A UNIQUE CLOUD COCKTAIL

Investigating the interaction between clouds, weather and climate with the HALO research aircraft.

By Silke Groß

Think of Barbados, and you will no doubt find yourself dreaming of Caribbean beaches, palm trees and sunsets. For the scientists working on the EUREC4A mission things are different. As far as they are concerned, Barbados is, first and foremost, the place where air masses that have been carried over the Atlantic for days meet land for the first time. Therefore, they see it as the perfect location for atmospheric research. An international team has been investigating this special mix of clouds and how it is being altered by climate change in the research project EUREC4A (Elucidating the role of clouds-circulation coupling in climate).

Before the air masses of the trade winds reach the Barbados mainland, low-level marine clouds form as they travel over the ocean – trade wind clouds. These clouds are an important piece of the jigsaw for scientists investigating climate change, as they are highly sensitive to their environmental conditions and thus to further global warming. However, these types of clouds and their impact on the climate are only described with great uncertainty in current climate models. This is because some of these clouds are relatively small and form over the middle of the ocean, making it difficult to examine them more closely. The EUREC4A research campaign is one of the biggest projects to investigate these clouds and their dependence on environmental conditions. During a four-week measuring phase in early 2020, the scientists were able to establish a comprehensive picture that will take climate research an important step forward.

EUREC4A – ELUCIDATING THE ROLE OF CLOUDS-CIRCULATION COUPLING IN CLIMATE

The EUREC4A field study is an international project with over 40 partners led by the Max Planck Institute for Meteorology in Hamburg and the French National Centre for Scientific Research (CNRS) in Paris. As part of the campaign, four research aircraft, four research ships, and ground-based measuring equipment on Barbados were coordinated for use, and the measurement results were combined with high-resolution climate models and advanced satellite-based remote sensing. The team is currently evaluating the data that they collected on the measurement flights in early 2020. The scientists involved in EUREC4A are focusing on four main points:

- Cloud configuration and feedback processes – investigating the impact of environmental conditions on cloud structure, the mesoscale configuration of clouds, and cloud feedback effects
- Aerosol and cloud physics – investigating the effects of aerosols on cloud formation, structure, and properties – in particular, the impact of dynamic processes on the microphysics of clouds
- Boundary layer dynamics – turbulence, mixing processes
- Atmosphere-ocean interactions – examining exchange processes

Hunting clouds at sea and in the air

Equipped with remote sensing instruments and dropsondes for meteorological measurements, the German High Altitude and Long Range Research Aircraft (HALO) was able to get a close look at the structure of the entire lower atmosphere during its overflights. Adopting a circular flight pattern at an altitude of approximately nine kilometres, the researchers examined the clouds and the humidity – and the air

HALO RESEARCH AIRCRAFT

HALO was equipped with remote sensing instruments for the research campaign. On board were a radar, a lidar (light detection and ranging), a spectrometer, radiometers and meteorological dropsondes. For the measurements over the ocean, the long flight time was particularly decisive – a unique selling point of the research aircraft. It flew the same circular flight path for nine hours. A further advantage of HALO is its flight altitude: in previous EUREC^{4}A campaigns the aircraft carried out measurements up to an altitude of 15 kilometres.

POLARISATION DIVERSITY DOPPLER RADAR (POLDIRAD)

Wavelength/frequency: 5.5 centimetres / five Gigahertz

Antenna diameter: five metres

Technical features:
transmitting and receiving with any polarisation

Field of application: measurement of precipitation (shape, phase and velocity vector)

flowing in and out of the weather system – important factors in determining the processes of cloud formation.

Below HALO, an ATR-42 – an aircraft operated by the French National Centre for Scientific Research (CNRS) – and a Twin Otter – a turboprop aircraft operated by the British Antarctic Survey – analysed the properties and structures of the clouds within the weather system. Flights made by the WP-3D from the US supplemented the observations with measurements made over the ocean further to the east. In addition to the aircraft measurements, four research ships – the German research vessels Meteor and Maria S. Merian, the US research ship Ronald H. Brown and the French research ship L'Atalante – studied the ocean and atmosphere around Barbados. The research ships served as remote sensing and in-situ platforms equipped with radiosondes, lidar and radar technology, kite balloons and uncrewed flight systems.

Approaching clouds in a controlled way and taking samples requires knowing their exact position. To that end, scientists from the DLR Institute of Atmospheric Physics brought their Polarisation Diversity Doppler radar (POLDIRAD) system to the island. With an antenna measuring five metres across, it provides information about clouds and precipitation over the ocean at great distances. These measurement data were sent to the research aircraft in real time so that the scientists and pilots could adapt their flight routes accordingly.

An obstacle course

The POLDIRAD cloud radar is usually installed on the roof of the Institute of Atmospheric Physics at the DLR site in Oberpfaffenhofen. For the EUREC^{4}A mission, the system was dismantled and safely stowed in five shipping containers for the Atlantic voyage to Barbados, which took several months. Of course, it was practically inevitable that not everything would go to plan.

The team encountered numerous difficult moments in the process of getting the equipment to its destination in the Caribbean – from the complex transport logistics, to altered import and customs procedures in Barbados. Thanks to support from colleagues on the ground, customs released the containers just in time for the start of the campaign. Everyone worked hard to set up, test and put POLDIRAD

During the EUREC^{4}A mission in February 2020 – a 360-degree image of the pilots, Marc Puskeiler (left) and Stefan Grillenbeck (right) with atmospheric researcher Manuel Gutleben in the flight deck.

into operation within a very short space of time. The potential of the radar system from Oberpfaffenhofen was evident from the very first day of measurements, when it recorded the horizontal and vertical structure of clouds up to a distance of 250 kilometres. The team worked around the clock in shifts to observe changes in the clouds over time throughout the day. The real-time measurement results enabled the pilots to head for the clouds over the Atlantic off the coast of Barbados and to coordinate the research aircraft effectively.

Round-the-clock measurements

The scientists were particularly interested in the formation and evolution of the different cloud structures. To obtain answers, they had to look at the complete lifecycle of clouds, ideally before they had even formed. Cloud systems usually form at the end of the night and change over the course of the day as they interact with incoming solar radiation. This meant that it was important to get up early. During the campaign, the HALO flights were staggered between 04:00 and 20:00 (the most active time for cloud systems). Flying multiple research aircraft made it possible to extend these observations into the night. Using the WP-3D, ATR-42 and HALO on a staggered schedule allowed the scientists to observe environmental conditions and cloud formation and development on an almost 24-hour basis.

If embarking on a night flight, for instance, the WP-3D would take off at around 20:00. The ATR-42 and HALO followed at four-hour intervals. The scientists had to arrive at the airport approximately three hours before the scheduled departure in order to prepare and calibrate the instruments for the flights. The pilots, technicians and scientists who would be flying on board came to the hangar one hour before take-off. There was plenty to do in the intervening time – reviewing the systems one last time and discussing the flight sequence were crucial tasks. Those who were not part of the crew would leave the aircraft 15 minutes before take-off, and then it would be 'all systems go'.

While HALO flew according to a fixed flight pattern, the ATR-42 focused on deliberately approaching and examining clouds and areas of precipitation – a difficult feat on a night flight. Fortunately, the POLDIRAD cloud radar was operational and able to supply the necessary information directly to the aircraft. After the flights, the aircraft landed back at Barbados Airport. The data were then saved and the team discussed the performance of the individual instruments, problems that occurred during the flight, and the achievement of the

The aerosol and water vapour lidar implemented by the DLR Institute of Atmospheric Physics

Silke Groß in the HALO research aircraft

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The Meteorological Observatory BCO (Barbados Cloud Observatory) operated by the Max Planck Institute for Meteorology Hamburg, located at Deebles Point, Barbados.

scientific objectives, before finally heading off for a well-deserved rest at the end of a long day.

In addition to the HALO measurements, the researchers had planned to use POLDIRAD to monitor the development of the clouds over the ocean over a longer period of time. Unfortunately, the team had to leave Barbados earlier than they had envisaged due to the Coronavirus pandemic. The POLDIRAD weather radar equipment is still in Barbados. It is playing an important role in weather forecasting in the Caribbean, as it is currently the only functioning weather radar on the island. The Oberpfaffenhofen team plans to head back to the Caribbean in autumn 2020 to continue its weather radar measurements.

Silke Groß works at the Lidar Department of the DLR Institute of Atmospheric Physics and leads the Radar and Lidar Synergies working group.

PREPARATIONS FOR THE EARTHCARE CLIMATE MISSION:

EarthCARE (Earth Cloud Aerosol Radiation Explorer) is a research mission devised by the European Space Agency (ESA) and the Japanese Space Agency (JAXA) to examine aerosols and clouds, as well as their interactions and climate impact. Equipped with sophisticated lidar (light detection and ranging) technology, a Doppler cloud radar (radio detection and ranging) and sensors for measuring radiation, it is one of the most complex satellites for researching aerosols and clouds.

In the EUREC^{4}A campaign, the HALO research aircraft flew with an almost complete suite of EarthCARE-like instruments (radar, lidar, spectrometer and radiometer). It is one of only two research aircraft worldwide for which this is possible. Such measurements emulate future EarthCARE studies and are providing some initial insight into how the instruments interact. This is also enabling the testing and further development of algorithms to be able to assess the strengths and weaknesses of future satellite measurements – an important step in preparing for the future satellite mission.

Planned launch:
2022

Duration:
3 years, plus 1 year of reserve fuel

Orbit:
Altitude 393 kilometres , Sun-synchronous

Instruments
Doppler radar (94 GHz), high spectral resolution lidar (355 nm), multispectral imaging spectrometer, broadband radiometer

THE CLOUD COLLECTOR

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In conversation with Bjorn Stevens, Director of the Max Planck Institute for Meteorology in Hamburg and Head of the EUREC^{4}A research campaign.

Professor Stevens, you have led the largest international cloud research campaign to date. What were the challenges?

: EUREC^{4}A is the result of more than a decade of work, largely in close collaboration with my French colleague, Sandrine Bony, and a particularly cooperative and creative community of German scientists from DLR and various universities who have worked in recent years to establish HALO as one of the world's most outstanding research platforms. So, the study went very well. Nevertheless, we had challenges. An interesting one arose of the different cultures of scientific practice among scientific groups. In atmospheric research, we are often interested in certain phenomena and then look for exactly these phenomena. In other words, we are chasing a signal. But this gives a distorted picture of how often and how strong effects occur. For a statistical study of the kind we wanted to conduct, the biggest challenge was convincing team members again and again that what you do not measure sometimes provides more information than what you measure. To see the big picture, you also need to understand what and how often things you expect to happen are not in the picture. So, things become meaningful through their absence.

> "What you do not measure sometimes provides more information than what you measure"

What do you remember most about the campaign? And what did you learn about cloud formation and its effect on the climate?

: It is too early to say exactly how clouds influence the pace of global warming. However, we are very confident that we have collected the data required to answer this question. What struck me most about the campaign was that changing circumstances help us see each other in a different light – be it that young scientists took on responsibility or that we received local support to carry out our measurements. In terms of nature, I also have indelible memories of the campaign – the impact of the winds on water as a layer of air over the ocean cooled by evaporating rain, or the way the clouds flowed into the colours of the setting sun.

Where would you like to travel next for research and why?

: In August 2023 or 2024 I hope to find myself near 35 degrees west and 10 degrees north, in the North Atlantic Ocean between Venezuela and Guinea. There, in the deep tropics, air masses from the southern and northern hemispheres meet and create violent rain bands, the formation of which releases enormous amounts of energy that influence the climate worldwide.

This interview was conducted by **Falk Dambowsky**, a Media Relations editor at DLR.

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