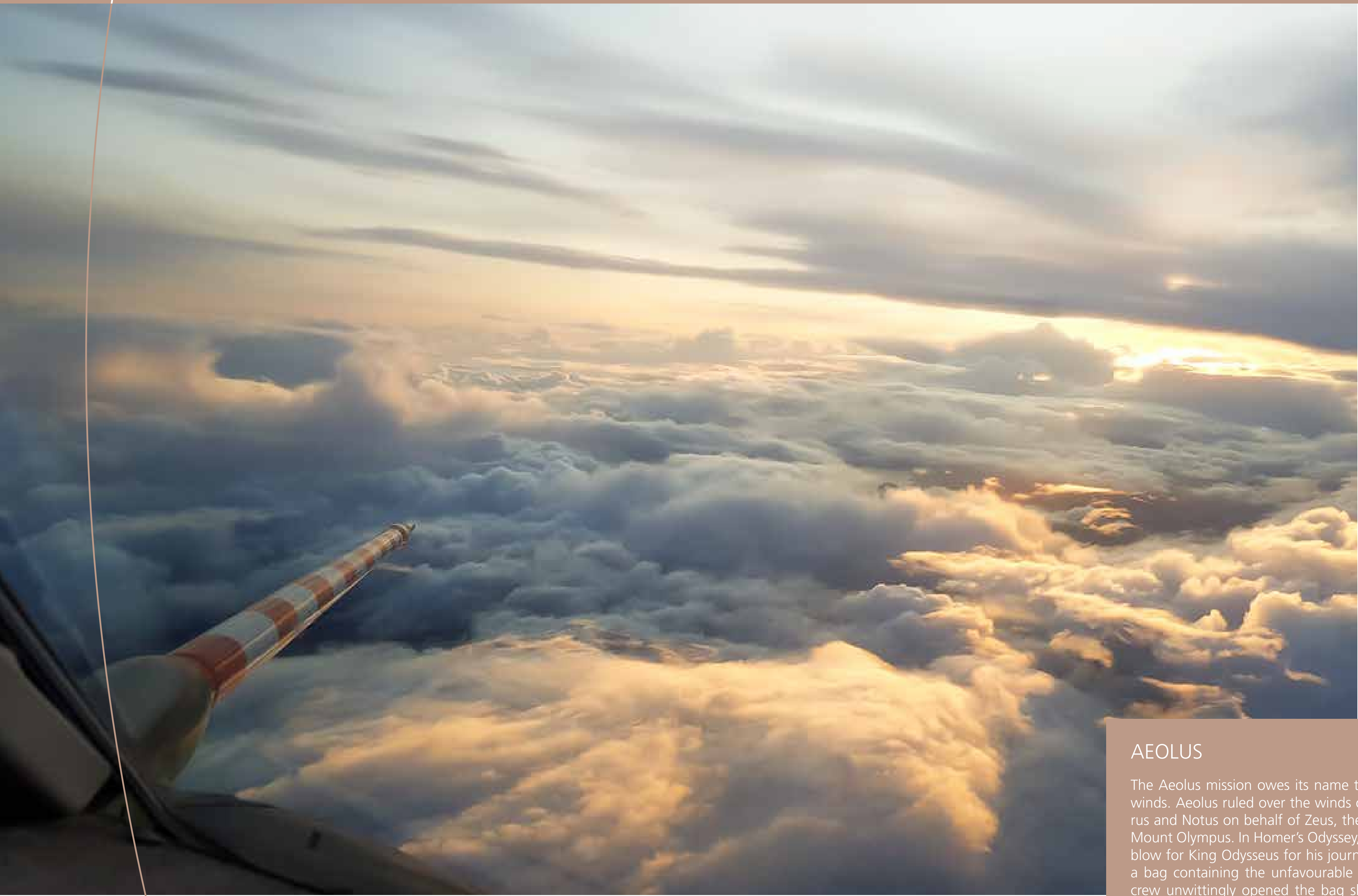
ON THE TRAIL OF THE WIND

DLR scientists take to the skies over Iceland for the Aeolus mission

By Manuela Braun



Icelanders are said to have more words for snow than even the Inuit, and likely many more for rain and wind. A team of DLR atmospheric scientists and research pilots spent three weeks in Iceland with the DLR Falcon 20E research aircraft to measure wind speeds. Their campaign took place at the same time and, to the greatest extent possible, followed the same route as the Aeolus satellite, which has been orbiting Earth with its on-board Atmospheric Laser Doppler Instrument (Aladin) since 22 August 2018. During their stay, the team also became well acquainted with the many different types of rain and wind – horizontal rain, dreadful drizzle, and the clammy cold rising from the wet floor in the aircraft hangar at Keflavik Airport. All of these were usually accompanied by dense cloud cover over the volcanic landscape. Alternating high and low pressure areas create variable wind speeds. The jet stream – a band of constantly shifting strong winds – often flows nearby. These are ideal conditions for the Aeolus Validation Through Airborne Lidars in Iceland (AVATARI) campaign. It compares the data acquired by the first satellite-borne wind lidar with measurements from an aircraft to validate the wind profiles acquired from space and improve the retrieval algorithms.

The situation is complicated. Nobody can anticipate how fast the low-pressure system will advance in the next few days or whether it might even act unpredictably. "If conditions here develop more quickly, the situation will change completely," says Andreas Schäfler of the DLR Institute of Atmospheric Physics. Oliver Reitebuch and Christian Lemmerz, who also work at the Institute, carefully study maps showing wind directions and speeds, as well as cloud cover for the next few days. The trio have converted the hostel's lounge into a conference room, in which they are planning the Falcon's next measurement flights. The room – with its cosy and somewhat worn armchairs, a coffee table, a floor lamp and a small bookshelf in the corner – is the meeting point for everyone at the end of the day.

Located 40 kilometres from Iceland's capital city of Reykjavik, the hostel is usually occupied by holidaymakers who either have a very early flight home from Keflavik airport or who arrived in the country late at night. In the past, US military personnel lived and worked here when it was part of the former NATO base, Ásbrú. Nowadays, the area is accessible to the public and some of the residential buildings have been transformed into simple, practical hotels with rooms looking out over the airport's perimeter fence. For the researchers, pilots and technicians of the Aeolus team, this is ideal as it takes just a few minutes by car to reach the hangar where the Falcon is parked. The hostel has therefore become the 'base camp' for DLR's three-week measurement campaign.

AEOLUS

The Aeolus mission owes its name to the Greek god of the winds. Aeolus ruled over the winds of Boreas, Eurus, Zephyrus and Notus on behalf of Zeus, the most powerful god on Mount Olympus. In Homer's Odyssey, he let favourable winds blow for King Odysseus for his journey by sea and gave him a bag containing the unfavourable winds. When the ship's crew unwittingly opened the bag shortly before arriving at their home port, the winds escaped and drove them back to their point of departure.

Under the track of the satellite

The first week went so well that the campaign team could hardly believe it. Already during the transfer flight from Oberpfaffenhofen, near Munich, to Iceland on 9 September 2019, the scientists switched on the instruments on board Falcon and followed the ground track of the Aeolus satellite north of Scotland. The 'A2D' lidar instrument has the same system architecture and receiving optics as Aladin on Aeolus, and was used alongside the 'two-micron wind lidar', a well-proven system that provides more accurate wind speed measurements. Thus, the first AVATARI dataset was stored even before the team arrived in Iceland. Over the following days, the Falcon took off almost daily to measure the wind as synchronously as possible with the satellite. Wind speeds of up to 60 metres per second, mixed cloud coverage – and then a flight on 17 September through the jet stream's strong winds. "A dream," says Oliver Reitebuch, Scientific Lead for the Aeolus Data Innovation and Science Cluster (Aeolus-DISC) at DLR.

Hoping for ideal conditions

Now, in the second week of the AVATARI campaign, the dream is crumbling a little. During the calibration flight over the Greenland ice, a safety mechanism on the wind lidar caused problems, and not all measurements could be carried out as planned. Troubleshooting will be conducted upon return to the hangar. At the same time, the weather around Iceland is becoming much more unstable. Twice a day, meteorologist Andreas Schäfler retrieves forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF).

An ideal measurement flight must meet certain conditions. The cloud coverage below the predicted satellite track should not be too high or too dense, as the laser pulses from space cannot penetrate dense cloud cover. "However, some clouds on the measurement path are also quite good for observing the reaction of the Aeolus instrument to them," Schäfler adds. Since the satellite orbits the Earth from pole to pole and only takes measurements transverse to the flight direction, east-west winds are easiest to capture. High wind speeds that vary at different altitudes above the ground are particularly suitable to calculate detailed wind profiles. The jet stream with its strong winds is therefore particularly interesting for atmospheric researchers. "We want sophisticated scenarios that are challenging for the satellite wind mesaurements," emphasises Campaign Coordinator Christian Lemmerz. Falcon's flight route may not extend south of Iceland into the North Atlantic flight corridor, in which a large proportion of air traffic from Europe to America takes place. If the Falcon comes too close to this area, Air Traffic Control will give a command via radio to turn back. When planning the measurement flights, the rest periods between flights required for the crew as well as the pilots Roland Welser and Thomas van Marwick must also be taken into account.

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Briefing in the breakfast room. From left to right: Christian Lemmerz, Frank Probst, Oliver Reitebuch and Andreas Schäfler decide when and over which route the next measurement flight should be conducted.

THE ALADIN INSTRUMENT

Aladin, the Atmospheric Laser Doppler Instrument, is the first lidar (light detection and ranging) system carried by a satellite for distance-resolved measurement of wind speeds. It fires laser pulses towards the atmosphere. The light scattered back from the atmosphere is used to determine the wavelength shift with spectrometers. The Doppler effect is proportional to the wind speed in the direction of the laser beam.

- Laser wavelength: 355 nanometres
- Laser pulse energy: 60 millijoules
- Pulse repetition rate: 50 Hertz
- Telescope diameter: 1.5 metres
- Vertical resolution: 500 metres to 2 kilometres
- Horizontal resolution: 10 to 90 kilometres
- Specified measurement accuracy:
  2 to 3 metres per second random error, 0.7 metres per second systematic error

LASER INSTRUMENT WITH EXPERTISE FROM GERMAN INDUSTRY AND RESEARCH

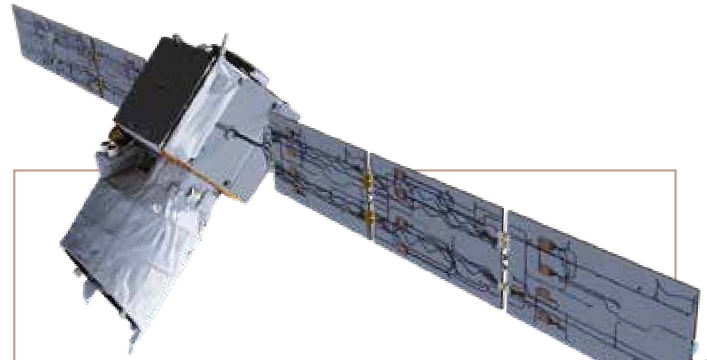
The Aeolus satellite was launched on 22 August 2018 from Europe's spaceport in Kourou, French Guiana, and orbits the Earth at an altitude of 320 kilometres. The mission is part of ESA's 'Living Planet' programme, in which Germany is the primary partner and contributor. The DLR Space Administration in Bonn manages Germany's contributions to ESA on behalf of the German federal government. Aeolus, and the Aladin laser system in particular, can improve medium-range weather forecasts. German industry and academia were involved in the development of the laser instrument. OHB System AG in Munich developed the transmit-receive optics for the ultraviolet laser. Tesat-Spacecom GmbH in Backnang built the communications system and the reference laser for the Aladin instrument. Airbus in Friedrichshafen was responsible for the electrical systems on the satellite platform. A number of small and medium-sized enterprises and research institutions achieved a technical breakthrough with the qualification of the laser optics for operation in vacuum. The companies Layertec GmbH (Mellingen) and Laseroptik GmbH (Garbsen) supplied optics and coatings, the Laser-Laboratorium Göttingen eV, the Laser Zentrum Hannover eV and the DLR Institute of Technical Physics in Stuttgart carried out the optical qualification and test measurements. These facilities contributed significantly to the integration of an optical system into the instrument that, despite the high laser power, will operate reliably for the planned three-year service life of the satellite.

More information: t1p.de/j1s4

Filling in the gaps in weather forecasting

Aeolus is a European Space Agency (ESA) satellite mission aimed at filling the gaps in medium-range weather forecasting. Such a mission has long been at the top of the wish list of the World Meteorological Organization (WMO), a part of the United Nations to which the German Weather Service also belongs. "We only have a few wind measurements in the upper layers of the atmosphere," says Reitebuch, referring to localised measurements performed over land with balloons or radiosondes. But what happens worldwide in the various layers of the atmosphere has not been sufficiently measured. "We are lacking data for the southern hemisphere, the tropics and over the oceans." The wind, however, is crucial for circulation in the atmosphere. Given that the data is sparse, weather forecasts for events such as tropical cyclones or for wind speeds in the jet stream – needed by aircraft operators for optimal route selection – are not very accurate, especially for more than three days ahead.

The first wind lidar workshop took place in the late 1980s, with the aim of determining the requirements for such a unique mission. The development of the Doppler lidar Aladin broke new ground. To reduce the risk and support the development, it was decided to build a prototype of the instrument for tests on board an aircraft. The first flight campaign finally was in 2009 with a demonstrator of the satellite instrument on board the Falcon. Now that the satellite is in operation, the airborne demonstrator collects comparative signals to validate the satellite data acquired from an altitude of 320 kilometres. Reitebuch has been working on the Aeolus mission for two decades – "Actually, most of my professional life". DLR's main task is to develop the algorithms and processors that convert the detector signals transmitted to Earth by the satellite into final products.



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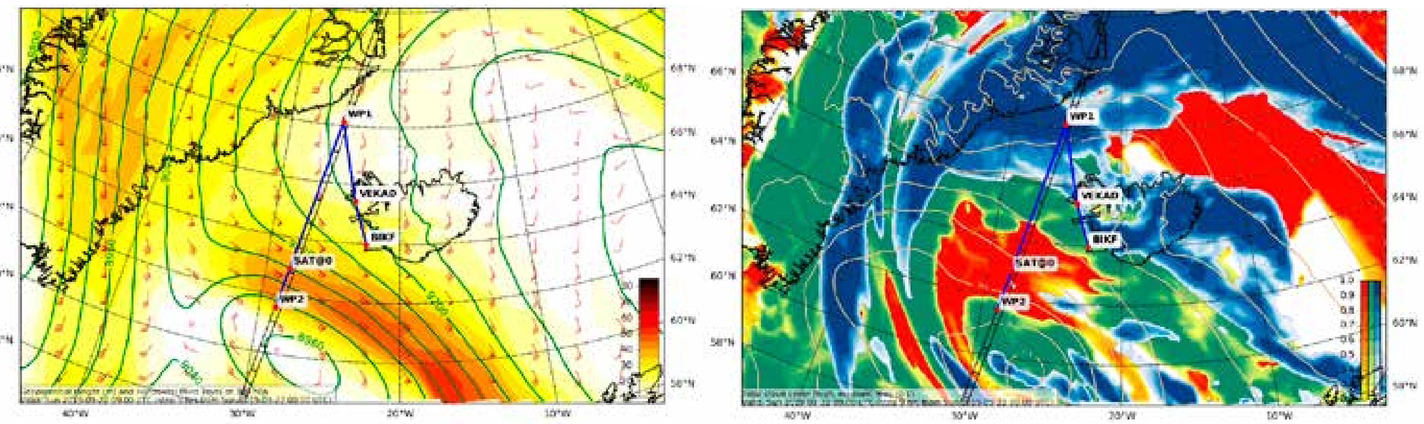
AEOLUS DATA INNOVATION AND SCIENCE CLUSTER

DLR coordinates the ESA-funded Aeolus Data Innovation and Science Cluster (Aeolus-DISC). Together with 10 international partners, including ECMWF, Météo-France or KNMI, the cluster has the task of monitoring and improving the performance of the Aladin instrument on board the Aeolus satellite and the quality of the resulting data. Another important task is the further development of algorithms and processors to convert the detector signals from the lidar into final wind and aerosol products. The cluster also conducts experiments with numerical weather forecasting models to investigate the influence of Aeolus data on medium-range weather forecasts.



The predictions by the European Centre for Medium-Range Weather Forecasts (ECMWF) for wind (left) and cloud cover (right) on 22 September 2019 show high wind speeds and relatively little high cloud cover along track. The Aeolus satellite – the probable track of which DLR scientists have marked with a black line on the weather maps – passes over a low-pressure area south of Iceland. The left image is colour-coded to show the wind speeds at an altitude of approximately 10 kilometres. The blue line indicates the Falcon's route from Keflavik, its flight under the satellite (WP1 to WP2) and its return to Keflavik. The image on the right shows the cloud cover as seen from the satellite. High clouds are shown in blue, medium-level clouds in green, and low-level clouds in red.

Rendezvous with Aeolus

The decision is made in the hostel lounge; the conditions for a measurement flight look favourable on Sunday morning. A band of south-easterly winds is within range and the point at which the Falcon can turn onto the predicted satellite track seems to be in a region with higher wind speeds. Even though the satellite travels at an altitude of 320 kilometres and a speed of 7.5 kilometres per second, and the Falcon 'only' flies at 200 metres per second and an altitude of approximately 10 kilometres, the instruments have the same field of view. The DLR flight operations staff can now take over. The pilots receive the data needed for their flight planning, and their coordinator, Frank Probst, registers the flight and route with Air Traffic Control. The Falcon is due to take off at approximately 07:00 local time and the rendezvous with the satellite will take place at 08:28.

The first team is already in the hangar by 04:10. The instruments are sensitive and need to be switched on before the flight, to achieve the correct temperature. It was cold in the hangar during the night. Christian Lemmerz squeezes between instrument racks and equipment to reach the laser instrument's control console. One more piece of equipment in the Falcon and there would be no room for the scientists. It took several days before the flight campaign to install and test everything for correct functioning and safety in Oberpfaffenhofen. Lemmerz knows the instruments inside out. Switches are flipped, the cooling for the laser is started, and computer programs are activated. Gradually, A2D and the two-micron lidar come to life. Technician Christoph Grad checks the Falcon's nose boom, in which sensors acquire information on wind direction and speed, as well as on temperature and humidity during the flight. For the scientists, this provides additional information with which they can classify their wind measurements in the direction of the ground over the course of the flight.

At 05:00, the rest of the team arrives at the hangar with the pilots and the scientist who will be operating the two-micron instrument during the flight. It is still dark outside the big metal doors and rain is falling steadily. Pilot Thomas van Marwick puts his bag in the aircraft and unpacks his sandwiches as he prepares for the three-and-a-half-hour flight. This campaign does not require any demanding flight manoeuvres. Roland Welser has been at the controls of the Falcon for decades and Thomas van Marwick joined DLR as a pilot six years ago. "This is not an exciting flight for us," he says. "There is plenty of time to eat breakfast, but flying over Iceland and Greenland always offers an incomparable view." The final preparations are carried out in a calm and focused manner. Everyone knows the schedule. Postponements are not possible, because the research aircraft has to fit with the departures of the big commercial airliners. The Falcon is rolled out of the hangar and takes off at 06:58.

After landing at 10:30 it is clear that the decision to conduct the flight was the right one. On the satellite track, the unwanted high clouds were only present over the northern part of the route. Elsewhere, the instruments encountered some clouds in the lower levels of the atmosphere. The wind speed ranged from moderate to higher speeds of about 50 metres per second. A hard drive with the data is transferred from the Falcon into the hands of Stefan Rahm. He has constructed a mission 'ground segment' in his hostel room with which the fresh data can be processed and examined to gain a first impression. Each flight yields 200 gigabytes of new data to be compared with that acquired by the satellite and for optimising the retrieval algorithms. "My colleagues like to fly the Falcon until it almost falls from the sky," jokes Rahm and disappears to his computer with the data.

The measurement instruments are sensitive – any failure during flight can lead to the loss of research data. Before the flight, Oliver Reitebuch makes sure all the instruments are ready for take-off.

In the Falcon's very confined cabin, Campaign Coordinator Christian Lemmerz (right) and Uwe Marksteiner prepare the instruments for the upcoming measurement flight.

The pilots Roland Welser (left) and Thomas van Marwick go through the final procedures before the Falcon takes off with the instruments and scientists on board.

Christoph Grad is responsible for ensuring that the Falcon is able to record parameters such as temperature, humidity and wind direction during flight using its on-board instruments.

Successful results for AVATARI

"There are several reasons why we need such DLR campaigns," explains Thorsten Fehr from ESA. "Firstly, they helped prepare the mission for launch. Now, they are also improving the mission by calibrating and validating the satellite data." A possible follow-up mission can only be defined if the weak points, successes and requirements have been carefully analysed. In addition to DLR and the DISC consortium, only a select group of international lidar teams and weather services currently have access to the Aeolus data from space. The global wind profiles can only be incorporated into existing weather forecasting models when the quality of the data is guaranteed and its processing is optimal. It is anticipated that the data will be made available to the broader scientific community from the beginning of 2020.

At the end of the AVATARI campaign, the Falcon will have followed the Aeolus satellite's track a total of 10 times. Additionally, the scientists were able to calibrate their instruments twice during flights over Greenland's ice. "This is more than in any of the earlier campaigns conducted for the Aeolus mission," says Oliver Reitebuch, summing up the missions. And also, more than would have been expected, judging from the weather situation during the campaign. This is a further step towards more accurate medium-range weather forecasting. The wind profiles recorded by Aeolus in the tropics, for example, will improve forecasts globally. "When it comes to the weather, everything is ultimately intertwined," says Reitebuch.

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Weather and wind were not always favourable, but in the end the scientists were able to obtain extensive datasets during a record number of measurement flights. This will enable them to put the data acquired by the satellite to the test and develop new evaluation algorithms.