12.11.2017	13:16:00
35	12.11.2017	15:30:00

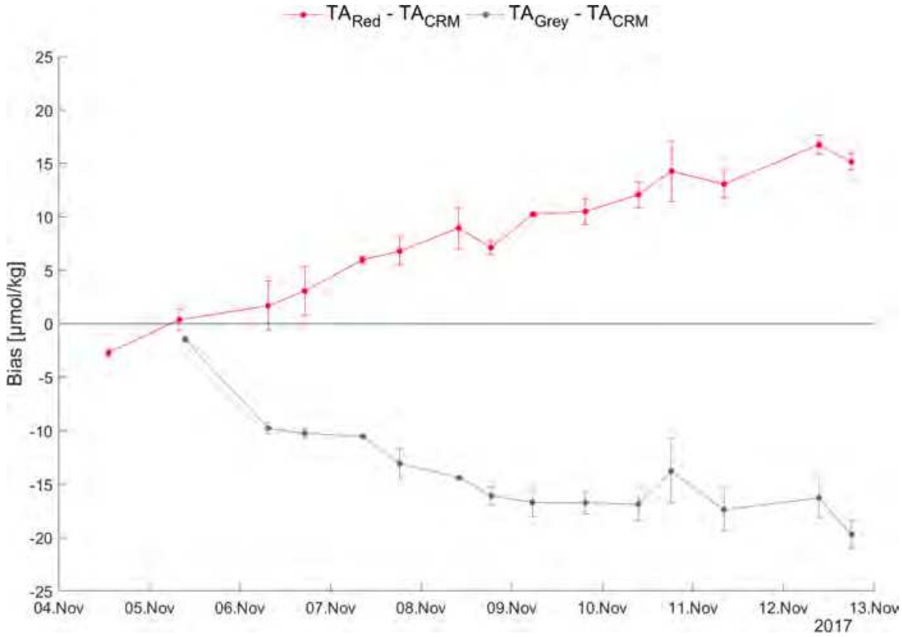

Figure 58: *Bias of the Contros HydroFIA® TA CRM measurements to the certified value in dependence of the measuring date (errorbars ⇒ standard deviation of the CRM measurements); TA (CRM160) = 2212.44 µmol/kg*

systematic behaviour. Relating to the precision, both systems show nearly the same behaviour under semi-continuous measurement conditions.

8.2.5.2 *Underway measurements*

First of all, it is important to mention that the sea-surface total alkalinities from this cruise are only a test and meant for characterising the seawater in the sampled region. While Figure 59 visualises the measured underway total alkalinities over time, Figure 60 shows them along the cruise track of MSM 68/2. The different behaviour of the two systems is clearly visible. One thing is also obvious: The bigger the difference between the TA of the sample and the calibration value, the higher the offset of the two automated systems. The highest offset was around 90 µmol/kg on November, 12th 2017.

8.2.5.3 *Recalibration*

Because both systems were not stable during the entire cruise a recalibration (based on the daily CRM measurements) of the underway data was necessary. So the systematic error (around the TA of the calibration) can be compensated. The recalibration was carried out after every CRM measurement and followed the same procedure like the very first calibration at the beginning of the cruise.

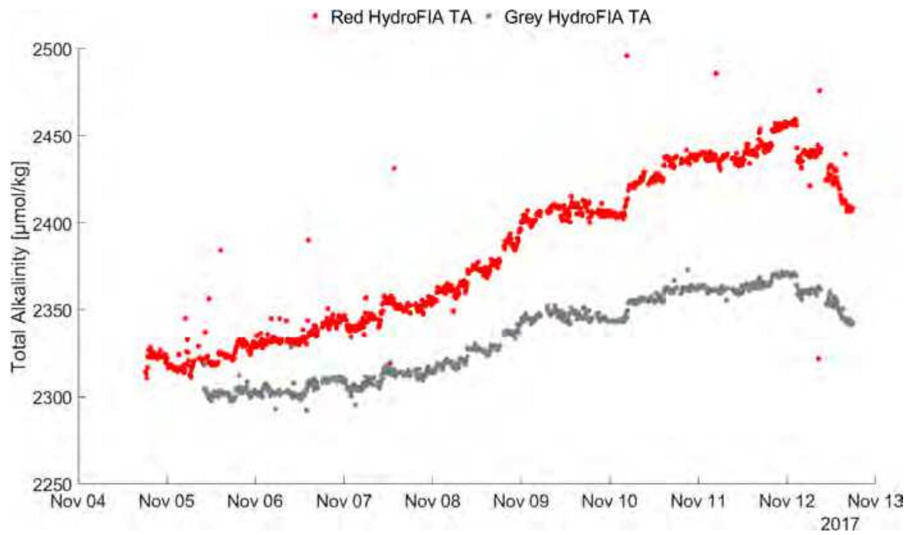

Figure 59: *The underway total alkalinities of the Contros HydroFIA® TA systems over the MSM68/2 cruise duration*

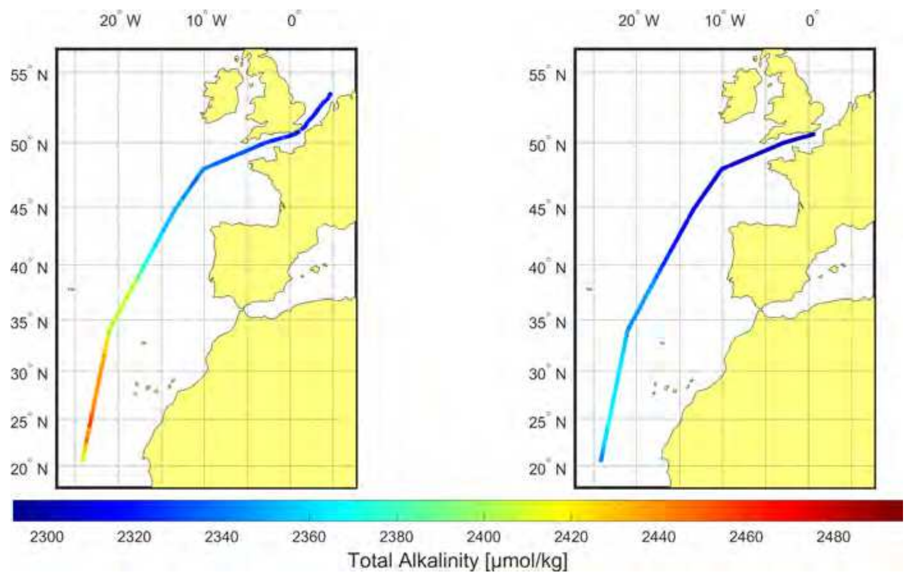

Figure 60: *The underway total alkalinities of the Contros HydroFIA® TA systems over the MSM68/2 cruise track (left: red system; right: grey system)*

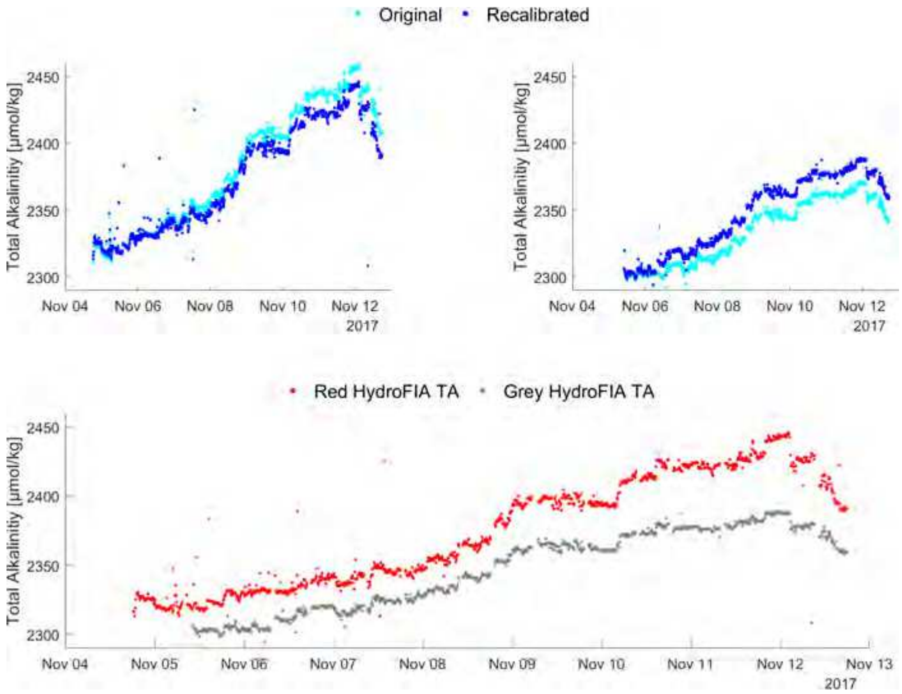

Figure 61: *Top: Original and recalibrated underway total alkalinities (left: red system; right: grey system)*
Bottom: Comparison between recalibrated underway measurements of both systems

Figure 61 shows the original and the recalibrated underway measurements as the recalibrated total alkalinities of both systems in comparison. Even if the systematic error (observed during CRM measurements) is compensated, there is still an offset between the red and the grey system. Now, the maximum offset (November, 12th 2017) is around 60 µmol/kg, i.e., 30 µmol/kg less than without the recalibration.

8.3 OUTLOOK

The results show that one of the two systems had a critical problem during the MSM 68/2 cruise and so the system was not able to accurately measure the alkalinity of the sea-surface water. It is of high importance to determine which of the *Contros HydroFIA® TA* systems is biased, what has caused the bias and why these problems occurred.

The first step to the answer of these questions is the analysis of the discrete samples. A comparison between the recalibrated data of the *Contros HydroFIA® TA* systems and the reference TA of these samples should give important information about the accuracy within the working range. Furthermore, additional questions have to be answered in future work:

- What is the reason for a different accuracy behaviour of two identical systems around the calibration value?
- What caused the unstable measurements over the entire duration of the cruise?
- How could the measurements be improved with regard to the monitored results?

9 CAPE VERDE OCEAN OBSERVATORY

K. Seelmann and A. Körtzinger

9.1 OBJECTIVES

9.1.1 *Cape Verde Ocean Observatory (CVOO)*

The Cape Verde Ocean Observatory (CVOO) is the ocean monitoring site of the Cape Verde Observatory with the co-located atmospheric observation site (Cape Verde Atmospheric Observatory, CVAO). It is located in the tropical Eastern North Atlantic Ocean at 17.6°N and 24.3°W. At the moment, the region has a poor observational coverage, but is important for understanding in air-sea interactions. In order to compensate the lack of long-term time-series observations in the tropical oceans, the CVOO was established in 2006 through a cooperation between the GEOMAR and the Instituto Nacional de Desenvolvimento das Pescas in Mindelo/Cape Verde (INDP). The time-series operations have two separate long-term observations, namely:

1. Multi-disciplinary long-term mooring with $p\text{CO}_2$ and O_2 sensors operating uninterruptedly since 2006 with recovery and redeployment approx. every 1.5 years.
2. Monthly 600 m-deep CTD hydrocasts carried out by the Cape Verdean research vessel Islandia with water sampling for a comprehensive analysis of biogeochemical parameters at INDP in Mindelo as well as GEOMAR in Kiel.

9.1.2 *Full-depth CTD hydrocast at CVOO*

The RV Islandia can only reach a depth of 600 m and has suffered major sampling gaps because of technical problems. CVOO is therefore striving to use other opportunities for carrying out full-depth CTD hydrocasts at this station that has considerably contributed to extending the time-series data base. The MSM 68/2 was a great opportunity to do a full-depth CTD hydrocast at CVOO. The cruise track passed the station and RV MARIA S. MERIAN has an own CTD-rosette for the water sampling and the profiling.

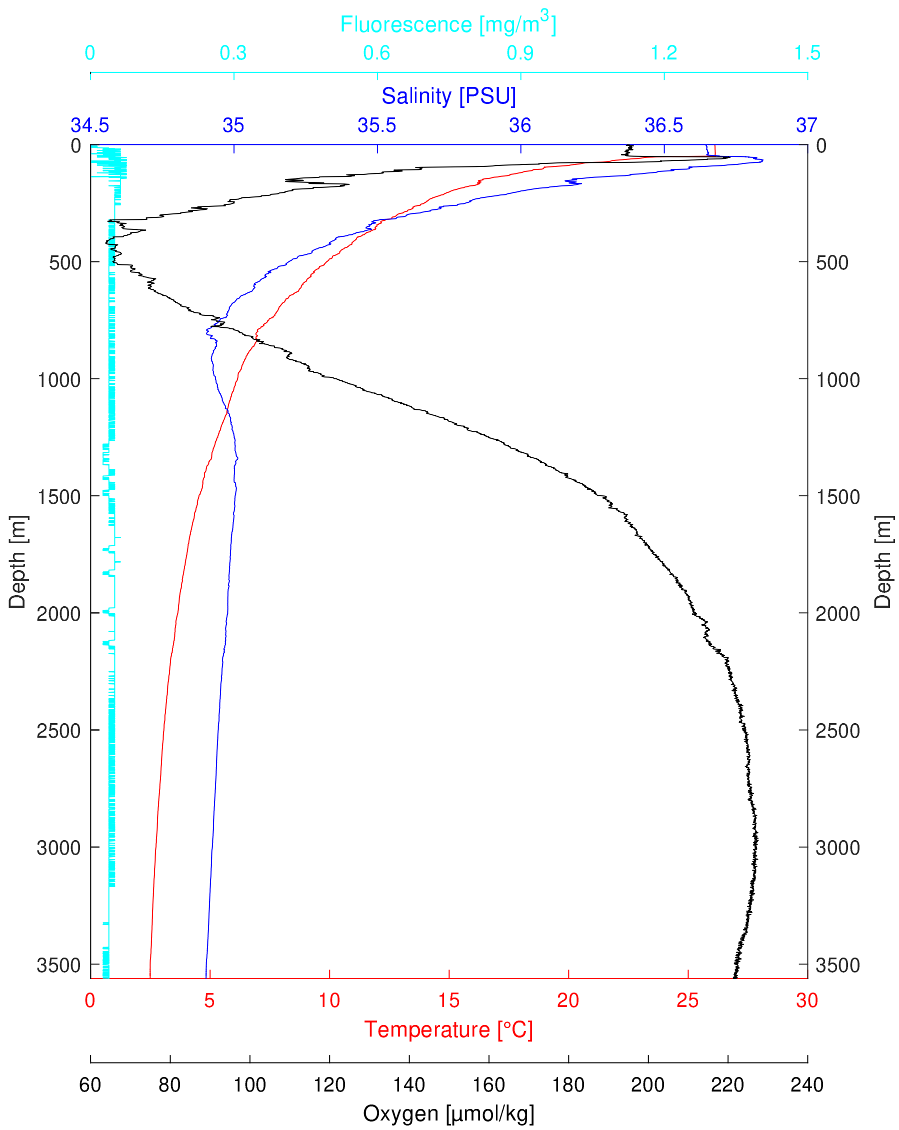

Figure 62: *CVOO CTD profile at 17°35′N and 24°18′W on 13 November 2017.*

9.2 WORK AT SEA AND FIRST ANALYSIS

9.2.1 *CTD and hydrocast sampling*

The full-depth CTD cast was deployed at 17°35'N and 24°18'W. The cast started on November, 13th 2017 at 09:16 UTC and ended at 11:28 UTC. The relevant equipment on the used CTD was:

- Two temperature sensors
  (last calibration: 15.07.2017)
- Two conductivity sensors
  (last calibration: 14.07.2017)
- Two oxygen sensors, SBE 43
  (last calibration: 16.08.2017)
- One fluorometer, WET Labs ECO-AFL/FL
  (last calibration: 18.04.2017)
- One pressure sensor, Digiquartz with TC
  (last calibration: 08.09.2015)

The cast reached a maximum depth of 3562 m. At this depth the sea floor at CVOO was almost reached (lot depth of the vessel: 3600 m).

For taking water samples, overall 19 bottles of the rosette were closed at specified water depths during the upcast. Samples for oxygen, dissolved inorganic carbon/total alkalinity (DIC/TA) and nutrients (NUT) were taken from the Nisken bottles. Table 5 gives an overview on all samples from the CTD hydrocast at CVOO. Due to non-functioning chemical dispenser, the oxygen samples has to be discarded such that this quantity was not measured. The samples for DIC/TA were filled in 500 mL glass bottles, poisoned with mercury chloride and airtight sealed. The analysis takes place in the lab at the GEOMAR Helmholtz-Centre for Ocean Research Kiel. The samples for NUT were filled in small plastic tubes, closed with a lid and frozen at -20 °C. The analysis of these measurements take place at the Ocean Science Centre Mindelo (OSCM).

9.2.2 *CTD comparison against the climatological mean*

Figure 62 shows the CTD downcast profile at CVOO with the parameters temperature [°C], salinity [PSU], oxygen concentration [µmol/kg] and fluorescence [mg/m^3] in dependence of the depth [m]. All parameters from the CTD cast are compared to data from the World Ocean Database 2013 at the CVOO coordinates in the following. We herein use the available data for computing climatologically averaged profiles for November, i.e., all monthly data for November from 1955 to 2012 (Boyer et al., 2013). This comparison allows to evaluate to

Table 5: *Samples from the CVOO CTD hydrocast on 13 November 2017.*

CTD Bottle No.	Water Depth [m]	Taken samples
1	3562 (Bottom)	DIC/TA and NUT
2	3511	DIC/TA and NUT
3	3011	DIC/TA and NUT
4	2009	DIC/TA and NUT
5	1508	DIC/TA and NUT
6	1006	DIC/TA and NUT
7	606	DIC/TA and NUT
8	456	DIC/TA and NUT
9	356	DIC/TA and NUT
10	255	DIC/TA and NUT
11	205	DIC/TA and NUT
12	155	DIC/TA and NUT
13	125	DIC/TA and NUT
14	105	DIC/TA and NUT
15	85	DIC/TA and NUT
16	65	DIC/TA and NUT
17	45	DIC/TA and NUT
18	25	DIC/TA and NUT
19	15	DIC/TA and NUT

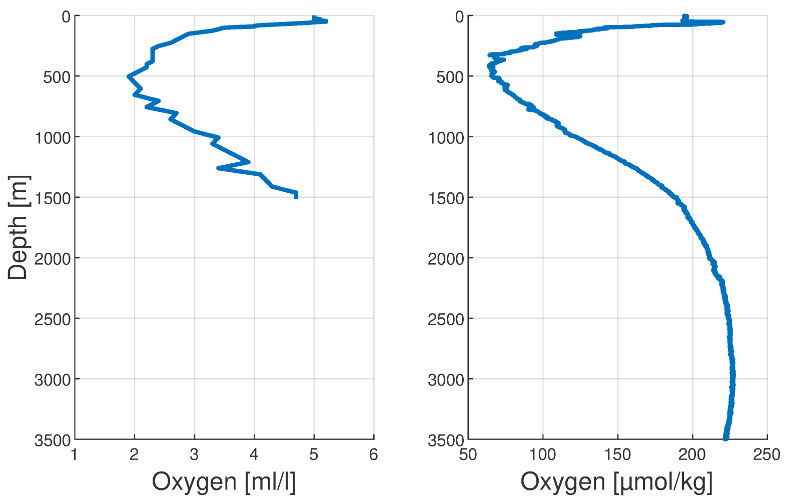

Figure 63: *CVOO oxygen profile from CTD cast (right) in comparison with the climatological averaged profile for November in 1955–2012, based on the World Ocean Database (2013, left)*

what extend the CTD of 13 November 2017 is representative for the long-term mean at the location.

Figure 63 shows the comparison between the oxygen data from the World Ocean Database and the oxygen concentration from the CTD cast at CVOO. Unfortunately, the units do not match, but the general characteristics of profiles can be compared. Both profiles show a similar shape for the available upper 1500 m with a minimum at approximately 500 m. The vertical change of the oxygen concentration with the water depth from November 2017 is therefore comparable to the climatological mean.

Figure 64 shows the comparison of the climatological mean salinity profile for November from the World Ocean Database and the salinity profile from the CTD cast at CVOO. Both profiles show that there is a good match, i.e., the CVOO salinity profile of November 2017 is representative for the climatological mean.

Figure 65 shows the comparison between the temperature data from the World Ocean Database and the temperature profile from the CTD cast at CVOO. Similar to other properties, also the temperature profile of November 2017 is representative for the long-term mean for November.

9.3 OUTLOOK

The next step is the analysis of the discrete samples at the GEOMAR and the OSCM. Furthermore, the long-term mooring at CVOO will be calibrated with these samples and the calibrated CTD data. Finally, all data will be added to the time-series data base of CVOO (https://portal.geomar.de/web/cvoo/meta-data).

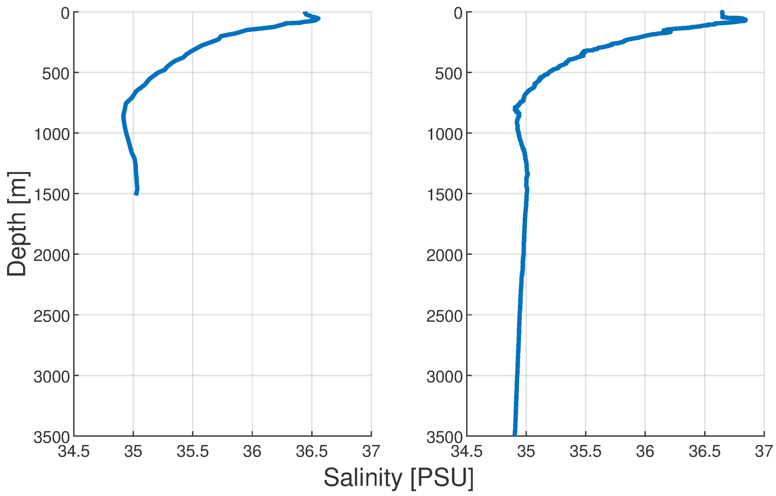

Figure 64: *CVOO salinity profile from CTD cast (right) in comparison with the climatological averaged profile for November in 1955–2012, based on the World Ocean Database (2013, left).*

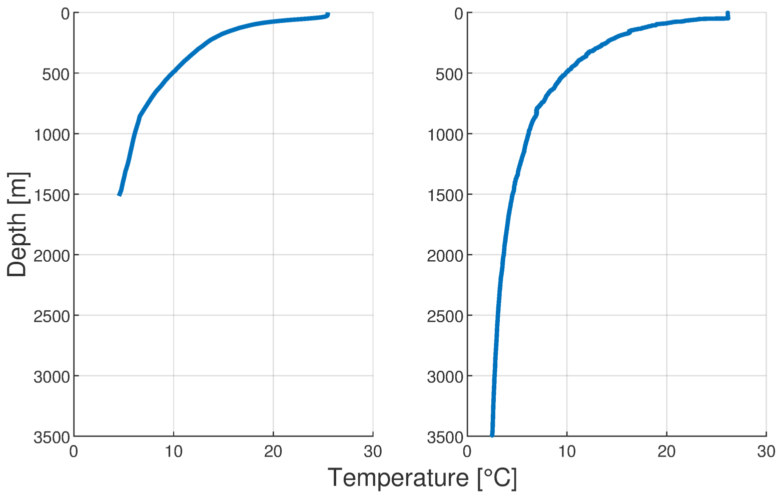

Figure 65: *CVOO temperature profile from CTD cast (right) in comparison with the climatological averaged profile for November in 1955–2012, based on the World Ocean Database (2013, left).*

10 UNDERWAY CETACEAN OBSERVATION

S. Neves[1]

10.1 OBJECTIVES

The present work was done within the MARCET project framework. MARCET is a Macaronesian project (INTERREG – MAC 1.1b/149) from the MAC 2014-2020 program, approved in the first call of the Program of Territorial Cooperation INTERREG V-A-MAC (Madeira, Açores, Canarias) 2014-2020, financed by Fondo FEDER. MARCET was created as a network that aims for the transfer of knowledge, as well as cutting-edge technology on a multidisciplinary level to protect and monitor both cetaceans and their environment. Marine mammals are emblematic of the Macaronesian area; it is considered a hot spot for cetaceans with more than 30 species sighted to date. The expedition MSM 68/2 was scheduled to transect the Macaronesian region, and was therefore used as an opportunistic platform for cetacean observation.

10.2 WORK AT SEA AND FIRST ANALYSIS

10.2.1 *Methodology*

The methodology was based on the guidelines of the Marine Mammal Association- MMOA (https://www.mmo-association.org/). There was just one observer on board and, therefore, observations were not done continuously, respecting the guidance on rest breaks suggested by the MMOA. The observation shifts did not exceed 12 hours, and the observation effort consisted of two hours followed by a one-hour break to promote a high concentration level during active observation. Observations were only undertaken during dry weather and when the sea state was 3 m or lower. The horizon was scanned by the observer using 10x50 binoculars on a 180° angle, and changes in environmental conditions such as wind and sea state, cloud cover, swell, and glare were recorded continuously. When an animal or group of animals was sighted, date and time, GPS coordinates, the angle to the group with respect to the cruise track, and the distance to the vessel (using a range-stick) were recorded. Photographs were taken to assist

1 PLOCAN (Consorcio para la Construcción, Equipamiento y Explotación de la Plataforma Oceánica de Canarias), Gran Canaria, Spain

Figure 66: *Looking out for marine mammals*

Figure 67: *Equipment used to look for and register marine mammals and birds*

with species identification, and information such as group size, group behaviour and composition were noted.

10.2.2 *Sightings and Species*

A total of 2923 nm were sailed, of which 287 nm involved actively searching for animals, at an average speed of 12 kn. In total, four different species of marine mammals were identified, as well as six species of birds. The following table describes the species identified.

Tables 6 and 7 show the species identified during the expeditions. For sightings of marine mammals, the list gives the species and group characteristics as well as the geographic location at the time of the sighting (Tables 7). For birds, species and geographic location are listed only (Tables 6). The following photo gallery illustrates the sightings.

Figure 68: *Map with cetacean sightings during the expedition MSM 68/2.*

Table 6: *Bird sightings.*

Species common name	Species scientific name	Date and Time (UTC) Latitud/Longitud GG°.GGGGGG
Northen Gannet	*Morus bassanus*	05/11/2017 13:14 50.455796 /-0.450637
Lesser black backed gull	*Larus fuscus*	06/11/2017 11:32 48.734148 / -7.524319
Great skua	*Catharacta skua*	06/11/2017 11:15 48.758111 /-7.438388
Cory´s shearwater	*Calonectris borealis*	11/11/2017 11:28 27.197225 / -22.687015 12/11/2017 15:44 21.087263 / -24.058398
Northern wheatear	*Oenanthe oenanthe*	12/11/2017 13:45 21.536027 / -23.959859
Storm petrel sp	*Oceanodroma sp*	13/11/2017 15:19 17.118071 / -24.840544

Table 7: *Marine mammal sightings.*

Species common name	Species scientific name	Number of animals minimum, maximum best	Behaviour	Distance angle (bow=0^o)	On effort (Yes/No)	Date and Time (UTC) Latitud/Longitud GG^o.GGGGGG
Common dolphin	*Delphinus delphis*	Min-4, Max-7 Best: 4	Approaching the boat	50m 135^o	No	06/11/2017 08:41 48.976234 /-6.653701
Common dolphin	*Delphinus delphis*	Min- 5, Max-10 Best: 6	Approaching the boat	200m -190^o	No	06/11/2017 10:26 48.827819 / -7.184653
Unidentified dolphin		Min-2	Travelling fast	100m -45^o	Yes	08/11/2017 08:46 41.093125 /-16.163655
Atlantic spotted dolphin	*Stenella frontalis*	Min-20, Max-30 Best-25	Travelling and socializing	50m -90^o	Yes	12/11/2017 13:11 21.6621 / -23.932113
Humpback Whale	*Megaptera novaengliae*	Min – 2, Max – 2	Socializing Best:2	900m -90^o	Yes	12/11/2017 13:13 21.654702 / -23.933701
Unidentified dolphin		Min-1	Undetermined	1000m 20^o	Yes	12/11/2017 15:28 21.147195 / -24.045259
Unidentified dolphin	*Stenella sp*	Min-3	Approaching the boat	100m -150^o	No	12/11/2017 18:23 20.484048/-24.190464
Pantropical spotted dolphin	*Stenella attenuata*	Min – 10, Max – 20 Best– 15	Travelling and socializing	1500m -80^o	Yes	13/11/2017 15:23 17.109632 / -24.850177

10.2.2.1 *Photo gallery of sightings.*

The following figures illustrate the marine mammal and bird species sighted during MSM 68/2.

Figure 69: *Common Dolphins, Delphinus delphis*

Figure 70: *Atlantic Spotted dolphins, Stenella frontalis*

Figure 71: *Pantropicak Spotted Dolphin, Stenella attenuata*

Figure 72: *Humpback Whale, Megaptera novaengliae, pectoral fin*

Figure 73: *Northern gannet, Morus bassanus*

Figure 74: *Lesser black backed gull, Larus fuscus*

Figure 75: *Great skua, Catharacta skua*

Figure 76: *Cory's shearwater, Calonectris borealis*

Figure 77: *Northern wheatear, Oenanthe oenanthe*

Figure 78: *Storm petrel, Oceanodroma sp*

10.3 OUTLOOK

Weather conditions were not favourable for marine mammal detection, particularly in the North Sea. However, cetaceans were sighted eight times, along with five different species of marine birds and one migratory terrestrial bird species, proving that opportunistic data can be successfully collected on board of research vessels. The data collected will be available to all users of the MARCET network (www.marcet-mac-eu), which comprises a variety of stakeholders, ranging from the whale watching industry to cetacean researchers, contributing to the knowledge of the distribution of species in the Macaronesian region.

Part IV

APPENDIX

A SOFTWARE GUIDE FOR THE CLOUD LAB

J. Mrziglod

A.1 INTRODUCTION

The purpose of the Semi-Automated Cloud Imager System (SACIS) is to measure the cloud coverage and further cloud statistics along a ship track over the sea. It consists of three (optional four) components:

- **Pinocchio:** A former surveillance dual-camera system made by MOBOTIX consisting of a visible and an infrared camera. While looking at the zenith, it creates images of the sky and clouds.
- **Ceilometer:** An instrument mady by Jenoptik measuring the cloud base height by using a laser system at near-infrared wavelength.
- **DShip:** Additional atmospheric data (such as air temperature, pressure, etc.) is so far coming from a weather station of the research vessel where SACIS is deployed.
- **Dumbo (optional):** A dual-camera system similar to Pinocchio but with a more advanced infrared camera. Since it needs more maintenance than Pinocchio and cannot be driven full-automatically, it is only used as calibration reference for Pinocchio.

The CLOUD toolbox (`https://github.com/JohnMrziglod/cloud`) contains python scripts and modules to process and analyse the data coming from SACIS. This document explains how to install, to use and to develop this toolbox. If you just want to use the CLOUD toolbox without dealing with the underlying python code, you should read the sections A.2, A.3 and A.4. If you want to develop it further, the section A.7 gives more information about the internal structure to you.
Send an e-mail to john.mrziglod@mail.de if you run into any problems.

A.2 SETUP THE CLOUD TOOLBOX

A.2.1 *Install dependencies*

CLOUD requires python 3.6 or higher and the following packages:

1. numpy >= 12.0
2. scipy
3. pandas
4. xarray >= 0.10
5. matplotlib >= 2.0
6. netCDF4
7. Pillow >= 2.0
8. typhon

To install the first seven packages type this into your console:[1]

```
$ pip3 install -user numpy scipy pandas xarray matplotlib netcdf4
Pillow
```

typhon is a python package developed by the Radiation and Remote Sensing group of the Meteorological Institute of the University Hamburg. Since the required features for CLOUD are only in the developer version at the moment, it has to be installed differently. Go to your favourite directory (wherever you want to put the typhon module) and type those lines into your console:

```
$ git clone https://github.com/atmtools/typhon.git
$ cd typhon
$ pip3 install -user -editable .
```

A.2.2 *Get the* CLOUD *toolbox*

You can get the CLOUD toolbox via this command (run it where you want to have CLOUD toolbox):

```
$ git clone https://github.com/JohnMrziglod/cloud.git
```

Just type `$ cd cloud` and you are in the toolbox folder. And it is done!

A.3 SCRIPTS & USER FILES

A.3.1 *Scripts*

The CLOUD toolbox contains scripts that are designed to be used from the command line without requiring special knowledge about Python:

1 The $ sign does only indicate the start of a command line - do not enter it into your console.

Table 8: *Scripts of the* CLOUD *toolbox.*

Script	Description
`processor.py`	• Converts raw files to netCDF format and applies calibration. • Masking of images. • Calculates cloud statistics of camera images.
`monitor.py`	• Produces overview and comparison plots for all components.
`pinocchio_calibration.py`	Generates a calibration file from a performed Pinocchio calibration (see section A.6). Note: this script is deprecated and should be rewritten

The scripts' behaviour can be adjusted via command line options or the configuration file. Each script has its command line documentation, simply run `$ script_name.py -h`.

A.3.2 *Configuration file*

To avoid long command line arguments there is a file (per default called `config.ini`) that contains the paths to all datasets, mask & calibration files and further configurations. All scripts load the configurations from this file automatically. If you want to use a configuration file with a different name, you can call the script with `-config filename.ini`.

The configuration file syntax is similar to Windows' INI format. See table 9 for a description of all configuration sections. A detailed documentation of the configuration keys can be found in the example file in the CLOUD toolbox.

You can define via paths which files should be processed by the scripts and where they should be created. The paths can contain placeholders (e.g. `{year}`, `{month}`, etc.) that are used to retrieve temporal information from the path names.

This manual and in the command line documentation of the scripts will refer to the configuration keys in the file via `[Section][key]`.

Table 9: *Sections of the configuration file.*

Section	Description
General	Keys for number of common basedir, parallel processes, etc.
Dumbo	Paths to the raw, netCDF, cloud parameters and mask files of Dumbo.
Pinocchio	Paths to the raw, netCDF, cloud parameters, calibration and mask files of Pinocchio.
Ceilometer	Path to the netCDF files of the Ceilometer.
DShip	Path to the ASCII files of the DShip metadata.
Plots	Output paths of the generated plots, window size of average, etc.

A.3.3 *Calibration file*

Pinocchio instruments need calibration files to convert the pixel brightness into a temperature. Those calibration files are in CSV format and must contain two columns: one with pixel brightnesses (between 0-255) and one with their corresponding temperatures (in degree Celsius). You can find current calibration files in the directory `calibration`. You can create your own calibration files after performing a calibration with `pinocchio_calibration.py` (see section A.6). Set the path to the calibration file that you want to use in the config file via the key `[Pinocchio][calibration]`.

A.3.4 *Mask file*

When installing the cameras on a ship or close to buildings, parts of the image should be masked to avoid incorrect cloud statistics (e.g. if a pole reaches into the camera's viewing area). Simply create a matching mask by using the templates in the `masks` directory (e.g. with gimp) and set the path to the mask file via configuration key `[instrument][mask]`.
It is important that the mask matches the size of the raw images (Dumbo: 384x288, Pinocchio: 336x252). The mask should be a gray scale PNG image. White pixels are interpreted as transparent, black pixels as opaque.

A.3.5 *Logbook file*

If one works on the instruments during measuring, some images might be falsified. To exclude those images from processing, you can write a logbook file. This should be a ASCII file with at least two columns separated by tabulators. The first column contains the starting time of the falsification of the measurements in UTC, the second column contains the ending time. All images that are measured between those two timestamps will be excluded from processing. You can specify one logbook file for each camera system (Dumbo and Pinocchio). Set the path to the logbook file via the configuration key `[instrument][logbook]`.

A.4 USAGE & WORKFLOW

Before running any scripts you should check whether all configuration keys in `config.ini` are correctly set and whether the paths point to existing files (unless they are for files that are going to be created). I recommend to put all data from the instruments into one folder with subdirectories. You can then use the configuration key `[General][basedir]` to point to that folder. Make sure that the scripts that you want to run have executive permissions.[2] Afterwards you can follow this workflow:

1. **Copy the new data to their locations:** After recording, copy the data from the cameras and other instruments to the locations that you have set in the configuration file. Pinocchio images should be saved in tarball archives as JPG files, Dumbo images as ASCII files in unzipped folders. The Ceilometer data should be in netCDF format and the DShip data in CSV files.

2. **Process the images:** Convert the raw files into netCDF files (which are easier to handle) and calculate cloud parameters. Those cloud parameters are going to be saved in additional netCDF files. You can use the `processor.py` script for this. When having Pinocchio files, it also can extract them from their daily tarball archives. Here are the most common calls of `processor.py`:

   - Extract and convert Pinocchio images and then calculate their cloud parameters for one day:
     `$ ./processor.py -xcs "2017-11-03" "2017-11-04"`
   - Same as above but with a shorter time period:
     `$ ./processor.py -xcs "2017-11-03 12:00:00" "2017-11-03 16:00:00"`
   - Dumbo images can be processed by using the `instrument` (`-i`) option. Note that the `extract` (`-x`) option is unnecessary for Dumbo files and can be left out.
     `$ ./processor.py -csi Dumbo "2017-11-03" "2017-11-04"`

2 If not, you may run `$ chmod 744 script_name.py` first.

- If you want to calculate cloud parameters from already existing netCDF files of Pinocchio:
  `$ ./processor.py -s "2017-11-03" "2017-11-04"`

3. **Create plots:** You can plot an overview of all instruments with `monitor.py`. It can also create comparison plots between Dumbo and Pinocchio. The most common calls of `monitor.py` are:
   - Plot an overview of all instruments from 2017-11-02 to 2017-11-10:
     `$ ./monitor.py -o "2017-11-03" "2017-11-10"`
   - Same as above but instead of creating one plot for the full time period, we create one plot for every three hours. For this, we are using the `frequency` (`-f`) option.
     `$ ./monitor.py -of 3H "2017-11-03" "2017-11-10"`
   - Comparison plots of Pinocchio and Dumbo can be created with this command:
     `$ ./monitor.py -c "2017-11-03" "2017-11-04"`

A.5 CLOUD PARAMETERS

The main goal of SACIS is to calculate parameters from cloud images and retrieve further climate statistics. With `processor.py` one can calculate basic cloud parameters which are saved in the statistics files (where they should be saved can be set via `[instrument][stats]`). All cloud parameters are available for three different height levels:

- Level 1 - Low clouds: All clouds with a base height up to 2 km.
- Level 2 - Middle high clouds: All clouds with a base height from to 2 to 6 km.
- Level 3 - High clouds: All clouds with a base height higher than 6 km.

The cloud base height is retrieved by using a temperature gradient. At the moment, the temperature gradient is simply a lapse rate which provides a linear temperature descent (no inversions included). You can set the lapse rate via the config key `[General][lapse_rate]`.

A.5.1 *cloud_coverage*

The cloud coverage CC is the ratio between the number of cloud pixels and the total number of all unmasked pixel of the image:

$$CC = \frac{n_{\text{cloud}}}{n_{\text{all}}} \qquad [0-1] \tag{1}$$

A.5.2 *cloud_inhomogeneity*

The cloud inhomogeneity CI is a number to quantity the jaggedness of the clouds. It is defined by the perimeter of the clouds divided by their area:

$$CI = \frac{p_{cloud}}{A_{cloud}} \qquad [0 - \infty] \tag{2}$$

Please note that this parameter is very experimental and may be influenced by image size and the used mask.

A.5.3 *cloud_mean_temperature*

The cloud mean temperature CT_{mean} is the mean temperature of all cloud pixels.

A.5.4 *cloud_max_temperature*

The cloud max temperature CT_{max} is the maximum temperature of all cloud pixels.

A.5.5 *cloud_min_temperature*

The cloud min temperature CT_{min} is the minimum temperature of all cloud pixels.

A.6 CALIBRATION OF PINOCCHIO

Since the current script for calibration file generation, `pinocchio_calibration.py`, is deprecated, further instructions of how to do the calibration of a Pinocchio camera and how to generate a calibration file are missing here.

A.7 DEVELOPMENT OF CLOUD

A.7.1 *Developer documentation*

There is a HTML documentation of all used modules and classes which can be generated by Sphinx. Before you use it, make sure that you have installed Sphinx and its python modules:

```
$ pip3 install -user sphinx sphinx_rtd_theme
```

Call these commands in the directory of your Cloud toolbox:

```
$ cd docs
$ make html
```

Now you can open the `build/html/index.html` file with your favourite browser.

A.7.2 *Code style and design*

I tried following the Coding Style Guide by Google which is based on modern Python coding practices. The code is object oriented to make its structure better maintainable and extendable. If you are not familiar with object oriented programming, here is a good youtube video as an introduction.

The files for each instrument are represented by `typhon.spareice.Dataset` objects (link to further documentation and tutorial). I developed those objects to make handling and processing of datasets with many files easier and faster. `typhon.spareice.Dataset` is still under development and may change its API and name in future. When those major changes come, I will contact you so that the CLOUD toolbox can be developed and still benefit from typhon updates.

The classes `Movie` and `ThermalCamMovie` bases upon `ArrayGroup` (coming from `typhon.spareice.array`). While this works with a good performance, you may consider switching to use pandas dataframe or xarray in future for having more features.

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