Airborne lidar system poised to improve accuracy of climate change models

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Researchers developed a new lidar system that was used aboard the German research aircraft HALO (High Altitude and Long-Range Research Aircraft) to acquire the first simultaneous measurements of the vertical structure of water vapor and ozone in the tropopause region of the atmosphere. Credit: DLR

Researchers have developed a laser-based system that can be used for airborne measurement of important atmospheric gases with unprecedented accuracy and resolution. The ability to collect this data will help scientists better understand how these atmospheric gases affect the climate and could help improve climate change predictions.

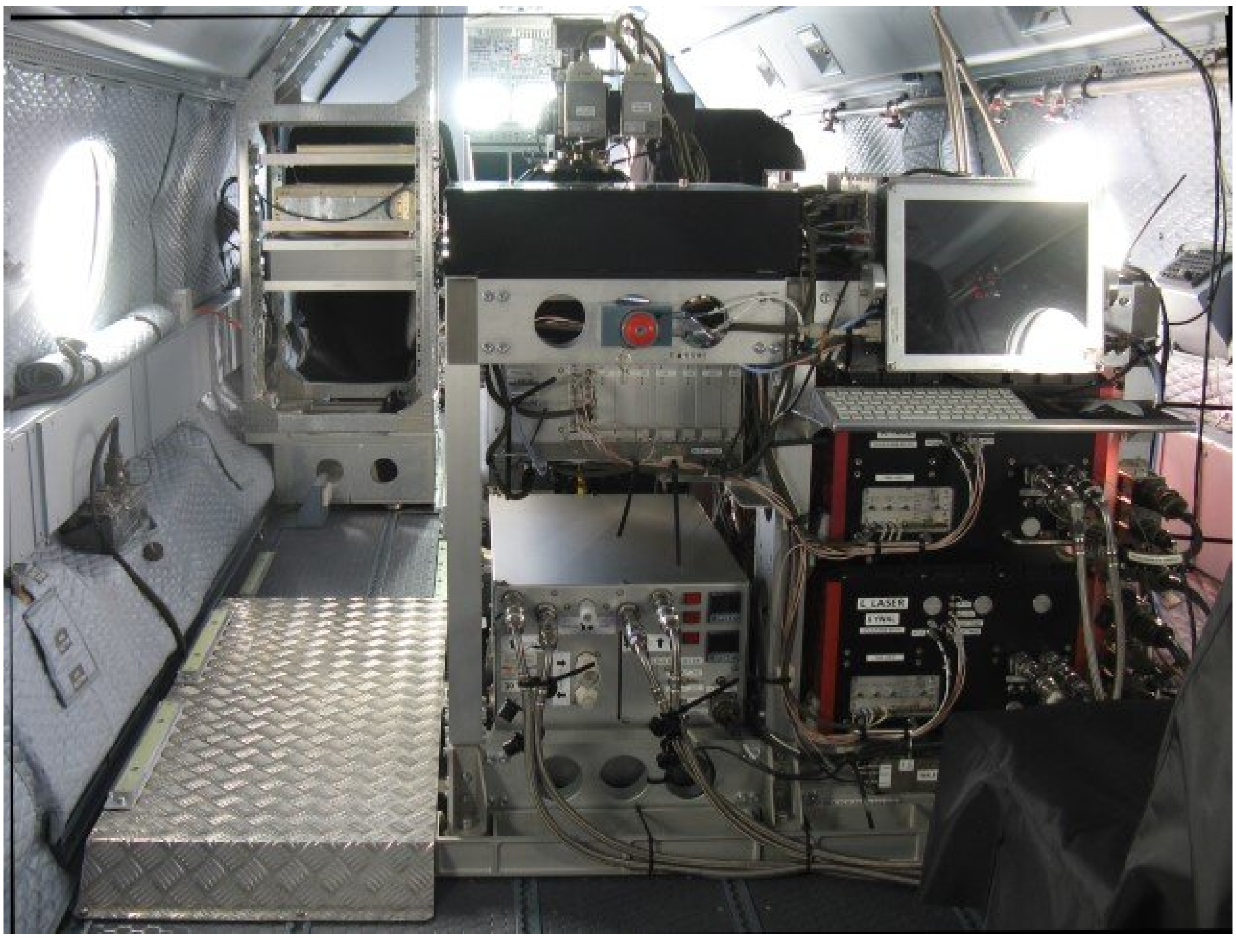
In the Optical Society journal *Applied Optics*, researchers from Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)—Germany's national center for aerospace, energy and transportation research—describe how their lidar instrument was used aboard an aircraft to acquire the first simultaneous measurements of the vertical structure of water vapor and ozone in the tropopause region of the atmosphere. The researchers say that the new system might even be useful for monitoring atmospheric gases from space.

The tropopause separates the surface-based troposphere layer where weather takes place from the overlying stratosphere that contains the ozone layer that protects life on Earth from harmful radiation. Scientists want to study water vapor and ozone in the tropopause because the distribution of these atmospheric gases in this layer plays a crucial role in the Earth's climate.

"The ability to detect the vertical structure of water vapor and ozone is critical for understanding the exchange of these atmospheric gases between the troposphere and the stratosphere," said Andreas Fix, who led the research team. "These measurements could help us identify errors and uncertainties in climate models that would help improve predictions of the future climate, which is one of the central challenges for our society and economy."

Gaining a 3-D perspective

Atmospheric gases can be assessed with instruments flown into the atmosphere or with data acquired from satellites. However, these methods haven't been able to provide a full picture of atmospheric gas distribution because they either lack the vertical component or don't provide high enough resolution. Although instruments carried with balloons—known as balloon sondes—can provide highly resolved vertical profiles, they don't offer detailed temporal resolution and can only be used at selected sites.



The new lidar system was used for airborne atmospheric measurements during the wave-driven isentropic exchange (WISE) mission, which involved multiple long-range flights over the North Atlantic and Northern Europe. Credit: DLR

To solve these problems, the researchers developed a lidar system that uses laser light to measure both ozone and water vapor at the same time. Their approach, called differential absorption lidar (DIAL), uses two slightly different UV wavelengths to measure each gas. The UV radiation at one wavelength is mostly absorbed by the gas molecules while most of the other wavelength is reflected. Measuring the ratio of the UV signals returning from the atmosphere allows calculation of a detailed gas profile.

The gas profiles created using the new lidar system exhibit a vertical resolution of around 250 meters and a horizontal resolution of about 10 kilometers below the aircraft's flight track.

"This vertical capability is a significant advancement in studying exchange processes at the tropopause," said Fix. "It helps overcome significant shortcomings in resolving the fine-scale distribution that have made it difficult to understand processes responsible for exchange at the tropopause."

Achieving energy efficiency

To perform this method aboard a plane, the researchers used a highly efficient optical parametric oscillator (OPO) they previously developed to convert the laser output to the UV wavelengths needed to measure water vapor and ozone. "The conversion needs to be very energy efficient to generate UV radiation with adequate pulse energies and high average power from the limited energy available on board an aircraft," explained Fix.

Tests of the new lidar system showed that its accuracy matched well with that of balloon sondes. In 2017, the researchers flew the new system aboard the wave-driven isentropic exchange (WISE) mission, which involved multiple long-range flights over the North Atlantic and

Northern Europe. They found that the instrument worked remarkably well, remained stable during use and could measure characteristic ozone and water vapor distributions at the tropopause.

The researchers plan to analyze the new vertical-component data acquired during WISE and integrate it into climate models. They expect to use the instrument to collect data atmospheric gas information aboard future flights.

More information: Andreas Fix et al, Development and application of an airborne differential absorption lidar for the simultaneous measurement of ozone and water vapor profiles in the tropopause region, *Applied Optics* (2019). DOI: 10.1364/AO.58.005892

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