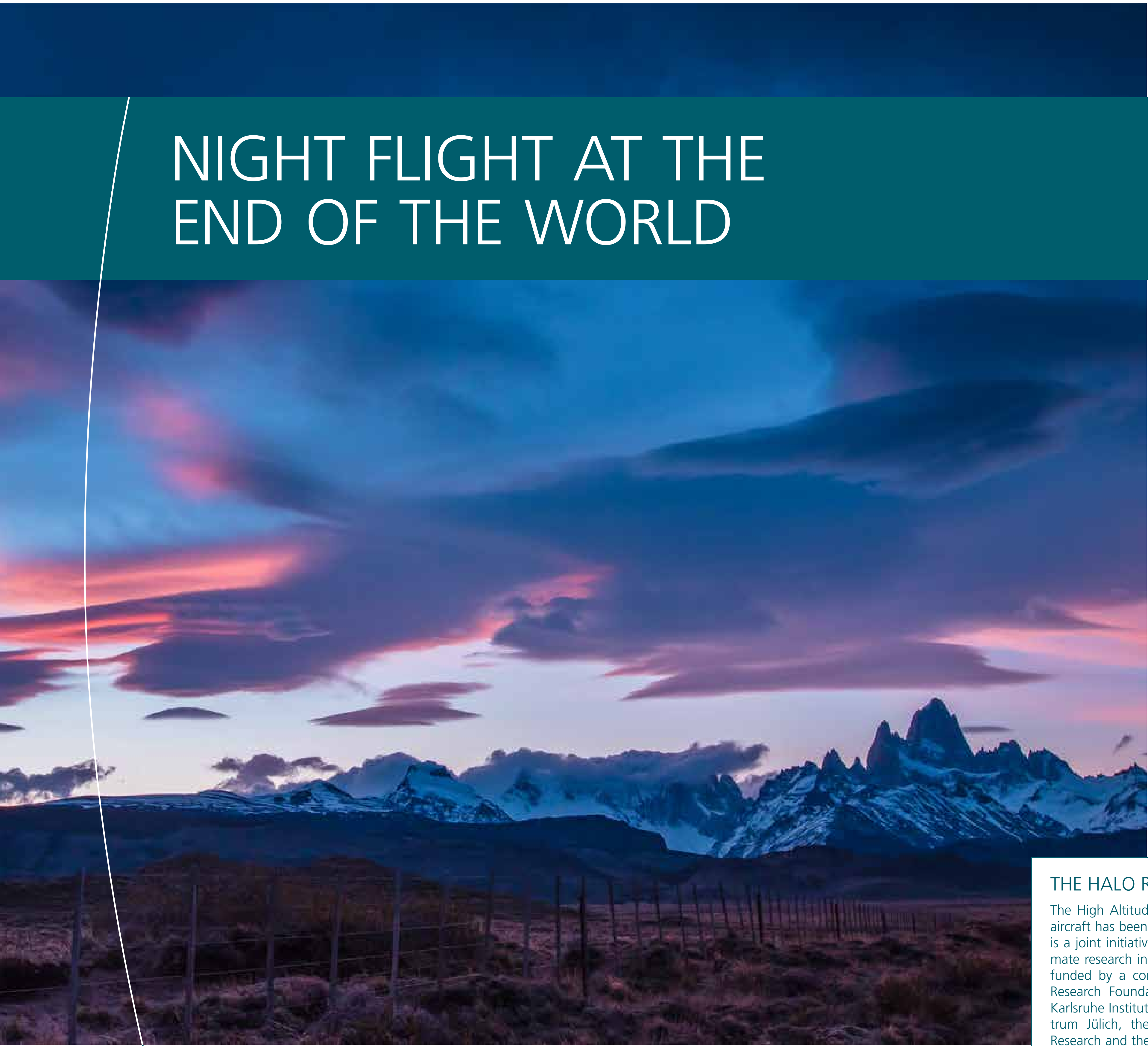

NIGHT FLIGHT AT THE END OF THE WORLD

DLR's HALO research aircraft is on a mission to investigate atmospheric gravity waves

By Falk Dambowsky

Antarctica is one of the most remote and least-explored regions on Earth. At first sight, what is happening there seems very distant, yet it has a great impact on the global climate and, therefore, on all of humankind. The behaviour of the global population, in turn, affects events in these distant polar regions. And although the ozone hole over Antarctica is now slowly shrinking again, the chemistry and physics of the atmosphere above Antarctica, and hence the processes relating to global warming at play there, will influence the global climate for decades to come. Only a few people – scientists, engineers, research pilots – travel deep into the southern sub-polar region to measure, explore and understand these interrelationships and processes. In 2019, a team from Germany joined them, on a mission with the High Altitude and Long Range (HALO) research aircraft.

On this occasion, HALO is staying in a rather worn old military hangar that has rarely been used since the now long past Falklands War. Behind it, an extensive landscape – endless grassland, dotted with grazing sheep. The town of Río Grande lies on the other side of the airfield. At night, all that can be seen above this town of 66,000 inhabitants on the Atlantic coast are lights. Besides the two scheduled flights from Buenos Aires that land here every day at 03:30 and 08:00, the airspace over Tierra del Fuego, at Argentina's southernmost tip, is very quiet.

The SOUTHTRAC (Transport and Composition of the Southern Hemisphere Upper Troposphere and Lower Stratosphere) campaign team comprises researchers from the DLR Institute of Atmospheric Physics, the Karlsruhe Institute of Technology, the Forschungszentrum Jülich, the universities of Mainz, Frankfurt, Wuppertal and Heidelberg, and DLR Flight Operations. They have set up a makeshift control room in a run-down, wood-panelled office adjacent to the hangar. This is where everything comes together – weather forecasts are analysed, flights are planned, and contact is maintained with air traffic control. As many of the HALO flights take place at night, the team works in shifts and the instruments are calibrated and serviced during the day. An average of 50 people work on the ground in Argentina over the entire campaign, with almost 150 experts involved in the SOUTHTRAC mission overall.

THE HALO RESEARCH AIRCRAFT

The High Altitude and Long Range (HALO) research aircraft has been in service for more than 10 years. It is a joint initiative of German environmental and climate research institutions. The operation of HALO is funded by a consortium consisting of the German Research Foundation, the Max Planck Society, the Karlsruhe Institute of Technology, the Forschungszentrum Jülich, the Leibniz Institute for Tropospheric Research and the German Aerospace Center (DLR).

Into the waves

In the event of a night flight, the crew arrives at the hangar in the early evening. Take-off is scheduled for 20:00, while the last twilight remains over the mountains. The cabin and flight deck offer room for 13 instruments, five scientists, two pilots and one on-board engineer, which means that each scientist has to work with several instruments simultaneously. In addition, various teams on the ground monitor the flight. After take-off this evening, HALO will first fly across the Chilean Andes to the Pacific Ocean. There, it will come into direct contact with mountain waves. This type of gravity wave is one of the subjects of the current research programme. Mountain waves are formed by the interaction of uplift and gravity in the atmosphere and are also referred to as lee waves, because they are generated on the sheltered (lee) side of mountains. “We notice that we are passing through the waves due to changes in airspeed,” explains DLR test pilot Marc Puskeiler. “When this happens, the autopilot gently oscillates back and forth between higher and lower thrust in order to maintain altitude and speed.”

Once over the open Pacific, HALO will make a 90-degree turn so that it is flying parallel to the Andes, until it is some 100 kilometres from Santiago de Chile. Then, the research aircraft can really show its capabilities, ascending to a maximum altitude of approximately 14 kilometres. During the nocturnal flight, only the Moon and stars can be seen from the flight deck windows, together with the laser that scans the skies above HALO for gravity waves up to just below the boundary of space, at an altitude of 100 kilometres.

ALIMA shines through the atmosphere

“HALO has an additional optical window at the top of the fuselage for the new Airborne LIdar for Middle Atmosphere research (ALIMA) experiment. The laser beam is directed upwards through this window and the instrument captures the backscattered return signals,” explains Bernd Kaifler of the DLR Institute of Atmospheric Physics. “To be more precise, we record periodic fluctuations in temperature, pressure and wind that extend up to 90 kilometres into the middle atmosphere – the stratosphere and mesosphere.” These are triggered when strong wind systems from the Pacific meet high mountains such as the Andes. In the tropopause region – the transition from the troposphere to the stratosphere – the research team on board is investigating the chemical and dynamic processes that influence the climate-relevant trace gases ozone and water vapour.

Following another 90-degree turn over the Pacific, HALO will embark on a course across the South American continent until it is 200 kilometres from Buenos Aires. Here the pilots will turn and fly a similar course back to the starting point. After approximately nine hours and a few cups of coffee on board, the crew will be back in remote Río Grande.

The most important atmospheric conditions for the formation of the ozone hole over Antarctica are low temperatures and a reduced exchange with mid-latitude air masses. The latter is ensured by a

The Andes is the longest mountain range on Earth and the world’s strongest source of gravity waves

The HALO research aircraft on the apron of the airport in Río Grande. Inlets can be seen on the upper edge of the fuselage. Air is drawn through these into the interior of the cabin for analysis.

Launch of a radiosonde near El Calafate airport. The launches were carried out by Ludwig-Maximilians-Universität München, also a project partner in SOUTHTRAC. From here, gravity wave measurements were also performed using a glider piloted by Klaus Ohlmann.

stable atmospheric system – the Antarctic polar vortex. But this can be weakened by strong wave activity. Until now, this effect has not been sufficiently taken into consideration in climate and weather models. SOUTHTRAC is now providing the data needed to supplement existing climate models with this crucial piece of the puzzle.

Other flights conducted as part of the mission flew out over the Atlantic, above the Andes and across the Antarctic Ocean all the way to the Antarctic Peninsula, which HALO overflew for the first time. In September and November, the team collected a wealth of data on the climate and climate change in the southern subpolar region. After travelling to the southernmost tip of the world for a total of eight weeks, the researchers have returned to Germany satisfied and confident that they have taken a major step towards understanding past and future climate changes on the basis of the data collected. At home, extensive analysis of the data will begin, while HALO is prepared for future missions to Barbados, Brazil and Iceland.

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WHAT ARE GRAVITY WAVES?

Gravity waves are waves in the atmosphere or ocean caused by gravity acting on a stable, layered medium (that is, by uplift in air or water). They should not be confused with gravitational waves, which are waves in space-time. Gravity waves occur if, for example, air masses encounter mountains, are lifted by the pressure of the wind and then descend again on the other side of the mountain. This vertical displacement of air masses generates waves that propagate vertically and horizontally through the atmosphere. The world’s strongest single source of atmospheric gravity waves is the southern Andes. In the region of the Antarctic peninsula and South America, the wind comes predominantly from the west, and the Andes – which run north to south – present an enormous obstacle; they thus form a powerful gravity wave generator. If there are high wind speeds at ground level. in the stratosphere and mesosphere, these waves can spread high into the atmosphere, up to an altitude of 90 kilometres. This happens at the southern tip of South America when the polar night jet reaches the Andes during winter. This creates a perfect waveguide upwards through the atmosphere. The SOUTHTRAC mission is investigating the effect of gravity waves on the climate.

Bernd Kaifler (right) and Thomas Gulde of KIT in the HALO research aircraft

Bernd Kaifler
works at the Lidar Department of the DLR Institute of Atmospheric Physics and is responsible for all projects dealing with lidar-based exploration of the middle atmosphere. Over the past seven years, he has developed systems that have been deployed in the most remote regions of the world – from New Zealand to northern Scandinavia – and for the last two years in Tierra del Fuego. Last year, he and his team flew the world's first balloon lidar for the middle atmosphere on a NASA balloon.

SCIENTIFIC WAVE SURFING

Numerous miles, great volumes of data and – most importantly – plenty of coffee. In this interview, DLR atmospheric physicist Bernd Kaifler explains the SOUTHTRAC mission in Argentina, where a team of scientists is investigating the impact of gravity waves on the climate and the transport of air masses in the atmosphere.

Dr Kaifler, in September 2019 you spent several weeks in Río Grande, Argentina, at the southernmost tip of South America. What impressed you most during your time there?
: I would have to say the weather. I had already been to Río Grande twice in the last two years, for the purpose of setting up and maintaining a ground-based lidar system there to investigate atmospheric gravity waves. It is always quite stormy at that time of year. Río Grande lies on the east coast, on the wide plain of Tierra del Fuego, and is completely exposed to the wind. Cape Horn and the Drake Passage, which are both feared by sailors because of their storms, are not far away. We soon became accustomed to battling with the wind on the walk from the hotel to the aircraft hangar every day. However, on this occasion there were two days when the air was completely still, which is far from typical. In addition, seeing the desert-like expanses, due to the low amount of precipitation, with a backdrop of snow-covered mountains, certainly makes a striking impression.

The southern Atlantic, the Pacific, the Andes and Antarctica are all far from Europe. Why do you need to fly there in a research aircraft? Could you not just obtain the information you need from space, using satellites?
: These gravity waves can be detected from space using suitable instruments on board satellites. However, from that distance the resolution of the measurements is not high enough to capture their complete spectrum. In addition, the orbits of the satellites mean that they only pass over any given location once or twice a day. In contrast, measurements conducted using an aircraft offer enormous advantages. For example, we can choose to fly a course that follows the direction of propagation of the waves over the Andes and thus record an accurate wave spectrum. In addition, we can fly the aircraft over a specific location several times in one day and record changes over time.

Measuring temperature profiles up to an altitude of 90 kilometres sounds very impressive indeed when you consider that during its mission HALO 'only' flew at a maximum altitude of 14 kilometres. What does the new laser-based ALIMA lidar do? What makes it special?
: ALIMA is a truly unique instrument and we reached the limits of what is technologically possible during its development. The laser has a power of 15 watts, the receiving telescope has a very small field of view to minimise sources of optical interference, we have extremely narrowband optical filters in the receiver to filter out as much daylight as possible, and we use optics with very high transmissivity and detectors with high quantum efficiency. These devices have been used in ground-based instruments for some years. What is different is that we have made the lidar instrument sufficiently compact and stable to fit into and work inside an aircraft. ALIMA delivered unique and scientifically very interesting data during its first measurement flights. For example,

Meteorological ground station in El Calafate, operated by Ludwig-Maximilians-Universität München.

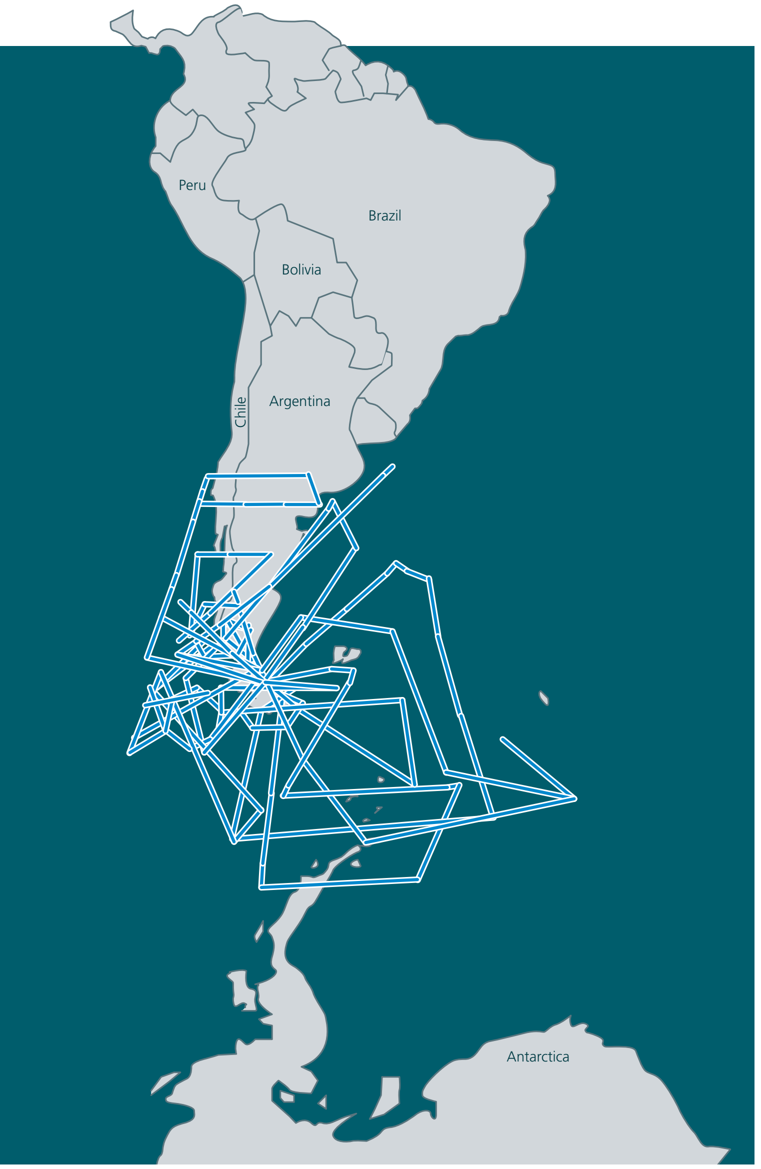
we were able to conduct temperature measurements at altitudes of up to 90 kilometres, despite turbulence and vibrations within the aircraft. During the next measurement campaign in two years time, we want to go a step further and measure wind profiles in the direction of the laser beam, high above the aircraft. Wind measurement is the hardest discipline when using lidar instruments. We have done pretty much everything we can to prepare ALIMA; all that remains is to improve the laser's stability.

"ALIMA delivered unique and scientifically very interesting data during its first measurement flights."

Space must be a bit tight inside HALO, with all the instruments. Who else is on board for this mission? How does it feel for the five of you to be responsible for so many measurement devices simultaneously, sometimes for 10 hours at a time?
: On board HALO there are two pilots, a flight engineer and five scientists, who look after the 13 scientific experiments. One of the scientists is appointed as mission scientist; this is a special role. The mission scientist is in constant contact with the pilots and the other scientists for matters such as adapting flight routes, turns and changes in altitude to the scientific requirements during the flight. But cooperation is always a must. Preparing and dropping probes is always a joint effort. The task of operating the inlet valves for the trace gas measurement devices is generally assigned to whoever is within reach of them, regardless of which experiments are officially their responsibility. We receive support from scientists and technicians on the ground, some in Río Grande itself and others back in Germany. We can communicate and get advice from people on the ground using a chat program connected via a satellite link. This comes in useful if a device is causing problems, the software crashes or simply if we see something interesting come up on the live instrument displays, which means that we might have to change the measurement device settings. The people who spend hours preparing and calibrating the instruments before every flight, and then switch them off under controlled conditions and service them afterwards, also play a vital role. It goes without saying that the crew on a 10-hour flight cannot manage everything on their own. Not only does this exceed the usual working hours, but nine to 10 hours of flying time is also physically and emotionally draining. The instruments require constant attention, which in most cases means checking a seemingly endless scroll of numbers, graphs and controls. Nowadays, this is mainly done electronically, on a laptop screen. The need to check everything constantly means that you even have to think twice about taking a bathroom break.

There is no lunch break; you cannot take your eyes off the screen as you eat. That said, you are willing to put up with a certain amount of

Aircraft and instrument maintenance in the hangar in Río Grande on a day of ground operations



Routes of the measurement flights performed by the HALO research aircraft during the SOUTHTRAC mission in September and October 2019

hardship for the sake of good measurement data, especially when you know that people on the ground are counting on your success. In addition to the scientists and technicians for the instruments, there is also the ground crew for operating the aircraft, the flight planning team, the weather forecasting team, the management team and many others. As part of the crew, you are essentially the visible tip of a huge pyramid of over 100 people who are all necessary to make the mission a success.

Can you describe a typical day during the campaign in Río Grande, at the end of the world? Did you have some free time alongside your routine tasks?

: On a flight day, everything runs according to a schedule that is determined by the departure time. For our night flights, for instance, this was 20:00 local time. That does not leave much room for leisure. Work in the hangar generally begins five to seven hours beforehand, with the preparations for the experiments. A colleague comes to collect me at 17:00 and takes me to the hangar. At that point, the decision is made as to whether or not the flight will take place. At the hangar, the team and I perform a functionality test on ALIMA. In the meantime, Sonja from the weather forecasting and flight planning team calls in and we go over the flight plan together, running through a few key issues. What is the weather like? Will the gravity waves in the latest forecast still be in the same place? Is there a chance that we might have to land at a different airport because the landing strip in Río Grande is icy?

The aircraft technicians tow HALO out of the hangar two hours before take-off. This is a dramatic event for the experiments, as taking the aircraft outside means interrupting the power supply. This is problematic, as heated detectors cool down and vacuum pumps come to a standstill. To keep the interruption to a minimum, all of the experiments have to be shut down as quickly as possible and, most importantly, at the same time, in a coordinated action. Once HALO has been rolled out of the hangar and the experiments have been powered up again, there is just one hour to get them into their flight configuration. All those who will not be flying exit the aircraft 15 minutes before take-off. We begin a ground test for the lidar, and the green laser beam is visible over the aircraft for two minutes. All those who have gathered to wave off the aircraft pull out their camera to take photographs of HALO and the green beam. No sooner has the laser been turned off than we start taxiing. HALO takes off at exactly 20:00, heading into the dark towards the Andes. And we begin our measurements.

Approximately nine hours later, just before 05:00, we land back at the airport in Río Grande. The ground team is already waiting for us at the hangar. They help us to shut down the experiments and secure the data. This takes about 45 minutes. There is a short debrief at about 06:00 and we finally make it back to the hotel at 07:30, just in time for breakfast. No one opts for the coffee, and shortly after we fall into bed, tired but happy. Once again, the measurement flight has been a success and tomorrow will be spent on the ground.

What will we learn about Earth's changing climate from the wealth of data acquired by the SOUTHTRAC HALO mission?

: We still know very little about the impact of climate change on the middle atmosphere. This is largely due to the fact that the current climate models do not incorporate gravity waves, and their effects are only taken into consideration in a very approximate way. In order for us to be able to better characterise the effects of gravity waves, we must first understand where the waves originate and how they propagate. One specific question, for instance, is whether a strong source is necessary for gravity waves to reach an altitude of 90 kilometres. Or do these waves become unstable along the way, breaking up and failing to reach high altitudes precisely because of their large initial amplitude? In that case, it would instead be the weak waves that could reach high altitudes under good propagation conditions. Acquiring data is essential to answer these and other questions. We can then use this information to detect wave packets in the atmosphere. This is one of the objectives of SOUTHTRAC – so these are process studies. In the medium term, we hope to be able to contribute our results to help achieve a more realistic incorporation of gravity waves into climate models.

Where would you like your next research destination to be, and why?

: I would like to return here, to Río Grande, and repeat the flights in the southern winter, perhaps in July. Shortly before our arrival in Río Grande there was an occurrence of stratospheric warming, which contributed in part towards the collapse of the polar vortex and had a massive effect on the propagation conditions for gravity waves. This happens extremely rarely in the southern hemisphere; the last time was in 2002. So, on the one hand, the campaign was fortunate enough to be able to study the effects of stratospheric warming. On the other, however, it could also be seen as rather bad luck, as it meant that studying the undisturbed propagation of gravity waves was no longer possible. That is why I am keen to repeat the measurements, and South America is still the perfect place to do this.

The interview was conducted by Falk Dambowsky

THE ALIMA INSTRUMENT

This airborne instrument for remote sensing in the middle atmosphere measures high-resolution air density and temperature profiles above the aircraft up to an altitude of 90 kilometres. It provides data within a range that would otherwise only be reached by sounding rockets. The Airborne LIdar for Middle Atmosphere research (ALIMA) instrument has been developed and constructed over the last six years at the DLR Institute of Atmospheric Physics and is now being used for the first time as part of the SOUTHTRAC campaign. The measurement principle is based on lidar technology. Five-nanosecond-long pulses of light generated by a powerful laser are beamed through a window at the top of the aircraft fuselage. As the light travels through the atmosphere, air molecules scatter part of the laser radiation back to the aircraft, where it is captured by a telescope and directed onto detectors. The length of time between the emission of a light pulse and the detection of the scattered light determines the altitude at which the scattering has taken place. The strength of the received signal makes it possible to determine the air density at this altitude.

Before take-off, the ALIMA instrument is tested one last time and the green laser beam, which is directed upwards through a window in the aircraft fuselage, is briefly visible.

Svetlana Cvetkova and Valentin Lauther from the University of Wuppertal keep an eye on the data. A total of five scientists are in charge of all the experiments on board HALO during the flight.