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Precipitation Trade Wind Cumuli within EUREC^{4}A Field Campaign Report

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Acronyms and Abbreviations

AERIS	Atmosphere and Service Data Pole
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
ATOMIC	Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign
EGU	European Geophysical Union
ESSD	Earth System Science Data
EUREC^{4}A	Elucidating the Role of Clouds-Circulation Coupling in Climate
FMCW	frequency-modulated continuous wave
MRR	micro rain radar
RPH	roll, pitch, and heave
RV	research vessel
TCPIC	Trades Cumuli Precipitation Initiation and Characterization
UTC	Coordinated Universal Time

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1.0 Summary

The campaign Trades Cumuli Precipitation Initiation and Characterization (TCPIC) within the overarching Elucidating the Role of Clouds-Circulation Coupling in Climate EUREC^{4}A campaign took place from 17 January 2020 to 20 February 2020, a total of 35 days. The campaign complemented the more extensive EUREC^{4}A campaign focusing on cumulus clouds' role in the Earth's climate. TCPIC concentrated on understanding what triggers the onset and development of precipitation in trade wind cumulus clouds. The campaign requested the deployment of the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) roll, pitch, and heave (RPH) stabilization platform to stabilize two radars on the *Maria S. Merian* research vessel (RV). The advanced remote-sensing techniques from stabilized radars characterized the entire precipitation life cycle, from the formation of larger cloud drops to precipitation evaporating on its way to the surface. Retrievals of evaporation rates, to track how rain affects the trade wind boundary layer, will be based on the zenith-pointing Doppler observations collected from the stabilized micro rain radar (MRR).

Figure 1 shows the instrumentation's deployment on the RV: we installed the AMF RPH stabilization platform and the radars on the uppermost deck (peil deck) of the ship. For installing the devices, we coordinated a test phase of the equipment on the *Maria S. Merian* RV from 25 to 29 October 2019 in Emden harbor, Germany. In this testing phase, we set up all the connections, tested how to mount the W-band and the micro rain radars firmly on the table, and experimented with guided movements of the table to test the resistance of the whole system. Figure 1 shows the final tests conducted in Emden with the stable platform and the radars mounted.

Figure 1. Instrument deployment on *Maria S. Merian*. Testing phase in Emden, Germany.

The cloud radar RPG FMCW 94 deployed on the RV is a frequency-modulated continuous wave (FMCW) radar that transmits sawtooth frequency chirps at 94 GHz. It belongs to the RPG GmbH company. Vertical profiles of reflectivity, Doppler velocity, Doppler spectral width, and skewness can be obtained from 100 m to 10000 m above the surface. These radar variables provide information on the macro- and microphysical properties of clouds. The system also has a passive radiometric channel at 89 GHz that is sensible to cloud liquid water. Passive and active receivers use the same antenna. Before usage, the FMCW cloud radar receiver and passive channel need calibration for a cold and a hot target. We performed calibration after the installation on the peil deck using liquid nitrogen as the cold target in the Bridgetown, Barbados harbor. When the stable table is working, the cloud radar is zenith pointing and can detect the radar targets' fall speed. However, due to the beam width of the antenna, the radar observes a cone of the atmosphere. At approximately trade wind cumuli cloud base height (~500 m), the beam width of the radar is 4.2 m, while at around cloud top the beam width is 16.7 m.

The MRR is a vertically pointing FMCW Doppler radar operating in the K-band (24.1 GHz; 12.4 mm wavelength). It belongs to the University of Leipzig and was deployed on the ship thanks to Professor Heike Kalesse, who lent it to University of Cologne. The signal emitted from this radar is backscattered by rain and other falling hydrometeors. As in the case of the cloud radar, it collects a Doppler spectrum from which reflectivity and mean Doppler velocity can be derived, when the instrument is stabilized from ship motions. For this reason, it was installed on the stable table together with the cloud radar. From the mean Doppler velocity, fall speed of the drops can be retrieved if the wind is known. In the particular case of rain, the Doppler spectra can be used to derive the vertical profiles of microphysical rain properties like the drop size distribution and rain rate.

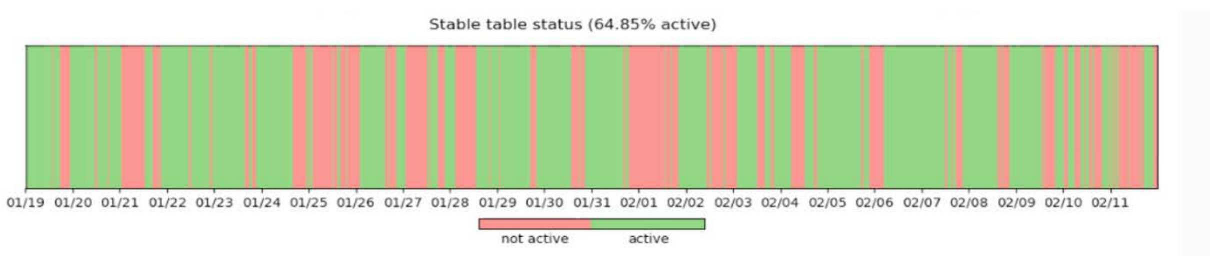


Figure 2. Stable table status for the entire campaign period.

During the campaign, the W-band and MRRs measured continuously 24/7 most of the time. Only on 20, 22, and 26 January 2020, some different settings were tested on the MRR. For unknown reasons, MRR data have not been collected from 00 to 04 UTC on 27 January 2020. The AMF RPH stabilization platform stabilized the FMCW W-band radar and the MRR from ship motion. The stabilization was crucial to obtain Doppler observations with vital information on the vertical movement of the hydrometeors. Unfortunately, the stable table did not operate all the time due to technical issues. The stable table got stuck unpredictably (see Figure 1) multiple times during the day. Various attempts were tried to find the reason, including reducing interference caused by other devices, and cable fixing. None of them really solved the problem. For this reason, we performed hourly surveillance of the device. However, this monitoring could not prevent some data being collected when the stable table was not working. From the data collected, currently:

- 64.5 % of the data have been collected with the stable table working
- 35.4 % of the data have been collected when the table was stuck.

Within the EUREC^{4}A campaign, the *Maria S. Merian* RV operations were carried out in concert with the *Meteor* and *L'Atalante* RVs and various airplanes and drones coordinated by EUREC^{4}A, as well as with the ships and sail drones of the American Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign (ATOMIC) project. Detailed information on the entire array of observing platforms can be found here: www.eurec4a.eu. The entire data set collected during the EUREC^{4}A campaign is free and available for download at the Atmosphere and Service Data Pole (AERIS) portal (https://observations.ipsl.fr/aeris/eurec4a/#/), under the EUREC^{4}A data policy agreement. On 17 January 2020, the RV's first operations took place offshore of Barbados in the so-called Trade Wind Alley, where it operated close to the *Meteor* RV (Figure 3). The ship then moved southward towards the region east of Trinidad/Tobago in the so-called Boulevard des Tourbillons (see Figure 2). The RV stayed above 10.5 degrees North latitude from 17 to 26 January 2020. It moved south and stayed in the Boulevard des Tourbillons region until 6 February, when it re-entered Trade Wind Alley.

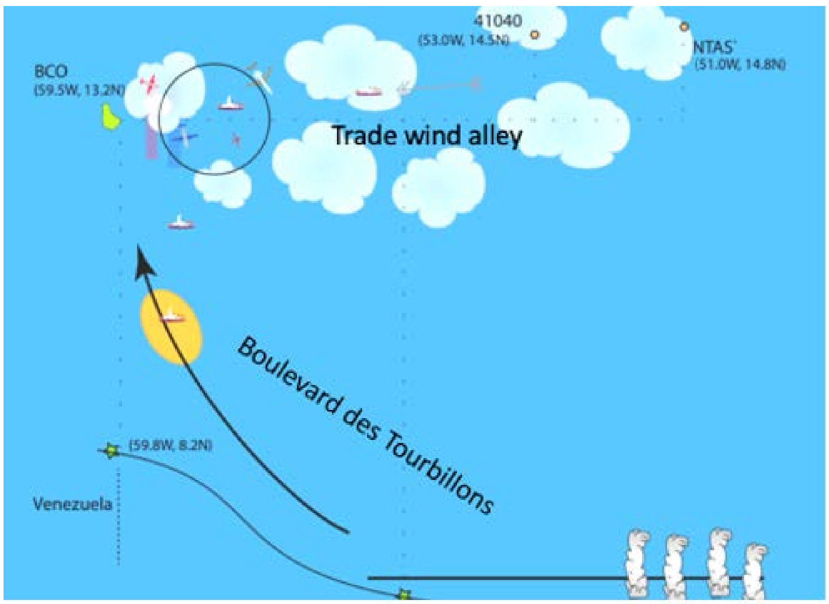


Figure 3. Areas of the operation of EUREC^{4}A campaign.

2.0 Results

We have to correct the data for ship motions to obtain significative results regarding precipitation. Only preliminary results have been derived using the non-corrected data set and are susceptible to changes. For correcting the data from ship motion, a detailed algorithm is under development, and it will be described in the planned Earth System Science Data (ESSD) data publication associated with this project.

Figure 4 shows the impact of the stabilization platform on the observations: the table completely attenuates fluctuations in the roll and correct for its biases induced by the uneven distributions of weights on the ship. When the table does not work, roll fluctuations are amplified.

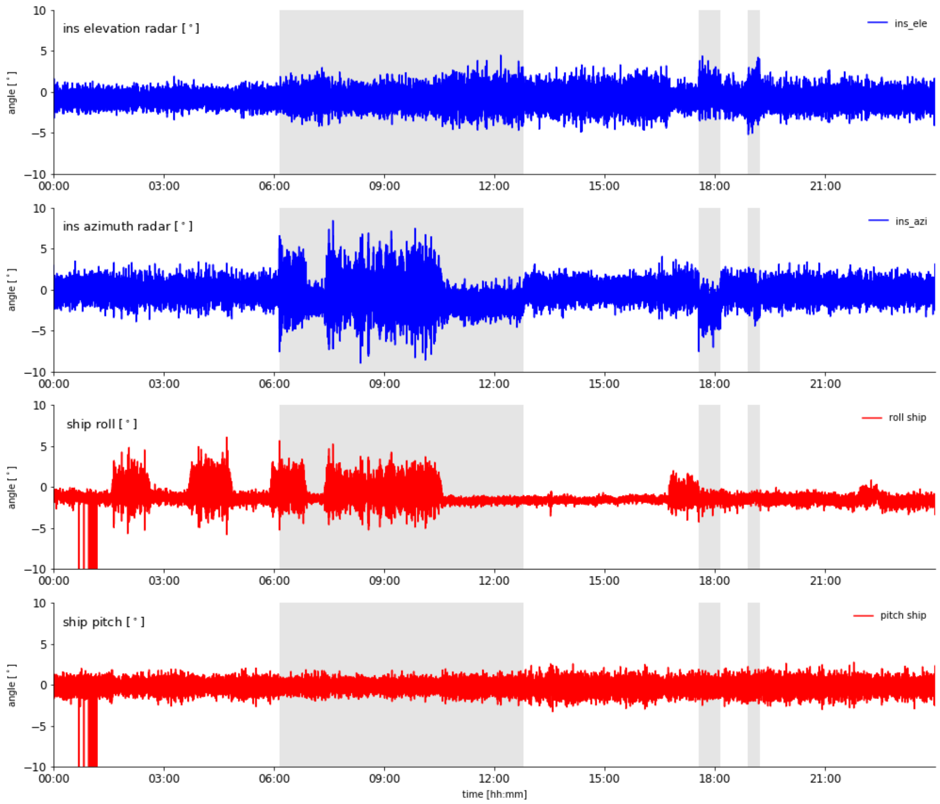


Figure 4. Time series of ship roll and pitch (in red), and of elevation and azimuth angles (in blue) from the radar sensor, corresponding to pitch and roll, respectively.

Figure 5 shows that the stabilization has a minor impact on the reflectivity distribution. For this reason, we used reflectivity to derive preliminary results regarding hydrometeor fraction.

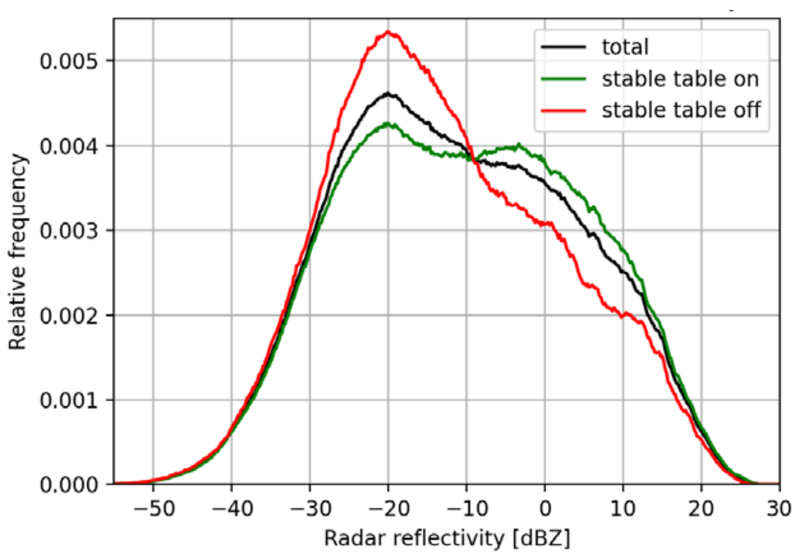
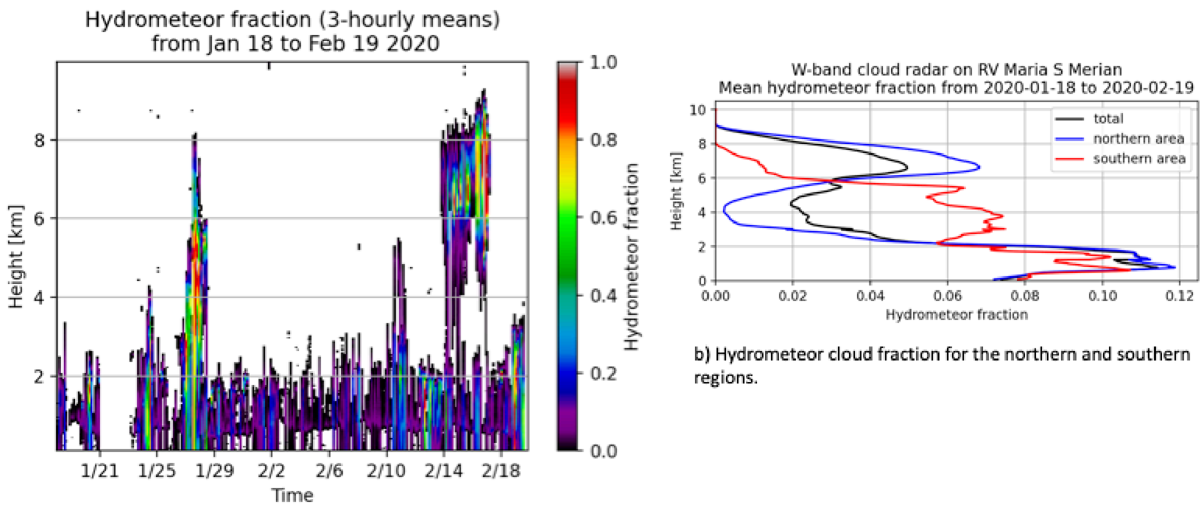


Figure 5. Influence of the stabilization of the radar reflectivity.

Figure 6 shows the 3h hydrometeor fraction for the entire campaign and its variability with latitude for data not corrected for ship motions. Only two major events with cloudiness above 3000 m height occurred during the campaign (Figure 6a), so the statistics of the variability above this height are too small to draw any conclusion. For the clouds developing in the boundary layer, however, we can observe a slightly lower cloudiness in the southern regions (below 10 degrees North latitude, Figure 6b) between 1 and 2 km heights, compared to the cloudiness observed above 10 degrees.



b) Hydrometeor cloud fraction for the northern and southern regions.

a) Time serie of hydrometeor cloud fraction calculated over 3h time intervals.

Figure 6. Hydrometeor cloud fraction calculated every 3h for the entire campaign period and its variability with latitude.

Finally, when comparing the diurnal cycle of the cloudiness, we found good agreement with modeling results obtained for the same region (Vial et al. 2019, in their Figure 3): the diurnal variability is similar to the one found in the model. However, the secondary maximum in the hydrometeor cloud fraction encountered in the model at night between 2 and 2.5 km is not really resolved by our observations. We still do not know if this can all be attributed to the attenuation the radar signal undergoes due to liquid droplets.

3.0 Publications and References

Preliminary results from the campaign have already been presented at the European Geophysical Union (EGU) 2020 conference held online on 4-8 May 2020. (Acquistapace, C, and T Boeck. Precipitation within EUREC^{4}A: a multi-sensor ship-based approach to tackle warm rain processes. EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-6265, https://doi.org/10.5194/egusphere-egu2020-6265)

Recently, a presentation has also been given in the EUREC^{4}A online conference, held on 11-12 August 2020.

Moreover, we plan an ESSD data publication associated with the publication on the data set on the ARM and AERIS portals, for which the current deadline is 3 November 2020. At the moment, a preliminary, non-corrected-for-ship-motion, version of the W-band radar data is available on AERIS. Associated with the ESSD publication, we plan to make the code for the calculation of the correction for ship motions available online for the scientific community using platforms like github.

The paper referenced in Section 2 is:

Vial, J, R Vogel, S Bony, B Stevens, DMM Winker, X Cai, C Hohenegger, AK Naumann, and H Brogniez. 2019. "A new look at the daily cycle of trade wind cumuli." *Journal of Advances in Modeling Earth Systems* 11(10): 3148– 3166, https://doi.org/10.1029/2019MS001746

4.0 Lessons Learned

I really enjoyed the collaboration with the ARM facility, in particular the support in the organization and the positive and constructive attitude of the people I worked with, including the entire board I met online for setting up the campaign. I am looking forward to developing new collaborations.

As a suggestion, I might add something on the practical side: we had bad luck and a lot of technical problems. This is not the fault of anyone. However, for the future, my recommendation might be to update the documentation on the stable table with the information that is really useful for operating the table. Also, I learned from the cloud kite scientists onboard with me that there are on market some modern devices that could really improve the performance of the stable table and make it more efficient. This would be great, for the future.

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